From:	FRUEH Terry
To:	Henning, Alan; Kubo, Teresa; Leinenbach, Peter
Cc:	GROOM Jeremy; ABRAHAM Kyle
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Alan, Teresa, and Peter,

It was good to meet with you folks today, and I appreciate your participation in the discussion. Attached are ODF publications (including pre-RipStream), and the link to the WRC coop is below. Please let me know if there's anything else I can do for you.

http://watershedsresearch.org/results/

Terry

W. Terry Frueh
Monitoring Specialist
Oregon Dept. of Forestry
2600 State St., Building D
Salem, OR 97310
tel. 503-945-7392
TFrueh@ODF.State.OR.US

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

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Prepared by

Oregon Department of Forestry

Marganne Allen

and

Liz Dent

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TABLE OF CONTENTS

INTRODUCTION **1**

MONITORING OBJECTIVES AND QUESTIONS **9**

Objectives *9*
Questions *9*
Study Design *10*
Strengths and Limitations of The Study *15*

RESULTS AND DISCUSSION **16**

Site characteristics *16*
Basal area compared to FPA standard basal area targets *19*
What are the ranges in shade conditions over Blue Mountain and Coast Range forested streams and how do the ranges compare between harvested and unharvested stands? *24*
Do particular Riparian Management Area prescriptions in harvested stands result in different average shade conditions? *28*
What are the relationships among shade and channel and valley morphology? *33*
How do disturbances, other than harvesting, affect shade on forested streams? *35*
What are the relationships between riparian stand characteristics and shade? *38*

PROPOSED MODELS **50**

Blue Mountains *50*
Coast Range *52*

SUMMARY AND CONCLUSIONS **56**

Site Characteristics *56*
Proposed Models *61*

RECOMMENDATIONS **63**

Further Analysis *63*
Monitoring *63*
Field Methods *64*
Policy *64*

REFERENCES **66**

APPENDIX A: SITE INFORMATION SUMMARIES **70**

APPENDIX B: SHADE AND COVER SUMMARY INFORMATION BY SITE **80**

APPENDIX C: VALLEY AND CHANNEL MORPHOLOGY RELATIONSHIPS TO SHADE **85**

APPENDIX D: VEGETATION TYPE AND SHADE **89**

APPENDIX E: SHADE VERSUS AVERAGE STAND CHARACTERISTICS OF BOTH SIDES OF THE STREAM **92**

LIST OF FIGURES

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. 6
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. 10
Figure 3. Schematic of plot location within harvest unit. 12
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)..... 14
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. 20
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. 22
Figure 7. Stream shade under harvested and unharvested RMAs by georegion. 24
Figure 8. Distribution of harvested and unharvested sites among shade classes by georegion. 25
Figure 9. Range in shade by ODF stream class, for harvested and unharvested streams in each georegion. 27
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. 29
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. 30
Figure 12. Relationship between shade and cover measurements. 31
Figure 13. Comparison of ODF cover and shade data to literature from other eastern (intermountain) sites. 32
Figure 14. Comparison of ODF cover and shade data to literature from other western sites. 32
Figure 15. Radial plot of stream valley aspect by georegion. 34
Figure 16. Box and whisker plots of stream shade by stream valley aspect and georegion. 35
Figure 17. Average shade in relation to the percent of blowdown by georegion. 36
Figure 18. Shade in relation to the percent of diseased or dying trees by georegion. 36
Figure 19. Fire and shade levels in harvested and unharvested Blue Mountain stands... 37
Figure 20. Grazing and shade in harvested and unharvested Blue Mountain stands..... 38
Figure 21. Dominant overstory, shade, and harvest designation by georegion. DF_ES = Douglas-fir/Englemann spruce, WF = White fir. 39
Figure 22. Grazing, shade, and dominant overstory type in the Blue Mountains. 39
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. 41
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... 43

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. 43
Figure 26. Stream shade over Blue Mountain streams by aspect, average tree height, and ODF stream class. 46
Figure 27. Stream shade over Coast Range streams by aspect, average tree height, and ODF stream class. 46
Figure 28. Shade versus basal area per acre for each georegion by aspect and live crown ratio (LCR). 48
Figure 29. Shade versus trees per acre for each georegion by aspect and live crown ratio (LCR). 49
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. 51
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. 51
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. 54
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. 55

LIST OF TABLES

Table 1. Riparian Management Area widths. 2
Table 2. Summary of canopy cover/shade research 7
Table 3. Codes used for size classification of channel substrate. 15
Table 4. Number of sites in each stand type, ownership, prescription, and stream size. . 17
Table 5. Percent and number of sites with disturbance, other than harvesting, overstory species/type, and valley form by georegion. 18
Table 6. Percent of total basal area available for harvest. 23
Table 7. Summary statistics for cover and shade by georegion and stand type. SD = standard deviation is based on average plot values. 25
Table 8. Shade and bankfull widths of harvested and unharvested sites in the Blue Mountain and Coast Range georegions. 26
Table 9. Summary of channel characteristics by georegion. 33
Table 10. Differences between three- and ten-foot height shade measurements. 40
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. 44
Table 12. Shade by aspect, harvest category, and georegion. 45

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.

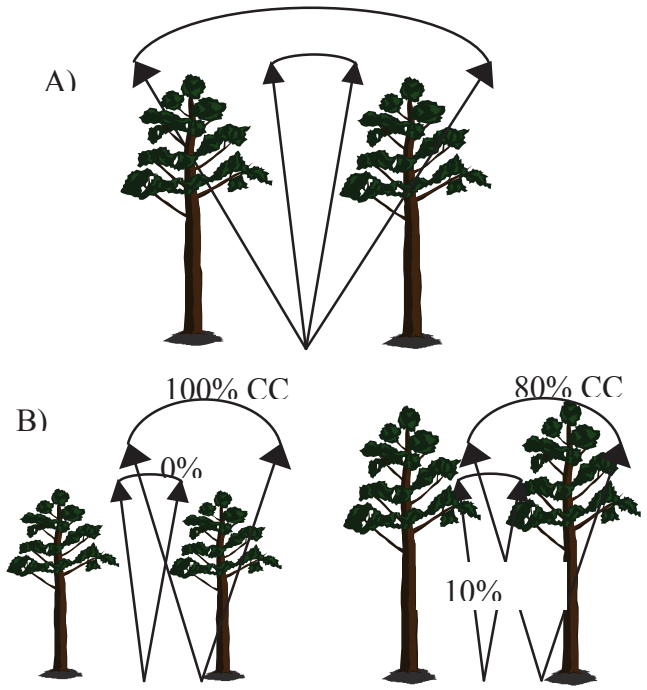


Figure 1. Angle of view and influence on canopy cover or shade measurements (adapted from Bunnel and Vales 1990). (A) Small angles produce large ranges in single point estimates. (B) Shorter heights to base of live crown produce large ranges in single point estimates.

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	Location	Source
52,67,91,95	Densiometer	Stream	Douglas-fir	--	30-50 ft/Clearcut	Coast Range, WA	TFW 1992
71,84	Densiometer	Stream	Douglas-fir	--	32-72 ft/Partial cut	N. Rockies, WA	TFW 1992
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	Brazier and Brown 1973
17	Angular Canopy Density	Stream	--	2-3 yrs	--/Clearcut	Coast Range, OR	Andrus and Froehlich 1988
75	Angular Canopy Density	Stream	--	5-10 yrs	--/Clearcut	Coast Range, OR	Andrus and Froehlich 1988
87	Angular Canopy Density	Stream	--	15-22 yrs	--/Clearcut	Coast Range, OR	Andrus and Froehlich 1988
82	Angular Canopy Density	Stream	--	>200 yrs	NA	Coast Range, OR	Andrus and Froehlich 1988
85	Angular Canopy Density	Stream	Red alder	2nd growth	--/Clearcut (30-40 yrs post)	Cascade Range, OR	Murphy et. al 1981
75	Angular Canopy Density	Stream	Douglas-fir, western hemlock	Old growth >450 yrs	NA	Cascade Range, OR	Murphy et. al 1981
81+ 82+	Clinometer	Stream	All cover types.	--	NA	Coast Range, OR:	Thom and Jones 1999
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	Minore and Weatherly 1994
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, OR Lower Columbia, OR Nehalem vicinity, OR Wilson/Trask/Nestucca, OR	Drake 1999

Mean Cover (%)	Method	Zone	Stand Type	Stand Age (years or category)	Stream Buffer/Upslope Harvest	Location	Source
70.1 29.3	Moosehorn	Upland	Grand fir – larch	Uneven: 50 years since last selective harvest	NA/Unharvested NA/Partial cut	Blue Mountains, OR	Cook et. al 1995
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, OR	Cook et. al 1995
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, Canada	Bunnel and Vales 1989
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, Canada	Bunnel and Vales 1989
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, Canada	Bunnel and Vales 1989
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, Canada	Bunnel and Vales 1989

*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?

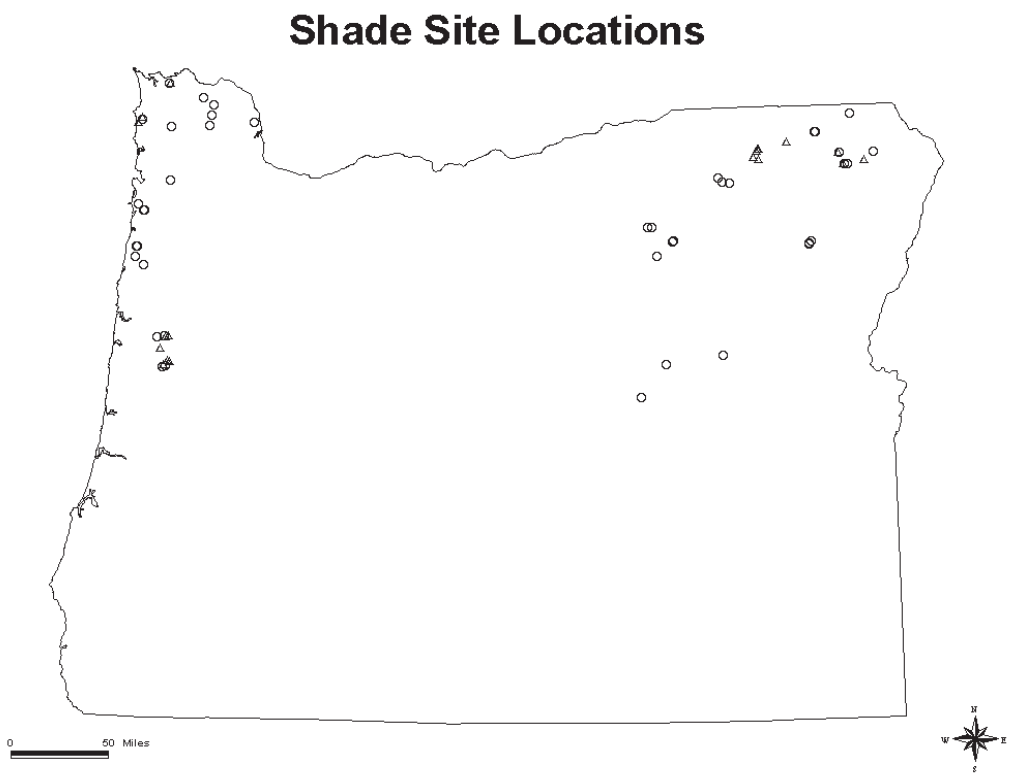
4. How do disturbances, other than harvesting, affect shade on forested streams?

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).

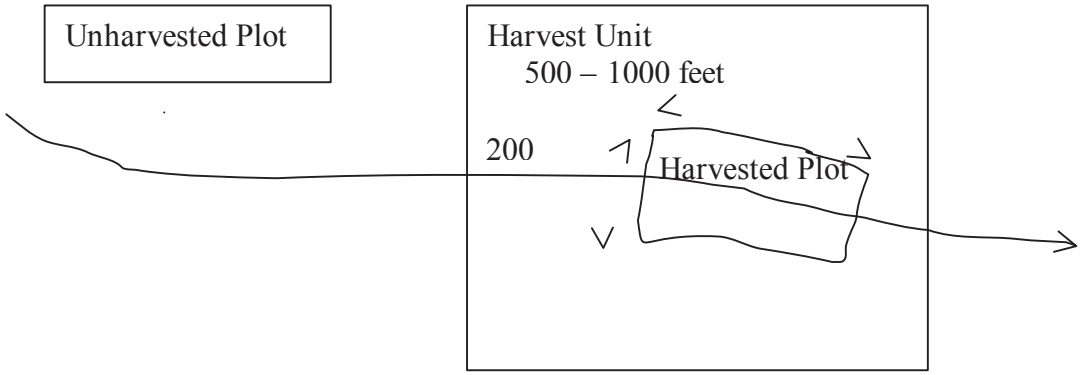


Figure 3. Schematic of plot location within harvest unit.

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.

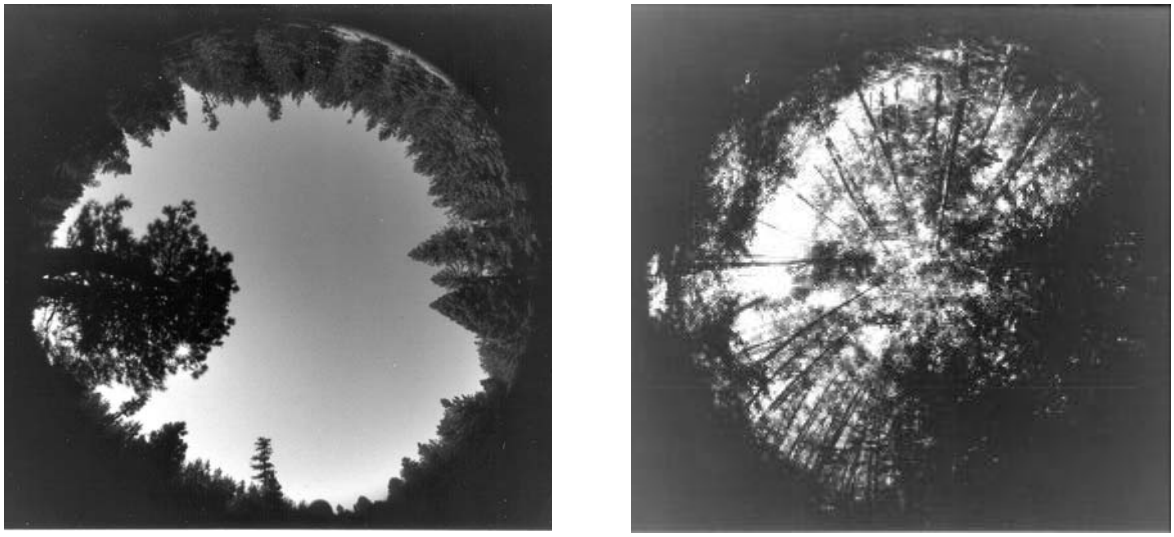


Figure 4. Examples of hemispherical (fish-eye) photographs taken at a site in the Blue Mountain georegion (left) and at a site in the Coast Range georegion (right).

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).

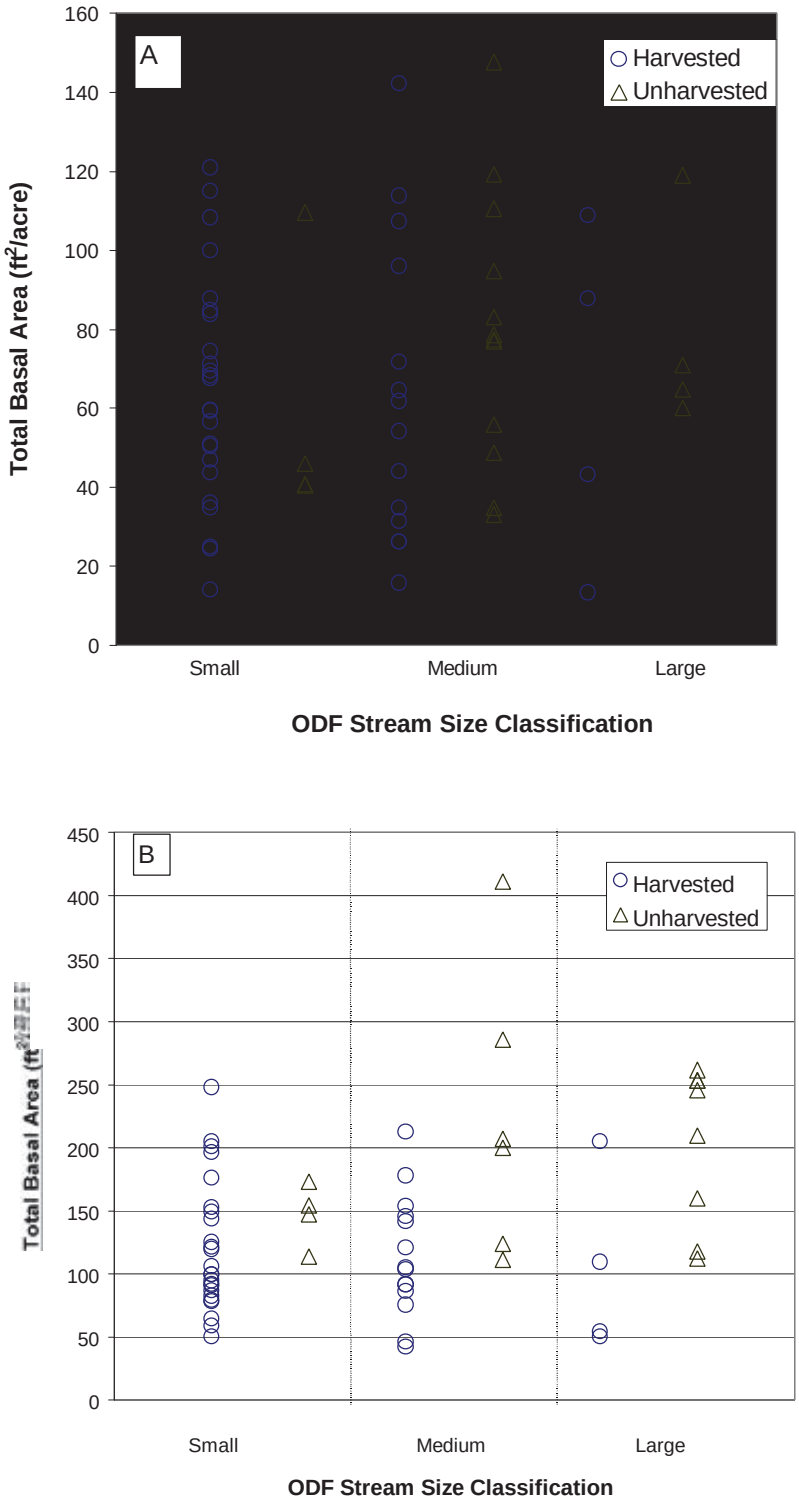


Figure 5. Total basal area (hardwoods and conifers) within RMAs on small, medium, and large streams in (A) Blue Mountain and (B) Coast Range georegions.

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).

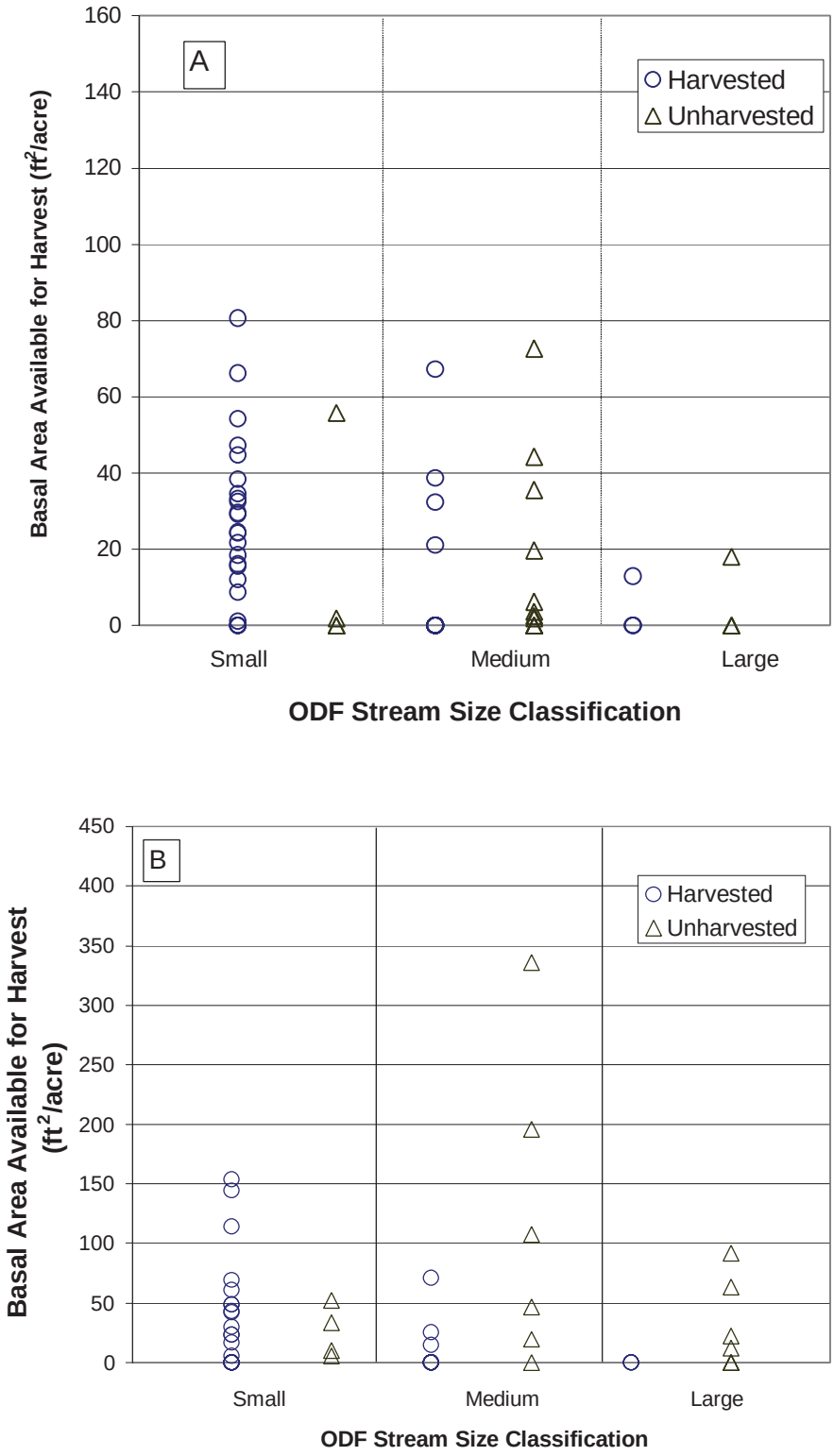


Figure 6. Basal area available for harvest under current FPA for RMAs on small, medium, and large streams in (A) Blue Mountain and (B) Coast Range georegions.

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).

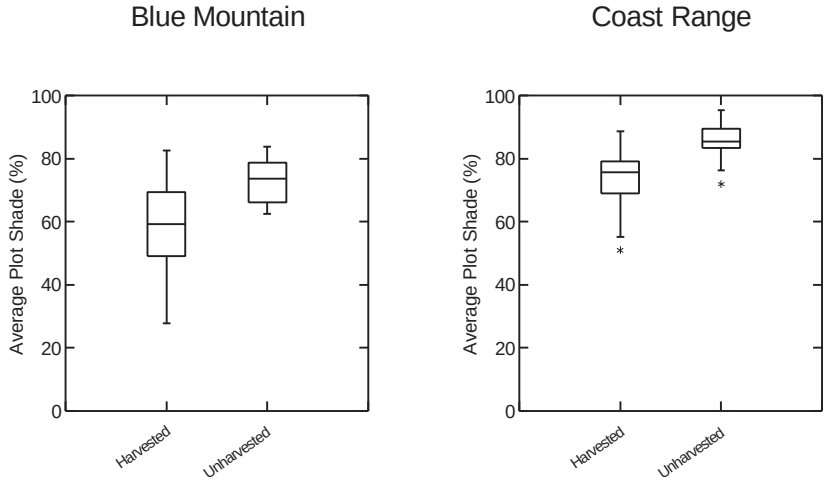


Figure 7. Stream shade under harvested and unharvested RMAs by georegion.

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

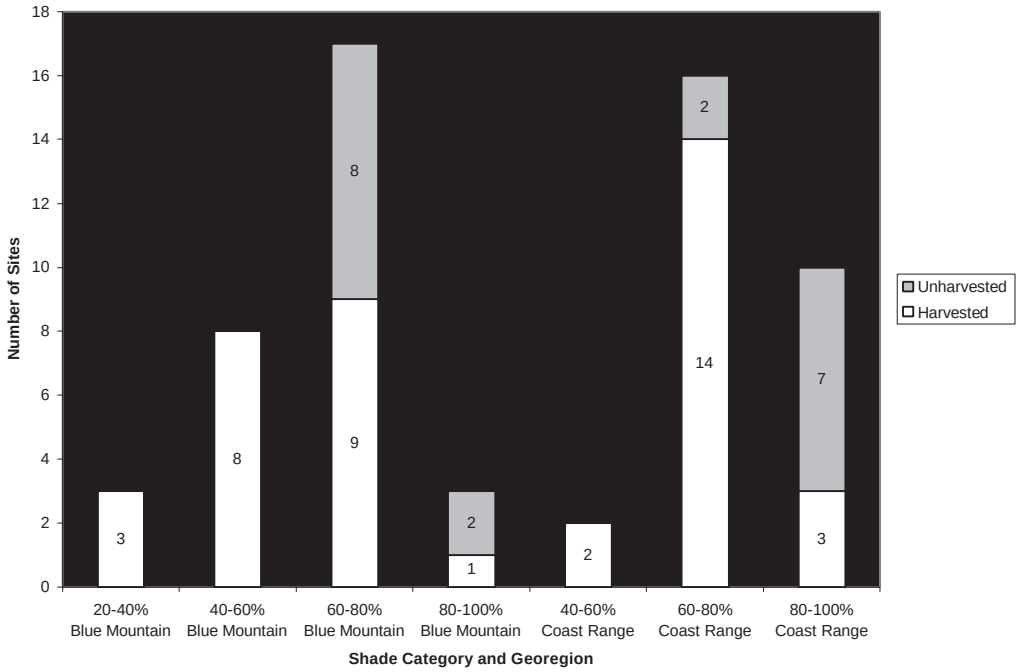


Figure 8. Distribution of harvested and unharvested sites among shade classes by georegion.

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.
Harvested	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
Unharvested	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.
Harvested	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
Unharvested	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

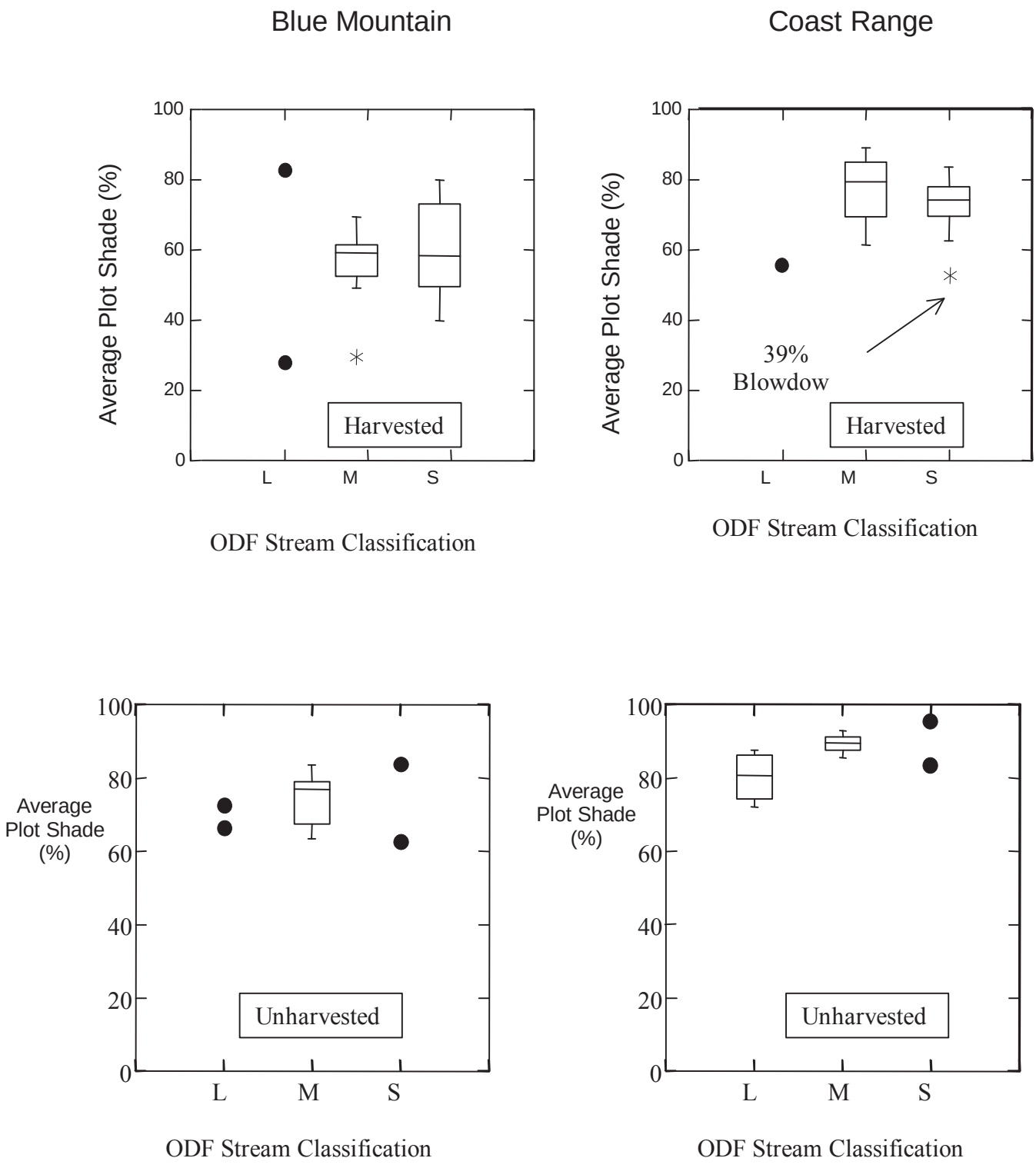


Figure 9. Range in shade by ODF stream class, for harvested and unharvested streams in each georegion. LF = large, M = medium F, S = small.

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.

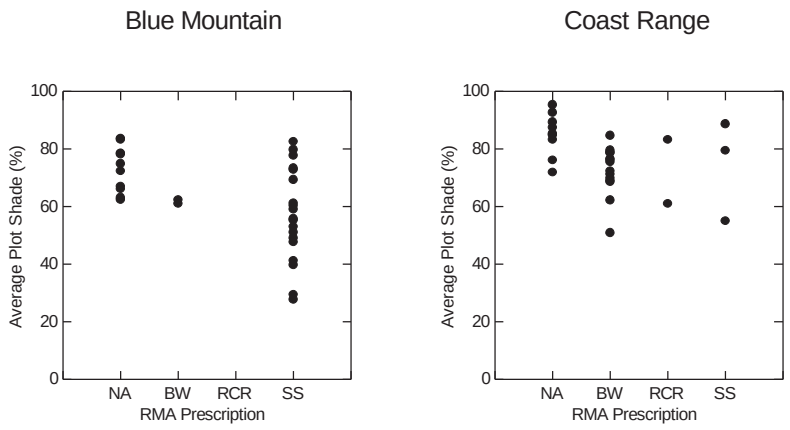


Figure 10. Scatterplot of shade by RMA prescription and georegion. NA = Not applicable, for unharvested sites, BW = No-Cut Buffer Width, RCR = Riparian Conifer Restoration, SS = Site-Specific Plan.

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.

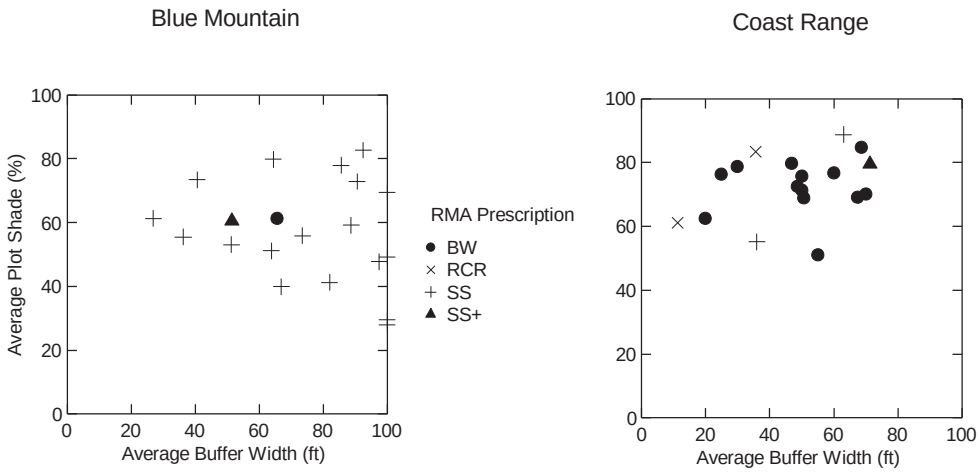


Figure 11. Average Plot Shade by average buffer width and RMA prescription for each georegion. SS = Site-Specific Prescription, SS+ = average buffer widths contain values that exceed 100 feet, BW = No-Cut Buffer, RCR = Riparian Conifer Restoration. Note: Only 38 sites had buffer width data.

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.

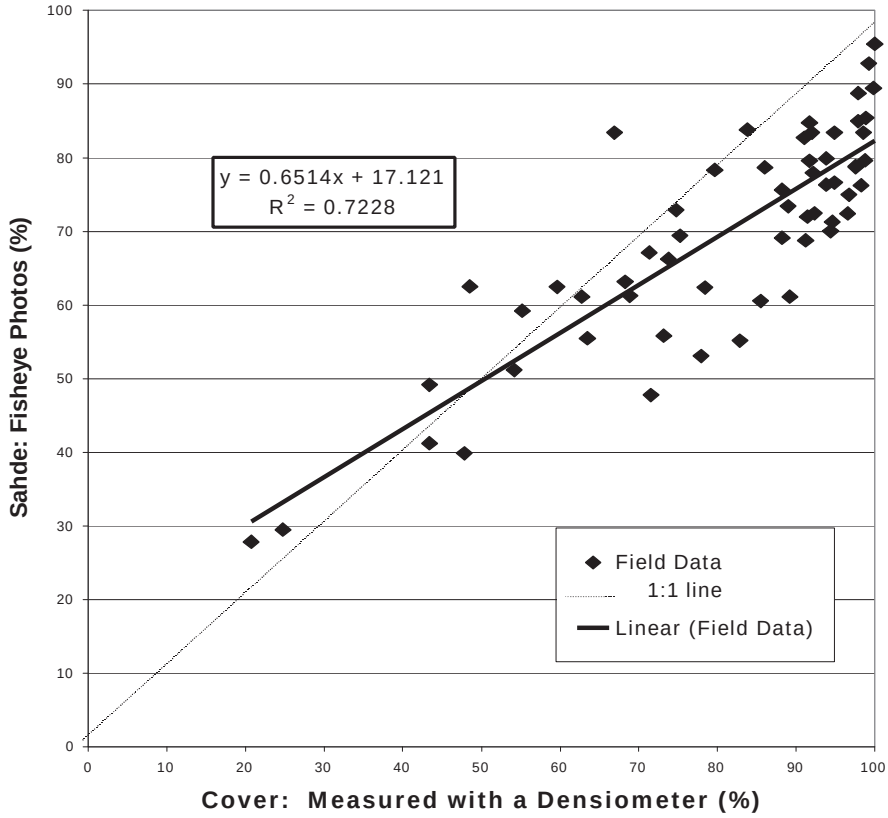


Figure 12. Relationship between shade and cover measurements.

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).

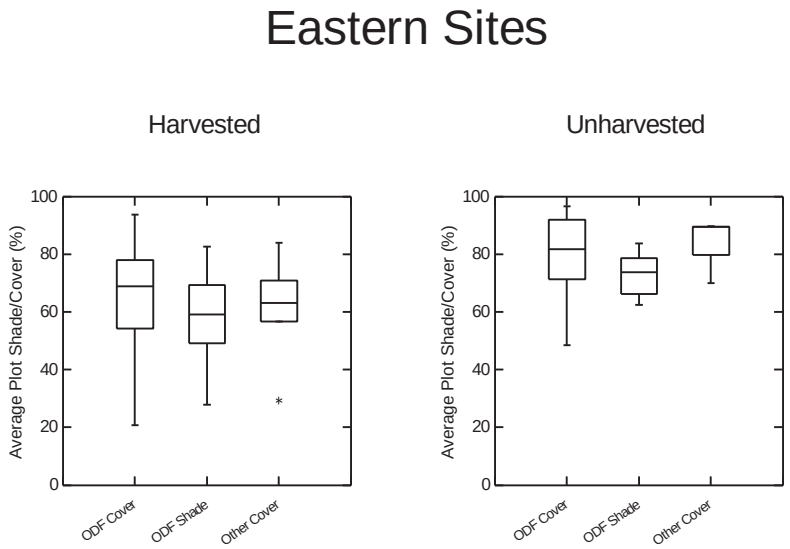


Figure 13. Comparison of ODF cover and shade data to literature from other eastern (intermountain) sites.

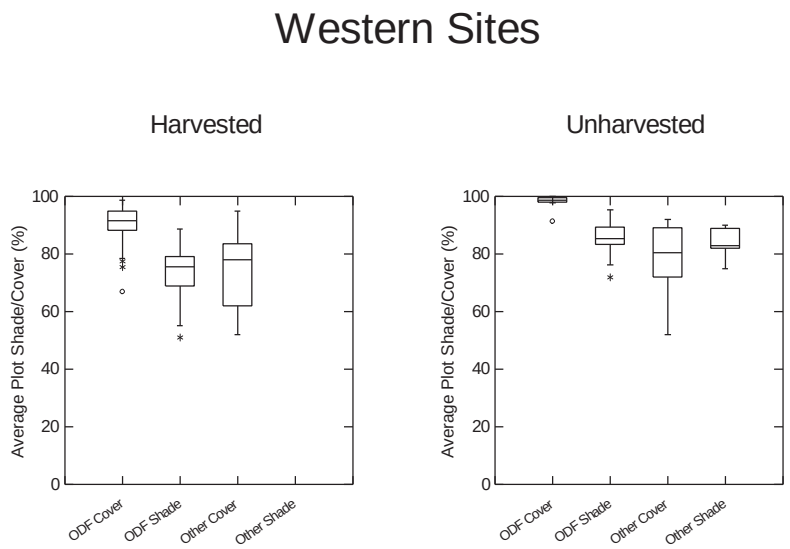


Figure 14. Comparison of ODF cover and shade data to literature from other western sites.

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. Krusksal-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.

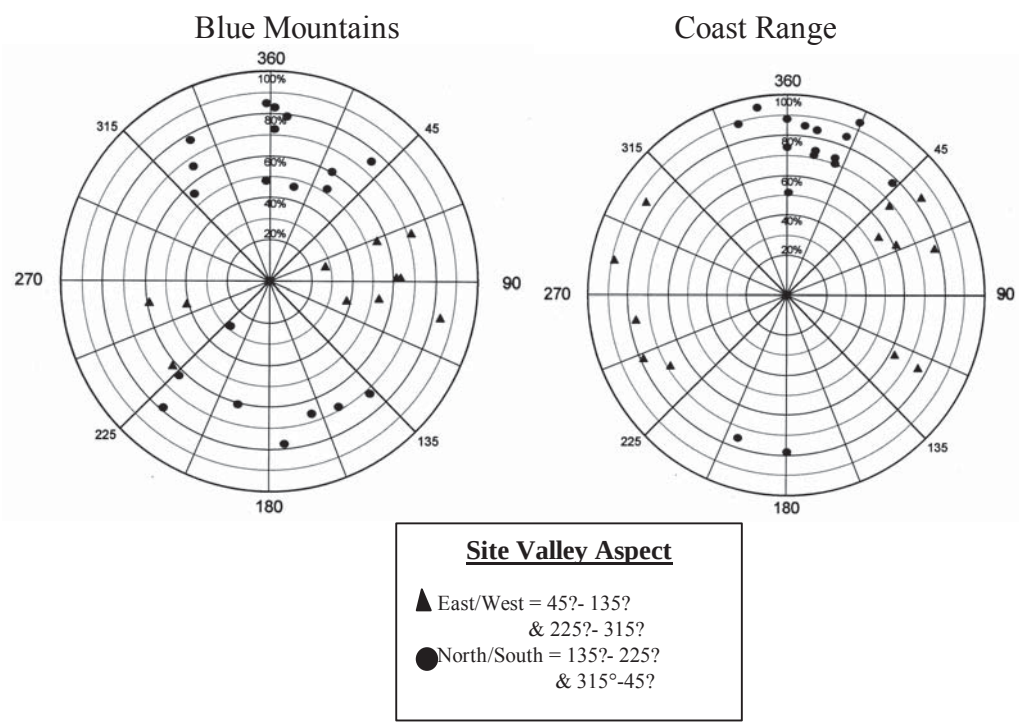


Figure 15. Radial plot of stream valley aspect by georegion.

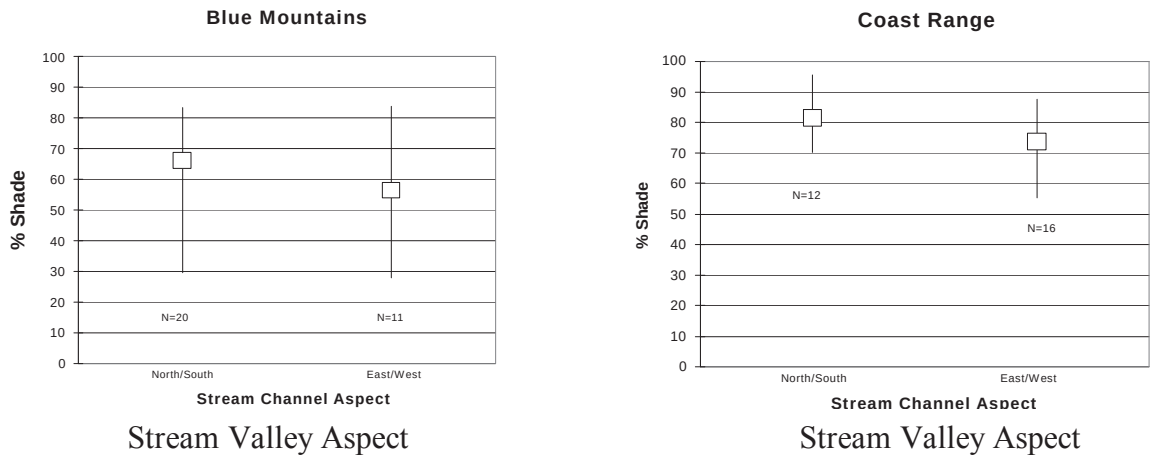


Figure 16. Box and whisker plots of stream shade by stream valley aspect and georegion.

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.

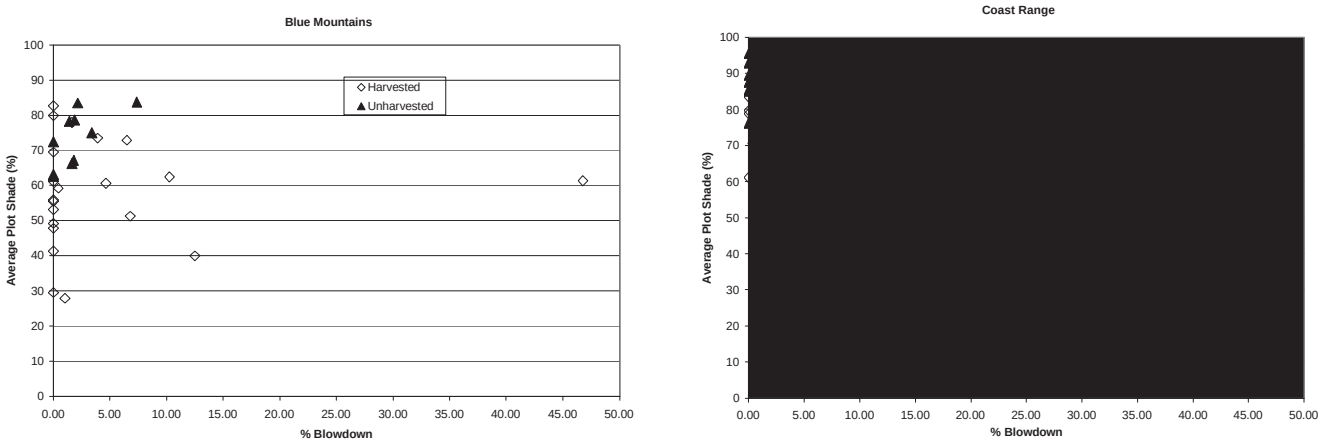


Figure 17. Average shade in relation to the percent of blowdown by georegion.

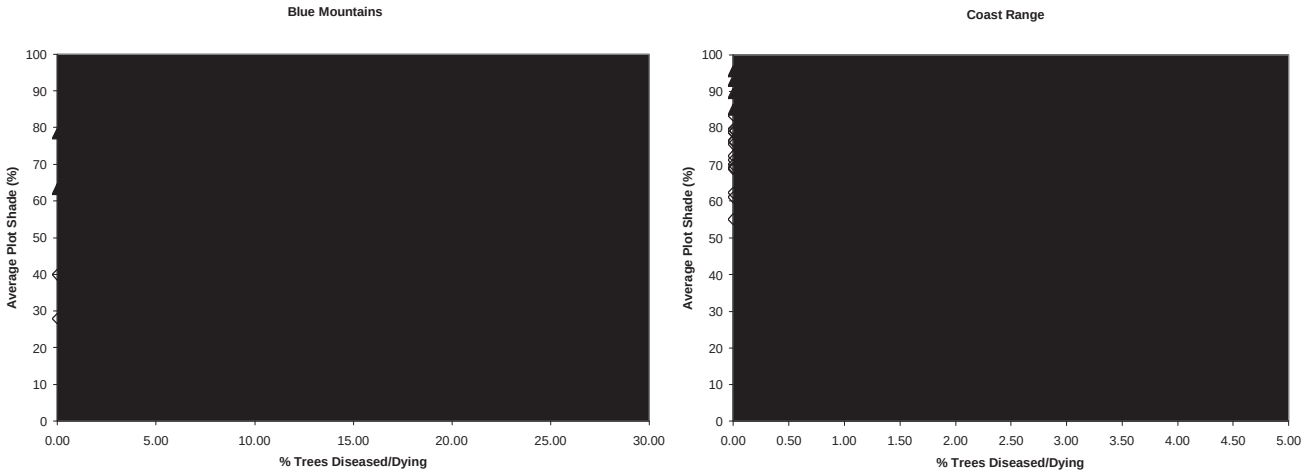


Figure 18. Shade in relation to the percent of diseased or dying trees by georegion.

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

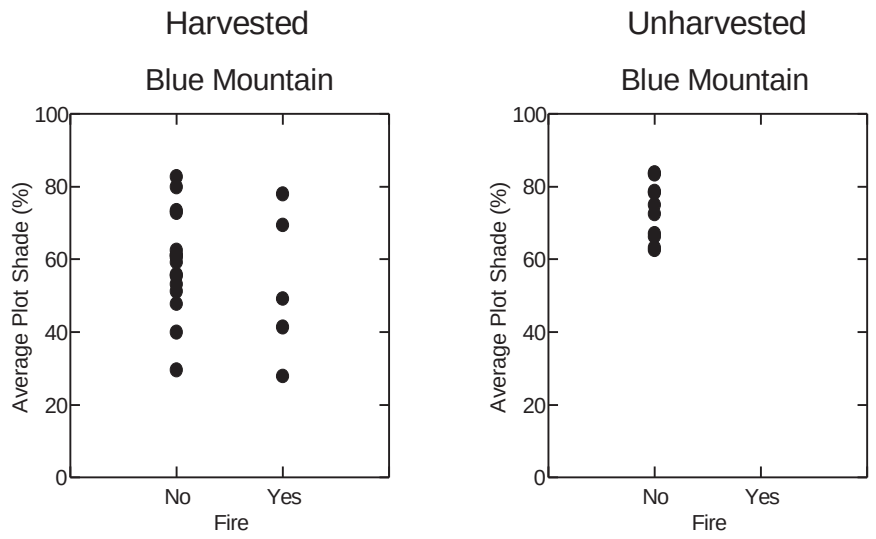


Figure 19. Fire and shade levels in harvested and unharvested Blue Mountain stands.

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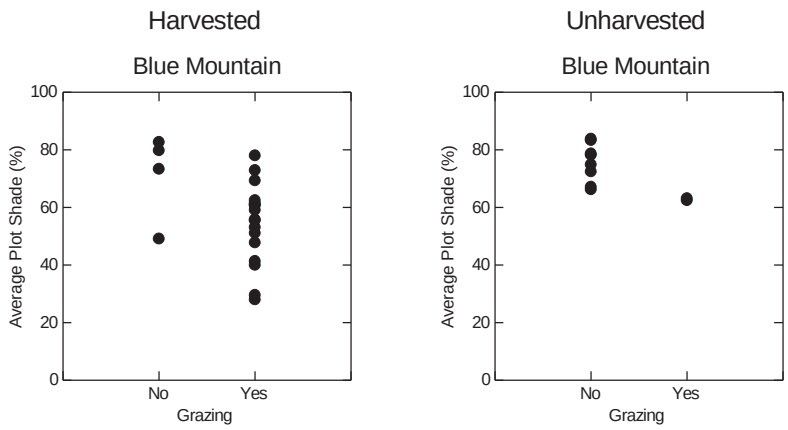


Figure 20. Grazing and shade in harvested and unharvested Blue Mountain stands.

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.

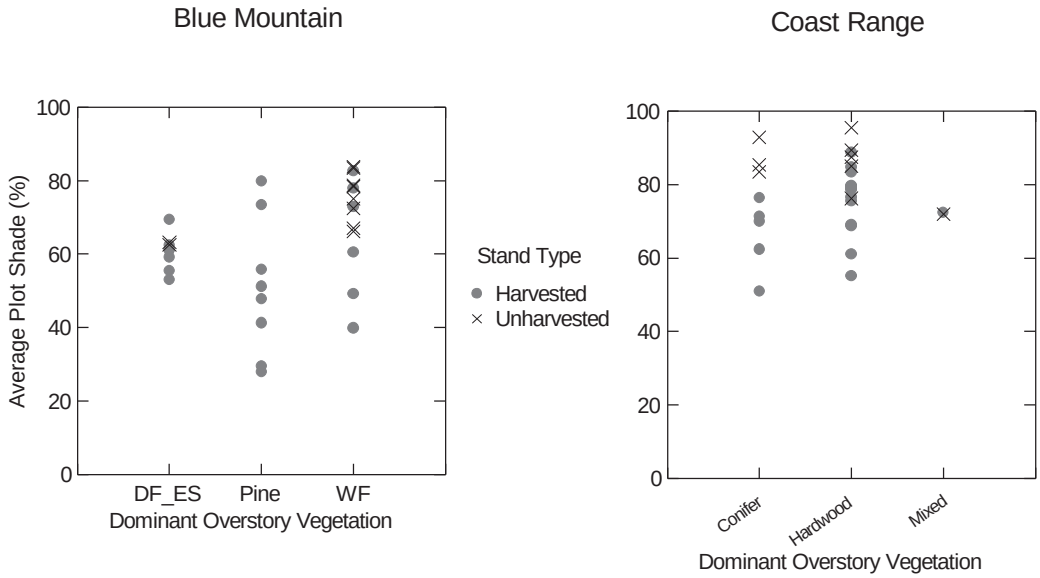


Figure 21. Dominant overstory, shade, and harvest designation by georegion. DF_ES = Douglas-fir/Englemann spruce, WF = White fir.

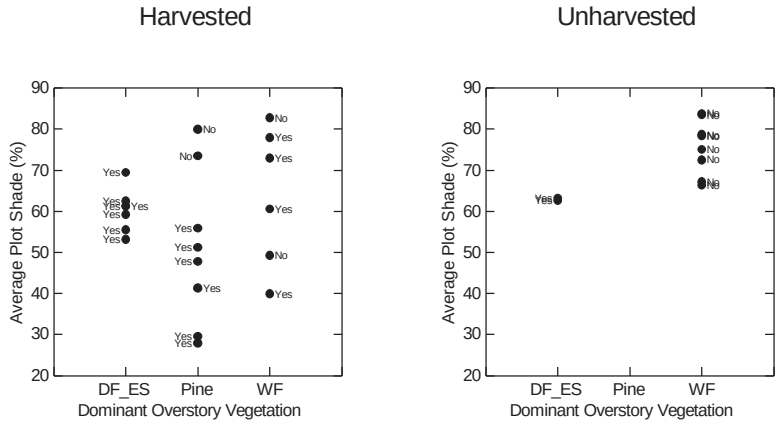


Figure 22. Grazing, shade, and dominant overstory type in the Blue Mountains.

UNDERSTORY VEGETATION

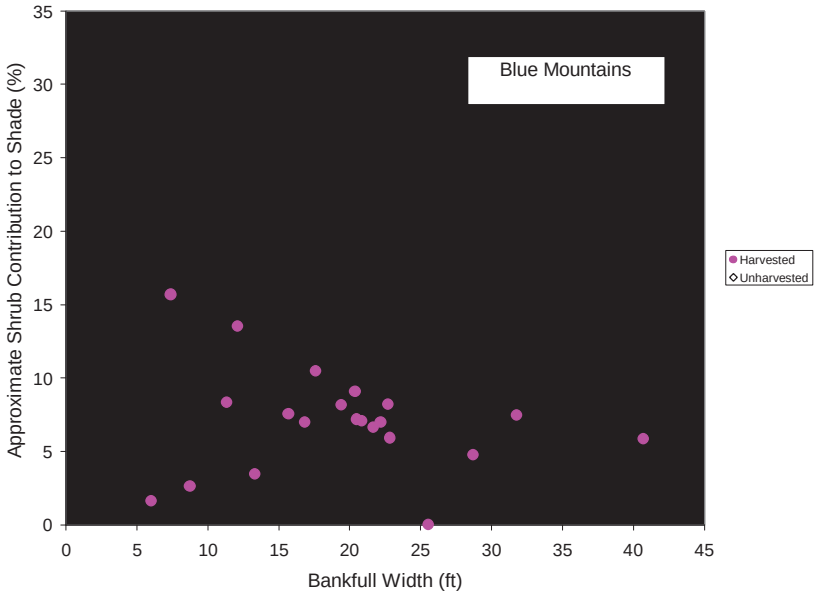
Hemispherical photographs (photos) were taken at heights of three (3ft.) and ten feet (10ft.) above the water surface in order to assess the influence of understory vegetation on stream shade. Since the 10ft. photos rarely eliminated understory shrubs from the photograph, the difference between the 3ft. 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.



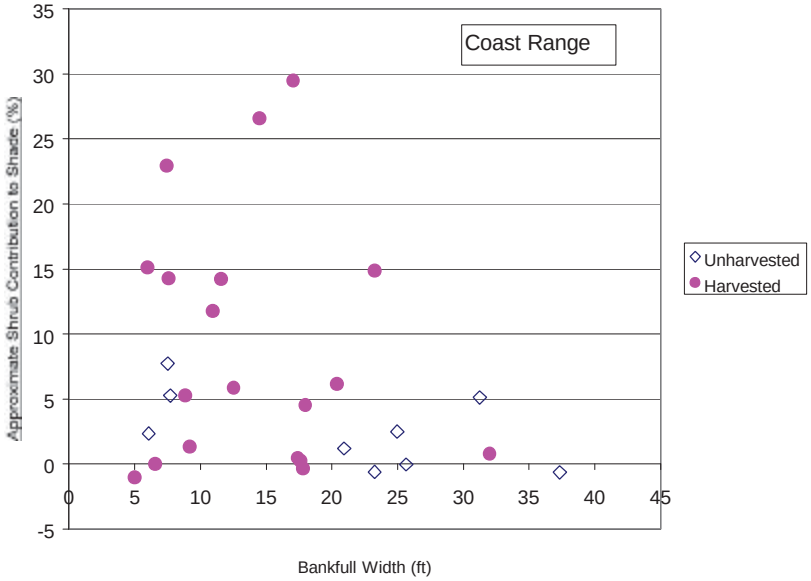


Figure 23. Approximate contribution by shrubs >10 ft tall to shade (3ft. – 10ft. photos) versus bankfull width for the Blue Mountain and Coast Range georegions.

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.

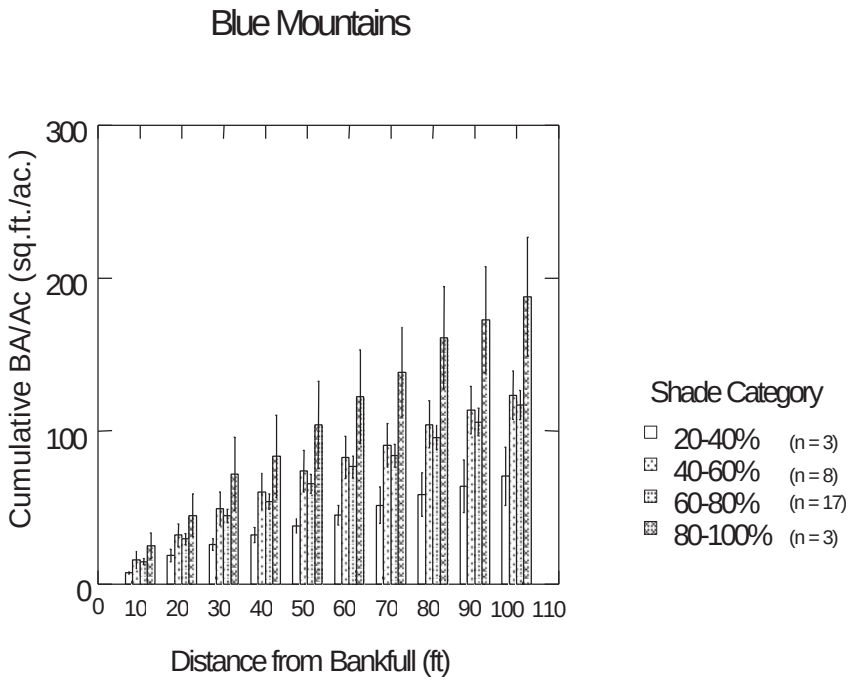


Figure 24. Mean cumulative basal area per acre by distance from bankfull and shade category in the Blue Mountains. Error bars show one standard error of the mean.

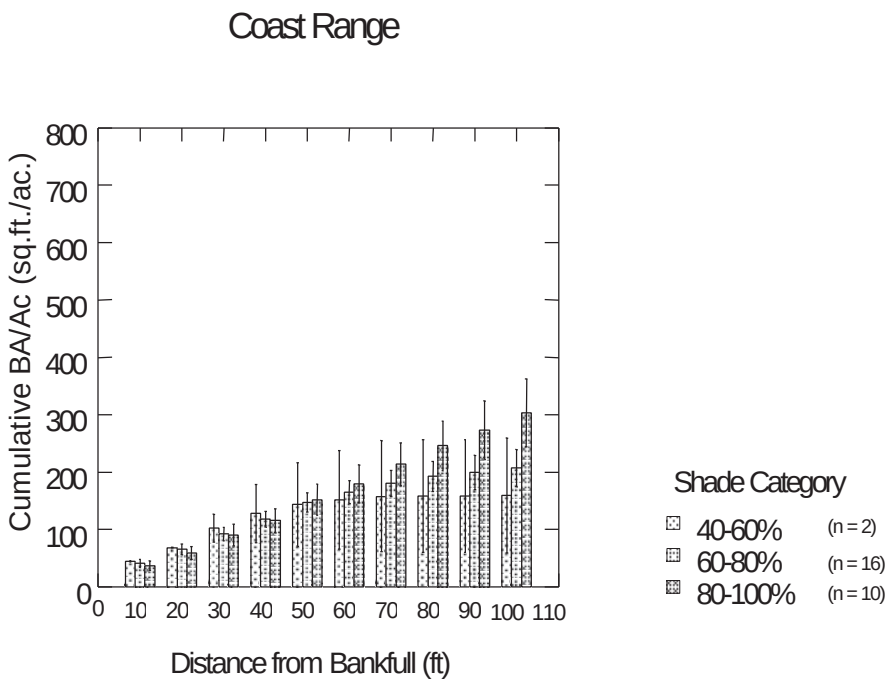


Figure 25. Mean cumulative basal area per acre by distance from bankfull and shade category in the Coast Range. Error bars show one standard error of the mean.

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.

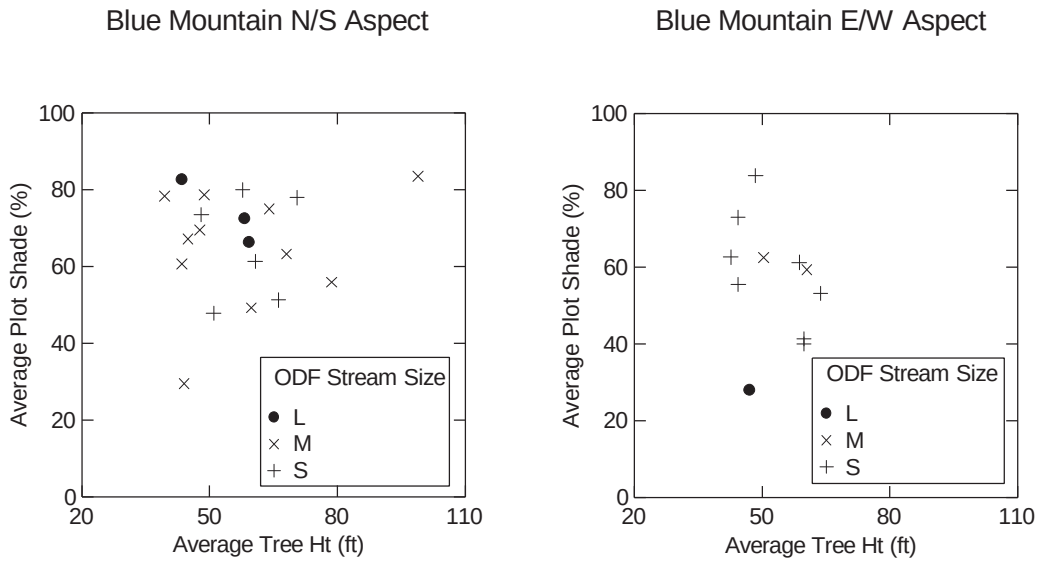


Figure 26. Stream shade over Blue Mountain streams by aspect, average tree height, and ODF stream class.

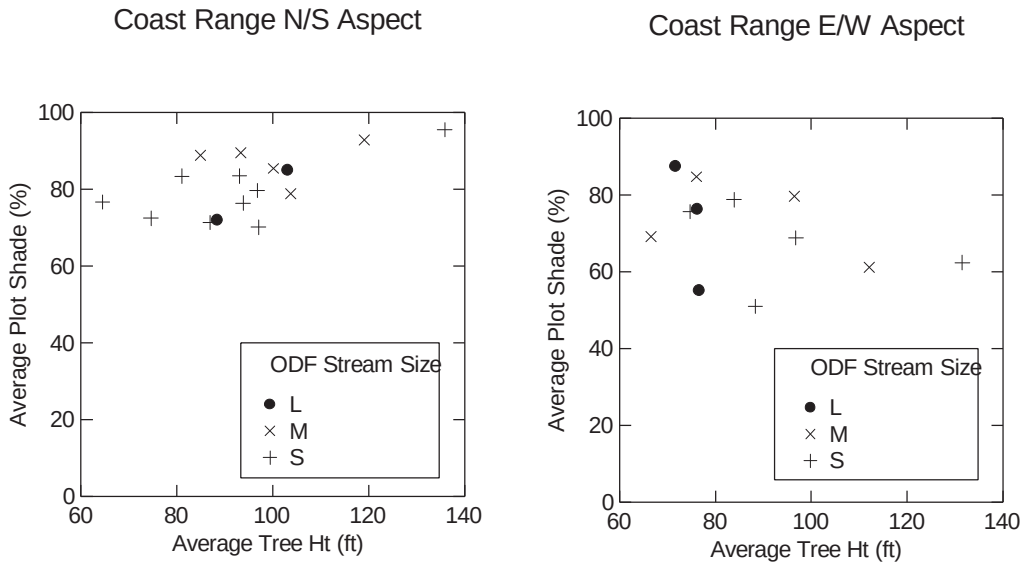


Figure 27. Stream shade over Coast Range streams by aspect, average tree height, and ODF stream class.

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.

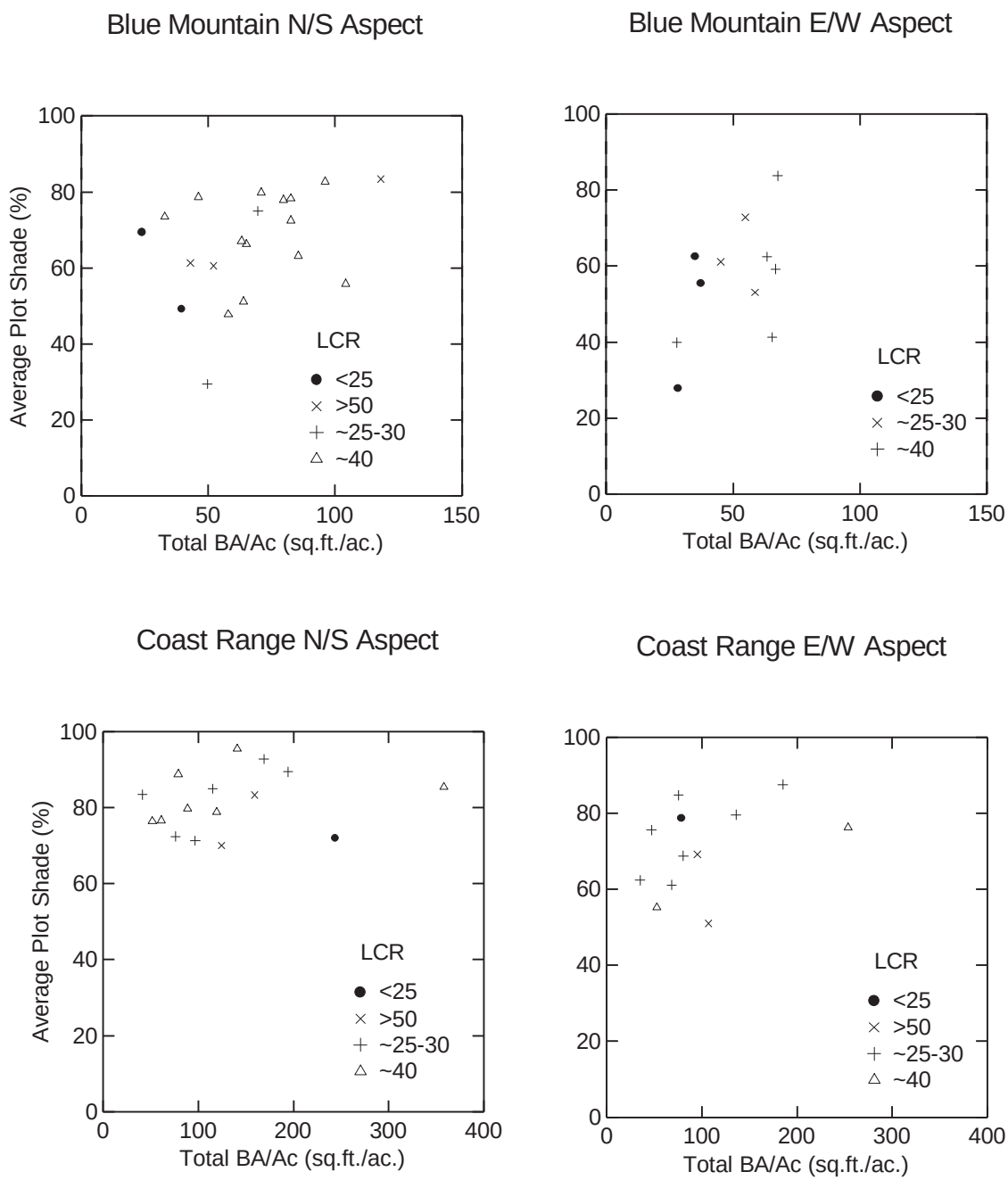


Figure 28. Shade versus basal area per acre for each georegion by aspect and live crown ratio (LCR).

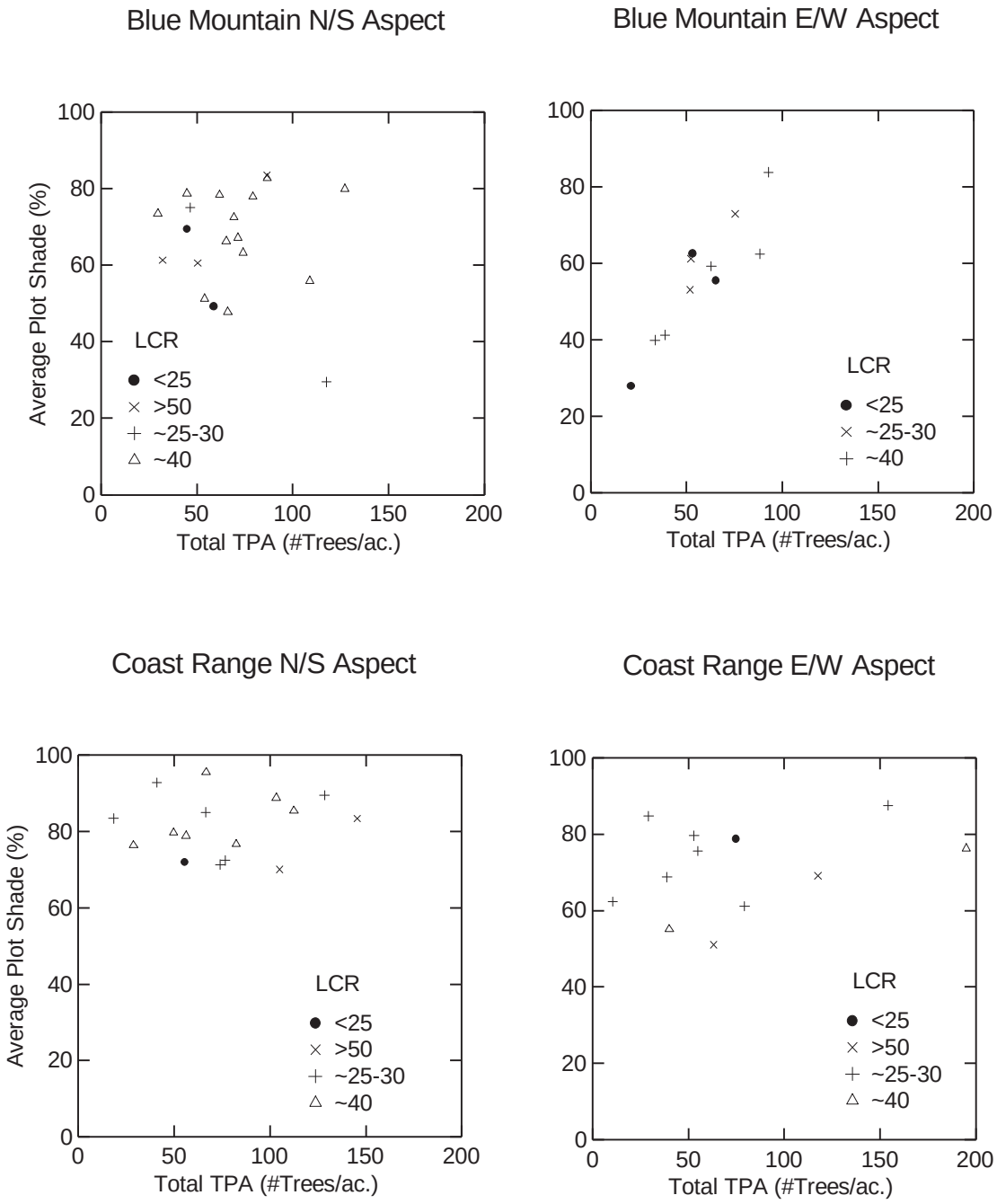


Figure 29. Shade versus trees per acre for each georegion by aspect and live crown ratio (LCR).

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.

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

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.

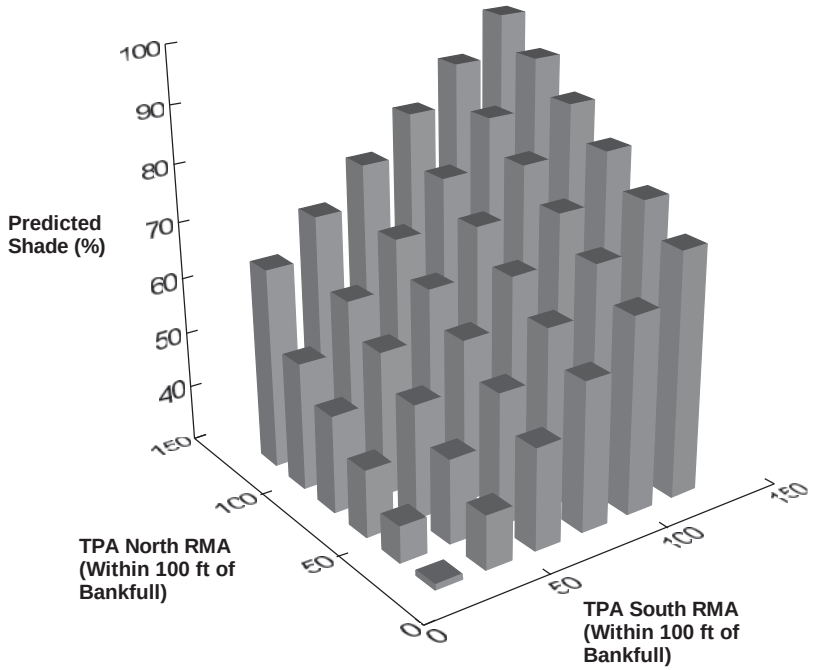


Figure 30. Predicted shade over east/west flowing Blue Mountain streams (Equation 1) across a range of live crown ratios (LCR) and basal area per acre within 100 feet of bankfull in the south RMA.

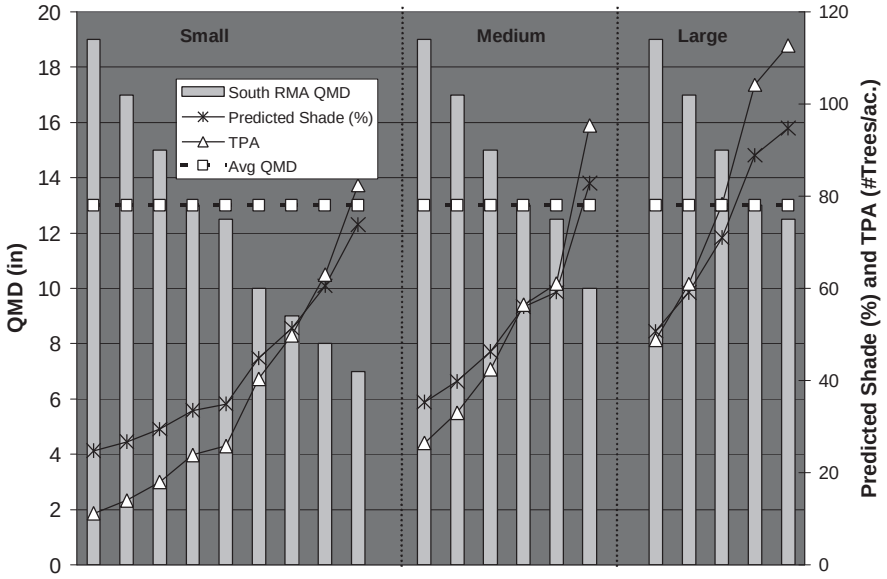


Figure 31. Predicted shade as QMD is held constant and different FPA standard basal area targets are applied for small, medium, and large streams. Calculated trees/acre (TPA) for each QMD is shown. Measured average QMD is also shown.

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.

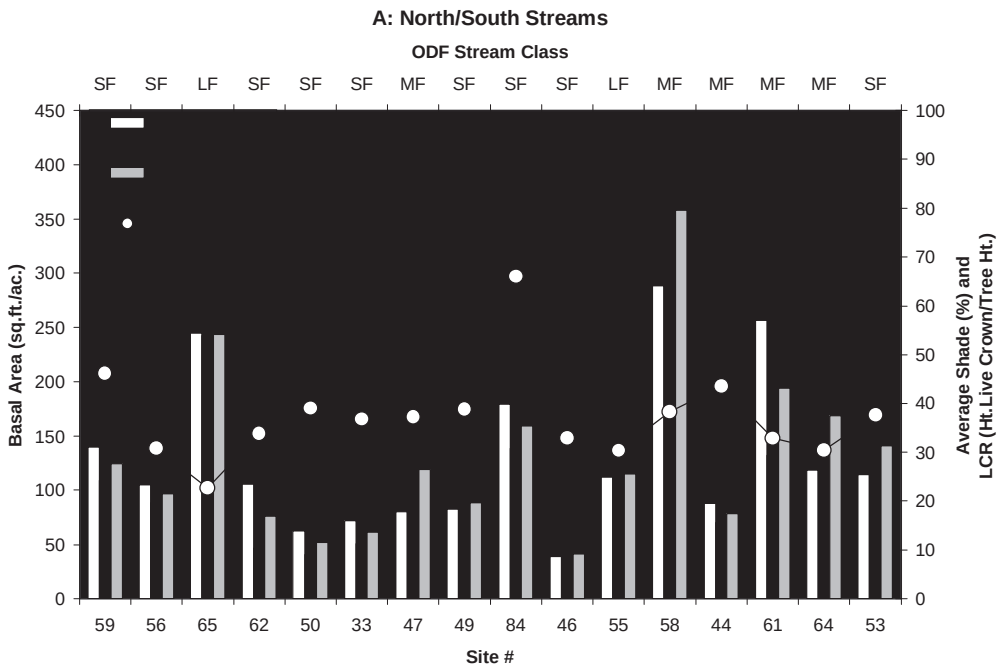
$$\text{Average \% Shade} = 96.153 - 1.041*\text{LCR} + 0.107*\text{South BA/Ac (100ft)}$$
$$(\text{adj. } r^2 = 0.656, n=12)$$

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.



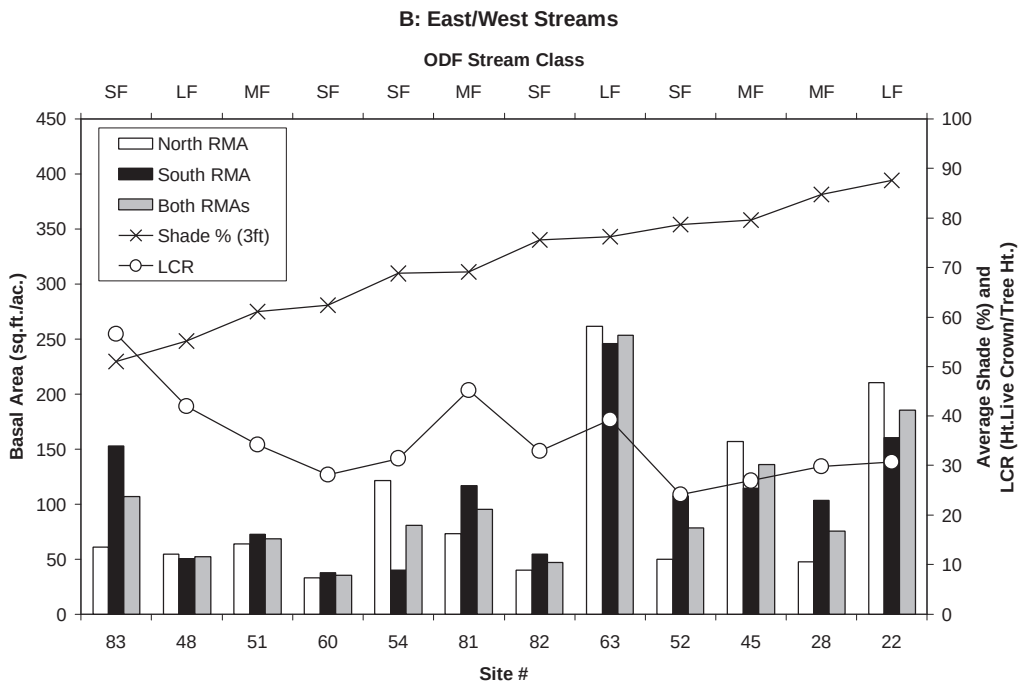


Figure 32. Coast Range basal area, shade, and average live crown ratio (LCR) for (A) north/south and (B) east/west flowing streams. Data are represented in ascending order by shade. SF = small type F stream, MF = medium type F stream, and LF = large type F stream.

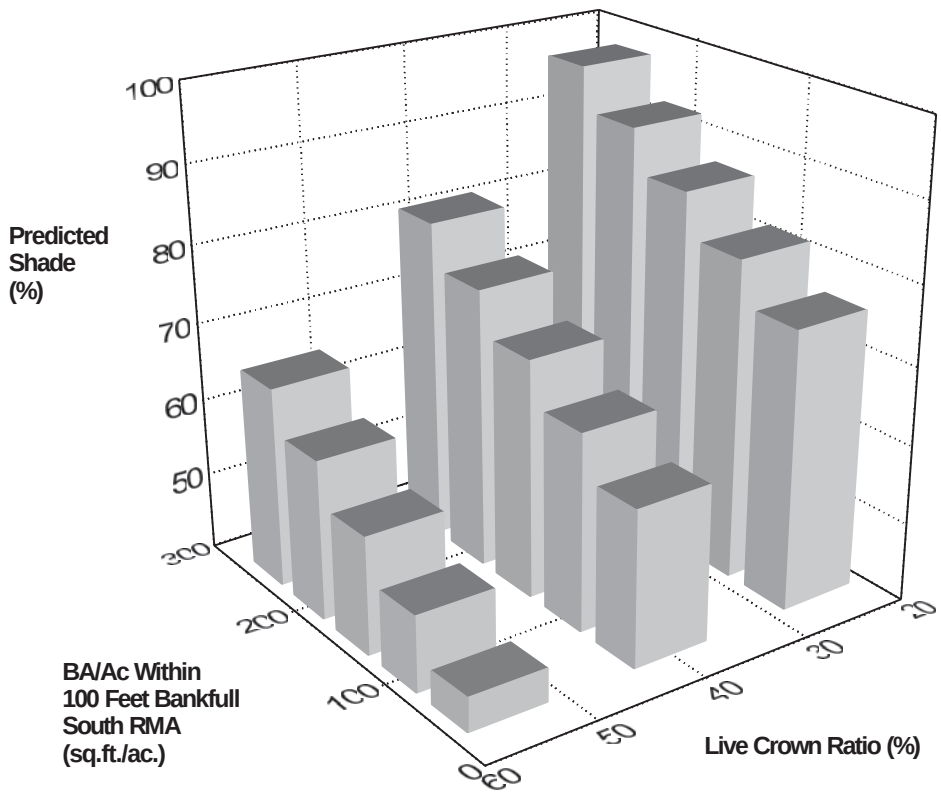


Figure 33. Predicted shade over east/west flowing Coast Range streams (Equation 2) across a range of live crown ratios (LCR) and basal areas within 100 feet of bankfull in the south RMA.

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.

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APPENDIX A: SITE INFORMATION SUMMARIES

SITE INFORMATION SUMMARIES

Table A-1: General stand and disturbance information.

						Legal Location			Other Disturbances			
SiteID	Georegion	Stand Type	Stream Class*	Harvest Type	RMA** Prescription	T	R	S	Grazing	Fire	% Blow-down	% Insects & Disease
20	Coast Range	Harvested	MF	Clearcut	BW	12S	08W	32	No	No		
21	Blue Mountain	Harvested	SF	Thin	SS	04S	29E	11	Yes	Yes	2	2
22	Coast Range	Unharvested	LF	NA	NA	08N	08W	35	No	No	0	0
25	Coast Range	Harvested	LF	Clearcut	BW	08N	08W	35	No	No		
28	Coast Range	Harvested	MF	Clearcut	BW	15S	08W	02	No	No	11	1
29	Blue Mountain	Harvested	SF	Thin	SS	05N	44E	03	Yes	No	6	1
30	Blue Mountain	Harvested	MF	Thin	SS	04N	41E	13, 14, 24	No	Yes	0	3
31	Blue Mountain	Harvested	LF	Thin	SS	01N	34E	22	Yes	Yes	1	0
32	Blue Mountain	Harvested	SF	Clearcut	SS	04S	29E	10	Yes	No	13	0
33	Coast Range	Harvested	SF	Clearcut	BW	07S	10W	4	No	No	2	0
34	Blue Mountain	Harvested	MF	Thin	SS	06S	30E	17	Yes	No	0	0
35	Blue Mountain	Late Seral	MF	NA	NA	04N	39E	3	No	No	2	1
36	Blue Mountain	Harvested	SF	Thin	SS	05S	41E	30	Yes	No	7	2
37	Blue Mountain	Harvested	SF	Thin	SS	05S	41E	30	Yes	No	47	8
38	Blue Mountain	Harvested	MF	Thin	SS	05S	41E	20	Yes	No	5	13
40	Blue Mountain	Unharvested	SF	NA	NA	02N	43E	36	Yes	No	0	3
41	Blue Mountain	Harvested	SF	Thin	BW	02N	43E	36	Yes	No	0	3
42	Blue Mountain	Harvested	MF	Thin	SS	05S	31E	17	Yes	No	0	27
44	Coast Range	Harvested	MF	Clearcut	SS	14S	08W	36	No	No	1	1
45	Coast Range	Harvested	MF	Clearcut	SS	07S	09W	20	No	No	0	0
46	Coast Range	Harvested	SF	Clearcut	RCR	07S	09W	19	No	No	0	0
47	Coast Range	Harvested	MF	Clearcut	BW	05N	05W	01	No	Yes	2	0

						Legal Location			Other Disturbances			
SiteID	Georegion	Stand Type	Stream Class*	Harvest Type	RMA** Prescription	T	R	S	Grazing	Fire	% Blow-down	% Insects & Disease
48	Coast Range	Harvested	LF	Clearcut	SS	01S	08W	01	No	No	5	0
49	Coast Range	Harvested	SF	Clearcut	BW	05N	01W	19	No	No	0	0
50	Coast Range	Harvested	SF	Clearcut	BW	05N	05W	35	No	No	20	0
51	Coast Range	Harvested	MF	Clearcut	RCR	07N	05W	32	No	No	0	0
52	Coast Range	Harvested	SF	Clearcut	BW	06N	04W	18	No	No	0	0
53	Coast Range	Late Seral	SF	NA	NA	14S	08W	35	No	No	0	0
54	Coast Range	Harvested	SF	Clearcut	BW	04N	08W	01	No	No	8	0
55	Coast Range	Late Seral	LF	NA	NA	14S	07W	19	No	No	0	0
56	Coast Range	Harvested	SF	Clearcut	BW	03S	10W	03	No	No	9	0
58	Coast Range	Late Seral	MF	NA	NA	12S	07W	29	No	No	0	0
59	Coast Range	Harvested	SF	Clearcut	BW	03S	10W	18	No	No	13	0
60	Coast Range	Harvested	SF	Clearcut	BW	12S	08W	36	No	No	4	0
61	Coast Range	Late Seral	MF	NA	NA	13S	08W	27	No	No	0	0
62	Coast Range	Harvested	SF	Clearcut	BW	03S	10W	13	No	No	2	0
63	Coast Range	Unharvested	LF	NA	NA	05N	10W	33	No	No	0	0
64	Coast Range	Late Seral	MF	NA	NA	12S	08W	36	No	No	0	0
65	Coast Range	Late Seral	LF	NA	NA	14S	07W	29	No	No	0	0
66	Blue Mountain	Harvested	SF	Thin	SS	02N	44E	32	Yes	No	0	4
67	Blue Mountain	Late Seral	MF	NA	NA	03N	37E	18	No	No	3	14
68	Blue Mountain	Harvested	MF	Thin	SS	04N	41E	13	Yes	Yes	0	4
69	Blue Mountain	Unharvested	MF	NA	NA	02N	45E	21	Yes	No	0	0
70	Blue Mountain	Harvested	SF	Thin	SS	02N	46E	6	Yes	No	0	1
71	Blue Mountain	Harvested	MF	Thin	BW	02N	43E	3	Yes	No	10	4
72	Blue Mountain	Late Seral	MF	NA	NA	02N	37E	7	No	No	1	0
74	Blue Mountain	Harvested	SF	Thin	SS	01N	34E	36	Yes	No	0	23
75	Blue Mountain	Unharvested	MF	NA	NA	02N	37E	5	No	No	2	2
76	Blue Mountain	Late Seral	LF	NA	NA	03N	37E	22	No	No	2	6

						Legal Location			Other Disturbances			
SiteID	Georegion	Stand Type	Stream Class*	Harvest Type	RMA** Prescription	T	R	S	Grazing	Fire	% Blow-down	% Insects & Disease
77	Blue Mountain	Late Seral	LF	NA	NA	03N	37E	22	No	No	0	11
78	Blue Mountain	Unharvested	SF	NA	NA	03N	43E	34	No	No	7	1
79	Blue Mountain	Harvested	MF	Thin	SS	05S	31E	09	Yes	No	0	14
80	Blue Mountain	Late Seral	MF	NA	NA	02N	37E	10	No	No	2	2
81	Coast Range	Harvested	MF	Clearcut	BW	06S	10W	14	No	No	16	0
82	Coast Range	Harvested	SF	Clearcut	BW	06S	10W	14	No	No	14	0
83	Coast Range	Harvested	SF	Clearcut	BW	05N	10W	23	No	No	39	1
84	Coast Range	Unharvested	SF	NA	NA	05N	10W	23	No	No	2	4
85	Blue Mountain	Harvested	SF	Clearcut	SS	01S	35E	04	No	No	0	25
86	Blue Mountain	Harvested	SF	Thin	SS	17S	29E	06	Yes	Yes	0	4
87	Blue Mountain	Harvested	SF	Thin	SS	14S	30E	24	No	No	4	6
88	Blue Mountain	Harvested	LF	Thin	SS	14S	35E	34	No	No	0	5

* 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 (%)	Dominant Overstory Vegetation Type
20	60	104	100	83	98	26	46	43	Conifer
21	100		71		71		37	37	White Fir
22	55	75	59	84	80	32	24	31	Hardwood
25	60	125	68	96	88	54	42	51	Hardwood
28	50	70	73	79	77	29	31	30	Hardwood
29	35	36	50	39	49	34	28	28	White Fir
30		104	60		60		23	23	White Fir
31		68	62	32	60	16	21	21	Pine
32		123	60		60		35	35	White Fir
33			59	70	69	36	39	37	Hardwood
34		100	44		44		26	26	Pine
35			82	116	83	43	62	61	White Fir
36			66		66		40	40	Pine
37			61		61		47	47	Doug.Fir/Englemann Spruce
38			62	25	61	36	51	51	White Fir
40		60	43		43		18	18	Doug.Fir/Englemann Spruce
41			59		59		32	32	Doug.Fir/Englemann Spruce
42			61		61		36	36	Doug.Fir/Englemann Spruce
44	27	90	85	85	85	44	33	44	Hardwood
45	45	80	91	102	99	29	21	27	Hardwood
46	49	56	67	120	108	31	40	33	Hardwood
47	50	90	124	83	98	36	40	37	Hardwood
48	35	50	72	81	80	43	33	42	Hardwood
49	45	70	98	96	96	41	30	39	Hardwood
50		55	108	79	106	33	39	39	Conifer

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 (%)	Dominant Overstory Vegetation Type
51	35	55	139	86	87	34	40	34	Hardwood
52	35	44	81	87	86	22	45	24	Hardwood
53	30	100	187	84	110	39	34	38	Hardwood
54	45	55	109	85	92	28	38	31	Hardwood
55	25	100	130	76	84	32	23	30	Hardwood
56	40	51	86	88	86	16	37	31	Conifer
58		100	122	78	121	40	38	38	Conifer
59	45	46	103	91	99	45	47	46	Conifer
60	67	92	126	137	128	28	28	28	Conifer
61	50	100	100	86	89	36	16	33	Hardwood
62	30	35	80	69	75	32	35	34	Mixed
63	43	120	68	84	79	44	29	39	Hardwood
64	60	100	144	94	129	17	36	30	Conifer
65	55	80	93	84	89	23	22	23	Mixed
66		107	44		44		24	24	Doug.Fir/Englemann Spruce
67	53	160	79	49	73	38	30	32	White Fir
68		26	48		48		24	24	Doug.Fir/Englemann Spruce
69		50	68		68		44	44	Doug.Fir/Englemann Spruce
70		55	51		51		35	35	Pine
71		78	57	44	57	14	37	36	Doug.Fir/Englemann Spruce
72	21	25	48	31	46	35	44	43	White Fir
74		29	64		64		32	32	Doug.Fir/Englemann Spruce
75	23	32	46	44	45	45	32	37	White Fir
76	51	49	71	47	60	47	35	40	White Fir
77	25	82	74	43	66	38	37	37	White Fir
78		92	48		48		40	40	White Fir
79		92	65	92	66	37	42	42	Pine

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 (%)	Dominant Overstory Vegetation Type
80	23	37	57	41	56	56	40	41	White Fir
81	30	43	58	75	72	46	44	45	Hardwood
82	35	45	67	82	79	35	25	33	Hardwood
83	31	53	98	79	93	56	57	57	Conifer
84	25	32	81	81	81	71	63	66	Conifer
85			58		58		41	41	Pine
86		53	60		60		38	38	Pine
87	88	53	71		71		41	41	Pine
88	43	29	61		61		44	44	White Fir

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.)				Half Plot TPA (#Trees/ac.)			
					East	West	North	South	East	West	North	South
20	2.3	35.0	13.5	1.1	26.9	43.2			9.6	17.4		
21	2.3	79.6	79.3	1.1	69.7	89.6			68.8	89.7		
22	2.3	185.1	154.2	1.1			210.0	160.1			186.4	122.0
25	2.3	157.2	71.4	1.1			109.4	205.1			48.8	94.1
28	2.3	75.4	29.2	1.1			47.4	103.4			23.5	34.8
29	2.3	54.7	75.4	1.1			59.5	49.9			68.8	81.9
30	2.3	39.6	58.8	1.1	50.1	29.1			57.5	60.1		
31	4.6	28.2	21.1	2.3			43.0	13.4			30.5	11.8
32	2.3	27.8	33.5	1.1			23.1	32.5			38.3	28.7
33	2.3	61.2	82.3	1.1	71.9	50.6			103.7	61.0		
34	2.3	49.7	117.6	1.1	55.2	44.2			118.5	116.7		
35	3.7	118.1	86.6	1.8	112.3	123.8			96.4	76.8		
36	2.3	63.9	54.0	1.1	63.7	64.2			42.7	65.3		
37	2.3	43.0	32.2	1.1	42.8	43.2			30.5	34.0		
38	3.7	52.1	50.4	1.8	50.7	53.6			45.7	55.0		
40	2.3	35.0	53.1	1.1			35.7	34.2			42.7	63.6
41	2.3	45.2	52.3	1.1			22.3	68.0			26.1	78.4
42	3.7	66.8	62.9	1.8			51.2	82.3			45.2	80.6
44	3.7	78.8	103.2	1.8	87.7	70.0			98.6	107.8		
45	4.6	135.7	52.9	2.3			156.9	114.5			48.4	57.5
46	2.3	41.2	18.3	1.1	39.1	43.3			13.9	22.7		
47	3.7	119.3	56.1	1.8	80.2	158.5			56.1	56.1		
48	3.7	52.4	40.0	1.8			54.5	50.4			46.3	33.8
49	2.3	88.5	49.7	1.1	82.9	94.1			55.8	43.6		
50	2.3	51.7	28.7	1.1	62.6	40.8			32.2	25.3		
51	2.3	68.3	79.3	1.1			64.0	72.6			81.0	77.5
52	2.3	78.5	74.9	1.1			49.8	107.3			38.3	111.5

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.)				Half Plot TPA (#Trees/ac.)			
					East	West	North	South	East	West	North	South
53	2.3	140.8	66.6	1.1	114.3	167.2			69.7	63.6		
54	2.3	80.5	38.8	1.1			121.1	39.9			39.2	38.3
55	3.7	115.0	66.4	1.8	112.1	117.9			32.7	100.2		
56	2.3	96.7	74.1	1.1	105.0	88.3			87.1	61.0		
58	3.7	358.0	112.4	1.8	288.8	427.2			106.7	118.2		
59	2.3	124.3	105.0	1.1	139.7	109.0			117.6	92.3		
60	2.3	35.1	10.5	1.1			32.8	37.4			10.5	10.5
61	3.7	194.2	128.5	1.8	256.6	131.9			76.8	180.2		
62	2.3	76.0	76.7	1.1	105.3	46.7			87.1	66.2		
63	4.6	253.7	194.9	2.3			261.6	245.7			166.8	223.0
64	2.3	168.8	40.9	1.1	118.7	219.0			28.7	53.1		
65	4.6	243.7	55.5	2.3	245.0	242.4			57.5	53.6		
66	2.3	37.2	65.3	1.1			35.9	38.6			42.7	88.0
67	3.7	69.7	46.6	1.8	79.9	59.6			51.2	41.9		
68	2.3	23.9	44.9	1.1	21.0	26.9			41.8	47.9		
69	2.8	85.6	74.1	1.4	70.3	100.8			69.0	79.1		
70	2.3	58.0	66.2	1.1	73.2	42.7			81.9	50.5		
71	3.7	63.4	88.2	1.8			96.0	30.7			137.2	39.2
72	2.3	82.6	61.9	1.1	114.0	51.1			73.2	50.5		
74	2.3	58.6	51.8	1.1			88.5	28.6			63.6	40.1
75	2.3	63.2	71.4	1.1	57.2	69.1			70.6	72.3		
76	4.6	65.1	65.3	2.3	59.4	70.8			48.4	82.3		
77	3.7	82.7	69.4	1.8	104.4	61.0			79.0	59.9		
78	2.3	67.5	92.8	1.1			92.4	42.6			128.1	57.5
79	3.7	104.3	108.9	1.8	117.6	90.9			104.5	113.3		
80	2.3	46.2	44.9	1.1	63.6	28.7			49.7	40.1		
81	2.3	95.2	117.6	1.1			73.5	116.9			66.2	169.0
82	2.3	47.1	54.9	1.1			39.6	54.5			45.3	64.5
83	2.3	107.0	63.2	1.1			61.2	152.7			32.2	94.1

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.)				Half Plot TPA (#Trees/ac.)			
					East	West	North	South	East	West	North	South
84	2.3	159.2	145.5	1.1	179.6	138.7			139.4	151.6		
85	2.3	71.0	127.2	1.1	46.1	95.9			78.4	176.0		
86	2.3	65.4	38.8	1.1			85.7	45.0			55.8	21.8
87	2.3	33.0	29.6	1.1	32.9	33.0			33.1	26.1		
88	4.6	96.2	86.7	2.3	85.3	107.1			91.5	81.9		

APPENDIX B: SHADE AND COVER SUMMARY INFORMATION BY SITE

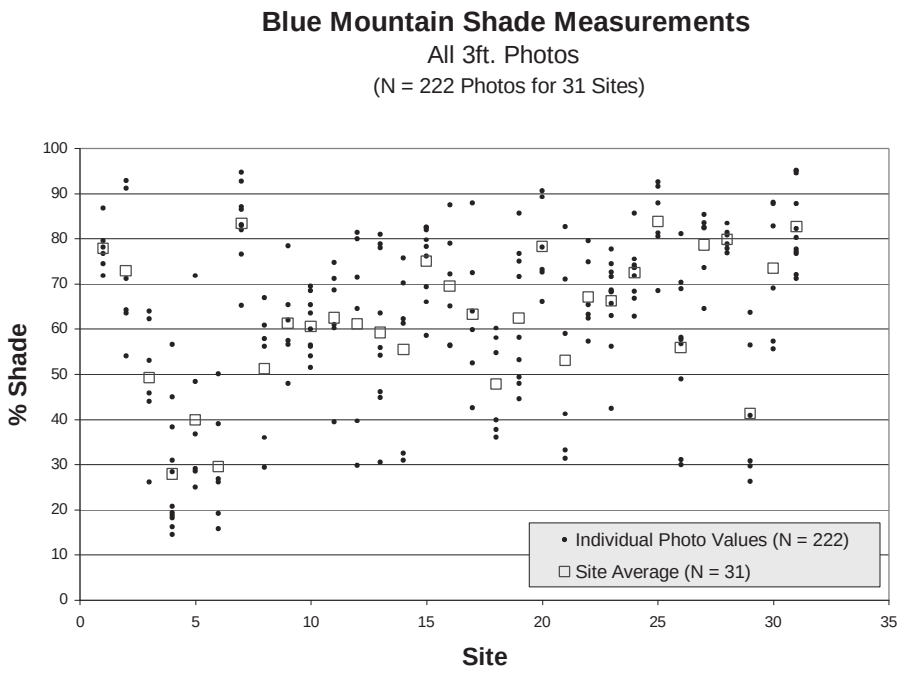
SHADE AND COVER SUMMARY INFORMATION BY SITE.

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 Cover %	Min Cover %	SD Cover %
20	Coast Range					75	97	43	20.0
21	Blue Mountain	78	87	72	4.8	92	97	87	3.3
22	Coast Range	88	94	77	6.2				
25	Coast Range					77	96	65	10.8
28	Coast Range	85	98	70	11.3	92	99	81	6.0
29	Blue Mountain	73	93	54	14.7	75	85	57	9.1
30	Blue Mountain	49	64	26	13.0	43	62	21	16.3
31	Blue Mountain	28	57	14	13.0	21	37	1	12.7
32	Blue Mountain	40	72	25	16.4	48	71	31	12.7
33	Coast Range	77	87	61	9.5	95	100	90	3.3
34	Blue Mountain	29	50	16	11.9	25	41	6	12.3
35	Blue Mountain	83	95	65	8.3	92	100	84	5.7
36	Blue Mountain	51	67	29	13.9	54	81	9	24.0
37	Blue Mountain	61	78	48	9.5	69	93	50	13.2
38	Blue Mountain	61	69	51	6.2	85	94	62	11.6
40	Blue Mountain	63	75	39	11.7	49	87	15	26.8
41	Blue Mountain	61	81	30	20.0	63	76	34	14.3
42	Blue Mountain	59	81	30	16.7	55	96	24	18.8
44	Coast Range	89	96	82	4.8	98	100	93	2.5
45	Coast Range	80	91	52	10.9	92	100	63	10.2
46	Coast Range	83	94	65	9.6	95	100	81	6.9
47	Coast Range	79	90	57	10.5	98	100	82	5.4
48	Coast Range	55	83	31	14.7	83	96	47	13.8
49	Coast Range	80	89	69	7.4	99	100	97	1.0
50	Coast Range	76	88	61	9.3	94	100	75	8.7

SiteID	Georegion	Avg. Shade %	Max Shade %	Min Shade %	SD Shade %	Avg Cover %	Max Cover %	Min Cover %	SD Cover %
51	Coast Range	61	73	52	7.7	89	100	74	9.1
52	Coast Range	79	86	70	7.3	98	100	90	3.7
53	Coast Range	95	98	91	2.3	100	100	100	0.0
54	Coast Range	69	88	54	11.6	91	97	81	5.6
55	Coast Range	85	93	78	5.5	98	99	97	0.7
56	Coast Range	71	83	60	7.5	95	99	90	2.8
58	Coast Range	85	91	78	4.3	99	100	99	0.6
59	Coast Range	70	83	64	6.2	94	97	90	2.9
60	Coast Range	62	84	45	16.8	78	91	62	12.3
61	Coast Range	89	95	83	2.9	100	100	99	0.5
62	Coast Range	72	80	58	8.1	97	100	91	2.8
63	Coast Range	76	83	64	6.3	98	100	96	1.5
64	Coast Range	93	98	80	6.2	99	100	99	0.7
65	Coast Range	72	96	51	14.1	91	100	81	5.8
66	Blue Mountain	55	76	31	17.7	63	94	22	29.9
67	Blue Mountain	75	83	59	8.1	97	100	91	2.7
68	Blue Mountain	69	87	56	11.6	75	91	51	14.5
69	Blue Mountain	63	88	43	14.6	68	90	53	11.8
70	Blue Mountain	48	60	36	10.2	72	94	37	21.7
71	Blue Mountain	62	86	44	14.2	60	72	44	8.9
72	Blue Mountain	78	91	66	9.0	80	99	63	13.5
74	Blue Mountain	53	83	31	19.6	78	99	56	15.7
75	Blue Mountain	67	80	57	7.8	71	81	63	6.6
76	Blue Mountain	66	78	42	9.4	74	100	40	15.6
77	Blue Mountain	72	86	63	6.1	92	96	88	2.4
78	Blue Mountain	84	93	68	8.4	84	97	66	11.9
79	Blue Mountain	56	81	30	16.3	73	87	56	10.2
80	Blue Mountain	79	85	65	7.5	86	99	76	7.0
81	Coast Range	69	81	46	12.1	88	100	65	13.5
82	Coast Range	76	90	68	7.0	88	100	78	6.9

SiteID	Georegion	Avg. Shade %	Max Shade %	Min Shade %	SD Shade %	Avg Cover %	Max Cover %	Min Cover %	SD Cover %
83	Coast Range	51	61	39	8.4	67	91	44	14.0
84	Coast Range	83	93	81	4.5	99	100	96	1.7
85	Blue Mountain	80	83	77	2.3	94	99	90	3.4
86	Blue Mountain	41	64	26	14.3	43	69	22	15.5
87	Blue Mountain	73	88	56	13.8	89	100	62	12.7
88	Blue Mountain	83	95	71	8.7	91	100	74	9.2



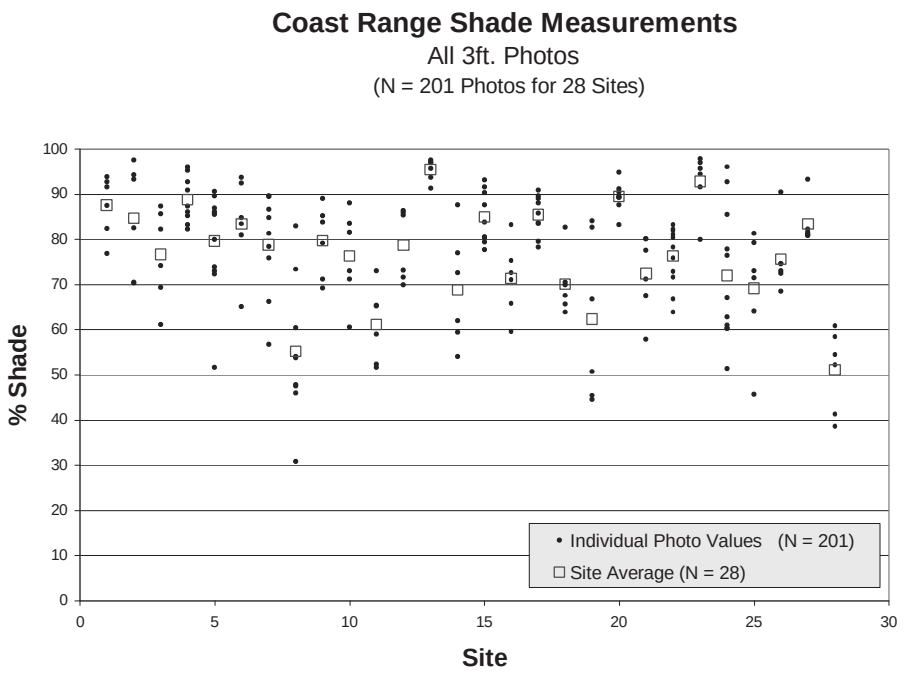


Figure B-1: Individual and average three-foot shade measurements for the Blue Mountain and Coast Range georegions.

APPENDIX C: VALLEY AND CHANNEL MORPHOLOGY RELATIONSHIPS TO SHADE

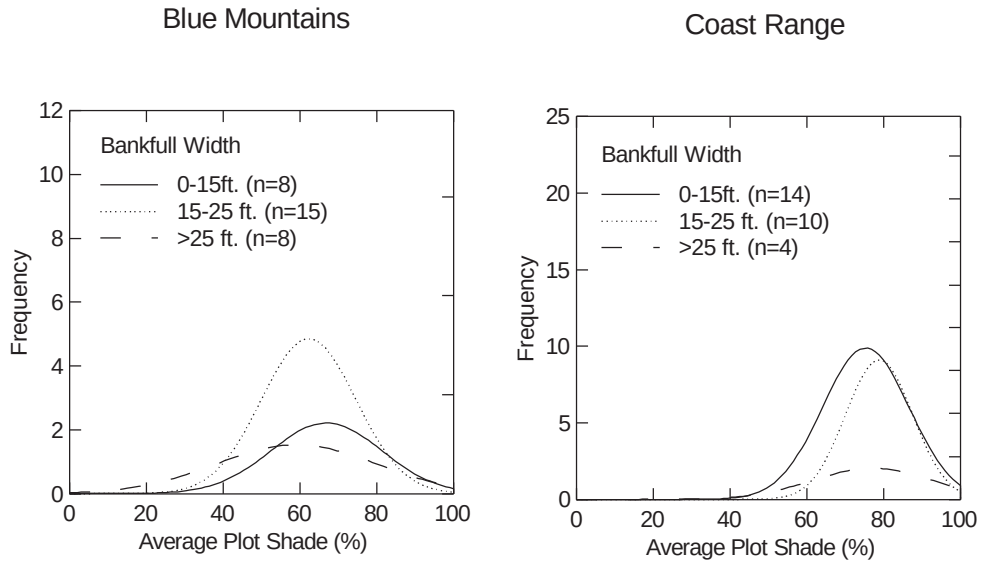


Figure C-1: Frequency of shade values by bankfull width categories and georegion.

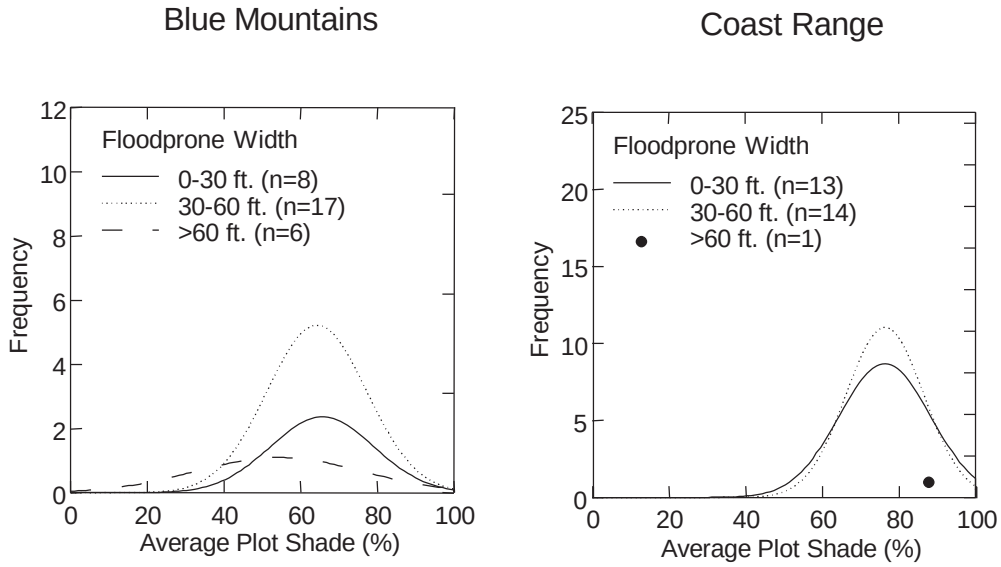


Figure C-2: Frequency of shade values by floodprone width categories and georegion.

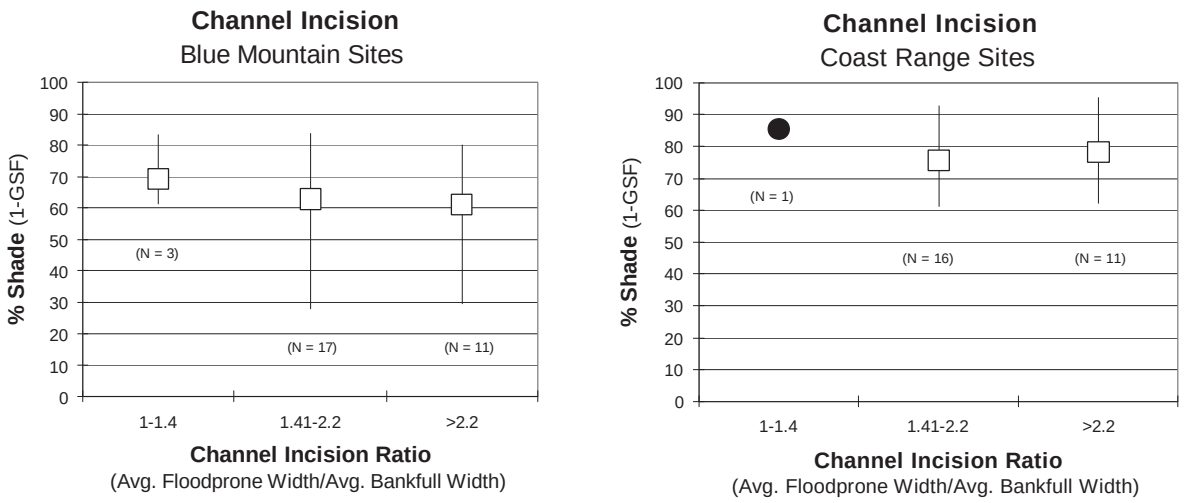


Figure C-3. Channel incision category versus shade by georegion.

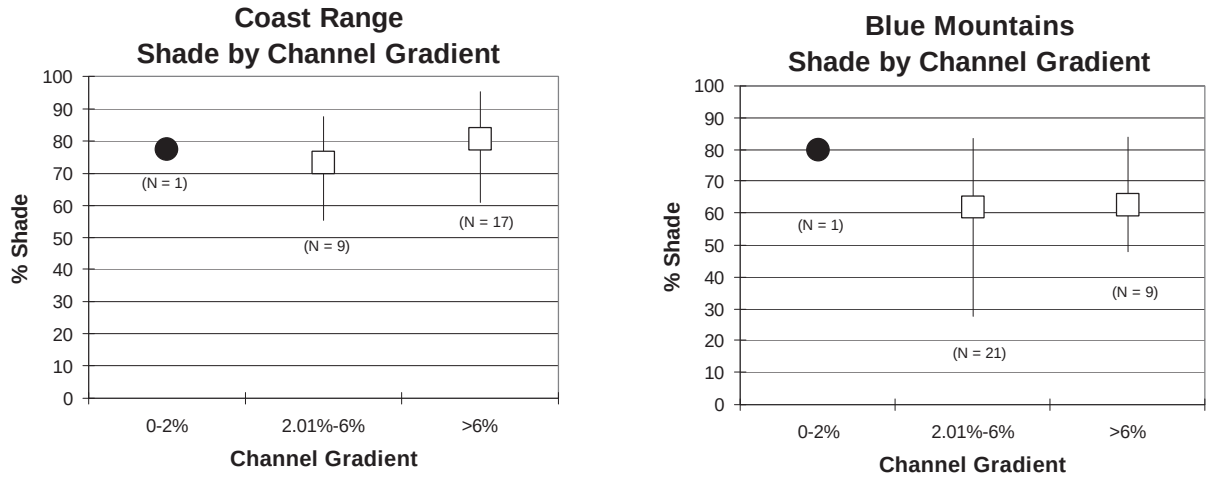


Figure C-4. Shade versus channel gradient by georegion.

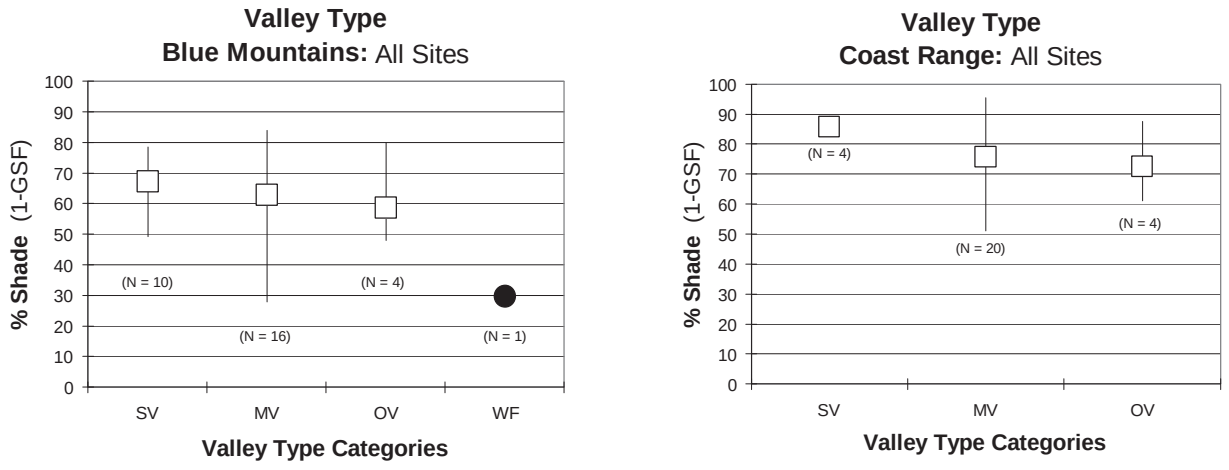


Figure C-5. Shade versus valley type by georegion.

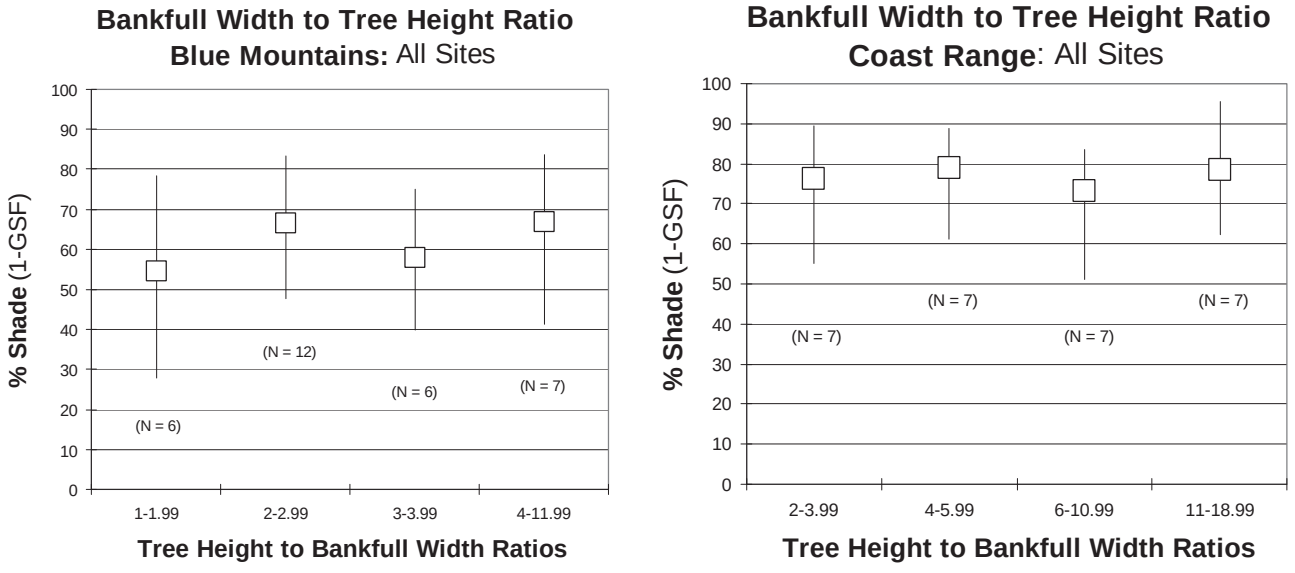


Figure C-6. Shade versus bankfull-width-to-tree-height ratio by georegion.

APPENDIX D: VEGETATION TYPE AND SHADE

AVERAGE PLOT SHADE BY STAND SPECIES COMPOSITION

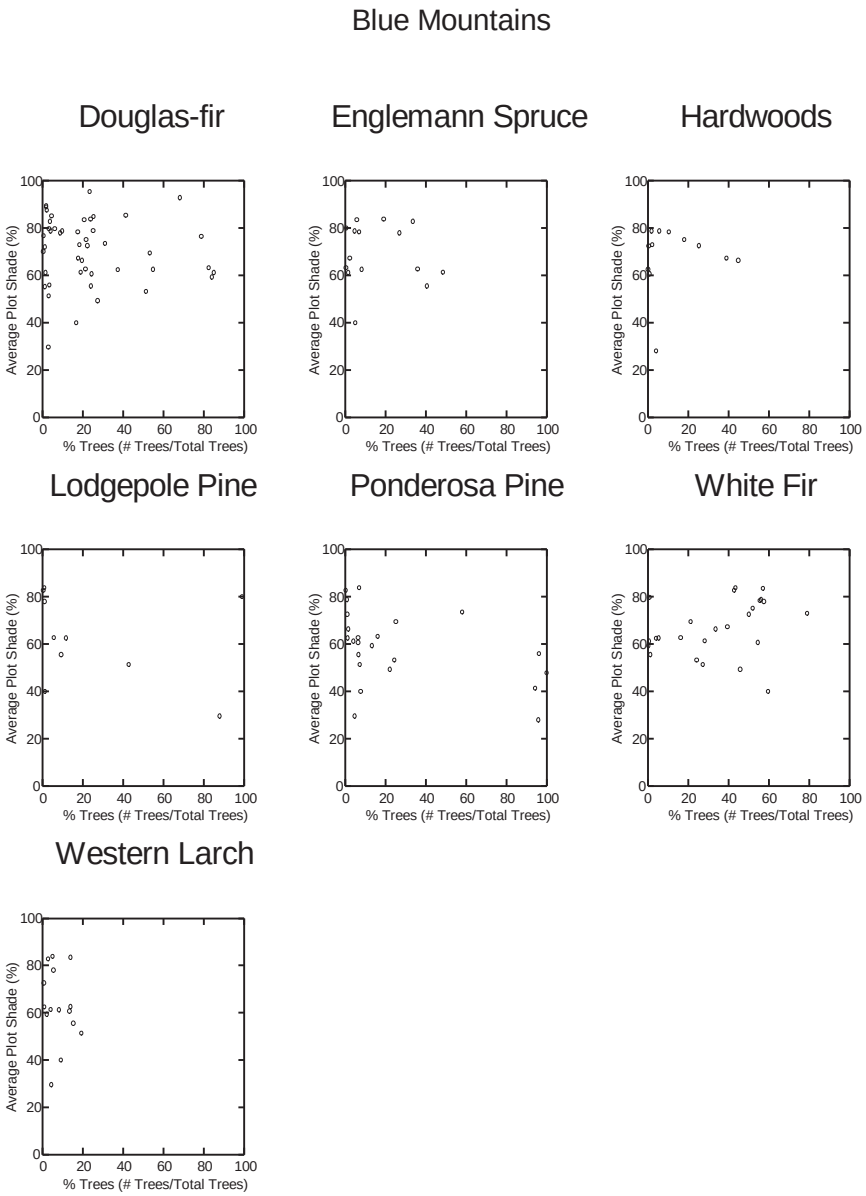


Figure D-1. Percent shade by plot species composition in the Blue Mountains.

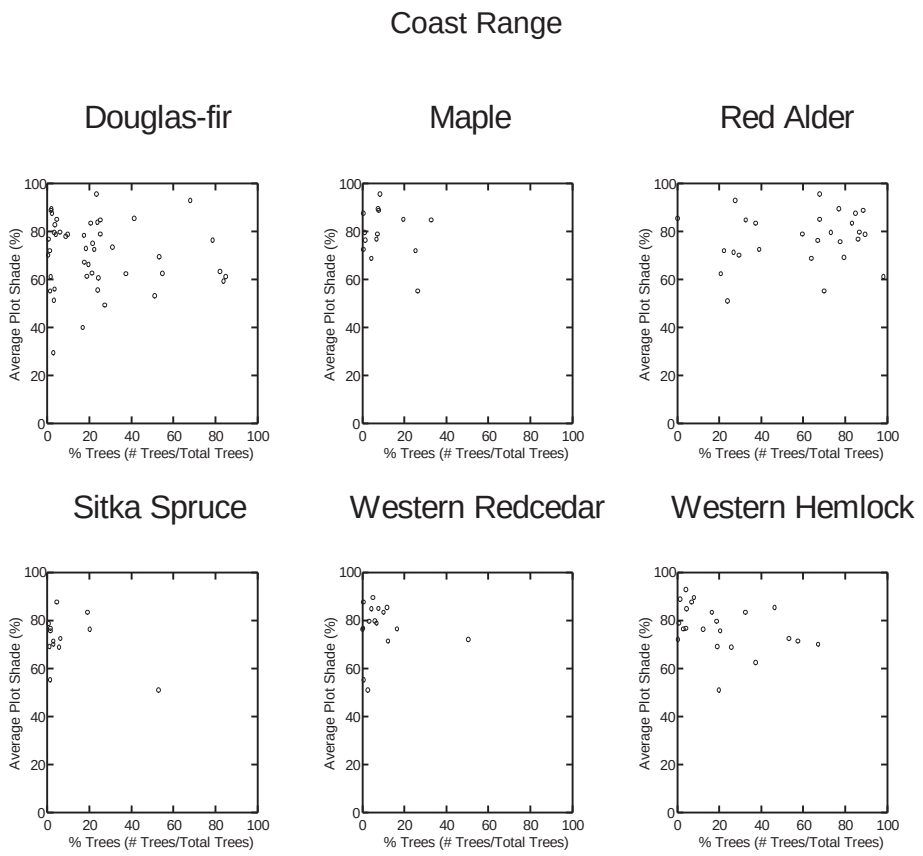


Figure D-2. Percent shade by plot species composition in the Blue Mountains.

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.

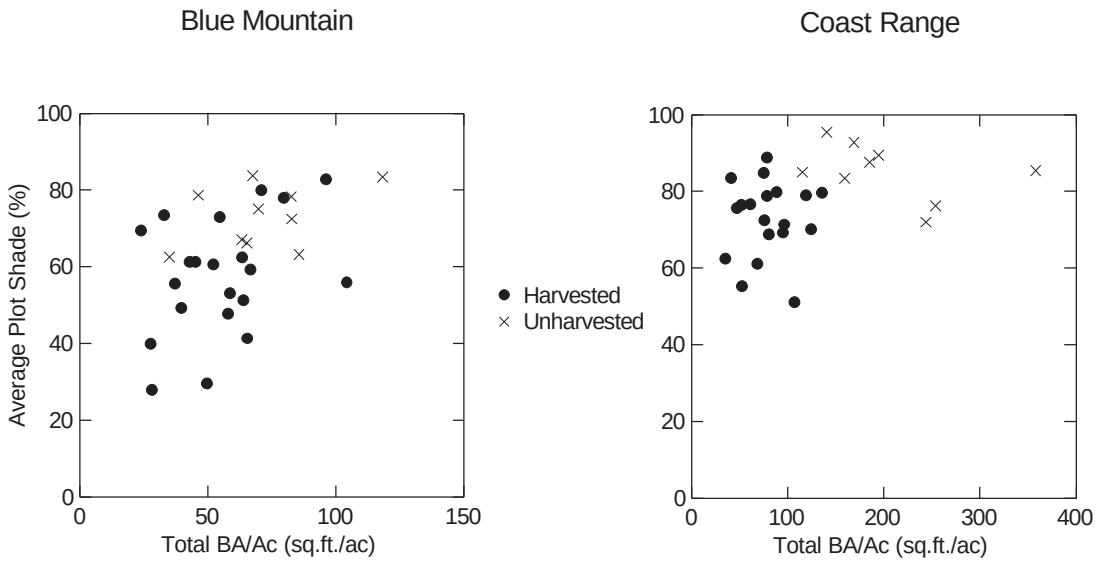


Figure E-1. Percent shade by whole-plot basal area per acre for each georegion in harvested and unharvested stands.

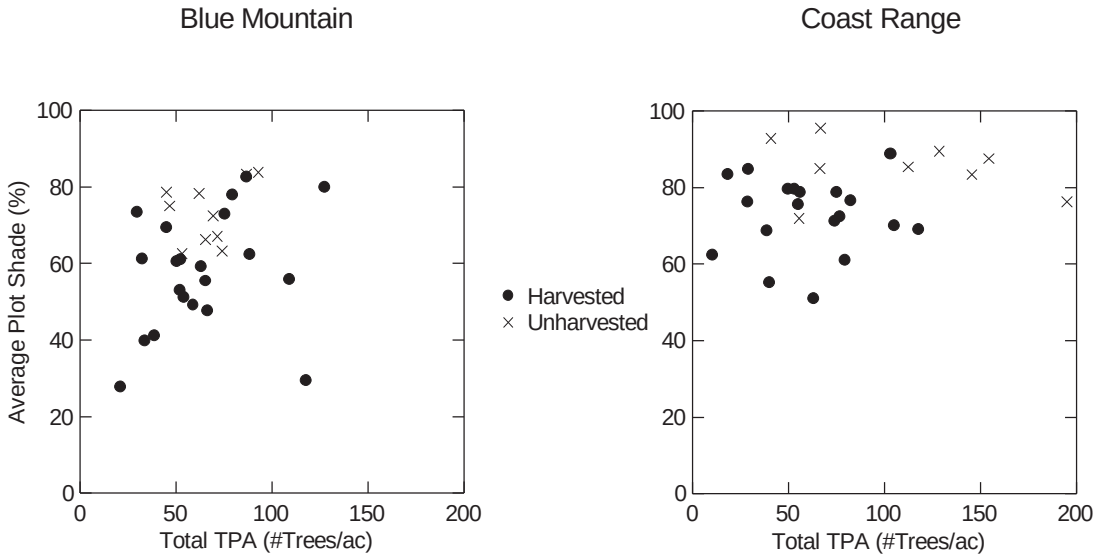


Figure E-2. Percent shade by whole-plot trees per acre for each georegion in harvested and unharvested stands.

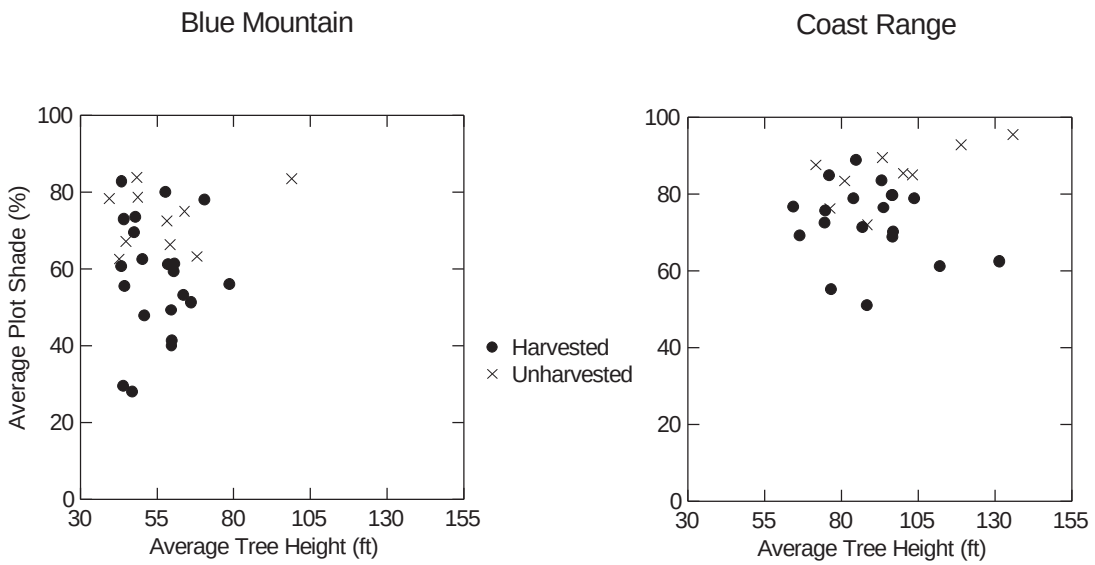


Figure E-3. Percent shade by average tree height for each georegion in harvested and unharvested stands.

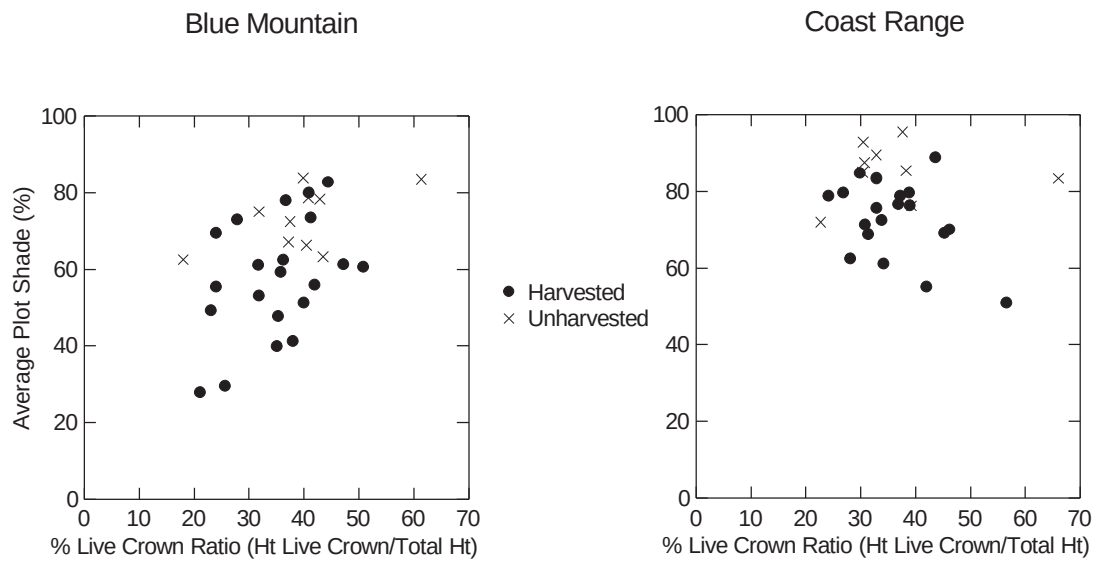


Figure E-4. Percent shade by whole-plot live crown ratio for each georegion in harvested and unharvested stands.

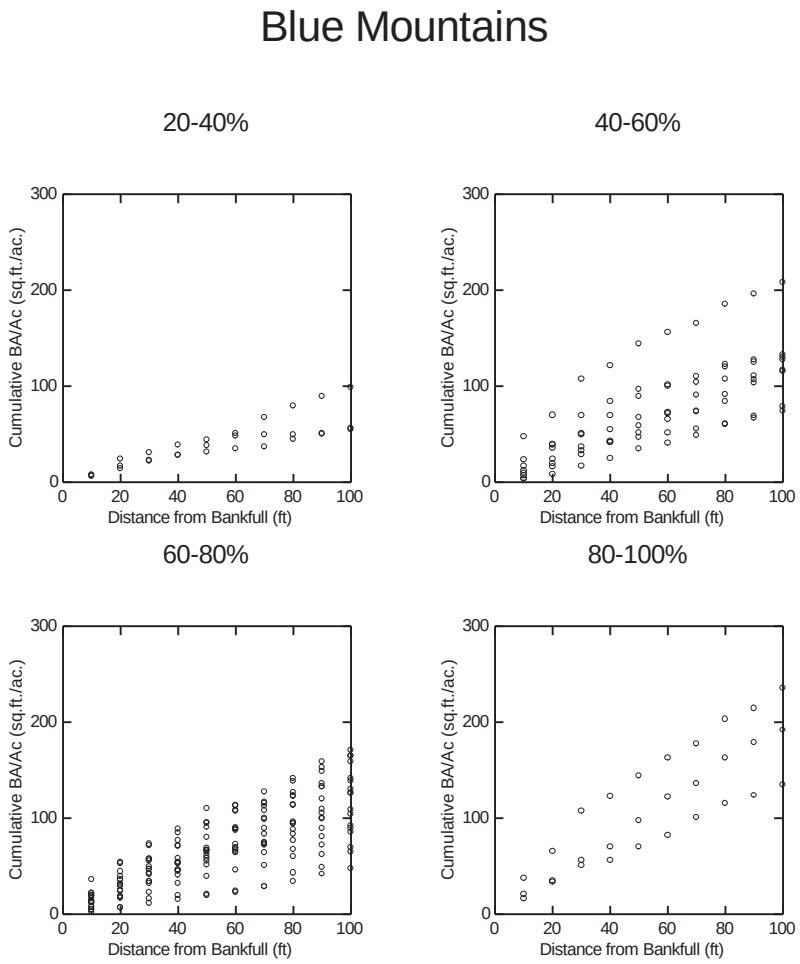


Figure E-5. Cumulative whole-plot basal area per acre versus distance from bankfull by shade category in the Blue Mountains.

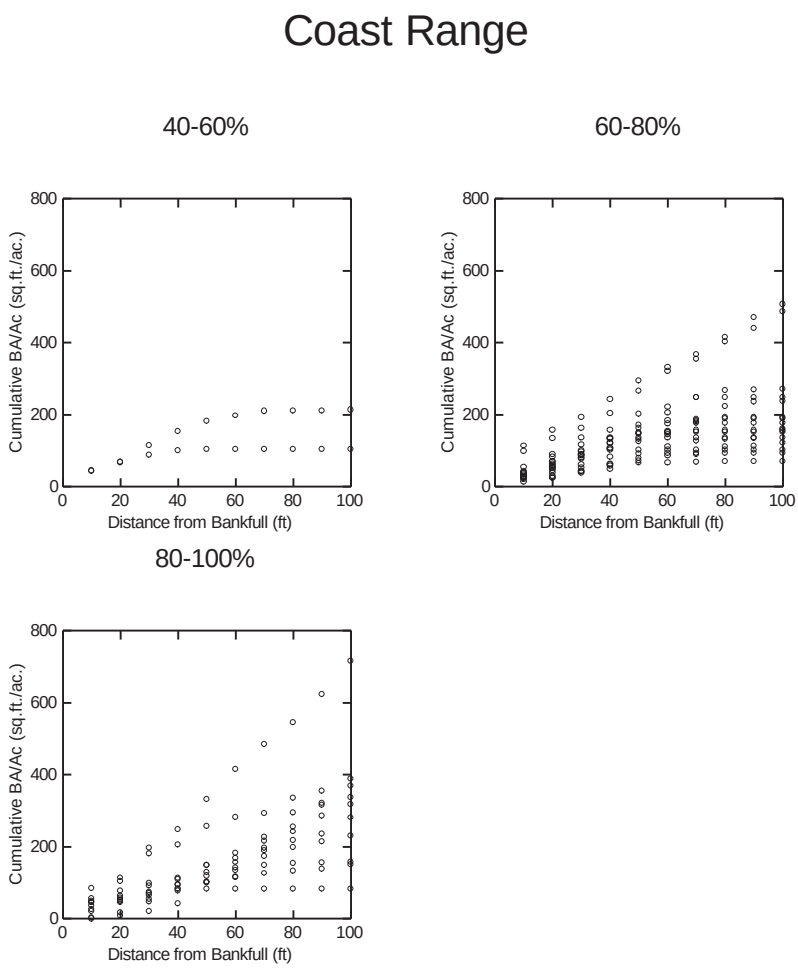


Figure E-6. Cumulative whole-plot basal area per acre versus distance from bankfull by shade category in the Coast Range

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SUMMER TEMPERATURE PATTERNS IN HEADWATER STREAMS OF THE OREGON COAST RANGE[1]

Liz Dent, Danielle Vick, Kyle Abraham, Stephen Schoenholtz, and Sherri Johnson[2]

ABSTRACT: Cool summertime stream temperature is an important component of high quality aquatic habitat in Oregon coastal streams. Within the Oregon Coast Range, small headwater streams make up a majority of the stream network; yet, little information is available on temperature patterns and the longitudinal variability for these streams. In this paper we describe preharvest spatial and temporal patterns in summer stream temperature for small streams of the Oregon Coast Range in forests managed for timber production. We also explore relationships between stream and riparian attributes and observed stream temperature conditions and patterns. Summer stream temperature, channel, and riparian data were collected on 36 headwater streams in 2002, 2003, and 2004. Mean stream temperatures were consistent among summers and generally warmed in a downstream direction. However, longitudinal trends in maximum temperatures were more variable. At the reach scale of 0.5-1.7 km, maximum temperatures increased in 17 streams, decreased in seven streams and did not change in three reaches. At the subreach scale (0.1-1.5 km), maximum temperatures increased in 28 subreaches, decreased in 14, and did not change in 12 subreaches. Models of increasing temperature in a downstream direction may oversimplify fine-scale patterns in small streams. Stream and riparian attributes that correlated with observed temperature patterns included cover, channel substrate, channel gradient, instream wood jam volume, riparian stand density, and geology type. Longitudinal patterns of stream temperature are an important consideration for background characterization of water quality. Studies attempting to evaluate stream temperature response to timber harvest or other modifications should quantify variability in longitudinal patterns of stream temperature prior to logging.

(KEY TERMS: stream temperature; water quality; shade; cover; riparian forest; rivers/streams; headwater streams.)

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INTRODUCTION

Small headwaters streams make up the majority of the stream network, generate most of the streamflow (MacDonald and Coe, 2007), and provide unique habitats for biological assemblages (Richardson and Danehy, 2007). These small streams contribute to valuable habitat for multiple salmonid species in coastal Oregon watersheds. Population viability for

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[2]Respectively, Hydrologist and Aquatic Specialist, Oregon Department of Forestry, 2600 State Street, Salem, Oregon 97310; Hydrologist, New Mexico Interstate Stream Commission, Santa Fe, New Mexico 25102; Monitoring Specialist, Oregon Department of Forestry, Salem, Oregon 97310; Director, Virginia Water Resources Research Center, College of Natural Resources, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061; and Research Ecologist, USFS PNW Research Station, Corvallis, Oregon 97331 (E-Mail/Dent: ldent@odf.state.or.us).

many of these species is in question (Nelson *et al.*, 1991). Among other habitat needs, these fish require cool stream temperatures in the summer. Increases in stream temperature at certain life stages can cause stress and/or mortality (Beschta *et al.*, 1987).

It is generally accepted that stream temperature tends to increase in a downstream direction. The rates of change and relationships between basin size and stream temperature patterns have been noted for larger streams and are predicted to increase in a downstream direction (Lewis *et al.*, 1999; Caissie, 2006). However, some studies have observed considerable variability in longitudinal stream temperature patterns, in larger rivers (Torgerson *et al.*, 1999), smaller streams (Johnson, 2004), or side channels (Ebersole *et al.*, 2003). For smaller streams, longitudinal patterns could be highly variable in response to a variety of instream, microclimatic, and geologic processes (Poole and Berman, 2001).

Stream temperature is a function of multiple energy transfer processes including direct solar radiation, longwave radiation, conduction, convection, and evaporation. Of these factors, direct solar radiation is the primary contributor to daily maximum summer stream temperature (Brown and Krygier, 1970; Sinokrot and Stefan, 1993; Johnson, 2004). Therefore, maintaining shade is an effective tool for reducing stream temperature heat flux (Johnson, 2004) during the summer months when maximum stream temperatures are observed.

Riparian forests provide a wide range of structures and functions including but not limited to diverse vegetation types and layered stand structure, snags, downed wood, large wood recruitment to streams, bank stability, nutrient cycling, and shade. Historical forest management that did not require retaining trees along streams resulted in significant reductions in shade and associated increases in stream temperature (Levno and Rothacher, 1967; Brown and Krygier, 1970; Murray *et al.*, 2000). Presently, retention of riparian trees is required along all fish-bearing streams in Oregon during timber harvest (OFPA, 2004) to maintain shade over streams as well as other riparian functions that maintain and protect aquatic habitat. Riparian restrictions around small streams have the potential to be especially costly (Adams *et al.*, 2002). It is important to evaluate stream temperature responses to forest management practices, given the importance of timber harvest to the Oregon economy, the significance of this region to salmonid conservation, and the prevalence of small streams in landscapes.

Geology and channel substrate also have important influences on spatial and temporal stream temperature trends in small streams (Poole and Berman, 2001). Johnson (2004) found that bedrock reaches had wide daily summer stream temperate fluctuations with relatively high maximum and low minimum temperatures. Stream reaches with gravel bottoms and subsurface flows had a much narrower range of daily fluctuations with lower maximums and higher minimums. Ground-water upwellings have potentially greater impacts in headwaters than in downstream reaches (Adams and Sullivan, 1989). Other factors that have been shown to correlate with stream temperature include stream depth (Adams and Sullivan, 1989) and streamflow (Beschta and Taylor, 1988).

In this paper, we describe preharvest spatial and temporal patterns in summer stream temperature for small streams in managed forests in the Oregon Coast Range. We also explore potential sources of variability in summer stream temperature conditions and patterns. The results presented herein are part of a long-term study designed to evaluate effects of forest management on temperature patterns of small streams.

METHODS

Study Area

Stream temperature was studied in 2002, 2003, and 2004 on 36 streams in the Oregon Coast Range. This region is characterized by steep slopes, highly dissected terrain, and sharp ridges with elevations that range from 450 to 750 m for main ridges with a maximum of 1,249 m at Marys Peak. Geology types of the Oregon Coast Range are predominantly layered sandstones and mudstones formed from uplifted ocean sediments that were deposited 60 to 40 million years ago. There are also many basalt intrusions in the north such as those in the vicinity of the Tillamook, Alsea, and Columbia River basins. The study area is influenced by maritime northwest climate patterns with cool, wet winters and mild, dry summers. Maximum air temperatures during study years were 19.0°C, 19.5°C, and 19.9°C from July to September 2002, 2003, and 2004, respectively (OCS, 2006). Rainfall was highly variable in all years and ranged from 2 to 60 mm, 2 to 20 mm, and 1 to 27 mm from July to September in 2002, 2003, and 2004, respectively.

Stream reaches selected for this study are in areas with harvest-regenerated or fire-regenerated forests between 50 and 70 years old (Figure 1). The stream reaches are on managed State of Oregon forests or privately owned industrial forests. In general, Oregon coastal riparian areas are hardwood-dominated, conifer-dominated, or conifer-hardwood mixed and

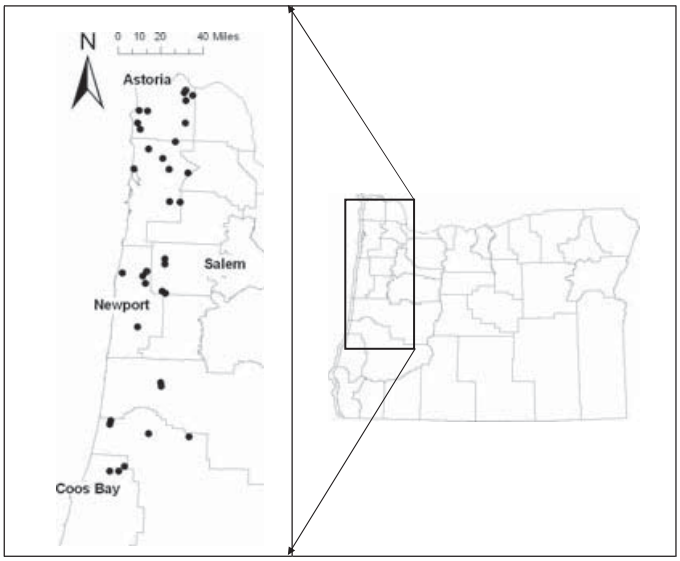

FIGURE 1. Locations of 36 Headwaters Stream Reaches in the Oregon Coast Range.

typically include shrub-dominated openings (Spies *et al.*, 2002). The most common conifer species for this study area is Douglas-fir (*Pseudotsuga menzeisii*) and the most common hardwood species is red alder (*Alnus rubra*). In general, conifer densities increase with increasing distance from stream, whereas hardwoods have not shown clear trends with distance from stream (Pabst and Spies, 1999; Spies *et al.*, 2002). Species composition and structure of riparian vegetation can be influenced by the same disturbances associated with upland stands such as fire, insect and disease, and windthrow. In addition, floods and debris flows have strong influences on riparian characteristics in this region. In general, riparian stands along high-gradient, headwater streams tend to be dominated by conifers. Exceptions include areas disturbed by landslides and debris torrents where red alder, salmonberry (*Rubus spectabilis*), and other deciduous vegetation are dominant (Pabst and Spies, 1999).

Study Design

Stream temperature, channel, and riparian data were collected on 36 stream reaches (defined as the entire length of stream being studied, encompassing two subreaches) as part of a long-term study that utilizes a before-after-control-impact (BACI) approach to examine harvest effects on stream temperature and riparian structure. The design targeted fish-bearing headwater streams classified as small or medium in the Oregon Forest Practices Act (OFPA, 2004). This paper focuses on the pretreatment period: 2002, 2003, and 2004. Because stream reaches were added and the timing of harvest varied, the preharvest sample sizes are 21, 36, and 19, for 2002, 2003, and 2004, respectively.

Because of BACI-related design constraints, a random sample was not practical. We asked all industrial private and state forest managers in the Oregon Coast Range to provide a list of stream reaches that would be harvested within a specific time frame and also met other criteria or constraints (Table 1). An initial list of 130 stream reaches was reduced to the final 36 and includes all stream reaches that met design constraints. Disturbances from beaver activities and debris-torrents, although common in the Oregon Coast Range, were avoided because such disturbances can overwhelm temperature patterns that otherwise could be influenced by harvesting in the posttreatment stage of this project. The final set of stream reaches, while not a random sample, is likely to represent conditions in 50-70-year-old forests, primarily managed for timber production, with small streams that lack recent debris torrent or beaver disturbance, on state and industrial private forest ownership in the Oregon Coast Range.

The majority (77%) of coastal forests in Oregon is under private (68%) or state (9%) ownership and managed for timber production (Spies *et al.*, 2002). Findings from this study are most applicable to streams in mid-successional forests (50-70-year-old conifer), which also make up the majority (82%) of Oregon state and private forests (Spies *et al.*, 2002). These sites do not represent, nor are they intended to represent unmanaged, old growth, or late-successional forest conditions and associated stream temperature patterns. Given that only 5-11% of the Oregon Coast Range is currently estimated to be in old growth or late-successional forest (Wimberly *et al.*, 2000), this study of stream reaches in mid-successional forests has relevance to regional conditions.

TABLE 1. Criteria Used to Select Stream Reaches for Evaluation of Summer Temperature Patterns of Headwater Streams in the Oregon Coast Range.

Site Selection Criteria
Ability to collect at least two years of pretreatment and seven years of posttreatment data
Fish-bearing streams
Minimum subreach lengths of 300 m
Streams must have an upstream "control" subreach that remains unharvested for duration of study
Estimated mean annual streamflow < 280 l/s
No major changes in channel and valley morphology, streamflow, or riparian attributes within streams reaches
No recent impacts from debris torrents
No active beaver ponds and ideally no large abandoned beaver ponds

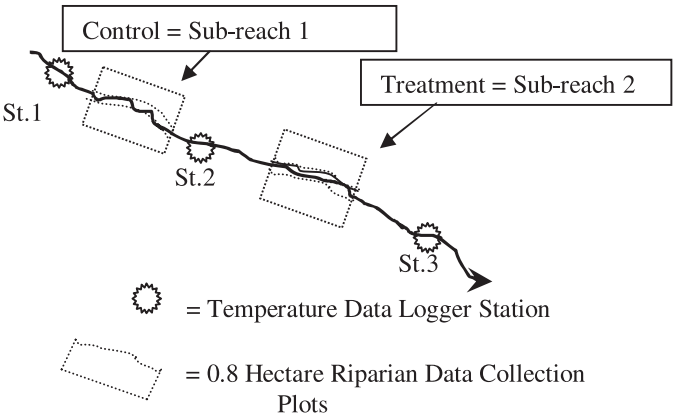

FIGURE 2. Schematic of Stream Reach (full length of stream being studied between Stations 1 and 3) Layout, Probe, and Riparian Plot Locations for 36 Headwater Streams in the Oregon Coast Range. "Subreach 1" (stream length between Stations 1 and 2) will remain as the control reach. "Subreach 2" (stream length between Stations 2 and 3) will become the treatment reach for the longer term study evaluating effects of harvesting on stream temperature. Canopy and channel data were collected at 60-m intervals in both subreaches.

Stream reach lengths varied from 525 to 1,768 m, with a mean of 932 m. Two subreaches (defined as a subsection of the study reach) were established on each stream reach (Figure 2). Subreach 1 will remain unharvested for the life of the study and serves as the "control" reach. Subreach 2, is immediately downstream of Subreach 1 and will eventually serve as the "treatment" reach after harvest. While the goal of the design was to have subreach lengths of ≥300 m, final subreach lengths varied from 137 to 1,494 m with a mean of 466 m. Factors which dictated final subreach lengths included future harvest unit boundaries in Subreach 2, large changes in valley or channel characteristics, or tributary inputs and junctions.

Stream Temperature and Flow Measures

Summer stream temperatures were recorded hourly between June and September 2002, 2003, and 2004 with continuously recording temperature data loggers (Optic Stowaway and Water Temp Pro, Onset Computer Corporation, Bourne, Massachusetts) at three stations in each reach. Predeployment and postdeployment accuracy checks were conducted using cold-water submersion and an NIST thermometer (Dunham *et al.*, 2005). Temperature stations were established at upstream and downstream boundaries of Subreaches 1 and 2 (Figure 2). Station locations were based on boundaries of future harvest units such that Station 1 would be approximately 300 m upstream of the future harvest unit, Station 2 at the upstream end of the harvest unit boundary, and Station 3 at the downstream end of the harvest unit boundary. Streamflow was calculated from measurements of velocity and cross-sectional areas at Station 3 in June, July, August, or September.

Channel Attributes

The following data were collected at measurement stations spaced 60 m apart throughout each subreach, following methods described in Lazorchak *et al.* (1998). Forest and shrub canopy cover was measured with a hand-held densiometer in each of four directions (upstream, left, right, and downstream) in the middle of the channel. Hemispherical photography was used to measure shade. A camera, with a "fish-eye" lens, was leveled at 1 m above the water surface and oriented to the north. Fish-eye photos were processed into electronic format and analyzed with Hemiview Software™ to calculate the amount of solar energy intercepted by canopy cover. Wetted width (wetted surface) and bankfull width (at the estimated average annual high water mark) were measured using a surveyor's rod or tape measure. Flood-prone width is the length measured at the elevation of two-times the bankfull height between flow-confining topographic features (Rosgen, 1994). It was measured using a surveyor's rod or tape measure. Channel gradient was measured using a clinometer. Substrate was characterized with a visual estimate of the percent of channel bed composed of each of six size classes of material (bedrock, boulder, cobble, gravel, sand, or fines). All instream wood jams in both subreaches were measured. A wood jam was defined as numerous pieces of wood functioning as a unit and piled together such that an individual wood tally was inaccurate. The length (L), width (W), and height (H) of each wood jam was measured and multiplied ($L \times W \times H$) to provide an estimate of wood jam volume.

Riparian-Structure Attributes

Riparian attributes were measured in permanent rectangular plots (0.8 ha), 152 m long (parallel to stream) by 52 m wide (horizontal distance from stream) centered within each subreach, one on each side of the stream, for a total of four plots per stream reach (Figure 2). The plot width was based on riparian buffers widths (52 m) that will be used when sites are harvested. Plot length was chosen to represent heterogeneous riparian forest conditions in a cost-effective manner. In heterogeneous forests,

large plots or multiple small plots are needed to accurately describe stand structure (Husch *et al.*,1972). We opted for fewer large plots to control costs associated with establishing the plot itself. The species and distance from stream were recorded for every tree with a diameter at breast height (DBH) ≥14 cm.

Analytical Methods

Stream Temperature Metrics. The daily mean, maximum, and minimum stream temperature for each station were derived from hourly data recorded between July 15th and August 30th in 2002, 2003, and 2004. Diurnal fluctuation and maximum seven-day moving mean of the daily maximum (7DAYMAX) were calculated from the daily statistics. Diurnal fluctuation is the daily maximum minus the daily minimum. The 7DAYMAX is used by the Oregon Department of Environmental Quality (ODEQ) as a metric for evaluating if streams meet Oregon water quality standards for temperature (ODEQ, 2006). The 7DAYMAX is calculated using a running average of daily maximum stream temperatures for a seven-day period, then repeating the calculation after dropping the first day and adding the eighth day of record. This is repeated for the entire period of record for each station yielding a seven-day moving mean of daily maximum for each day, the warmest of which is the 7DAYMAX for the season. We identified the 7DAYMAX for each season at Station 3 for each stream reach. The date when the 7DAYMAX occurred at Station 3 was then used to select the corresponding temperature metrics for Stations 1 and 2 to be used for within-reach comparisons.

The ODEQ establishes two numeric standards for fish bearing headwater streams in the Oregon Coast Range (ODEQ, 2006). Streams that provide salmonid spawning habitat are expected to have 7DAYMAXs ≤ 16°C, whereas streams that provide salmonid migration habitat must have 7DAYMAXs ≤ 18°C. We calculated 7DAYMAX between July 15th and August 30th, in 2002, 2003, and 2004 and evaluated it against the appropriate DEQ standard.

Longitudinal Patterns. Streams were designated as having a "warming" pattern if the 7DAYMAX was warmer at the downstream Station 3 relative to the upstream Station 1 or a "cooling" pattern if the 7DAYMAX was cooler at the downstream Station 3 relative to the upstream Station 1. A "no-change" designation was defined as ±0.2°C between Stations 1 and 3, which reflects the factory-established accuracy of temperature probes used for this research.

To account for differences in subreach lengths, we calculated a normalized rate of change in 7DAYMAX per 300 m. Differences between 7DAYMAX at the downstream and upstream stations were divided by the distance between stations and multiplied by 300 m (change in °C/300 m).

Statistical Analyses. We used SAS Version 9.1 (SAS Institute Inc., Cary, North Carolina) for all statistical analyses. Stream temperatures at each sampling location are influenced by upstream channel- and riparian-zone attributes. Therefore, a paired *t*-test for dependent samples was used to evaluate differences in mean channel and riparian attributes between Subreaches 1 and 2. A paired *t*-test for dependent samples was also used to evaluate differences in average of the daily mean, minimum, maximum, and 7DAYMAX stream temperatures between stations. A Pearson correlation analysis was conducted to examine potential sources of observed variability in stream temperature. This analysis was performed on data from 2003 because that year had the greatest sample size and most complete record of stream temperatures.

RESULTS

Stream Channel and Riparian Characteristics

Twenty-three stream reaches were in sedimentary and 13 were in igneous geologic types. Stream reaches were steep, shallow, narrow, confined, and well shaded, with substrates composed primarily of fines and gravel (Table 2). Stream channel attributes were consistent between subreaches with the exception of gradient ($p = 0.02$), wetted width ($p = 0.001$), and bankfull width ($p = 0.0002$). The upstream subreaches had higher mean gradients, narrower wetted widths, and narrower bankfull widths than the downstream subreaches (Table 2). The stream reaches had low streamflows that varied from a low of 1 l/s to a high of 38 l/s, with a mean of 9 l/s.

Mean conifer basal area increased with distance from stream. The near-stream zones (within 8 m of stream) were dominated by a hardwood overstory stand type with a mean hardwood basal area of 28 m^2/ha as compared with a mean conifer basal area of 14 m^2/ha (Table 3). Conifers were more common beginning at 9-15 m zone from the stream. At 31-52 m from the stream, conifer basal area (36 m^2/ha) was four times that of hardwoods (9 m^2/ha).

TABLE 2. Mean and Standard Deviation of Channel and Riparian Attributes for Subreaches 1 and 2 for 36 Streams in the Oregon Coast Range.

	Mean (standard deviation)	
Attribute	**Subreach 1**	**Subreach 2**
Streamflow (l/s)	NA	9.1 (7.7)
Channel gradient (%)*	9.6 (8.9)	6.5 (4.2)
Fines (%)	38 (23)	34 (21)
Gravel (%)	38 (17)	38 (13)
Cobble (%)	18 (13)	19 (12)
Boulder (%)	3 (5)	4 (7)
Bedrock (%)	4 (12)	6 (11)
Thalwag depth (m)	0.2 (0.1)	0.2 (0.1)
Wetted width (m)*	1.7 (0.7)	2.1 (0.8)
Bankfull width (m)*	3.5 (1.1)	4.3 (1.4)
Flood prone width (m)	10.1 (8.8)	12.3 (7.0)
Distance from divide (m)	1551 (805)	2203 (867)
Shade (%)	86 (7)	87 (6)
Cover (%)	93 (4)	93 (4)
Wood jam index (m^3/m)	2 (14)	1(8)
Basal area (m^2/ha)	43 (14)	45 (13)
Trees/ha	870 (252)	914 (301)
Sedimentary geology type	23 sites	
Igneous geologic type	13 sites	

Note: For a given attribute, statistical difference ($\alpha = 0.05$) between Subreaches 1 and 2 is indicated with *.

Range of Observed Stream Temperature Conditions

Stream temperatures among individual reaches in this study were highly variable. During the three summers, daily maximum ranged from 7.3°C to 20.4°C, daily minimum from 6.7°C to 16.2°C, and daily mean from 7.0°C to 17.0°C. Daily diurnal fluctuation in summer varied from 0°C to 9.3°C (Figures 3A, 3B, and 3C). The rate of change in 7DAYMAX/300 m varied from −1.6°C/300 m to +3.6°C/300 m (Figure 4). There were no significant differences in mean rate of change among reaches. When we compared rate of change in 2002 to rate of change in 2003 for only those streams sampled in both years, there was no statistical difference between years.

We observed a narrow range of mean temperature conditions. Mean maximum temperatures observed at all stations over the three-year period varied from 12.2°C to 13.9°C, mean minimums from 11.3°C to 12.7°C, overall mean values varied from 11.7°C to 13.2°C, and mean diurnal fluctuation varied from 0.9°C to 1.3°C. The mean 7DAYMAX ranged from 12.2°C to 13.8°C (Table 4). Thirty percent (5/16) and 10% (2/20) of the stream reaches exceeded the ODEQ 7DAYMAX water quality standard at least one day during one of the summers for the 16°C and 18°C standards, respectively.

TABLE 3. Mean Conifer and Hardwood Basal Area in Riparian Zones With Increasing Distance From Streams (n = 36).

Distance From Stream (m)	Conifer Basal Area (m^2/ha)	Hardwood Basal Area (m^2/ha)
0-8	14	28
9-15	25	13
16-23	29	12
24-30	34	10
31-52	36	9

Note: Plots along both subreaches were averaged for this summary.

Longitudinal Patterns

Statistically significant differences in mean values between Stations 1 and 2 and 1 and 3 were observed in all three years (Table 5). Differences between Stations 2 and 3 were only significant in 2003. The results were consistent in that all statistically significant changes represent an increase in temperature in a downstream direction. However, changes were not observed for all temperature metrics, for all reaches, or for all years.

Longitudinal patterns in 7DAYMAX stream temperatures were more variable at both the reach and subreach scales. This analysis was performed on 27 streams because of missing data on nine streams. Longitudinal stream temperature patterns were variable between subreaches and among streams in 2003. Of 27 streams, some displayed a warming pattern in both subreaches, a cooling pattern in both subreaches (Figures 5 and 6), no-change in both subreaches, or some combination of the three. Overall, 63% of the streams warmed, 26% cooled, and 11% had no-change at the stream reach scale with variable patterns at the subreach scale (Table 6).

Sources of Variability

Correlations between 7DAYMAX temperature and stream attributes showed significant positive correlations for bedrock and negative correlations for fines for Subreach 1. In Subreach 2, gradient, wood jam volume, and riparian stand density were negatively correlated with 7DAYMAX, while sedimentary geology was positively correlated. No attributes were significantly correlated with 7DAYMAX in both subreaches (Table 7).

The rate of change in 7DAYMAX/300 m was positively correlated with mean bedrock in Subreach 1 and negatively correlated with cover. In Subreach 2, however, rate of change in 7DAYMAX/300 m was negatively correlated with mean bedrock and positively correlated with percent fines (Table 7).

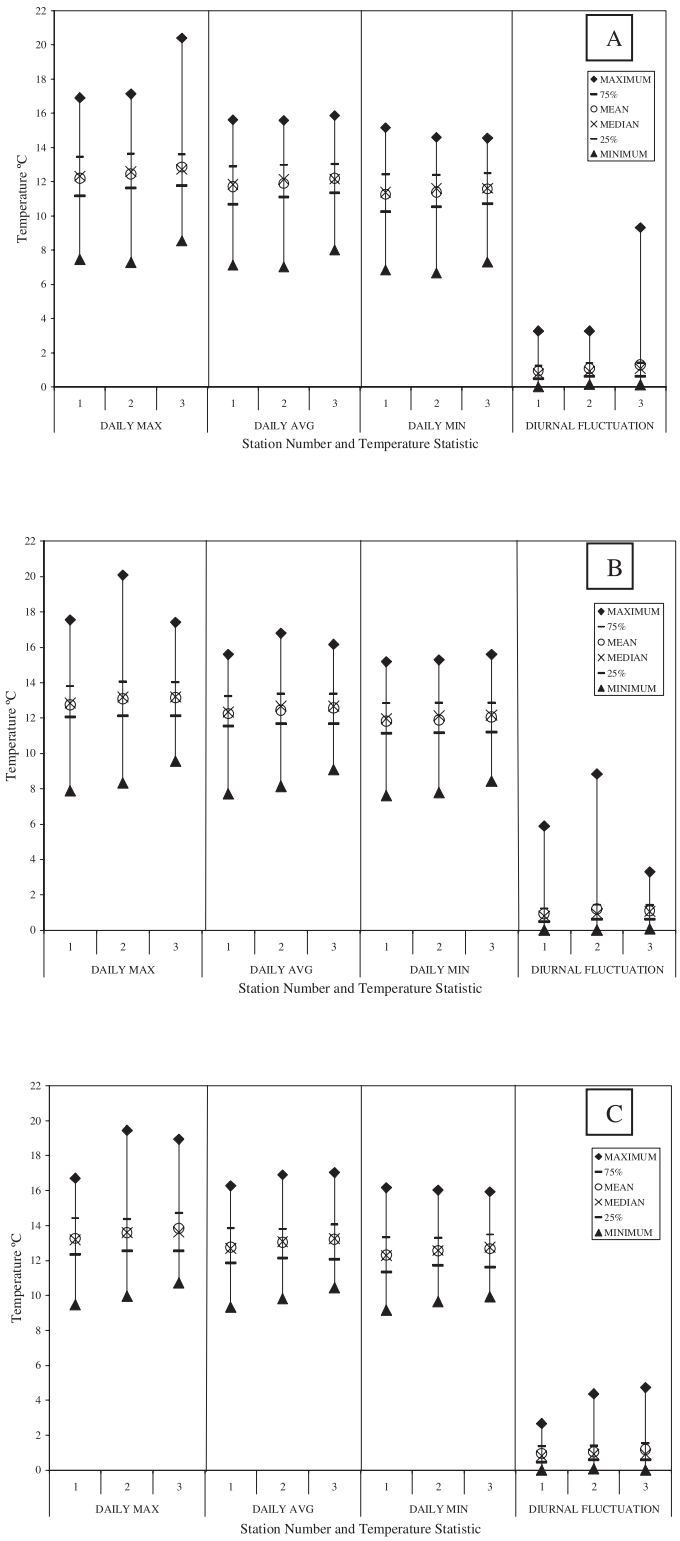

FIGURE 3. Stream Temperature Statistics for (A) 2002, (B) 2003, and (C) 2004 at Stations 1, 2, and 3 (n = 21, 36, and 19 for 2002, 2003, and 2004, respectively) for Headwater Streams in the Oregon Coast Range. Daily statistics were calculated from hourly data collected from 7/15 to 8/30 each year. Observed daily minimums, maximums, 75th and 25th quartiles, mean and medians of the distributions are shown.

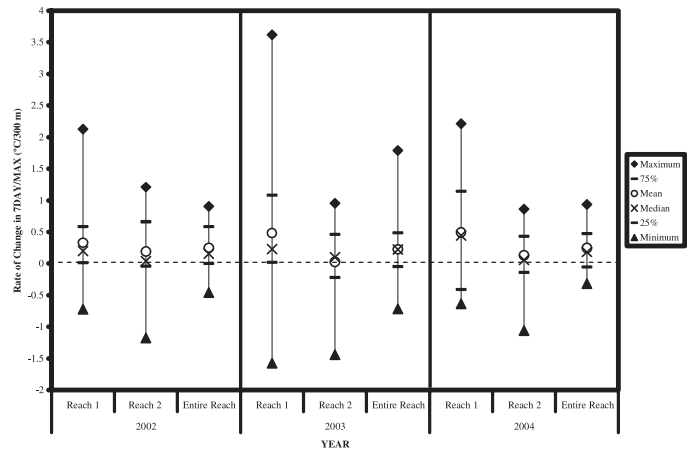

FIGURE 4. Rate of Change in 7DAYMAX/300 m for Subreach 1, Subreach 2, and the Entire Reach for 2002, 2003, and 2004 (n = 21, 36, and 19, respectively) for Headwater Streams in the Oregon Coast Range. The 7DAYMAX and associated rate of change were calculated using daily statistics from hourly data collected from 7/15 to 8/30 each year. The observed daily minimums, maximums, 75th and 25th quartiles, mean and medians of the distributions are shown.

DISCUSSION

We observed a high degree of variability in summertime stream temperature conditions and patterns in these headwater streams. Most notable from this set of streams was the observed variability in longitudinal patterns at small subreach scales. In general mean stream temperature increased in a downstream direction. However, longitudinal patterns for 7DAYMAX temperatures were more complex displaying alternating warming and cooling trends at subreach scales. These findings suggest that a simple model of increasing temperature in a downstream direction does not adequately characterize temperature patterns for many of these small streams. Observed reach-to-reach variability was likely a result of spatially variable instream processes that influence temperature patterns at small reach scales (0.5-2 km in length).

Similar variability in stream temperature patterns is cited by Poole and Berman (2001). Torgerson *et al.* (1999) and Ebersole *et al.* (2003) also found heterogeneous longitudinal patterns of summer stream temperature in northeastern Oregon. In contrast, Brown (1970), Zwieniecki and Newton (1999), and Lewis *et al.* (1999) found predictable patterns of warming in a downstream direction under full canopy cover. While not quantified in this study, possible explanations for observed longitudinal patterns include entrance of cool tributaries and influx of ground water (Beschta *et al.*, 1987; Ebersole *et al.*, 2003). Hewlett and Fortson (1982) determined ground-water input to be

TABLE 4. Mean Values of Temperatures Calculated From Hourly Data Collected From July 15 to August 30.

Year	Station (*n*)	Daily Maximum (°C)	Daily Minimum (°C)	Daily Mean (°C)	Diurnal Fluctuation (°C)	7-Day Maximum (°C)
2002	1 (19)	12.2	11.3	11.7	0.9	12.2
	2 (20)	12.5	11.4	11.9	1.1	12.5
	3 (21)	12.9	11.6	12.2	1.3	12.9
2003	1 (31)	12.8	11.8	12.2	0.9	12.8
	2 (30)	13.1	11.9	12.5	1.2	13.1
	3 (36)	13.2	12.0	12.6	1.1	13.1
2004	1 (19)	13.3	12.3	12.8	1.0	13.3
	2 (18)	13.6	12.6	13.0	1.0	13.6
	3 (19)	13.9	12.7	13.2	1.2	13.8

TABLE 5. Paired *t*-Test Results (for dependent samples) Comparing Mean Stream Temperature Metrics Between Stations.

		Difference in Mean Temperature Between Stations		
Temperature Metric	Stations Being Compared	2002 °C (*p*-value)	2003 °C (*p*-value)	2004 °C (*p*-value)
Daily max	1 & 2		0.87 (0.02)	0.08 (0.02)
	2 & 3			
	1 & 3	1.02 (0.03)	0.72 (0.01)	0.03 (0.02)
Daily min	1 & 2		0.53 (0.01)	
	2 & 3		0.30 (0.01)	
	1 & 3		0.51 (<0.01)	0.34 (0.04)
Daily average	1 & 2	0.68 (0.03)	0.41 (0.05)	0.16 (0.05)
	2 & 3			
	1 & 3		0.23 (<0.01)	0.50 (0.01)
7DAYMAX	1 & 2	0.29 (0.05)	0.43 (0.03)	0.42 (0.04)
	2 & 3			
	1 & 3	0.90 (0.02)	0.63 (0.01)	0.73 (0.01)

Note: Statistically significant differences in mean values and *p*-values are provided. All observed changes represent increases between stations.

the primary driver of stream temperature in small streams in the southeastern United States Adams and Sullivan (1989) also argued that ground-water contributions play an important role in temperature patterns. Studies attempting to evaluate stream temperature response to timber harvest should consider the variable longitudinal patterns of stream temperature that can exist prior to disturbance as observed in these study sites.

Streams in this study were consistently well-shaded with high levels of canopy cover. Selection criteria for this study that excluded sites with recent human and natural disturbances such as beaver and debris torrents, in part explain consistently high cover conditions. Such conditions limited the usefulness of cover or shade as a predictor of stream temperature variability prior to logging. Other studies (Levno and Rothacher, 1967; Brown and Krygier, 1970; Beschta and Taylor, 1988; Jackson *et al.*, 2001) of canopy cover prior to logging in the Pacific Northwest have reported similar canopy conditions as observed in this study. Solar radiation is a key driver of midday high stream

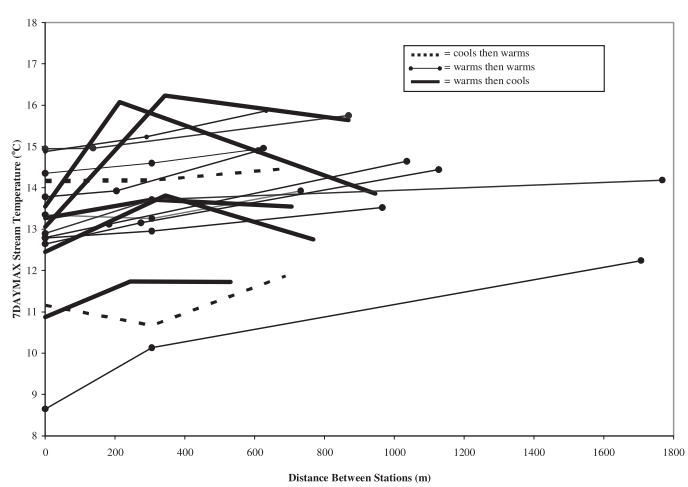

FIGURE 5. 7DAYMAX Temperature *vs.* Distance Between Stations (Station 1 = 0 m) for Streams in the Oregon Coast Range That had an Overall *Warming* Pattern (between Stations 1 and 3) in 2003 (n = 17). Thin solid line represents streams that warmed in both reaches, heavy solid line represents streams that warmed in Subreach 1 but cooled in Subreach 2, and dashed line represents streams that cooled in Subreach 1 but warmed in Subreach 2.

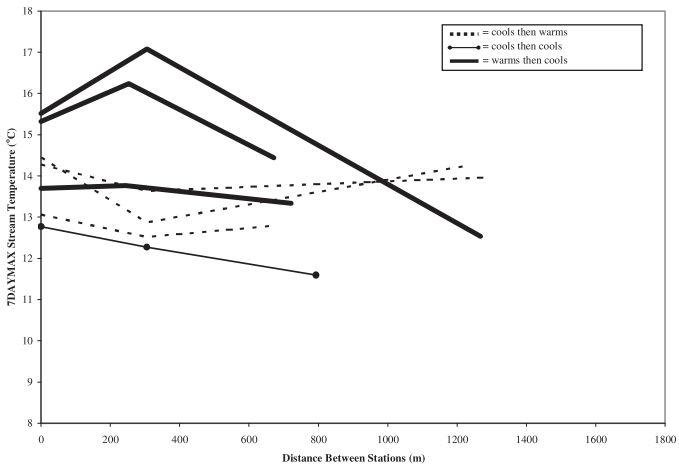

FIGURE 6. 7DAYMAX Temperature *vs.* Distance Between Stations (Station 1 = 0 m) for Streams in the Oregon Coast Range That Had an Overall *Cooling* Pattern (between Stations 1 and 3) in 2003 (n = 7). Thin solid line represents streams that cooled in both reaches, heavy solid line represents streams that warmed in Subreach 1 but cooled in Subreach 2, and dashed line represents streams that cooled in Subreach 1 but warmed in Subreach 2.

temperatures (Beschta and Taylor, 1988; Brown, 1988; Sinokrot and Stefan, 1993) and several studies have established the importance of shade for maintaining stream temperature (Brown, 1970, 1988; Beschta *et al.*, 1987; Lewis *et al.*, 1999; Zwieniecki and Newton, 1999). If future harvest reduces shade, we expect the correlative relationships between shade and stream temperature for these stream reaches to strengthen.

We observed greater extremes in stream temperature and rate of change than reported in other studies (Brown and Krygier, 1970; Amaranthus *et al.*, 1989; Dupuis and Steventon, 1999; Jackson *et al.*, 2001). Higher variability in temperature patterns observed in this study may be a result of our focus on small streams, regional differences, and our larger sample size. Small streams may be more susceptible to temperature variations as a result of low flow volumes and interactions with ground water and substrate. A large sample size may have increased the likelihood of capturing a greater range in conditions.

Channel substrates, specifically the percent fines, percent bedrock, and geologic type were correlated with stream temperature and rate of change with alternating positive and negative relationships by subreach. Johnson (2004) found that streams dominated by bedrock tended to have wide daily summer stream temperate fluctuations with relatively high maximum and low minimum temperatures. Ebersole *et al.* (2003) described cool water in streams as associated with substrate characteristics and localized conditions. Cool temperatures may be responding to conductive heat exchange with the substrate, whereby the slightly warmer stream water is losing heat to the still seasonally cool substrate (Brown, 1988). This hypothesis corresponds to the findings of Sinokrot and Stefan (1993), who found that conduction among shallow, small streams, and the streambed should be considered in heat budget estimates. While similarly variable results have been reported in other research, it is possible that alternating positive and negative correlations between temperature and substrate in this study may reflect over-simplified substrate measures that are inadequate to explain complex cooling and heating processes that result from surface water/channel interactions.

CONCLUSIONS

This study provided several observations with important implications for management and research

TABLE 6. Number and Percent of Streams With Cooling, Warming, or No-Change Patterns in 2003 for 7DAYMAX at the Stream Reach (Stations 1-3) and Subreach Scales for 27 Headwater Streams in the Oregon Coast Range.

Site Level Pattern (percent of sites)	Number of Sites	Subreach 1 Pattern	Subreach 2 Pattern	Percent of Sites With Subreach Pattern
Overall warming pattern	6	Warms	Warms	22
between Stations	5	No change	Warms	19
1 and 3 (63%)	3	Warms	Cools	11
	2	Warms	No change	7
	1	Cools	Warms	4
Overall cooling pattern	3	Cools	Warms	11
between Stations	2	Warms	Cools	7
1 and 3 (26%)	1	No change	Cools	4
	1	Cools	Cools	4
No-change between	2	No change	Cools	7
Stations 1 and 3 (11%)	1	No change	No change	4

Note: No-change was defined as ±0.2°C based on the accuracy of temperature probes.

TABLE 7. Pearson Correlation Results Relating 2003 7DAYMAX at Stations 2 and 3 to Upstream Attributes for Subreaches 1 and 2, Respectively, for Headwater Streams in the Oregon Coast Range.

Channel or Riparian Parameter (n = 25 except when shown)	7DAYMAX (°C) Subreach 1 r (p-value)	7DAYMAX (°C) Subreach 2 r (p-value)	Rate of Change (°C/300 m) Subreach 1 r (p-value)	Rate of Change (°C/300 m) Subreach 2 r (p-value)
Distance from divide (30)	0.31 (0.09)	0.32 (0.06)	0.00 (0.99)	0.01 (0.95)
Mean % bedrock	0.49 (0.01)*	−0.14 (0.45)	0.43 (0.05)*	−0.52 (0.01)*
Mean % gravel	−0.07 (0.75)	−0.24 (0.18)	−0.11 (0.61)	−0.11 (0.58)
Mean % cobble	0.14 (0.50)	−0.17 (0.36)	−0.28 (0.21)	−0.07 (0.72)
Mean % boulder	0.31 (0.13)	−0.01 (0.97)	0.22 (0.33)	0.00 (0.98)
Mean %fines	−0.40 (0.05)*	0.31 (0.08)	−0.07 (0.77)	0.40 (0.04)*
Mean wetted width	0.24 (0.25)	0.10 (0.60)	0.04 (0.87)	0.19 (0.35)
Mean bankfull width	0.26 (0.21)	−0.04 (0.84)	0.12 (0.59)	−0.10 (0.65)
Mean flood-prone width	0.11 (0.61)	0.23 (0.21)	−0.07 (0.75)	0.24 (0.24)
Mean max depth	−0.09 (0.68)	0.14 (0.44)	−0.13 (0.58)	0.15 (0.46)
Mean % gradient	−0.25 (0.23)	−0.48 (0.01)*	−0.13 (0.57)	−0.12 (0.56)
Mean % cover	−0.03 (0.90)	0.23 (0.21)	−0.54 (0.01)*	−0.18 (0.39)
Mean % shade (27)	−0.17 (0.38)	0.05 (0.76)	−0.31 (0.14)	−0.07 (0.73)
Wood jam volume (34)	−0.19 (0.33)	−0.38 (0.02)*	−0.17 (0.46)	0.20 (0.29)
Mean basal area/ha (28)	−0.12 (0.53)	−0.01 (0.95)	−0.04 (0.86)	0.25 (0.21)
Mean no. of trees/ha (28)	−0.12 (0.53)	−0.36 (0.04)*	−0.17 (0.42)	0.10 (0.61)
Sedimentary geology	0.18 (0.36)	0.45 (0.01)*	−0.18 (0.37)	0.17 (0.37)

Notes: Rate of change in 7DAYMAX/300 m in Subreaches 1 and 2 was likewise compared with Subreaches 1 and 2, respectively.
*Statistically significant correlation (α = 0.05).

on small streams in similar ecological settings as the Oregon Coast Range. Findings highlight the complexity of processes influencing stream temperature at small reach scales in the stream reaches we studied. We intentionally selected small streams that had similar forest management and disturbance histories and channel characteristics which were reflected in narrow ranges of shade and channel conditions. Nevertheless, we observed a wide range of stream temperature conditions and spatial patterns prior to harvest.

Under current forest management, shade is provided by maintaining riparian buffer zones in part to prevent adverse impacts of harvest operations on stream temperature. This is appropriate as greater canopy cover can be a significant predictor of cooler stream temperatures. However, the inherent complexity in small streams observed in this study indicates that additional processes may determine stream temperature conditions and patterns when shade and canopy cover are consistently high. Given the potential influence of substrate and streamflow on temperature patterns in small streams, future studies should consider precise measures of substrate, streamflow, and/or hyporheic exchange. An examination of ground-water-surface water interactions in small streams may explain if this interaction has a modifying affect on harvest response. Given the observed variability in temperature patterns and correlations between temperature and stream characteristics, postharvest evaluations will need to account for inherent variability observed prior to harvest.

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Effectiveness of Riparian Management Areas and Hardwood Conversions in Maintaining Stream Temperature

Oregon Department of Forestry
Forest Practices Monitoring Program

Liz F. Dent, Monitoring Coordinator
Jennifer B.S. Walsh, Monitoring Assistant
March 1997

Forest Practices Technical Report Number 3

Table of Contents

	Page
Introduction	1
Purpose	2
Objectives	2
Background and literature review	2
Regulatory background	2
Effects of harvesting and other environmental variables	3
Fisheries	4
Past ODF Stream temperature monitoring	5
Study sites	5
RMA's and HWC's	6
Georegions	6
Field methods	7
Stream temperature	7
Environmental data	7
Analytical methods	8
Temperature parameters	8
Environmental parameters	8
Statistical methods	9
Brush Creek Basin Trends	11
Limitations of the study	11
Results and Discussion	11
Observations of changes in 7-day maximum stream temperature through Harvest units	11
Relationship between environmental parameters and stream temperature	16
Effect of RMA and HWC harvest units on stream temperature	18
Distribution tests and water quality standards	24
Brush Creek	26
Summary and Conclusions	28
Recommendations	30
Appendix A. Physical and vegetation characteristics averaged by reach	32
Appendix B. Monitoring schematics for each stream's experimental design	33
Appendix C. Period of record for water temperature data on each stream and station	34
Appendix D. Seven day moving mean of daily maximum for each stream July through August 1995	35

List of Figures

Figure 1. Boundaries of Oregon Department of Forestry georegions. .....…. 7

Figure 2. Stations used for statistical analysis. .....…..... 9

Figure 3. Change in 7-day maximum through harvest units and downstream reaches for (a) HWC and (b) RMA units.....…..... 12

Figure 4. Seven-day maximum stream temperature at stations 1, 2, and 3 for streams harvested with (a and b) HWC's and (c) RMA's. .....…13

Figure 5. (a) Seven-day maximum (a), 7-day minimum, and (b) 7-day average versus distance from divide. Predicted temperature based on empirical equations 1, 2 and 3 given in text. Symbols differentiate between Interior and Coastal geo-region sites……..……..……..20

Figure 6. Change in 7-day maximum for harvest, downstream and study reaches…….. 22

Figure 7. Diurnal fluctuation for control, RMA, and HWC reaches.....….....22

Figure 8. Cumulative frequency of 7-day maximum versus stream temperature for (a) all streams and all stations (b) RMA's and HWC's and (c) stations 1, 2 and 3.....…..... 23

Figure 9. Brush Creek harvest units and location of air and water monitoring locations. .....…….....…..25

Figure 10. Seven-day maximum versus distance from divide for highest stream temperature week in July 1994, 1995, and 1996 on Brush Creek. … 27

Figure 11. Change in 7-day maximum in the upstream, HWC and downstream reaches on Brush Creek for 1994 (pre-harvest), 1995 and 1996 (1st and 2nd years post-harvest)……..…..... 27

List of Tables

Table 1. Optimum and lethal limit temperature ranges for coho, chinook and bull trout. …..... 4

Table 2. Site description. .....……..... 6

Table 3. Stream temperature parameters, cover and distance from divide for each stream. .....…….....… 15

Table 4. Correlation relationships, Pearson correlation coefficients (r), and p-values for statistically significant findings with all stations pooled. Positive relationships = +, negative relationships = -. Actual p-value < = reported value…..……17

Executive Summary

Temperature in forested streams is a critical component of fish habitat. Management alongside forested streams has the potential to significantly affect the amount of solar radiation reaching the stream surface as well as the condition of other environmental parameters that are correlated with stream temperature response. In 1995, the Oregon Department of Forestry conducted a monitoring project to evaluate the effectiveness of the forest practice rule in preventing increases in stream temperature associated with forest harvesting. The project set out to answer the question: Are *the best management practices resulting in unacceptable temperature increases at the site and watershed level?*

Temperatures recorded continuously on 13 stream reaches and one basin were used to analyze the effects of Riparian Management Areas (RMA's) and Hardwood Conversions (HWC's) on maintaining stream temperature throughout the summer lowflow season. RMA's are unmanaged forest buffers of varying widths depending on stream size and type situated between upslope harvest operations and streams. HWC's are managed riparian buffers that are capable of supporting conifers but which are currently dominated by hardwoods. Active management is not permitted within a RMA (OAR 629-635-310) and is permitted within a HWC (OAR 629-640-300). Using various statistical methods, including repeated measures on analysis of variance and distribution tests, stream temperatures recorded immediately below the harvest units and those recorded approximately 500 feet below the harvest units.

Results from this monitoring project are limited by a lack of pre-harvest data and variability among the sample sites. Differences in elevation, harvest methodology, and georegion as well as data collection problems, especially with canopy cover, contributed to a highly variable sample population. However, consistent, if not significant, increases in stream temperature below harvested reaches indicate that the forest protection rules may not always provide adequate protection to meet water quality standards.

In general, the 7-day moving average of maximum, minimum and average temperature increased through the harvest units, whether it was a RMA or a HWC. Average 7-day maximum increase for RMA's was 2.5°F and 2.5°F for HWC's. However, four out of eight streams experienced stream temperature increases greater than 3°F while only on out of five RMA streams showed increases greater than 3°F. When variance in temperature contributed by distance from divide was theoretically accounted for, temperature increases were not significant. Without accounting for the natural downstream increase in temperature, temperature increases throughout the harvest units were statistically significant. Depending on the position of the harvest units within a water shed, stream temperature did or did not decrease downstream again after returning to an unmanaged canopy. Those reaches that were sampled higher in the basin did show a corresponding decrease in temperature 500 ft downstream, while those reaches sampled lower in the basin did not show a decrease in stream temperature 500 ft downstream.

The water quality standard for 7-day moving average of maximum (64°F) was exceeded more often downstream of harvested units than upstream. On all streams the standard was exceeded only 9.4% of the time. However, only three of the thirteen streams never exceeded the water quality standard.

Continued monitoring and assessment will be completed to address the limitations of this monitoring project and attempt to better determine where rules can be improved and how forested stream systems respond to management.

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Effectiveness of Riparian Management Areas and Hardwood Conversions in Maintaining Stream Temperature

Oregon Department of Forestry
Forest Practices Monitoring Program
Liz Dent
Jennifer Walsh

March 1997

Introduction

In 1994 the Oregon Department of Forestry (ODF) adopted new rules designed to protect the waters of the state during and after forest operations. The revised stream protection rules are designed to meet state standards for water quality and provide adequate protection for fish and other aquatic habitat.

The objectives of the water protection rules are to produce desired future conditions for the wide range of stand types, channel conditions and disturbance regimes existing throughout forest lands in Oregon. The desired future condition for fish bearing streams is growing and retaining riparian vegetation so over time average conditions across the landscape are similar to those of mature streamside stands. Such riparian stands supply nutrients, shade, large woody debris and bank stability to stream systems, contributing to high quality fish and wildlife habitat.

Under the Oregon Forest Practices Rules, Riparian Management Areas (RMA's) are established on streams running through or adjacent to harvest areas (OAR 629-635-310). The width of the RMA depends on the stream size (small, medium or large) and stream type or beneficial use (fish, domestic or none). For example, medium-sized (M), fish-bearing (F) streams have an RMA that is 70 feet wide measured as slope distance from the normal high water mark. All understory vegetation must be retained within 10 feet of the high water mark, all overstory vegetation must be retained within 20 feet of the high water mark, and all trees that lean over the stream must be retained. Trees can be harvested beyond the 20 foot distance and within the 70 foot RMA if there is sufficient basal area in the RMA. Basal area requirements vary with stream size, type and georegion and are described as standard and management targets. The standard basal area target for medium type F streams ranges, depending on the geographic area, from 90 to 140 square feet on each side of the stream, per 1000 feet of stream (OAR 629-640-100).

In addition, there are diameter, mimumum tree numbers and species requirements for the stand composition of the RMA.

Alternative prescription 2 (OAR 629-640-300) can be prescribed for riparian areas capable of supporting coniferous tree communities that are currently dominated by hardwood overstories. The intent of this rule is to achieve the desired future condition by restoring the riparian area to historic coniferous condition "in a timely manner." The practice is intended to provide adequate shade and bank stability while creating conditions that will improve on the future recruitment of large coniferous debris to the channel. Areas to be managed under this prescription will be divided into conversion and retention blocks. No more than half the total stream length to be harvested can be included in conversion blocks. The conversion block must be no more than 500 feet long and must be separated by at least 200 feet of retention block or a 200 foot segment where the general prescription is applied. Operators can clearcut harvest to within 10 feet from the normal high water mark within the conversion block if the following conditions are met: conifer basal area is less than half of the standard target; the site historically supported conifers; and the site is capable of supporting conifers again. All trees within 20 feet of the high water mark and leaning over the stream and all overstory and understory vegetation within 10 feet of the stream must be retained. The operator/landowner will then replant with coniferous species. This treatment is referred to as a hardwood conversion (HWC).

During the summer of 1995 ODF in partnership with Oregon State University (OSU) evaluated the effectiveness of the new rules in maintaining stream temperature. The project monitored stream temperature through RMA's and HWC's along small, medium and large fish bearing streams. In addition, the Department continued to monitor stream temperature throughout the entire basin of Brush Creek. The Brush Creek project is a long-term project that was initiated in 1994.

Purpose

This project will help answer a critical water quality question identified in the Oregon Department of Forestry's 1994 Forest Practices Monitoring Strategic Plan:

Are best management practices resulting in unacceptable temperature increases at the site and watershed level?

Objectives

The specific objectives designed to answer the monitoring question are:

Investigate stream and riparian characteristics which influence stream temperature.

Test the effectiveness of riparian management areas and hardwood conversions in maintaining stream temperature at a site and a watershed level.

Determine if riparian management areas and hardwood conversions maintain stream temperatures at or below the Department of Environmental Quality (DEQ) state standard for water quality.

Background and Literature Review

Regulatory Background

Growing concern for fish habitat on forested and agricultural lands has heightened public awareness and regulatory concerns over the effects of land management practices on water quality. Stream temperature is one regulatory parameter used to determine if streams meet water quality standards. The parameter used in Oregon to index water quality is the seven-day moving mean of daily maximum stream temperature (7-day maximum). Standards are a 7-day maximum equal to or less than 64°F for salmonid habitat and 50°F for bull trout. The DEQ documented over 800 Oregon streams as water-quality limited on the 1996 303(d) list (DEQ 1995). Of the streams listed, over 700 were listed, in part, due to water temperature concerns.

Stream temperature on forested streams has been extensively researched and monitored. Studies have investigated the effects of management on stream temperature, developed models to predict stream temperature, and evaluated the effects of elevated temperature on aquatic biota.

Effects of Harvesting and Other Environmental Variables

Many studies have documented increases in stream temperature due to timber harvesting. Degree of impact varies with particular practices and stream characteristics. Clearcut harvesting without leave trees or riparian buffer strips is consistently shown to increase mean, maximum and diurnal fluctuation of stream temperature (Brown and Krygier 1967, Levno and Rothacher 1967, Meehan et al. 1969, Meehan 1970, Feller 1981, Hewlett and Fortson 1982). Maintaining riparian vegetation has 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: 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).

Few basin-level studies have been conducted. Basin stream temperature studies in Washington documented increasing stream temperature in a downstream direction (Sullivan et al. 1990). The relationship appears to be asymptotic. At a given distance,

from the divide average stream temperature reaches an equilibrium temperature that approximates the average basin air temperature (Sullivan et al. 1990). The distance required to reach an "equilibrium" temperature varies from basin to basin. At this distance factors such as riparian cover and groundwater input play a less significant role in maintaining stream temperature due to increasing channel width and stream flow. In the 1990 study, average stream temperatures reached a maximum at approximately 24 to 36 miles from the divide. This study did not determine how management affected the basin trend.

Basin trends may not be as predictable on East-side Oregon streams (Beschta et al. 1996, unpublished data). Stream temperature was monitored continuously from headwaters to the mouth using aerial sensor equipment on a tributary to the John Day. Temperatures increased and decreased a number of times from headwaters to the mouth. The trend resulted in headwater temperatures which approximated temperatures at the mouth of the river. This implies that East-side streams may not follow West-side basin trends, and that monitoring at individual points throughout a basin may identify different trends depending on where individual thermistors are placed.

Fisheries

Stream temperature is an important parameter for predicting fish habitat quality (Baltz et al. 1987, Eaton et al. 1995). The effect of stream temperature on aquatic biota, in particular fish and amphibians, varies between species and within the life cycle of a given species (DEQ 1995). Critical chinook salmon life stages occurring during the summer months include juvenile rearing, adult holding and adult migration. For coho salmon, juvenile summer rearing and late summer/early fall migration are the critical life stages affected by increases in summer stream temperature. Bull trout spawning and within-stream migration both occur during summer months. Preferred temperature ranges for these species and the particular life stages are shown in Table 1.

Table 1. Optimum and lethal limit temperature ranges for coho, chinook, and bull trout.

Fish species	DEQ standard	Preferred juvenile temperature range	Adult migration, holding, or spawning	Lethal limit
Coho	64°F	54 -57°F	45 - 60°F	77°F
Chinook	64°F	50 - 60°F	46 - 55°F	77°F
Bull Trout	50°F	39 - 50°F	39 - 54°F*	NA

* Spawning occurs below 50°F.

Increases in stream temperature cause an increase in an organisms' metabolic rate (Warren 1971). If the food supply is not limiting then growth rates can actually increase. Growth rate is positive at temperature ranges of 40 - 66 °F, but approaches zero at the extremes. More commonly, research has found elevated stream temperature results in increased competition for an often limited food supply, potentially displacing juveniles out of their preferred habitat. This can increase susceptibility to predation by warm-

water-tolerant species. As food availability goes down so does growth rate. In addition, elevated stream temperatures increase the risk of disease-related mortality.

As stream temperature increases the amount of dissolved oxygen (DO) available to fish and other aquatic biota decreases. This occurs because as temperatures increase, the ability of the water to hold oxygen decreases. Concurrent increases in fish and other organisms' metabolic activity increases their oxygen requirements. The greater demand for oxygen also increases the removal rate of oxygen from the water column. As a result, even if food is abundant at higher temperatures, decreases in DO may metabolically stress salmonids, further increasing their susceptibility to disease.

Refugia. The presence and use of cool water refugia by sensitive species can serve to sustain the population (Bilby 1984, Sedell et al. 1990). A warm-water sensitive species can inhabit patches of cool water habitat when ambient conditions are too warm. Cool-water habitat can be sustained in deep pools, cold springs, hyporheic flow, the junction of cooler tributary streams and in different segments of the same channel.

A study done in Northern California found stratification of stream temperature in deep pools (3 to 9 feet), pools with large gravel bars at the upstream end, and shallow (1.5 feet) pools with subsurface seepage. Differences ranged from 7.0 - 8.0°F between the bottom and surface of the stream (Matthews et al. 1994, Nielsen et al. 1994). Temperature differentials between cool pools and ambient stream have been documented at 6.3°F.

Past ODF Stream Temperature Monitoring

In 1993, ODF monitored stream temperature upstream and downstream of harvest units. Results showed recovery of maximum stream temperature within 1000 feet downstream of harvest units when stream temperatures were elevated through harvest units (Andrus 1993). This was substantiated by a 1994 project monitoring stream temperatures on small type N (non-fish bearing, non-domestic use) streams flowing out of harvest units (Robison et al. 1995). Five out of six of the study streams never reached the DEQ water quality standard. In addition, the greater the maximum temperature observed flowing out of the unit the greater the rate of temperature decrease downstream.

There has been a substantial amount of research on stream temperature, the influential parameters and the effects of elevated stream temperature on aquatic biota. However, implications of management effects on stream temperature trends has rekindled discussions on stream temperature and associated regulatory parameters. Stream temperature is a function of the complex interaction of a number of environmental variables. The following project investigates these parameters further and assesses the effectiveness of the ODF forest practices in maintaining stream temperature.

Study Sites

Stream temperature was monitored on thirteen streams harvested with either a riparian management area (RMA) or a hardwood conversion (HWC) (Table 2). A total of five RMA and eight HWC units were monitored. They were all type F streams of which eight were medium, three large and two were small.

The requirements for site selection were: intact riparian condition 1000 feet upstream and 1000 feet downstream of the harvest unit, and harvesting conducted under the 1994 stream rules. All of the units were harvested prior to the monitoring period so there is no pre-treatment data, with the exception of Brush Creek. Brush Creek was harvested in the fall after one summer of data collection.

Stream characteristics varied greatly. For example, elevations ranged from 200 to 1560 feet, distances from divide varied from 0.20 to 11.5 miles, and wetted widths ranged from 2 to 26 feet. Harvest units vary between 1100 feet to nearly one mile in length. Buffer widths varied from 18 feet to 131 feet. Individual stream characteristics are given in Appendix A.

Table 2. Site description

Site	Stream Name	Georegion	Stream Type and Size	Forest Practice ^	Location
1	Brush Creek Basin with Thistle Burn Tributary	Interior	Entire Basin S-M-L	HWC Clearcut both sides	T.23 S, R.6 W
2	West Agency Creek	Coast Range	S-M type F	HWC	T.5 S, R.8 W Sec 6
3	January Creek	Coast Range	M type F	HWC	T.17 S, R.7 W Sec 14
4	Little Fall Creek	Interior	M type F	HWC	T.17 S, R.2 E Sec 33
5	Coleman Creek	Coast Range	L type F	HWC	T.14 S, R.7 W Sec 36
6	Sheele Creek	Coast Range	M type F	HWC *	T.12 S, R.7 W Sec 3
7	Mill Creek	Coast Range	M type F	HWC *	T.9 S, R.9 W Sec 26,27
8	Cascade Creek	Interior	M type F	HWC *	T.14 S, R.1 W Sec 33
9	Sheythe Creek	Coast Range	M type F	RMA	T.9 S, R.7 W Sec 26, 35
10	Eagle Creek	Coast Range	M type F	RMA	T.8 S, R.8 W Sec 7
11	Talbot Creek	Coast Range	S type F	RMA	T.26 S, R.13 W Sec 31
12	Douglas Creek	Interior	M type F	RMA	T.20 S, R.5 W Sec 10
13	Beaver Creek	Interior	L type F	RMA	T.2 N, R.5 W Sec 15

^ HWC = Hardwood conversion, RMA = Riparian Management Area
* HWC's designed to limit openings on the south side of streams.

RMA's and HWC's

The 1994 stream rules were designed to allow increased flexibility to the landowner and/or operator in managing riparian areas. Therefore, correct application of the riparian rules can result in a variety of vegetative conditions between sites. This variability, coupled with a mosaic of land ownerships (federal property adjacent to private ownership) results in different vegetative conditions under application of the same rules. In addition, three sites harvested under the HWC rule were intentionally designed to limit openings on the south side of the streams. Therefore the results of this study represent a variety of conditions described as either RMA or HWC.

Georegions

The Oregon Forest Practice Rules use the term "georegion" to describe large areas with similar combinations of climate, geomorphology and potential natural vegetation. The Forest Practices Monitoring Program stratifies sample sites on a georegion basis (Figure 1). There were only two georegions sampled in this study. The "Coast Range" includes the cooler, wetter and typically steeper portions of coastal mountains with a combination of igneous and sedimentary rock. The "Interior" region is warmer, drier and typically consists of foothills on both sides of the Willamette valley. For this project there were eight streams in the Coast Range and five in the Interior.

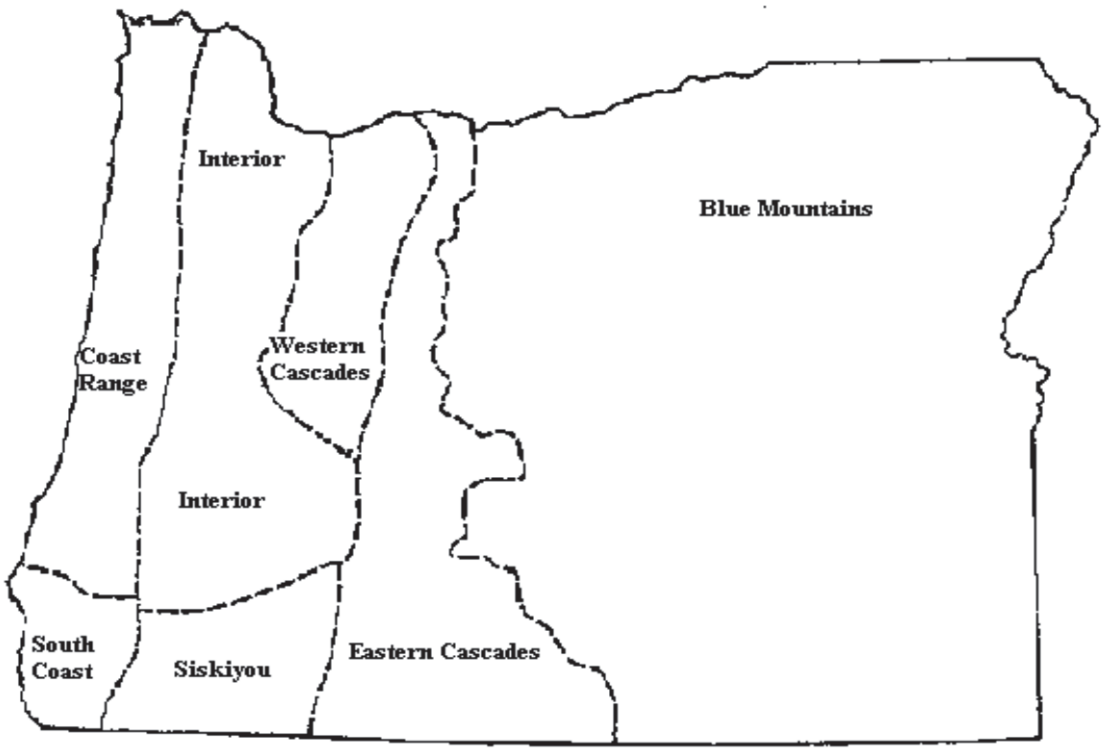


Figure 1. Boundaries of Oregon Department of Forestry georegions.

Field Methods

Stream Temperature

ODF's stream temperature monitoring protocol (Runyon and Andrus 1994) was used in selecting 16 streams and individual monitoring station locations. In general, stream temperature was monitored on the boundary of the upstream and downstream ends of harvest units and 500 and 1000 feet (ft) downstream of the harvest unit. Additional monitoring sites were established as needed to account for tributary effects. Monitoring schemes for the individual streams are shown in Appendix B. Temperature data were collected every 48 minutes using HOBO-temp monitoring thermistors. Periods of record

varied from stream to stream, but in general data are available from July through September 1995 (Appendix C shows the period of record for each station).

Environmental Data

Physical and vegetative data were collected on each stream. Eleven stations were established upstream, within the harvest unit and downstream of the harvest unit for a total of 33 stations on each stream. The following parameters were measured for each station unless specified otherwise.

Physical Data:

1) *Stream flow* was measured with a Marsh McBurney velocity meter at the downstream edge of the cutting unit and at the farthest downstream temperature monitoring station. Measurements were taken once during the summer.
2) *Aspect* was taken from USGS 1:24 000 maps.
3) *Elevation* was taken from USGS 1:24 000 maps.
4) *Gradient* was measured in percent with a clinometer.
5) *Thalweg depth*, *wetted* and *bankfull width* and *terrace height* were measured using a meter stick.
6) *Substrate* was characterized as the percent of the cross-section composed of bedrock, boulder, cobble, gravel and fines.
7) *Distance from divide* was measured for each temperature monitoring site from a 1:24000 USGS map. Distance was measured in a downstream direction from the ridge to the monitoring station, following forks contributing the greatest proportion of flow.

Management and Vegetation Data:

1) *Width of left and right buffer* or riparian stand were measured by pacing or with a hip chain.
2) *Harvest unit length* was measured by pacing or with a hip chain.
3) *Cover* was measured using a concave densiometer and fish-eye lens camera.

Analytical Methods

Temperature parameters

Stream temperatures were used from three stations on each stream: station 1, on the upstream boundary of the harvest unit; station 2, on the downstream boundary of the harvest unit; and station 3, 1000 feet downstream of the harvest unit (Figure 2). Due to missing data there were four streams (Beaver, Sheythe, Talbot and West Agency) in which a station 500 feet downstream was used instead of a station 1000 feet downstream. The third stations on Mill and Brush Creeks were located 1640 feet and 2.4 miles, respectively, downstream of the harvest units.

The 7-day moving mean of daily maximum, minimum and average (7-day maximum, minimum, average) stream temperature and diurnal fluctuation were used to analyze effectiveness of RMA's and HWC's in maintaining stream temperature. Period of record when the highest 7-day maximums were observed on all streams was chosen for analyses.

On a subset of streams, the number of days that 7-day maximum was above 55°F and 64°F from July 21 through August 16 was also analyzed.

Environmental Parameters

Environmental data were averaged for the 11 stations upstream of the harvest unit, within the harvest unit and downstream of the harvest unit. These averages were used to investigate relationships between environmental characteristics and stream temperature. Averages for each reach are given in Appendix A.

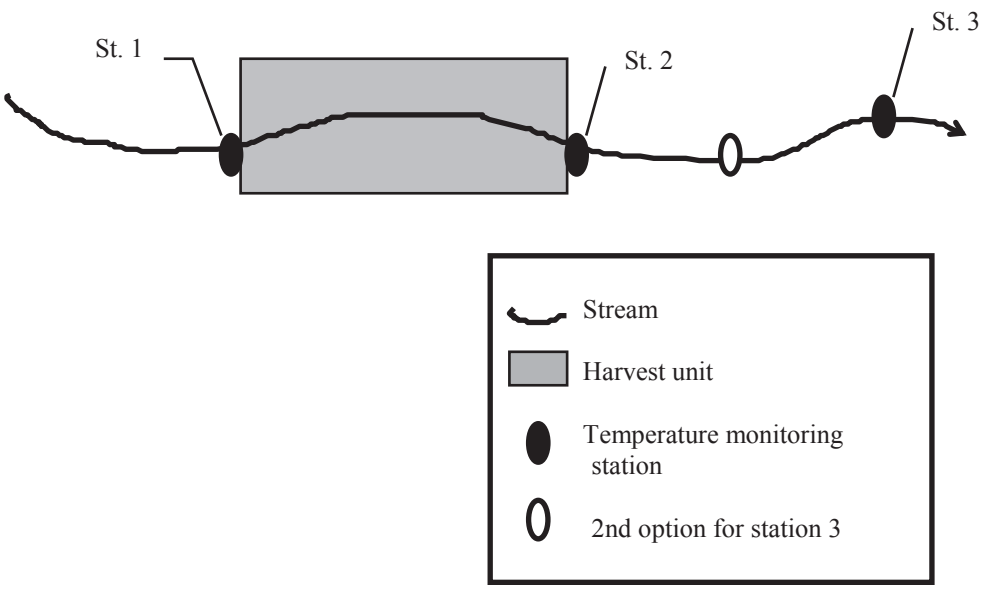


Figure 2. Stations used for statistical analyses.

Statistical Methods

Statistical analyses were used to investigate relationships between environmental parameters and stream temperature and to test for effects of harvesting with RMA's versus HWC's on stream temperature. Three statistical methods were applied: *correlation analysis, repeated measures analysis of variance (ANOVA), and distribution tests*. These analyses were performed on 13 streams. The statistical methods are described below.

1) *Correlation analysis* (SAS/STAT 1988): This procedure tested the relationship between environmental parameters (i.e., distance from divide, stream gradient) and stream temperature. The data were correlated in two ways. Initially, all the stations were pooled and 7-day maximum, minimum and average were correlated against the corresponding average environmental parameters. Secondly, a correlation analysis was performed separately for each station 1, 2 and 3. Results of the station-stratified correlation were applied to the repeated measures ANOVA discussed below. Level of

significance for Pearson correlation coefficients (r) was determined at a p-value less than or equal to 0.001, 0.01 and 0.05.

2) *Repeated measures ANOVA* (SAS/STAT 1988): Repeated measures ANOVA was used rather than a "straight" ANOVA because the data were spatially dependent on each other. Both residuals and "raw" stream temperature data were analyzed.

Residuals. Given the lack of pre-harvest data, residuals were used in the repeated measures ANOVA as a means to account for stream temperature variability attributable to factors other than harvesting. The intention was to account for "natural" increases in stream temperature which occur in a downstream direction. Station-stratified correlation analyses (described above) identified distance as a parameter which significantly (p-value < 0.01) and most consistently (at each station) influenced stream temperature. Station 1 was the only station which provided a distance/temperature relationship which was not affected by the harvest units. Therefore residuals were calculated using the empirical model of stream temperature at station 1 versus distance at station 1. The residual at any station was the difference between the predicted stream temperature (station 1 model) and the actual stream temperature at that station.

Raw Data. Repeated measures ANOVA of "raw" stream temperature data (7-day maximum, minimum, average and diurnal fluctuation not adjusted for distance) was important since residuals were based on correlation using a relatively small data set with a high amount of variability. Therefore, the empirical relationships may not have accurately predicted pre-harvest conditions.

Both of the above repeated measures ANOVA's tested the effect of RMA's and HWC's on stream temperature (7-day maximum, minimum, average and diurnal fluctuation). A statistically significant increase between stations 1 and 2 would indicate a harvest effect. A significant decrease between stations 2 and 3 would indicate downstream cooling. A significant difference between stations 1 and 3 would indicate either a reach level increase or decrease in 7-day maximum, minimum, average and diurnal fluctuation.

3) *Distribution Tests* (SAS/STAT 1988): A Chi-squared test was applied to frequency distributions of stream temperature data to test for harvest effect on frequency with which stream temperature was above 64°F and 55°F. This procedure tests the effectiveness of rules in maintaining stream temperature at or below the DEQ standard. Since the DEQ standard is linked with temperature effects on fisheries, this technique was an index of the potential effects of harvest units on fisheries. This analysis was performed on 11 streams for the period of record in which the highest stream temperatures were observed, July 21 through August 16. It is important to note this analysis assesses a 21-day period while the ANOVA's assess a seven day period.

Brush Creek Basin Trends

The hardwood conversion on Brush Creek was analyzed with the rest of the streams in the analyses described above. In addition, overall basin trends and differences between 1994, 1995 and 1996 will be discussed.

Limitations of the Study

Limitations of the study must be considered when interpreting the data. There were no pre-harvest data and no data 1000 ft upstream of harvest units. Therefore a direct measure of background variability was not available. Other means (described above) were used in an attempt to account for natural variability and to address the influence of environmental parameters, other than harvesting, on increases in temperature. In addition, relatively small sample sizes and high variability in the data reduce the power of statistical methods and increase the possibility of erroneously accepting or rejecting a hypothesis that harvesting with RMA's and HWC's does not affect stream temperature.

There was variability in vegetative condition under the same harvest treatment. This made it difficult to accurately assess the effectiveness of HWC's versus RMA's in maintaining stream temperature. In addition, poor quality canopy data limited the ability to assess the effect of shade on stream temperature.

The ability to determine the effect of RMA's and HWC's on fish habitat is limited. Effect of harvesting on fisheries was determined based on preferred temperature regimes of salmonids. The DEQ water quality standard was used as an index of high quality fish habitat.

Results and Discussion

The DEQ standard is based on 7-day maximum and provides a means of assessing weekly trends versus an instantaneous high. The highest 7-day maximums were recorded on July 20th and August 3rd consistently for all stations. Graphical displays of these data are found in Appendix D. On average the August peak was 0.41°F higher than the July peak. The period of record chosen for analysis was the week of July 31 to August 6, thereby capturing the August 3 peak.

Observations of Changes in 7-day Maximum Stream Temperature through Harvest Units

The average increase in 7-day maximum stream temperature through harvest units was 2.5°F for HWC and 2.1°F for RMA units (Figure 3a,b). At five sites stream temperatures changed very little (< or = 1.0°F) through the harvest units (Cascade, Little Fall, Mill, Beaver, and Eagle Creeks) while for the remainder of the sites, changes in stream temperature varied from 2.1 to 5.7°F.

Stream temperature increases *greater than* 3.0°F were observed on four out of eight HWC sites (Brush, Coleman, January and Agency). Three out of four of these HWC sites had stream temperatures less than 60°F upon entering the harvest unit (Figure 4a,b,c).

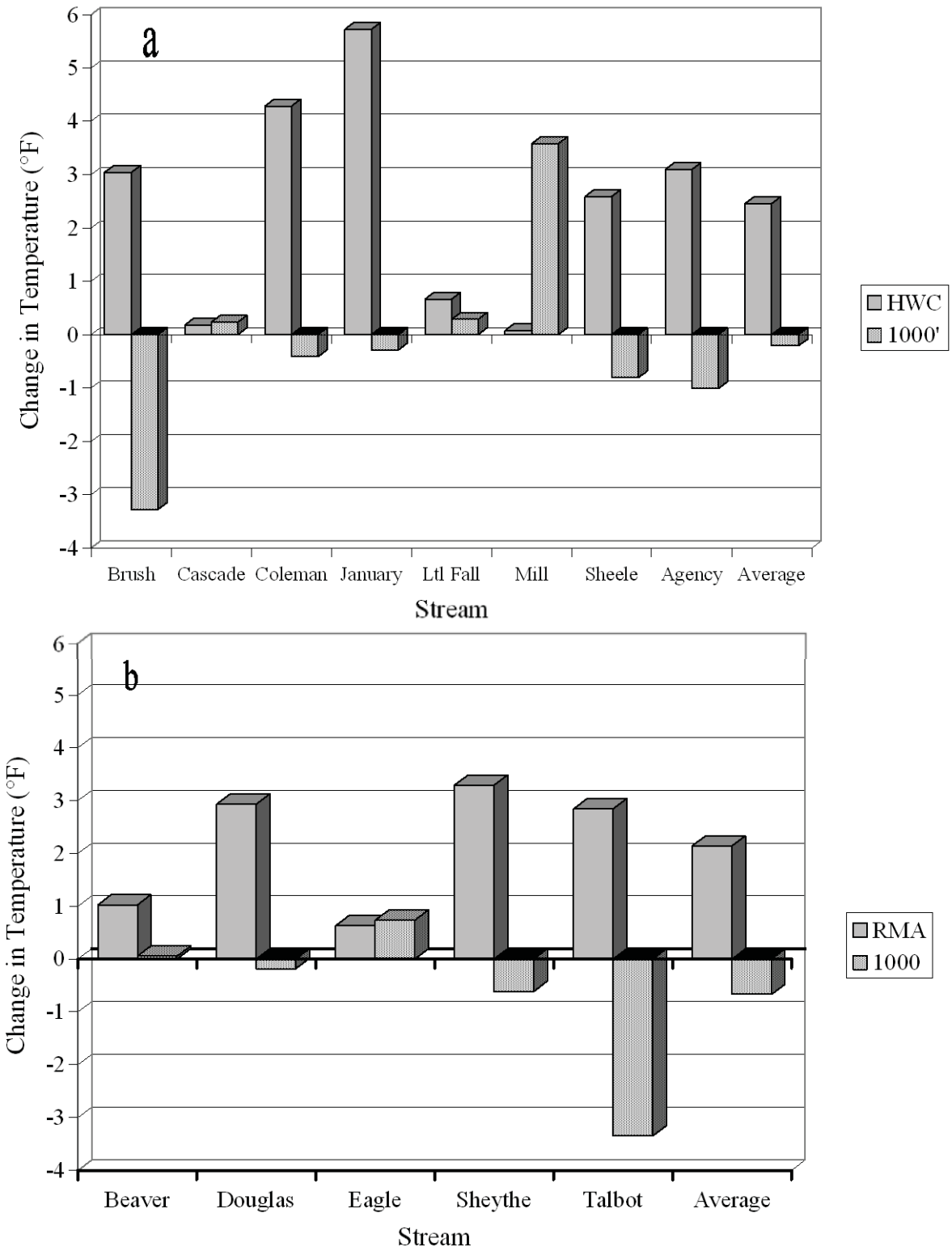


Figure 3. Change in 7-day maximum through harvest units and downstream reaches for (a) HWC and (b) RMA units.

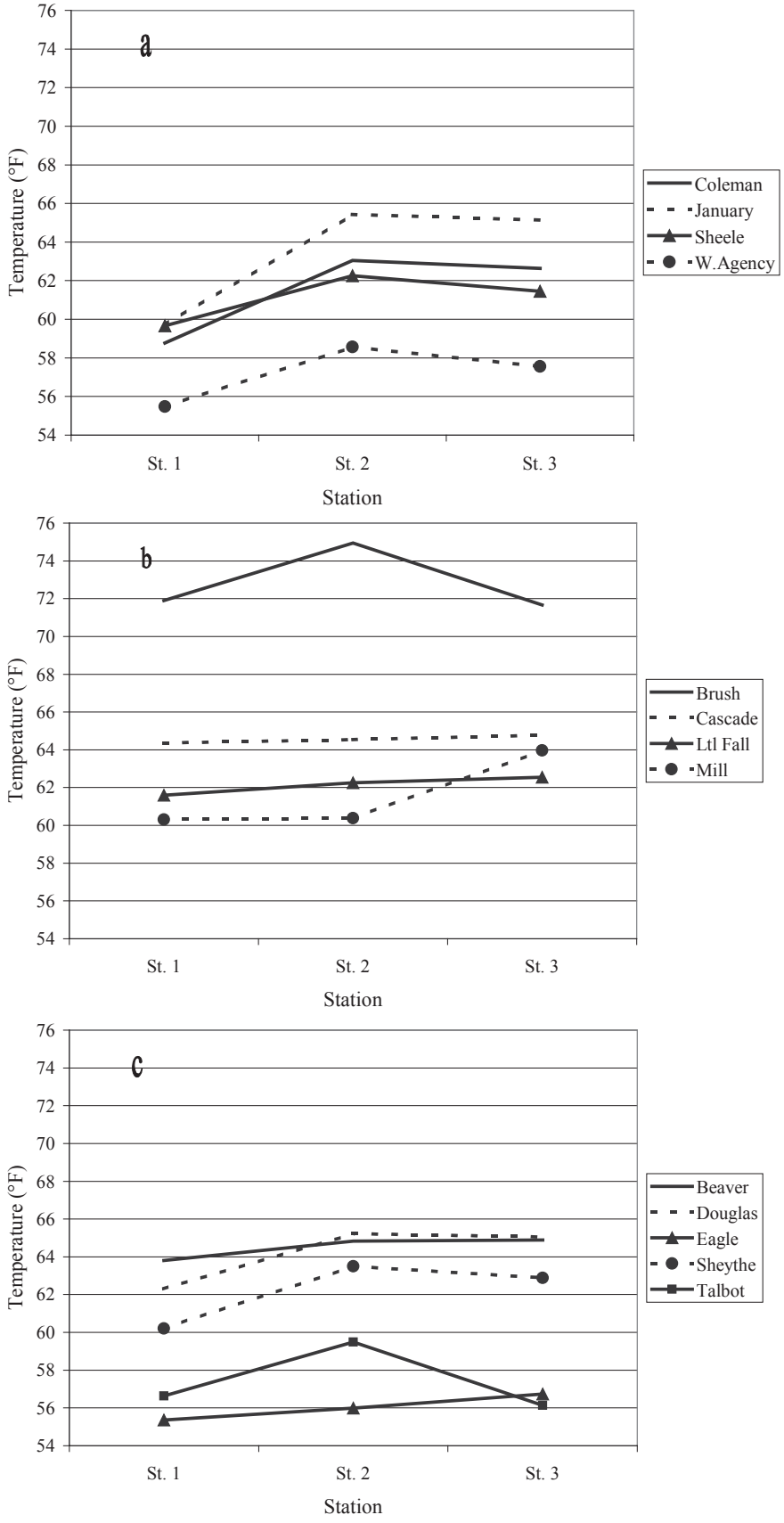


Figure 4. Seven-day maximum stream temperature at stations 1, 2, and 3 for streams harvested with (a and b) HWC's and (c) RMA's

This may have increased the potential for greater changes in temperatures through harvest units. January Creek showed the greatest increase of 5.7°F through the HWC. This sight was a relatively low gradient stream with slightly meandering, beaver-influenced channel morphology. Canopy cover was reduced to less than 10 percent in some areas. These characteristics would have increased the time of exposure of the stream to incoming solar radiation which in turn results in increased stream temperature.

Stream temperature increases *greater than* 3.0°F were observed on only one out of five RMA's. However, stream temperature increases of 2.9 and 2.8°F were observed on Douglas and Talbot Creeks. Douglas Creek had a number of beaver ponds with lower than average canopy cover (10%) throughout parts of the RMA. These characteristics increase the exposure of the streams to solar radiation. Talbot Creek was a small stream, the lowest elevation (200 ft) site, very close to the headwaters (0.20 miles) with narrow RMA widths. These characteristics may have made it more susceptible to a greater flux in temperature through the harvest unit.

Stream temperature increases *less than* 3.0°F were observed on four out of eight HWC sites (Cascade, Mill, Sheele and Little Fall Creeks). Three of these sites, Cascade, Mill and Sheele Creeks were specifically designed to limit the amount of southern exposure that would result from that prescription. Stream temperatures increased on these streams by 0.2, 0.1 and 2.6°F, respectively. The buffers on these streams were designed to remove most of the basal area from the north side of the stream and leave more trees on the south side of the stream, thereby providing increased shade and protection from incoming solar radiation. This approach was marginally successful on Sheele Creek. That may be because Sheele Creek was a cooler stream (59.7°F) upon entering the HWC (Figure 4b). Little Fall Creek was the other HWC site on which minimal increases in 7-day maximum (0.7°F) were observed. This stream was the highest elevation stream (1568 ft) and had the shortest openings (1148 ft) of all the HWC's.

Stream temperature increases *less than* 3.0°F were observed on four out of five RMA streams. Stream characteristics varied greatly other than being harvested with an RMA rather than a HWC.

Observations suggest that the performance of RMA's and HWC's was variable. In some instances temperature increases greater than 3°F were observed on both RMA's and HWC's, possibly attributable to greater exposure to solar radiation. At other sites stream temperature increases were less than 1.0°F for both RMA's and HWC's. Furthermore, the special-prescription HWC sites may have maintained stream temperature more effectively through harvest units than the conventional HWC's. This would be attributable to greater protection from incoming solar radiation afforded by a prescription which limits southern exposure.

The average rates of increase in 7-day maximum through RMA's and HWC's were 0.94 and 1.0°F/1000 ft (standard deviation = 0.75 and 0.79°F), respectively. These rates are somewhat consistent with background rates observed on Brush Creek. The rate of

warming upstream from the treatments, on Brush Creek over a three year period ranged from 0.54 to 0.64°F/1000 ft of stream. This occurred over a 2.8 mile reach which began approximately 1.6 miles from the divide. The rate was more variable at 5.5 miles from the divide, 1.52, 0.17, 0.45°F/1000 ft in 1994, 1995, and 1996.

The greatest rates of warming for RMA's and HWC's were observed on Sheythe and West Agency Creeks, 2.05 and 2.30°F/1000 ft respectively (Table 3). The lowest rates of warming for RMA's and HWC's were observed on Eagle and Cascade Creeks, 0.24 and 0.08°F/1000 ft, respectively.

Rate of increase through harvest units was not always proportionate to measures of change in canopy cover. This is most likely a function of poor quality canopy measurements and no pre-harvest data on canopy cover. Without pre-harvest data, change in canopy cover was assumed to be proportionate to the difference in canopy cover between the upstream reach and within the harvest unit. Based on this assumption canopy cover actually increased with some of the harvest units. The maximum decrease in canopy cover was 20% for a HWC and 18% for an RMA (Table 3). Rates of increase on these same sites were 3.1 and 1.2°F/1000 ft, respectively. Minimum decreases for HWC's and RMA's were 0 and 1%. Average decreases in canopy cover for HWC's and RMA's were 4.1 and 3.2%, respectively (standard deviation of 5.8 and 12.4).

Table 3. Stream temperature parameters, cover and distance from divide for each stream.

Stream	Treatment	7-day Maximum Below unit (°F)	7-day Minimum Below unit (°F)	7-day Average Below unit (°F)	Change in 7-day maximum through unit (°F)	Rate of warming through harvest unit (°F/1000ft)	Change in Canopy cover (%)	Distance From Divide at bottom of unit (miles)
Brush	HWC	75.0	62.7	69.0	+ 3.0	1.0	+ 6	9.0
Cascade	HWC	64.5	56.9	60.5	+ 0.18	0.08	- 7	3.55
Coleman	HWC	63.1	56.1	59.4	+ 4.3	1.3	- 3	4.16
January	HWC	65.4	58.4	61.7	+ 5.7	1.7	- 10	2.69
Little Fall	HWC	62.3	54.9	58.2	+ 0.66	0.58	- 10	6.23
Mill	HWC	60.4	57.6	58.9	+ 0.07	0.01	- 5	4.41
Sheele	HWC	62.2	54.5	57.6	+ 2.6	1.0	0	3.80
W Agency	HWC	58.6	53.4	55.7	+ 3.1	2.3	- 20	0.88
Beaver	RMA	64.8	59.6	62.5	+ 1.0	0.29	- 14	5.22
Douglas	RMA	65.2	59.1	61.8	+ 2.9	0.89	+ 9	3.11
Eagle	RMA	56.0	53.5	54.8	+ 0.63	0.24	+ 8	2.57
Sheythe	RMA	63.5	55.9	58.8	+ 3.3	2.0	- 1	3.52
Talbot	RMA	59.5	53.2	56.3	+ 2.8	1.2	- 18	0.64

While some of the above observations suggest a treatment effect it is necessary to perform statistical analyses on the data to determine if the observations are statistically significant. The potential disadvantage of statistical analyses is pooling streams together that vary greatly in site and vegetative characteristics and treating them as two populations. A larger sample size would have countered the high variability. However,

the benefit of statistical analyses is to objectively determine rule effectiveness. In addition, since the rules apply to a wide variety of streams, it is appropriate to analyze them accordingly.

Relationship Between Environmental Parameters and Stream Temperature

Previous studies indicate that stream temperature will increase as width, depth, stream flow and distance from divide increases and velocity, elevation and gradient decrease (Beschta and Weatherred 1984, Sullivan and Adams, 1989, Sullivan et al 1990, Caldwell et al. 1991). As buffer width and canopy cover increase, stream temperature changes are minimized (Levno and Rothacher 1967, Brown and Krygier 1970, Meehan 1970, Brazier and Brown 1973, Lynch et al 1985). In the following correlation analyses, 7-day maximum, minimum and average stream temperatures for all stations were correlated against environmental parameters to explore these hypotheses.

As depth, wetted width, bankfull width, bank height, percent bedrock and distance from divide increased, 7-day maximum, minimum and average increased. As gradient andelevation increased 7-day maximum, minimum and average stream temperature decreased. These results were consistent with findings from other studies (Table 4).

As buffer width increased, 7-day maximum and average stream temperature decreased. The buffer width relationship was only significant for 2 of 6 comparisons (Table 4), however, the negative relationship was consistent with findings from previous studies.

Past studies have shown that as canopy cover increases lower stream temperatures will be observed. Our data did not reveal this relationship. Rather than disprove previous studies, however, it is more likely the data from this study did not accurately represent actual canopy cover at all the sites. This may be attributable to three factors. First, correct procedure may not have been followed when measures of cover were collected. This was determined by revisiting the sites after the sampling period and spot checking the data. Vastly different measurements for some sites were documented. Secondly, even with proper use of a densiometer, two people can obtain different measurements, reducing the accuracy of the measure. Finally, the high variability observed in change in canopy cover (+9 to -20%) reduced the ability to define a relationship between canopy cover and temperature using correlation analysis. Future monitoring will emphasize accurate measurements of canopy cover.

Some of the physical parameters were cross-correlated with each other. For example as distance from divide increased, elevation and gradient decreased while width, bankfull width, bank height and maximum depth increased. As wetted width increased, bankfull width and maximum depth increased. Significant correlation simply shows a parameter and temperature have consistent linear trends beyond a level explained by random chance.

Table 4. Correlation relationships, Pearson correlation coefficients (r), and p-values for statistically significant findings with all stations pooled. Positive relationships are noted with a "+" and negative relationships with a "-". Actual p-value is less than or equal to reported value.

Temp Statistic	Depth	Wet width	Bank-full width	Left bank height	Right bank height	% Fines	% Gravel	% Cobble	% Bolder	% Bed-rock	% ChannelGrad.	% Cover	Left buffer width	Right buffer width	Dis-charge	Harvest length	Dist. from divide	Elev-ation
7-day Max																		
r	+0.42	+0.67	+0.52	+0.45	+0.40					+0.52	-0.51			-0.37			+0.81	-0.36
pvalue	0.01	0.001	0.001	0.01	0.01					0.001	0.001			0.05			0.001	0.05
7-day Min																		
r	+0.46	+0.48	+0.36	+0.59	+0.44			-0.33		+0.45	-0.64						+0.67	-0.47
pvalue	0.01	0.01	0.05	0.001	0.01			0.05		0.01	0.001						0.001	0.01
7-day Avg																		
r	+0.44	+0.59	+0.56	+0.52	+0.43					+0.52	-0.59			-0.36			+0.77	-0.42
pvalue	0.01	0.001	0.01	0.001	0.01					0.001	0.001			0.05			0.001	0.01

It does not suggest that any *one* parameter drives stream temperature. For example, distance does not *cause* increases in width, just as distance does not *cause* increases in stream temperature. On the contrary, *many* parameters show significant and consistent relationships with stream temperature, supporting the hypothesis that stream temperature at a given site is a result of a combination of several environmental parameters.

The morphological descriptors (depth, width, bank height, gradient, elevation, and distance from divide) are all factors which generally increase or decrease in a downstream direction or as streams get larger. Distance from divide provides an easy-to-measure parameter which captures the downstream dynamics and inter-relatedness of environmental parameters. It was also the most consistently correlated parameter with stream temperature when correlation analyses were performed on individual stations. Therefore, in the following assessment of the effectiveness of RMA's and HWC's in maintaining stream temperature, the relationship between distance from divide and stream
temperature was used as a tool to account for increases in temperature which might have occurred in a downstream direction regardless of harvest activities.

<u>Effect of RMA and HWC Harvest Units on Stream Temperature</u>
Stream temperature upstream from harvest units was compared to stream temperature downstream of harvest units. Repeated measures ANOVA was performed on the residuals of stream temperature versus distance and on the "raw" data (7-day maximum, minimum, average and diurnal fluctuation).

Calculating residuals. Station 1 is the only station at which stream temperature was not affected by RMA's and HWC's. Therefore, the empirical relationship between distance and temperature at station 1 was used to predict the increase in stream temperature that might have occurred in a downstream direction without harvest activities. Stream temperature was regressed versus distance from divide for station 1 data to develop the following empirical equations:

Equation 1: $\text{7-day Maximum}_{(st.\ 1)} = (1.69) * \text{Distance}_{(st.\ 1)} + (55.13)$
$(R^2 = 0.72,\ \text{p-value} = 0.0003)$

Equation 2: $\text{7-day Minimum}_{(st.\ 1)} = (0.76) * \text{Distance}_{(st.\ 1)} + (52.90)$
$(R^2 = 0.49,\ \text{p-value} = 0.0076)$

Equation 3: $\text{7-day Average}_{(st.\ 1)} = (1.23) * \text{Distance}_{(st.\ 1)} + (53.75)$
$(R^2 = 0.65,\ \text{p-value} = 0.0009)$

Predicted 7-day maximum, minimum, and average stream temperatures (Y^) at stations 2 and 3 were calculated using the slope and intercept defined by equations 1, 2 and 3.

$$Y\hat{}_{1,2,3} = m_1(\text{distance}_{1,2,3}) + B_1$$

Wherein,
m_1 = slope empirically defined from equations 1, 2 or 3.
$(distance_{1,2,3})$ = distance from divide at stations 1, 2 or 3 (miles).
B_1 = intercept empirically defined from equations 1, 2 or 3 (°F).

The difference between the predicted stream temperature and the actual stream temperature (residual) for each station was then calculated.

$$Residual_{1,2,3} = Observed_{1,2,3} - Y\hat{}_{1,2,3}$$

Wherein,

$Residual_{1,2,3}$ = residual at stations 1, 2, or 3.
$Observed_{1,2,3}$ = the observed stream temperature (°F) at stations 1, 2, or 3.
$Y\hat{}_{1,2,3}$= predicted stream temperature at stations 1,2, or 3 (°F).

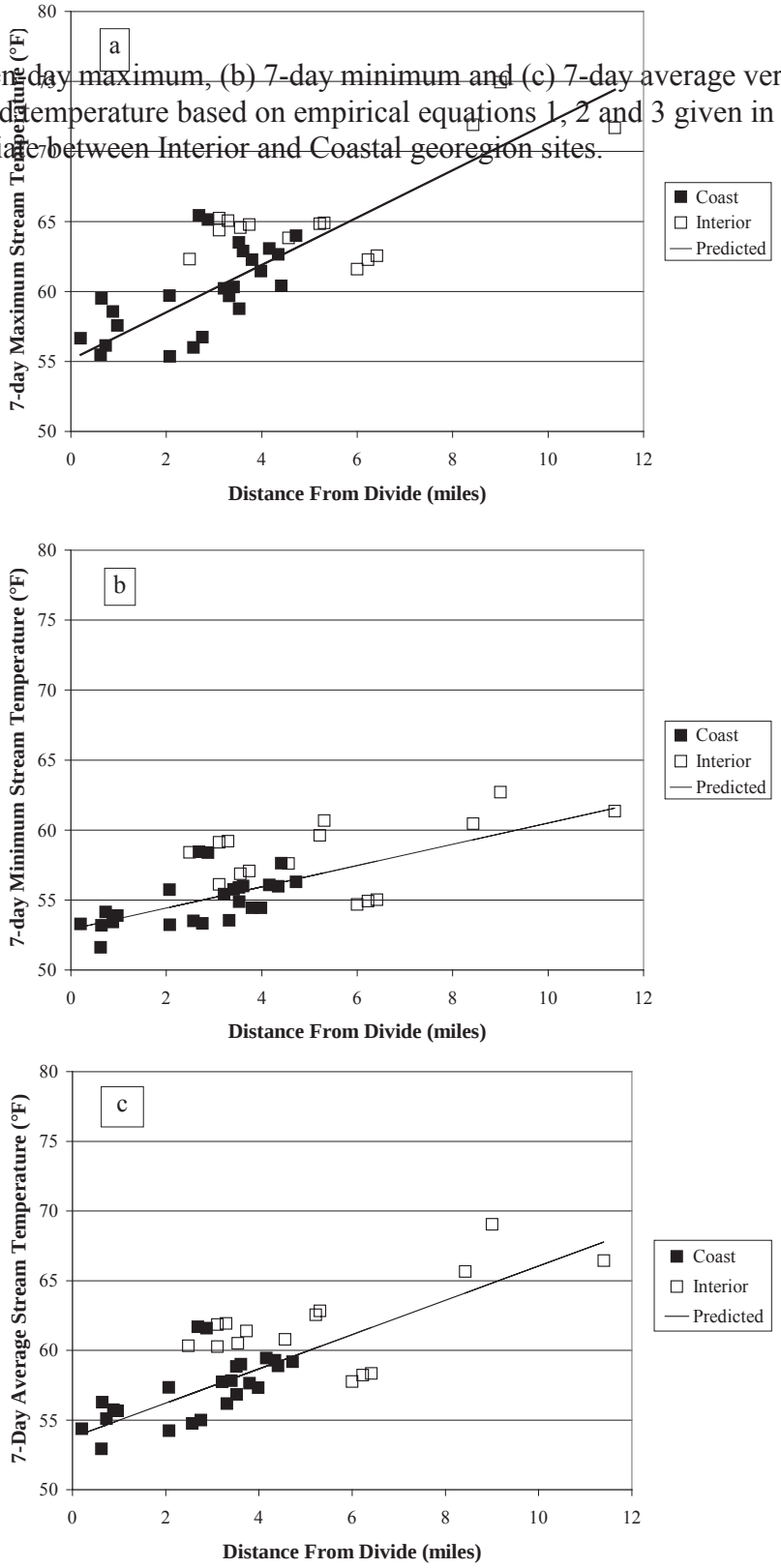
The empirical equations for 7-day maximum, minimum and average had to be extrapolated to calculate residuals for two sites: Brush stations 2 and 3. All other sites were at distances from the divide that were within the upper and lower extremes of distances for station 1 (Figure 5a,b,c).

Georegion Differences. Figure 5a,b,c differentiates data from the Interior versus Coast Range georegions. A separate statistical analysis of streams stratified by georegion was not appropriate due to small sample sizes. Furthermore, there were more sites in the Coast Range than in the Interior which were closer to the headwaters. Where distances were similar, temperatures observed on Coast Range sites were generally cooler than those of the Interior.

Effect of RMA's and HWC's on 7-day maximum, minimum and average. A repeated measures ANOVA on the residuals revealed no significant difference between stations. In addition there was no significant difference between performances of HWC's and RMA's. This result was consistent for 7-day maximum, minimum and average. These results indicate that when the data were adjusted to account for the effect of distance from divide, there was no significant effect of harvest units on stream temperature. This would indicate that RMA's and HWC's are effective at maintaining stream temperature through harvest units.

A repeated measures ANOVA of the raw temperature data showed a significant difference between stations in 7-day maximum, minimum and average. Stream temperatures were significantly higher at station 2 (immediately downstream from the harvest unit) than at station 1 (upstream from the harvest unit). Likewise, stream temperatures were significantly higher at station 3 (500 to 1000 feet downstream of the harvest unit) than at station 1 (p-value < 0.01 and 0.001). There was no significant difference between stations 2 and 3 for any of the temperature parameters.

Figure 5. (a) Seven day maximum, (b) 7-day minimum and (c) 7-day average versus distance. Predicted temperature based on empirical equations 1, 2 and 3 given in text. Symbols differentiate between Interior and Coastal georegion sites.



The ANOVA results from the raw data indicated stream temperatures increased through harvest units and remained elevated 1000 feet downstream. Specifically, 7-day maximum increased by an average of 2.1°F through RMA's and 2.5°F through HWC's. Increases were not countered by decreases downstream. As a result, temperatures remain significantly higher, 2.2°F for RMA reaches and 1.5°F for HWC reaches, 1000 ft downstream of harvest units than above harvest units (Figure 6). There was no significant difference between RMA's and HWC's.

Results from these two analyses are contradictory. Results from an ANOVA of the residuals indicated no statistical effect of harvest units on stream temperature. Stream temperatures increase naturally in a downstream direction. When the data were analyzed in an attempt to account for this (using residuals), the increases in stream temperature observed through the harvest units were sufficiently small that they were not statistically significant. The raw data results indicate the opposite. Stream temperatures were significantly higher downstream of harvest units than upstream of harvest units. Furthermore, increases observed through harvest units were not countered by cooling in the downstream reach.

Contradictory results may be a manifestation of a relatively small sample size and high variability within the data. Modest regression relationships ($r^2 = 0.41, 0.35, 0.55$) from empirical equations 1, 2 and 3 result in a lack of precision in predicting pre-harvest stream temperature. Thus the residual analysis may lead to erroneously accepting the null hypothesis that there is no significant effect of harvesting on stream temperature.

Both analyses indicate no statistical difference between RMA's and HWC's. As described previously, some of the HWC's were intentionally designed to reduce southern exposure and resulted in smaller increases in 7-day maximums than conventional HWC's. The above analyses were also repeated without these streams (Cascade, Mill and Sheele) to ensure that results were not affected by this differential treatment. Results of these analyses were consistent with those described above.

Effect of RMA's and HWC's on Diurnal Fluctuation. Diurnal fluctuation is the change in stream temperature occurring in a 24-hour period at one station (Daily maximum - Daily minimum). Diurnal fluctuation was averaged for each station for July 31 - August 6 and analyzed using a repeated measures ANOVA.

There was no significant difference in diurnal fluctuation between stations, suggesting that harvesting does not increase diurnal fluctuation. However, diurnal fluctuation was significantly different between treatments (p-value < 0.05). Diurnal fluctuation was higher downstream of HWC's than it was downstream of RMA's, 7.5 and 4.7°F respectively. Diurnal fluctuation associated with intact riparian areas was 5.8° F (Figure 7). Higher diurnal fluctuation with HWC's indicates that overall energy loading may be greater for HWC's than RMA's.

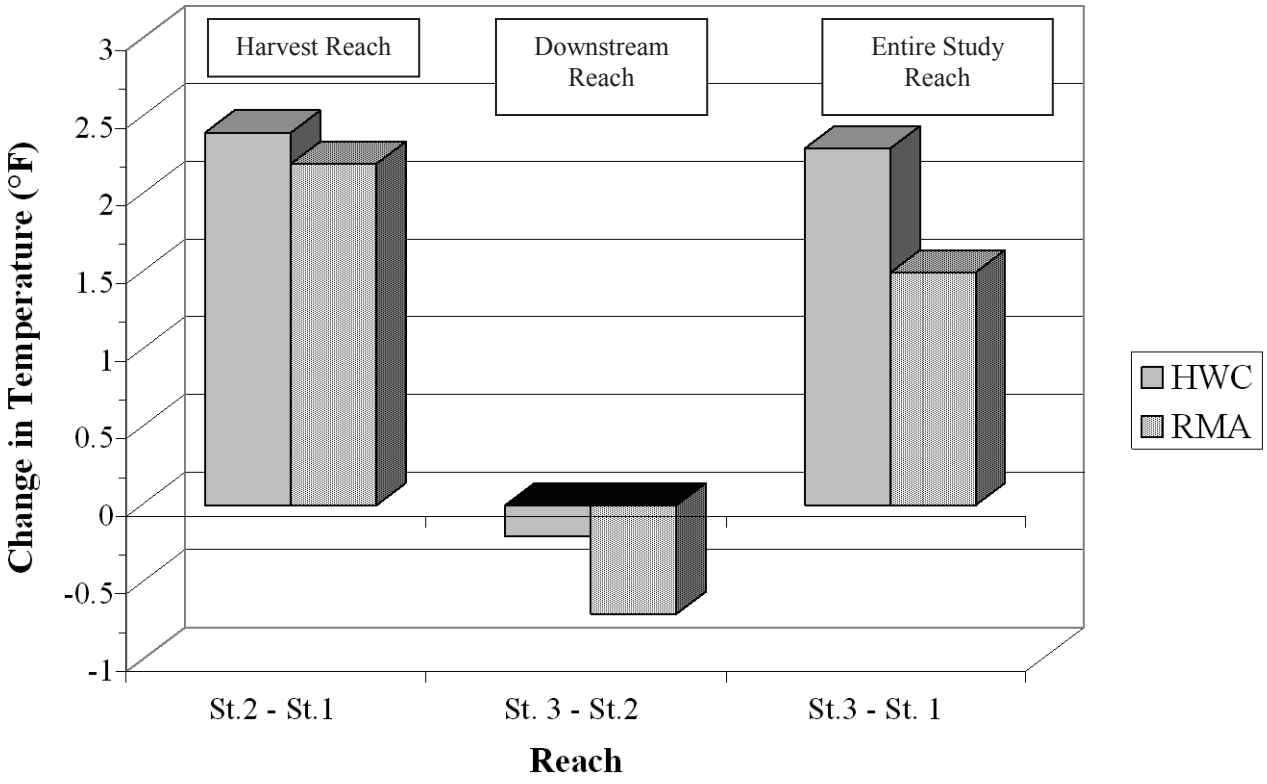


Figure 6. Change in 7-day maximum for harvest, downstream and study reaches

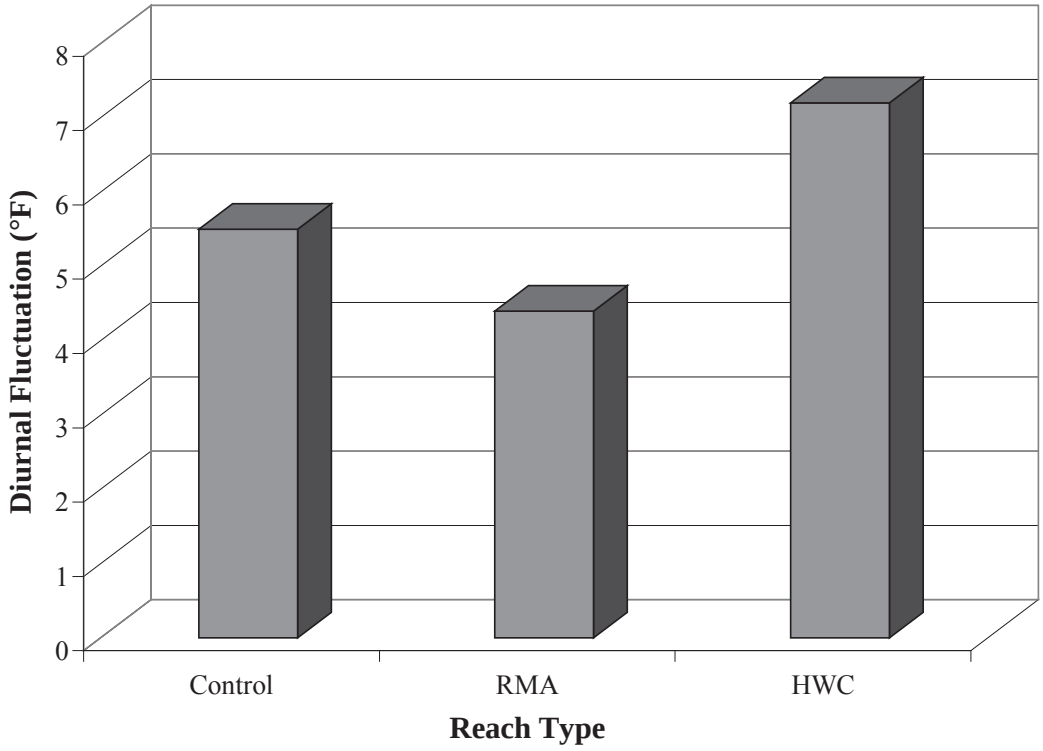


Figure 7. Diurnal fluctuation for control, RMA and HWC reaches.

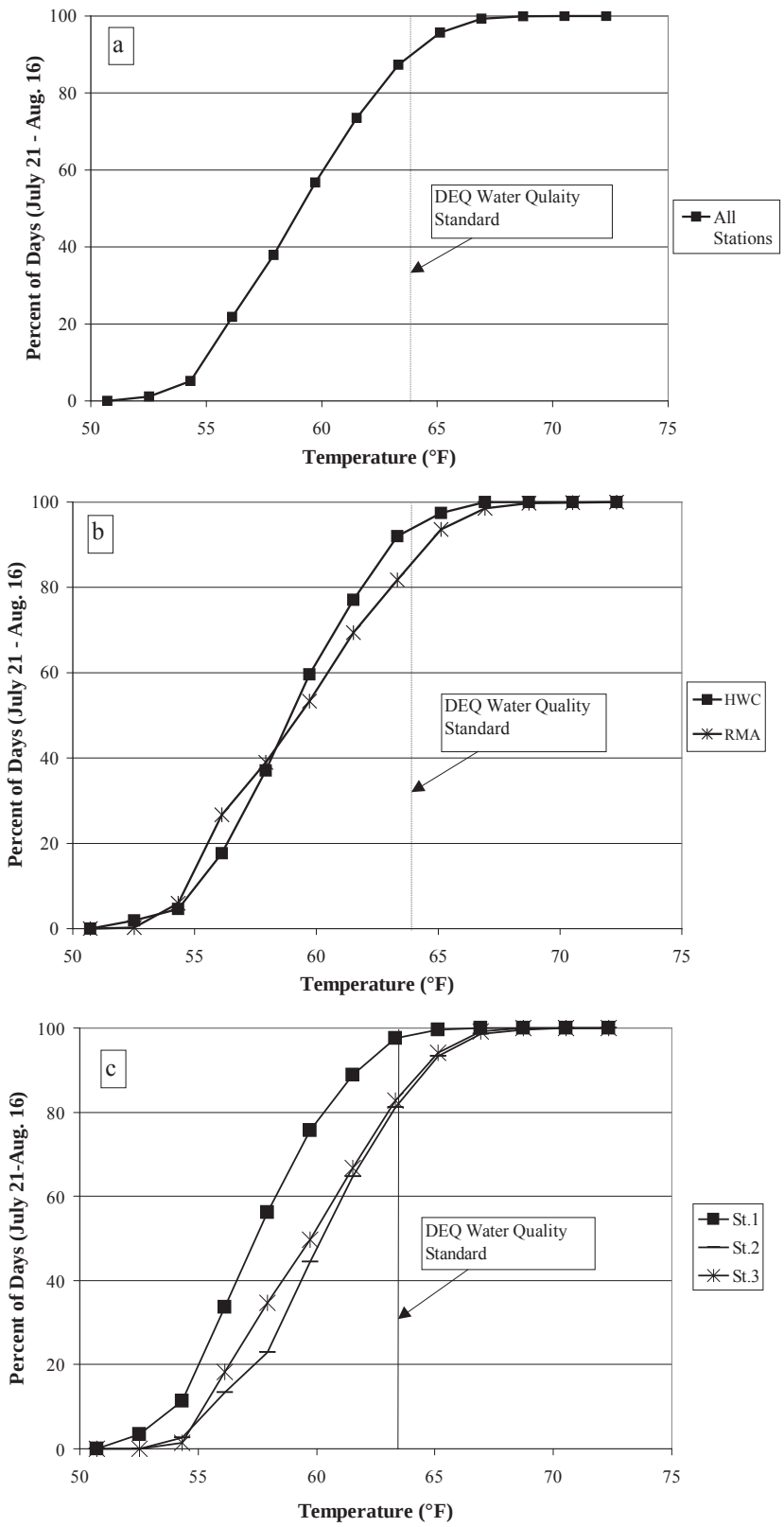


Figure 8. Cumulative frequency of 7-day maximum versus stream temperature for (a) all streams and all stations (b) RMA's versus HWC's and (c) stations 1,2 and 3.

Distribution Tests and Water Quality Standards

DEQ standards for water quality were used to assess the frequency effects of stream temperature on fish habitat. A temperature of 55°F is considered preferred habitat for juvenile cutthroat and coho salmon. A 7-day maximum of 64°F is linked with the upper limit of preferred habitat for many salmonid species and is the DEQ standard for salmonid habitat.

The number of days 7-day maximum was greater than or equal to 55°F, less than or equal to 64°F, or greater than 64°F was analyzed from July 21 through August 16. This was the period of the summer in which the highest stream temperatures were observed. Using this period represents the worst case scenario.

Frequency distributions were compared for all stations, between HWC's versus RMA's and upstream and downstream of harvest units (between stations) (Figures 8a,b,c). Eleven of the thirteen streams were analyzed in this way. Brush and Cascade were not included in this analysis due to missing data.

For all streams, stations, and harvest types stream temperature was less than or equal to 64°F 90.6% of the time. Of that time, 7-day maximum was less than or equal to 55°F 11.4% of the time. There was no difference in overall distributions between HWC's and RMA's (Figure 8a and b).

When distributions were compared between stations, there was greater frequency of temperatures exceeding 64°F downstream of harvest units (Station 2 and 3) then above harvest units (Figure 8c). This trend was the same for HWC's as it was for RMA's.

Only three out of eleven streams never exceeded the water quality standard. Three streams exceeded the DEQ standard less than 3%, and two streams exceeded it between 7 and 9% of the time. Three other streams exceeded it between 20 and 38% of the time. The latter three are all located in the Interior georegion. Two streams (Beaver and Douglas Creeks) were harvested with RMA's and one stream (January Creek) was harvested with a HWC. Change in 7-day maximum for January Creek was 5.7°F, the highest observed out of all 13 streams. Changes on Beaver and Douglas were 1.0°F and 2.9°F respectively. Stream temperatures were initially high upon entering the harvest units on Beaver and Douglas Creeks, 63.8°F and 62.3°F respectively. Therefore it took a relatively small increase to exceed the standard. Temperatures were elevated on January Creek from 59.7°F to 65.4°F.

Frequency distributions suggest stream temperature exceeded water quality standards more commonly downstream of harvest units than upstream of harvest units. When streams were assessed individually, it is apparent that the majority of the streams (eight of eleven) exceeded the standard less than 10% of the time. However, of the eleven streams analyzed only three of them never exceeded the standard. Standards were exceeded for the longest period of time (20- 38%) on three streams. These sites were all in the Interior georegion.

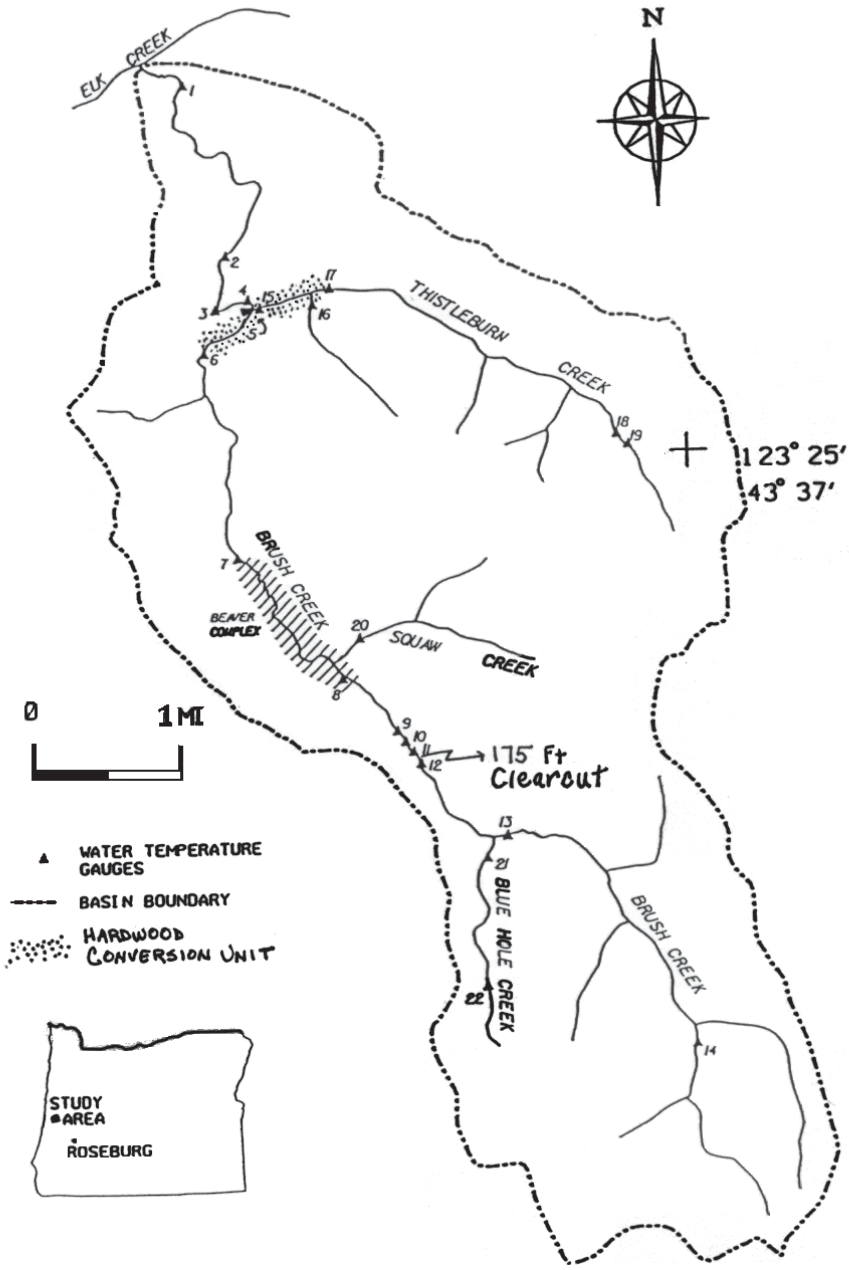


Figure 9. Brush Creek harvest units and locations of air and stream monitoring stations.

Brush Creek

Brush Creek

Brush Creek is a tributary to the Umpqua River Basin. It is located in the interior georegion and has one major tributary, Thistleburn (Figure 9). The basin is 13,000 acres in size and provides significant potential for coho, steelhead and sea-run cutthroat production. The watershed is a focus of a locally organized and managed watershed group emphasizing sound forest management practices tied to the enhancement and monitoring of fish habitat.

Thistleburn and Brush Creek both were harvested with HWC prescriptions in Fall 1994. The Brush Creek HWC is located 8.5 miles from the divide. The Thistleburn HWC is located at the confluence of Thistleburn and Brush Creeks. Higher up on mainstem Brush Creek, approximately 5 miles from the divide, a 175 foot unbuffered clearcut was harvested in spring of 1994. This unit was harvested under a site-specific prescription and prevented the need for new road construction and stream crossings. There is also a large beaver complex, consisting of a number of large beaver dams, between the two harvest units.

In 1994, 22 water temperature and 3 air temperature gages were installed throughout the basin. The purpose of the temperature project is to test the effectiveness of the HWC and the 175 foot site-specific prescription in maintaining stream temperature. The inherent basin trend is also being documented.

The HWC was harvested in fall of 1994, therefore the 1994 stream temperature data represent a pre-harvest period. Stream temperature data from 1995 and 1996 represent post-harvest years for the HWC. However, all data for the 175 foot clearcut are post-harvest data since the unit had already been harvested in 1994. Missing data on Thistleburn precludes it from this analysis.

Air Temperature. Air temperature was monitored in the headwaters area, 1.5, 5 and 6 miles downstream from the divide. A repeated measures ANOVA was performed to test for differences between years. There was no significant difference in 7-day maximum, minimum or mean air temperature between 1994, 1995 and 1996.

Figure 10 shows the 7-day maximum for 1994, 1995 and 1996. Stream temperature tends to increase in a downstream direction, a trend consistent with results presented earlier from the correlation analysis. Changes in temperature associated with the 175 foot clearcut and the HWC initially raise stream temperature above the basin trend.

Changes in temperature associated with the 175 foot clearcut. Temperature increases observed through the 175 foot clearcut ranged from 1.8 (1995) to 6.9°F (1994). These increases were countered by decreases within 1000 ft downstream of 2.3 (1995) and 6.3°F (1994). Previous repeated measures ANOVA indicated temperature increases through

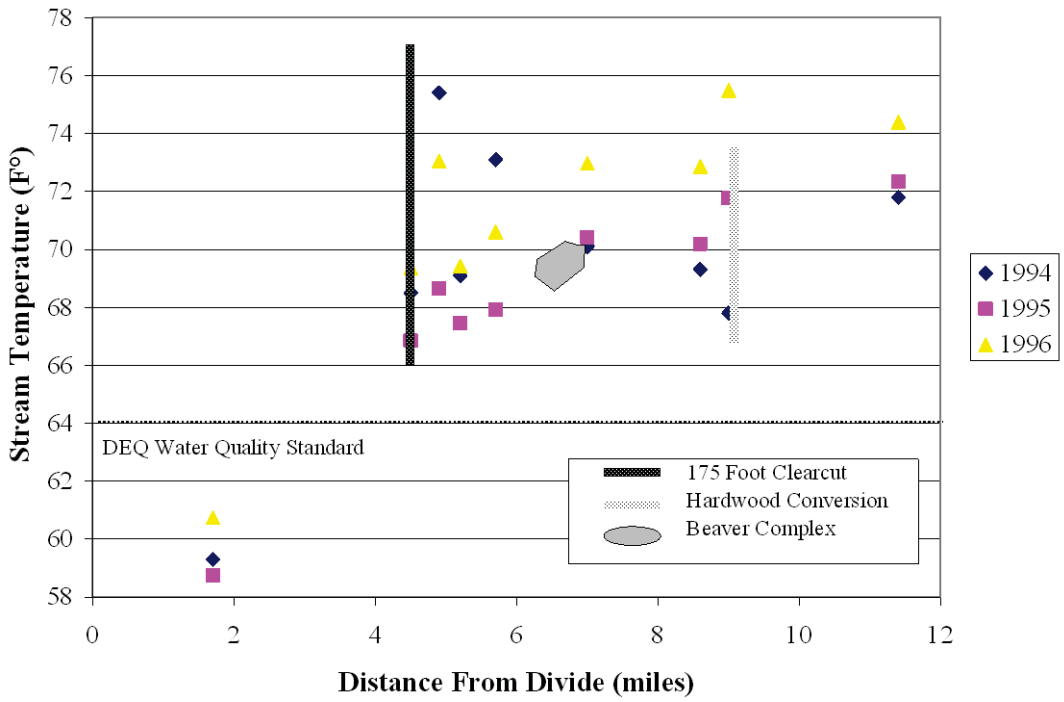


Figure 10. Seven-day maximum versus distance from divide for July 1994, 1995 and 1996.

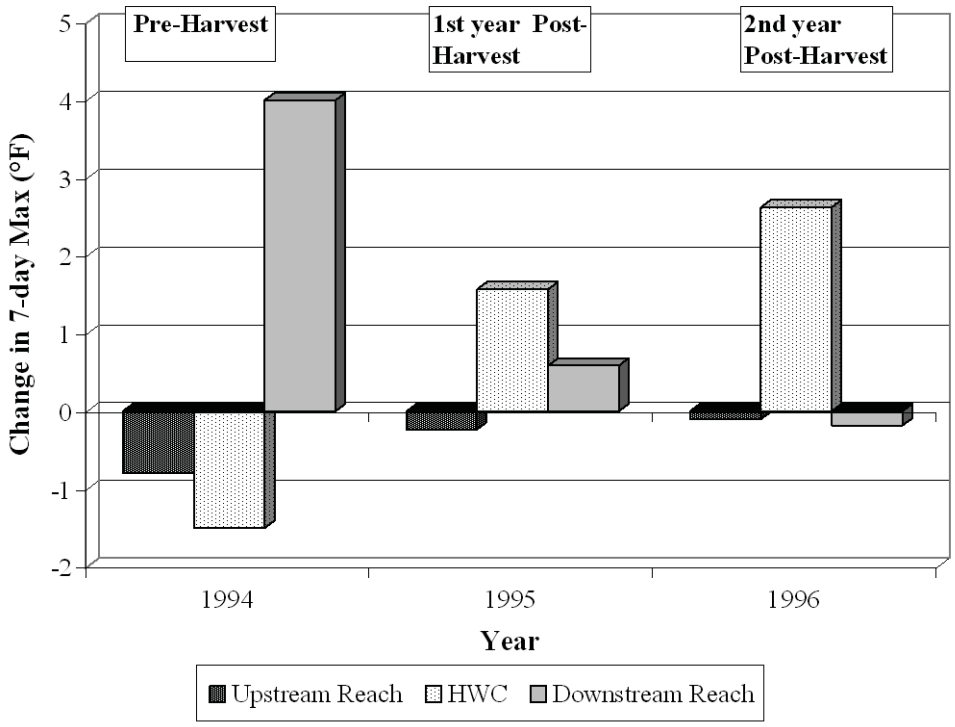


Figure 11. Change in 7-day maximum in the upstream, HWC and downstream reaches on Brush Creek for 1994 (pre-harvest), 1995 and 1996 (1st and 2nd year post-harvest).

harvest units were not countered by downstream decreases. The 175 foot unit was not included in that analysis due to the nature of the unit. Past ODF monitoring (Robison et al. 1995) found that greater increases through harvest units were countered by greater downstream rate of cooling. Results from the 175 foot clearcut are consistent with this finding. Significant groundwater input through the downstream reach is a plausible mechanism that would contribute to such rapid cooling.

Differences between years for the HWC. A repeated measures ANOVA was performed on the 7-day maximum, minimum and average of stream temperature for the HWC. For the HWC, 7-day maximum, minimum and average temperatures were higher in post-harvest years than pre-harvest years (p-value < 0.10) (Figure 11). Increases in 7-day maximum through the HWC ranged from 1.6 to 2.6°F in post-harvest years. A decrease of 1.5°F was observed in the same reach in the pre-harvest year.

Stream temperature increases were not countered by decreases at the station 2.4 miles downstream of the HWC. In post-harvest years, stream temperatures increased by 0.59°F (1995) and decreased by 0.18°F (1996) through the downstream reach. Stream temperature increased in this same reach by 4.0°F during the pre-harvest year. It may be that stream heating has been propagated upstream due to the HWC. Therefore increases which took place farther downstream in pre-harvest years (4°F 2.4 miles downstream of HWC) were occurring higher up in the system due to the HWC (1.6 to 2.6°F through HWC).

The Brush Creek study indicates that stream temperatures increased through the HWC in post-harvest years and increases were not countered by downstream cooling. Elevated stream temperature may have been propagated upstream in post-harvest years due to the effects of the HWC. This trend was not observed higher in the basin where the 175 foot clearcut was located. Stream temperature increased through the 175 foot clearcut, however increases were countered by downstream cooling.

Summary and Conclusion

The purpose of this study was to test the effectiveness of RMA's and HWC's in maintaining stream temperature and meeting water quality standards. Relationships between stream temperature and physical and riparian characteristics were also investigated. Results indicate stream temperatures increased through harvest units but that those increases may be within the expected downstream trends.

Effectiveness of RMA's and HWC's varied between streams. The average increase in 7-day maximum was 2.1°F through RMA's and 2.5°F through HWC's. Observed increases were as low 0.63 and 0.07°F and as high as 3.3 and 5.7°F for RMA's and HWC's, respectively. Statistical analyses revealed that 7-day maximum, minimum and average stream temperatures were significantly higher downstream of harvest units than upstream of harvest units. In addition, increases were not countered by cooling in downstream

reaches. These findings were supported by an analysis which revealed that 7-day maximum temperatures exceeded the water quality standard more frequently downstream of harvest units than upstream of harvest units. Finally when pre- and post-harvest data were compared on Brush Creek (only stream with pre-harvest data), changes through the HWC were higher in post-harvest years than pre-harvest years and higher than the overall basin trend. Results indicate that Brush Creek temperatures have not returned to pre-harvest conditions after two post-harvest years.

While this is compelling evidence to indicate that the rules are not uniformly effective at maintaining stream temperature, it is critical to note that this study lacks sufficient pre-harvest data. Stream temperatures inherently increase in a downstream direction. The rate of change varies with distance from divide. Greater rates of change are observed closer to the headwaters than farther down in the basin. The relationship most likely varies between basins as well. The Brush Creek project and correlation analysis of distance and temperature provide data to support this hypothesis.

When the data were adjusted in an attempt to account for the relationship between distance and temperature, observed changes in stream temperature were not statistically significant. This result indicates that inherent increases in stream temperature account, in part, for changes in temperature observed through harvest units. How much of the observed increase is attributable to an inherent increase and how much is attributable to the effects of harvesting has not been adequately answered with this study.

Physical parameters were found to influence stream temperature in ways consistent with previous studies. Characteristics which may make a stream sensitive to unacceptable increases in stream temperature include stream reaches that are: predominately bedrock, low gradient, wide and shallow, at a greater distance from the divide and lower in elevation.

Vegetative manipulation in the harvest units resulted in a wide variety of buffer widths and canopy cover. Average decreases in cover due to harvesting were low. Changes in temperature were not always consistent with change in riparian cover. This may have been due in part to high variability in canopy cover measures associated with the harvest units. There was some indication that special-prescription HWC's designed to minimize solar exposure by leaving more trees on the south side, may have been more effective at maintaining stream temperature than the remaining HWC's. There was also indication that as buffer widths decreased, 7-day maximum and average stream temperature increased.

There was no statistical difference between the performance of RMA's and HWC's in terms of increases in 7-day maximum, minimum and average. However, diurnal fluctuation associated with HWC's were higher than diurnal fluctuations associated with RMA's.

Results of this study suggest RMA's and HWC's do not always protect streams from increases in temperature. Only three of eleven streams never exceeded the DEQ water quality standard. However, the strength of this conclusion is tempered by the inability to adequately account for increases in stream temperature which naturally occur in a downstream direction. Given the limitations of the study, continued monitoring and research is needed to better understand background variability and the effectiveness of the forest practice rules in maintaining stream temperature at a site-specific and basin-level.

Recommendations

1) *Modify monitoring protocol with advice of a Technical Advisory Committee (TAC) to address limitations of the study.*

Future temperature monitoring will be coupled with more accurate measurements of shade, incoming solar radiation and buffer characteristics. In addition, pre- and post-harvest data should be collected for all the parameters. Other considerations for protocol review include monitoring temperature control basins/reaches at distances from divide corresponding to managed reach distances and monitoring managed and unmanaged basins and reaches over the same time frame to reduce both spatial and temporal variability.

2) *Review hardwood conversion and riparian management area rules with the advice of a TAC to explore how basin characteristics or site-specific plans might be used to better ensure that potential site and cumulative effects are minimized.*

a) Identify basin characteristics (distance from divide) where increases in temperature might be countered by downstream cooling. On the Brush Creek Basin study, harvest-related increases observed higher in the basin (closer to the divide) were countered by downstream cooling, while harvest-related increases observed lower in the basin were not. This suggests there is a zone in which management-related increases will not be countered by downstream cooling which in turn is a function. This is due in part to naturally occurring increases in temperature which occur in a downstream direction. Current forest practices monitoring on 4 basins in Oregon may give further insight as to how this zone varies regionally and between basins. With more basin-level data, practices could be designed to restrict the use of hardwood conversions to areas in a basin where downstream cooling is more likely to counter potential harvest-related increases.

b) Define individual site and basin characteristics which influence the success of hardwood conversions in maintaining stream temperature so that site-specific prescriptions can be developed in place of the alternative prescription. A risk assessment of the potential for harvest-related increases in temperature and downstream cooling could be incorporated in the site-specific plan.

3) *Further test the relationship between temperature, shade and buffer widths under correct application of the rules.*

Because of the questionable data, shade measurements and buffer widths in this study did not provide adequate opportunity to test and explore relationships between stream temperature, differences in shade over the stream, and differences in riparian buffer width. Forest practices 1996/1997 riparian monitoring project has accurate pre- and post-harvest shade measurements as well as incoming solar radiation. Stream temperature monitoring will be coupled with this study in the 1997 field season to further test the relationships between temperature, shade and buffer widths under correct application of the rules.

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Appendix A

Physical and vegetation characteristics averaged by reach.

Appendix A

Table A1. Average physical and vegetative characteristics for each reach.

Stream	Station	Reach Type *	Stream size +	Reach Length (Ft)	Cover (%)	Lt.Buffer Width (Ft)	Rt.Buffer Width (Ft)	Elevation (Ft)	Aspect	Gradient (%)
Brush	1	control	L	0	50	95	121	280	N	2
	2	HWC	L	3018	56	18	39	280	N	1
	3	downstream	L	12677	57	121	66	200	N	1
Beaver	1	control	L	0	63	131	120	540	E	1
	2	RMA	L	3477	49	61	89	540	E	1
	3	downstream	L	492	60	131	75	540	E	1
Cas.Brush	1	control	M	0	65	.	.	800	W	2
	2	HWC	M	2329	58	.	.	680	W	4
	3	downstream	M	492	63	131	131	680	W	2
	4	downstream	M	984	63	131	131	680	W	2
Coleman	1	control	L	0	65	131	131	900	NE	.
	2	HWC	L	3346	62	64	51	880	NE	1
	3	downstream	L	492	51	118	108	880	NE	1
	4	downstream	L	984	51	118	108	880	NE	1
Douglas	1	control	M	0	30	98	98	720	SW	1
	2	RMA	M	3280	39	40	119	720	SW	1
	3	downstream	M	492	49	94	131	680	SW	1
	4	downstream	M	984	43	66	131	680	SW	1
Eagle	1	control	M	0	56	131	105	880	W	3
	2	RMA	M	2624	64	69	131	800	W	2
	3	downstream	M	492	60	131	131	800	W	3
	4	downstream	M	984	60	131	131	800	W	.
January	1	control	M	0	65	131	131	700	SE	2
	2	HWC	M	3280	55	44	126	600	SE	2
	3	downstream	M	492	58	49	131	560	SE	.
	4	downstream	M	984	45	75	117	560	SE	3
Litl. Fall	1	control	U	0	63	131	131	1560	SW	1
	2	HWC	U	1148	53	41	131	1560	SW	2
	3	downstream	U	492	63	131	131	1520	SW	1
	4	downstream	U	984	55	131	131	1520	SW	2
Mill	1	control	L	0	58	118	118	280	W	1
	2	HWC	L	5248	53	85	82	240	W	1
	3	downstream	L	1640	45	117	95	240	W	1
Sheele	1	control	M	0	61	112	121	840	N	2
	2	HWC	M	2558	61	62	31	760	N	2
	3	downstream	M	492	57	115	107	760	N	4
	4	downstream	M	984	28	66	98	760	N	2
Sheythe	1	control	M	0	61	122	118	560	SE	3
	2	RMA	M	1607	60	67	128	480	SE	1
	3	downstream	M	984	65	131	119	440	SE	1
Talbot	1	control	S	0	63	131	131	280	NW	4
	2	RMA	S	2296	45	23	131	200	NW	6
	3	downstream	S	492	55	104	131	200	NW	3
Wst.Agency	1	control	S	0	.	.	.	1760	S	5
	2	HWC	S	1345	47	41	41	1560	S	3
	3	downstream	S	984	67	111	127	1340	S	3

* Control = the reach upstream of the harvest unit, usually > 1000 feet of intact riparian condition.
HWC = Harvest unit with hardwood converion, RMA = harvet unit with riparian management area
Downstream = the reach downstream of the harvest unit with intact riparian areas.

\+ Stream size as defined in the Oregon Forest Practice rules. L = large, M = Medium, and S = small

Appendix A

Table A1 (continued). Average physical and vegetative characteristics for each reach.

Stream	Sta-tion	Reach Type *	Max Depth (Ft)	Wetted Width (Ft)	Bankful Width (Ft)	Lt.Bank Height (Ft)	Rt.Bank Height (Ft)	Fines (%)	Gravel (%)	Cobble (%)	Bolder (%)	Bedrock (%)
Brush	1	control	1.06	19.89	30.12	4.06	3.41	10	11	8	4	67
	2	HWC	0.59	24.90	40.13	4.89	5.90	8	6	10	0	76
	3	downstream	0.82	21.56	31.79	4.50	5.58	8	15	22	6	49
Beaver	1	control	0.54	11.64	28.31	5.97	6.26	30	51	2	0	18
	2	RMA	1.21	14.76	21.77	7.48	7.04	63	33	0	0	5
	3	downstream	0.80	15.50	24.27	5.92	6.97	31	46	0	0	23
Cas.Brush	1	control	0.71	13.25	21.81	2.28	2.83	41	15	29	12	2
	2	HWC	0.65	13.87	22.69	2.72	4.64	18	21	21	38	2
	3	downstream	0.57	10.17	20.62	4.20	3.77	25	17	9	44	5
	4	downstream	0.57	10.17	20.62	4.20	3.77	25	17	9	44	5
Coleman	1	control	0.47	9.43	26.32	5.41	4.76	8	13	40	40	0
	2	HWC	0.54	12.41	23.62	3.83	4.24	17	19	51	13	0
	3	downstream	0.63	12.14	28.14	3.84	4.14	8	15	71	0	6
	4	downstream	0.63	12.14	28.14	3.84	4.14	8	15	71	0	6
Douglas	1	control	0.89	5.00	9.84	5.33	4.92	38	0	50	0	13
	2	RMA	1.84	19.23	30.27	7.54	5.81	84	13	0	0	4
	3	downstream	1.48	10.31	22.26	3.87	6.33	89	4	0	0	7
	4	downstream	1.56	13.12	16.40	4.92	3.69	100	0	0	0	0
Eagle	1	control	0.76	9.38	19.68	4.10	4.03	22	32	19	9	18
	2	RMA	0.35	7.63	29.61	2.97	2.59	21	61	3	0	15
	3	downstream	0.81	11.81	23.38	3.02	3.14	21	24	24	6	23
	4	downstream	0.59	10.28	21.10	2.41	4.26	7	17	43	0	33
January	1	control	0.45	8.40	15.65	3.65	3.26	30	20	44	0	6
	2	HWC	0.66	8.88	25.00	2.66	1.83	60	14	26	0	0
	3	downstream	0.38	8.42	15.63	2.30	3.39	41	15	24	0	20
	4	downstream	0.44	5.65	20.52	3.17	2.30	44	28	21	0	7
Litl. Fall	1	control	1.31	25.67	35.83	4.55	6.27	8	8	43	43	0
	2	HWC	0.95	22.17	35.59	2.73	2.93	5	27	44	16	-0
	3	downstream	1.31	25.67	35.83	4.55	6.27	8	8	43	43	0
	4	downstream	1.08	22.83	36.01	4.26	5.48	10	10	32	18	32
Mill	1	control	1.13	10.59	19.88	3.33	3.93	43	19	29	2	0
	2	HWC	0.86	8.57	27.09	3.43	3.64	30	46	22	2	1
	3	downstream	0.00	0.00	36.44	3.28	8.75	32	66	0	0	2
Sheele	1	control	0.61	14.30	26.04	3.54	4.10	31	9	27	0	33
	2	HWC	0.58	14.22	21.20	4.58	3.62	32	22	22	22	2
	3	downstream	0.77	17.88	25.83	6.23	6.15	22	17	20	41	0
	4	downstream	1.00	11.07	20.50	3.20	4.76	32	32	30	6	0
Sheythe	1	control	0.80	8.41	17.29	2.72	2.68	35	18	41	4	3
	2	RMA	0.84	10.50	20.88	4.72	2.38	41	23	35	2	0
	3	downstream	0.52	8.28	22.55	3.28	3.35	36	34	31	0	0
Talbot	1	control	0.02	1.38	5.54	1.75	2.10	100	0	0	0	0
	2	RMA	0.11	1.91	6.05	1.61	1.61	95	4	2	0	0
	3	downstream	0.23	3.94	7.54	2.23	2.23	46	33	2	0	19
Wst.Agency	1	control	0.16	5.71	22.63	1.51	1.51	26	26	47	0	0
	2	HWC	0.62	6.60	17.52	3.09	3.16	13	34	24	16	0
	3	downstream	0.30	5.99	14.35	3.79	4.55	0	27	38	16	19

* Control = the reach upstream of the harvest unit, usually > 1000 feet of intact riparian condition.
HWC = Harvest unit with hardwood converion, RMA = harvet unit with riparian management area
downstream = the reach downstream of the harvest unit with intact riparian areas.

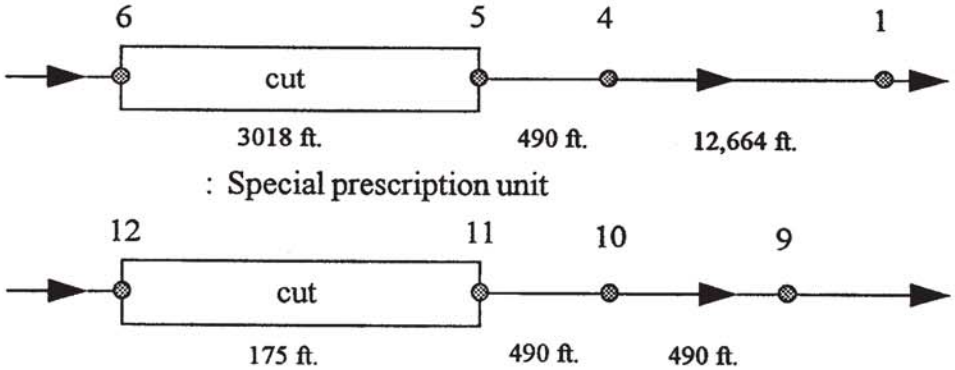
\+ Stream size as defined in the Oregon Forest Practice rules. L = large, M = Medium, and S = small

Appendix B

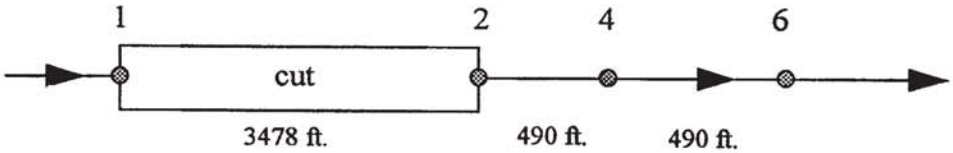
Monitoring schematics for each stream's experimental design.

Appendix B. Schematic of each stream's specific experimental design. Stations are at the top of the diagram and distances between stations are below.

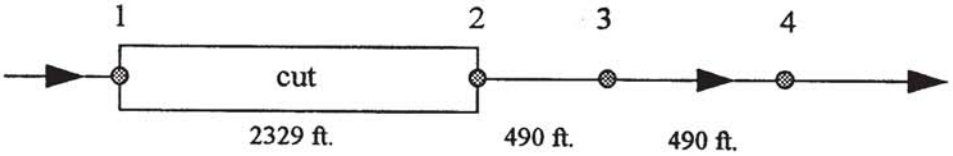
A. Brush Creek: HWC



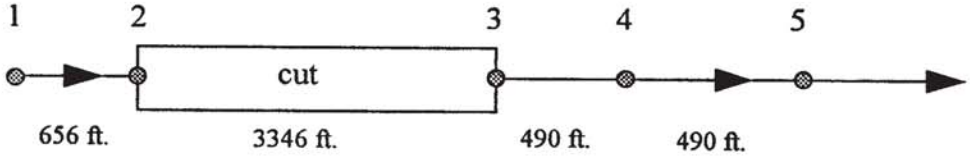
B. Beaver Creek: RMA



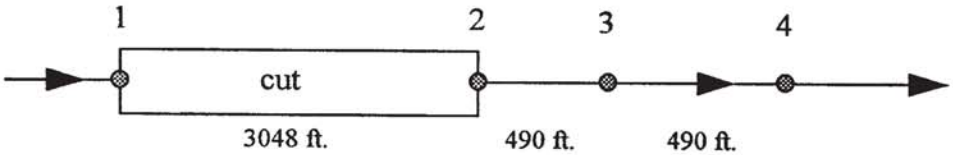
C. Cascade Brush: HWC



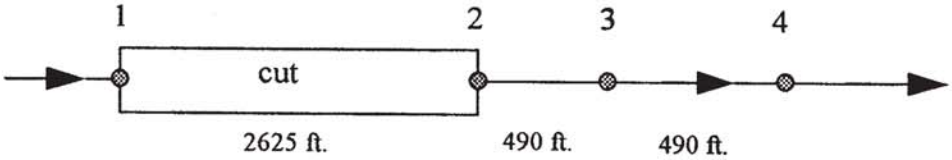
D. Coleman Creek: HWC



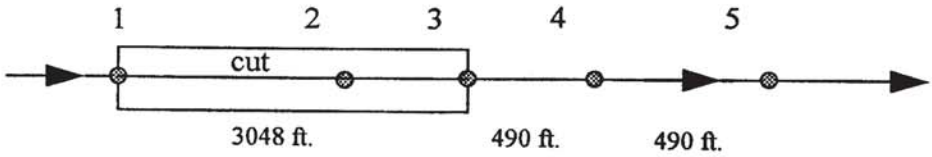
E. Douglas Creek: RMA



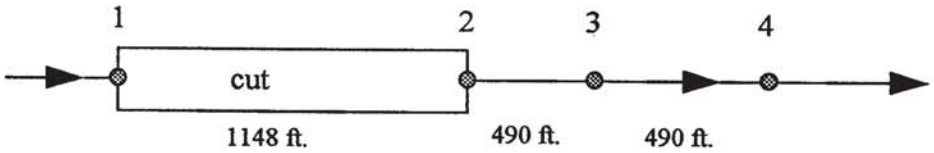
F. Eagle Creek: RMA



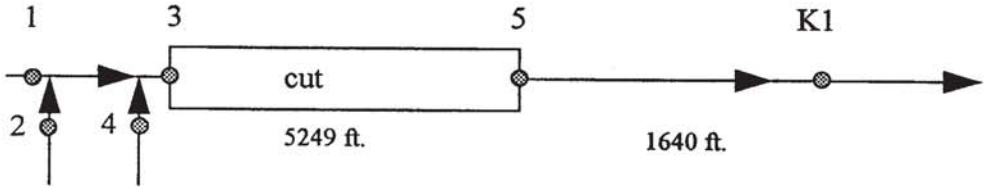
G. January Creek: HWC



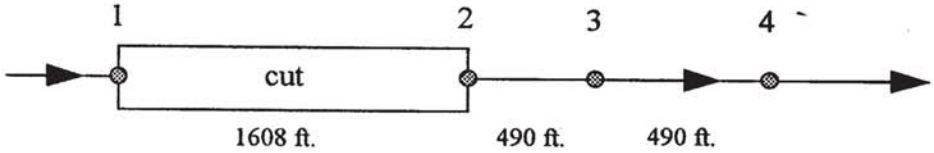
H. Little Fall Creek: HWC



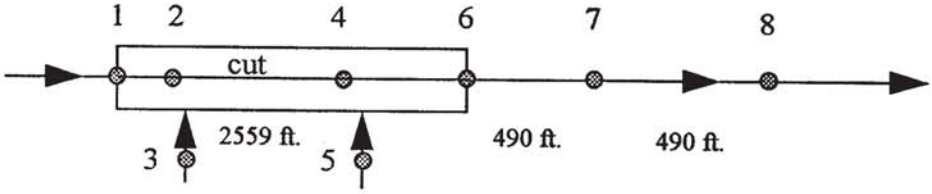
I. Mill Creek: HWC



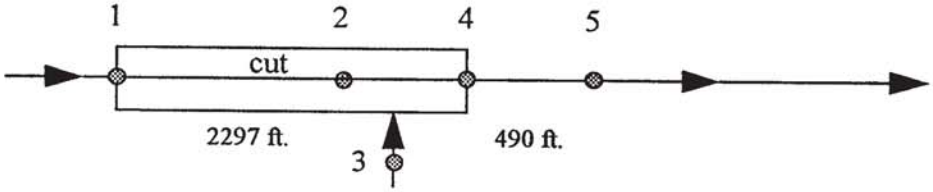
J. Sheythe Creek: RMA



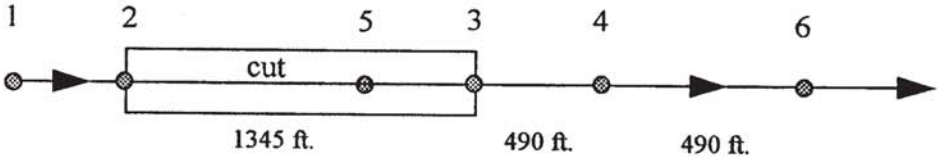
K. Scheele Creek: HWC



L. Talbot Creek: RMA



M. West Agency Creek: HWC



Appendix C

Period of record for water temperature data on each stream and station.

APPENDIX C

BEAL CREEK

Station #	Period of Record
1	7/06-09/02
2	no data
3	07/06-09/02
4	no data

GRIFFITH CREEK

Station #	Period of Record
1	07/20-08/17
2	no data
3	no data
4	07/20-08/17

BRUSH & THISTLEBURN

Station #	Period of Record
1	06/18-09/12
2	08/14-09/12
3	06/07-07/11
4	08/23-09/12
5	07/13-08/10
6	06/07-08/10
7	06/16-09/12
8	06/16-09/12
9	06/16-09/12
10	08/15-09/12
11	06/16-09/12
12	06/07-08/10
13	08/14-09/12
14	06/07-08/10
15	no data
16	06/07-07/11
17	06/16-08/10
18	06/07-08/10
19	no data
20	06/15-09/12
21	06/07-09/12
22	06/07-09/12
A1	06/13-07/11
A2	06/13-07/11 07/26-08/13
A3	07/25-08/22

JANUARY CREEK

Station #	Period of Record
1	07/15-09/20
2	no data
3	07/15-09/20
4	07/15-09/11
5	07/15-09/11

LITTLE FALL CREEK

Station #	Period of Record
1	07/15-10/07
2	07/15-10/07
3	07/15-10/07
4	07/15-10/07

MILL CREEK

Station #	Period of Record
1	05/19-09/14
2	05/19-06/21 08/18-09/14
3	05/19-05/30 06/23-08/16
4	06/23-09/14
5	06/23-09/14

BEAVER CREEK

Station #	Period of Record
1	07/18-0911
2	07/18-09/08
3	no data
4	07/18-09/11
5	07/18-09/11
6	08/02-09/11

STARKER BRUSH CREEK

Station #	Period of Record
1	07/04-08/31
2	no data
3	07/04-08/31
4	07/04-08/31
5	07/04-08/31
6	07/04-08/31

CASCADE BRUSH CREEK

Station #	**Period of Record**
1	05/19-07/16 07/21-09/09
2	0519-07/16 07/21-09/09
3	05/19-07/16 07/21-09/09
4	07/05-09/02

SHEELE CREEK

Station #	**Period of Record**
1	05/28-09/10
2	06/29-09/05
3	06/01-09/05
4	06/01-09/05
5	06/01-07/12
6	06/01-09/05
7	07/14-09/02
8	07/14-09/02
A1	06/14-07/12 08/09-09/05

COLMAN CREEK

Station #	Period of Record
1	07/14-09/06
2	07/14-09/06
3	07/14-09/06
4	07/14-09/06
5	07/14-09/06

DOUGLAS CREEK

Station #	Period of Record
1	07/07-09/03
2	07/07-09/03
3	07/07-08/19
4	07/07-09/03

SHEYTHE CREEK

Station #	Period of Record
1	06/30-09/07
2	06/29-10/05
3	06/30-10/11
4	06/30-10/11

EAGLE CREEK

Station #	Period of Record
1	07/01-08/28
2	07/01-08/28
3	07/01-08/28

TALBOT CREEK

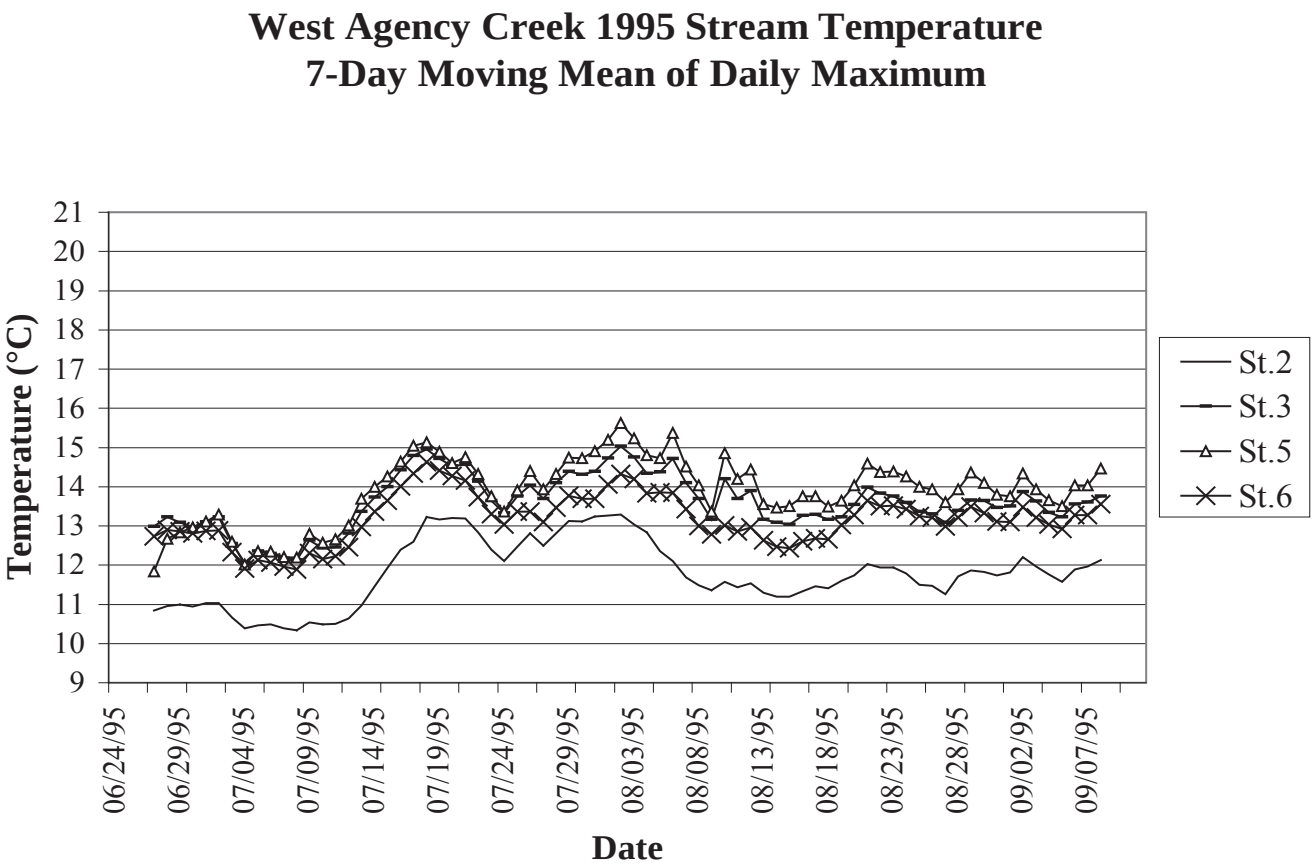
Station #	Period of Record
1	07/11-08/30
2	07/11-08/30
3	07/11-08/30
4	07/11-08/30
5	07/11-08/30

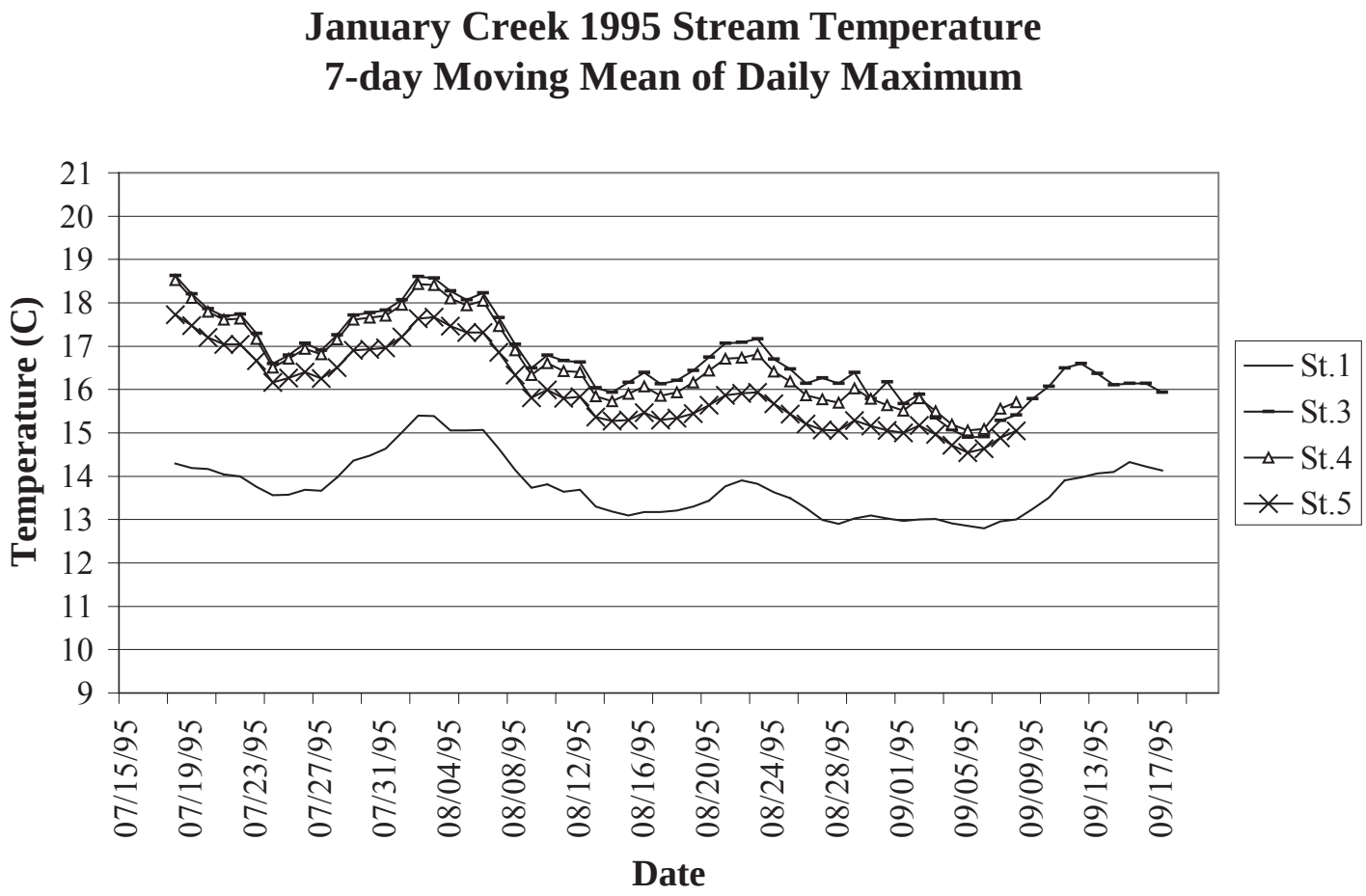
WEST AGENCY CREEK

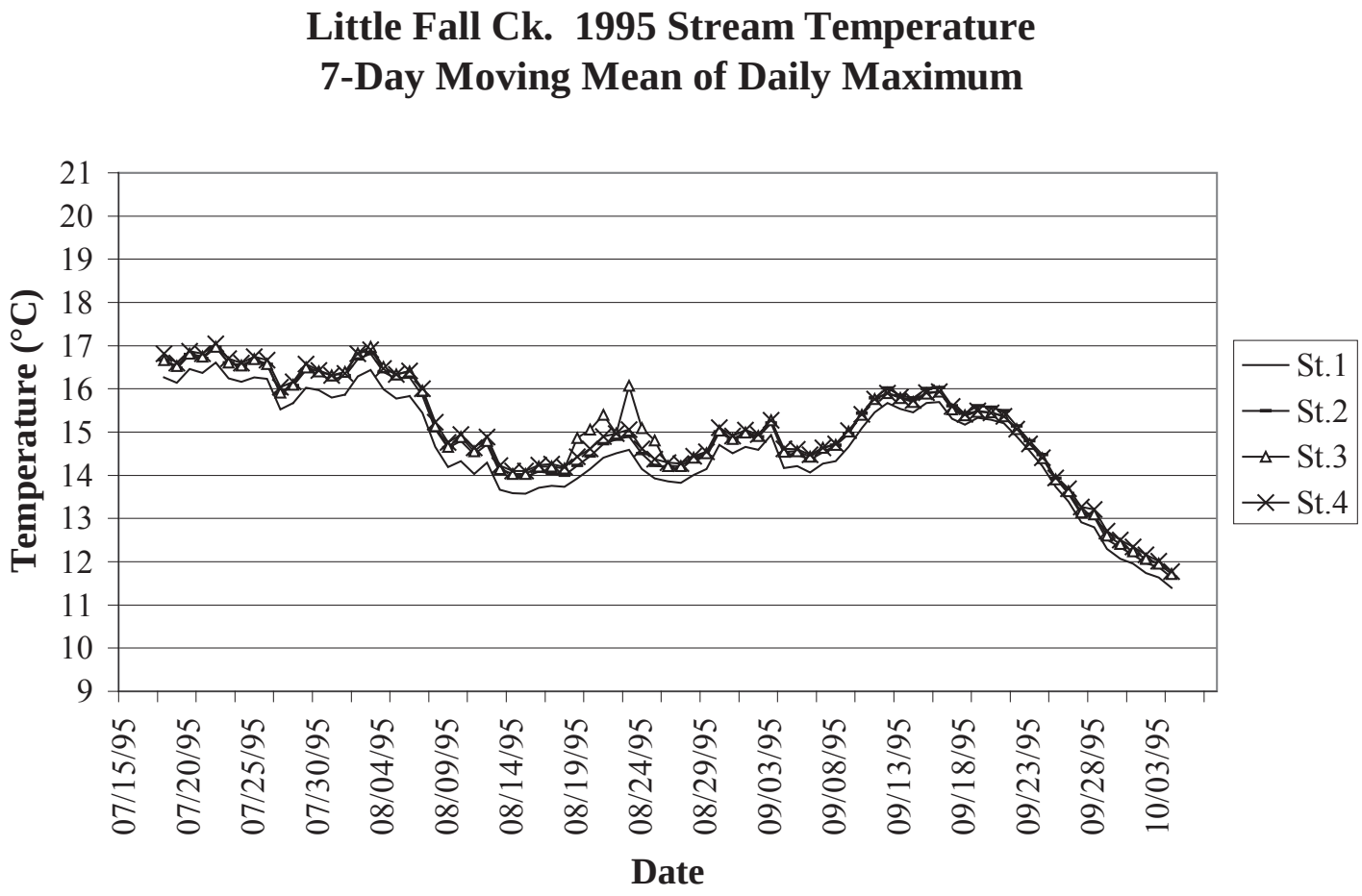
Station #	Period of Record
1	no data
2	0624-09/11
3	06/24-09/11
4	no data
5	06/24-09/11
6	06/24-09/11

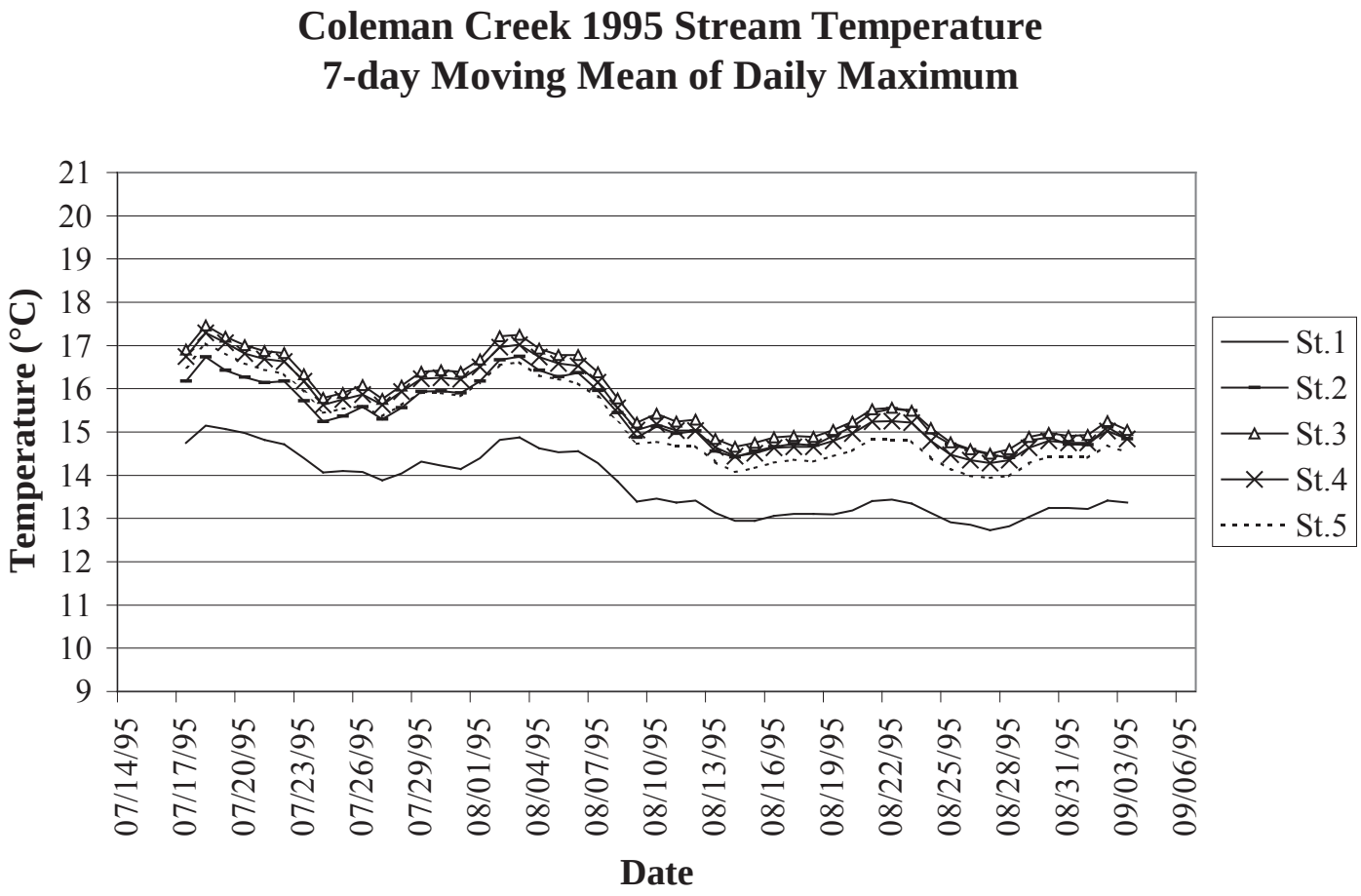
Appendix D

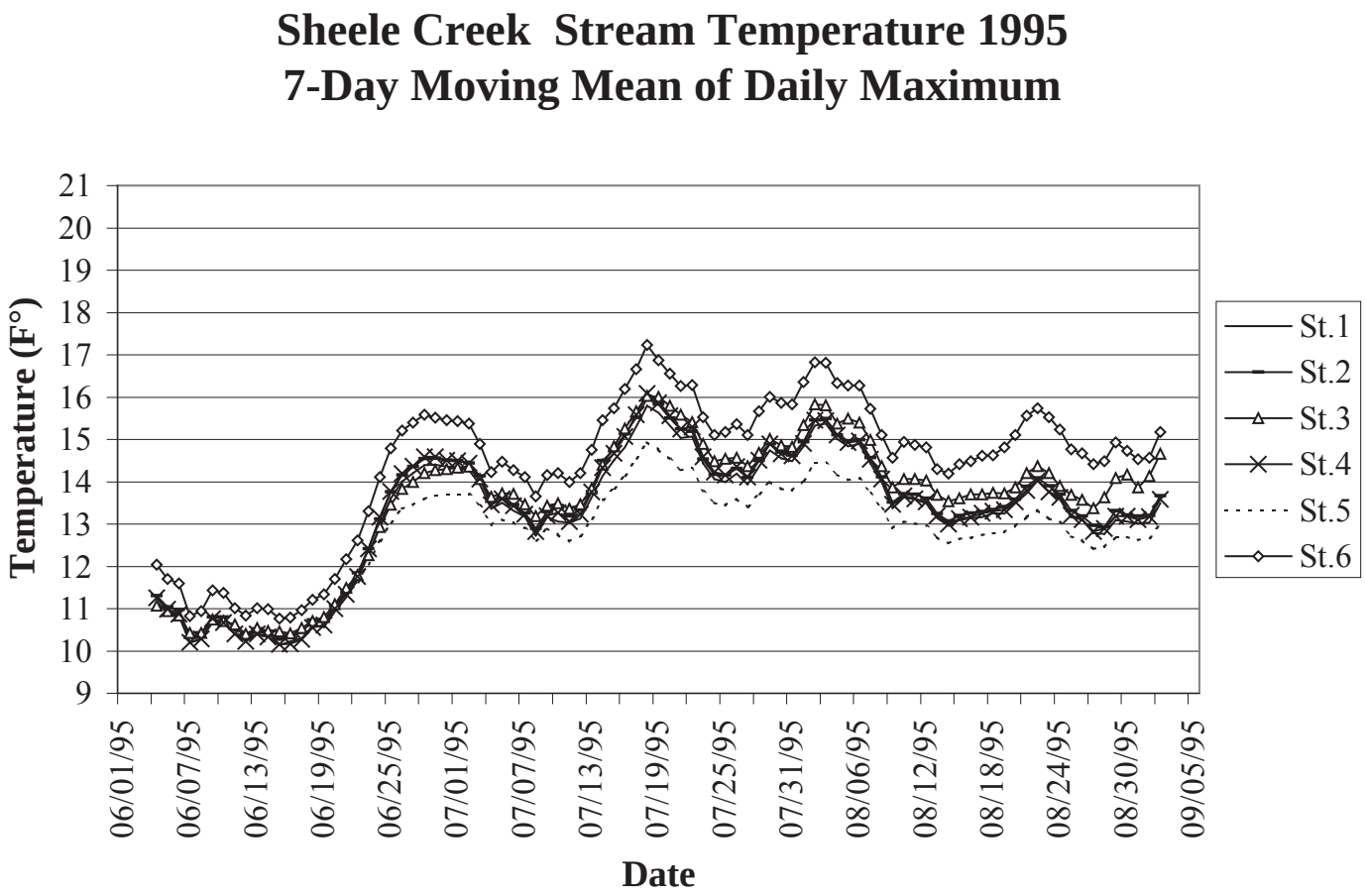
Seven-day moving mean of daily maximum for each stream.
July through August 1995.


West Agency Creek 1995 Stream Temperature
7-Day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/24/95
06/29/95
07/04/95
07/09/95
07/14/95
07/19/95
07/24/95
07/29/95
08/03/95
08/08/95
08/13/95
08/18/95
08/23/95
08/28/95
09/02/95
09/07/95
Date
St.2
St.3
St.5
St.6

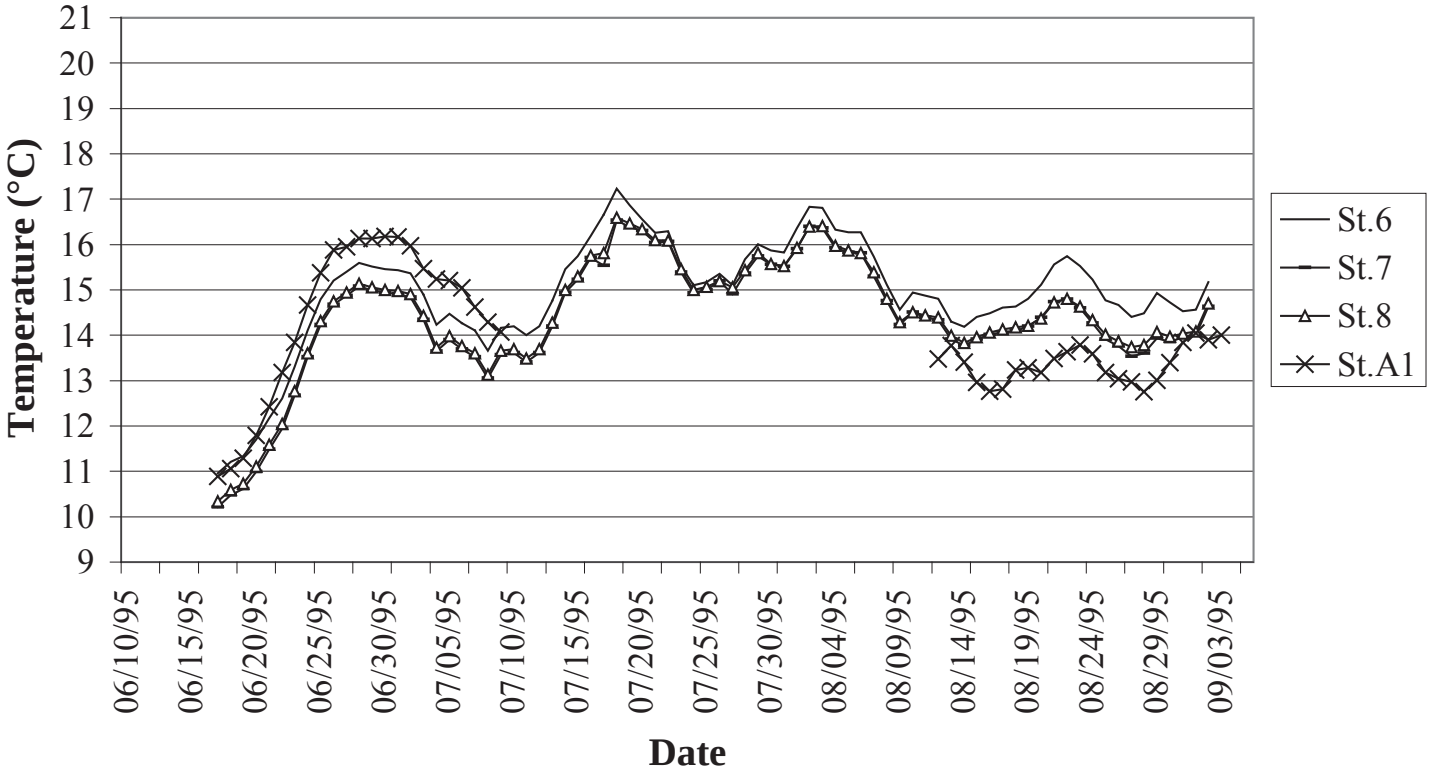

January Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (C)
21
20
19
18
17
16
15
14
13
12
11
10
9
07/15/95
07/19/95
07/23/95
07/27/95
07/31/95
08/04/95
08/08/95
08/12/95
08/16/95
08/20/95
08/24/95
08/28/95
09/01/95
09/05/95
09/09/95
09/13/95
09/17/95
Date
St.1
St.3
St.4
St.5

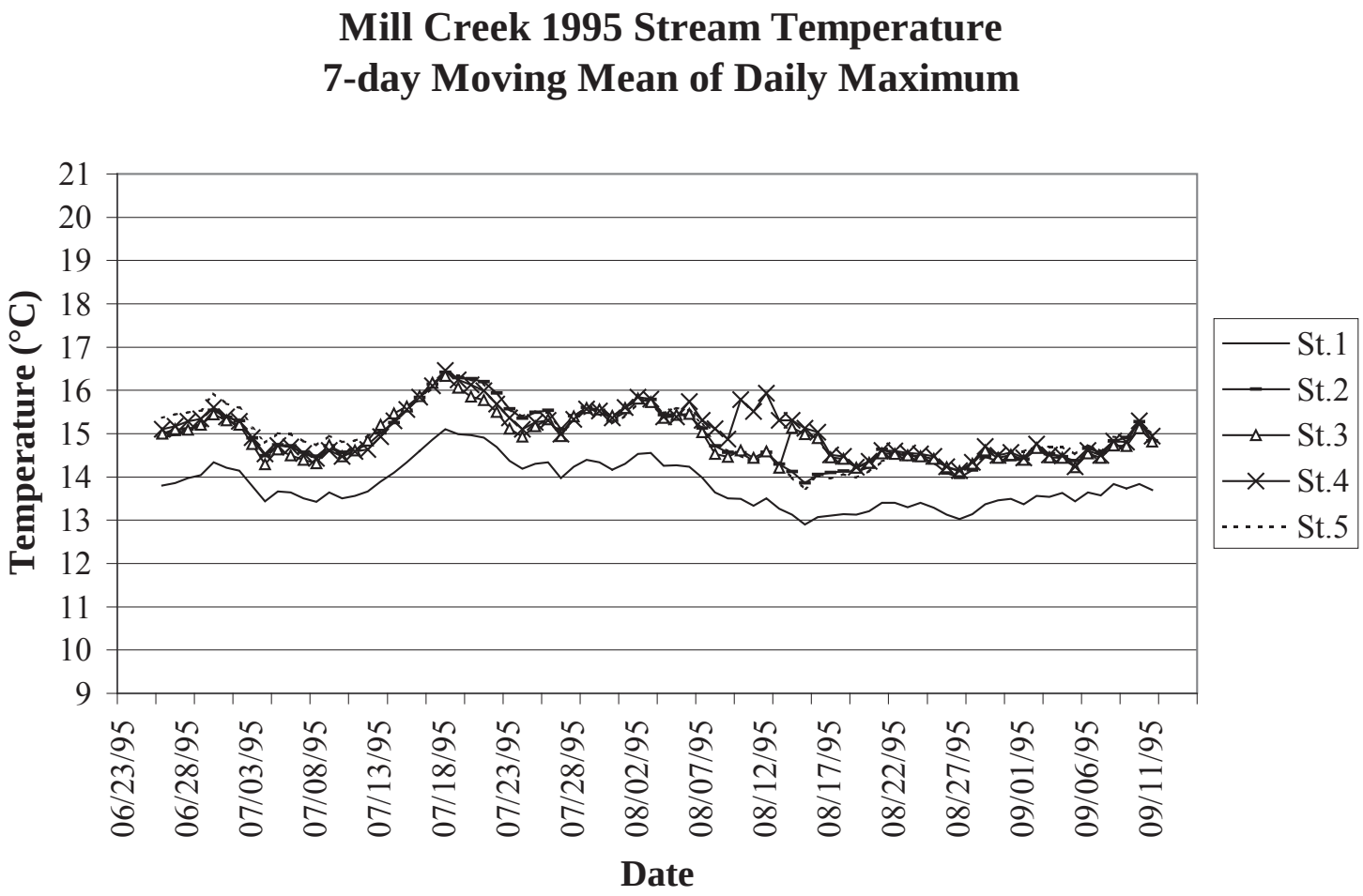

Little Fall Ck. 1995 Stream Temperature
7-Day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
07/15/95
07/20/95
07/25/95
07/30/95
08/04/95
08/09/95
08/14/95
08/19/95
08/24/95
08/29/95
09/03/95
09/08/95
09/13/95
09/18/95
09/23/95
09/28/95
10/03/95
Date
St.1
St.2
St.3
St.4

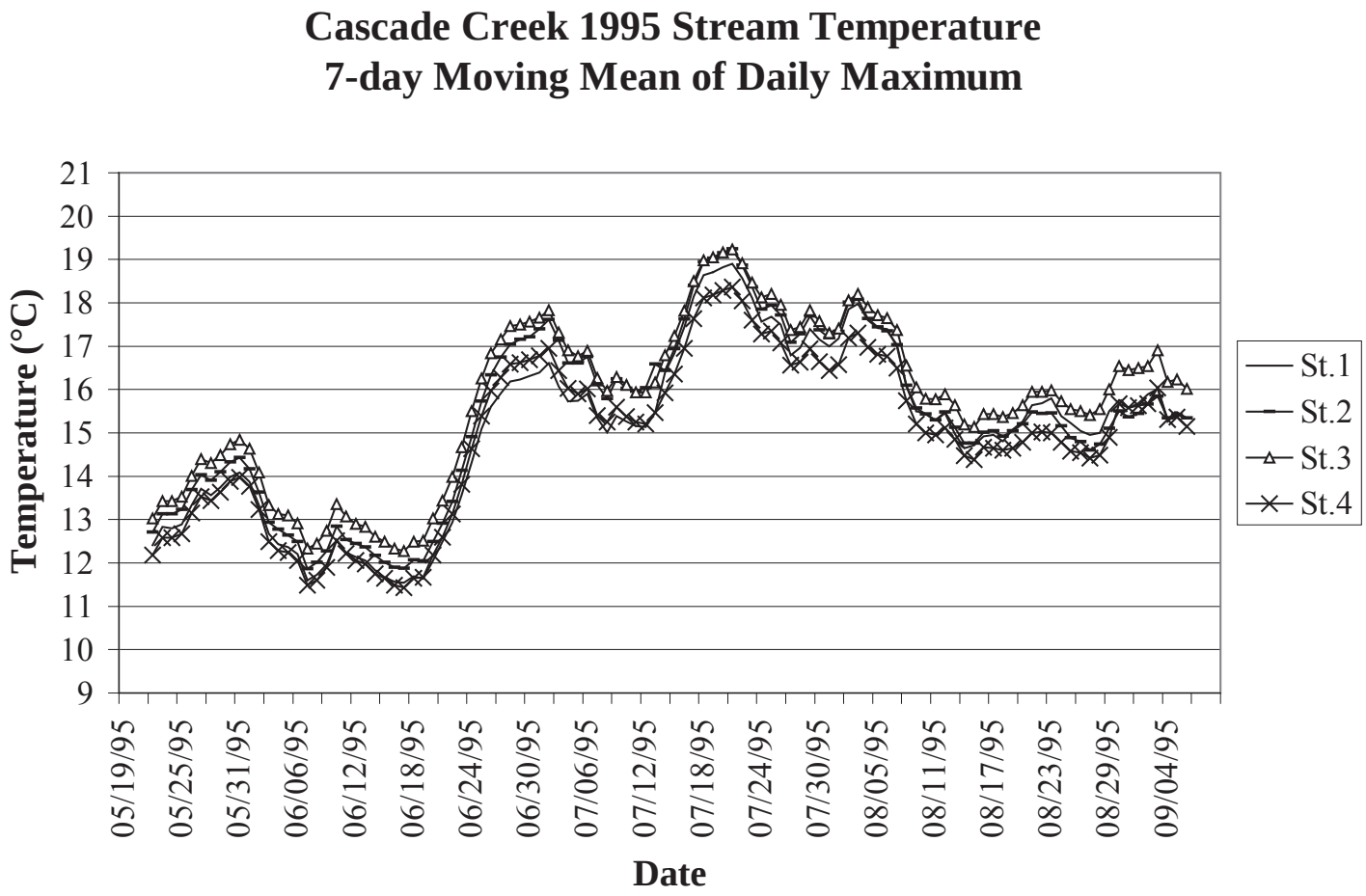

Coleman Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
07/14/95
07/17/95
07/20/95
07/23/95
07/26/95
07/29/95
08/01/95
08/04/95
08/07/95
08/10/95
08/13/95
08/16/95
08/19/95
08/22/95
08/25/95
08/28/95
08/31/95
09/03/95
09/06/95
Date
St.1
St.2
St.3
St.4
St.5

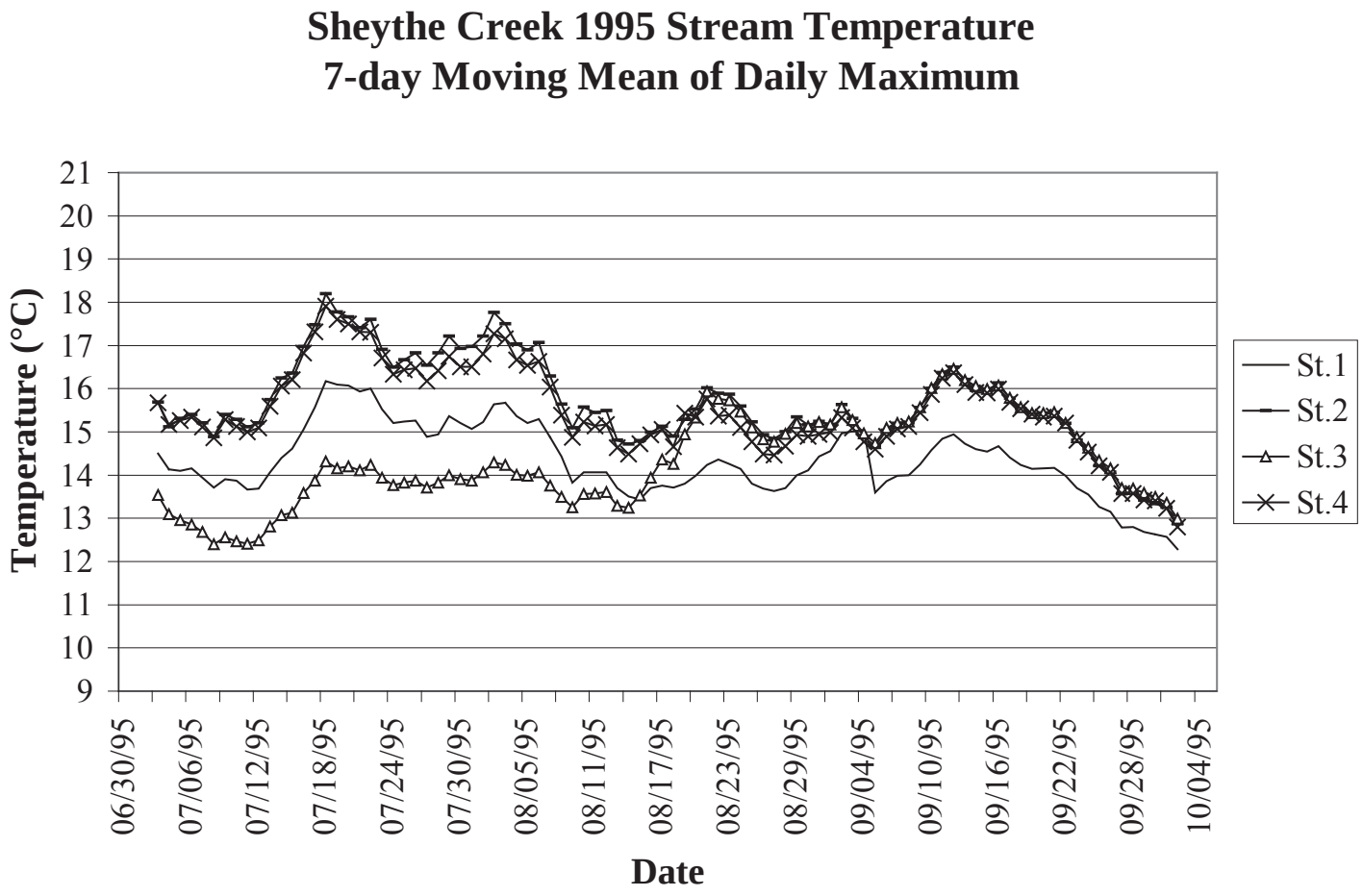

Sheele Creek Stream Temperature 1995
7-Day Moving Mean of Daily Maximum
Temperature (F°)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/01/95
06/07/95
06/13/95
06/19/95
06/25/95
07/01/95
07/07/95
07/13/95
07/19/95
07/25/95
07/31/95
08/06/95
08/12/95
08/18/95
08/24/95
08/30/95
09/05/95
Date
St.1
St.2
St.3
St.4
St.5
St.6

Sheele Creek (Continued)
7-day Moving Mean of Daily Maximum




Mill Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/23/95
06/28/95
07/03/95
07/08/95
07/13/95
07/18/95
07/23/95
07/28/95
08/02/95
08/07/95
08/12/95
08/17/95
08/22/95
08/27/95
09/01/95
09/06/95
09/11/95
Date
St.1
St.2
St.3
St.4
St.5


Cascade Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
05/19/95
05/25/95
05/31/95
06/06/95
06/12/95
06/18/95
06/24/95
06/30/95
07/06/95
07/12/95
07/18/95
07/24/95
07/30/95
08/05/95
08/11/95
08/17/95
08/23/95
08/29/95
09/04/95
Date
St.1
St.2
St.3
St.4


Sheythe Creek 1995 Stream Temperature
7-day Moving Mean of Daily Maximum
Temperature (°C)
21
20
19
18
17
16
15
14
13
12
11
10
9
06/30/95
07/06/95
07/12/95
07/18/95
07/24/95
07/30/95
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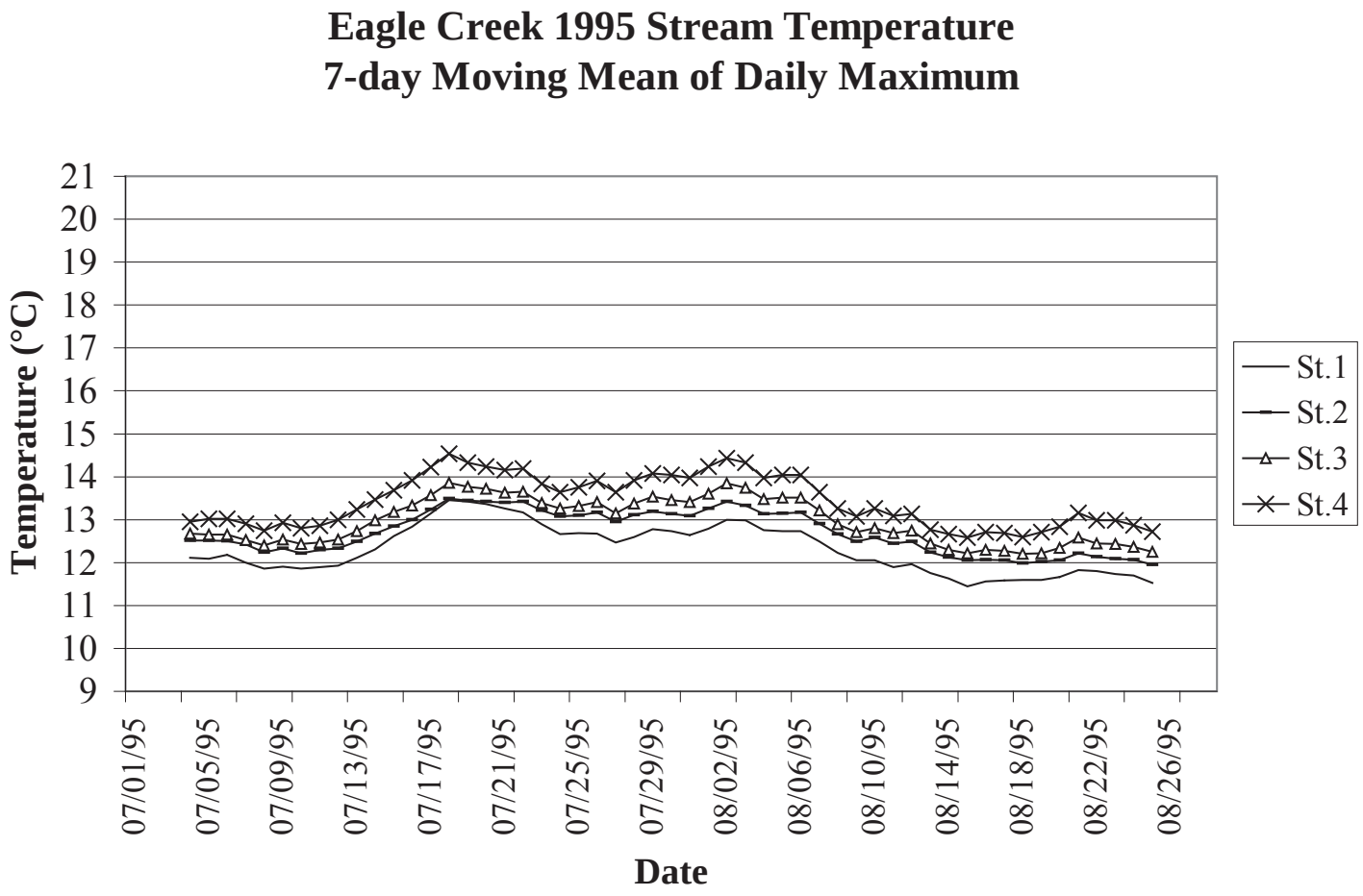
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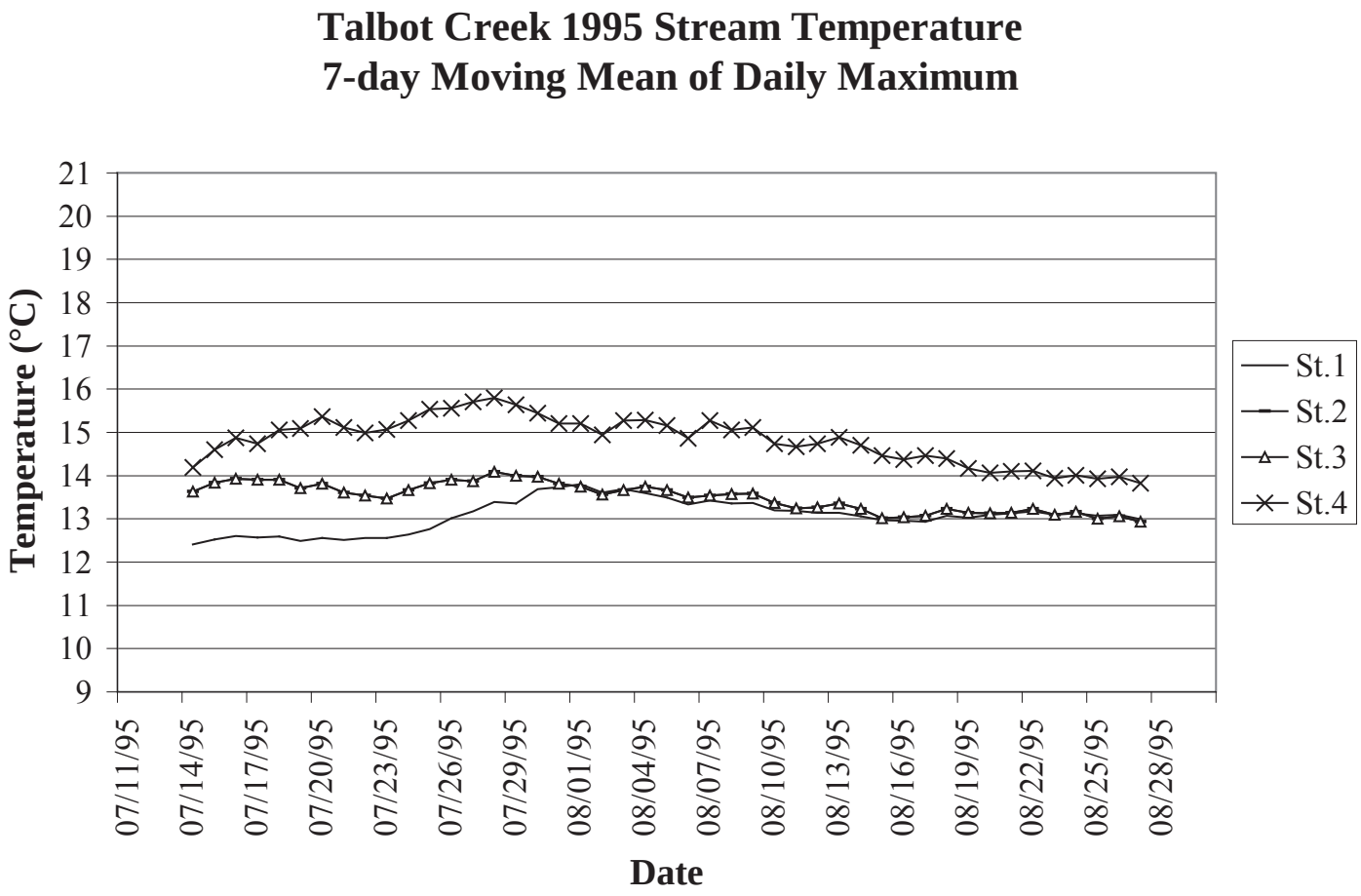
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7-day Moving Mean of Daily Maximum
Temperature (°C)
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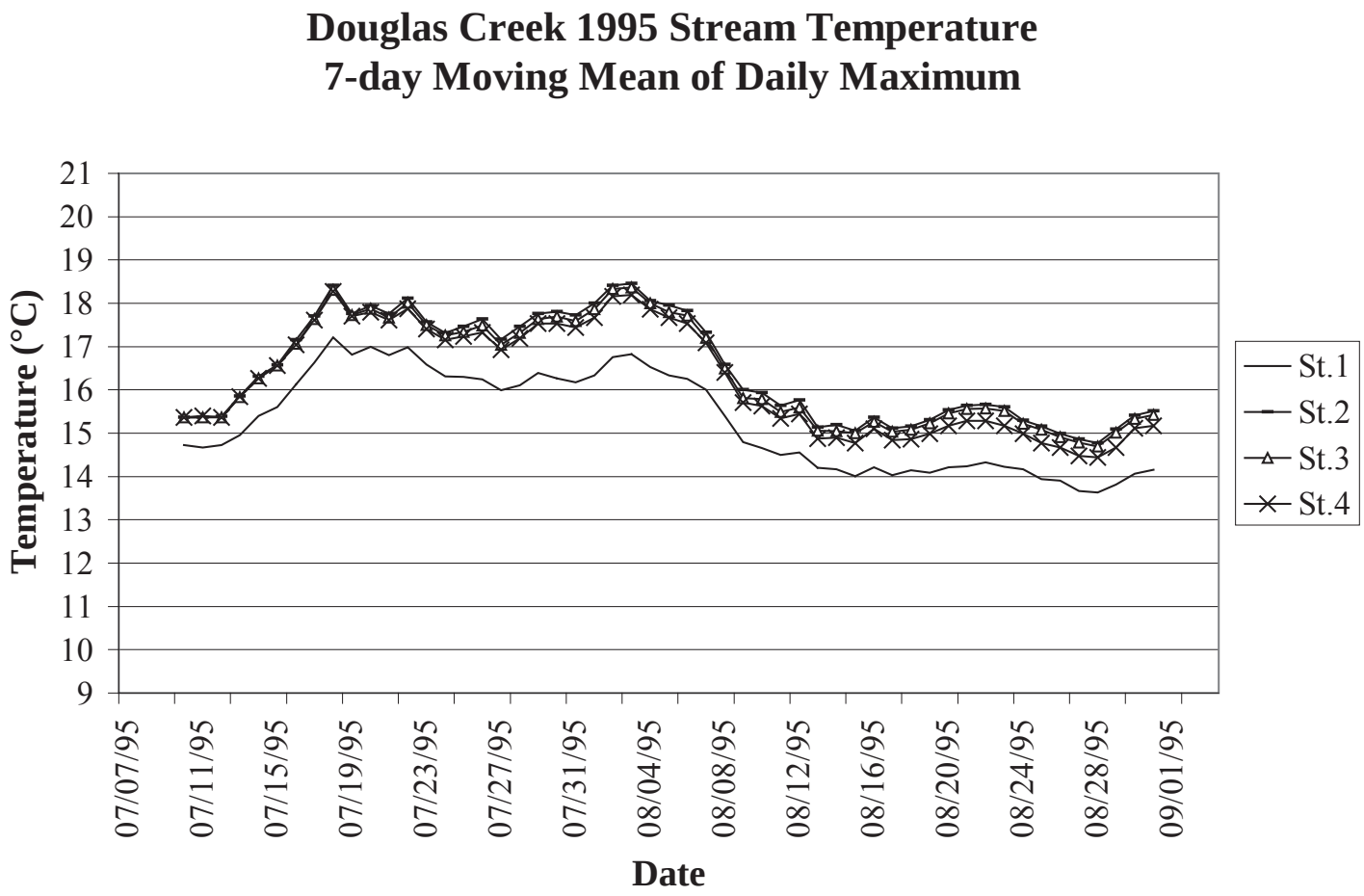
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Temperature (°C)
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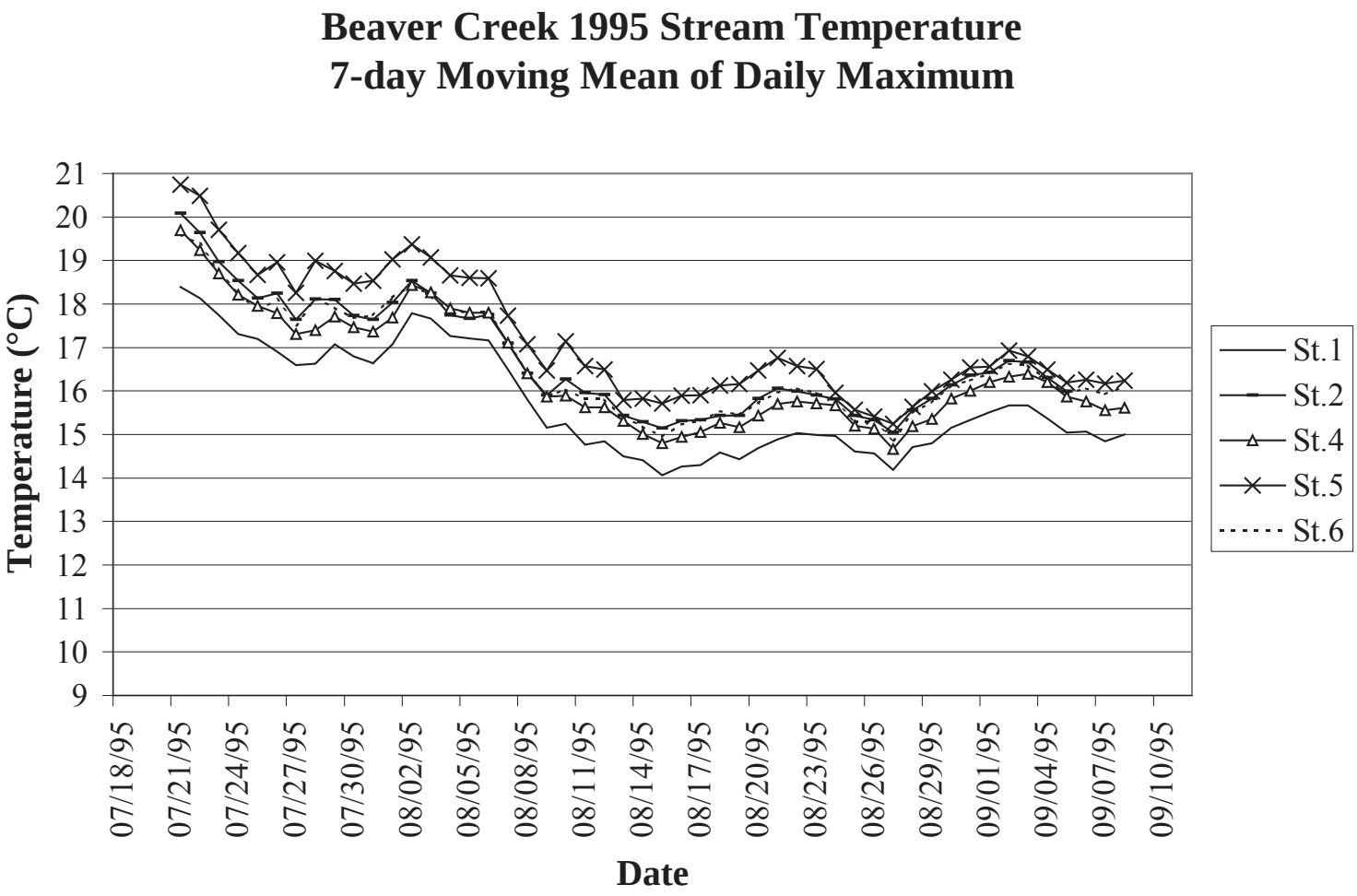
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7-day Moving Mean of Daily Maximum
Temperature (°C)
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Harvest Effects on Riparian Function And Structure Under Current Oregon Forest Practice Rules

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Table of Contents

INTRODUCTION **7**

FOREST PRACTICE RULES 7
LITERATURE REVIEW: RIPARIAN STRUCTURE AND FUNCTION 9
Riparian Structure *9*
Conifer Regeneration *9*
Large Wood Recruitment *10*
Shade *10*
Effects of Management *11*

MONITORING OBJECTIVES AND QUESTIONS **11**

MEASURES OF EFFECTIVENESS **12**

BASAL AREA TARGETS, LARGE WOOD RECRUITMENT, AND SHADE 12

STUDY DESIGN **12**

SITE SELECTION 12
STUDY AREA 13
Georegion Descriptions *15*
Riparian Prescriptions *16*
FIELD METHODS 16
Riparian Structure *17*
Shade, Cover, and Channel Morphology *17*
Regeneration *17*
Other Data *17*

LIMITATIONS AND STRENGTHS OF THIS STUDY **17**

RESULTS **18**

STANDARD TARGETS FOR BASAL AREA 18
Comparing Basal Area Targets to Data from Mature Stands *18*
HARDWOOD AND CONIFER DISTRIBUTIONS 19
Available Basal Area Prior to Harvest *22*
LARGE WOOD RECRUITMENT 28
Diameter Distribution Before and After Harvesting *28*
Probability of Large Conifer Trees Falling Into the Stream *31*
COVER 35
REGENERATION WITHIN 100 FEET OF THE STREAM 38

SUMMARY AND CONCLUSIONS **47**

RECOMMENDATIONS **48**

OVERALL FINDINGS 48

REFERENCES **50**

APPENDIX A **54**

CHARACTERISTICS OF UNMANAGED RIPARIAN STANDS IN OREGON THAT ORIGINATED AFTER WILDFIRE 54

APPENDIX B: **65**

PRE-HARVEST BASAL AREA FOR ALL SITES 65

APPENDIX C **67**

Statistical Comparisons of Pre- and Post-Harvest Average Diameters 67

APPENDIX D:..... 69

Coefficients for tree height prediction equations 69

APPENDIX E 71

Statistical Results of Pre- and Post-Harvest Predicted Large Wood Recruitment Potential..... 71

APPENDIX F..... 75

Statistical Results: Pre- and Post-harvest Comparisons of Cover 75

APPENDIX G..... 78

Summary Statistics for Regeneration on Individual Sites 78

List of Figures

Figure 1. Study Sites and Georegion Boundaries....13
Figure 2. Plot Design....16
Figure 3. Basal area in unmanaged riparian areas and current basal area standard targets. Numbers above each line represent sample size. 19
Figure 4. Western Oregon average conifer and hardwood distributions with distance from stream....20
Figure 5. Eastern and Southern Oregon average conifer and hardwood distributions with distance from stream....21
Figure 6. Available basal area versus the standard target for 40 RMAs. The line represents the standard target. Sites that are displayed above the line exceed the standard target while sites that fall below the line do not have enough coniferous basal area to meet the standard target. 23
Figure 7. Percent of the standard target for basal area, available prior to harvest, within 20 feet and within the RMA. Georegions are labeled as Coast = Coastal, Int&W.Cas = Interior and West Cascades, EC = East Cascades, Sisk = Siskiyou, Blue Mnt. = Blue Mountain....25
Figure 8. Average cumulative coniferous basal area versus distance from stream before and after harvesting for RMAs managed with unknown, no-cut or basal area prescriptions. The tops of the gray boxes represent the standard target and the right-hand sides of the gray boxes represent the RMA width. The area between the curves represents the basal area removed with harvesting....26
Figure 9. Average cumulative coniferous basal area before and after harvesting for sites managed with riparian conifer restoration (RCR) prescriptions. 27
Figure 10. Average conifer diameter distributions before and after harvesting on small, medium, and large streams....29
Figure 11. Box plots of conifer diameter distributions before and after harvesting on small, medium, and large streams before and after harvesting. 30
Figure 12. Predicted heights versus measured tree height for measured trees....32
Figure 13. Average predicted large wood recruitment before and after harvesting for small, medium and large streams. Vertical lines represent the standard error....34
Figure 14. Change in cover after harvesting....36
Figure 15. Change in percent cover after harvesting versus stream width. 36
Figure 16. Regeneration density (number of trees/plot) versus distance from stream for the Coast (Sites 11-17) and Interior georegions (Sites 24-29)....39
Figure 17. Coast Georegion: Seedling and sapling density (trees/acre) for each site by species. BM = bigleaf maple, DF = Douglas-fir, RA = red alder, SI = Sitka spruce, WC = western redcedar, WH = western hemlock. 42
Figure 18. Interior Georegion: Seedling and sapling density (trees/acre) for each site by species. BM = bigleaf maple, DF = Douglas-fir, RA = red alder, SI = Sitka spruce, WC = western redcedar, WH = western hemlock, YE = Pacific yew. 43
Figure 19. Relative seedling species abundance at 20 feet, 50 feet, and 80 feet from the stream for Coast streams (N = 5)....45
Figure 20. Relative seedling species abundance at 20 feet, 50 feet, and 80 feet from the stream for Interior streams (N = 5). 46

List of Tables

Table 1. Riparian Management Area Widths. 8
Table 2. Georegion, stream size, and riparian prescription, if known. 14
Table 3. Average basal area within RMAs. 23
Table 4. Percent of sites that exceeded standard basal area targets, exceeded standard basal area targets by more than 50%, met or exceeded within 20 feet, or did not meet standard targets prior to harvest. 24
Table 5. Average number of trees/1000 ft. in each probability class before and after harvesting and the *percent change after harvesting. 33
Table 6. Percent cover before and after harvesting on 24 streams. 37
Table 7. Regeneration summary statistics by georegion. 40
Table 8. Percent of plots with conifers or hardwoods present, or an absence of regeneration. 40
Table 9. Regeneration stocking for conifers and hardwoods. 41

Harvest Effects on Riparian Function And Structure Under Current Oregon Forest Practice Rules

ODF Technical Report 12

July 2001

INTRODUCTION

The purpose of this study was to evaluate the effectiveness of the 1994 Oregon Department of Forestry's Forest Practices Stream Rules. The particular focus was on rules designed to address riparian forest stands along fish-bearing streams. The purpose of the vegetation retention rules is to maintain and promote *desired future riparian stand conditions* that will provide ample shade, an abundance of large wood to the channel, bank stability, snags, nutrient input and nutrient uptake. Under the 1994 stream rules, riparian stands can be managed to the extent that these goals can be met. This study was designed to answer the question:

> *Are the new (1994) forest practices regulations effectively maintaining and promoting riparian conditions that will achieve the desired future condition?*

This technical report summarizes the forest practice (FP) rules and relevant research on riparian function and structure. The study objectives, monitoring questions, and study design are described. The results are presented in detail followed by summary, conclusions, and recommendations.

FOREST PRACTICE RULES

The water protection rules require the establishment of riparian management areas (RMAs) on most streams that are within or adjacent to a harvest unit. The RMA width requirements vary depending on the stream classification (OAR 629-635-300)(Table 1). Oregon Department of Forestry (ODF) classifies streams by "Type" and by stream size. The "Type" designations include Type F for fish-bearing streams, Type N for non-fish-bearing streams, and Type D for domestic water sources without fish presence. Stream sizes are based on average annual stream flow in cubic feet per second (cfs). The stream size classifications are small (< 2 cfs), medium (≥ 2cfs and < 10 cfs), or large (≥ 10cfs).

A landowner has multiple options for harvesting within the RMA. One scenario under which RMAs can be managed is if the existing basal area exceeds the "standard target" for basal area. Normal conifer yield tables from average upland stands were used to develop conifer basal area standard targets. The effects of riparian influences on stocking, growth and mortality were used to lower the basal area targets to a level thought to be reasonable for riparian areas (Lorensen et al. 1994). Landowners have the option to harvest conifer trees within riparian management areas that are in "excess" of the basal area targets while maintaining a 20-foot no-cut buffer zone as measured from the average annual high water mark. This standard target prescription as well as five other prescriptions are 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)
Large	100 Feet	70 Feet	70 Feet
Medium	70 Feet	50 Feet	50 Feet
Small	50 Feet	20 Feet	--

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

Standard Target Basal Area (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 doesn't have the option to manage. There were 11 RMAs in this study managed with the standard target prescription.

Active Management (OAR 629-640-110): A landowner can place large wood in the stream and receive a basal area credit. Piece size and credit vary by stream size and Type. The credit allows for additional harvest in the RMA but never below the active management basal area target. This option was not used on any of the sites in this study.

Small Type N Streams: (OAR 629-649-200): Most small Type N streams do not have RMA requirements other than equipment and site preparation restrictions. There were no small Type N streams 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 capable of supporting conifers which currently is 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 four 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 no RMAs managed with a site specific plan in this study.

LITERATURE REVIEW: RIPARIAN STRUCTURE AND FUNCTION

Riparian areas fill a special environmental niche between aquatic and terrestrial systems and provide a unique linkage from the headwaters of a basin to the outlet (Beschta 1991, Gregory et al. 1991). Structural characteristics of riparian areas vary greatly because the plant communities reflect fluvial and fire disturbances, soil and geomorphic characteristics and management practices (Gregory et al. 1991, Hayes et al. 1996). Many of today's forested streams reflect past management strategies that did not require leave trees, but included the use of splash dams and removal of large wood from the stream. They also reflect changes in disturbance regimes that result from fire suppression, flood control and beaver trapping.

Riparian areas provide a variety of functions such as shade and cover over the stream, introduction of large wood and nutrients to the stream, floodplain development, hydrologic controls, and bank stability (Beschta 1991). The structure and functions addressed by this study include coniferous and hardwood distributions, regeneration densities, large wood recruitment (LWR), and shade levels found in RMAs before and after harvesting under the current forest practice riparian rules (adopted in 1994).

Riparian Structure

While there has been ample research on the importance of riparian functions such as large wood and shade to in-stream habitat, relatively few studies have documented riparian stand characteristics such as basal area, species composition and diameter distributions. Additionally, most of the available research in Oregon has focused on the Oregon Coast Range. Studies completed on older riparian forests demonstrate a range of riparian stand structures best described as patchy, with combinations of conifer-dominated, hardwood-dominated and mixed stands. Studies in the Oregon Coast Range show that, in general, conifer density increases with increasing distance from stream, elevation, channel gradient and with decreasing stream size (Minor and Weatherly 1994, Hayes et al. 1996, Nierenberg and Hibbs 1999, Pabst and Spies 1999). Hardwoods remain fairly consistent with distance from stream. In the Oregon Coast Range, hardwoods are more commonly the dominant overstory species on wider streams with floodplains than they are on smaller streams without floodplains (Minor and Weatherly 1994).

Vegetative trends are highly dependent on local geomorphology. Constrained reaches commonly have little variation with distance from stream while unconstrained reaches (wider floodplain systems) have great variation. For example, terraces, meandering channels, abandoned channels, beaver complexes, and wetland areas are common in unconstrained systems. These variable conditions favor some species over others and thus result in patchy vegetation types (Kovalchik and Chitwood 1990, Nierenberg and Hibbs 1999).

Conifer Regeneration

Few studies have documented regeneration characteristics, but the findings consistently show very low conifer regeneration within riparian areas in the Oregon Coast Range (Minor and Weatherly

1994, Hibbs and Giodano 1996). Higher conifer regeneration was associated with higher coniferous basal area in the overstory, proximity to shade-tolerant seed trees, less competition from shrubs, and the presence of nurse logs or mineral soil (Minor and Weatherly 1994, Hibbs and Giodano 1996, Beach and Halpern 2001). Conifer regeneration is an important component of riparian structure. These seedlings represent the future stand characteristics. If study results accurately represent the regeneration rate in riparian areas on a larger scale, land managers may need to intervene to assure a future source of large coniferous wood to stream channels.

Large Wood Recruitment

Large wood controls many of the structural and functional properties of small forested streams in ways that are important to fish (Lisle 1986, Bisson et al. 1987, Bilby and Ward 1989). The benefits of large wood for fish habitat have been well documented. Large wood modifies sediment routing, provides cover to fish from predation, provides unique habitats for invertebrates, and velocity refuges during high flows (Bisson et al. 1987, Gregory et al. 1991). Large wood influences flood plain and bar formation, pool size and frequency (Bisson et al. 1987, Bilby and Ward 1989).

The longevity of wood in streams depends in part on species and size. Large-diameter conifer trees tend to last longer and form pools faster in the aquatic environment than smaller-diameter deciduous trees (Bisson et al. 1987, Bilby and Ward 1989, Beechie et al. 2000). Other factors that influence mobility and wood accumulations include tree length in proportion to the channel width, hydrologic and physical characteristics of the stream, and management and disturbance history (Lienkaemper and Swanson 1987, Carlson et al. 1990, Bilby and Ward 1991, Gurnell and Sweet 1998, Duvall and Grigal 1999). Larger trees are also important because they provide an anchoring point upon which other wood can accumulate to increase the complexity of fish habitat (Keim et al. 2000).

In general, studies have documented that the near-stream area is a critical source of large wood to the stream channel and that wind is a primary agent of delivery (Lienkaemper and Swanson 1987). Efforts to predict wind-firmness of riparian buffer strips have identified many factors that influence the rate at which trees will be delivered to the stream. In an Oregon study, Steinblums et al. (1984) identified direction of prevailing winds, distance to the ridge, orientation, elevation, stand condition, stand mortality, overstory species, channel migration, and water table level as contributing factors to wind-firmness. Regardless of the delivery agent, direction of fall, tree height, distance from stream, slope steepness, and bole breakage determine if a fallen tree will land in the stream (Robison and Beschta 1990, Van Sickle and Gregory 1990). Modeling efforts have shown that the majority of large wood (70% or more) is recruited from within 60 feet of the stream (McDade et al. 1990, Van Sickle and Gregory 1990).

Shade

Riparian vegetation provides cover to the stream surface. In the summer time, shade from forest and shrub cover minimizes the amount of sunlight that reaches the stream surface, thus preventing further increases in stream temperature above background. In the winter time, coniferous cover can serve to reduce long-wave radiation losses that may further decrease stream temperatures below background (Beschta 1991).

Effects of Management

Much of the available research on the effects of harvesting on riparian function and structure is derived from study sites that were harvested prior to the *current* forest practice rules. The harvest practices on these sites typically involved clearcut harvesting down to the stream's edge followed with intense burning. Such studies document dramatic losses in shade and cover, associated increases in stream temperature, and losses in large wood recruitment and loading in the stream channel. Studies on these practices conducted throughout Oregon demonstrate that the impaired functions are typically shown to recover within 5 to 15 years for shade and temperature, depending on the stream size (Brown et al. 1971, Feller 1981, Andrus and Froehlich 1987, Beschta et al 1987, Johnson and Jones 2000). Recovery of both large wood recruitment and instream large wood is expected to take much longer (Beechie et al. 2000).

Fewer studies assess the effects of *current* harvest practices on riparian structure and function. Those that do have demonstrated increased protection of shade and LWR above that provided under previous regulations in Oregon (Brazier and Brown 1973, Hairston-Strang and Adams 1997, Hairston-Strang and Adams 2000) and Southeast Alaska (Koski et al. 1984). Hairston-Strang and Adams (2000) concluded that Oregon Forest Practices Act's current water protection rules adopted in 1994 strengthen protection for riparian forest resources over that provided by the previous rule set. This study aims to test if Oregon's current forest practice RMAs are adequate to promote and maintain large wood recruitment, shade, and conifer regeneration.

MONITORING OBJECTIVES AND QUESTIONS

The objectives of this monitoring project were to determine if the forest practice riparian rules promote riparian conditions that are consistent with levels observed in mature riparian forests and if the rules are effective at maintaining structure that will promote the desired future conditions for large wood recruitment and shade. The specific monitoring questions to be addressed include:

1. *Do estimates of average basal area that were used to craft the standard targets for basal area accurately represent mature riparian forests?*

2. *Do hardwoods dominate the near-stream area on all stream sizes?*

3. *How does the available basal area in riparian management areas compare to standard targets?*

4. *Are the 1994 forest practices riparian rules effective in maintaining potential sources of large wood recruitment for in-stream habitat as compared with pre-harvest condition?*

5. *Are the 1994 stream protection rules effective in maintaining stream shade as compared with pre-harvest condition?*

6. *What are the trends in conifer regeneration within riparian areas?*

MEASURES OF EFFECTIVENESS

BASAL AREA TARGETS, LARGE WOOD RECRUITMENT, AND SHADE

Testing the effectiveness of the water protection rules in meeting resource protection goals is problematic, in part because of a lack of established numeric standards (either regulatory or scientific). This is particularly true when evaluating large wood recruitment and, to some extent, when evaluating shade (Department of Environmental Quality (DEQ) is currently establishing shade standards through the Total Maximum Daily Load process). The goals pertaining to large wood recruitment and shade for forested riparian areas (the primary functions evaluated in this study) are described qualitatively in OAR 629-630-0100 and 629-640-000. The vegetation retention goals for streams are based on the concept of desired future condition. This desired future condition for riparian areas along streams with fish is:

> *" to grow and retain vegetation so that, over time, average conditions across the landscape become similar to those of mature streamside stands."*

The rule recognizes 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." In turn, the rule articulates numerical standards for riparian structure 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 streamside stands" (at age 120) for each geographic region. Estimates were necessary due to a lack of sufficient mature riparian forest data at the time.

Nearly seven years after the 1994 rules were adopted more mature riparian forest data are available. The estimates of conifer basal area for unmanaged mature riparian forests are evaluated by comparing the targets to data from mature riparian forests. The attainability of the targets is evaluated by comparing the pre-harvest basal area to the targets themselves.

In light of a lack of agreed-upon, numerical standards for shade and large wood recruitment, this study uses before and after harvest comparisons and evaluates effectiveness by the degree to which potential large wood recruitment and shade are retained. The estimates of conifer basal area for unmanaged mature riparian forests are evaluated by comparing the targets to data from mature riparian forests.

STUDY DESIGN

SITE SELECTION

Landowners and forest practice foresters volunteered sites throughout the state for this study. The only constraint was that the harvest units were adjacent to fish-bearing streams. Data were

collected before harvesting on 40 sites. Twenty-five of those 40 sites were revisited one year later after harvesting and the measurements were repeated.

STUDY AREA

This study was conducted at sites distributed throughout the state of Oregon (Figure 1). Fourteen sites were in the Coastal georegion, 12 in the Interior, four in the West Cascades, two in the East Cascades, two in the Siskiyou, and six in the Blue Mountain georegion (Table 2).

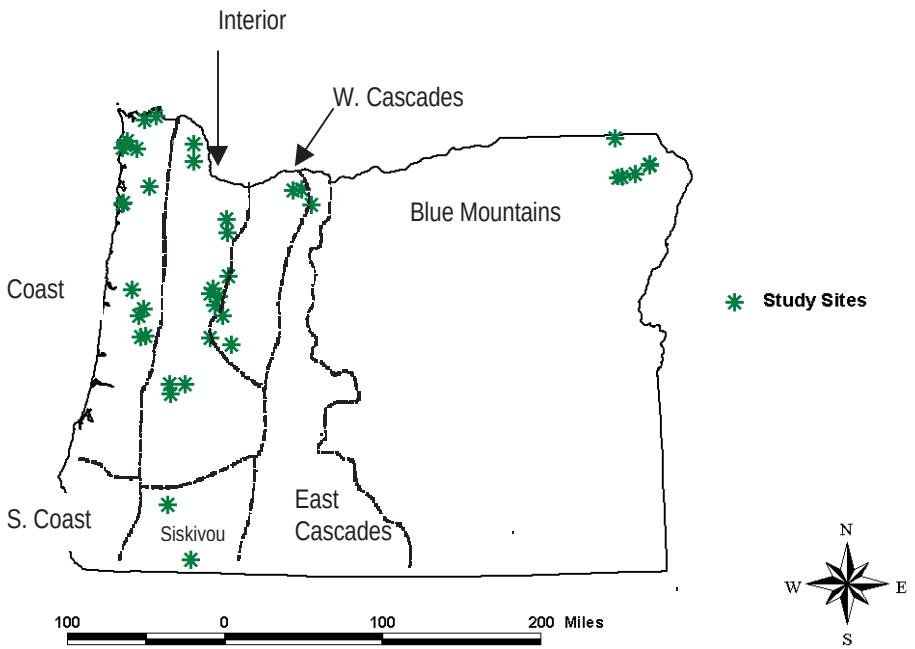

Figure 1. Study Sites and Georegion Boundaries

Table 2. Georegion, stream size, and riparian prescription, if known.

Stream Name (site #)	Georegion	Stream Size	Riparian Prescription
Fish (10)	Coast Range	Small	Unknown
Gnat (11)	Coast Range	Medium	Riparian Conifer Restoration
Hamlet (12)	Coast Range	Small	Riparian Conifer Restoration
Klootchy (13)	Coast Range	Medium	Standard Target
Lake (14)	Coast Range	Large	Riparian Conifer Restoration
NF Beaver (15)	Coast Range	Small	Unknown
Salty (16)	Coast Range	Small	Riparian Conifer Restoration
Yellow Fir (17)	Coast Range	Small	Unknown
^ Bear Creek (18)	Coast Range	Small	Not Harvested
^ Jordan (19)	Coast Range	Large	Not Harvested
^ Wolf Trib (19.1)	Coast Range	Small	Not Harvested
* ^ Shade Bear Creek (19.2)	Coast Range	Large	Not Harvested
* ^ Ecola Creek (19.3)	Coast Range	Large	Not Harvested
* ^ Trib of Necanicum (19.4)	Coast Range	Small	Not Harvested
Blue School (20)	Interior	Small	Standard Target
Cartright (21)	Interior	Large	Standard Target
Cedar (22)	Interior	Medium	No-cut RMA
Cox (23)	Interior	Large	Unknown
Dicky (24)	Interior	Medium	Standard Target
Hopkins (25)	Interior	Medium	Standard Target
Kelley (26)	Interior	Medium	Standard Target
Little Wiley (27)	Interior	Large	No-cut RMA
McClaferty (28)	Interior	Small	Standard Target
Trib A (29)	Interior	Small	Standard Target
^ Ford's Mill (29.1)	Interior	Small	Not Harvested
^ Hunter (29.2)	Interior	Medium	Not Harvested
Deer (30)	W. Cascades	Large	No-cut RMA
Snake (31)	W. Cascades	Large	No-cut RMA
Tony (32)	W. Cascades	Large	Standard Target
^ Green Mountain (33)	W. Cascades	Large	Not Harvested
Ramsey (40)	E. Cascades	Medium	Standard Target
^ Ivanhoe (41)	E. Cascades	Large	Not Harvested
Glade (50)	Siskiyou	Large	Standard Target
Jamison (51)	Siskiyou	Small	Unknown
^ Alder (60)	Blue Mountains	Medium	Not Harvested
Bear (61)	Blue Mountains	Small	Unknown
Sterling (62)	Blue Mountains	Small	Not Harvested
* ^ Elk Creek (63)	Blue Mountains	Medium	Not Harvested
* ^ NF Whiskey Creek (64)	Blue Mountains	Small	Not Harvested
* ^ Tope Creek Trib. (65)	Blue Mountains	Small	Not Harvested

* = Data collection for these sites was conducted under a separate 1999 ODF Shade Study.
^ = Data from these sites are only used in pre-harvest basal area analyses.

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 Environmental Protection Agency (EPA) ecoregion map United States Geological Survey (USGS) and descriptions (CEC 1987).

The *Coastal* 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.

The *Interior* georegion is characterized by high precipitation (from 37 to 120 inches annually) with infrequent snow events on the Willamette Valley floor. Riparian area vegetation varies greatly depending partly on location with respect to the Willamette Valley. Riparian areas on the west-side of the valley are similar to those of the Coast Range with alder-dominated stands and patchy Douglas-fir. Conifers are more common in the riparian overstory on the east-side of the valley. The parent material is predominately volcanic with both deep, well-drained soils and poorly drained soils.

The *West Cascades* georegion is characterized by high precipitation (ranging form 75 to 160 inches) with a transient snow zone around 2,000 to 5,000 feet of elevation. Rain-on-snow events are common. The dominant riparian tree species are red alder, western hemlock, western redcedar, and Douglas-fir. Noble fir, white fir, grand fir and Pacific fir grow at higher elevations. The parent material is volcanic with both poorly drained silt- and clay-textured soils, as well as coarser, better-drained soils.

The *East Cascade* georegion gets substantially less precipitation than the West Cascades due to the orographic effect of cool marine air losing its moisture as it flows over the Cascades. Annual precipitation ranges from 14 to 30 inches except along the crest of the Cascades where it averages 79 inches. The riparian areas are commonly lined with alder and cottonwood and generally have a coniferous overstory of fir and pine species, although these are rare on the floodplains. The parent material is volcanic.

The *Siskiyou* georegion has a mezic/xeric temperature and moisture regime with substantially lower precipitation (ranges from 25 – 70 inches) than the georegions to the north and west of it. The upland vegetation typically includes ponderosa pine, Douglas-fir, Oregon white oak, California black oak, madrone, incense cedar, and grand fir. The riparian areas are more typically red alder, white alder, and conifer-dominated than the Coast or Interior georegions. The geology is fairly diverse throughout the region including basalt, shale, sandstone, and granitics, and the soils range from poorly drained to well-drained.

The *Blue Mountain* georegion is characterized with low precipitation (ranges from 8 to 20 inches annually) most of which falls as snow during the winter. 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, red and white alder and Engleman spruce.

Riparian Prescriptions

All the RMAs surveyed for this study were on Type F streams. There were 11 RMAs managed with a standard target prescription, four managed with a riparian conifer restoration prescription, four with a no-cut RMA, six that were unknown, and 15 that were not harvested prior to the second survey. (See introduction for detailed discussion on riparian prescriptions).

FIELD METHODS

A detailed field protocol is available on the ODF website (http://www.odf.state.or.us/internal.htm) and/or upon request. Riparian sample sites were 500 ft long by 100 ft wide, running parallel to the stream. The plot location was placed at a randomized distance from the bottom of the unit. The plot was located on the left side of the stream if both sides were to be harvested (Figure 2). Plot borders and subplots (zones) were established with a hip chain. Flagging was tied at 25-ft. intervals to aid in defining the sampling and cruising areas. Plots were permanently marked at the downstream 20-ft. corner with aluminum tags and tree paint and were referenced with a Global Positioning Systems (GPS) unit where possible.

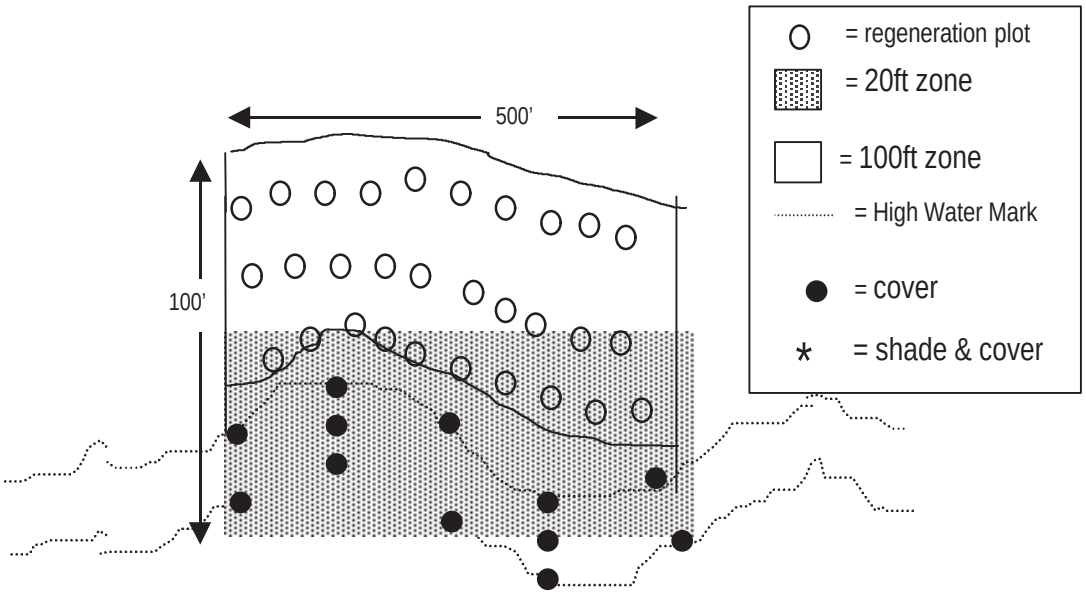

Figure 2. Plot Design

Riparian Structure

The riparian stand was separated into two zones. Within the first 20 feet of the stream channel (20ft. zone), a 100% cruise of trees was conducted. All trees with a diameter at breast height (dbh) greater than or equal to six inches (") were measured. Measurements included: dbh, distance from the stream, degree of lean to the stream, percent slope, and species. In addition, tree height and age were measured for one tree of each species in each diameter class. Diameter classes were 6-10", 11-15", 16-20", and 21"+. Trees smaller than 6" dbh were counted and identified by species.

In the area from 20 feet to 100 feet (100ft. zone) from the stream channel, an Individual Tree Sampling (ITS) method was conducted. Twenty percent of the stand was sampled, distributed systematically through the 100ft. zone and independent of species. The same tree parameters measured in the 20ft. zone were also measured in this 100ft. zone.

Shade, Cover, and Channel Morphology

Shade and cover were measured along five evenly spaced transects (one every 100 feet) starting at one end of the plot. Cover was measured with a convex densiometer at all five transects at mid-channel and on both banks. Shade was measured with a Solar Pathfinder at the upstream, downstream, and middle transects. Stream gradient, stream orientation, dominant substrate, wetted channel width, and bankfull width were measured at each of the five transects.

Regeneration

Regeneration sampling was done only on those sites that had been replanted prior to the post-harvest survey (n = 10, Interior and Coastal georegions). Seedlings and saplings were counted and identified by species in 20-ft. diameter circular plots. A seedling is defined as a young tree with a diameter less than one inch at breast height and a height of at least 12 inches. A sapling is defined as any tree with a diameter greater than 1 inch and less than 6 inches. At each site, sampling was conducted on a total of 30 plots on three transects running parallel to the stream, 25, 50 and 80 feet from the stream (10 plots per line). Plot centers were spaced systematically 50 feet apart along the transects.

Other Data

Snags, down wood, dominant and co-dominant shrub cover, and instream large wood counts were also conducted. These data are not presented in this paper, therefore the methods are not reported here. However, the methods are described in detail in the field protocol that is available upon request.

LIMITATIONS AND STRENGTHS OF THIS STUDY

One limitation of this study is the use of volunteered sites. Implications of a volunteered sample include a potential bias in the type of sites that were volunteered and the way in which the sites were ultimately managed. One way to evaluate this bias is to compare the percent of sites

managed with a standard target prescription in this study to the percent in another ODF monitoring project that relied on a randomly selected sample. Preliminary results from the random selection indicate that 22% of sites (42 out of 182 sites) were managed with a standard target (Josh Robben, ODF, personal communication) compared with 44% (11 of 25) in this study. In general, sites managed with a standard target would have greater coniferous basal area prior to harvest and, potentially, a greater impact on large wood recruitment and shade as a result of harvesting. In addition to the non-random selection, the relatively small sample size is another limitation. A small sample increases the potential that the monitored sites do not represent the range of riparian characteristics across the landscape. Finally, conclusions about rule effectiveness are tempered by the lack of agreed-upon measures of effectiveness.

The strengths of the study are based, in part, on the use of riparian data collected before and after harvesting. Pre- and post-harvest data allow for accurate evaluation of changes that result from harvesting, unencumbered with assumptions about what conditions might have been like before harvesting. Another strength of the study is the use of data collected on sites managed under the current set of forest practice rules on private industrial forestland. There is a great deal of debate about the role that forestry currently plays in the efforts for salmon recovery. While there has been ample research on the role of historic forest management practices, fewer studies rely on data that reflect current practices.

RESULTS

STANDARD TARGETS FOR BASAL AREA

The key monitoring questions addressed in this section include:

1. *Do estimates of average basal area that were used to craft the standard targets for basal area accurately represent mature riparian forests?*

2. *Do hardwoods dominate the near-stream area on all stream sizes?*

3. *How does the available basal area in riparian management areas compare to standard targets?*

Comparing Basal Area Targets to Data from Mature Stands

The desired future condition for streamside areas along fish-bearing streams is to grow and retain vegetation so that, over time, average conditions across the landscape become similar to those of mature streamside stands (OAR 629-640-0000 [2]). The standard targets were established with limited basal area information for mature riparian stands (Lorensen et al. 1994). Currently available field data (Steinblums 1977, Andrus and Froehlich 1987, Heimann 1988, Carlson et al. 1990, Night 1990, Ursitti 1990, Papst and Spies 1999, Thom et al. 1999) have been compiled from nine studies that documented basal areas of mature riparian stands (Appendix A). Field methods

such as plot designs, age, and diameter determinations vary somewhat between the studies, but the compilation is useful for evaluating current basal area standard targets.

During the rule-revision process, it was assumed that if riparian areas were managed with the proposed standard targets, the average basal area within these managed riparian areas would, over time (30-60 years after harvest), equal the average for mature riparian forests. A comparison of mature forest conditions to the assumed basal area for 120-year-old managed stands, indicates the standard targets underestimate conifer stocking for West Cascade and Interior streams, and approximate conifer stocking for Coastal, NE Oregon and Central Oregon areas. (Figure 3).

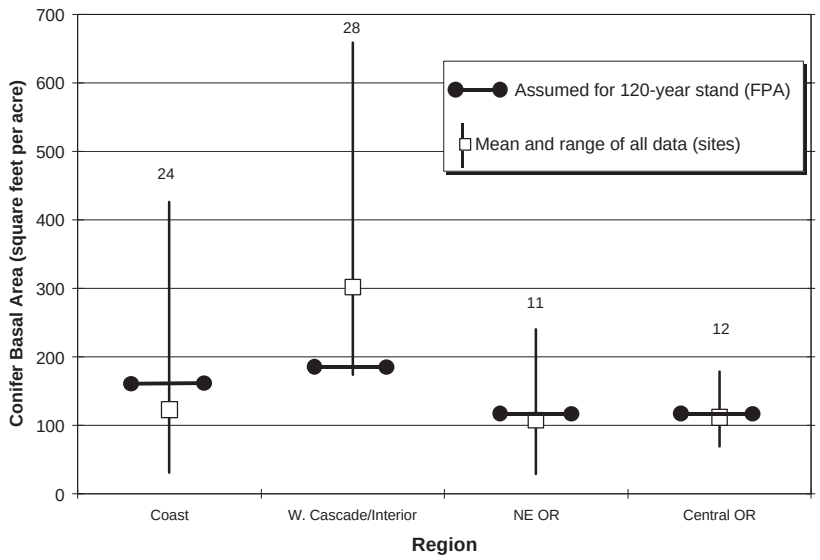

Figure 3. Basal area in unmanaged riparian areas and current basal area standard targets. Numbers above each line represent sample size.

HARDWOOD AND CONIFER DISTRIBUTIONS

When basal area targets were developed in 1994, they were based, in part, on the assumption that hardwood species dominated the first 20 feet of the RMA (Lorensen et al. 1994). Any conifer stocking in this area was assumed to be negligible. Results from this study indicate that in western Oregon, the near-stream area (within 20-40 feet of the high water mark) was commonly dominated by hardwoods (Figure 4). However, the trend was most pronounced on large and small coastal streams.

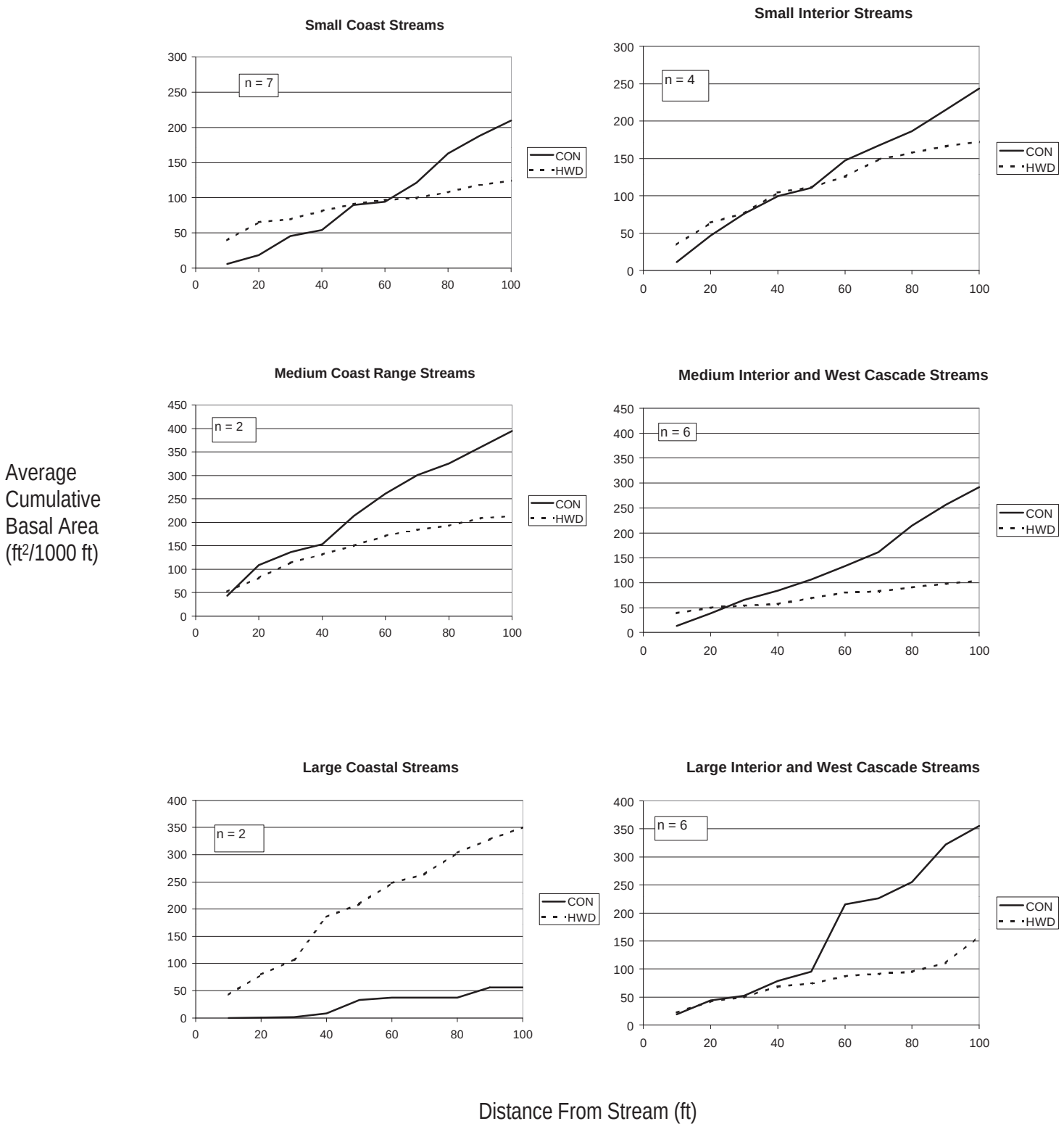

Figure 4. Western Oregon average conifer and hardwood distributions with distance from stream.

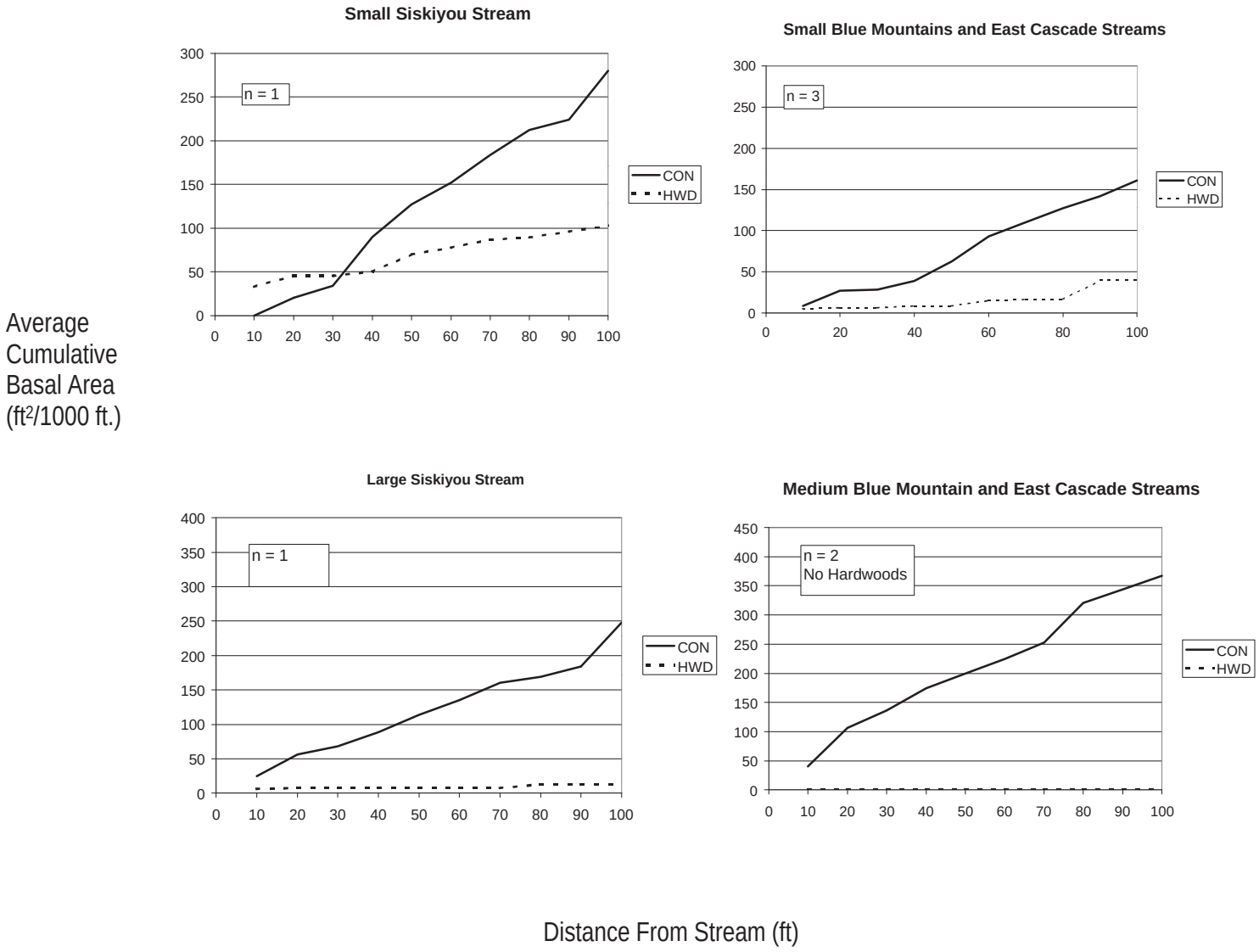

Figure 5. Eastern and Southern Oregon average conifer and hardwood distributions with distance from stream.

Conversely, conifer stocking within 20–40 feet of the high water mark was substantial on medium and Interior streams. The medium and Interior riparian stands are best described as mixed. Conifers comprise slightly less than 50% of the trees within 30 feet of the stream. At about 30 feet

from the stream, there is a shift and conifers comprise slightly more than 50% of the stand. Conifers continue to increase in dominance as distance from the stream increases. This finding is consistent with results reported in the literature.

In the Blue Mountain and East Cascade georegions, the hardwood component was very low or, in some cases, absent within the first 20 feet of the stream, as well as the riparian management area as a whole. Results were mixed for the Siskiyou georegion (Figure 5).

The assumption of hardwood domination within the first 20 feet of the stream was reasonable for large and small coastal streams. When these data are stratified by stream size and georegion, the sample size diminishes such that strong conclusions are not possible. However, in the cases of other georegions and medium coastal streams, reducing the standard target to account for hardwood domination was not supported by these data.

Available Basal Area Prior to Harvest

Results indicate substantial variability in conifer stocking within and between georegions and stream sizes (Table 3 and Figure 6). On small streams, coniferous basal area ranged from 0 to 180 ft^2/1000 ft., on medium streams from 42 to 392 ft^2/1000 ft, and on large streams from 0 to 927 ft^2/1000 ft. (For a discussion on standard targets, refer to the introduction section). Even with this kind of variability, the existing basal area commonly exceeded that required to meet standard targets along small and medium streams.

The basal area prior to harvest was compared to the standard target. Standard targets for basal area were commonly exceeded on small (72% of sites) and medium streams (81% percent of sites). On large streams, existing basal area exceeded the target on approximately 54% of the sites (Table 4). The degree to which basal area was exceeded was most pronounced on small streams. On average, the standard target was exceeded by 114% on small streams, by 65% on medium streams, and by 12% on large streams (Figure 7). The forest practice rules allow for harvesting within the RMA to within 20 feet of the high water mark if the standard target can be met within the 20ft. zone. Basal area was met within the 20ft. zone more commonly on small streams (28% of sites) than on medium and large streams (18% and 0% of sites respectively) (Table 4 and Figure 7). The actual total basal area and other RMA data for each site are provided in Appendix B.

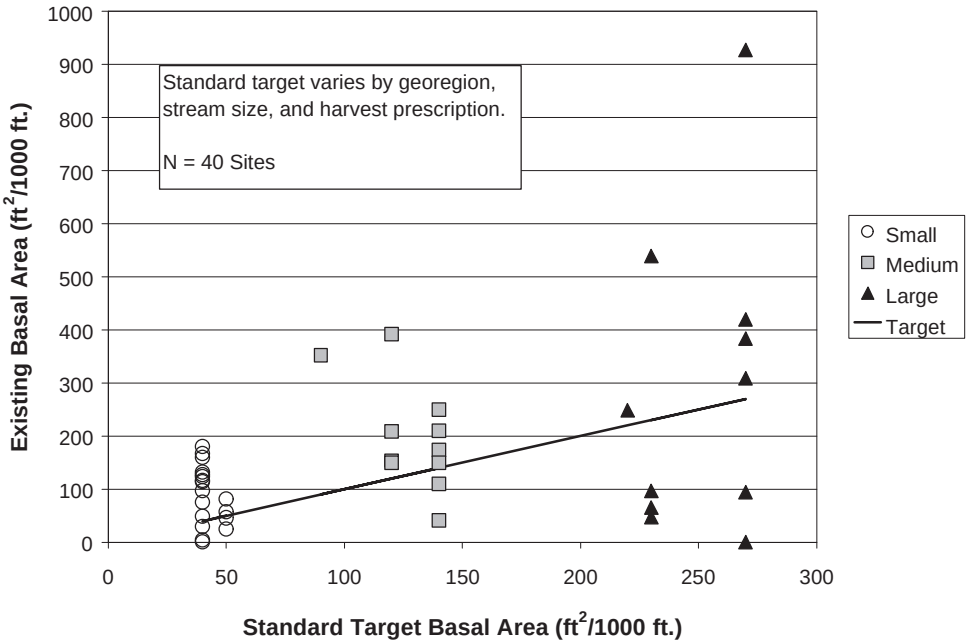

Figure 6. Available basal area versus the standard target for 40 RMAs. The line represents the standard target. Sites that are displayed above the line exceed the standard target while sites that fall below the line do not have enough coniferous basal area to meet the standard target.

Table 3. Average basal area within RMAs.

	Basal Area (ft^2/1000 ft) for Each Stream Size		
	Small	Medium	Large
Minimum Basal Area	0	42	0
Maximum Basal Area	180	392	927
Average Basal Area	88	199	285

Table 4. Percent of sites that exceeded standard basal area targets, exceeded standard basal area targets by more than 50%, met or exceeded within 20 feet, or did not meet standard targets prior to harvest.

Basal Area Statistic	Percent of Sites in Each Stream Size		
	Small	Medium	Large
Exceed the Standard Target within the RMA	72%	81%	54%
Exceed the Standard Target by > 50%	61%	36%	27%
Meet or Exceed within 20 Feet of Stream	28%	18%	0%
Less than the Standard Target within RMA	28%	18%	45%

Cumulative curves illustrate the average distribution of basal area before and after harvesting with relation to distance from stream (Figure 8). This analysis was only done on sites with *both* pre- and post-harvest data (n = 25). While available basal area greatly exceeds the standard target on average, only 44% (11 out of 25 sites) of the sites were known to use a basal area prescription. However, an evaluation of measured buffer widths indicates that fewer than 11 sites entered the RMA. Only 28% (7 of 25 sites) of the sites had average buffer widths less than the RMA widths. Six of these seven sites were in the Interior georegion. Buffer widths are reported in Appendix B.

Riparian areas that were managed with riparian conifer restoration (RCR) prescriptions were generally well stocked with conifers, with the exception of one large Coast Range stream (Figure 9). It is possible the randomly placed sample plots landed in unusually well-stocked conifer patches that were not representative of the entire stand. RCR rules require that well-stocked conifer patches be treated as retention blocks when possible. Within retention blocks, the landowner may apply general prescriptions if the patch meets the basal area target. If the retention blocks do not meet the standard target, the landowner can harvest all conifers to within 50, 30, and 20 feet on large, medium and small streams respectively. This practice should be evaluated on a larger scale and in more detail to determine if the application adequately maintains patches of potential LWR.

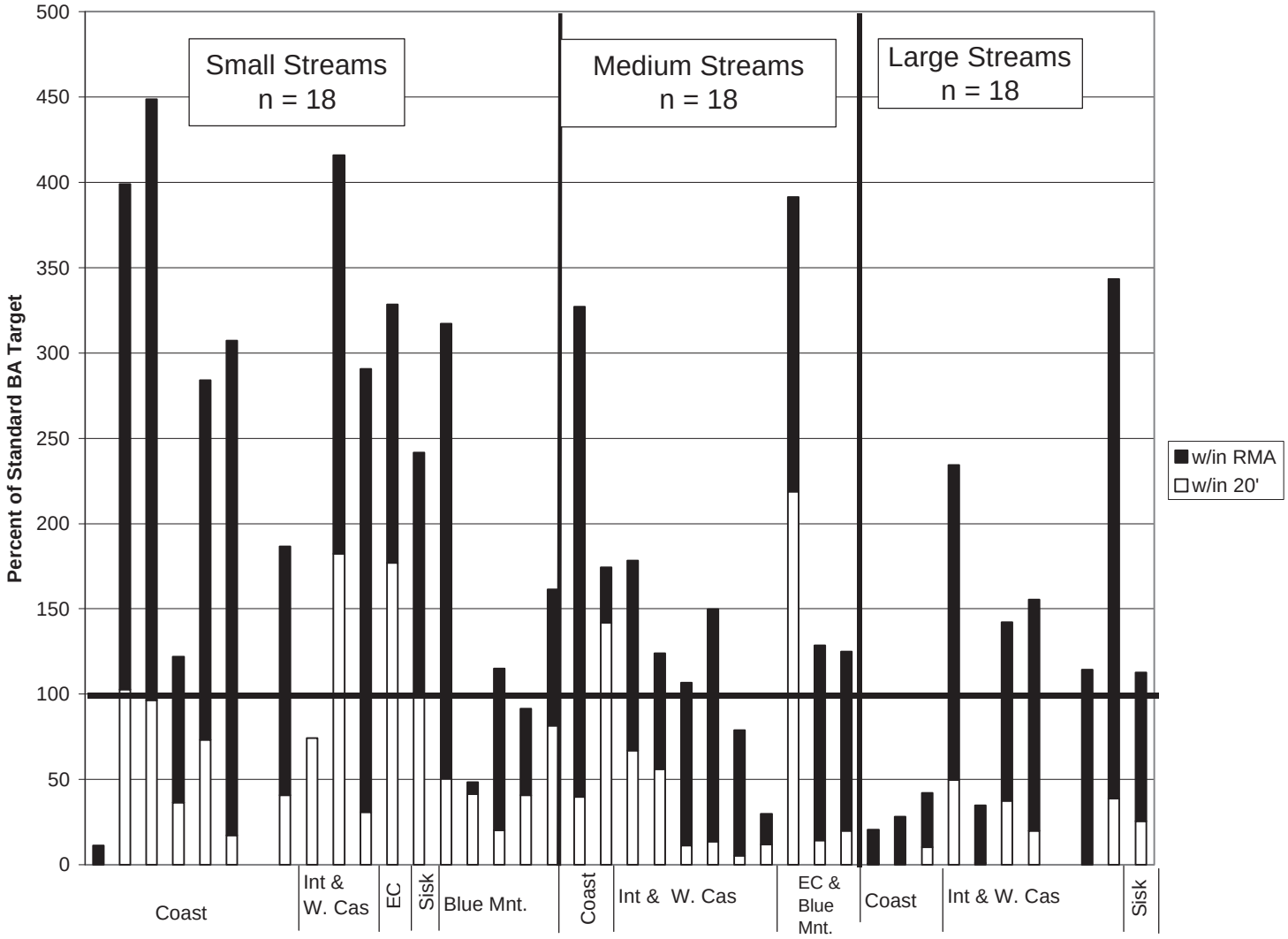

Figure 7. Percent of the standard target for basal area, available prior to harvest, within 20 feet and within the RMA. Georegions are labeled as Coast = Coastal, Int&W.Cas = Interior and West Cascades, EC = East Cascades, Sisk = Siskiyou, Blue Mnt. = Blue Mountain.

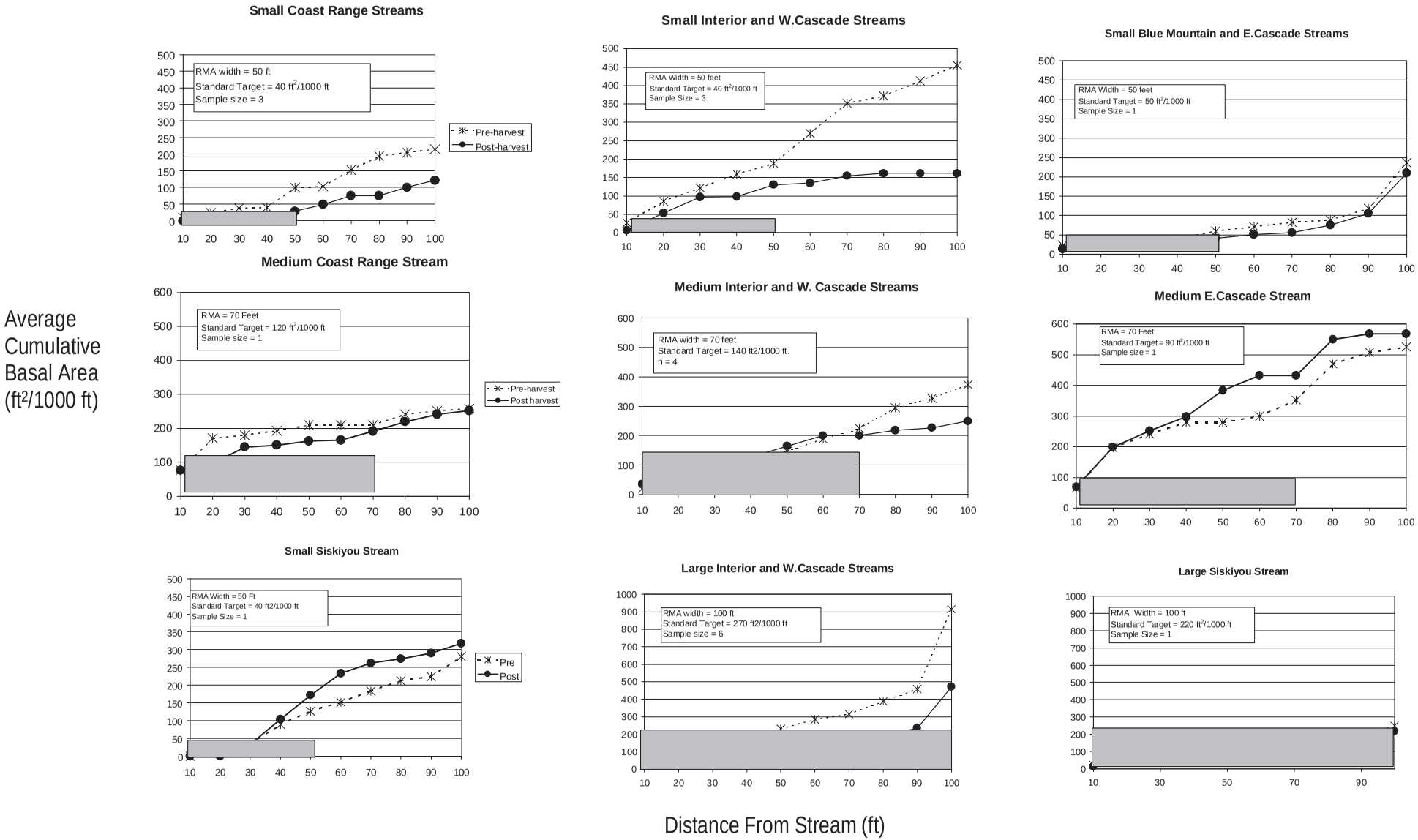

Figure 8. *Average cumulative coniferous basal area versus distance from stream before and after harvesting for RMAs managed with unknown, no-cut or basal area prescriptions. The tops of the gray boxes represent the standard target and the right-hand sides of the gray boxes represent the RMA width. The area between the curves represents the basal area removed with harvesting.*

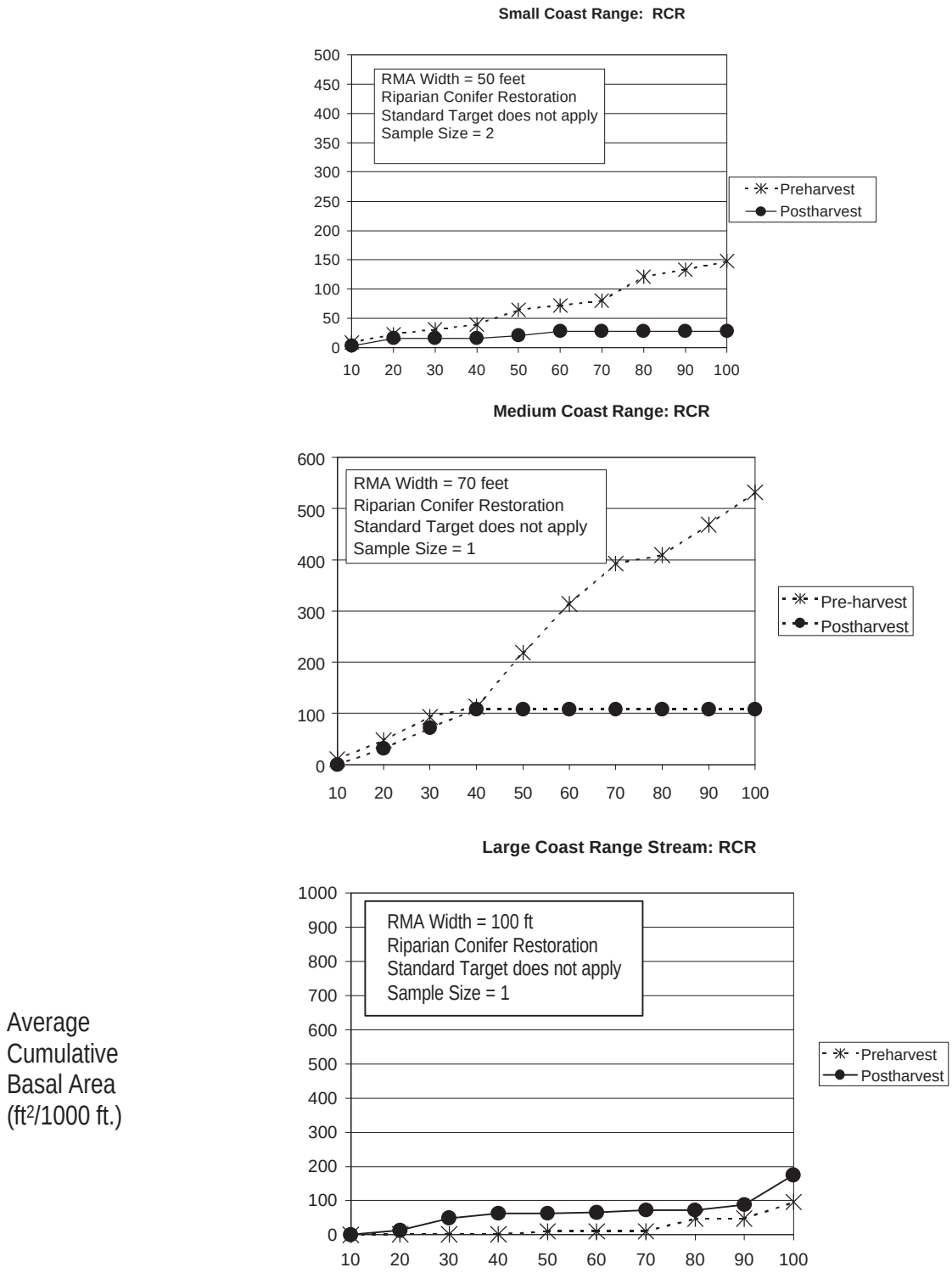

Figure 9. Average cumulative coniferous basal area before and after harvesting for sites managed with riparian conifer restoration (RCR) prescriptions.

LARGE WOOD RECRUITMENT

Large wood recruitment (LWR) is a key function of riparian areas that can be affected by harvesting. Diameter distribution data and a probability analysis were used to answer the question:

4. *Are the 1994 forest practices riparian rules effective in maintaining potential sources of large wood recruitment for in-stream habitat as compared with pre-harvest condition?*

Diameter Distribution Before and After Harvesting

Research has shown that large-diameter conifer trees in riparian areas are important sources of future large wood to the stream. Large conifer wood tends to last longer in the stream and provide an anchoring point upon which other wood can accumulate to increase the complexity of fish habitat.

Diameter distributions of RMAs were evaluated to determine if the numbers of large coniferous trees were disproportionately harvested. Average diameters were compared before harvesting and after harvesting with a two-sample t-test. The average diameter distributions within RMAs (within 50, 70 and 100 feet) of small, medium, and large streams did not change significantly with harvesting (p-value = 0.74, 0.48, and 0.18 respectively) (Figures 10 and 11). While the average diameter was not affected by harvesting, the very largest conifer trees were harvested on small and large streams. Small streams lost the 50-inch class and large streams lost the 60-, 70- and 110-inch diameter classes. Detailed results from the statistical analyses are provided in Appendix C.

The number of very large trees within RMAs was limited to begin with. Generally lacking were the largest diameter (>31 inches) conifers. Specifically, on average for small streams, there were nine and six trees/1000 ft. and for medium streams there were six and five trees/1000 ft. before and after harvesting, respectively. For large streams there were nine trees/1000 ft. prior to harvest and six trees/1000 ft. after harvesting.

This analysis demonstrates that, in general, large trees are not disproportionately harvested, and that diameter distributions are maintained. However, the question still remains of how harvesting in RMAs affects numbers of large conifer trees that could have potentially fallen in the stream.

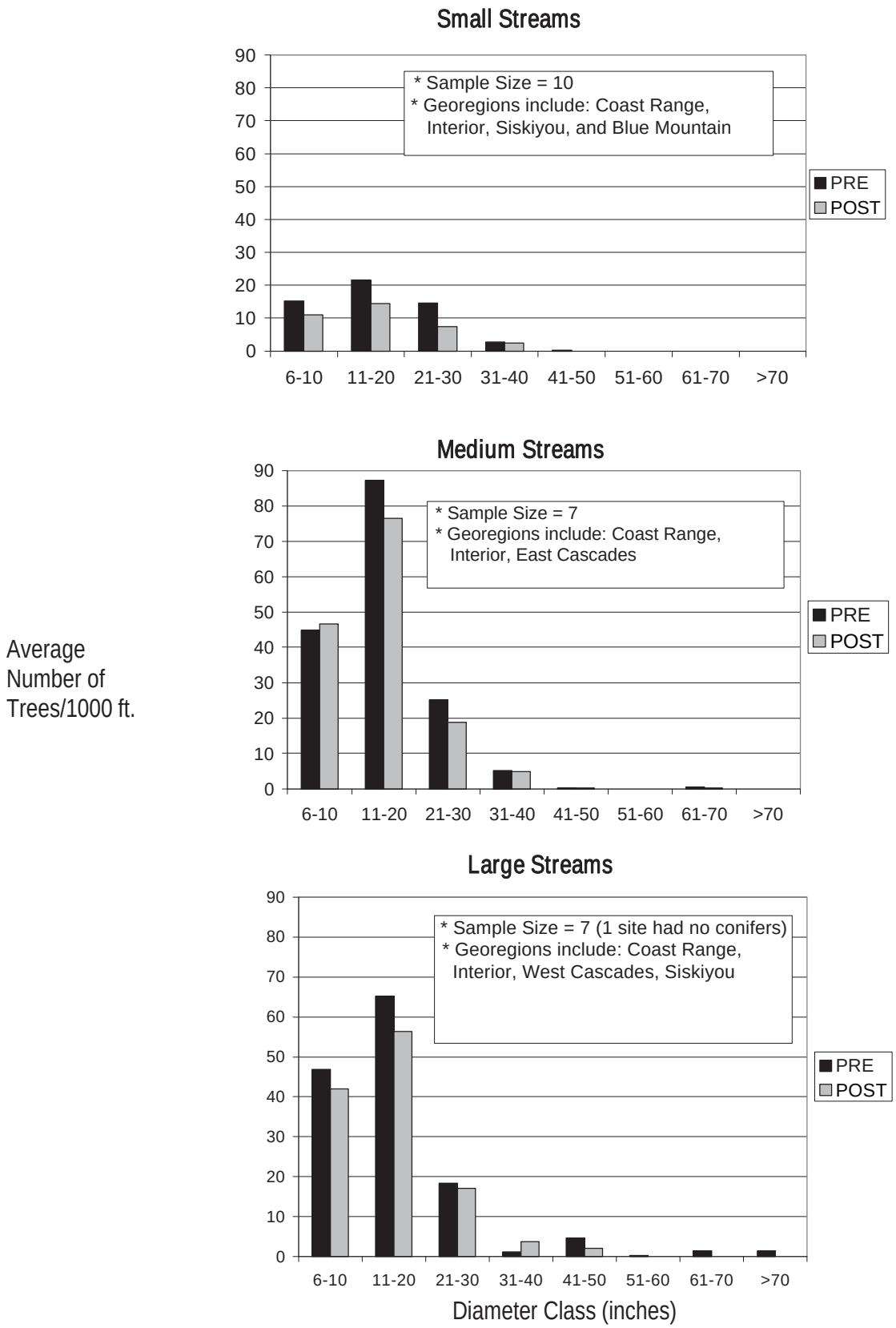

Figure 10. Average conifer diameter distributions before and after harvesting on small, medium, and large streams.

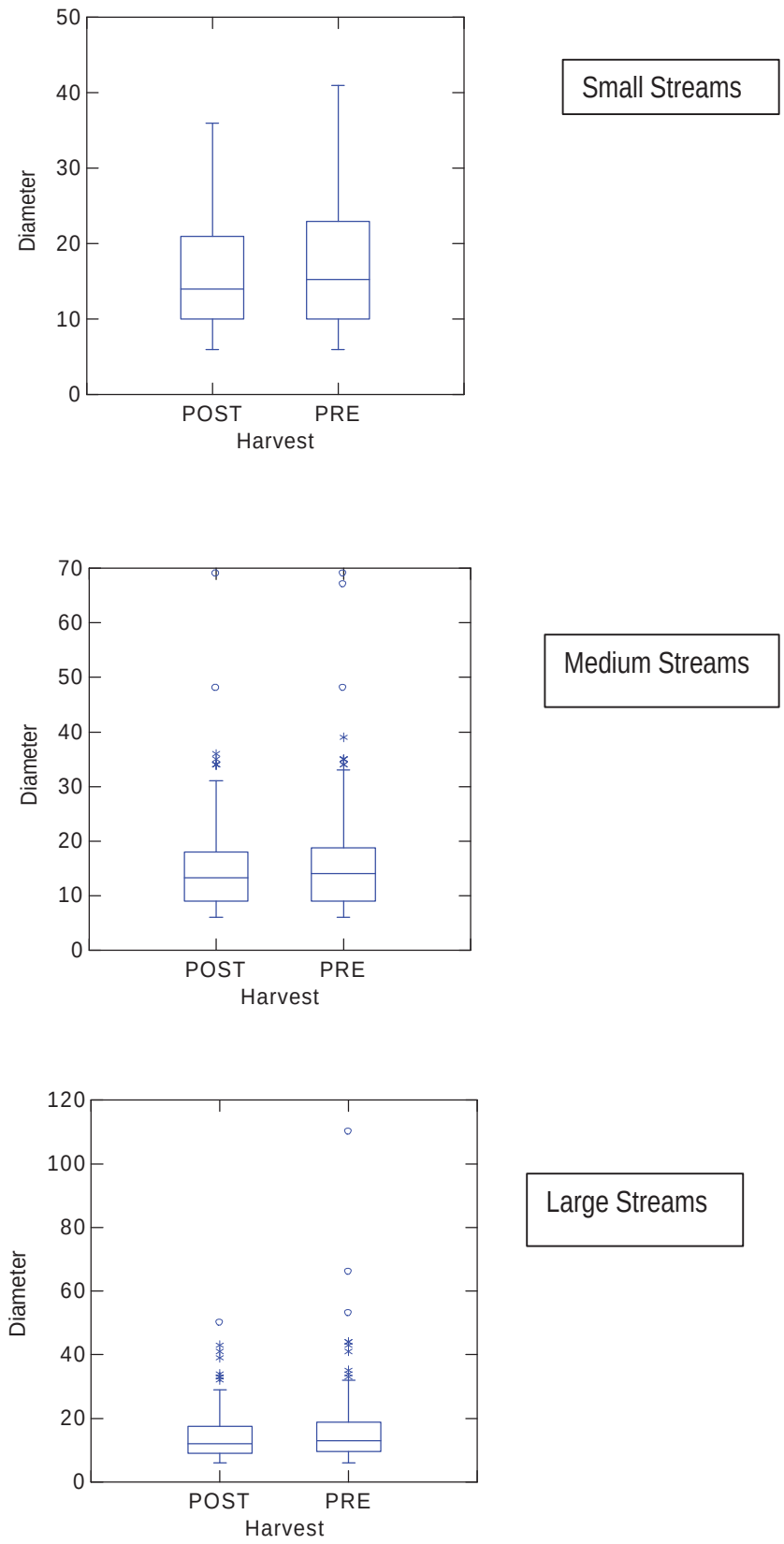

Figure 11. Box plots of conifer diameter distributions before and after harvesting on small, medium, and large streams before and after harvesting.

Probability of Large Conifer Trees Falling Into the Stream

The effect of harvesting on large trees that could potentially fall into the stream was evaluated using calibrated height-prediction models and a probability prediction function. Tree heights were predicted for unmeasured trees based on Equation 1 (Hanus et al. 1999). The prediction equations were calibrated using Equation 2 (Hanus et al. 1999) based on the measured tree-height data that were collected for each species in each diameter class. The calibrated equations performed well for predicting tree heights ($r^2 = 0.79$, Figure 12). Tree height/diameter relationships will vary by species, site index, and stand characteristics. Therefore, heights were predicted for each species in each stand.

Equation 1: *Predicted Tree Height* $= 4.5+\exp(a_0 + a_1 DBH^{a_2})$

Where:
a_0, a_1, and a_2 are coefficients that vary with tree species (Appendix D).
DBH = diameter at breast height

Equation 2: *Calibrated Predicted Height* $= 4.5+B\,(X_i)$

Where:

$B = Yxs/Xss$

$Yxs = \sum_{i=1}^{n} (Y_i * X_i / Wt_i)$ (summed for each stand)

$Xss = \sum_{i=1}^{n} (X_i^2 / Wt_i)$ (summed for each stand)

Y_i = Measured Height – 4.5 ft.
X_i = Predicted Height – 4.5 ft.
WT_i = Measured /DBH
n = number of trees with measured heights and DBH

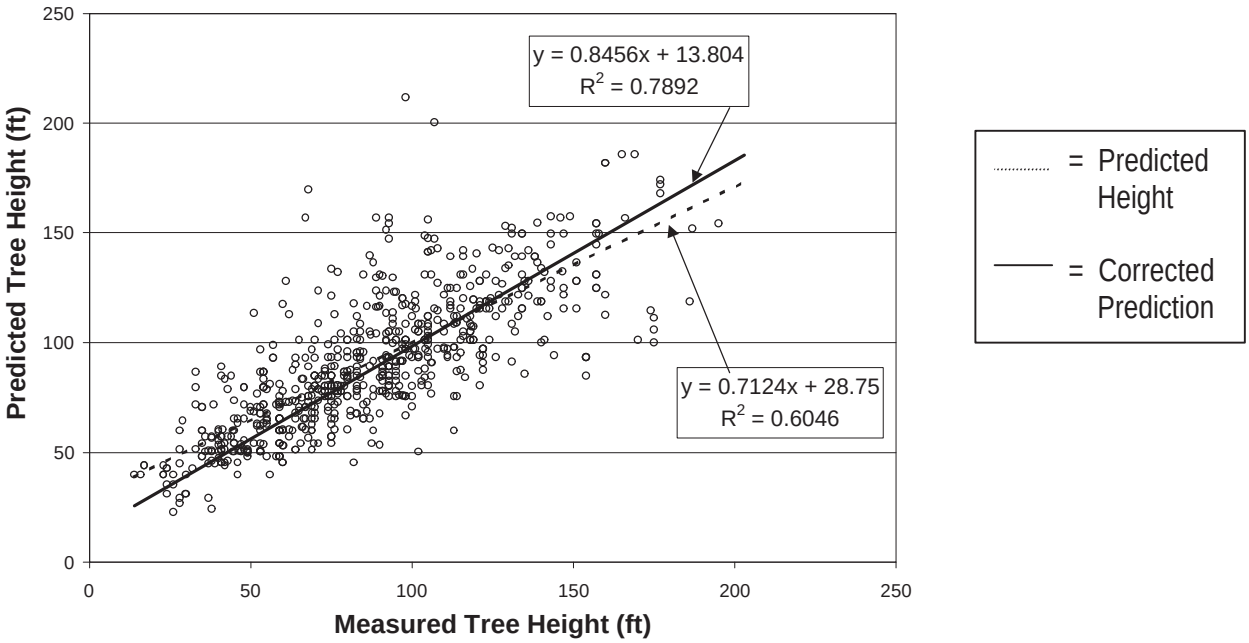

Figure 12. Predicted heights versus measured tree height for measured trees.

Next, the probability of an individual tree falling into the stream was calculated based on Equation 3 (Robison and Beschta, 1990). This analysis was done for all coniferous trees over 20 inches in diameter.

Equation 3: $$P = \frac{\cos^{-1}(D/H_e)}{180°}$$

Where:

P = probability that the tree will fall in the stream
D = distance away from the stream
H_e = effective tree height (predicted with Equation 2)

Equation 3 was developed with the assumptions that trees have an equal chance of falling in any direction, that the average diameter of the stand also represents the median diameter, and without considering breakage. Also, use of Equation 3 only provides an evaluation of potential LWR at the time the trees were measured. This potential will change over time as trees grow, channels migrate and/or when other disturbances such as wind, fire and flood are accounted for. Finally, because there is some evidence that trees are more likely to fall downhill (towards the stream) on steep slopes, it is likely that the probabilities resulting from Equation 3 underestimate LWR on steeply-sloped riparian areas. However, for relative comparisons between pre-harvest and post-harvest conditions, the use of Equation 3 is adequate.

Given the assumption that trees have an equal chance of falling in any direction, trees right on the bank would have, at best, a 50% probability of falling in the stream when other sources of disturbance are not accounted for (wind, debris torrents, fire). Evaluation of riparian stands using Equation 3 indicated that the greatest reductions on potential LWR immediately after harvest were on small and medium streams (Figure 13). This analysis was only conducted with regard to numbers of potential wood recruitment from the RMA and does not address the volume of potential wood recruitment.

In comparison to unharvested RMAs, harvested RMAs are predicted to have reductions in the average potential LWR of 59%, 32%, and 18% respectively for small, medium, and large streams. The greatest reductions on small streams were on trees that had a 21 to 50% chance of falling into the stream. The greatest reductions in LWR for medium streams were on trees that had a 21 to 40% chance of falling in the stream (Figure 13 and Table 5). Statistical significance of these reductions was tested using a paired t-test. The only statistically significant changes were on small streams associated with trees that were predicted to have a 41 to 50% chance of falling in the stream (p-value = 0.04). See Appendix E for detailed statistical results.

*Table 5. Average number of trees/1000 ft. in each probability class before and after harvesting and the *percent change after harvesting.*

Probability of Falling into Stream (%)	Small Streams		Medium Streams		Large Streams	
	# Trees/1000ft		# Trees/1000ft		# Trees/1000ft	
	Pre	Post (percent change)	Pre	Post (percent change)	Pre	Post (percent change)
0-10 (percent change)	2.0	1.0 (-50%)	0.0	1.4 (+)	0.0	1.4 (+)
11-20 (percent change)	2.0	1.0 (-50%)	29	1.4 (-50%)	5.7	2.9 (-50%)
21-30 (percent change)	9.0	4.0 (-56%)	14.3	4.3 (-70%)	10.0	5.7 (-43%)
31-40 (percent change)	21.0	8.0 (-62%)	24.3	15.7 (-35%)	5.7	7.1 (+25%)
*41-50 (percent change)	10.6	4.2 (-60%)	14.6	15.1 (+3%)	10.0	8.6 (-14%)
Total (percent change)	44.6	18.2 (-59%)	56.0	38.0 (-32%)	31.4	25.7 (-18%)

***** The only statistically significant change in LWR was on small streams within the 41 to 50% probability of falling in the stream (p-value = 0.04).

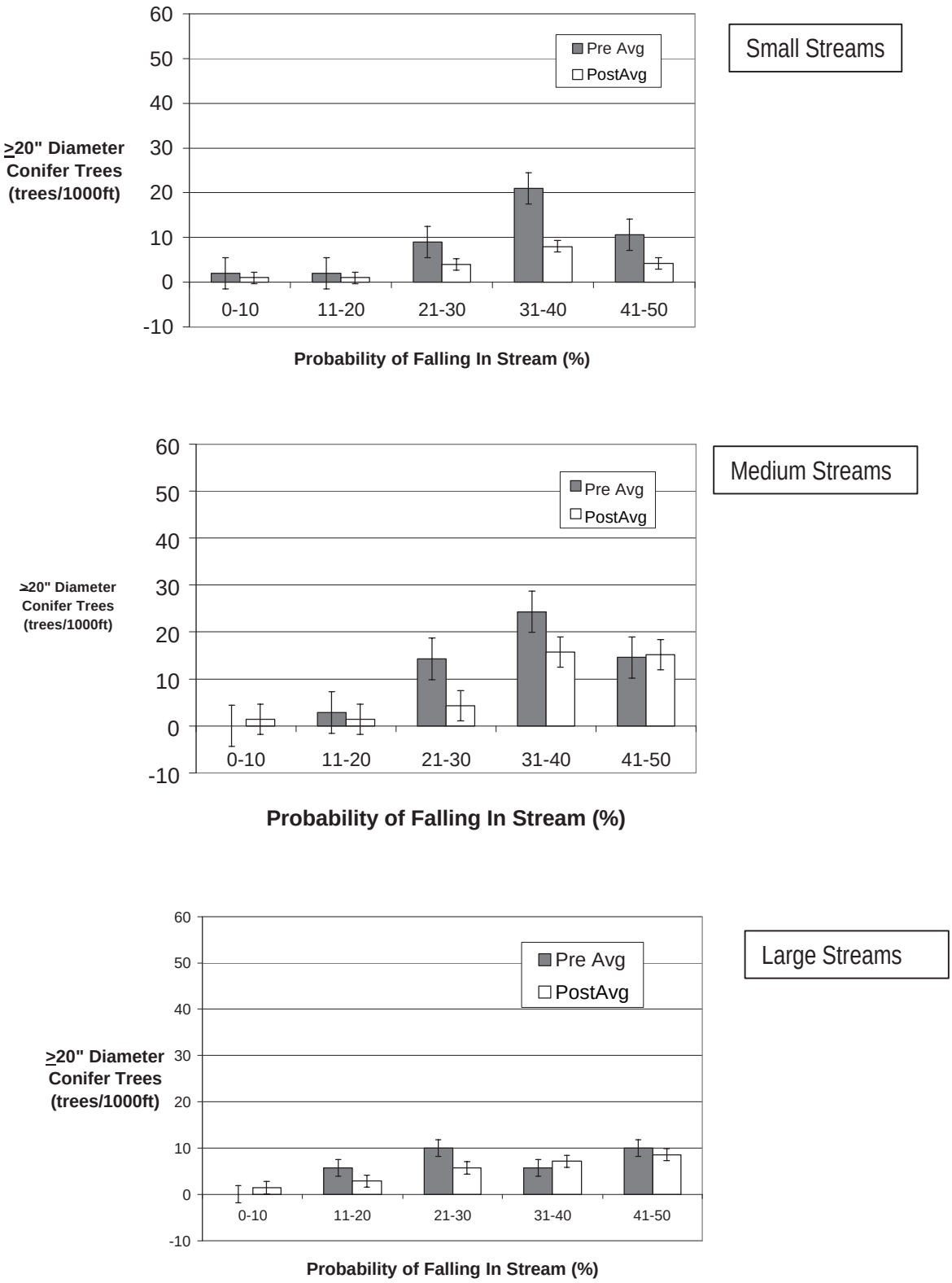

Figure 13. Average predicted large wood recruitment before and after harvesting for small, medium and large streams. Vertical lines represent the standard error.

Significant blowdown was documented on site #17, a small stream in the Coast Range. A survey of instream wood was conducted before and after harvesting. After harvesting, approximately 39% of the instream wood at site #17 was comprised of new blowdown. However, only 13% of the total wood was newly recruited *conifer* wood. Therefore, at site #17, 13% of the predicted reductions in future LWR has already contributed to the stream system. When site #17 is eliminated from the above analysis, the average reduction for small streams changes to 52%. While significant blowdown was not documented at any of the other sites, it is possible that, as in the case of site #17, some percentage of the predicted reduction in LWR has already contributed to the stream channel.

COVER

Although often spoken of interchangeably, shade and cover are not the same parameter. 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. Canopy cover is the percent of the sky covered by vegetation or topography. Shade-producing features will cast a shadow on the water while canopy cover may not. While both shade and cover were measured for this study, this analysis focuses on cover measurements because there was greater repeatability with the cover field methodology (+/- 10%). Therefore, the cover data will be used to answer the question:

5. *Are the 1994 stream protection rules effective in maintaining stream shade as compared with pre-harvest condition?*

Reductions in cover of greater than 10% were common for small streams, were uncommon for medium streams, and were not observed on large streams (Figure 14). The average reduction in cover was 12%, 7%, and 1% for small, medium, and large streams respectively. Statistical significance of these changes was tested with a paired t-test. The only statistically significant change in average cover was associated with small streams (p-value = 0.03). See Appendix F for detailed statistical results.

Although cover reductions were greatest for small streams, the average cover was still relatively high (78%) and is expected to recover over a relatively short period of time (2-3 years). This is because shrub cover, which can recover relatively quickly, has a greater effect on narrow streams. Cover in small streams before harvesting ranged from 83 to 95%, and after harvesting, ranged from 60 to 95% (Table 6).

The two greatest reductions in cover (-36 and 34%) were observed on two out of four of the RCR sites (one medium stream and one small stream). No measurable change in cover occurred on the other two RCR sites (one large and one small stream) (Table 6). The remaining cover reductions greater than 20% were all observed on narrow streams (<5 feet). The observed reductions in cover decreased as stream width increased (Figure 15).

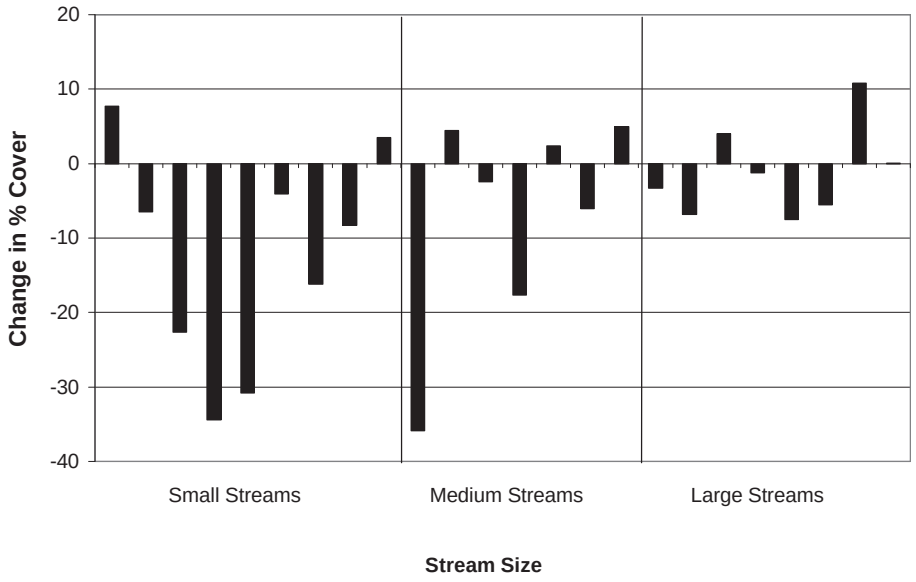

Figure 14. Change in cover after harvesting.

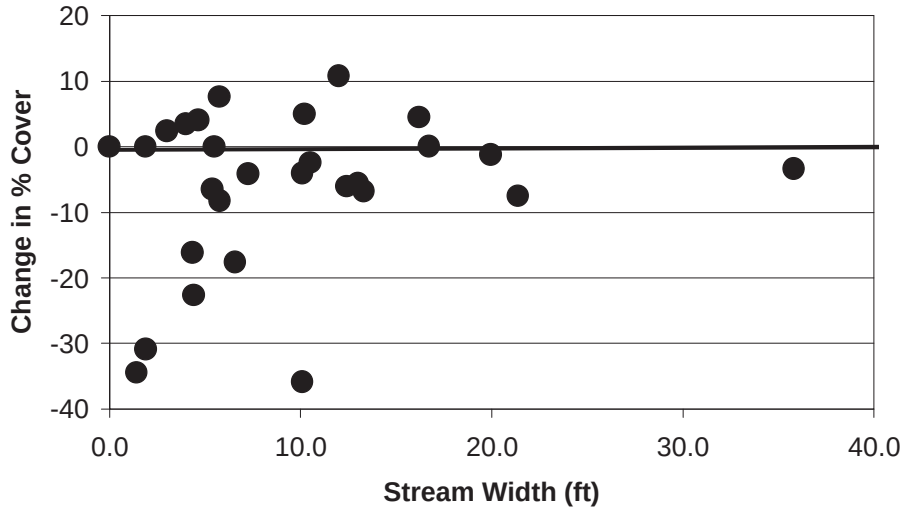

Figure 15. Change in percent cover after harvesting versus stream width.

Table 6. Percent cover before and after harvesting on 24 streams.

Site Number	* Riparian Prescription	Stream Size	Stream Width (ft)	Change in Cover	Pre-Harvest Cover (%)	Post-Harvest Cover (%)
10	Unknown	Small	5.8	8	88	95
12	RCR	Small	5.4	-6	91	84
15	Unknown	Small	4.4	-23	83	60
16	RCR	Small	1.4	-34	97	63
17	Unknown	Small	1.9	-31	95	64
20	BA	Small	7.3	-4	86	82
28	BA	Small	4.4	-16	94	78
29	BA	Small	5.8	-8	94	85
51	Unknown	Small	4.0	4	91	94
11	RCR	Medium	10.1	-36	91	55
13	BA	Medium	16.2	4	90	95
22	BW	Medium	10.5	-2	93	91
24	BA	Medium	6.6	-18	90	73
25	BA	Medium	3.0	2	88	90
26	BA	Medium	12.4	-6	83	77
40	BA	Medium	10.2	5	81	86
14	RCR	Large	35.8	-3	90	86
21	BA	Large	13.3	-7	94	87
23	Unknown	Large	4.7	4	76	80
27	BW	Large	20.0	-1	80	79
30	BW	Large	21.4	-8	76	69
31	BW	Large	13.0	-6	94	88
32	BA	Large	12.0	11	80	91
50	BA	Large	16.7	0	80	80
Average Cover Levels:						
				Small	91	78
				Medium	88	81
				Large	84	82

* Riparian prescriptions are described in detail under the forest practice rules section on pages 6 through 8.

BA = Harvested within RMA using the standard target for basal area prescription.
BW = No harvest within the RMA.
RCR = Riparian conifer restoration.

REGENERATION WITHIN 100 FEET OF THE STREAM

Regeneration is an important component of streamside vegetation because it dictates the long-term structure and function of riparian areas. Regeneration surveys were conducted on 10 sites at which the adjacent harvest unit had been planted prior to the post-harvest survey. Five sites were in the Coast and five sites were in the Interior georegions. Surveys consisted of seedling and sapling counts in 20-foot diameter circular plots. Number of plots per site ranged from 30-48 with a total of 336 plots. The plots were established on three transects, one each at 20, 50, and 80 feet from the stream. Because plot locations span areas that both do and do not require reforestation, the results cannot be used to evaluate compliance with reforestation rules. These data are used to address the question:

6. What are the trends in conifer regeneration within riparian areas?

Both conifer and hardwood regeneration in the Coast and Interior georegions is best described as highly variable, both within sites and between sites (Figure 16). There were 165 plots in the Coast and 171 plots in the Interior georegions. The total number of seedlings observed per site ranged from 5 to 70 in the Coast and 19 to 163 in the Interior. While all sites had some regeneration, two of the five sites in the Coast had less than 10 seedlings and saplings (sites 11 and 12), while two of the five sites in the Interior had less than 20 seedlings and saplings (sites 25 and 28).

The median number of trees/plot was zero for both georegions (Table 7). On two out of five sites in the Coast, the median number of trees/plot was zero. On three out of five sites in the Interior, the median number of trees/plot was also zero. The number of trees/plot varied from 0 to 14 and 0 to 24 in the Coast and Interior georegions respectively. Fifty-one percent and 58% of the plots had no regeneration in the Coast and Interior georegions, respectively (Table 8). Conifer regeneration was present on more plots than hardwood regeneration in both georegions, 45% and 26% of the plots in the Coast and Interior georegion, respectively. Hardwood regeneration was more common in the Interior than in the Coast: 15% and 4% of plots, respectively. Summary statistics for individual sites are reported in Appendix G.

The percents of plots with conifer regeneration observed in this study are comparable to those reported by Beach and Halpern (2001). They evaluated regeneration on *managed* riparian stands in Washington and reported 59-18% of plots with conifer regeneration as compared with 45-26% of plots in this ODF study. Higher conifer frequency in the Washington study was attributed to closer proximity to shade-tolerant seed trees. These ODF data can also be compared to two studies that measured regeneration in the Oregon Coast in *unmanaged* riparian areas: Pabst and Spies 1999, and Nierenberg and Hibbs 2000. Pabst and Spies, and Nierenberg and Hibbs both reported remarkably higher percentages of plots with no regeneration (82-98%) than this ODF study. In addition, the greater presence of conifer regeneration than hardwood regeneration observed in this ODF study was not observed by Pabst and Spies (Table 8). Pabst and Spies concluded that higher conifer regeneration was associated with higher basal area of shade-tolerant conifers and was limited by shrub competition. It is likely that the greater prevalence of conifer regeneration and fewer plots lacking regeneration in the ODF study is attributable to reforestation efforts required after harvesting.

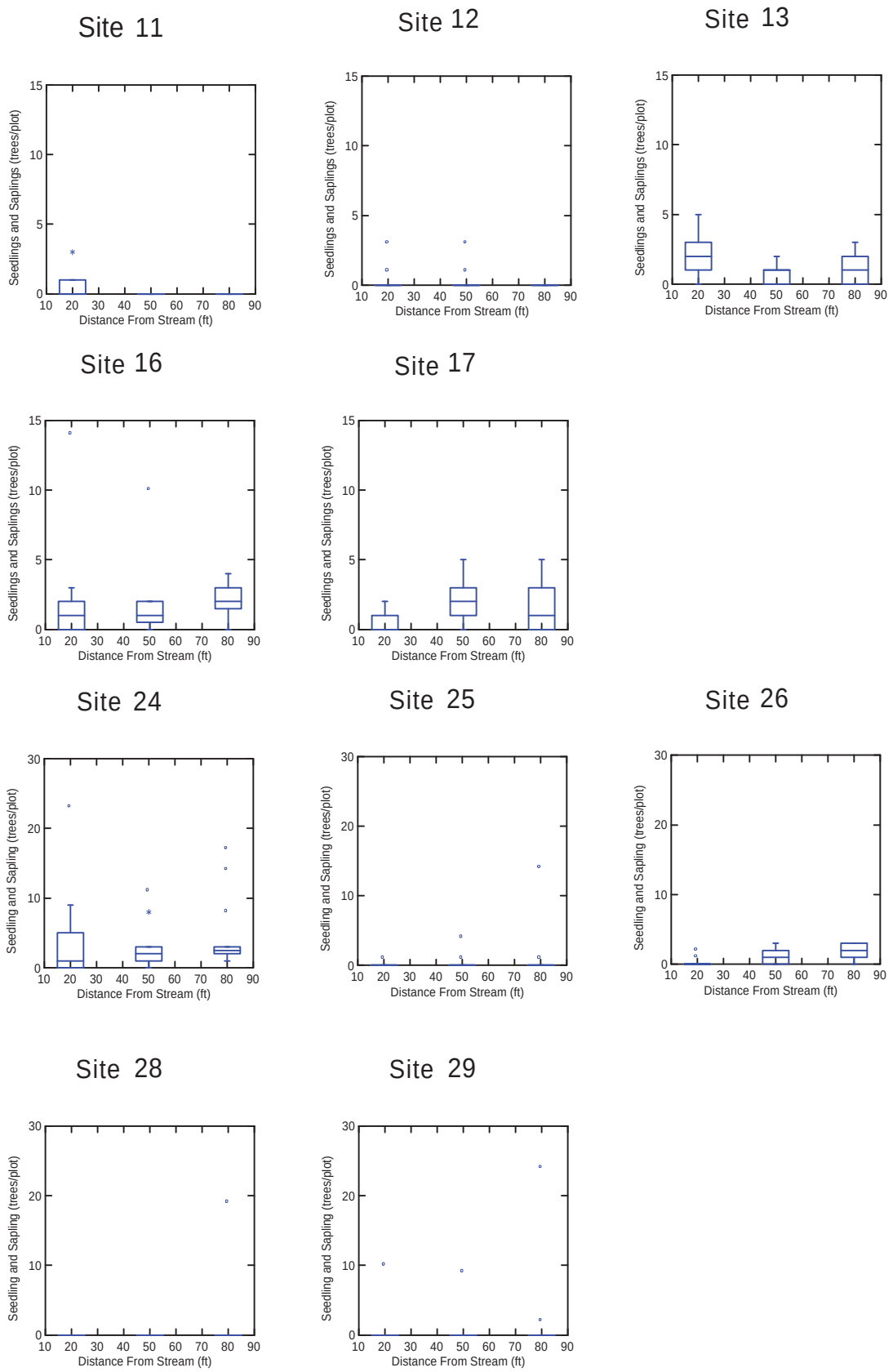

Figure 16. Regeneration density (number of trees/plot) versus distance from stream for the Coast (Sites 11-17) and Interior georegions (Sites 24-29).

Table 7. Regeneration summary statistics by georegion.

Coast Georegion	Seedlings and Saplings(trees/plot)	Seedlings and Saplings (trees/acre)
N of cases	165	165
Minimum	0.0	0.0
Maximum	14.0	1941.0
Median	0.0	0.0
Mean	1.1	153.8
Standard Deviation	1.7	242.1
Interior Georegion	**Seedlings and Saplings(trees/plot)**	**Seedlings and Saplings (trees/acre)**
N of cases	171	171
Minimum	0.0	0.0
Maximum	24.0	3328.0
Median	0.0	0.0
Mean	1.7	229.5
Standard Deviation	3.8	531.1

Table 8. Percent of plots with conifers or hardwoods present, or an absence of regeneration.

Study	Sub-Groups	Coast Range Georegion (Number of Plots)			Interior Georegion (Number of Plots)		
		Conifers Present	Hardwoods Present	No Regeneration	Conifers Present	Hardwoods Present	No Regeneration
ODF (this study)	20ft. from stream	25	2	29	7	7	41
	50ft. from stream	24	5	25	19	10	32
	80ft. from stream	25	0	30	19	9	27
	Total	74 (45%)	7 (4%)	84 (51%)	45 (26%)	26 (15%)	100 (58%)
Pabst and Spies (1999)	North Coast	9 (6%)	13 (13%)	122 (85%)	--	--	--
	Central Coast	10 (1%)	5 (1%)	939 (98%)	--	--	--
	South Coast	24 (8%)	29 (10%)	247 (82%)	--	--	--
*Beach and Halpern (2001)	With seed tree	(59%)	--	--	--	--	--
	Without seed tree	(18%)	--	--	--	--	--
Nierenburg and Hibbs (1999)			21 (18%)	97 (82%)	--	--	--

* = Beach and Halpern study sites were in the coastal and Cascade Mountains of Washington. Results were not reported by georegion.

Due to the patchy nature of regeneration in the near-stream area, representation of the data in terms of trees/acre has the potential to inflate perception regarding overall regeneration density. However, used cautiously, the metric does provide a standard statistic with which to compare riparian regeneration trends observed in this study with other studies.

The average conifer regeneration densities were 277 and 324 trees/acre in the Coast and Interior georegions respectively (Table 9). The average hardwood regeneration densities were 693 and 949 trees/acre in the Coast and Interior georegions respectively. Minore and Weatherly (1994) measured regeneration in managed riparian areas in the Coast. They reported lower average stocking densities (101 conifer seedlings/acre, and 303-506 hardwood seedlings/acre) than this ODF study. Beach and Halpern studied regeneration in managed riparian stands in the coastal and Cascade Mountains of Washington. They reported higher conifer densities, 648-931 trees/acre, than observed in this study and concluded that the higher densities were associated with proximity to shade-tolerant seed trees. The regeneration densities observed in *managed* riparian forests dwarfed those observed by Hibbs and Giordano (1996) in a study conducted on *unmanaged* riparian areas in the Coast Range. Hibbs and Giordano reported a total of 6.5 trees per acre out of the 4.25 acres surveyed. Conifer seedling density was 4 trees/acre and hardwood density was 2 trees/acre. Plots of regeneration densities for each ODF site are provided in Appendix G.

Table 9. Regeneration stocking for conifers and hardwoods.

Study	Sub-groups	Coast Georegion Regeneration (trees/acre)		Interior Georegion Regeneration (trees/acre)	
		Conifer	Hardwood	Conifer	Hardwood
ODF (this study)	20ft. from stream	272	1,179	713	574
	50ft. from stream	254	499	219	652
	80ft. from stream	305		285	1,571
	Average	277	693	324	949
Minore and Weatherly (1994)	16ft. from stream	101	303	--	--
	33ft. from stream	101	303	--	--
	49ft. from stream	101	506	--	--
*Beach and Halpern (2001)	With shade-tolerant seed source	931			
	Without shade-tolerant seed source	647			
Hibbs and Giordano (1996)	Not reported	4	2	--	--

* = Beach and Halpern study sites were in the coastal and Cascade Mountains of Washington. Results were not reported by georegion.

Regeneration trends varied greatly between species (Figures 17 and 18). Species diversity was greatest on site 17 in the Coast (1 hardwood and 4 conifer species observed) and site 24 in the Interior range (2 hardwood and 4 conifer species observed). Western hemlock and Sitka spruce were observed on more sites than any other species in the Coast georegion. Red alder and bigleaf maple were observed on more sites than any other species in the Interior georegion.

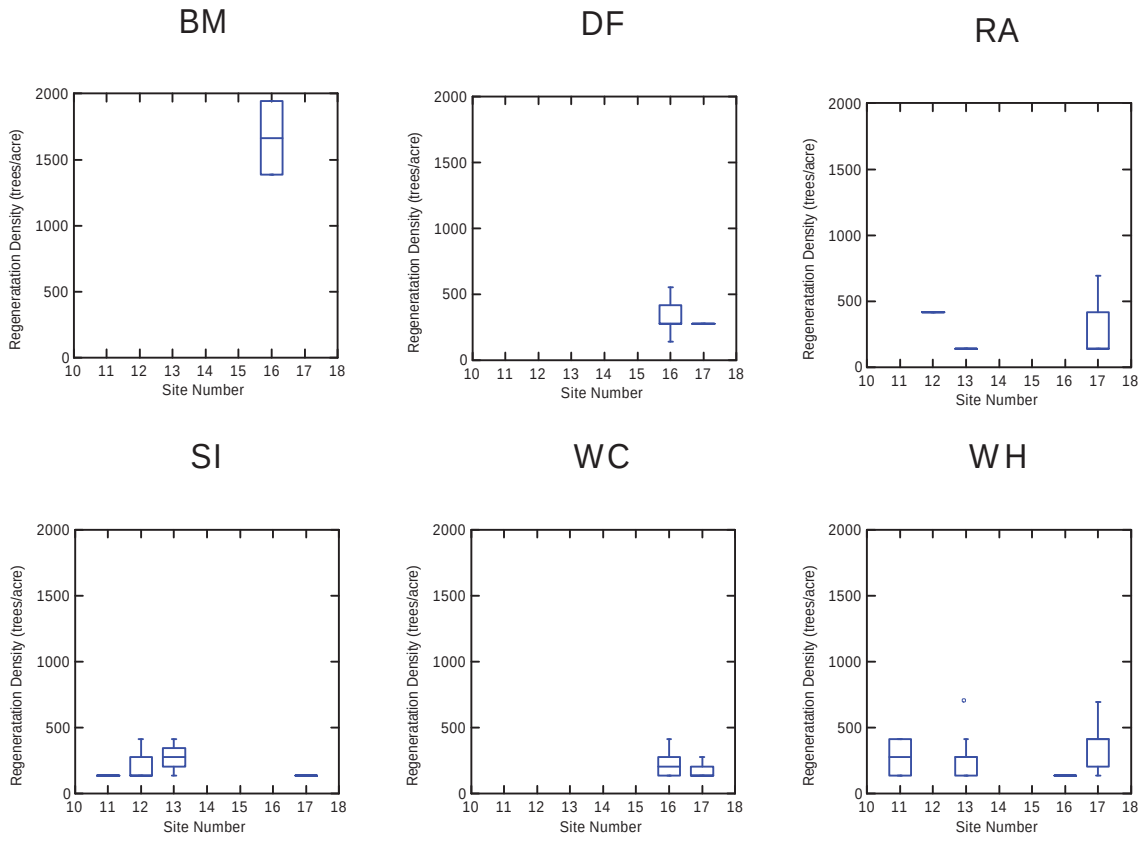

Figure 17. Coast Georegion: Seedling and sapling density (trees/acre) for each site by species. BM = bigleaf maple, DF = Douglas-fir, RA = red alder, SI = Sitka spruce, WC = western redcedar, WH = western hemlock.

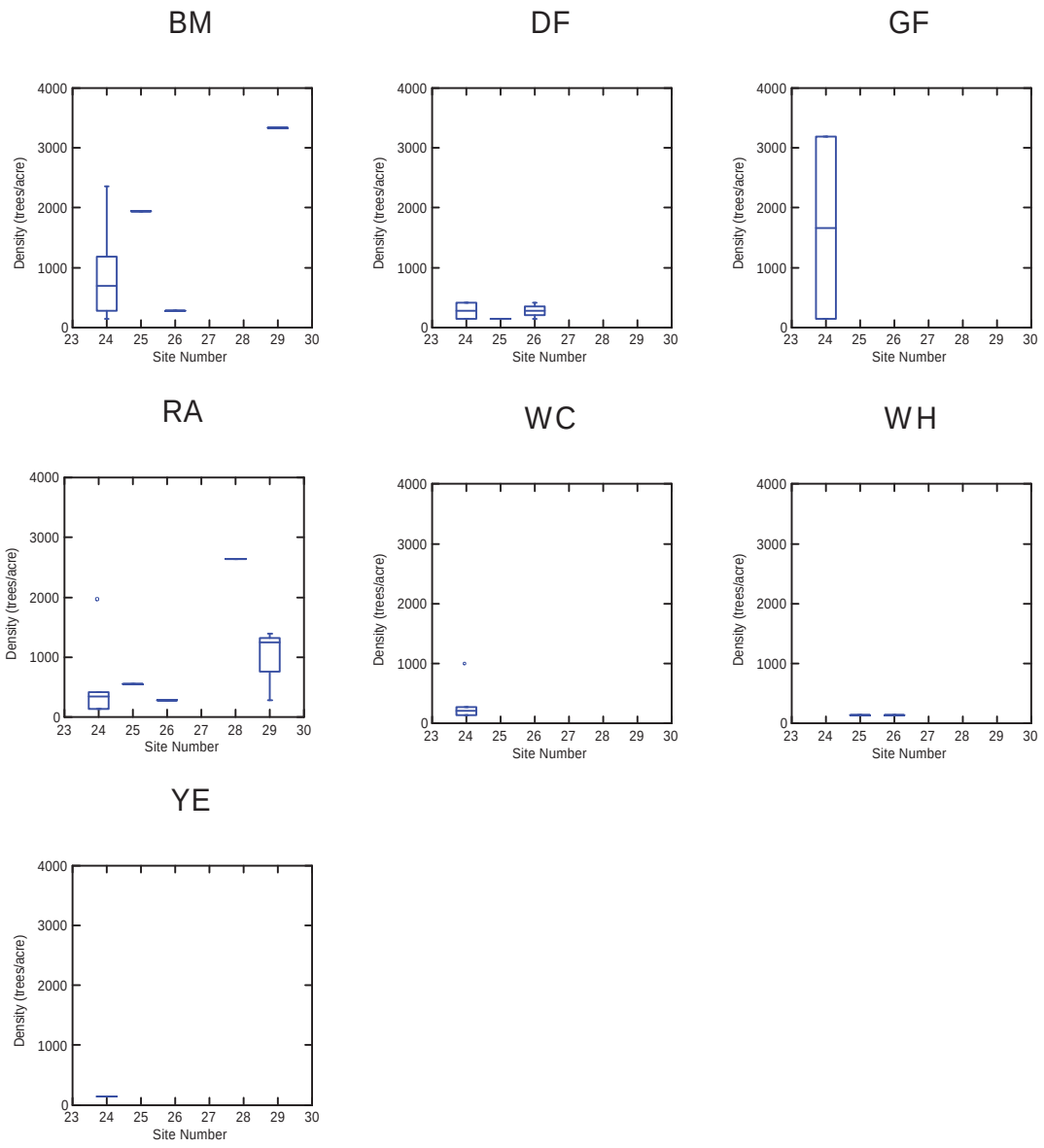

Figure 18. Interior Georegion: Seedling and sapling density (trees/acre) for each site by species. BM = bigleaf maple, DF = Douglas-fir, RA = red alder, SI = Sitka spruce, WC = western redcedar, WH = western hemlock, YE = Pacific yew.

Because of the variability in species composition between sites, one must be cautious about interpretation of data that combines sites. Therefore, only very general trends will be discussed.

The mix of species changed with distance from stream. In general, Douglas-fir seedlings and saplings increased with distance from stream in both georegions. In the Coast georegion, hardwood (bigleaf maple and alder) and western redcedar seedlings and saplings decreased with distance from stream, while in the Interior, hardwood regeneration was common throughout the near-stream area (Figures 19 and 20).

In the Coast georegion, conifers dominated regeneration at 20ft., 50ft., and 80ft. from the stream (69%, 66%, and 100% respectively). In the Interior, regeneration in all three zones (20ft., 50ft. and 80ft. from the stream) was predominantly hardwood (54%, 68%, and 72%, respectively).

In the Coast georegion, western redcedar and western hemlock were the dominant conifer species within 20 feet (34 and 42% of all regeneration, respectively) and Douglas-fir was the dominant conifer species at 80 feet from the stream (49% of all regeneration). In the Interior, grand fir accounted for 44% of the conifer regeneration within 20 feet of the stream. However, grand fir was only observed at one site. Were it not for the grand fir site, the 20ft. zone would be nearly absent of conifers (2% western redcedar). In the Interior, Douglas-fir was the dominant conifer species at 50 feet and 80 feet from the stream (29 and 27%, respectively).

Regeneration in both the Coast and Interior georegions was highly variable. However, when compared with data from unmanaged riparian forests, these data indicate relatively good conifer stocking in the Coast georegion. The most commonly observed conifer seedling and sapling species in the Coast georegion were western hemlock and Sitka spruce. Hardwood seedlings and saplings dominated regeneration in the Interior georegion. In the Interior georegion, Douglas-fir accounted for the most commonly observed conifer species, with the exception of one site with substantial grand fir regeneration. The higher incidence of conifer regeneration on these sites as compared with studies on unmanaged stands is most likely a result of reforestation efforts.

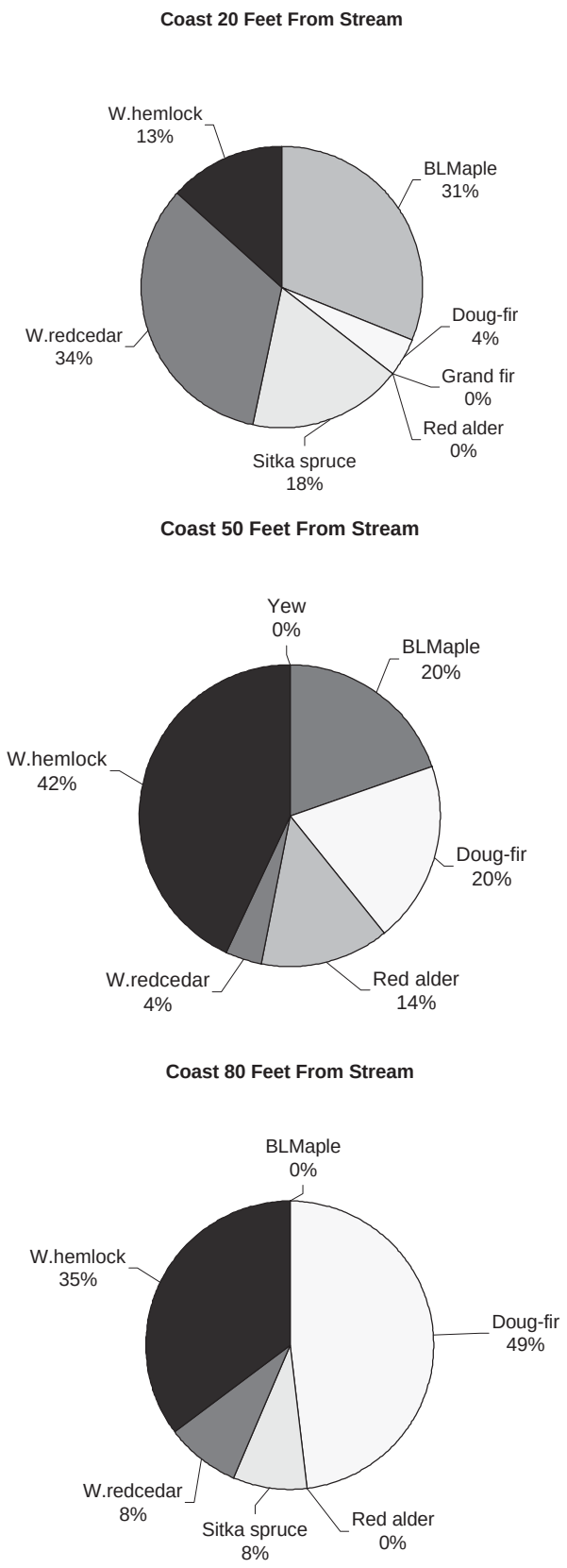

Figure 19. Relative seedling species abundance at 20 feet, 50 feet, and 80 feet from the stream for Coast streams (N = 5).

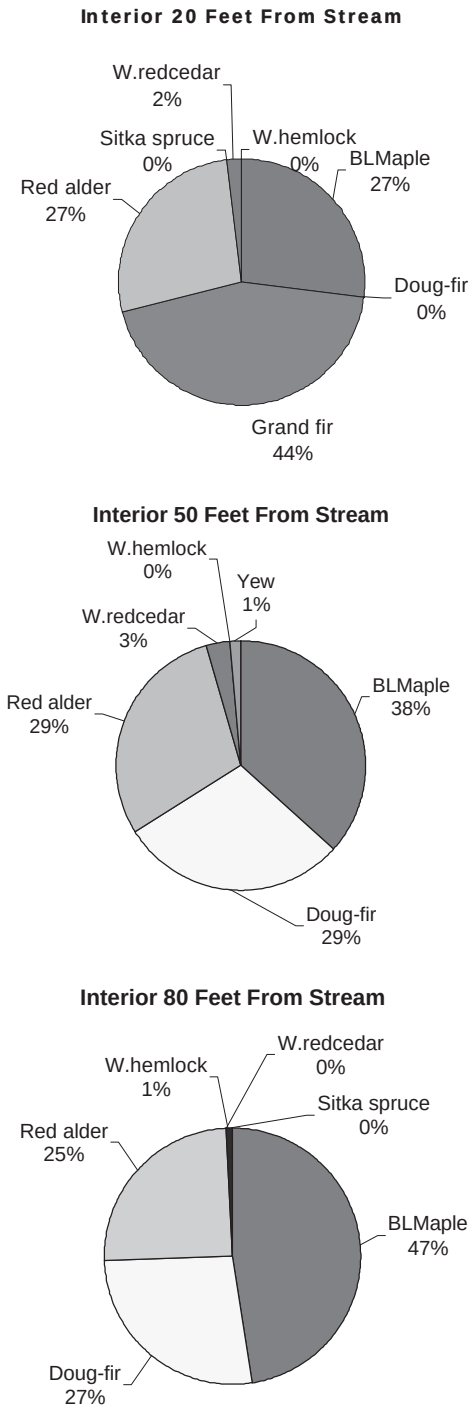

Figure 20. Relative seedling species abundance at 20 feet, 50 feet, and 80 feet from the stream for Interior streams (N = 5).

SUMMARY AND CONCLUSIONS

1. *Do estimates of average basal area that were used to craft the standard targets for basal area accurately represent mature riparian forests?*

The desired future condition for streamside areas along fish-bearing streams is to grow and retain vegetation so that, over time, average conditions across the landscape become similar to those of mature streamside stands. A comparison of mature forest conditions to the assumed basal area for 120-year-old managed stands indicates that the standard targets often underestimate average conifer stocking for West Cascade and Interior streams, and approximate average conifer stocking for Coastal, Northeast Oregon and Central Oregon areas.

2. *Do hardwoods dominate the near-stream area on all stream sizes?*

When crafting the basal area standard targets, an assumption was made that small and medium streams would have lower coniferous stocking in the first 20 feet from the stream due to presence of hardwoods. Hardwood domination was a good assumption for large and small coastal streams. In the cases of other georegions and for medium coastal streams, reducing the standard target to account for hardwood domination was not supported by these data. In addition, while hardwoods dominated the first 20 feet, conifer stocking was still greater than expected on small streams.

3. *How does the available basal area in riparian management areas compare to standard targets?*

Results indicate substantial variability in conifer stocking within and between georegions and stream sizes. However, the current basal area targets consistently underestimate the available basal area on small and medium streams. While targets are commonly met within 20 feet of the stream on small and medium streams, these data indicate that, in most instances, landowners are not exercising the option to clearcut harvest to within 20 feet of the stream.

These data indicate that portions of RMAs managed with an RCR prescription were actually well stocked with conifers. The RCR prescription should be evaluated on a larger scale and in greater detail to determine if the application adequately maintains existing patches of potential LWR.

4. *Are the 1994 forest practices riparian rules effective in maintaining potential sources of large wood recruitment for in-stream habitat as compared with pre-harvest condition?*

Reductions in potential large wood recruitment (LWR) were minimal on large streams under the current rules. However, statistically significant reductions in large wood recruitment were observed on small streams. Observed reductions in potential LWR on medium streams, while substantial in some cases, were not statistically significant on average. Furthermore, while the sample size is small, results also indicate a notable decrease in LWR potential with the application of the RCR rule.

The intention of the RCR rule is to provide for long term sources of large wood, even though there may be a short-term impact on stream temperature. The possibility that the application of RCRs may be contributing to a reduction in potential LWR is an unintended consequence of that alternative. This potential consequence needs to be evaluated in greater detail on both a larger scale and on a site-by-site basis as the rule is applied. If the findings from this study do accurately represent the larger population, it is clear that the success of the prescription heavily relies on achieving regeneration and retention goals in *both* "conversion" and "retention" blocks. If achieved, then the long-term LWR of such sites would be improved through this management strategy.

4. *Are the 1994 stream protection rules effective in maintaining stream shade?*

The current rules are effective at protecting cover on large streams. Although the actual cover levels were relatively high, shade retention results were mixed for medium and small streams, with the greatest impacts observed on RCR sites. The most consistent reductions in cover were observed along small streams.

5. *What are the trends in conifer regeneration within riparian areas?*

Regeneration in both the Coast and Interior georegions was highly variable. However, when compared with data from unmanaged riparian forests, these data indicate relatively high conifer stocking in the Coast georegion. The most commonly observed conifer seedling and sapling species in the Coast georegion were western hemlock and Sitka spruce. Hardwood seedlings and saplings dominated regeneration in the Interior georegion. In the Interior georegion, Douglas-fir accounted for the most commonly observed conifer species, with the exception of one site that had substantial grand fir regeneration. The higher incidence of conifer regeneration on these sites as compared with studies on unmanaged stands is most likely a result of reforestation efforts that follow harvesting. Further monitoring is needed to evaluate this trend with a statistically reliable study.

RECOMMENDATIONS

OVERALL FINDINGS

The great amount of variability observed in existing basal areas indicates that a single basal area target is problematic. In general, the rules are adequate at maintaining structure that is predicted to protect large wood recruitment and shade on large streams. The degree to which and the frequency with which pre-harvest basal area exceeded the standard target on small and medium streams indicates the existing targets are likely to be too low to achieve the desired future condition as described in OAR 629-640-110. This conclusion is supported by the findings of substantial reductions in LWR and cover on small streams and for riparian areas managed with an RCR prescription. Moderate reductions were also observed on medium streams. This conclusion is further supported by the finding that the standard targets underestimated average basal area for mature riparian forests in Interior and West Cascade streams.

The following recommendations are made:

The Board of Forestry should re-evaluate the standard targets for basal area to better address the range of conditions and better reflect the capabilities of riparian areas on medium and small streams, particularly in the Interior and West Cascade georegions.

The Board of Forestry should consider changes to vegetation retention rules to increase the maintenance and promotion of shade and potential LWR on small and medium streams.

The Board of Forestry should investigate the advantages and disadvantages of the RCR prescription with greater detail and on a larger scale. In the interim, riparian areas that are going to be managed under this prescription should undergo a detailed assessment to ensure that existing sources of future large wood are adequately maintained and that regeneration stocking standards are achieved.

The Board of Forestry should evaluate on a larger scale the trends in both conifer and hardwood regeneration within riparian areas. The goal should be to determine if the results from this study are reliable and if there are management strategies that will continue to improve regeneration within 100 feet of the stream.

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APPENDIX A

CHARACTERISTICS OF UNMANAGED RIPARIAN STANDS IN OREGON THAT ORIGINATED AFTER WILDFIRE

Figure A-1: Characteristics of unmanaged riparian stands in Oregon that originated following wildfire.

Coast Range & Northeast Oregon

Study and Site Region	Site Number	Stream Size	Overstory Tree Age *	Basal Area Ft2/acre	
				Conifer	Hardwood
ODF Shade Study Coast Range DBH > 8"	53L	S	100	77	38
	53R	S	100	118	49
	58L	M	100	289	0
	58R	M	100	426	1
	61L	M	100	190	67
	61R	M	100	31	101
	64L	M	100	107	12
	64R	M	100	194	25
	55L	L	100	48	64
	55R	L	100	49	69
	65L	L	80	155	90
	65R	L	80	181	61
	Average		**97**	**155**	**48**
ODF Shade Study Blue Mountains DBH > 8"	67L	M	160	78	2
	67R	M	160	52	8
	72L	M	25	49	2
	72R	M	25	108	6
	80L	M	37	29	0
	80R	M	37	63	1
	35L	M	?	108	4
	35R	M	?	120	4
	76L	L	49	55	5
	76R	L	49	51	20
	77L	L	82	55	6
	77R	L	82	95	10
	Average		**76**	**72**	**6**

* Although some tree ages are quite young, the stands had not been managed. Trees in the riparian area are younger than the surrounding upland stand due to fluvial disturbances.

Coast Range

Study and Region	Site Number	Stream Size	Stand Age **	Basal Area (ft2/acre)	
				Conifer	Hardwood
Pabst & Spies (1999) * North Coast	Average	1st Order (S/M)	130 - 150	119	44
	Average	2nd Order (M/L)	130 - 150	40	75
	Average	3rd Order (L)	130 - 150	49	74
	Average			*69*	*64*
Central Coast	Average	1st Order (S/M)	130 - 150	130	27
	Average	2nd Order (M/L)	130 - 150	68	48
	Average	3rd Order (L)	130 - 150	66	53
	Average			*88*	*43*
South Coast	Average	1st Order (S/M)	130 - 150	108	19
	Average	2nd Order (M/L)	130 - 150	95	41
	Average	3rd Order (L)	130 - 150	48	59
	Average			*84*	*40*
Coast Range		Mix	> 150	139	19
All Coast Range	**Average**	**1st Order (S/M)**	**130 - 150**	**119**	**30**
	Average	**2nd Order (M/L)**	**130 - 150**	**67**	**55**
	Average	**3rd Order (L)**	**130 - 150**	**54**	**62**

*No data on stand density.

** Stand age based on the upland stand. Trees within the riparian area may be younger.

Coast Range, Western Cascades, & the Interior

Study and Site Region	Site	Location	Stream Size	Overstory Tree Age	Stand Density (trees/acre)		Basal Area (ft^2/acre)	
					Conifer	Hardwood	Conifer	Hardwood
ODFW Stream Surveys: Coast Range "reference sites" DBH > 6"	Drift	Coast	M/L	O.G.	151	139	126	77
	Franklin	Coast	M/L	O.G.	11	100	62	127
	Cummins	Coast	M/L	O.G.	113	47	174	29
	Average				**92**	**95**	**121**	**78**
ODFW Stream Surveys: West Cascades and Interior "reference sites" DBH > 6"	Elkhorn	Santiam	M/L	O.G.	181	57	281	37
	Opal	Santiam	M/L	O.G.	264	8	233	3
	L NF Santiam	Santiam	M/L	O.G.	178	8	264	3
	Limpy	Umpqua	M/L	O.G.	159	21	659	9
	Williams	Umpqua	M/L	O.G.	202	168	388	125
	Lost	Umpqua	M/L	O.G.	105	40	202	38
	Coffee	Umpqua	M/L	O.G.	69	17	217	13
	Shafer	McKenzie	M/L	O.G.	121	13	267	25
	Mack	McKenzie	M/L	O.G.	98	8	204	7
	Racks T1	Cascades	M/L	O.G.	87	4	174	2
	Anderson	Cascades	M/L	O.G.	260	11	433	5
	Average				**157**	**32**	**302**	**24**

Central Oregon

Study and Region	Site Number*	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer	Hardwood	Conifer	Hardwood
Knight (1990) Mature stands in central Oregon DBH >= 6"	1	80-150	116	0	155	0
	2	80-150	81	0	95	0
	3	80-150	50	0	94	0
	4	80-150	67	0	135	0
	5	80-150	94	0	69	0
	6	80-150	68	0	80	0
	7	80-150	100	0	157	0
	8	80-150	222	0	108	0
	9	80-150	68	0	93	0
	10	80-150	115	0	178	0
	11	80-150	72	0	85	0
	12	80-150	68	0	91	0
	Average	**80-150**	**93**	**0**	**112**	**0**

*Mixture of large and medium streams.

Northeast Oregon

Study and Region	Site Number*	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer	Hardwood	Conifer	Hardwood
Carlson et al. (1990)	1	80-150	72	0	105	0
	2	80-150	59	0	74	0
Mature stands in northeast Oregon	3	80-150	97	0	135	0
	4	80-150	86	0	131	0
DBH >=6"	5	80-150	91	0	122	0
	6	80-150	99	0	109	0
	7	80-150	85	0	118	0
	8	80-150	116	0	157	0
	9	80-150	249	0	192	0
	10	80-150	122	0	135	0
	11	80-150	26	0	74	0
	12	80-150	121	0	240	0
	13	80-150	82	0	161	0
	14	80-150	93	0	153	0
	15	80-150	81	0	105	0
	16	80-150	133	0	135	0
	Average	**80-150**	**101**	**0**	**134**	**0**

*Mixture of large and medium streams.

Coast Range

Study and Region	Site Number	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer	Hardwood	Conifer	Hardwood
Andrus and Froehlich (1987) Mature stands in the northern and central Coast Range, OR DBH >= 8"	15	140	40	23	209	27
	17	130	21	14	65	26
	19	110	27	14	109	23
	20	100	41	7	126	10
	21	130	27	0	95	0
	22	130	41	24	84	43
	23	115	30	25	78	39
	24	135	6	28	52	44
	25	135	40	7	187	13
	26	130	35	3	99	5
	29	110	29	7	93	12
	30	100	43	4	166	7
	Average	**120**	**32**	**13**	**114**	**20**
Heimann 1988 Mature stands in the central Coast Range, OR DBH >=6"	1	94	55	12	139	16
	2	110	48	6	214	4
	3	135	38	6	155	15
	4	135	28	41	162	20
	5	120	16	8	127	21
	Average	**125**	**37**	**15**	**159**	**16**

Mixture of large and medium streams.

Coast Range

Study and Region	Site Number	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer	Hardwood	Conifer	Hardwood
Ursitti (1990)	1	> 250	16	57	170	61
Old-growth and mature stands in the south-central Coast Range, OR	2	> 250	46	44	200	48
	3	> 250	60	52	248	57
	4	> 250	12	19	109	61
	5	> 250	54	1	392	4
DBH >= 4"	6	> 250	62	2	409	4
	Old-growth avg.	**> 250**	**42**	**29**	**255**	**39**
	7	80-150	11	93	65	87
	8	80-150	10	50	48	83
	9	80-150	9	50	48	83
	10	80-150	34	51	113	83
	11	80-150	76	0	213	9
	12	80-150	36	34	309	22
	13	80-150	28	70	87	100
	14	80-150	40	44	144	48
	15	80-150	16	49	61	57
	Mature avg.	**80-150**	**29**	**49**	**122**	**61**

Mixture of large and medium streams.

Western Cascades

Study and Region	Site Number	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer	Hardwood	Conifer*	Hardwood
Steinblums (1977) Old-growth stands in the Mt. Hood National Forest, OR DBH >?"	1	O.G.	58		518	
	2	O.G.	87		308	
	3	O.G.	69		559	
	4	O.G.	36		148	
	5	O.G.	112		809	
	6	O.G.	81		308	
	Average	**O.G.**	**74**		**442**	

* A small but unknown portion may be hardwoods.
Mixture of large and medium streams.

Western Cascades

Study and Region	Site Number	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer*	Hardwood	Conifer*	Hardwood
Steinblums (1977) Old-growth stands in the Willamette National Forest , OR DBH >?"	1	O.G.	98		409	
	2	O.G.	77		482	
	3	O.G.	44		187	
	4	O.G.	41		311	
	5	O.G.	67		262	
	6	O.G.	79		386	
	7	O.G.	56		326	
	8	O.G.	56		452	
	9	O.G.	59		362	
	10	O.G.	39		368	
	11	O.G.	39		378	
	12	O.G.	100		526	
	13	O.G.	71		605	
	14	O.G.	50		269	
	15	O.G.	23		215	
	16	O.G.	25		272	
	17	O.G.	28		246	
	18	O.G.	66		144	
	19	O.G.	57		177	
	20	O.G.	56		429	
	Average	**O.G.**	**57**		**340**	

* A small but unknown portion may be hardwoods.
Mixture of large and medium streams.

Interior

Study and Region	Site Number	Stand Age (years)	Stand Density (# trees/acre)		Basal Area (sq.ft./acre)	
			Conifer*	Hardwood	Conifer*	Hardwood
Steinblums (1977) Old-growth stands in the northern part of the Umpqua National Forest , OR DBH >?"	1	O.G.	40		205	
	2	O.G.	21		81	
	3	O.G.	39		117	
	4	O.G.	58		143	
	5	O.G.	51		151	
	6	O.G.	30		110	
	7	O.G.	23		58	
	8	O.G.	49		304	
	9	O.G.	43		118	
	10	O.G.	38		100	
	11	O.G.	23		220	
	12	O.G.	27		37	
	13	O.G.	66		50	
	Average	**O.G.**	**39**		**130**	

* A small but unknown portion may be hardwoods.
Mixture of large and medium streams.

APPENDIX B:

PRE-HARVEST BASAL AREA FOR ALL SITES

Table B-1. Pre-harvest basal area within 20 feet of the stream and within the entire RMA, post-harvest measured buffer width, and RMA width for each site.

Stream Size	Site Code	Within 20 Feet		Within Entire RMA				
		Conifer Basal Area (ft2/1000 ft)	Hardwood Basal Area (ft2/1000 ft)	Conifer Basal Area (ft2/1000 ft)	Hardwood Basal Area (ft2/1000 ft)	Standard Target (ft2/1000 ft)	Post-Harvest Buffer Width (ft)	RMA Width (ft)
L*	14	1	100	48	502	230	105	100
L*	19	0	59	65	198	230	ND	100
L	19.2	23	ND	97	ND	230	NA	100
L	19.3	114	ND	539	ND	230	NA	100
L	21	3	97	94	144	270	137	100
L	23	101	27	384	47	270	20	100
L	27	54	32	420	170	270	103	100
L	30	0	34	0	360	270	102	100
L	31	0	26	308	185	270	113	100
L	32	105	40	927	50	270	102	100
L	50	56	7	248	13	220	100	100
M	11	48	48	392	70	120	100	70
M	13	170	115	209	299	120	80	70
M	22	94	18	250	49	140	53	70
M	24	78	89	174	104	140	33	70
M	25	16	68	149	122	140	70	70
M	26	19	38	210	44	140	50	70
M	29.2	8	50	111	125	140	ND	70
M	33	17	37	42	44	140	ND	70
M	40	197	0	352	0	90	123	70
M	60	17	0	154	0	120	NA	70
M*	63	24	ND	150	ND	120	NA	70
S	10	0	37	4	57	40	133	50
S	12	41	168	160	168	40	47	50
S	15	39	60	180	145	40	103	50
S	16	15	51	49	67	40	30	50
S	17	29	57	114	90	40	32	50
S	18	7	33	123	55	40	70	50
S	19.1	0	52	0	55	40	93	50
S*	19.4	16	ND	75	ND	40	NA	50
S	20	30	88	30	184	40	93	50
S	28	73	56	166	70	40	13	50
S	29	12	110	116	164	40	35	50
S	29.1	71	3	131	27	40	40	50
S	41	40	15	97	22	40	ND	50
S	51	20	45	127	70	40	83	50
S	61	21	4	24	4	50	121	50
S	62	10	0	57	0	50	ND	50
S*	64	20	ND	46	ND	50	NA	50
S*	65	41	ND	81	ND	50	NA	50

*Data from 6 sites came from a separate ODF 1999 Shade Study (63,64,65,19.2,19.3,&19.4) and only contain pre-harvest measures.

ND = No Data. Hardwood data are available for these sites, although they were not included in this report. Buffer width data are not available for sites that were not harvested

APPENDIX C

STATISTICAL COMPARISONS OF PRE- AND POST-HARVEST AVERAGE DIAMETERS

Statistical Results of Diameter Distribution Analysis

Table C-1. Small Streams: No significant change in diameter distribution.

Two-sample t-test on DIAM grouped by HARVEST$

Group	N	Mean	SD
POST	68	16.441	8.034
PRE	112	16.857	8.133

Separate Variance t = -0.335 df = 142.9 Prob = 0.738
Difference in Means = -0.416 95.00% CI = -2.869 to 2.037

Pooled Variance t = -0.334 df = 178 Prob = 0.739
Difference in Means = -0.416 95.00% CI = -2.872 to 2.040

Table C-2. Medium Streams: No significant change in diameter distribution.

Two-sample t-test on DIAM grouped by HARVEST$

Group	N	Mean	SD
POST	216	14.889	7.861
PRE	247	15.429	8.708

Separate Variance t = -0.701 df = 460.5 Prob = 0.483
Difference in Means = -0.540 95.00% CI = -2.054 to 0.973

Pooled Variance t = -0.697 df = 461 Prob = 0.486
Difference in Means = -0.540 95.00% CI = -2.064 to 0.984

Table C-3. Large Streams: No significant change in diameter distribution.

Two-sample t-test on DIAM grouped by HARVEST$

Group	N	Mean	SD
POST	164	14.585	7.771
PRE	175	16.029	11.515

Separate Variance t = -1.360 df = 306.9 Prob = 0.175
Difference in Means = -1.443 95.00% CI = -3.531 to 0.645

Pooled Variance t = -1.344 df = 337 Prob = 0.180
Difference in Means = -1.443 95.00% CI = -3.556 to 0.670

APPENDIX D:

COEFFICIENTS FOR TREE HEIGHT PREDICTION EQUATIONS

*Table D-1. Coefficients for tree height prediction equations. Taken from Hanus, Marshall, & *Hann, and Hanus, Hann & Marshall 1999.*

Damaged and Undamaged trees

Species	a_0	a_1	a_2
*Douglas-Fir	7.153156143	-5.36900835	-0.25832512
*Grand/White firs	6.638003799	-5.44399465	-0.33929196
*Incense-cedar	8.776627288	-74383668	-0.16906224
*Pacific yew	6.402691396	-4.79802411	-0.16317997
*Ponderosa pine	7.181264435	-5.90709219	-0.27533719
Sitka spruce	5.404491308	-6.570862442	-0.819705048
Western hemlock	6.58804	-5.35325461	-0.31897786
*Western redcedar	7.232880669	-5.746899904	-0.271564741

* = coefficients from Hanus, Hann and Marshall. The analysis in this paper was based on data and prediction equations which grouped damaged and undamaged trees.

APPENDIX E

STATISTICAL RESULTS OF PRE- AND POST-HARVEST PREDICTED LARGE WOOD RECRUITMENT POTENTIAL

Table E-1: Small Streams: Statistical results of predicted pre- and post-harvest large wood recruitment potential by probability class.

Small Streams:

10% probability of falling in the stream: no significant change.

Paired samples t-test on POST10 vs PRE10 with 10 cases

Mean POST10	=	1.000			
Mean PRE10	=	2.000			
Mean Difference =		-1.000	95.00% CI =	-5.061 to	3.061
SD Difference =		5.676	t =	-0.557	
df =	9	Prob =	0.591		

20% probability of falling in the stream: no significant change.

Paired samples t-test on POST20 vs PRE20 with 10 cases

Mean POST20	=	1.000			
Mean PRE20	=	2.000			
Mean Difference =		-1.000	95.00% CI =	-5.061 to	3.061
SD Difference =		5.676	t =	-0.557	
df =	9	Prob =	0.591		

30% probability of falling in the stream: no significant change.

Paired samples t-test on POST30 vs PRE30 with 10 cases

Mean POST30	=	4.000			
Mean PRE30	=	9.000			
Mean Difference =		-5.000	95.00% CI =	-14.080 to	4.080
SD Difference =		12.693	t =	-1.246	
df =	9	Prob =	0.244		

40% probability of falling in the stream: no significant change.

Paired samples t-test on POST40 vs PRE40 with 10 cases

Mean POST40	=	8.000			
Mean PRE40	=	21.000			
Mean Difference =		-13.000	95.00% CI =	-34.606 to	8.606
SD Difference =		30.203	t =	-1.361	
df =	9	Prob =	0.207		

50% probability of falling in the stream: significant change.

Paired samples t-test on POST50 vs PRE50 with 10 cases

Mean POST50	=	4.200			
Mean PRE50	=	10.600			
Mean Difference =		-6.400	95.00% CI =	-12.574 to	-0.226
SD Difference =		8.631	t =	-2.345	
df =	9	Prob =	0.044		

Table E-2: Medium Streams: Statistical results of predicted pre- and post-harvest large wood recruitment potential by probability class.

Medium Streams:

10% probability of falling in the stream: no significant change.

Paired samples t-test on POST10 vs PRE10 with 7 cases

```
Mean POST10      =      1.429
Mean PRE10       =      0.000
  Mean Difference =     1.429   95.00% CI  =    -2.067 to     4.924
   SD Difference =      3.780                 t =      1.000
                          df =    6   Prob =       0.356
```

20% probability of falling in the stream: no significant change.

Paired samples t-test on POST20 vs PRE20 with 7 cases

```
Mean POST20      =      1.429
Mean PRE20       =      2.857
  Mean Difference =    -1.429   95.00% CI  =    -7.811 to     4.953
   SD Difference =      6.901                 t =     -0.548
                          df =    6   Prob =       0.604
```

30% probability of falling in the stream: no significant change.

Paired samples t-test on POST30 vs PRE30 with 7 cases

```
Mean POST30      =      4.286
Mean PRE30       =     14.286
  Mean Difference =   -10.000   95.00% CI  =   -24.127 to     4.127
   SD Difference =     15.275                 t =     -1.732
                          df =    6   Prob =       0.134
```

40% probability of falling in the stream: no significant change.

Paired samples t-test on POST40 vs PRE40 with 7 cases

```
Mean POST40      =     15.714
Mean PRE40       =     24.286
  Mean Difference =    -8.571   95.00% CI  =   -47.234 to    30.091
   SD Difference =     41.805                 t =     -0.542
                          df =    6   Prob =       0.607
```

50% probability of falling in the stream: no significant change.

Paired samples t-test on POST50 vs PRE50 with 7 cases

```
Mean POST50      =     15.143
Mean PRE50       =     14.571
  Mean Difference =     0.571   95.00% CI  =    -5.629 to     6.772
   SD Difference =      6.705                 t =      0.225
                          df =    6   Prob =       0.829
```

Table E-3: Large Streams: Statistical results of predicted pre- and post-harvest large wood recruitment potential by probability class.

Large Streams:

10% probability of falling in the stream: no significant change.

Paired samples t-test on POST10 vs PRE10 with 7 cases

Mean POST10	=	1.429			
Mean PRE10	=	0.000			
Mean Difference =		1.429	95.00% CI =	-2.067 to	4.924
SD Difference =		3.780	t =	1.000	
df =	6	Prob =	0.356		

20% probability of falling in the stream: no significant change.

Paired samples t-test on POST20 vs PRE20 with 7 cases

Mean POST20	=	2.857			
Mean PRE20	=	5.714			
Mean Difference =		-2.857	95.00% CI =	-9.848 to	4.134
SD Difference =		7.559	t =	-1.000	
df =	6	Prob =	0.356		

30% probability of falling in the stream: no significant change.

Paired samples t-test on POST30 vs PRE30 with 7 cases

Mean POST30	=	5.714			
Mean PRE30	=	10.000			
Mean Difference =		-4.286	95.00% CI =	-11.562 to	2.991
SD Difference =		7.868	t =	-1.441	
df =	6	Prob =	0.200		

40% probability of falling in the stream: no significant change.

Paired samples t-test on POST40 vs PRE40 with 7 cases

Mean POST40	=	7.143			
Mean PRE40	=	5.714			
Mean Difference =		1.429	95.00% CI =	-8.458 to	11.316
SD Difference =		10.690	t =	0.354	
df =	6	Prob =	0.736		

50% probability of falling in the stream: no significant change.

Paired samples t-test on POST50 vs PRE50 with 7 cases

Mean POST50	=	8.571			
Mean PRE50	=	10.000			
Mean Difference =		-1.429	95.00% CI =	-6.289 to	3.432
SD Difference =		5.255	t =	-0.719	
df =	6	Prob =	0.499		

APPENDIX F

STATISTICAL RESULTS: PRE- AND POST-HARVEST COMPARISONS OF COVER

Table F-1: Statistical Results: Pre- and post-harvest comparisons of cover by stream size.

Large Streams: No significant change in cover

Paired samples t-test on PRESHADE vs POSTSHADE with 8 cases

Mean PRESHADE = 83.750
Mean POSTSHADE = 82.500
Mean Difference = 1.250 95.00% CI = -3.995 to 6.495
SD Difference = 6.274 t = 0.564
df = 7 Prob = 0.591

Medium Streams: No significant change in cover

Paired samples t-test on PRESHADE vs POSTSHADE with 7 cases

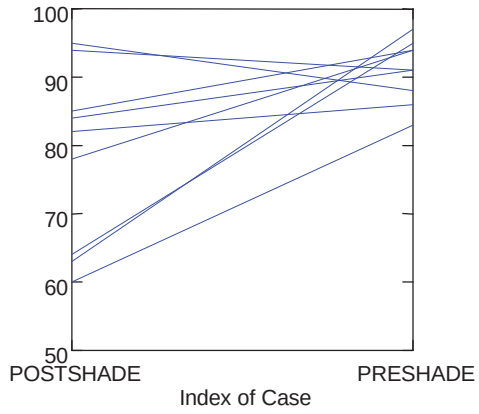
Mean PRESHADE = 88.000
Mean POSTSHADE = 81.000
Mean Difference = 7.000 95.00% CI = -6.801 to 20.801
SD Difference = 14.922 t = 1.241
df = 6 Prob = 0.261

Small Streams: Significant change in cover

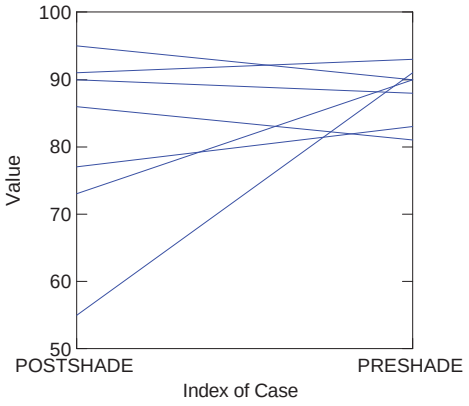
Paired samples t-test on PRESHADE vs POSTSHADE with 9 cases

Mean PRESHADE = 91.000
Mean POSTSHADE = 78.333
Mean Difference = 12.667 95.00% CI = 1.587 to 23.746
SD Difference = 14.414 t = 2.636
df = 8 Prob = 0.030

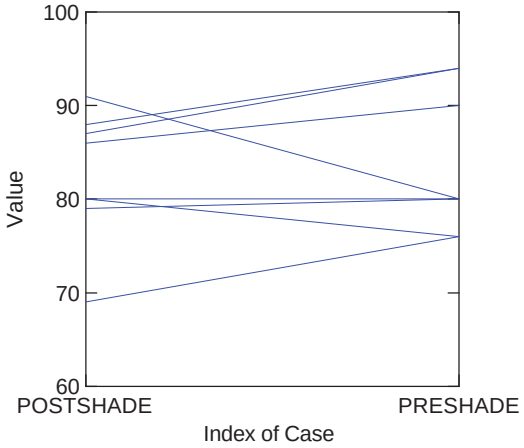
Small



Medium



Large



APPENDIX G

SUMMARY STATISTICS FOR REGENERATION ON INDIVIDUAL SITES

Table G-1. Coastal regeneration summary statistics by site number.

Site Number 11	Seedlings and Saplings (trees/plot)	Seedlings and Saplings (trees/acre)
N of Plots	30	30
Minimum	0.000	0.000
Maximum	3.000	416.000
Median	0.000	0.000
Mean	0.167	23.133
Standard Deviation	0.592	82.136

Site Number 12	Seedlings and Saplings(trees/plot)	Seedlings and Saplings (trees/acre)
N of Plots	30	30
Minimum	0.000	0.000
Maximum	3.000	416.000
Median	0.000	0.000
Mean	0.267	37.000
Standard Deviation	0.785	108.863

Site Number 13	Seedlings and Saplings(trees/plot)	Seedlings and Saplings (trees/acre)
N of Plots	33	33
Minimum	0.000	0.000
Maximum	5.000	693.000
Median	1.000	139.000
Mean	1.303	180.667
Standard Deviation	1.237	171.434

Site Number 16	Seedlings and Saplings(trees/plot)	Seedlings and Saplings (trees/acre)
N of Plots	34	34
Minimum	0.000	0.000
Maximum	14.000	1941.000
Median	1.500	208.000
Mean	2.059	285.500
Standard Deviation	2.795	387.598

Site Number 17	Seedlings and Saplings(trees/plot)	Seedlings and Saplings (trees/acre)
N of Plots	38	38
Minimum	0.000	0.000
Maximum	5.000	693.000
Median	1.000	139.000
Mean	1.500	208.026
Standard Deviation	1.466	203.197

Table G-2. Interior regeneration summary statistics by site number.

Site Number 24	Seedlings and Saplings (trees/plot)	Seedlings and Saplings (trees/acre)
N of cases	48	48
Minimum	0.000	0.000
Maximum	23.000	3189.000
Median	2.000	277.000
Mean	3.396	470.875
Standard Deviation	4.602	638.052

Site Number 25	Seedlings and Saplings (trees/plot)	Seedlings and Saplings (trees/acre)
N of cases	32	32
Minimum	0.000	0.000
Maximum	14.000	1941.000
Median	0.000	0.000
Mean	0.656	91.031
Standard Deviation	2.548	353.247

Site Number 26	Seedlings and Saplings (trees/plot)	Seedlings and Saplings (trees/acre)
N of cases	31	31
Minimum	0.000	0.000
Maximum	3.000	416.000
Median	1.000	139.000
Mean	1.129	156.516
Standard Deviation	1.118	154.917

Site Number 28	Seedlings and Saplings (trees/plot)	Seedlings and Saplings (trees/acre)
N of cases	30	30
Minimum	0.000	0.000
Maximum	19.000	2634.000
Median	0.000	0.000
Mean	0.633	87.800
Standard Deviation	3.469	480.900

	Seedlings and Saplings (trees/plot)	Seedlings and Saplings (trees/acre)
N of cases	30	30
Minimum	0.000	0.000
Maximum	24.000	3328.000
Median	0.000	0.000
Mean	1.500	208.000
Standard Deviation	4.890	678.123

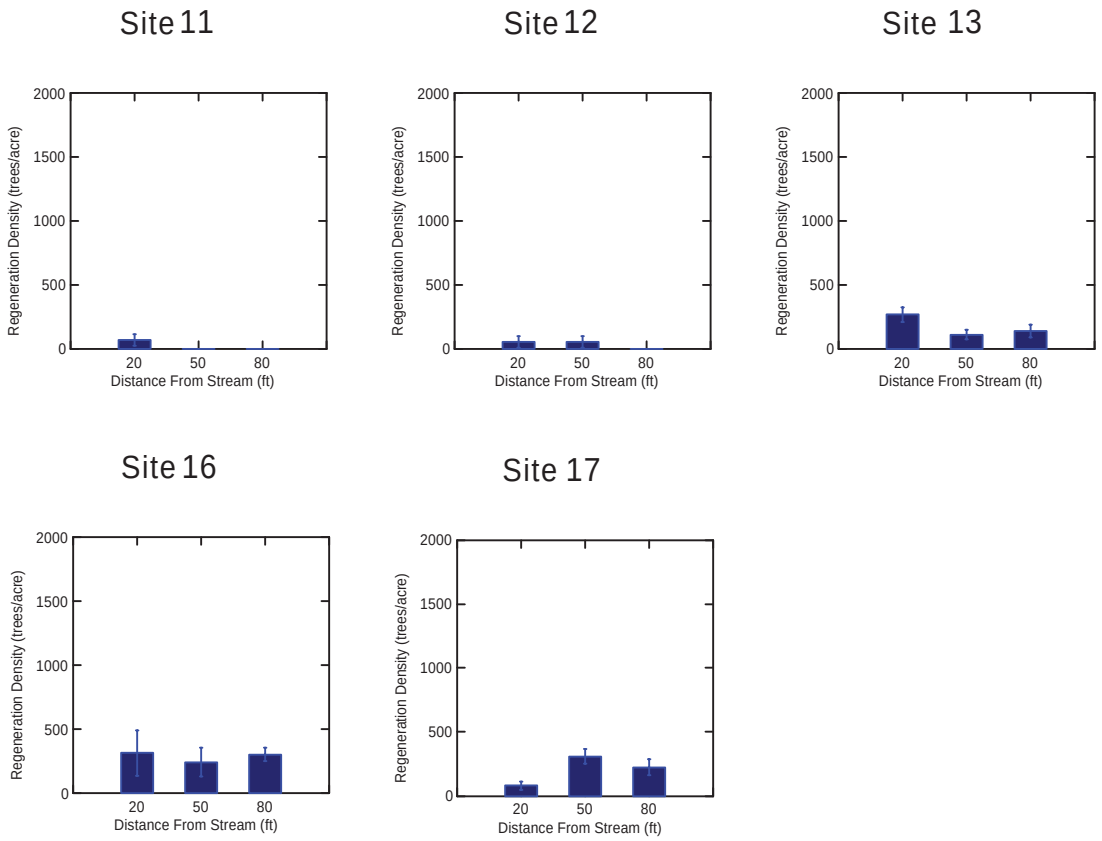


Figure G-1: Coast Range: Average seedling and sapling density and standard error versus distance from stream for each site.

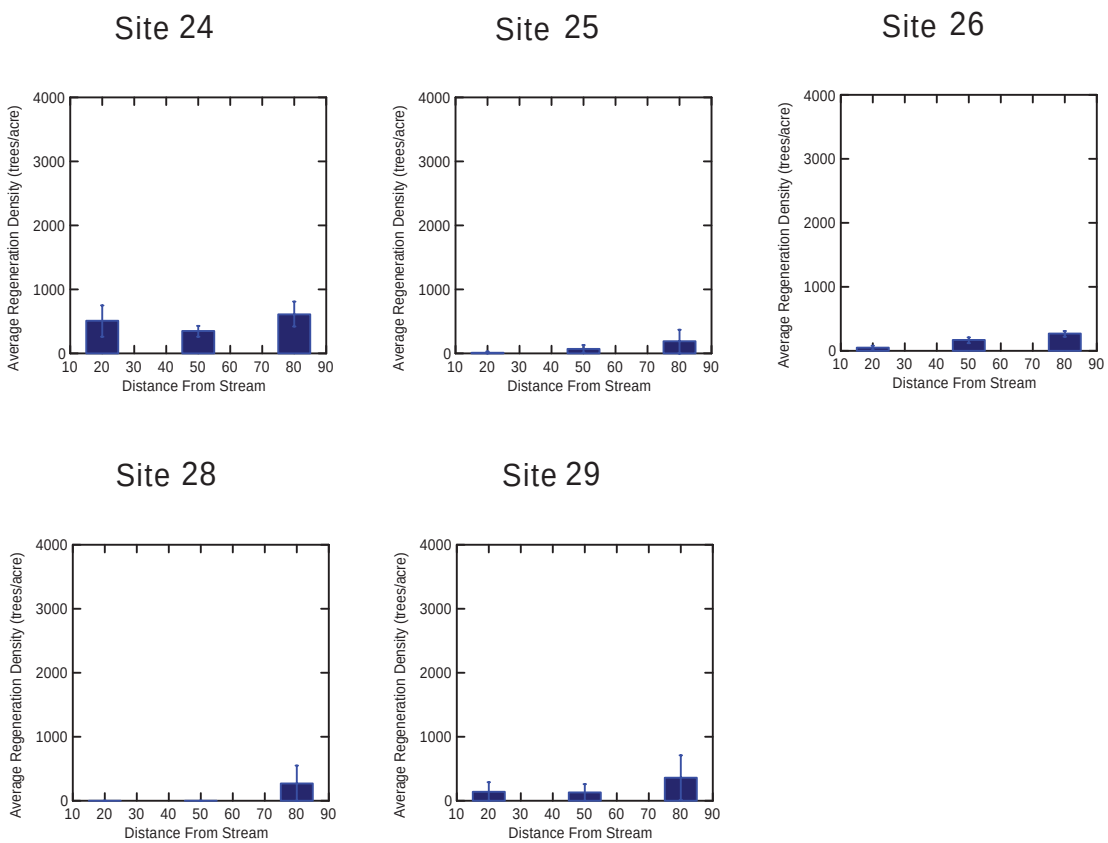


Figure G-2: Interior: Average seedling and sapling density and standard error versus distance from stream for each site.

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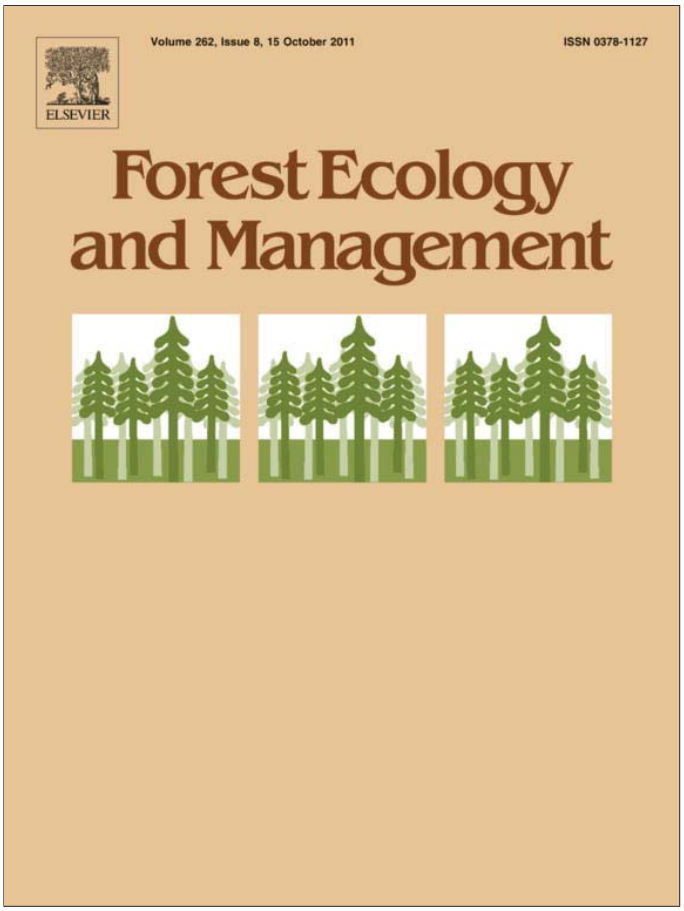

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Response of western Oregon (USA) stream temperatures to contemporary forest management

Jeremiah D. Groom [a,*], Liz Dent [b], Lisa J. Madsen [c], Jennifer Fleuret [d]

[a] Department of Forest Engineering, Resources, and Management, Oregon State University, 204 Peavy Hall, Corvallis, OR 97331, USA
[b] Oregon Department of Forestry, 2600 State St., Salem, OR 97310, USA
[c] Department of Statistics, Oregon State University, 44 Kidder Hall, Corvallis, OR 97331, USA
[d] 923 W Pine St., Rawlins, WY 82301, USA

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ABSTRACT

A replicated before–after-control-impact study was used to test effectiveness of Oregon's (USA) riparian protection measures at minimizing increases in summer stream temperature associated with timber harvest. Sites were located on private and state forest land. Practices on private forests require riparian management areas around fish-bearing streams; state forest's prescriptions are similar but wider. Overall we found no change in maximum temperatures for state forest streams while private sites increased pre-harvest to post-harvest on average by 0.7 °C with an observed range of response from −0.9 to 2.5 °C. The observed increases are less than changes observed with historic management practices. The observed changes in stream temperature were most strongly correlated with shade levels measured before and after harvest. Treatment reach length, stream gradient, and changes in the upstream reach stream temperature were additionally useful in explaining treatment reach temperature change. Our models indicated that maximum, mean, minimum, and diel fluctuations in summer stream temperature increased with a reduction in shade, longer treatment reaches, and low gradient. Shade was best predicted by riparian basal area and tree height. Findings suggest that riparian protection measures that maintain higher shade such as the state forests were more likely to maintain stream temperatures similar to control conditions.

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1. Introduction

The Oregon Coast Range supports several cold-water fisheries (e.g. salmon, steelhead, cutthroat) which are important to the region's economy, culture, and recreational activities. These fish are thermally adapted to specific water temperatures for various life stages such as egg and smolt survival, spawning, and adult migration (Richter and Kolmes, 2005). Because forest management can influence stream temperature regimes it is important to evaluate the effectiveness of contemporary riparian management strategies to protect stream temperature.

Stream temperature patterns are the result of several energy transfer processes and reflect both the seasonal change in net solar radiation and the spatial and temporal changes in other energy transfer processes including evaporation, convection, conduction, and advection (Brown, 1969; Caissie, 2006; Johnson, 2004). The magnitude and direction of these energy transfer processes are influenced by atmospheric conditions (solar radiation, air temperature, wind speed, cloud cover and relative humidity), basin level physical factors such as surrounding topography, surface and groundwater flow, and streamside vegetation (Poole and Berman, 2001; Sinokrot and Stefan, 1993). The amount of shade provided by streamside vegetation is perhaps the most important single variable affecting summertime stream temperatures in forested environments (Brown, 1969; Johnson and Jones, 2000; Danehy et al., 2005).

Historic forest management along streams often resulted in dramatic reductions in shade and associated increases in stream temperature (Brown and Krygier, 1970; Levno and Rothacher, 1967; Harris, 1977; Holtby and Newcombe, 1982; Feller, 1981; Johnson and Jones, 2000; Moore et al., 2005). Moore et al. (2005) summarize findings from several historic and contemporary studies in the rain-dominated region of the Pacific Northwest. Reported changes in maximum stream temperature for sites harvested without a riparian buffer ranged from 1.4 to 11.6 °C. The changes were

Abbreviations: AZ, azimuth; BAPH, basal area per hectare; ChannelBD, channel blowdown; CR, crown ratio; CT, control reach temperature change standardized by reach length; EL, elevation; FPA, Forest Practices Act; GR, gradient; HS, harvest status; ODEQ, Oregon Department of Environmental Quality; OW, owner; PlotBD, plot blowdown; PP, private site post-harvest; RMA, riparian management area; SH, shade; TL, treatment reach length; TPH, trees per hectare; WS, watershed area.

* Corresponding author. Tel.: +1 541 737 1502; fax: +1 541 737 4316.
E-mail addresses: jeremy.groom@oregonstate.edu, jeremygroom@gmail.com (J.D. Groom), ldent@odf.state.or.us (L. Dent), madsenl@onid.orst.edu (L.J. Madsen), jenniferfleuret@gmail.com (J. Fleuret).

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considered to be a result of increased solar radiation at a time when harvesting did not require riparian buffers, slopes were broadcast burned to the edge of the stream, and equipment operation occurred in stream channels.

Varying levels of effectiveness for contemporary riparian buffers have been reported in the literature. Moore et al. (2005) reported a range of 2.5–5.0 °C for streams with riparian buffers in the Pacific Northwest. The variability in stream temperature responses may be due in part to different management practices. Within the reported literature sites differ according to harvest strategy (clearcut harvest or different levels of thinning) and levels of riparian vegetation retention (Moore et al., 2005). The variability in temperature responses may additionally be a function of multiple biological and physical site factors that affect the energy transfer processes. For example, while removal of vegetation can decrease shade it can also result in an increase in summer low flows. This may result in an increase in cool groundwater that would moderate the effects of a shade reduction on stream temperature (Moore and Wondzell, 2005). Stream velocity and depth also influence the sensitivity of the stream to change (Brown, 1969). Danehy et al. (2005), Isaak et al. (2010), and Isaak and Hubert (2001) found elevation to serve as a predictor of stream temperature. Gomi et al. (2006) posited that valley azimuth may have influenced the effectiveness of leave-tree buffers at intercepting incoming solar radiation. Geomorphic features such as channel sediment deposits (Johnson, 2004) or channel reaches scoured by debris flows (Levno and Rothacher, 1967) can also influence the sensitivity of the stream to changes in temperature changes.

Determining the effects of contemporary harvest practices on stream temperature involves detecting relatively small changes in stream temperature within a wide range of background variability. Background variability is a function of several factors including basin size [Caissie, 2006; Lewis et al., 1999], microclimatic and geologic processes (Brosofske et al., 1997; Hawkins et al., 1997; Kasahara and Wondzell, 2003), and annual and spatial hydrological variability (Poole and Berman, 2001; Quinn and Wright-Stow, 2008). As such, longitudinal patterns can be highly variable in small streams (Dent et al., 2008; Torgerson et al., 1999). Study and analysis designs must therefore be able to separate this inherent variability from potential harvest effects.

Groom et al. (2011) evaluated changes in stream temperature following harvest in the Oregon Coast Range. Their study design was developed to account for aforementioned spatial and temporal variability. They reported a 40% increase in the probability that stream temperatures would exceed 0.3 °C following timber harvest conducted according to Oregon harvest regulations for small and medium fish-bearing streams. The frequency of temperature increases did not surpass background levels for sites harvested according to state forest standards. While their analysis allowed them to address a state water quality standard it hindered their ability to provide estimates of the actual magnitude of change or to evaluate potential drivers of stream temperature change (e.g., treatment reach length, shade, riparian and stream characteristics).

Quantification of the magnitude of stream temperature change allows for the comparison of results to other studies and historical effects of harvest, and provides insight into background variability. Also, the development of changes in riparian policy requires an understanding of how management-controlled factors affect shade and temperature changes. Therefore the objectives of this analysis are to:

1. Identify site physical and vegetative factors, including shade, that relate to stream temperature change.
2. Determine the magnitude of stream temperature change that results from timber harvest.
3. Quantify riparian characteristics that predict shade retention after harvesting.

We expand our assessment of stream temperature beyond the water quality standard-focused weekly maximum temperatures reported by Groom et al. (2011) and examine daily maximum, minimum, and mean temperatures as well as diurnal fluctuation, in order to better capture the spectrum of temperature changes following harvest. The implications of findings for this study likely extend to other regions with similar physical and biological characteristics, stream temperature concerns, cold-water fisheries, and prescriptive riparian zone protections such as Idaho, Alaska, British Columbia, Washington, and California.

2. Methods

2.1. Study location and design

This study was conducted at 33 sites in the Oregon Coast Range (see Fig. 1 in Dent et al., 2008). Sites were situated along first- to third-order streams on 18 private and 15 state forest sites dominated by Douglas fir (*Pseudotsuga menzeisii*) and red alder (*Alnus rubra*). Forest stands were 50–70 years old and were fire- or harvest-regenerated. Openings were dominated by shrubs such as vine maple (*Acer circinatum*), stink currant (*Ribes bracteosum*), salmonberry (*Rubris spectabilis*), and devil's club (*Oplopanax horridus*).

The study design rendered a probabilistic sampling approach impractical due to the specificity of site inclusion criteria and the resulting scarcity of sites. The criteria included an ability to collect at least 2 years of pre-treatment and 5 years of post-treatment data at every site, minimum treatment reach lengths of 300 m, and assurance that the upstream "control" reaches would remain unharvested for the duration of the study. Streams needed to qualify under the Oregon Forest Practices Act (FPA) as "Small" or "Medium" (mean annual streamflow <57 or between 57 and 283 L/s, respectively), and streams needed to be free of recent impacts from debris torrents and active beaver ponds. We obtained sites by requesting that industrial private and state forest managers in the Oregon Coast Range provide ODF with a list of stream reaches that met the criteria and would be harvested no sooner than 2004. An initial list of 130 stream reaches was reduced to 36 (three more were subsequently dropped due to changes in harvest plans) that met study design constraints. Assuming selected sites were geographically representative (all available sites that met selection criteria were included in the study), inferential scope of study results pertain to

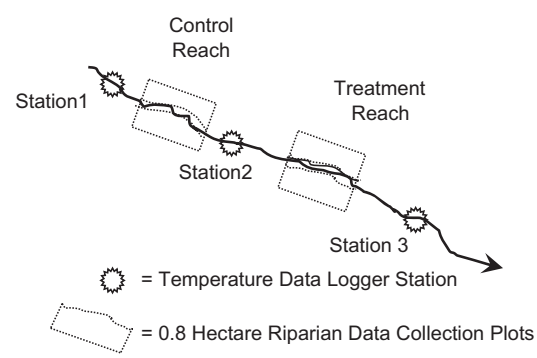

Fig. 1. Schematic of a stream reach (from Dent et al. 2008). Data loggers were placed starting upstream at Stations 1, 2, and 3. The upstream Control reach laid between Stations 1 and 2, the treatment reach between Stations 2 and 3. Riparian Data Collection Plots were located on either side of the stream in the Treatment and Control reaches; in this study we only used riparian data from the Treatment reach plots.

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first- to third-order streams within the Coast Range, on 50–70-year-old non-federal forestlands primarily managed for timber production that lack recent debris torrent or beaver disturbance. While there was an initial attempt to exclude sites with beaver activity, a beaver dam ponded 220 m of the 1.16 km treatment reach for site 7801 during the first and second post-harvest years.

A site's control reach was located immediately upstream of its treatment reach (Fig. 1). The control reaches were continuously forested to a perpendicular slope distance of at least 60 m from the average annual high water level. Reach lengths varied from 137 m to 1,829 m with means of 276 m and 684 m for the control and treatment reaches, respectively.

2.2. Treatments

Forest Practices Act On Private Sites: Eighteen sites were established on private forest streams. Sites were harvested following contemporary FPA standards which require riparian buffers along fish-bearing streams to protect stream temperature, provide future large wood for streams, and retain other ecological services (Oregon Department of Forestry, 2007). Under the FPA, Coast Range RMAs are 15 and 21 m wide around small and medium fish-bearing streams, respectively. Both small and medium streams may not be harvested within a 6 m zone immediately adjacent to the stream. Harvesting is allowed in the remaining RMA to a minimum basal area of 10.0 (small streams) and 22.9 (medium streams) m^2/ha.

Oregon State Forest Management Plan (FMP) on State Sites: Land administered directly by Oregon Department of Forestry (state forests) is managed under the FMP for multiple resource objectives including timber production (e.g., recreation, wildlife) and require riparian protections that exceed FPA minimum values. State RMAs are 52 m wide for all fish-bearing streams, with an 8-m no cut zone. Limited harvest is allowed within 30 m of the stream only to create mature forest conditions. Harvest operations within this zone must maintain 124 trees per hectare and a 25% Stand Density Index (Oregon Department of Forestry, 2001). If mature forest conditions exist or will develop in a timely manner without management, then no harvest is allowed within 30 m of the stream. Additional tree retentions of 25–111 conifer trees and snags/hectare are required between 30 and 52 m.

2.3. Data collection

Optic Stowaway Temp and HOBO Water Temp Pro data loggers (Onset Computer Corporation, Bourne, Massachusetts) were annually deployed at three stations within each site beginning in 2002 or 2003 (Fig. 1). Station 1 was located at the upstream end of the control reach, Station 2 was located at the downstream end of the control reach and the upstream end of the treatment reach (i.e. shared logger) and Station 3 was situated at the downstream end of the treatment reach. Temperature loggers were deployed in shaded locations where stream flow was relatively constant at a reliable summer depth and within a well-mixed water column. Logger accuracy was checked prior to installation, in the field, and following retrieval with National Institute for Standards and Technology-calibrated digital thermometers according to Oregon Watershed Enhancement Board (1999) stream temperature protocol. Although both types of loggers are listed as ±0.2 °C accuracy, we found that for over 500 pre- and post- deployment assessments, in only two instances did loggers register errors of >0.1 °C. Daily temperatures that exhibited increases in diel fluctuation and increases and decreases in daily maximum and minimum temperatures that were not reflected in other probes during the same year or at the same location during other years were excluded from the analysis.

Channel data were collected at 60 m intervals within each reach. Data included wetted width, bankfull width, thalweg depth, and stream gradient according to the protocol described by Kaufmann and Robison (1998). Stream shade was quantified at each 60 m interval using a self-leveling fisheye lens digital camera (Valverde and Silvertown, 1997). Shade values were measured once pre-harvest and once post-harvest. Fish-eye photographs were taken in the middle of the stream, 1 m above the water level, and oriented due north. Photographs at this height may slightly underestimate stream shading due to shading from the banks, lower-growing vegetation, and channel wood (Davies-Colley and Quinn, 1998). An effort was made to take photos when the sun would not be in the picture (e.g. overcast conditions, when the sun was below the topographic horizon) and under dry conditions. Shade values were calculated from the photographs using HemiView™ 2.1 software (Delta-T Devices, Cambridge, UK) as one minus the June 30 Global Site Factor (1 -GSF). 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. Shade and gradient values were averaged for each reach.

Vegetation data were collected in four 152 by 52 m plots on either side of a study stream in the treatment and control reach (Fig. 1). Plots were centered midway along each reach and altered in layout to accommodate stream nonlinearity. Vegetation plot data describe understory, overstory, downed wood, blowdown, and snag characteristics. The original purpose of including extensive vegetation plot data collection was to assess large wood recruitment, shade, and riparian structure following timber harvest. For this analysis we use a portion of the available riparian structure data (e.g. blow down, tree heights, basal area) that both influence stream temperature and relate to timber management. Within each plot all living trees with a diameter at breast height (DBH, or diameter at 1.4 m above ground level) >14 cm were tallied by species and the distance from those trees to the bankfull edge of the stream recorded. Height and live crown ratio were additionally measured for 20% of the trees. Data were collected in all four vegetation plots per site pre-harvest and re-measured in treatment plot or plots (if one or both stream sides were harvested, respectively) post-harvest. Blowdown was quantified in all plots post-harvest.

We determined stream elevation (elevation at the Station 3 logger), treatment reach azimuth, and watershed area from a geographic information system (GIS). We determined study site elevation from examining GPS-determined logger locations against 10-m digital elevation models (USGS National Mapping Program; overall absolute vertical root mean square error of 2.44 m). Azimuth was calculated using GPS locations of treatment reach upstream and downstream loggers. Since an east-west valley azimuth is expected to deliver the most solar radiation to a stream (Gomi et al., 2006; Sridhar et al., 2004), we "folded" (rendered equivalent) the azimuth north to south by subtracting 180 degrees (Hawkins et al., 1997; Bartholow, 1989), then folded the azimuth east to west by subtracting an additional 90 degrees. The result represents a 0–90° deviation from either east or west. Watershed area was calculated using the Spatial Analyst extension's Watershed tool for ArcGIS 9.3.1 (Earth Systems Research Institute, Redlands, CA). The tool relies on the same 10-m DEM as was used for elevation. Watershed area was calculated at the downstream end of the treatment reach (Station 3).

2.4. Analysis

We limited this analysis to include all pre-harvest data and data from the first and second post-harvest years. This decision was made due to a staggered harvest schedule and some prolonged

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pre-harvest periods resulting in incomplete five-year post-harvest data. Data collection included hourly stream temperature data (collected annually between July 1 and September 15) and both channel data (for a complete list see Dent et al., 2008) and riparian vegetation data (overstory and understory) during the first years pre-harvest and post-harvest.

We examined our stream temperature, riparian vegetation, and channel data with two distinct analyses. We constructed one analysis to functionally understand processes influencing stream temperature, which addressed the first two of our three objectives. This analysis involved four measures of temperature as separate dependent variables and stream, shade, and riparian characteristics as independent variables. We developed several models for this analysis to determine a reasonable fit for the data as well as to obtain magnitude of effects estimates. To address the third objective, we conducted another analysis that examined several riparian vegetation metrics to determine which best related to observed stream shade values post-harvest. For both analyses we plotted and assessed potential explanatory variables by examining Pearson's correlations and variance inflation factors (VIF) to determine degrees of multicollinearity. We retained all temperature and shade analysis variables as VIF scores were all <10, indicating a lack of multicollinearity (temperature maximum = 1.76, shade maximum = 2.50; Neter et al., 1996). Prior to analysis we centered all independent variables by subtracting the variable mean from all values. We assessed dependent variables (change in treatment reach temperature for the four temperature analyses and Shade for the shade analysis) graphically to determine whether transformations appeared appropriate.

2.4.1. Analysis I: stream temperature

We summarized hourly stream temperature data to provide daily maximum, mean, minimum, and fluctuation (maximum-minimum) values for each data logger. Our analysis objectives 1 and 2 concerned detecting changes in stream temperature due to site factors including harvest. We therefore defined the response variable as the difference between treatment reach Stations 2 and 3. To reduce analysis complexity we computed the average of this difference over a forty day period for each year (July 23 to August 15). This represents the time frame when we had the most functional loggers recording temperatures during a central portion of the summer months when maximum temperatures are observed in the Oregon Coast Range. Averaging of temperature differences removed the variability associated with temperature differences from shorter time periods, such as single days. Temperature changes observed in this study therefore reflect prolonged alterations in stream conditions. The stream temperature analyses utilize the averaged differences in daily maximum, mean, minimum, and fluctuation values as separate dependent variables and we refer to these metrics as Maximum, Mean, Minimum, and Diel Fluctuation.

Independent variables used for modeling temperature included treatment reach length (TL), average treatment reach shade (SH), elevation (EL), average treatment reach gradient (GR), treatment reach valley degree deviation from east or west (AZ), change in control reach temperature standardized by control reach length (CT; ControlMax, ControlMean, ControlMin, ControlFluc), and watershed area calculated at Station 3 (WS). We also included state and private ownership (OW), the harvest status or whether a temperature measurement occurred during a pre-harvest or post-harvest year (HS), or a variable that indicated temperature data were from private forest during post-harvest (PP; included due to its importance in Groom et al., 2011). Except for shade and harvest status, all other explanatory variable values were static over all years. The variables TL and CT were included in all temperature models considered except an intercept model (Intercept) and one that only included CT (Upstream, Table 1).

Our modeling approach involved first selecting an appropriate random-effects model structure, followed by an evaluation of potential explanatory models of interest. We modeled the temperature data using mixed-effects linear regression (Pinheiro and Bates 2000). We selected this technique due to a concern of potential data non-independence within sites and within specific years. To determine the appropriate random effects structure for each of the temperature analyses we created an over-fit "beyond optimal" linear model (BO; Zuur et al., 2009) that additively included all independent variables and accounted for as much of the fixed-effects variation as possible. We then compared different random-effects structures that used this fixed-effects model structure. The random effect structures differed according to data groupings and

Table 1
Comparisons of different fixed-effects parameterizations for temperature models with similarly structured random effects. A set of model results are presented for each of the treatment reach changes in daily Maximum, Mean, Minimum, and Fluctuation values. Results are sorted by Maximum ΔAIC values. Rank indicates relative AIC order within a type of temperature analysis; a rank of 1 indicates the lowest AIC score. The symbol ro indicates model weight. All models include an intercept; linear combinations of independent varibles are provided[a]. See text for a definition of variables.

Model name	Independent variables[a]	Maximum			Mean			Minimum			Diel fluctuation		
		Rank	ΔAIC	ω	Rank	ΔAIC	ω	Rank	ΔAIC	ω	Rank	ΔAIC	ω
Grad_Shade	GR, SH, TL, CT	1	0.00	0.40	1	0	0.43	2	0.4	0.20	3	0.7	0.18
ShadeGradWS	GR, SH, WS, TL, CT	2	0.40	0.33	2	0.8	0.29	5	1.6	0.11	4	1.7	0.11
StreamShade	SH, TL, CT	3	2.70	0.10	3	1.9	0.17	1	0	0.24	6	1.8	0.11
FullStream	GR, SH, WS, AZ, TL, CT	4	3.40	0.07	5	4.5	0.05	7	3.1	0.05	5	1.7	0.11
El_Shade	EL, SH, TL, CT	5	3.70	0.06	4	3.8	0.06	4	1.2	0.13	2	0.3	0.22
BO	GR, SH, WS, AZ, HS, OW, TL, CT, EL	6	5.30	0.03	6	7.5	0.01	12	7.1	0.01	1	0	0.26
Harvest_PXLength	PP, PP×TL, TL, CT	7	25.70	0.00	7	20	0.00	6	3	0.05	7	18.4	0.00
Harvest_Private	PP, TL, CT	8	33.60	0.00	8	23.1	0.00	3	1	0.15	8	29.4	0.00
Harvest	HS, TL, CT	9	57.50	0.00	9	38.6	0.00	10	6.5	0.01	9	49	0.00
Harvest_S_P	HS, OW, TL, CT	10	59.40	0.00	10	39.3	0.00	11	6.9	0.01	10	50.9	0.00
Upstream_TRlength	TL, CT	11	71.70	0.00	11	51.6	0.00	8	5.8	0.01	13	63.4	0.00
GradWS	GR, WS, TL, CT	12	72.30	0.00	12	52.8	0.00	14	8.1	0.00	17	66	0.00
Phys	GR, WS, EL, TL, CT	13	72.90	0.00	15	54.8	0.00	16	9	0.00	15	64.9	0.00
StreamAzimuth	AZ, TL, CT	14	73.60	0.00	13	52.9	0.00	9	6.3	0.01	16	65.4	0.00
Upstream	CT	15	73.90	0.00	17	56.3	0.00	17	15.6	0.00	12	61.9	0.00
AzimuthGradWS	AZ, GR, WS, TL, CT	16	74.00	0.00	14	53.7	0.00	15	8.2	0.00	18	68	0.00
El_Azimuth	EL, AZ, TL, CT	17	74.30	0.00	16	54.9	0.00	13	7.5	0.01	14	64.2	0.00
Intercept	–	18	74.50	0.00	18	61.5	0.00	18	16.3	0.00	11	60.5	0.00

[a] Gradient = GR, shade = SH, treatment length = TL, control temperature change = CT, watershed area = WS, valley azimuth = AZ, elevation = EL, owner = OW, Harvest Status = HS, private site post-harvest = PP, PP × treatment length = PP×TL.

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Table 2
Annual weather and stream flow conditions at a representative weather station[a] and stream gage[b]. Air temperature data are the mean of daily maximum temperatures across the 40-day study period. Spring Precipitation is cumulative precipitation from 1 January to the beginning of the study period. Study Precipitation is cumulative precipitation during study period. Stream Flow is the average daily flow averaged over the study period.

Year	2002	2003	2004	2005	2006	2007	2008
Air temperature (°C)	24.4	26.0	25.8	26.5	25.1	21.8	24.2
Spring precipitation (cm)	126.9	134.5	139.9	139.9	129.8	93.9	112.5
Study precipitation (cm)	0.38	0.30	0.30	0.30	0.08	5.56	6.15
Stream flow (L/s)	53.1	44.3	72.5	79.7	51.4	52.5	72.8

[a] Rye Mountain Remote Area Weather Station. Lat: 45.2172; long: −123.5358.
[b] US Geological Survey gage 14303200 near Blaine, OR. Lat: 45.1928; long: 123.3243.

random-effects parameterization. The models were fit using Maximum Likelihood estimation to enable comparison of model AIC values (Zuur et al., 2009). Random effects structures included a generalized least squares model (no grouping), a random intercept model grouped by site, another by year (2002 through 2008), and a third by a cross of site and year. We examined grouping data by year to potentially account for inevitable interannual differences in air temperature, stream flow, and precipitation (Table 2). Three additional models included a random intercept and slope for control temperature change and grouped data respectively by site, year, and a cross of site and year. The best-supported (smallest AIC) Beyond-Optimal model for all four temperature metrics grouped data by site and fit random effects parameters for intercept and control reach temperature change (respectively the control change in Maximum, Minimum, Mean, or Diel Fluctuation).

Once we selected an appropriate random-effects parameterization we altered the fixed effects and fit a suite of 18 explanatory models (Table 1). The models were constructed a priori to account for variation in stream temperature according to the stream's in-channel, riparian, and/or shade characteristics (Objective 1, Table 1 Maximum Rank models 1 through 5, 12 through 14, 16, and 17). To obtain temperature change magnitude estimates as a function of timber harvest we included models that specified harvest status (pre- or post-harvest), ownership, or a combination (Objective 2, Maximum Rank models 7 through 10). We included two more models, BO, and Intercept, to serve as overfitting and underfitting extremes. We included models Upstream and Upstream_TR-length to verify that CT and TL were indeed assisting model fits. Models for comparison were fit using Maximum Likelihood estimation to enable comparison of model AIC values; best-performing models were re-fit using Restricted Maximum Likelihood to reduce bias in parameter estimates (Zuur et al., 2009). We compared model weights (ω) to determine the probability that a model or subset of models represented or included the best model of the set (Burnham and Anderson, 2002).

2.4.2. Analysis II: shade

Shade analysis variables from the vegetation plots included trees per hectare (TPH), tree height (Height), live crown ratio (CR), vegetation plot blowdown (PlotBD), and basal area per hectare (BAPH). These variables were calculated by using vegetation plot data from the edge of the bank to a perpendicular distance of 30 m, a distance at which tree canopies have likely ceased to influence stream shade during daily periods of the greatest radiation intensity (mean measured tree height = 25.7 m). We obtained site values for these variables by calculating mean values for the two treatment reach plots. In instances where only a single side of the treatment reach was harvested we calculated the mean TPH, BAPH, and CR values from the harvested side's post-harvest values and the unharvested side's pre-harvest values. Height and CR values were obtained from pre-harvest data. Non-vegetation plot variables included the number of riparian banks harvested (Nsides), buffer width (BuffWidth), and channel blowdown (ChannelBD). We quantified BuffWidth as the perpendicular distance from the stream bank to the first stump encountered within 10 m of the observer, measured every 60 m along the treatment reach. ChannelBD represented a tally of treatment reach within- or above-channel blowdown pieces >15 cm diameter.

Shade data were logit transformed due to observed skewness. We performed a linear regression analysis of shade data ($n = 33$) and compared small-sample AIC values (AICc, Hurvich and Tsai, 1989) to determine relative model performance among 8 *a priori* models (Table 3). Models were comprised of variable combinations we believed could potentially describe variations in observed post-harvest site shade levels. Allen and Dent (2001) found that riparian basal area and live crown ratio served as useful shade predictor variables for east-west flowing streams in the Oregon Coast range. DeWalle's (2010) riparian shade model found combinations of specific tree height, density, and basal area maximized stream shade. We therefore created several models that contained combinations of BAPH, CR, TPH, and Height. At a more coarse level of analysis, we anticipated that buffer width and the number of stream sides harvested might serve as reasonable predictors of shade (model BuffWidth). An additional model anticipated that shade values would be predicted by the quantity of blowdown both across the channel and within vegetation plots (model Blowdown).

2.4.3. Analysis assessment

For both the stream temperature and shade analyses we examined q–q normal and residual plots to verify that the best-performing models met their respective required statistical assumptions. Linear models assume a linear relationship between independent and dependent variables, independence of errors, a constant variance and normality of errors. Linear mixed effects models additionally assume (1) within-group errors are independent and identically, normally, distributed with a mean of zero and a variance of σ^2, and are independent of random effects; and (2) random effects are normally distributed, with a mean equal to zero and a homogeneous random effects covariance matrix (Pinheiro and Bates, 2000). Visual assessment of residual and q–q plots indicated that the assumptions of within-group normality were plausible and within-group residuals were symmetrical around zero. Within-group variances did not appear equal (not surprisingly, given that the maximum number of points per site was six with a mean of four (Pinheiro

Table 3
AIC ranking for seven of the eight Shade models. Only the R^2 value is presented for the model Blowdown as the parameter BD_Channel had 31 observations. For all other variables $n = 33$.

Model	Variables	k	ΔAICc	ω	R^2
BasalXHeight	BAPH, Height, BAPH∗Height	4	0.00	0.99	0.69
BasalHeight	BAPH, Height	3	10.70	0.00	0.50
BasalCR	BAPH, CR	2	15.08	0.00	0.43
BasalArea	BAPH	4	16.10	0.00	0.33
BufferWidth	NSides, BuffWidth, Nsides∗BuffWidth	4	16.91	0.00	0.33
TreesXBasal	TPH, BAPH, TPH∗BAPH	3	17.89	0.00	0.46
Intercept	–	1	25.03	0.00	0.00
Blowdown	PlotBD, ChannelBD	–	–	–	0.06

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Table 4
Fixed- and random-effect parameter values for four linear mixed-effects models and their assocaited temperature response variables. Model StreamShade lacks a parameter for gradient and model El_Shade replaces gradient with the parameter elevation. Parameters for treatment length and gradient are expressed as change in temperature per 1 km of distance or elevation. Observations = 119, Groups (Sites) = 33.

Response	Maximum temperature				Mean temperature				Minimum temperature				Diel fluctuation[b]			
Model	Grad_Shade				Grad_Shade				StreamShade				El_Shade			
Fixed[a]	DF	Value	SE	*p*	DF	Value	SE	*p*	DF	Value	SE	*p*	DF	Value	SE	*p*
Intercept	29.1	0.494	0.125	0.001	28.1	0.282	0.080	0.001	28.6	0.183	0.059	0.004	30.2	0.238	0.094	0.017
CT	21.5	−1.232	0.459	0.014	21.7	−1.230	0.345	0.002	22.8	−0.518	0.310	0.109	23.2	−0.783	0.583	0.193
TL	28.2	0.800	0.304	0.014	27.6	0.638	0.194	0.003	27.8	0.549	0.144	0.001	31.5	0.627	0.279	0.031
SH	94.5	−5.866	0.572	0.000	97.5	−3.050	0.371	0.000	101.0	−0.881	0.314	0.006	99.6	−4.698	0.503	0.000
GR[b]	30.3	−0.076	0.036	0.040	29.6	−0.043	0.023	0.067	–	–	–	–	31.1	−0.104	0.057	0.079
Random			Std.Dev				Std.Dev				Std.Dev				Std.Dev	
Intercept			0.441				0.181				0.095				0.241	
ControlTemp			3.564				1.134				0.975				6.175	
Residual			0.079				0.040				0.031				0.060	

[a] Control reach temperature change = CT, gradient = GR, shade = SH, treatment length = TL.
[b] For Diel Fluctuation the variable for GR is replaced by elevation (EL). Other parameters in the model are the same.

and Bates, 2000); at the same time no site appeared to behave as an obvious outlier. Plots of observed vs. fitted values indicated that the linear models agreed with observed values. For daily temperature Maximum, Mean, and Diel Fluctuation, three values from two sites appeared to be outliers, while we found one potential outlier for Minimum temperatures.

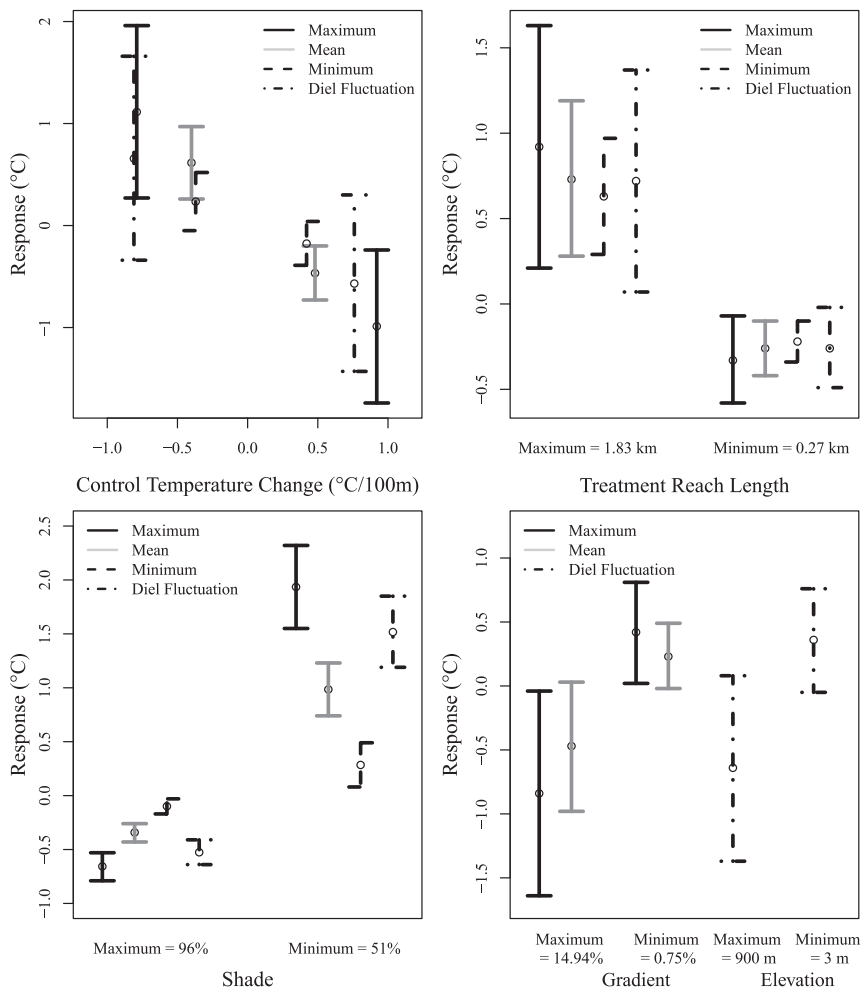

Fig. 2. Predicted temperature response for Maximum, Mean, Minimum, and Diel Fluctuation metrics at the observed extreme values of single explanatory variables and at the mean of all other variables. Explanatory variables presented appear in the models Grad_Shade and El_Shade. The El_Shade model, best supported by the Diel Fluctuation temperature metric, differs from Grad_Shade in that it replaces the Gradient parameter with Elevation. Influences of Gradient and Elevation extremes for those models appear in the lower right figure. Circles in each figure represent point estimates with 95% confidence intervals. In the upper left graph control temperature change represents change over 100 m.

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For the second assumption, normal q–q plots for the intercept and Control random effects provided no indication of non-normality. Normal q–q plots of Maximum, Mean, and Minimum intercept values revealed two potential outliers out of 33; Diel Fluctuation exhibited three. For the CT random effect Maximum, Minimum, and Diel Fluctuation plots we found one outlier apiece and zero for Mean. Homogeneity of random effects by group was difficult to assess due to the general paucity of data for each site.

3. Results

3.1. Analysis I: stream temperature

Our ranking of models explaining observed temperature changes indicated that shade was critical, with all other variables marginally improving model fit (Table 1). For change in daily temperature Maximum, Mean, and Fluctuation the best-supported six models are those that included SH; models that lacked shade exhibited a substantial drop in explanatory power (increase in ΔAIC by >13). We found little support for non-shade models as the cumulative model weight for models that included shade was effectively 1.0. For changes in the Maximum and Mean treatment reach temperatures the model with shade and gradient (Grad_Shade) and gradient, shade, and watershed area (ShadeGradWS) performed best. The lowest-AIC model for Diel Fluctuation was the overparameterized model BO. However, we interpret a more parsimonious model El_Shade as better supported as it performed virtually as well (ΔAIC = 0.3; Burnham and Anderson, 2002) and note that five other models performed similarly (ΔAIC < 2).

We do not believe that our models described Minimum temperature behavior well (Table 1). The best-supported models for

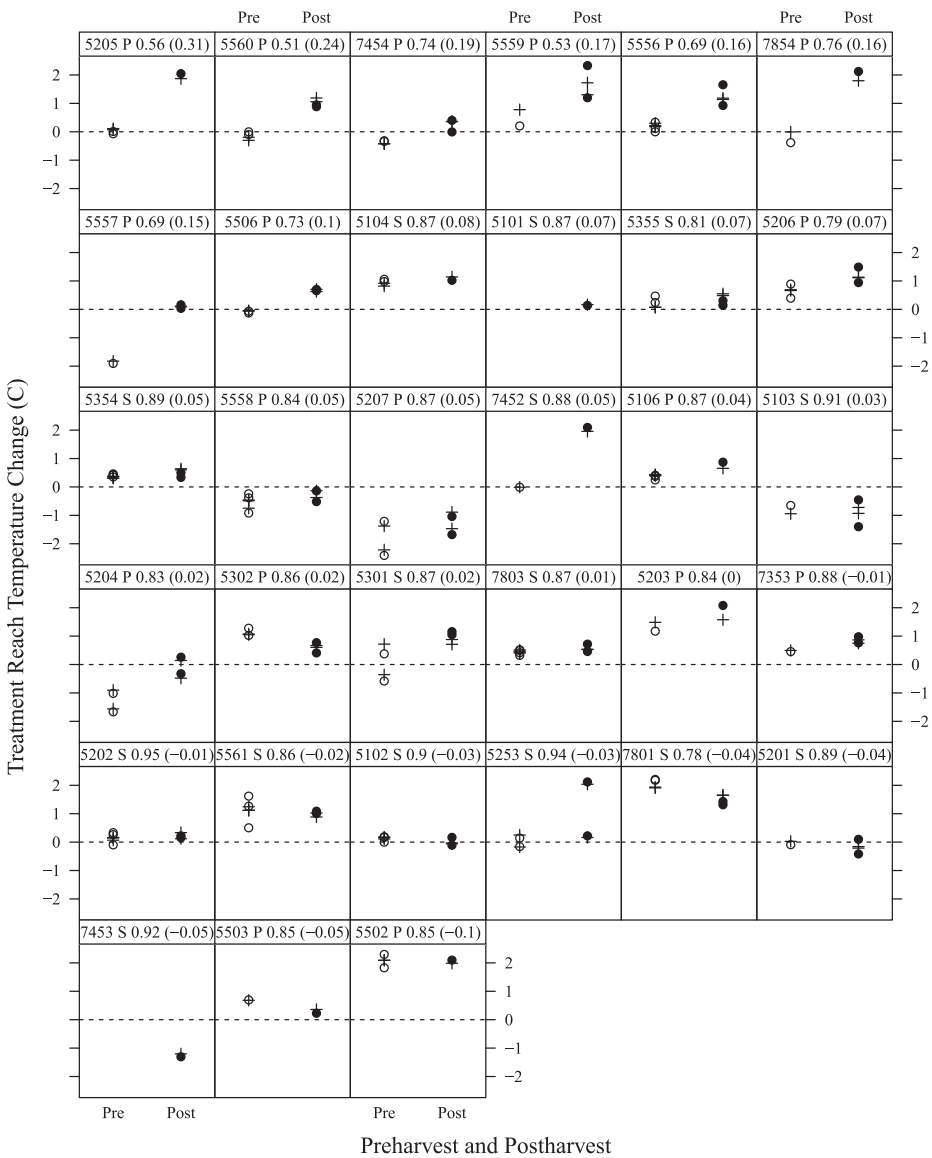

Fig. 3. Observed and predicted temperature changes for maximum temperatures (°C) by site. Pre-harvest and post-harvest observations are represented by open and filled circles, respectively. Each point represents one year of data collection at a site. The crosses represent predicted values from model Grad_Shade. Above each site's data is listed its site number, ownership ([S]tate or [P]rivate), post-harvest shade value, and in parentheses the change in shade value pre-harvest to post-harvest. Sites are ordered from the upper left to lower right by the observed change in shade values. Vertical differences of points within a pre-harvest or post-harvest category indicate a between-year change in the temperature relationship between Stations 1 and 2.

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Table 5
Mean and range values for State and Private independent variables and site characteristics. Values are calculated from 15 State sites and 18 Private sites. Pre and Post refer to measurements taken preharvest or postharvest. For Shade ranges see Fig. 4; basal area and trees per hectare are BAPH and TPH, respectively.

Variable	State		Private	
	Mean	Range	Mean	Range
Gradient (%)	6.5	1.5–13.2	6.4	1.0–17.5
treatment Length (km)	0.8	0.3–1.5	0.6	0.3–1.8
Elevation (m)	350	160–570	300	3–900
Watershed area (ha)	222	72–593	208	27–626
Crown ratio	0.43	0.30–0.56	0.40	0.26–0.57
Buffer width (m)[a]	51.8	25–61	31	19–41
Bankfull width (m)	4.6	2.7–7.9	4.1	2.2–7
Wetted width (m)	2.3	1.3–3.7	2.0	1.0–3.0
Thalweg (cm)	17	9–30	15	8–24
Basal area (m /ha)				
Pre-harvest	41	19–74	43	23–73
Post-harvest	42	25–73	25	11–40
Trees per ha				
TPH pre	368	147–665	465	196–664
TPH post	387	128–645	270	111–429
Tree height (m)	26	17–37	25	18–31

[a] Means reported in Groom et al. (2011); 95% CI for State sites = 45.6 m, 58.0 m; 95% CI for Private sites = 26.7 m, 35.3 m.

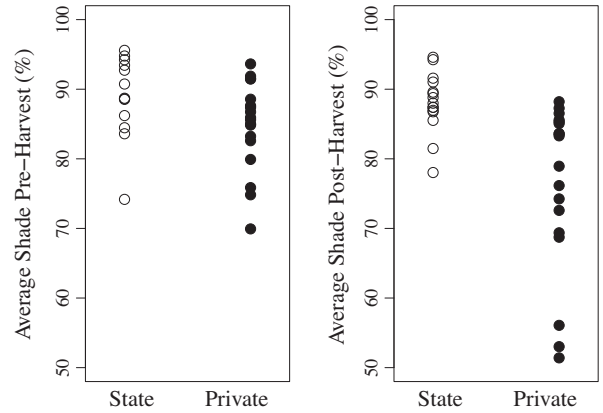

Fig. 4. Plot of average treatment reach shade values (%) for each site, grouped by harvest status (pre-harvest, post-harvest). On the left are state forest shade values, on the right shade are private forest values.

Minimum temperatures were StreamShade, Grad_Shade, and a model with an indicator variable for private sites post-harvest (Harvest_Private, combined weight = 0.59), with StreamShade receiving the most support. Shade appeared to be important; those models that contained SH provided a combined model weight of 0.74. However, the indicator variable that distinguished private sites post-harvest from all other observations (PP) explained the variation nearly as well as models that included SH (model weight for Harvest_Private = 0.15) while the remaining predictor variables improved model fit marginally.

Parameter estimates for the best-supported models retained directionality but contributed to model fit differently across temperature metrics (Table 4). For Maximum and Mean temperatures, the variable CT appeared to account for expected changes in the treatment reach given an observed temperature increase or decrease in the control reach. The decrease in temperature between Stations 1 and 2 on average resulted in an increase in temperature between Stations 2 and 3 and vice versa (Fig. 2). CT was not a significant parameter for Minimum temperatures or Diel Fluctuation. The parameters GR and EL were not strongly supported (Table 1) and exhibited overlap in their estimates at the extremes of observed values (Fig. 2). The directionality of parameter TR indicated that streams warmed with increasing treatment reach length. We estimated an increase in Maximum and Minimum temperatures of 0.73 and 0.59 °C per km, respectively (Fig. 2). Low SH values were associated with temperature increases in all models (Table 4).

Among explanatory variables, shade exhibited the greatest potential to alter stream temperatures with minimum shade levels producing a predicted increase of ~2 °C and maximum shade levels a temperature decrease of ~−1 °C (Fig. 2). We generally observed an increase in Maximum temperatures pre-harvest to post-harvest for sites that exhibited an absolute change in shade of >6%; otherwise, directionality appears to fluctuate (Fig. 3).

State and private sites exhibited similarities in the mean and range of their site values for gradient, treatment reach length, watershed area, crown ratio, wetted width, and pre-harvest vegetation metrics (Table 5). Following harvest, Maximum temperatures at private sites increased relative to state sites on average by 0.71 °C (Table 6, coefficient of PP, 95% CI = 0.51, 0.92). Similarly, Mean temperatures increased by 0.37 °C (0.24, 0.50), Minimum temperatures by 0.13 °C (0.03, 0.23), and Diel Fluctuation increased by 0.58 °C (0.41, 0.75). This increase appears to coincide with a decline in shade for some private sites (Fig. 4). Harvest on state sites did not produce a temperature change signal that differed from pre-harvest background levels. Models for Maximum, Mean, and Diel Fluctuation that considered state harvest to have negligible impact on stream temperature (Harvest_Private) received more support than those that considered it an influence (model Harvest_S_P; Table 1) with an observed ΔAIC increase respectively of 25.8, 16.2, and 5.9. The model which considered the variables PP and TL and their interaction (Harvest_PXLength) generally had greater explanatory power (lower ΔAIC) than the Harvest_Private models. However, the Harvest_PXLength model exhibited unexpected parameter estimates, indicating greater increases in private stream temperatures along shorter treatment reaches. A plot of post-harvest shade values against treatment reach length (Fig. 5A) suggests this relationship may be due to

Table 6
Fixed- and random-effect parameter values for the HarvestPrivate model fit by restricted maximum likelihood. Observations = 119, Groups (Sites) = 33. TRLength is expressed as change in temperature over 1 km.

Parameters	Maximum temperature				Mean temperature				Minimum temperature				Diel fluctuation			
Fixed	DF	Value	SE	p	DF	Value	SE	p	DF	Value	SE	p	DF	Value	SE	p
Intercept	33.9	0.280	0.143	0.058	32.7	0.191	0.088	0.037	32.3	0.152	0.060	0.017	33.1	0.076	0.116	0.515
CT	21.5	−0.798	0.520	0.140	18.8	−1.018	0.393	0.018	24.2	−0.407	0.315	0.209	23.4	-0.528	0.631	0.412
TL	30.2	0.745	0.335	0.034	29.4	0.602	0.208	0.007	27.8	0.538	0.141	0.001	30.1	0.216	0.275	0.440
PP	92	0.711	0.101	0.000	92.4	0.369	0.063	0.000	91	0.128	0.049	0.011	88.6	0.578	0.084	0.000
Random			Std.Dev				Std.Dev				Std.Dev				Std.Dev	
Intercept			0.535				0.206				0.091				0.355	
CT			4.554				1.596				1.036				7.008	
Residual			0.111				0.049				0.032				0.076	

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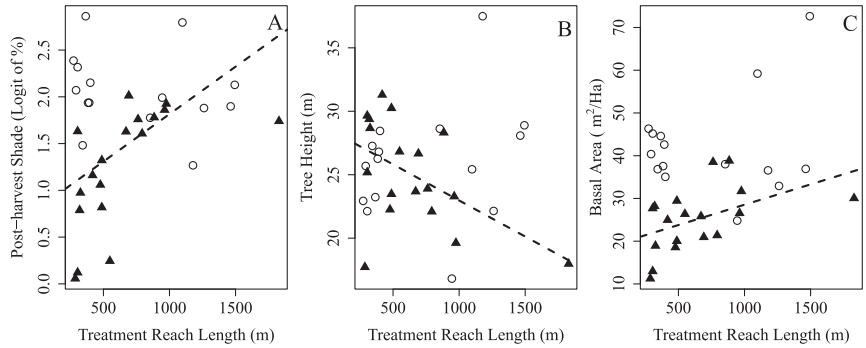

Fig. 5. Post-harvest values for treatment reach (A) logit-transformed percentages of mean shade values, (B) tree heights, and (C) basal area (m^2/Ha) by Treatment Reach length. Triangles represent privately-owned sites; circles are state sites. The dashed line represents the best linear fit for the filled circles (*y*-axis variable = intercept + *x*-axis variable). Shade values ranged from 0.51 to 0.95.

shade loss along the shorter private reaches. This in turn may be related to the presence of taller trees in the shorter reaches (Fig. 5B) or lower post-harvest basal area along the shorter reaches (Fig. 5C).

A comparison of within-site changes in Maximum temperatures pre-harvest to post-harvest indicated an overall increase in private site temperatures while observed changes at state sites were as frequently positive as negative (Fig. 6). The average of Maximum state site changes = 0.0 °C (range = −0.89 to 2.27 °C). Observed Maximum temperature changes at private sites averaged 0.73 °C (range = −0.87 to 2.50 °C), and exhibit a greater frequency of post-harvest increases from 0.5 to 2.5 °C compared to state sites. We repeated this comparison while controlling for the effects of control reach temperature change, treatment reach length, and gradient by plotting differences in partial residuals from the Maximum temperature model Grad_Shade (each datum = model residuals + predicted effect of Shade). We found that state site differences became less extreme for positive increases (<1.5 °C) while private comparisons appeared to occupy the same range of responses (Fig. 6).

3.2. Analysis II: shade

Correlations among shade variables were greatest for comparisons with BAPH. Sites with higher stocking levels, wider uncut buffers, or fewer stream banks harvested had greater basal area. The variable BAPH exhibited a positive Pearson's correlation with TPH (0.54) and Width (0.47) and a negative correlation with Nsides (−0.55). Variable combinations Height and CR were negatively correlated (−0.30) as were TPH and NSides (−0.52).

The shade model BasalXHeight which included parameters for basal area per hectare (BAPH), tree height, and their interaction was best-supported (Table 3; $\Delta AIC_c = 0.0$, $n = 33$, $R^2 = 0.69$, $\beta_{intercept} = 1.795$, $\beta_{BAPH} = 3.100e^{-2}$, $\beta_{Height} = -6.250e^{-2}$, $\beta_{BAPA\ *Height} = -4.680e^{-4}$, model $p < 0.001$) with an AIC_c distance of 10.7 between itself and the next-best supported model, BasalHeight (additive parameters BAPH and tree height). Its model weight ($\omega = 1.00$) indicated strong relative support for this model and virtually no support for the remaining models. The model BasalXHeight predicted
greater shade coverage with shorter trees and more basal area per hectare. An interpretation of the interaction term suggests that the effect of tree height is most acute for riparian areas with greater basal area. Residual, normal *q*–*q*, and standardized residual plots of the model parameterized by BAPH (BasalArea) indicated that certain points exhibited substantial leverage to the extent that a linear model may not be appropriate. Examination of paired variable plots suggested that plot blowdown may have influenced the leveraging outliers. A post hoc linear model that included plot blowdown in additional to basal area per hectare, tree height, and their interaction resolved the model fit issues and fit the data better than BasalXHeight (AIC_c = 7.5 lower than for BasalArea, $R^2 = 0.75$). However, site 5354 appeared responsible for contributing the blowdown effect; with its removal the interaction term in BasalXHeight ceased to confer statistical significance ($p = 0.18$) and BasalHeight graphically fits the data adequately ($R^2 = 0.70$). We did not find a relationship between hardwood predominance among sites and tree height; the Pearson's correlation between average percent hardwood at a site within 30 m of the stream and Height was 0.083 ($t = 0.466$, df = 31,

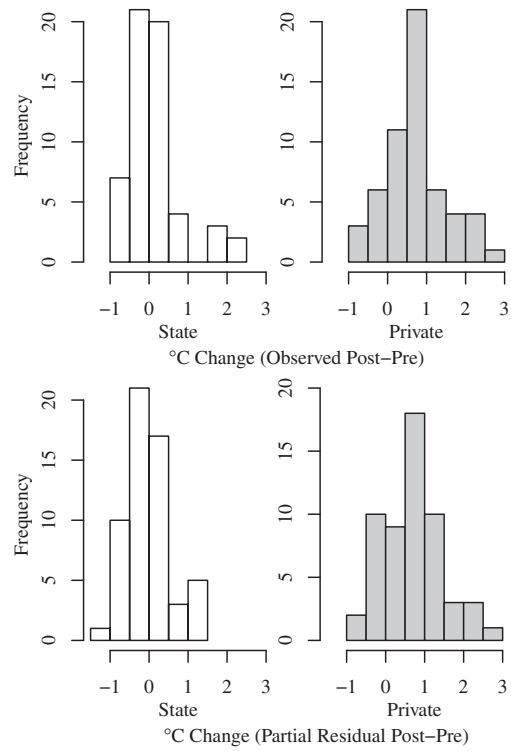

Fig. 6. Within-site pairwise differences in temperature change between post-harvest and pre-harvest values for Maximum observed data and partial residuals. Observed values are presented individually in Fig. 3. Partial-residual values represent observed values but control for site treatment reach length, upstream control temperature change, and stream gradient.

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$p = 0.644$). An alternate shade model, BufferWidth (variables: number of sides harvested, buffer width, and their interaction; Table 3), contained no vegetation plot variable information, only the buffer width and number of riparian sides harvested. Its ΔAIC_c value distanced it from the best-supported model yet it accounted for almost 50% of data variation ($n = 33$, $R^2 = 0.477$, $\beta_{intercept} = 2.294$, $\beta_{NSides} = -0.699$, $\beta_{BuffWidth} = -4.470e^{-3}$, $\beta_{NSides*BuffWidth} = 1.230e^{-2}$, model $p < 0.001$).

Private site shade values appeared to decrease pre-harvest to post-harvest. Private post-harvest shade values differed from pre-harvest values (mean change in Shade from 85% to 78%, $n_{Private} = 18$, df = 17, paired $t = -3.678$, $p = 0.002$); however, no difference was found for state site shade values pre-harvest to post-harvest (mean change in Shade from 90% to 89%, $n_{State} = 15$ df = 14, paired $t = -1.150$, $p = 0.269$). We did not find evidence that shade differed if one or both banks were harvested for private sites ($n_{SingleSide} = 4$, $n_{TwoSides} = 14$, df = 7.589, $t = 1.978$, $p = 0.085$) although the sample size for single sided harvests was low. Similarly, private site shade values did not appear to differ between Medium or Small streams ($n_{Small} = 4$, $n_{Medium} = 14$, df = 3.595, $t = -1.345$, $p = 0.257$).

4. Discussion

We estimated the magnitude of temperature changes by examining differences between pre- and post-harvest summer maximum temperatures, evaluating predicted variable contributions to temperature change, and comparing estimates of temperature change associated with private and state forests. Maximum, Average, Minimum, and Diel Fluctuation stream temperatures increased as a consequence of timber harvest on private forests. State forest stream temperature patterns remained similar before and after harvest. The increases on private sites coincide with a decline in shade due to timber harvest. In turn, the best predictor of post-harvest shade was a model including basal area within 30 m of a stream, tree height, and their interaction.

4.1. Shade and temperature change

A primary driver of changes in stream temperature was stream shade. For the four temperature values we examined, the mixed-effects models that included shade outperformed models that lacked shade. The best-supported shade models indicated that the lowest-observed shade value of 50% is associated with a predicted increase in Maximum stream temperatures by as much as 2 °C and for Minimum temperatures as little as 0.3 °C. At the greatest observed shade levels (96%) the predicted response for Maximum and minimum temperatures was −0.7 °C and −0.1 °C, respectively. This range of estimated temperature responses to site shade values is similar to results from a manipulative experiment by Johnson (2004). She determined that for a 200 m bedrock reach the temperature difference between 100% (artificial) shading and full exposure stream temperatures differed by about 4 °C. Similar to our regression estimates of negative Maximum stream temperatures at high shade values (−0.66 °C at 96% shade), Johnson found a decline of about 1 °C in maximum stream temperatures with 100% shade.

Other shade model parameter estimates indicated that stream temperatures were expected to increase with greater treatment reach lengths and low gradients (Table 4). The finding for treatment reach length is consistent with Caissie (2006), who reported general stream temperature increases with distance downstream. Our negative estimate for the coefficient of gradient indicated that temperature increases over the length of our treatment reaches were less for steeper reaches, a result that is echoed in Danehy et al. (2005), and that Subehi et al. (2009) attribute to the reduced residence time of water within the stream. An alternative explanation is that more frequent hyporheic exchange in steeper streams with step-pool morphologies may moderate stream temperatures (Anderson et al. 2005). Our negative relationship between temperature change in the control reach vs. the treatment reach was graphically described by Dent et al. (2008). They found that an abrupt temperature increase in the control reach was generally accompanied by an opposite change in the pre-harvest treatment reach. We suspect that local hydrological conditions at one of the control probe stations, resulting in locally warmer or cooler water temperatures (Bilby, 1984), could produced this temperature pattern. The temperature of the downstream station would not reflect this condition and would therefore appear to reverse the increase or decrease in temperature observed in the control reach.

4.2. Magnitude of temperature changes

The average increase in Maximum temperatures on private sites following timber harvest was estimated to be 0.7 °C. However, sites did not all behave similarly; some decreased in temperature while others exhibited higher increases. Although Mean, Minimum, and Diel Fluctuation temperatures also increased overall post-harvest, they similarly exhibited variability in response.

Overall, we did not observe a temperature increase on state sites as a result of timber harvest. While some changes in stream temperature were observed, state forest treatment effects were not substantial enough to support modeling them as differing from pre-harvest conditions. We interpret these results and the general lack of observed changes in stream temperature for state forest to indicate that treatment buffer widths and conditions on state forest sites were generally sufficient to protect against timber harvest-related increases in stream temperature. Even so, two state sites registered temperature changes between a pre-harvest year and a post-harvest year of >2.3 °C; after controlling for site factors the increases were <2 °C.

Our stream temperature models were parameterized using channel and local riparian conditions. We did not examine variables outside of study reaches such as the influence of proportion of watershed harvested. Solar exposure of clear-cut soils may affect evapotranspiration and soil temperatures (Kim and Ek, 1995). St-Hilaire et al. (2000) improved empirical stream temperature model fits by including the effect of solar exposure on soil temperatures. Hewlett and Fortson (1982) found that despite the presence of a 10–15 m wide riparian buffer along their study site in Georgia, USA, their study stream temperatures increased by more than 11 °C, much more than the authors estimated would occur under conditions of complete riparian zone removal. The authors suspected, based on ancillary data, that effluent groundwater may have been warmed in the exposed areas and then flowed into their study stream. However, a follow-up study on the same site with a more substantial riparian buffer has found no temperature increase (Dr. Rhett Jackson, Univ. of Georgia, personal communication). Bourque and Pomeroy (2001) found a relationship between stream temperature gains and proportions of upstream catchments harvested. Pollock et al. (2009) similarly found a relationship between proportion of a watershed harvested and maximum stream temperatures, although Ice et al. (2010) argue that these results are best explained by riparian conditions such as shade and channel conditions. Our models appear to have explained a substantial portion of the observed variability in stream temperature and relationships to timber harvest; however, these factors may have played an additional role in influencing our sites' stream temperatures.

The magnitudes of change in observed stream temperatures reported for this study are similar to findings from other studies which evaluated contemporary harvest practices with riparian buffers and substantially lower than values associated with older har-

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vest practices or harvesting without buffers. Levno and Rothacher (1967) found maximum temperature increases of 2.23 °C after harvest but before stream scouring (logging debris partially shaded the stream) and 6.67 °C increase post-scour. During the years 1965–1967 in the Alsea Watershed Study maximum water temperature increased 10 °C at the bottom of the Needle Branch Watershed following logging to the stream's edge, stream cleaning, and slash burning (Ice, 2008). Gomi et al. (2006) found that for four headwater streams subject to clearcut harvesting with no buffer retention, daily maximum temperatures increased between 1.9 and 8.8 °C while increases for streams with buffers ranged from 1.1 to 4.1 °C, similar to our findings.

Gomi et al. (2006) reported that treatment effects were more subdued post-harvest with inclusion of a 30 m buffer; maximum daily temperatures increased by <2 °C. When examining streams with 10 m buffers, Jackson et al. (2001) found that two out of three streams produced an increase of <2.4 °C and the third a change of −0.3 °C. Wilkerson et al. (2006) studied stream water temperature response to harvesting in Maine with different buffer widths. Streams without buffers experienced the largest temperature increases (1.4–4.4 °C). Stream with 11 m buffers showed small, but not statistically significant increases (1.0–1.4 °C) while streams with 23 m buffers as well as sites with partial harvest treatments showed no temperature increases. The results from these contemporary studies including our findings for our private forest sites indicate that some buffer retention practices likely reduce the magnitude of change but do not necessarily completely eliminate harvest effects on stream temperature. However, temperature increases and shade decreases were not ubiquitous among private sites; some did not indicate increases in temperature following harvest (Fig. 3). Other site conditions likely drove this observed range of response.

4.3. Relationships between shade and riparian characteristics

Increases in stream temperature were related to decreases in shade, both of which only occurred on private sites. These results coincide with the findings of Groom et al. (2011). However, there were ranges in shade and temperature responses on private sites reflecting variability in riparian conditions after harvesting according to minimum Forest Practices Act regulations. The variability may have been related to site differences in shade and factors related to shade.

Between 68% and 75% of variability in post-harvest shade may be accounted for by basal area within 30 m of the stream, tree height, and possibly blowdown. Sites with higher basal area within 30 m of the stream resulted in higher post-harvest shade. We anticipated that the variable TPH would inform regression models containing basal area per hectare (BAPH), as total basal area would depend on number of trees as well as tree size. The shade model ranking indicated that inclusion of the TPH variable or its interaction with BAPH did not improve model fit; given their correlation, we believe the two variables shared a similar relationship over this landscape.

Our findings suggest that sites with shorter trees had higher post-harvest shade. DeWalle (2010) found in a modeling study that buffer height and density were as important as buffer width at providing shade. However, their results predicted an increase of shade values with tree height which is counter to our findings. It may be possible that our negative relationship between tree height and shade is due to the negative correlation between crown ratios and tree height. Buffers comprised of trees with canopies tens of meters above the stream may not protect streams from mid-morning or afternoon sun exposure. We observed that private sites with low basal area generally had taller trees. The relationship between the percent stream basal area represented by hardwoods and height was not significant, suggesting that hardwood/conifer dominance did not play a role. The negative relationship between plot blowdown basal area values and stream shade appears reasonable, although the blowdown effect may be driven by extensive plot blowdown at a single site.

We found that modeling stream shade as a function of riparian buffer width and the number of stream banks harvested informative. While not as good a predictor as basal area, this model did explain 50% of the observed variability in post-harvest shade. Collectively the two models suggest that harvesting timber within riparian areas on both sides of the stream, reducing basal area and leaving narrower buffers are actions which contribute to decreases in shade.

5. Conclusion

Two years following timber harvest in our Oregon Coast Range streams, Maximum, Mean, Minimum, and Diel Fluctuation summer temperatures increased along some sites. We detected no differences between pre-harvest and post-harvest stream temperature on state forests, indicating that state forest riparian buffers prevent harvest-related increases in shade and stream temperature. Temperature increases on private sites were related to reduction in shade. Reductions in shade were related to decreases in basal area for sites with greater tree heights. Results correspond with the finding of elevated stream temperatures for private sites post-harvest in the Groom et al. (2011) temperature standard analysis. Although our study's inference is limited to the Oregon Coast Range, our determination of the relative efficacy of different buffer designs at influencing shade and stream temperatures are likely relevant to other high-rainfall low-order Douglas Fir dominated streams in the Pacific Northwest that are subject to similar harvest practices.

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Effectiveness of riparian buffers at protecting stream temperature and shade in Pacific Northwest Forests: A systematic review

Final Report
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Prepared by:
Dr. Nicole Czarnomski
Environmental Science Associates
522 SW Fifth Avenue, Suite 820
Portland, OR 97204

Dr. Cody Hale
Nutter & Associates, Inc.
360 Hawthorne Lane
Athens, GA 30606

With assistance from:
W. Terry Frueh, Marganne Allen, Dr. Jeremy Groom
Oregon Department of Forestry
2600 State St.
Salem, OR 97310

Table of Contents

Key to abbreviations and acronyms ..... *viii*

Executive Summary *1*

ES 1. Introduction **1**
ES 1.1 Background 1
ES 1.2 Objective of the Review 1

ES 2. Methods **2**

ES 3. Results and Synthesis **2**
ES 3.1 Geographical ranges and physical settings 3
ES 3.2 Rule Alternatives 3
ES 3.3 Summary 4

1. Introduction *6*

1.1 Background **6**

1.2 Objective of the Review **7**

2. Methods *8*

2.1 Purpose of protocol for systematic review **8**

2.2 Review partners **8**

2.3 Review questions **10**
2.3.1 Primary review question 10
2.3.2 Secondary question 10

2.3 Search strategy **11**

2.4 Study inclusion criteria **11**

2.5 Potential effects modifiers **12**

2.6 Data extraction strategy **12**

2.7 Study quality assessment and relevance **13**

2.8 Data synthesis **13**

3. Results and Synthesis *14*

3.1 Literature search and filter **14**

3.2 Summary of studies and management prescriptions **14**
3.2.1 Summary of publications 14
3.2.2 Study design variability 19

3.3 Geographical ranges and physical settings **20**

3.4 Measurements **24**

3.5 Variations in Statistical Analyses **28**

3.6 Rule Alternatives **28**

3.6.1 Forest Practices Act (FPA) 29
3.6.2 State Forest Management Plan (FMP) 32
3.6.3 Derived Variable Retention 34
3.6.4 Shrub Shade 35
3.6.5 Derived No-cut Buffer 36
3.6.6 Plan for Alternate Practice 40
3.6.7 One-sided Buffer 43

3.7 Study Limitations and Knowledge Gaps **45**

4. Lessons Learned – External Scientists' perspective ***46***

5. References ***48***

Appendix A. Protocol and Data Table format ***52***

A.1 Introduction **52**

A.1.1 Background 52
A.1.2 Protocol for Systematic Review 54
A.1.3 Review partners 54

A.2 Objective of the Review **55**

A.2.1 Primary review question 56
A.2.2 Secondary question 57

A.3 Methods **57**

A.3.1 Search strategy 57
A.3.2 Study inclusion criteria 60
A.3.3 Potential effect modifiers 61
A.3.4 Data extraction strategy 62
A.3.5 Study quality assessment and relevance 63
A.3.6 Data synthesis 63

A.5 Rule alternatives **65**

A.6 Data extraction and summary tables **68**

A.7 Discussion of significant modifications to the protocol **73**

Appendix B. Completed data extraction and study comparison tables ***76***

Appendix C. Data for Geographic Regions analysis. ***168***

Appendix D. Draft report, with additions ***170***

D.1 Draft Report **171**

1. Draft Introduction 171
2. Draft Methods 173
3. Draft Results and Synthesis 178

4. Draft Lessons Learned – External Scientists' Perspective 206
5. Draft References 207

D.2 Additions to the draft report 210
Draft Executive Summary 210
Draft ES 1. Introduction 210
Draft ES 2. Methods 211
Draft ES 3. Results and Synthesis 212
3.2.3 Draft Geographical ranges and physical settings 214

Appendix E. External comments, and responses to these comments, on draft report and associated additions 219

E.1 External comments, and responses to these comments, on the draft report 219

E.2 External comments, and responses to these comments, on additions to the draft report (Executive Summary, and Geographic ranges and physical settings) 248

List of Figures

Figure 1. Oregon Department of Forestry Geographic Regions. 21

Figure 2. Decrease in shade for combinations of Geographic Regions and associated buffer prescriptions. 23

Figure 3. Increase in temperature for combinations of Geographic Regions and associated buffer prescriptions. 24

Figure 4. Decrease in shade for sites with FPA buffers. 30

Figure 5. Increase in temperature for sites with FPA buffers. 31

Figure 6. Decrease in shade for sites with FMP buffers. 32

Figure 7. Increase in temperature for sites with FMP buffers. 33

Figure 8. Decrease in shade for sites with variable retention buffers. 34

Figure 9. Increase in temperature for sites with shrub shade buffers. 35

Figure 10. Decrease in shade for sites with no-cut buffers. 37

Figure 11. Increase in temperature for sites with no-cut buffers. 39

Figure 12. Decrease in shade for sites with alternate practices buffers. 41

Figure 13. Increase in temperature for sites with alternate practices buffers. 42

Figure 14. Decrease in shade for sites with south-sided buffers. 44

Figure 15. Increase in temperature for sites with south-sided buffers. 45

Draft Figure 1. Decrease in shade for sites with FPA buffers. 191

Draft Figure 2. Increase in temperature for sites with FPA buffers. 192

Draft Figure 3. Decrease in shade for sites with FMP buffers. 193

Draft Figure 4. Increase in temperature for sites with FMP buffers. 194

Draft Figure 5. Decrease in shade for sites with variable retention buffers. 195

Draft Figure 6. Increase in temperature for sites with shrub shade buffers. 196

Draft Figure 7. Decrease in shade for sites with no-cut buffers. 197

Draft Figure 8. Increase in temperature for sites with no-cut buffers..... 199

Draft Figure 9. Decrease in shade for sites with alternate practices buffers..... 201

Draft Figure 10. Increase in temperature for sites with alternate practices buffers. 202

Draft Figure 11. Decrease in shade for sites with south-sided buffers. 203

Draft Figure 12. Increase in temperature for sites with south-sided buffers. 204

Draft Figure 1b. Oregon Department of Forestry Geographic Regions. 215

Draft Figure 2b. Decrease in shade for each Geographic Region..... 217

Draft Figure 3b. Increase in temperature for each Geographic Region. 218

List of Tables

Table 1. Authors for each section of the report. 9

Table 2. Summary information on publications included in the review. 15

Table 3. Summary of publications: outcomes measured and study relevance to the primary review question. 19

Table 4. Publications with overlap of data, or same sites, from the same study. 20

Table 5. Information on effects modifiers addressed in publications. 27

Table 6. Total number of studies of high relevance to each rule alternative. 29

Table A.1 Elements described in a protocol for conducting a systematic review. 54

Table A.2.2 Definition of components of the primary systematic review question. 57

Table A.5.1 Recommended initial range of alternatives for riparian rule analysis on small and medium fish bearing streams. 66

Table A.6.1 Determination of inclusion of studies, found in the search for potentially relevant literature, in this review. 68

Table A.6.2 Data to be extracted from each publication included in evaluating the review question "For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?" 69

Table A.6.3 Summary of information from each study that indicates its quality and relevance to the review question. 71

Table A.6.4 Relevance of each study to each rule alternative as listed in Table A.5.1. 73

Completed Tables A.6.2 Data to be extracted from each publication included in evaluating the review question "For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?" 76

Completed Table A.6.3 Summary of information from each study that indicates its quality and relevance to the review question. An X indicates the study incorporates this characteristic. 162

Completed Table A.6.4 Relevance of each study to each rule alternative as listed in Table A.5.1. 166

Table C1. Data to compare effectiveness of different buffer prescriptions between ODF Geographic Regions for each study. 168

Draft Table 1. Summary information on publications included in the review. 180

DraftTable 2. Publications with overlap of data from the same study..... 184

Draft Table 3. Summary of publication measure and relevance to the primary review question. 185

Draft Table 4. Information on effects modifiers. 188

Key to abbreviations and acronyms

Board - Oregon Board of Forestry

cfs - cubic feet per second (a unit of streamflow)

FPA - Forest Practices Act (for private land)

FMP - Forest Management Plan (for Oregon State Forests)

HWC - hardwood conversion

OAR - Oregon Administrative Rules

ODEQ - Oregon Department of Environmental Quality

ODF - Oregon Department of Forestry

ORS - Oregon Revised Statutes

PCW - Protecting Cold Water criterion

RipStream – Riparian Function and Stream Temperature Study

RMA - Riparian Management Area

RSERT - RipStream External Review Team

SR - Systematic Review

Executive Summary

ES 1. Introduction

ES 1.1 Background

The Oregon Board of Forestry ("Board") made a finding of degradation that stream protections afforded to small- and medium-sized fish-bearing streams under the Forest Practices Act (FPA) were not likely protective of the Oregon Department of Environmental Quality (ODEQ) Protecting Cold Water (PCW) criterion. This criterion prohibits human activities, such as timber harvest, from increasing stream temperatures by more than 0.3 ºC, for all sources taken together at the point of maximum impact, at locations critical to salmon, steelhead or bull trout. The Board's finding was based on scientific outcomes of the Oregon Department of Forestry (ODF) Riparian and Stream Function (RipStream) monitoring project. ODF has therefore undertaken a systematic science review in support of a riparian rule analysis to address concerns about meeting the PCW criterion.

The geographic scope of the RipStream findings is limited to streams in the Coast Range and Interior Geographic Regions of Oregon (as defined in Oregon Administrative Rules [OAR] 629-635-0220). The geographic extent of the rule analysis is therefore limited to Geographic Regions in western Oregon. This limitation is due to the riparian vegetation, climate and hydrologic characteristics of eastern Oregon being significantly different enough from those included in the RipStream study to preclude extending a rule change to eastern Oregon. Whether all five western Oregon Geographic Regions, or only a subset of the five, will be included in the rule analysis has yet to be determined. At their July 2012 meeting, the Board approved consideration of 16 rule alternatives (contributed by stakeholders) for meeting the PCW criterion during harvest operations.

ES 1.2 Objective of the Review

This systematic review is designed to provide scientific guidance to the Board on the efficacy of the 16 rule alternatives in addressing the following rule analysis objective developed by the Board at their April 2012 meeting:

> **Establish riparian protection measures for small and medium fish-bearing streams that maintain and promote shade conditions that insure, to the**

maximum extent practicable, the achievement of the Protecting Cold Water criterion.

A secondary purpose of this review is to inform the Board's decision on the geographic extent of the rule analysis within western Oregon.

ES 2. Methods

A protocol for this systematic review was developed following guidance on conducting systematic reviews in the natural resource sciences. This method was selected because it provides for rigor and transparency concerning how studies are searched for, which ones are included in the review, and how they are analyzed. This protocol provided a road map for how to conduct the review of scientific literature relevant to the focused question:

For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?

The review seeks to answer this question with evidence, as opposed to the authors' interpretation of such evidence, from existing studies. Studies are rigorously screened for quality and relevance to this question. Finally, the entire process of conducting the review allows for greater inclusion of review partners (e.g., stakeholders and technical experts), as all steps of the review are fully documented for transparency. ODF requested and received input from these partners, thereby strengthening the quality of this systematic review.

To minimize bias in the review, ODF hired external scientists to review the studies and synthesize their analyses. ODF coordinated the work of the scientists and all other partners, and wrote portions of this report.

ES 3. Results and Synthesis

The systematic search found 1,456 publications, of which 25 passed all the inclusion criteria for the review. Of included publications, 10 were governmental reports, 13 were peer reviewed journal articles, and two documents were unpublished and in review. Since several of the publications are from the same study, these 25 publications represent 19 distinct studies. The publications were divided between those measuring shade only (9), temperature only (7), or both (9).

ES 3.1 Geographical ranges and physical settings

Due to the geographically-focused review question, all publications were limited to areas within, or similar to, Oregon west of the Cascade crest. Considered in terms of ODF Geographic Regions, twelve publications had study sites in the Coast Range, two in the Western Cascades, and eleven in the Interior.

To gain insight on geographic extent of the rule analysis, effectiveness of buffer prescriptions were compared between ODF Geographic Regions. These comparisons revealed no obvious pattern in differences by Geographic Region for the various buffer prescriptions. The inability to discern a pattern may be influenced by the small amount of data available for robust comparisons.

ES 3.2 Rule Alternatives

Each reviewed publication was rated for relevance to the sixteen rule alternatives proposed by the Board. Seven of the sixteen rule alternatives had at least one highly relevant study (i.e., the study provides quantitative data that addresses the effectiveness of a particular prescription of a rule alternative at protecting stream temperature or shade). Nine rule alternatives only had studies that were of low relevance, and therefore are not examined because they lack evidence concerning their ability to protect cold water and shade in western Oregon.

Only two classes of rule alternatives were shown to be clearly effective at protecting cold water or shade by high quality studies (quality gauged via a "confidence score"): Variable retention and Derived no-cut buffers. It is important to note the large degree of variability in the findings - both across publications and within publications containing numerous sites – indicates there would be uncertainty in identifying a buffer prescription that would achieve the PCW criterion. Additionally, we recognize that contributing factors (i.e., exclusive of characteristics of each buffer studied) may influence stream temperatures. These factors were not systematically assessed for this review due to the different ways contributing factors were considered and incorporated into each study.

The variable retention group includes two Board-approved rule alternatives considered in the review (State Forest Management Plan [FMP] and Forest Practices Act [FPA]), and studies of two other rules (ODF's previous riparian protection rule, and Alaska's version of the FPA).

The only FMP study available, which had a high confidence score, showed that both shade (average change in shade: -1%) and temperature (average change in temperature: 0.0 °C) were protected using that prescription. Of the four studies that examined the FPA, results showed a change in percent shade between -0.5% and -9%, yet none of those with temperature data met the PCW criterion. Confidence scores for these studies ranged from low to high. Of the other two variable retention prescriptions tested, one study had some sites that appeared to protect shade. This study was based on the ODF riparian rules from before 1994, had a low confidence score, and the average change in shade was -19% (temperature data were not collected).

No-cut buffers were the most extensively studied of all the rule alternatives with 12 studies. It should be noted that many of the studies included multiple sites of differing buffer widths and thus their data could not be averaged in a meaningful way. Nearly all studies that examined shade had some sites wherein shade was protected, and their confidence scores ranged from low to high. Four of seven studies that measured stream temperatures had some sites that appeared to meet the PCW criterion, three of which had a range of buffer widths.

Three other rule alternatives were assessed for their effectiveness at protecting cold water and/or shade. The shrub shade alternative had a low confidence study with three sites, and came close to, but appeared to not achieve, the PCW criterion. Similarly, the south-sided buffers had one study of low confidence with three sites. The results show this buffer was protective of shade, and came close to, but appeared to not achieve, the PCW criterion.

The final rule alternative, plan for alternate practices, acts as a catch-all for riparian management prescriptions that did not fit into other rule alternatives. As such, it includes six different prescriptions analyzed in seven studies. Two prescriptions (undefined “site specific” plans, and hardwood conversions (HWC) following each of Washington and Oregon’s rules) had sites wherein shade was protected (low to medium confidence scores), and only Washington’s HWC (low confidence score) had some sites wherein the PCW criterion appeared to be met.

ES 3.3 Summary

This review provides three key components that inform the Riparian Rule Analysis:

1. Nineteen studies (with 25 publications) have assessed the effectiveness of riparian buffers to protect cold water or shade in forest harvest operations in the Pacific Northwest. These studies vary widely in both their designs and in confidence of their findings.
2. The evidence from this suite of studies only supports two classes of rule alternatives as effective in meeting the Protecting Cold Water criterion:

   A. Variable retention buffers (including State Forest Management Plan)

   B. No-cut buffers

3. No consistent pattern presented itself when comparing temperature and shade results between Geographic Regions of western Oregon, although there are not enough data available to support this assessment with a high degree of confidence.

1. Introduction

1.1 Background

Stream temperature is an important control on aquatic community composition and the chemical and biological processes that support them (Beitinger and Fitzpatrick, 1979). Many Oregon streams support several cold-water fisheries (e.g., salmon, steelhead, cutthroat) which are important to the region's economy, culture, and recreational activities. These fish are thermally adapted to specific water temperature regimes for various life stages such as egg and smolt survival, spawning, and adult migration (Richter and Kolmes, 2005). These regimes are affected by several natural processes including direct exposure to sunlight, the transfer of thermal energy between the stream and its environment, evaporation, water exchange with groundwater or the hyporheic zone, and others (Brown, 1969; Johnson, 2004). Of these factors, direct exposure to sunlight is a major contributor to maximum daily summer temperatures for smaller streams, and this exposure may increase following timber harvest (Brown and Krygier, 1970; Johnson, 2004; Sinokrot and Stefan, 1993). Therefore, maintaining riparian shade may serve as an effective tool for minimizing the increases in stream temperature for small- to medium-sized streams during the summer months when maximum stream temperatures are observed (Johnson, 2004).

Oregon has enacted timber harvest regulations to maintain shade on streams following timber harvest (Oregon Department of Forestry, 2010). Timber harvest operations are considered in compliance with ODEQ water quality standards (ODEQ, 2004) if harvest operations comply with the Forest Practices Act (FPA; Oregon Revised Statutes [ORS] 527.770). The Oregon Department of Forestry (ODF) must establish best management practices and rules that will meet state water quality standards and periodically conduct studies to determine if the FPA effectively meets state water quality standards (ORS 527.765, 527.710).

ODF initiated its Riparian Function and Stream Temperature (RipStream) monitoring project in 2002 to assess the effectiveness of the FPA and State Forests standards at complying with ODEQ water quality standards for temperature. One of the temperature criteria examined was the Protecting Cold Water (PCW) criterion, which is designed to prevent warming of salmonid-bearing streams as a result of anthropogenic activities. This criterion prohibits human activities, such as timber harvest, from increasing stream temperatures by more than 0.3 ºC at the

point of maximum impact where: a) salmon, steelhead or bull trout are present; b) streams are designated as critical habitat for salmonids; or c) streams are necessary to provide cold water to a) (Oregon Administrative Rules [OAR] 340-041-0028 (11)). An analysis of the pre- and post-harvest data indicated that the PCW criterion was likely not being met at all study sites with FPA buffers (i.e., these sites frequently exhibited temperature increases greater than 0.3 ºC; [Groom et al., 2011a]). This finding of degradation (officially approved by the Oregon Board of Forestry [Board], January, 2012) initiated an FPA riparian rule analysis (ORS 527.714(5)(a)). As part of this analysis, stakeholders contributed, and the Board approved, 16 alternative methods of riparian management as options for meeting the PCW criterion during future near-stream harvest operations.

The geographic scope of the findings of degradation are based on Groom et al. (2011b), which studied streams in the Coast Range and Interior Geographic Regions of Oregon (as defined in OAR 629-635-0220). While the exact geographic extent of the rule analysis is yet to be determined, it will be limited to western Oregon. This limitation is due to the vegetation, climate and hydrologic characteristics of eastern Oregon being significantly different enough from those included in the RipStream study to preclude extending a rule to eastern Oregon.

This systematic review (SR) was completed to fulfill a requirement of the rule analysis process: proposed rules must reflect available scientific information (ORS 527.714 (5)(c)). The SR will also serve to inform the decision on the geographic extent of the rule analysis relative to the RipStream findings on FPA sufficiency. Therefore, this SR will, through evaluating a focused question, directly assist in evaluating the 16 alternative scenarios for riparian management and help inform the ODF rule analysis. However, this review does not recommend which alternative is the best to choose, nor explicitly define a particular rule prescription. ODF staff will draft a report with Board recommendations based on the outcomes of the SR and data analyses related to the rule analysis.

1.2 Objective of the Review

This systematic review is designed to provide scientific guidance, per ORS 527.714 (5)(c), to the Board in addressing the following objective of the rule analysis, developed by the Board at their April 2012 meeting:

Establish riparian protection measures for small and medium fish-bearing streams that maintain and promote shade conditions that insure, to the maximum extent practicable, the achievement of the Protecting Cold Water criterion.

Small streams are defined as having average annual flows ≤57 L/s (2 cfs), and medium streams are defined as having flows >57 L/s (2 cfs) and ≤283 L/s (10 cfs; Oregon Department of Forestry, 2010). Fish-bearing streams are those for which anadromous, game, or threatened and endangered fish presence has been observed or modeled. Specifically, this review is designed to provide insight on the efficacy of the 16 rule alternatives that were approved by the Board at their July 2012 meeting (Table A.5). A secondary purpose is to inform the Board's decision on the geographic extent of the rule analysis.

2. Methods

This section summarizes the protocol for conducting the systematic review (for details of the protocol, refer to Appendix A). Note that blank copies of the tables to be completed by the reviewers are listed in Section A.6, whereas the associated completed tables are in Appendix B. The protocol was approved by the Board (March 2013), and was modified slightly during the review process (Appendix A).

2.1 Purpose of protocol for systematic review

Protocols provide a road map for how to conduct a systematic review of scientific literature relevant to a narrowly-defined question (Centre for Evidence-based Conservation, 2013). A systematic review seeks to answer this question with evidence, as opposed to the authors' interpretation of such evidence, from existing studies that are rigorously screened for quality and relevance to this question. The structured process provides for rigor and transparency concerning how studies are searched for, which ones are included in the review, and how they are analyzed. This process also allows for a review to be either updated in the future, or completed by another party.

2.2 Review partners

Numerous partners strengthened the quality of this systematic review. ODF staff composed an initial draft of the protocol, then obtained input on it from a group of stakeholders and the RipStream External Review Team (RSERT). These groups included university, federal,

forest industry, and state scientists; staff from the Oregon Departments of Forestry, Environmental Quality, and Fish & Wildlife; and non-governmental organizations (e.g., Wild Salmon Center, Pacific Rivers Council). Similarly, a reference librarian from the Oregon State Library assisted in refining the search strategy. Finally, ODF coordinated the work of these partners, plus that of the external reviewers. All partners had the opportunity to provide input on:

- The protocol and question for this review;
- A draft list of publications to consider for inclusion in the review to assess if any studies were not found;
- A draft list of included publications to assess whether or not the inclusion criteria were appropriately applied;
- A draft of the completed SR report.

To minimize bias in the review, ODF hired external scientists ("the reviewers", Drs. Nicole Czarnomski and V. Cody Hale) to conduct the review. These reviewers cross-checked their work by reviewing the same subset of studies (including comparisons of assessments for study relevance, quality, and data extraction). Each reviewer then independently reviewed half the remaining studies included in the review. Where the reviewers, in coordination with ODF, found ways to improve the protocol, it was modified with alterations documented in Appendix A. ODF staff helped calculate numbers for figures (double-checked by Drs. Czarnomski and Hale) and provided additional support. After analyzing the articles, the reviewers collaboratively wrote this report synthesizing their analyses. Table 1 outlines contributing authors of each section of the report.

Table 1. Authors for each section of the report.

Report section*	ODF staff	Drs. Czarnomski & Hale
Executive Summary	X	
1, 2, 3.1	X	
3.2-3.7, 4		X
3.3	X	X
A, C, D, E	X	X
Completed Table A.6.1	X	
Completed Tables A.6.2-4		X

*Each party reviewed the work of the other party.

2.3 Review questions

2.3.1 Primary review question

Systematic reviews are designed to assess a body of literature through the lens of a focused question regarding the efficacy of active treatments, rather than a general topic of concern to policy or practice. The question should be value-free to the extent possible, answerable in scientific terms, and specify the subject, treatment, comparator, and outcome(s) of interest. The question is also important since it is used to generate terms used in the literature search and to determine relevance criteria for including or excluding articles from the review.

The elements of this review's question are based on the rule analysis objective and the finding of degradation, and were developed in stages. ODF staff (T. Frueh, J. Groom, and M. Allen) developed a draft review question and protocol. The question was refined in consultation with representative stakeholders and RSERT to ensure the question's importance and appropriateness of scope for this review. The question was then further refined with ODF input. Although the rule objective focuses on fish-bearing streams, "fish-bearing" was not included in the review question because many, if not most, studies do not explicitly state whether or not they were conducted in streams determined to be fish-bearing according to ODF protocol. Had we included "fish-bearing", the number of included studies would have dropped substantially, and thereby increasing the likelihood that we miss important evidence. The review question is:

> ***For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?***

2.3.2 Secondary question

This review evaluated differences between studies that might explain variations among study outcomes. These differences may be due to effects modifiers (see Section A.3.3 for more information on these modifiers), and this secondary question explicitly addresses the causes of these differences. To the extent that relevant information is available in reviewed studies, this secondary question was addressed:

> ***For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, how do effects modifiers (e.g., discharge, substrate characteristics, length of buffers, stream aspect), in combination with near-stream forest management, change stream temperatures or riparian shade?***

2.3 Search strategy

An important aspect of systematic review is the use of a search strategy that specifies, *a priori*, how a comprehensive and unbiased sample of the literature will be searched. We decided to search as widely as possible, then use rigorous inclusion criteria to determine which studies to include. All publications found in each searched source were saved in a database, except for internet searches from which the first 100 results were reviewed for relevant publications (this restriction follows CEBC [2013] guidance). Results with indeterminate information (e.g., incomplete citation) or duplicates were discarded. For every search, the following information is documented (see Data Supplement 1, Lit-Search_Filter.xls):

- Date when search was conducted
- Database, search engine, website, library, or professional contact that was queried
- Exact search strings used

2.4 Study inclusion criteria

Study inclusion criteria are predefined to ensure an objective selection of the relevant literature. For this review, the studies must directly inform the primary review question in the context of the rule alternatives and rule objective. Only primary studies (i.e., studies with original data, not reviews, modeling, or meta-analyses) were included since ODF wants to base the rule analysis on evidence, not authors' interpretation of the evidence. While peer-reviewed articles are the gold standard in science, we decided to include "gray literature" (i.e., articles that might have less rigor in either peer-review or research methods / analysis, e.g., government reports, graduate theses) and manuscripts in review because some of these studies are most relevant to the review question. This relevancy stems from a common requirement that agencies (e.g., ODF, Washington Dept. of Natural Resources) assess the effectiveness of their respective rules via studies. In addition, only studies that measure the effects of recent forest harvests, with near-stream areas managed for protecting water (e.g., similar to OAR 629-635-0100), on stream temperature or riparian shade were included since these elements are essential to inform the objective of the rule analysis that provides the impetus for conducting this study. Restricting studies to those where harvest was recent (<5 years) with respect to data collection is warranted due to the decline, with time, of adverse impacts of harvest on stream temperature and riparian shade (Hale, 2007; Johnson and Jones, 2000). The final inclusion criteria are:

- Studies must have proper controls with which to measure the effects of buffer treatments;
- Studies must have been conducted in sites with similar stream sizes as ODF's classification of small and medium streams (Oregon Department of Forestry, 1994); and,
- Studies must have been located in similar forests as those of western Oregon.

Inclusion criteria are further detailed in Table A.6.1.

With these criteria in mind, inclusion was determined initially on viewing the titles of articles. When titles provided insufficient information to determine meeting all inclusion criteria, the ODF review coordinator read abstracts to determine inclusion. Where there was still insufficient information to make a decision, an article's inclusion was determined by reading the full text. Studies that meet all inclusion criteria were reviewed by the external reviewers. For transparency, the fate (i.e., inclusion or exclusion), and basis for this decision, of each publication found in the search are documented in Data Supplement 1.

2.5 Potential effects modifiers

Although studies may have very similar methods, they may show differences in the measured outcomes. These differences may be due to circumstances ("effects modifiers") that alter the outcomes. For example, two studies may have identical buffer widths, yet if they have different buffer lengths, they might exhibit different changes in stream temperatures. Thus, these effects modifiers are important to consider when synthesizing the information extracted from studies. The role effects modifiers played in study outcomes is assessed using Table A.6.2 and discussed in the narrative synthesis (Section 3).

2.6 Data extraction strategy

When conducting a systematic review, it is important to extract both information about the studies and their respective primary data. This information focuses the review on evidence instead of authors' interpretation of the evidence. Data extraction tables allow for objective, consistent, and transparent extraction of these data. In addition, these tables help to highlight gaps in our understanding. Each study's data were compiled using Table A.6.2. This table was developed by modifying those of Bowler et al. (2008) and Burnett et al. (2008), testing data extraction with several studies, and with input from RSERT and stakeholders. Reviewers also assessed various components (e.g., bias, effects modifiers) that provide a more complete

understanding of the context, relevance and relative strength of studies (Completed Tables A.6.2).

2.7 Study quality assessment and relevance

When synthesizing data from the studies, it is important to consider both the quality of each study and its relevance to the review question. For example, a study might have directly addressed the review question, yet was poorly conducted so as to provide little confidence in the study's results. Conversely, a study may have been conducted very well, yet has only weak relevance to the review question.

External reviewers completed tables that enable quick, objective comparisons of studies. Table A.6.3 addresses the quality of studies by determining e.g., the rigor of their controls and number of replicates. A summary metric, the Confidence Score, combines the various aspects that make for a high quality study (Table A.6.3). This metric is designed to help assess the quality of the information when looking at the effectiveness of a particular buffer type. This table also determines study relevance to the review question by determining how close studies are geographically and in stream size to those of Groom et al. (2011a). Table A.6.4 determines whether studies directly or indirectly addressed a rule alternative. Notes additionally provided by reviewers using Table A.6.2 further illuminate study quality and relevance (e.g., robustness of study measures, sources of bias, consideration of effects modifiers).

2.8 Data synthesis

To make sense of the information extracted and analyzed from the studies, a narrative synthesizes the information collected in Completed Tables A.6.2-A.6.4 (Appendix B). This synthesis assesses the differences and commonalities between riparian management scenarios used in studies, their respective outcomes, and Geographic Regions. For each rule alternative, the synthesis discusses:

- Number of studies that directly or indirectly address the alternative;
- Results discussed by Geographic Region;
- Evidence from a suite of studies regarding the effectiveness of the alternative, including:
    - range of variation in metrics defining each alternative (e.g., buffer width, basal area retention)
    - range of variation in outcomes measured

    - degree of effectiveness at protecting cold water or riparian shade
- Role of effects modifiers in the stream temperature and riparian shade outcomes that were measured; and
- Significant gaps in our understanding.

3. Results and Synthesis

3.1 Literature search and filter

In a search of studies relevant to this review, 1,456 studies were identified, of which 25 met all criteria for inclusion in the review (Table 2; Data Supplement 1, Lit_Search_Filter.xls). Of studies excluded from the review, approximately 80% were rejected by reading the title, ~10-15% were rejected by reading the abstract, and the remainder required reading a portion of the complete text. When stakeholders and technical experts were asked to provide input on the results of the literature search and filtering process, zero comments were received.

3.2 Summary of studies and management prescriptions

3.2.1 Summary of publications

Of the 25 publications reviewed, 10 were governmental reports, 13 were peer reviewed journal articles, and two publications were unpublished and in review (Table 2). Of the publications considered to have a high focus on the SR question, they were evenly divided among those providing measures of temperature and those measuring shade (Table 3). However, government reports more often provided measures of shade (90% of publications) and peer review / in review articles more often provided measures of temperature (91% of publications). Only four publications were considered to have a low relevance to the SR question (i.e., they were indirectly related, though still included because they met the inclusion criteria and provided useable data), and they were all peer reviewed articles that primarily measured shade (Table 3; Completed Table A.6.3).

Table 2. Summary information on publications included in the review.

ID*	Study	Location (Georegion/# of sites)†	Pub. typeα	Rel.?Δ	Buffer Prescriptions±	Conf. Sc.**	Effectiveness data (location of data within a publication, method of extraction if applicable)††	Measurements	
								Temp.	Shade
A	Allen and Dent, 2001	OR (CR/18)	Gov't.	Y	14 no-cut buffers (20-70 ft.; 6-21 m), 2 riparian conifer restorations (RCR), 2 site-specific (SS) plans	7	Range in difference in shade (Table B1, excluding large streams and Blue Mtn. data, measured with respect to avg. forested shade) no-cut (n=14): -38 to -4%; RCR (-28, -6%), SS (-9, 0%)		X
B	Brazier and Brown, 1973	OR (CR/7, I/4)	Gov't.	Y	11 no-cut buffers (10-60 ft.; 3-18 m)	5	Range in change in canopy cover (Fig. 5; 10-60' buffers values compared with those at 100'): 0 to -60% Observed temp. change (Table 1) +0.6 to +5 ºC	X	X
C	Brosofske et al., 1997	WA (Cascades)	PR	N	14 no-cut buffers (26-141 ft.; 8-43 m)	6.5	Range in change in radiation (Fig. 8): 0 to +0.1 kW/m2		X
D	Danehy et al., 2007	OR (CR/7)	PR	N	7 no-cut buffers (49 ft.;15 m; Note: outside of buffers was thinned and not clearcut)	7	Change in insolation (Table 1, measured with respect to mean mature; MJ/m2/day): uncut (mean: +95, std. dev.: ±89), thinned (mean: +137, std. dev.: ± 28)	X	X
E	Dent, 2001	OR (CR/4, I/7)	Gov't.	Y	1 no-cut buffer (70 ft.; 21 m); 3 riparian conifer restorations; 7 standard Forest Practices Act (FPA) prescriptions.	6.5	Change in cover (averages for medium (M) and small (S) streams west of Cascade crest, Table 6): No-cut, medium (n=1): -2%; FPA: small (n=3): -9% (range -4 to -16), Med (n=4): -4.5% (range -18 to +4); RCR: small (n=2): -20% (-6, -34); Med. (n=1): -36%		X
F_1	Dent and Walsh, 1997	OR (CR/7, I/4)	Gov't.	Y	4 standard FPA prescriptions; 4 hardwood conversions (HWCs); 3 HWCs limiting openings on south side of streams	6	From Table 3: Rule / n / Avg. Change 7-D max., ºC (range) / Avg. change in cover, % (range) FPA / 4 / +1.4 (+0.4 to +1.8) / -0.5 (-18 to +9) HWC / 4 / +1.7 (+0.4 to +3.2) / -8.5 (-20 to +6) S. Side / 3 / +0.5 (+0.0 to +1.4) / -4 (0 to -7)	X	X

ID*	Study	Location (Georegion/# of sites)†	Pub. typeα	Rel.?Δ	Buffer Prescriptions±	Conf. Sc.**	Effectiveness data (location of data within a publication, method of extraction if applicable)††	Measurements	
								Temp.	Shade
G_2	Gomi et al., 2006	BC	PR	Y	No-cut buffers (1 33 ft/10 m, 2 98 ft./30 m)	9.5	Mean (maximum) treatment effect summer maximum temp. (Table 3): 10 m: +1.0 (+4.1) ºC; 30 m: +0.2 (+1.4) ºC	X	
H_3	Groom et al., 2011a	OR (CR/30, I/3)	PR	Y	18 standard FPA prescriptions; 15 State Forest Management Plan (FMP) prescriptions	12	Avg. temp. change (text, p. 1626): FPA: 0.7 ºC (range -0.9 to +2.5 ºC); FMP: 0.0 ºC (range -0.9 to +2.3 ºC) Avg. change in shade (text p. 1627): FPA: -7%; FMP: -1%	X	X
I_3	Groom et al., 2011b	OR (CR/30, I/3)	PR	Y	18 standard FPA prescriptions; 15 State Forest Management Plan (FMP) prescriptions	12	Chance of exceeding PCW standard (increase of 0.3 ºC): FPA: 40%; FMP: 9%	X	
J_3	Groom et al., 2013	OR (CR/30, I/3)	IR	Y	18 standard FPA prescriptions; 15 State Forest Management Plan (FMP) prescriptions	12	Number of sites exceeding 16 or 18 ºC criteria: 3	X	
K	Hunter, 2010	WA (Coast Ranges)	Gov't.	Y	7 hardwood conversions	6	Range in difference of mean shade (pre-post, from text at each site): -3 to -13% Range in temperature changes (difference in temp. at upstream vs. downstream end of harvest unit, from figure for each site): -1.8 to +2.0 ºC.	X	X
L_4	Jackson et al., 2007	WA (Coast Ranges)	PR	N	3 no-cut buffers (7-69 ft.; 2-21 m); 2 nonmerchantable tree buffers	7	Change in cover (Table 4; average for both post-harvest years) no-cut: -54% (range: -15 to -78%); nonmerchantable tree: -58% (-35, -80%)		X
M_4	Jackson et al., 2001	WA (Coast Ranges)	PR	Y	3 no-cut buffers (7-69 ft.; 2-21 m); 2 nonmerchantable tree buffers	6	Range in change in temperature (Table 3) no-cut buffers: -0.5 to +2.6 ºC; nonmerchantable tree buffers: +2.8 to +4.9 ºC	X	
N_5	Janisch et al., 2012	WA (Coast Ranges)	PR	Y	6 no-cut buffers (33-49 ft.; 10-15 m); 5 patch buffers	12	Mean disturbances, Maximum Daily Temperature (Figure 3b; range): no-cut: +0.7(0.0 to +1.9) ºC; patch: +0.6 (+0.1 to +1.2) ºC Change in canopy-topographic density (text p. 408), %: no-cut: -8; patch: -18	X	X
O_2	Kiffney et al., 2003	BC	PR	Y	No-cut buffers (3 33 ft./10 m, 3 98 ft./30 m)	6	Difference in PAR, µmol/m2/s (Fig. 2): 10 m: +78 ; 30 m: +8	X	X

ID*	Study	Location (Georegion/# of sites)†	Pub. typeα	Rel.?Δ	Buffer Prescriptions±	Conf. Sc.**	Effectiveness data (location of data within a publication, method of extraction if applicable)††	Measurements	
								Temp.	Shade
							Increase in maximum summer water temperatures with respect to control reaches (text p. 1066): 10 m: 3 ºC; 1.6 ºC		
P	Martin, 2004	SE AK	Gov't.	Y	3 RMAs with inner no-cut (25 ft.; 8 m) & outer partial cut (41 ft.; 12 m)	8	Avg. change in shade (difference pre-post means for each reach, Table 3): -29% (-24%, -26%, -38%)		X
Q	Morman, 1993	OR (CR/9, I/8)	Gov't.	Y	17 Variable-retention RMAs (39-154 ft.; 12-47 m)	6	Change in aquatic area shading (compiled from data on pp. 49-117): +1 to -35%		X
R	Newton and Cole, 2013a	OR (CR/1, I/2)	IR	Y	3 standard FPA prescriptions[αα]	11	Average change 7-day moving mean maxima temperature over the reach, post- pre (Figure 7): +0.6 ºC (range: -0.1 to +1.3 ºC)	X	
S	Newton and Cole, 2013b	OR (CR/1, I/1, WC/1)	PR	Y	3 shrub only buffers[αα]	7	Average temperature differentials across 180 m shrub shade reaches, with respect to pre-treatment data[ΔΔ]: +0.7 ºC (range -0.3 to +1.2 ºC)	X	
T	Rashin et al., 1992	WA (Cascades, Coast ranges)	Gov't.	Y	9 no-cut buffers (5-190 ft.; 1.5-58 m)	4	Range in median max. daily water temp. differentials (Table 1): +0.1 to +4.6 ºC	X	
U	Schuett-Hames et al., 2012	WA (Cascades, Coast ranges)	Gov't.	Y	13 with ½ of length no-cut buffers (50 ft.; 15 m), ½ length cut to stream edge; 3 with radial no-cut buffers at point of initiation of perennial flow (PIP) (56 ft. (17 m) radius)	7.5	Average change in shade (Table 49; average of 3 years difference between mean value for patch type and that of reference) 1/2-length no-cut buffers: -29% (range -24% to -38%); PIP: -30% (range -28% to -34%)		X
V	Steinblums et al., 1984	OR (I/17 to 19, WC/21 to 23)	PR	Y	40 no-cut buffers (25-115ft.; 8-35 m)	5	Fig. 2: Range in change in cover (Fig. 2; measured with respect to value at 140'): 0 to -73%		X
W	Veldhuisen and Couvelier, 2006	WA (N. Cascades)	Gov't.	Y	9 no-cut buffers (16-105 ft.; 5-32 m)	6	Range in change in shade (Appendix 4A, Upr Childs, Red Dog, Full Sail, Anchor Stm., WhiteWash; 10-31 m): -3 to -33%; Range in change in 7DAD max. temp. (Appendices 2 (Powell, Savage), 3(Long Tom, RoundAgain, SingleShot, & 4B (Powell, RedDog, AnchorStm, Grisdale, Miller Pt.) : +1.0 to +8.3 ºC	X	X

ID*	Study	Location (Georegion/# of sites)†	Pub. typeα	Rel.?Δ	Buffer Prescriptions±	Conf. Sc.**	Effectiveness data (location of data within a publication, method of extraction if applicable)††	Measurements	
								Temp.	Shade
X_5	Wilk et al., 2010	WA (Coast Ranges)	PR	N	7 no-cut buffers (33-49 ft.; 10-15 m); 3 patch buffers	10	Difference in canopy closure (Table 1): no-cut: -9%; patch buffers (average of patch (cut) and patch (leave) since same sites): -45%		X
Y_1	Zwieniecki and Newton, 1999	OR (CR/7, I/4)	PR	Y	6 standard FPA prescriptions; 5 hardwood conversions (HWCs); 3 HWCs limiting openings on south side of streams	6.5	For all prescriptions, no stat.sig. difference in shade; changes in temperature (differences between top and bottom of unit, averaged per prescription, from Fig.3‡‡ FPA: +1.3ºC; HWC: +1.3 ºC; S-sided HWC: +0.5 ºC	X	X

*Relates publications to ID for graphing purposes. Publications with the same subscript are from the same study (see Table 4).
† For studies located in Oregon, the Oregon Department of Forestry Geographic Regions (per OAR 629-635-0220) in which studies were completed is listed in parentheses, along with the associated number of sites included in this review; Geographic Regions: CR=Coast Range; I=Interior; WC=West Cascades; no data were collected in South Coast and Siskyous Geographic Regions. Blue Mountains and East Cascades Geographic Regions are not listed because they were outside the region considered in this review.
α Gov't.=government report (including OSU research papers not published in peer-reviewed journal); PR=peer-reviewed; IR=in review.
Δ Is the study's objective or questions directly relevant to this review's question? Y = yes, N = no.
±All forest harvests outside of buffers are clearcuts, except those of Danehy et al. (2007) which were thinned from 200-300 down to 80 trees per acre.
**Confidence score is a metric of the quality of a study (ranging from 4-12), with its calculation listed in a footnote of Table A.6.3.
††In this column, references to tables and figures are those of respective studies, not this report.
αα While other prescriptions were studied, they were not included in the analysis because of lack of adequate controls. Also note that data collected more than 5 years after harvest were not included in this review.
ΔΔData from Dent (1995; p. 6).
‡‡ Trendlines in Figure 3 of Zwieniecki and Newton (1999) are not used since the analysis method does not allow for deriving values that are similar enough to the other studies for comparison; note that their temperature data are not plotted in this report because the data are ostensibly the same as those of Dent and Walsh (1997), and the latter report those data in a table, whereas those of the Zwieniecki and Newton (1999) were determined by measuring directly from the publication figure.

Table 3. Summary of publications: outcomes measured and study relevance to the primary review question.

High Relevancy	**Temperature**	**Shade**	**Both**	**Total**
Government	1	5	4	**10**
Peer Review	4	1	4	**9**
In Review	2	-	-	**2**
Sub-total	***7***	***6***	***8***	***21***
Low Relevancy				
Peer Review	-	3	1	**4**
Total	**7**	**9**	**9**	**25**

3.2.2 Study design variability

The studies varied greatly in the inclusion of pre-treatment data, intensity of data collection and replication. For example, fourteen of the publications had pre-treatment data that could be used for analysis. Shade data collection efforts ranged from just a few points along a reach to measurements taken every 25 m. Temperature data collection efforts ranged from data collected during several days to several weeks, and reported measures were frequently seven-day maximums, means, minimums and diel fluctuations. However, not necessarily all of these parameters were reported in any given study. The number of replicates for a particular combination of Geographic Region and harvest prescription ranged from 1 to 22 for the studies. Several publications were most appropriately characterized as compilations of single stream case studies, as they lacked design principles that allowed proper statistical analysis across sites (Rashin et al., 1992; Dent and Walsh, 1997; Martin, 2004; Hunter, 2010).

Though there are 25 publications selected for review, several of the publications had overlapping studies and share data (Table 4). For example, all three of the publications by lead author Groom utilized the same temperature dataset from the same study, but explore different relationships. Similarly, Wilk et al. (2010) collected habitat data (including canopy cover) for wildlife and Janisch et al. (2012) focused on stream temperature response due to management. Other situations with shared study designs include reporting on shade in one publication and temperature in another (e.g. Jackson et al., 2001, 2007).

Table 4. Publications with overlap of data, or same sites, from the same study.

ID*	Study	Publications
1**	W. Oregon	Dent and Walsh, 1997; Zwieniecki and Newton, 1999
2	BC	Gomi et al., 2006; Kiffney et al., 2003
3	RipStream	Groom, 2013; Groom et al., 2011a, 2011b
4	SW WA	Jackson et al., 2001, 2007
5	W. WA	Janisch et al., 2012; Wilk et al., 2010

* For each set of studies, a number identifies it; these numbers are the subscripts which appear in Table 2 and Figures 2-15.
** Newton and Cole (2013b) included or collected data from W. Oregon study, but these data were not included in this review because they were either collected more than 5 years post-harvest, or are not summarized in a usable manner.

3.3 Geographical ranges and physical settings

Due to the selection criteria for this review, all publications were limited to areas within, or similar to Oregon, west of the Cascades Crest. These areas were selected due to their similarities in climate, vegetation, hydrology, and topography with those from the study (Groom *et. al*, 2011b) that initiated this rule analysis. Vegetation composition was generally dominated by Douglas-fir (*Pseudotsuga menziesii*), with sub-dominants such as red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*), and several conifer species. All but one of the publications chosen for the review had study sites west of the Cascades in Oregon, Washington and British Columbia, and many were set in multiple ODF Geographic Regions (per OAR 629-634-0220; Table 2, Figure 1). The remaining publication was conducted in southeast Alaska. Twelve publications had study sites in the Oregon Coast Range, two in the western Cascades and eleven in the Interior (i.e. most of the Willamette Basin and upper Umpqua Basin). Nine publications had sites in western Washington (five in the Coast Range, two in the Cascades, and two in both regions).

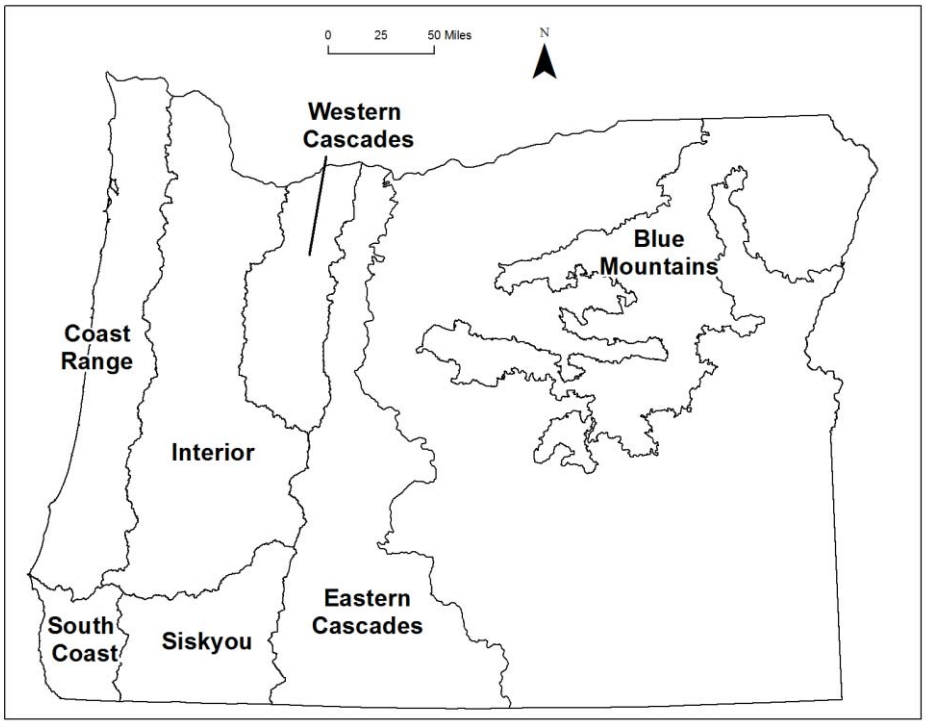

Figure 1. Oregon Department of Forestry Geographic Regions.

A secondary purpose of this systematic review is to inform the Board's decision on the geographic extent of the rule analysis process. Overall, most sites studied are located in the Coast Range (n=82), followed by Interior (n=47), and West Cascades (n=23); no data were found in the South Coast or Siskyous Geographic Regions. However, data are only comparable between Geographic Regions when a single study applies the same buffer prescription in more than one Geographic Region (comparison across studies requires analysis beyond the scope of this SR). Thus, there are fewer data available for comparison across Geographic Regions (15 combinations of temperature or shade data for specific rule prescriptions; Figures 2 and 3). Whereas data from publications are included in these comparisons regardless of their confidence score, it is worth noting:

- Most comparisons are from studies with low confidence scores (<7);
- Although the Coast Range and Interior are the only Geographic Regions with sites from studies with high confidence scores (≥10; n=31 and 5, respectively), only two sites from each Geographic Region are comparable with one-another; and,
- All of the Western Cascades sites are from studies with low confidence scores (< 7), and only one of these sites is comparable with those of another Geographic Region.

No clear picture emerges when comparing prescription effectiveness between Geographic Regions for any given study (Figures 2 and 3). This lack of clarity may be due to insufficient data with which to make robust comparisons since no comparison between Geographic Regions has more than two sites for each combination of buffer prescription, Geographic Region, and study. Additionally, existing data present no clear pattern. The Coast Range appeared to have greater change in shade or temperature for particular buffer prescriptions in seven comparisons with those of Interior, whereas the latter appeared to have greater change in shade or temperature in four comparisons (Figures 2 and 3). The remaining four comparisons of these two regions appeared to have similar changes in shade or temperature by buffer prescription. The only Western Cascades site assessed had the same increase in temperature as the associated Interior site, both of which were larger than that of the Coast Range site (Figure 3).

The finding of degradation by the Board was based on the results of the RipStream study, which largely focused on streams within the Coast Range Geographic Region. Results from non-RipStream studies included in this review indicate that exceedances of the PCW criterion also appear to occur[1] in the Interior Geographic Region for FPA buffers (Figure 3). Data are not available for other western Oregon Geographic Regions, or for the FMP buffer type that was also included in the RipStream study.

[1] Note that to determine whether the PCW criterion is met, the study needs to be designed specifically to test the criterion. Only RipStream specifically tested for achieving the PCW criterion, thus the use of wording similar to "appeared to meet the PCW criterion" is used when discussing whether or not other studies met the PCW criterion since they did not test for it.

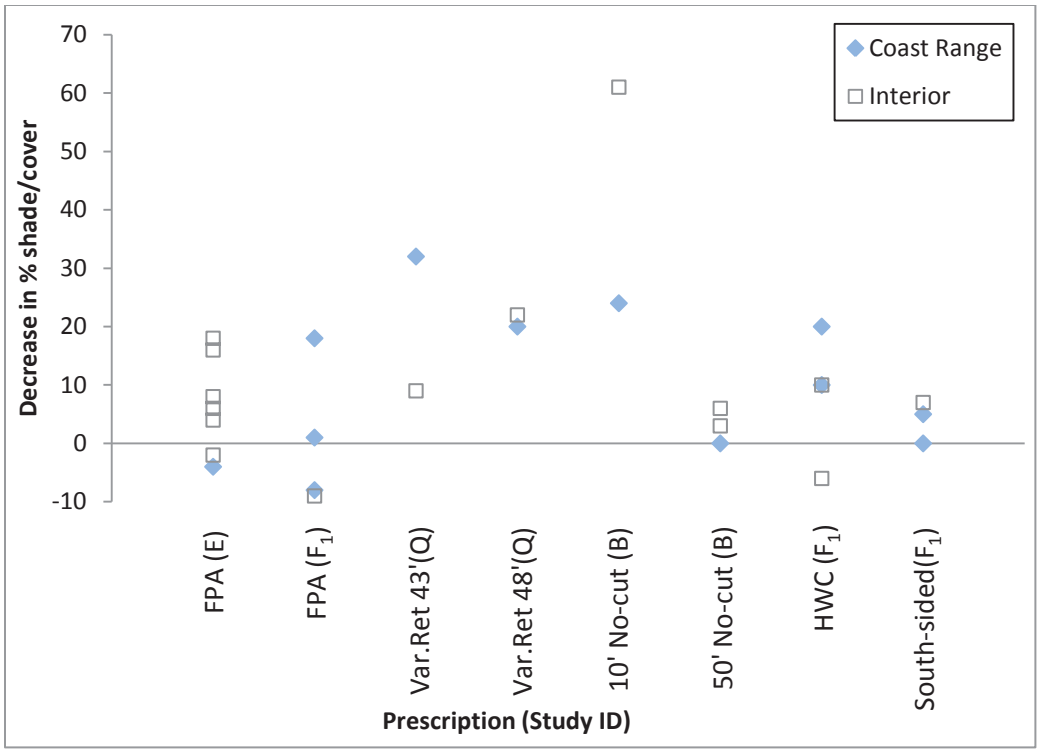

Figure 2. Decrease in shade for combinations of Geographic Regions and associated buffer prescriptions.

Each symbol represents data from one site for a particular rule prescription from a particular study (Appendix C). The symbol type denotes the ODF Geographic Region: blue diamonds are Coast Range sites, hollow squares are Interior sites. Prescriptions are: FPA = Forest Practices Act; Var.Ret = Variable Retention with 43 or 48 foot buffers; 10' and 50' are for No-cut buffers of 10 and 50 feet, respectively; HWC = hardwood conversion; South-sided = buffers retained on southern side of streams. Letters in parentheses denotes study ID (Table 2): E=Dent, 2001; F_1=Dent and Walsh, 1997; Q= Morman, 1993; B=Brazier and Brown, 1973.

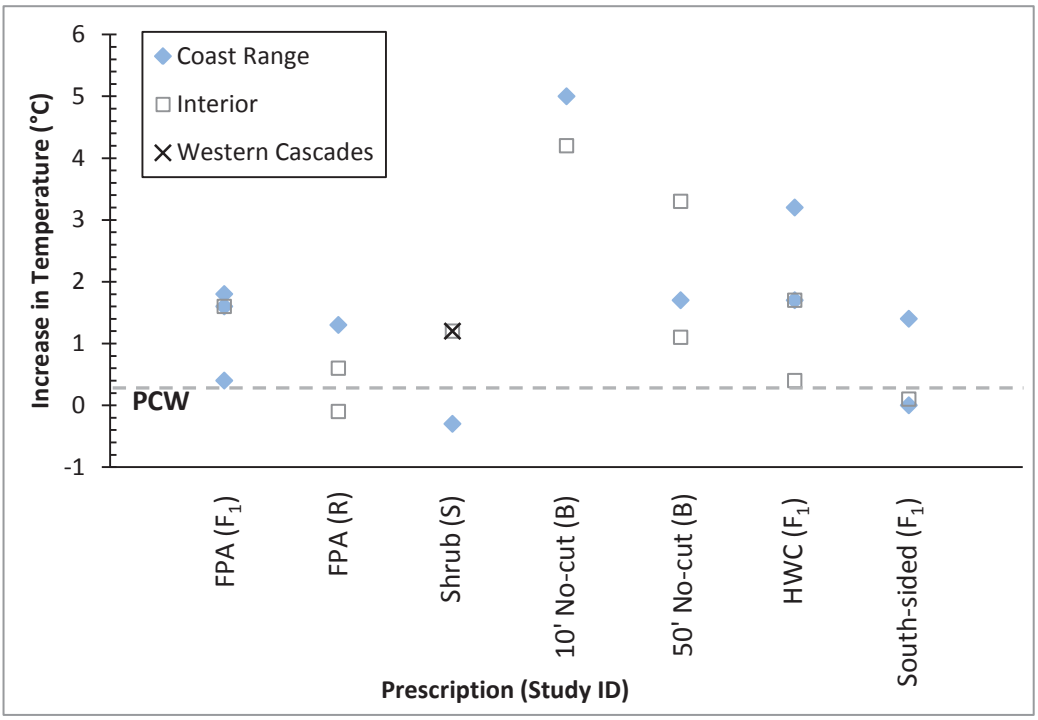

Figure 3. Increase in temperature for combinations of Geographic Regions and associated buffer prescriptions.

Each symbol represents data from one site for a particular rule prescription from a particular study (Appendix C). The symbol type denotes the ODF Geographic Region: blue diamonds are Coast Range sites, hollow squares are Interior sites, and "X" is a Western Cascades site. Prescriptions are: FPA = Forest Practices Act; Shrub = shrub shade; 10' and 50' are for No-cut buffers of 10 and 50 feet, respectively; HWC = hardwood conversion; South-sided = buffers retained on southern side of streams. Letters in parentheses denotes study ID (Table 2): F_1=Dent and Walsh, 1997; R=Newton and Cole, 2013a; S=Newton and Cole, 2013b; B=Brazier and Brown, 1973. The dashed line labeled PCW is the Protecting Cold Water criterion.

3.4 Measurements

The primary systematic review question focuses on two factors associated with protecting core cold water habitat: 1) stream temperature and 2) riparian shade. Of the twenty-five publications reviewed, seven included only measurements of stream temperature, nine included only measures of riparian shade, and nine included measures of both stream temperature and riparian shade (Table 3). Stream temperature is a water quality parameter that can be measured directly using a number of sensing technologies: most commonly a thermometer, recording thermograph (a thermistor coupled with a data logging device), or, recently, fiber optics. Contrastingly, shade is difficult to measure directly because, for any given location, it changes

both throughout the day and seasonally as a function of the position of the sun. Researchers have overcome this problem by using various measures of canopy density or light as proxies for shade (Davies-Colley and Payne, 1998).

All of the systematic review papers reporting stream temperature results collected time series of data measured at sub-daily intervals with recording thermographs. The duration of temperature data collection ranged from as little as two weeks (Rashin, 1992) during the critical summer low flow period to year-round (Gomi et al., 2006; Kiffney et al., 2003). Measurement accuracy varied across studies for papers that actually reported such values, ranging from +/-0.2 to +/-1.0 °C. Resolution was only reported by Janisch et al. (2012) who had one sensor type with resolution of +/-0.16 and another with a resolution of 0.5 °C. As a frame of reference, most current sensors are advertised with +/-0.2 °C accuracy and 0.02 °C resolution.

Overhead canopy cover was measured with either a spherical densiometer (Dent, 2001; Dent and Walsh, 1997; Martin, 2004; Morman, 1993; Schuett-Hames et al., 2012; Veldhuisen and Couvelier, 2006; Zwieniecki and Newton, 1999) or via hemispherical photography (Allen and Dent, 2001; Dent and Walsh, 1997; Groom et al., 2011b; Hunter, 2010; Janisch et al., 2012; Wilk et al.,2010), whereas oblique canopy cover or angular canopy density (ACD) was measured with an angular canopy densiometer (Brazier and Brown, 1973; Steinblums et al., 1984). Despite the spherical densiometer being the most common device used to measure canopy cover, measurements obtained are subject to user-bias (Davies-Colley and Payne, 1998). Hemispherical photography is a less subjective means for quantifying canopy cover. However, multiple methods were used to analyze the photographs making direct comparison of results across studies difficult. Allen and Dent (1997), Groom et al. (2011a), and Hunter (2010) report hemispherical photography results as a Global Site Factor (GSF), the ratio of direct and diffuse energy at the point of the photograph to the total available direct and diffuse energy for that latitude, longitude, and day of year. Janisch et al. (2012) reports Canopy and Topographic Density (CTD), a metric that, as its name implies, takes into account both the density of the canopy and the topographic obscurance. Wilk et al. (2010) present the photographic analysis from the same study only as a percent canopy cover.

Photosynthetically active radiation (PAR; Kiffney et al., 2003) and solar insolation (Brosofske et al., 1997; Danehy et al., 2007) are both measures that describe the amount of light

reaching a certain point. Direct measures of light are sensitive to subtle changes in cloud cover and the position of the sun, a factor that was considered when evaluating the robustness of outcome measures of light reported by Brosofske et al. (1997) and Kiffney et al. (2003). Danehy et al. (2007) estimated total solar insolation indirectly using hemispherical photography.

Reporting of measurement accuracy and resolution, for both temperature and shade, was inconsistent across studies. Therefore, systematically incorporating this uncertainty into the summary plots created as a part of this SR was not feasible. The reader is thus cautioned to keep this source of uncertainty in mind when evaluating actual values of stream temperature and shade extracted as a part of this systematic review (when reported in the publication, we included accuracy and resolution data in Completed Table A.6.2 of Appendix B).

The secondary review question focused on how effects modifiers interact with near-stream forest management. In order to properly evaluate the influence of a particular effects modifier, formal inclusion in the statistical analysis of a publication was necessary. The most commonly evaluated effects modifiers were the length and width of the riparian management area, stream width and depth, and stream gradient (Table 5). A number of publications presented data for variables that likely acted as effects modifiers without actually assessing their influence statistically; most frequently, the types of trees, tree density, and stream/watershed aspect were reported but not evaluated (Table 5). In general, there was a lack of consistency in assessing effects modifiers across studies. This point is highlighted by the large number of effects modifiers that were assessed in only one, two, or three studies and the fact that the most often assessed modifier (length, width of riparian reserve) was only addressed in approximately one-third of the reviewed studies. Since the main purpose of the SR was to test outcomes for temperature associated with shade, fully addressing the effects modifiers would require a more extensive analysis that is beyond the scope of this report.

Table 5. Information on effects modifiers addressed in publications.

First two columns list effects modifiers statistically analyzed for the respective measure (i.e., column heading); number of publications for each effects modifier listed in parentheses. Effects modifiers from the protocol (Appendix A) that are not listed were not considered in any publications.

Temperature	**Shade**	**Measured & Reported but not used in analysis**
Length, width of riparian reserve (7)	Length, width of riparian reserve (10)	Types of trees (5)
Gradient (7)	Stream width/depth (6)	Tree density (5)
Stream width/depth (6)	Other riparian vegetation (5)	Aspect (5)
Aspect (4)	Gradient (5)	Tree/basal area retention (4)
Harvest on both or single sides of riparian reserve (4)	Discharge (3)	Time since harvest (4)
Canopy cover (4)	Substrate (3)	Discharge (4)
Discharge (3)	Aspect (3)	Length, width of riparian reserve (3)
Elevation (3)	Types of trees (2)	Logs or slash left in stream (3)
Air temperature (3)	Tree/basal area retention (2)	Windthrow (3)
Time of year (2)	Harvest on both sides or single side of riparian reserve (2)	Continuity of flow (3)
Substrate (2)	Logs or slash in stream (2)	Gradient (3)
Time since harvest (2)	Elevation (2)	Other riparian vegetation (2)
Types of trees (1)	Tree harvest in part of riparian reserve (1)	Canopy cover (2)
Residual stand composition (1)	Tree height, age (1)	Groundwater-surface water interactions (2)
Tree/basal area retention amount (1)	Crown height (1)	Elevation (2)
Other riparian vegetation (1)	Windthrow (1)	Air temperature (2)
Clearcut vs. thin (1)	Distance from stream source (1)	Tree height, age (1)
Distance from stream source (1)	Groundwater-surface water interactions (1)	Crown height (1)
Groundwater-surface water interactions (1)	Geology and soils (1)	Residual stand composition (1)
Flow through/from a wetland (1)	Time of year and season (1)	Method of tree removal (1)
	Air temperature (1)	Stream width/depth (1)
		Substrate (1)
		Geology and soils (1)

3.5 Variations in Statistical Analyses

Methods for analyzing temperature varied widely among the studies, depending on the study design and measures selected for study. The majority of temperature studies included some type of statistical analysis of data, primarily analysis of variance (ANOVA) if differences between groups were considered by separating samples into groups prior to analysis (e.g. Dent and Walsh, 1997; Danehy et al., 2007), and regression analysis if the goal was to directly account for the effects of modifiers (e.g. Jackson et al., 2001; Veldhuisen and Couvelier, 2006; Groom et al., 2011b). A few of the studies used the measured data to develop predictive models to explore the importance of multiple effects modifiers, such as in Groom et al. (2011a,b; 2013) and Veldhuisen and Couvelier (2006). Autocorrelation of temperature time series data was addressed, but not consistently among the studies, which affected their statistical robustness score (Completed Table A.6.3).

Methods for analyzing shade were more consistent, with most of the studies conducting simple statistical tests of differences between both a control and the buffer type(s). The exception tended to be if studies had too few samples for a statistical comparison or only presented results graphically for comparison (e.g. Rashin et al., 1992; Martin, 2004; Hunter, 2010). For shade and cover studies, a sample was considered a control if it was collected pre-treatment or at a similar landscape unit at a nearby location.

3.6 Rule Alternatives

Each reviewed paper was rated for relevance to the sixteen rule alternatives proposed by the Board (Completed Table A.6.4). Seven of the sixteen rule alternatives had at least one highly relevant study (i.e., provides quantitative data that addresses the effectiveness of a particular prescription of a rule alternative at protecting stream temperature or shade), whereas nine rule alternatives had no studies that were highly relevant to them (Table 6). Since these latter alternatives lack geographically-relevant evidence, they are not discussed further. Several publications were highly relevant to more than one rule alternative: 14, 8, and 3 publications were highly relevant to 1, 2, and 3 different rule alternatives, respectively. All rule alternatives had at least one study of low relevance.

In the following sub-sections, rule alternatives with highly relevant studies are discussed with respect to the range of variation in metrics defining each alternative, the range of variation

in outcome measures, the degree of effectiveness at protecting against increases in stream temperature or decreases in riparian shade, and the overall confidence in the findings. Where applicable, the role of effects modifiers in influencing effectiveness is also addressed.

Table 6. Total number of studies of high relevance to each rule alternative.

A study is considered highly relevant if it provides quantitative data that addresses whether or not a particular design or prescription of a rule alternative is effective at preventing warming or maintaining shade. See Table A.5.1 for description of each rule alternative, and Completed Table A.6.4 for details of which studies were highly relevant to which rule alternatives.

	Current FPA	State Forests Standards	Derived variable retention	Large tree variable retention	Minimize gaps	Basal area retention by aspect	Field-based shade standard	Shade approach from WA DNR method	Shrub shade	Hardwood sites	Hardwood shade	Derived no-cut buffer	No-cut aspect buffers	Oregon Plan	Plan for alternate practice	One-sided buffer
Total # studies (pubs) *	4 (7)	1 (3)	2	0	0	0	0	0	1	0	0	12 (15)	0	0	7 (10)	1 (2)

*Sum of all studies that are highly relevant for each rule alternative; parentheses indicates the total number of publications relevant to a particular alternative if different than the number of studies. See Table 4 for clarification of relationship between studies and publications.

3.6.1 Forest Practices Act (FPA)

Description of rule alternative: *FPA is a specific prescription of a variable retention buffer: no cutting is allowed in the first 20 feet from the high water level, with the remainder of a riparian management area (RMA) extending to different widths depending on stream size (small, medium, large) and type (fish, domestic use, non-fish). For the portion of the RMA outside the 20-foot no-cut zone, limited harvest is allowed (Oregon Department of Forestry, 2010).*

Seven publications covering four different studies were rated as highly relevant to describing changes in temperature and/or shade with harvest using FPA buffer management practices; nine publications were determined to have low relevance (Completed Table A.6.4). In some cases, clearcut harvesting outside of the buffers occurred on both sides of the stream, but there were also cases where there was harvest on just one side of the stream. Requirements for

tree retention within the RMAs differs based on ODF Geographic Region, and though the majority of study sites were in the Coast Range, there were also sites in the Interior for all studies except for Allen and Dent (2001).

All studies reported an average decrease in shade or cover in the range -0.5% to -9%; (Figure 4) as a result of FPA management practices, regardless of whether it was a small or medium stream (Dent and Walsh, 1997; Dent et al. 2001; Groom 2011a). Confidence in study design was low for the Dent and Walsh (1997) and Dent et al. (1999) studies, primarily due to low number of sites resulting in an inability to make robust statistical comparisons of the results. Due to the nature of the data collection method, there can be considerable error, and thus variability, in these measures leading to a wide range in results. Therefore, it is even more important to have larger sample sizes, and thus a decrease in shade of 0.5% as interpreted from Dent and Walsh (1997) should be considered inconclusive.

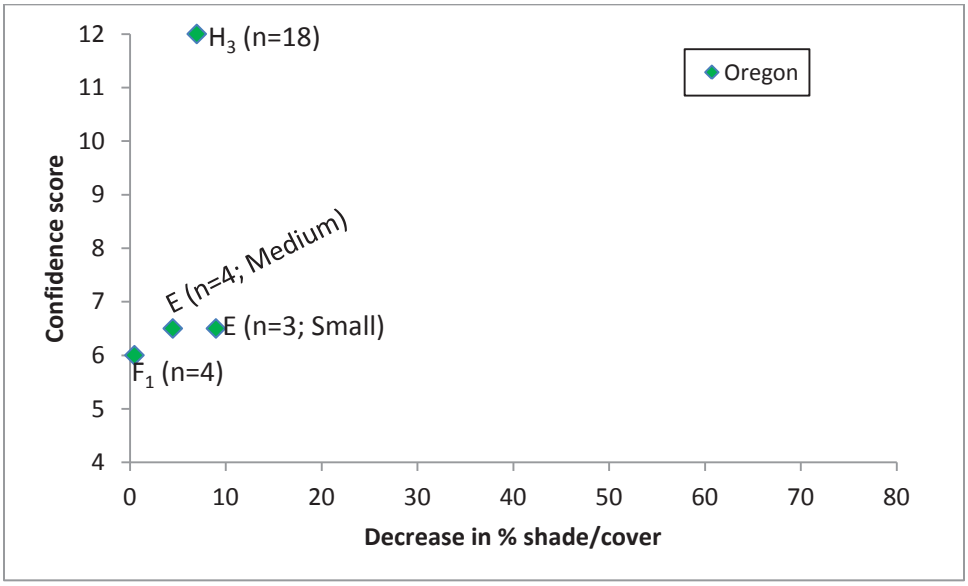

Figure 4. Decrease in shade for sites with FPA buffers.
Letter refers to publication ID (Table 2), n is the number of sites, and Small and Medium refer to stream size as defined in the FPA. Data from X- and Y-axes are listed in Table 2[2].

[2] Buffer effectiveness data, and associated confidence in these data, are illustrated in Figures 4-15. A study's buffer prescription is more effective at protecting cold water or shade when its X-axis data (i.e., change in shade/cover or temperature data) are closer to zero. The quality of the study from which these data were obtained is plotted on the Y-axis: the better the study, the higher its confidence score; note that the range of scores (4 to12) spans the entire range of possible confidence scores.

Increases in temperature were also observed for all relevant studies, though the amount of increase varied (Figure 5). Groom et al. (2011a) and Newton and Cole (2013a) reported temperature increases of 0.7 °C and 0.6 °C, respectively, and there is high confidence that their results provide reliable information. Those publications with lower confidence in reported results had higher increases in their temperature: 1.3 °C (Zwieniecki and Newton, 1999) and 1.4 °C (Dent and Walsh, 1997; note that these two publications report the same data though reduced and analyzed differently; only data from Dent and Walsh, 1997 are plotted). In all cases, the increase in temperature appeared larger than the PCW criterion. Groom et al. (2011a) found large variation in temperature responses, ranging from -0.9 to 2.4 °C, and thus there is evidence that not all observed streams experienced an increase in temperature. Groom et al. (2011b; 2013) explored the probability of exceeding stream temperature criteria. The chance of a site managed using FPA rules exceeding the PCW criterion between a pre-harvest year and a post-harvest year was 40%, and 7 out of 18 sites exceeded the 16 or 18 °C criteria for salmonids (only 4 of the 18 sites exhibited a potential harvest signal in that they did not exceed pre-harvest but did exceed post-harvest; 2 of the 4 sites had exceeded upstream of the study reach pre-harvest).

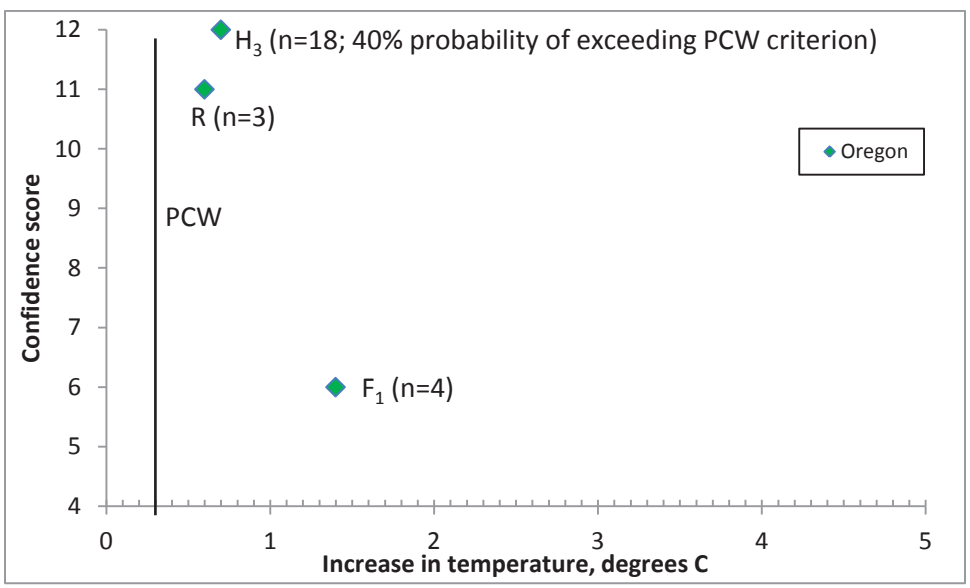

Figure 5. Increase in temperature for sites with FPA buffers.
Letter refers to publication ID (Table 2), n is the number of sites, PCW is the Protecting Cold Water criterion, and Small and Medium refer to stream size as defined in the FPA. Data from X- and Y-axes are listed in Table 2.

3.6.2 State Forest Management Plan (FMP)

Description of rule alternative: FMP is a specific prescription of a variable retention buffer: no cutting is allowed in the first 25 feet from the high water level, with the remainder of the riparian RMA extending to different widths depending on stream size (small, medium, large) and type (fish, domestic use, non-fish). For the portion of the RMA outside the 25-foot no-cut zone, limited harvest is allowed (Oregon Department of Forestry [ODF], 2001).

Three publications from one study (RipStream) contained highly relevant results of temperature and/or shade using buffer rules from the State Forest Management Plan (FMP; Groom et al. 2011a,b, Groom et al. 2013); eleven publications were determined to have low relevance (Completed Table A.6.4). The highly relevant study had 15 sites, set in the Oregon Coast Range and Interior Geographic Regions; therefore, all samples are from small and medium streams in a geographically similar area.

Shade comparisons were made pre- and post-harvest and there was no detectable change in shade post-harvest from pre-harvest conditions (Figure 6; mean decrease of 1%, n=15, p = 0.269, Groom et al., 2011a). Shade pre- and post-harvest was between 80-95% for all sites.

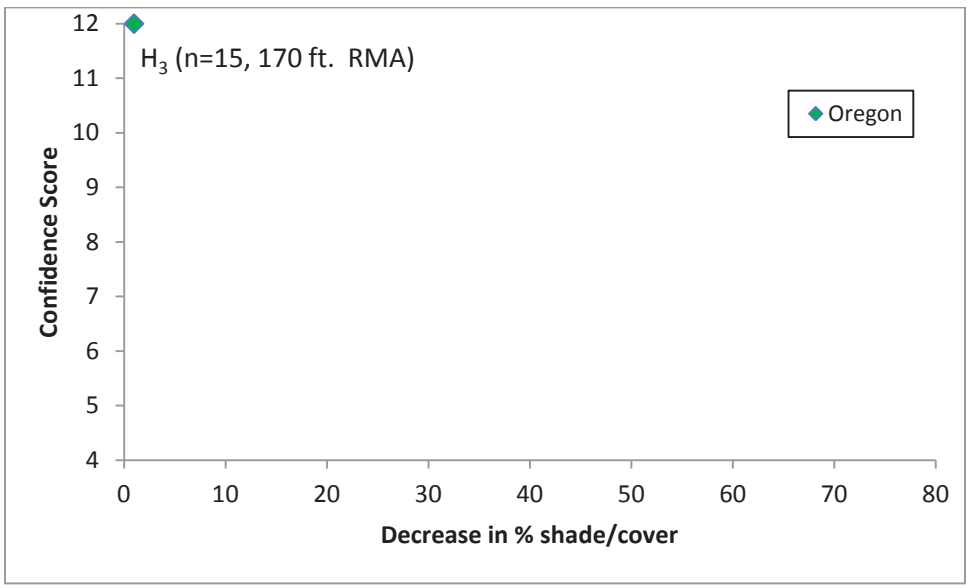

Figure 6. Decrease in shade for sites with FMP buffers.
Letter refers to publication ID (Table 2), n is the number of sites, and 170 ft. is the one-sided RMA (riparian management area) width. Data from X- and Y-axes are listed in Table 2.

Findings from this study suggest there also are little to no noticeable changes in temperature using FMP practices (Figure 7). Changes in temperature were reported by looking at both change in temperature and probability of exceedances of criteria. Change in temperature at FMP sites averaged 0.0 °C, although there was large variability in these changes as evidenced by the range of -0.9 to +2.3 °C (Groom et al, 2011a). The chance of exceeding the 0.3 °C PCW criterion was found to be 9% and not statistically different from zero[3]. Of the 15 sites, none exceeded the 16 °C or 18 °C criteria (Groom et al, 2011b; 2013). Strengthening the confidence in the results, data analysis for this study included measurement of effects modifiers (e.g., discharge, length and width of the reserve, characteristics of the stand, landscape position and air temperature), and thereby taking into consideration a number of factors that have a high likelihood of influencing stream temperatures.

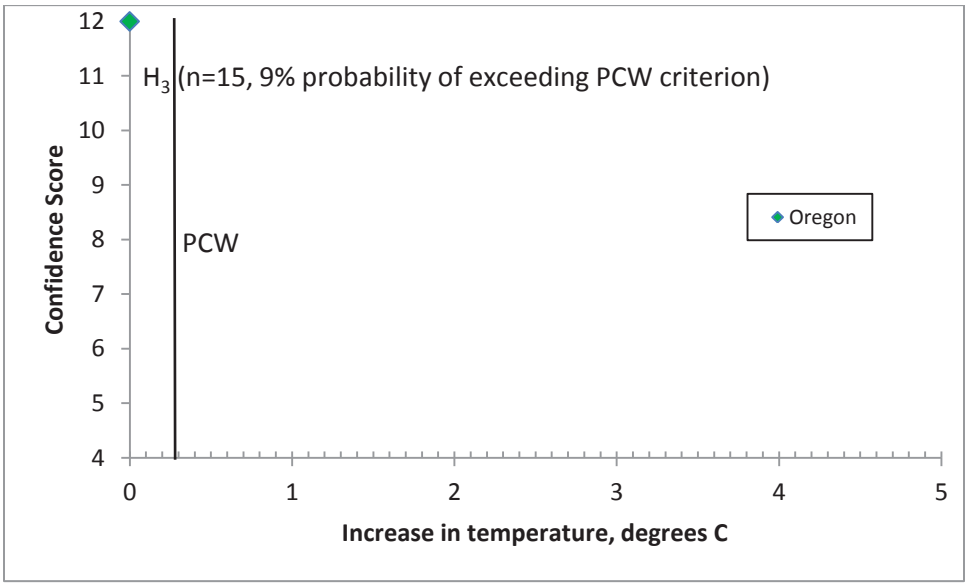

Figure 7. Increase in temperature for sites with FMP buffers.
Letter refers to publication ID (Table 2), n is the number of sites, 170 ft. is the one-sided RMA (riparian management area) width, and PCW is the Protecting Cold Water criterion. Data from X- and Y-axes are listed in Table 2.

[3] Note that from a regulatory perspective, achievement of the PCW criterion is evaluated with respect to a group of sites, and thus a site might not meet the criterion but the entire group of sites could still be considered to achieve it.

3.6.3 Derived Variable Retention

Description of rule alternative: This alternative allows spatially-variable harvest intensity determined by e.g., the density of stems, basal area, or other stand metric required to be left within a specific locale or zone of the RMA.

Two studies were highly relevant to the variable retention buffer rule alternative (in addition to the FPA- and FMP-related studies not included in this part of the discussion). Morman (1993) evaluated canopy density for seventeen variable retention buffers ranging from 25 to 100 feet in width in the Coast Range and Interior Geographic Regions. Martin et al. (2004) measured stream temperature and riparian shade for three sites with 25-foot no-cut buffers and an additional 41-foot width of partial cut buffer in southeastern Alaska. However, the stream temperature control site was compromised, so only the shade data is considered in this synthesis. Six studies were considered to have low relevance to this rule alternative.

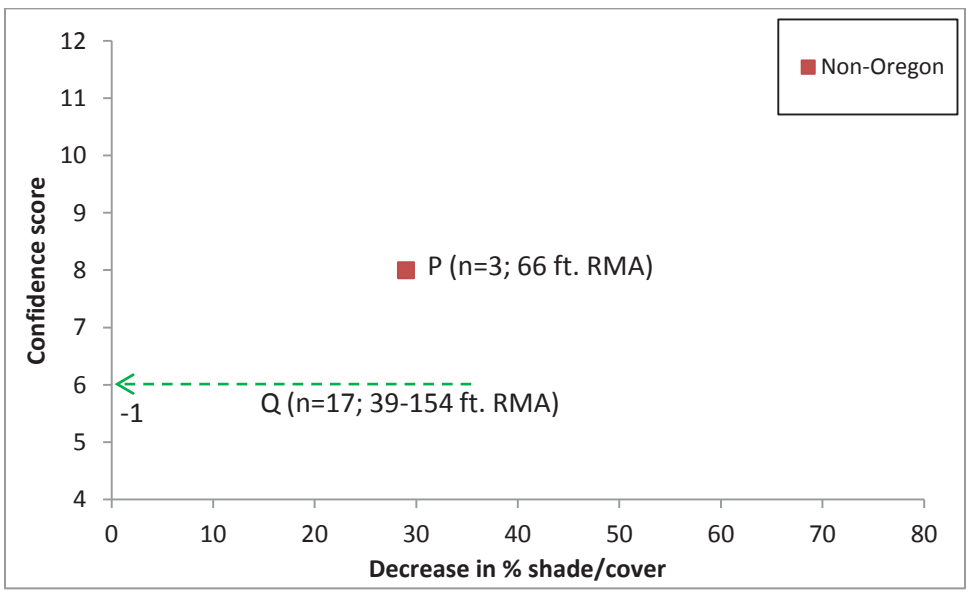

Figure 8. Decrease in shade for sites with variable retention buffers.
Letter refers to publication ID (Table 2), n is the number of sites, distance is the one-sided RMA width. Dashed line indicates a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths), with arrow head and accompanying number indicate range extended beyond X-axis. Data from X- and Y-axes are listed in Table 2.

Both studies showed a decrease in shade where variable retention buffers were applied (Figure 8). Martin et al. (2004), who had a low sample size but a relatively sound study design, measured an average canopy density decrease of 29%. Morman (1993) used a larger sample size

(17 sites) and found an average decrease of 19% (range: +1 to -35%). Morman's study evaluated the role of aquatic area width and hardwoods versus conifers in relation to the amount of shade provided. However, despite the significantly larger sample size and assessment of effects modifiers, the confidence in the Morman study is lower than that of Martin et al. (2004; Figure 8). Additional data is required to definitively assess the effectiveness of this prescription at protecting stream shade.

3.6.4 Shrub Shade

Description of rule alternative: This alternative considers the contribution of shade from shrubs to protect cold water.

Newton and Cole (2013b) provided highly relevant results for Shrub-shade management practices by examining "no-tree buffers". In their study, different management practices were instituted along a length of stream where harvested and unharvested blocks lie adjacent to each other along the length of channel. Widths of RMAs ranged from 15 to 70 feet, depending on stream width, and were interspersed with no-tree buffers along a harvested reach 600 feet long. Although harvest was conducted so that damage to shrubs was minimized, it is possible that there were locations within the buffer without shrub shade. Only the upstream-most treatment was considered for this review due to inadequate controls on downstream reaches.

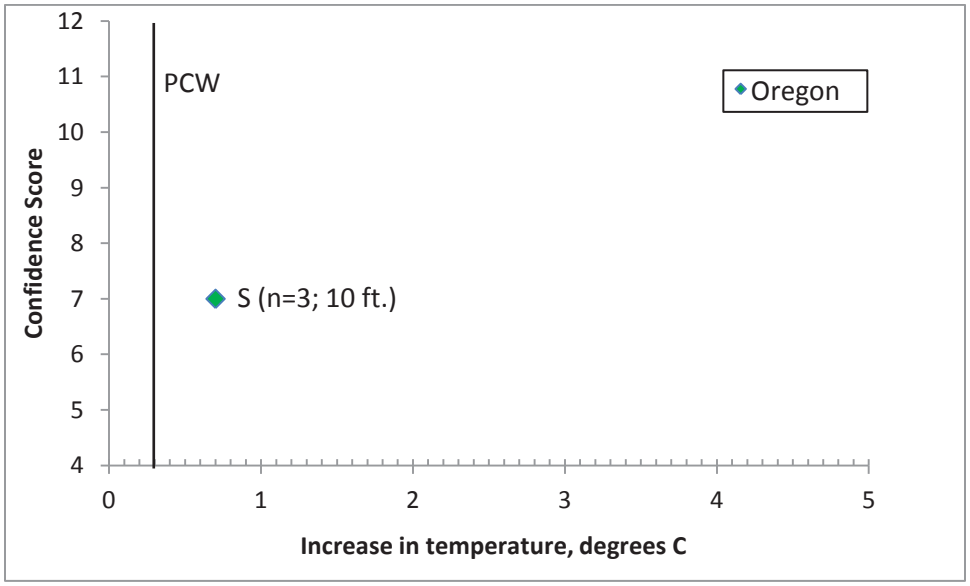

Figure 9. Increase in temperature for sites with shrub shade buffers.

Letter refers to publication ID (Table 2), n is the number of sites, distance is the width of leaving shrubs, and PCW is the Protecting Cold Water criterion. Data from X- and Y-axes are listed in Table 2.

Stream temperature differentials increased in the no-tree buffers by an average of +0.7 ºC (Figure 9; range: -0.3 to +1.2 ºC) post-harvest (Newton and Cole 2013b). Effects considered when analyzing data include stand characteristics and some landscape characteristics, though sample sizes were low and analysis focused on differences by site and year.

3.6.5 Derived No-cut Buffer

Description of rule alternative: This rule alternative prescribes no cutting of trees within a specific distance of the stream.

The no-cut buffer was the most frequently studied rule alternative: twelve studies (fifteen publications) were rated as highly relevant and an additional four publications had low relevance (Completed Table A.6.4). Of the highly relevant publications, eight presented data on riparian shade, three presented data on incoming solar radiation, and seven included stream temperature data. Four of the nine highly relevant riparian shade publications presented data collected in Oregon (Allen and Dent, 2001; Brazier and Brown, 1973; Dent, 2001; and Steinblums et al., 1984). However, only one of the seven stream temperature publications presented data collected in Oregon (Brazier and Brown, 1973).

No-cut buffer widths in highly relevant riparian shade studies ranged from 7 to 115 feet per side (Figure 10; Table 1). The effectiveness of the no-cut buffer in preventing an increase in shade varied considerably. The two publications with the highest confidence score, Janisch et al. (2012) and Wilk et al. (2010), found that a continuous buffer, ranging from 33 to 49 feet (10 to 15 m), resulted in a 10% decrease in canopy density (both publications originated from the same study). Similarly, Schuett-Hames et al. (2012) measured an average canopy density reduction of 12% across thirteen 50-foot no-cut buffers in western Washington.

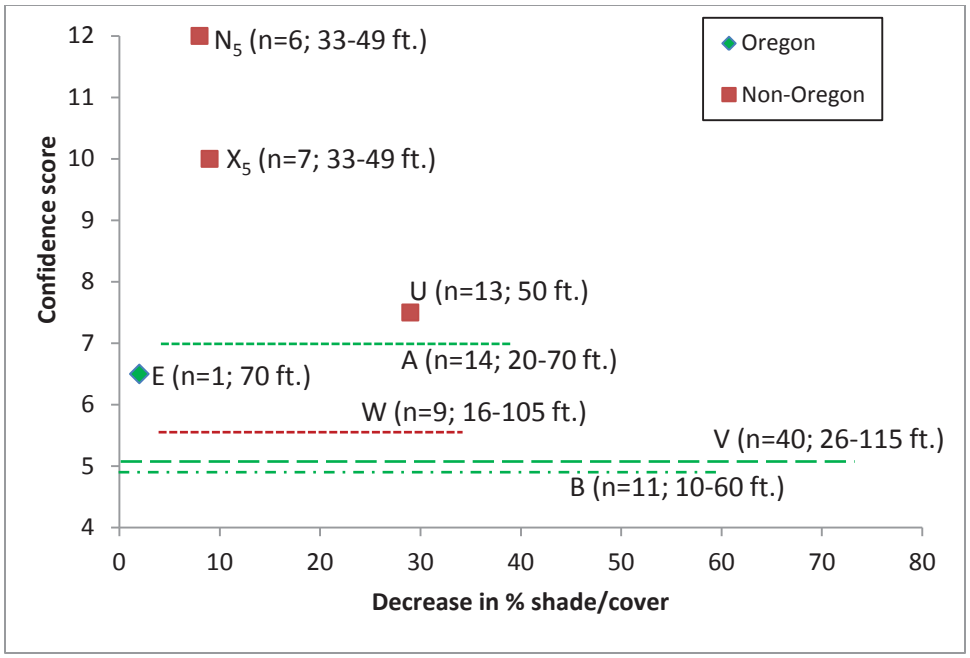

Figure 10. Decrease in shade for sites with no-cut buffers.
Letter refers to publication ID (Table 2), n is the number of sites, and distance is the no-cut buffer width. Dashed lines indicate a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths). Data from X- and Y-axes are listed in Table 2.

Several studies included multiple buffer widths in their assessment of riparian shade (Allen and Dent, 2001; Brazier and Brown, 1973; Jackson et al., 2007; Steinblums et al., 1984; Veldhuisen and Couvelier, 2006). A positive relationship between angular canopy density and buffer width was evident in the data of both Brazier and Brown (1973) and Steinblums et al. (1984) despite considerable variability amongst the responses at individual measurement locations. Contrastingly, no strong positive relationship between canopy density and no-cut buffer width was visually evident in the data presented by Allen and Dent (2001; no regression performed for no-cut data only) or Veldhuisen and Couvelier (2006). Jackson et al. (2007) caution against use of their canopy cover data because of concern that the survey reach was not necessarily representative of the entire stream; therefore, their results are not included in this assessment (see Completed Table A.6.2 for results).

Three studies evaluated buffer effectiveness based on a change in solar insolation (solar insolation results are not included in Figure 10 because units are not directly relatable to percent

shade). Kiffney et al. (2003) found that photosynthetically active radiation was approximately 5-times greater in the 33-foot buffer than in the 98-foot buffer. Brosofske et al. (1997) found a logarithmically-decreasing relationship between solar insolation and buffer widths ranging from 26 to 141 feet (r^2=0.60, inclusive of control sites; n=18). Danehy et al. (2007) measured the difference in solar insolation between uncut control streams and streams with 49-foot no-cut buffers surrounded by thinned harvest units upslope (as opposed to clearcuts for the rest of the studies). Based on the large variability in control measurements (95 +/- 89 MJ/m^2/day; n=6), the difference in the Danehy et al. (2007) control and treatment is considered negligible (treatment = 137+/- 28 MJ/m^2/day; n=7). Caution is suggested in considering these results as it is difficult to relate insolation values to protection of stream shade based solely on the data provided in these studies.

No-cut buffer widths in highly relevant stream temperature studies ranged from 5 to 190 feet and, as with the riparian shade studies, responses to treatment were highly variable (Figure 11; Table 2). Four publications reported results where the temperature response to a no-cut buffer appeared to meet the PCW criterion: the 98-foot buffer of Gomi et al. (2006), two sites of Janisch et al. (2012), one site of Rashin et al. (1992), and one of the 26- to 33-foot buffers of Jackson et al. (2001; note that data from these latter two could not be meaningfully averaged due to the large range of buffer widths). It should be noted that Danehy et al. (2007) measured temperature within the substrate and thus these data are not included in the review, and the Jackson et al. (2001) stream was significantly covered by blowdown. Gomi et al (2006) and Janisch et al. (2012) found that 33-foot and 33- to 49-foot no-cut buffers, respectively, resulted in an about a 1 °C increase in temperature over the study reach (these studies had the two highest confidence scores) while the 33-foot buffer of Kiffney et al. (2003) resulted in a 3 °C increase (a 1.5 °C increase was reported for their 98-foot buffer). Note that the discrepancy in temperature results between Kiffney et al. (2003) and Gomi et al. (2006), which report on the same study, is a result of the latter using a longer post-treatment data record in their analysis (1 year versus 4 years). Veldhuisen and Couvelier (2006) reported the largest temperature increase of all the highly relevant studies, an 8.3 °C increase in the maximum value of the 7-day moving mean of the daily maximum (buffer width unknown; it should also be noted that the forested controls had upstream-to-downstream increases ranging from +1.0 to +2.7 °C during the same monitoring

period). The eleven sites of Brazier and Brown (1973) had a modest inverse relationship between temperature response and buffer width. The smallest differences in upstream-to-downstream temperature change (no information was provided on the exact temperature metric presented) were for a 60-foot and a 100-foot buffer (both had a 0.6 °C increase); however, one of the 100-foot no-cut buffers had a measured increase of 2.2 °C (note that although Brazier and Brown (1973) received a relatively low confidence score, the temperature and buffer width data assessed here are considered robust).

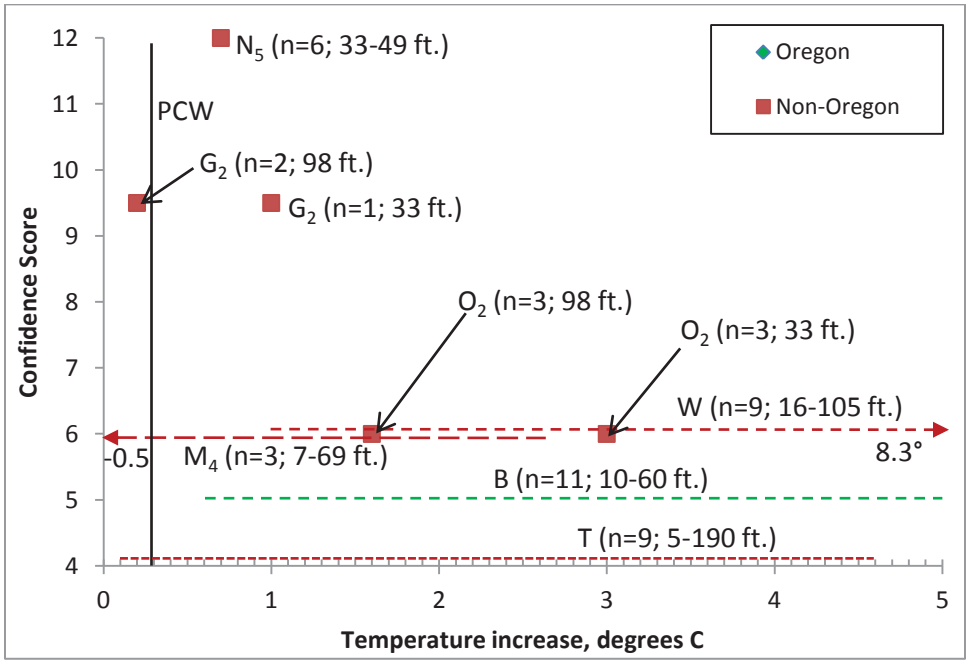

Figure 11. Increase in temperature for sites with no-cut buffers.
Letter refers to publication ID (Table 2), n is the number of sites, distance is the no-cut buffer width, and PCW is the Protecting Cold Water criterion. Dashed lines indicate a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths) dashed lines with arrow heads and accompanying number indicate range extended beyond X-axis. Data from X- and Y-axes are listed in Table 2.

The publications reviewed showed that while no-cut buffers have the potential to protect against exceeding the PCW criterion, the generally implied notion that wider buffer widths provide better protection is not fully supported by all studies. For example, five studies showed greater protection of temperature or shade with wider buffers (Brazier and Brown, 1973; Kiffney et al., 2003; Gomi et al., 2006; Steinblums et al., 1984 Veldhuisen and Couvelier, 2006; note that

the strength of relationship between level of protection and buffer width was variable amongst these studies) whereas Allen and Dent (2001) showed no relationship between buffer width and protection. The large degree of variability in the findings across publications means there would be uncertainty when specifying a no-cut buffer width, based on these data, that would achieve the PCW criterion. The variability in magnitude of response is presumably related to the confounding role of effects modifiers in combination with the various buffer width treatments.

Unfortunately, there was no consistency in evaluation of effects modifiers between studies. Janisch et al. (2012) found a significant correlation between mean daily temperature response and elevation, catchment area, aspect, channel gradient, channel length, depth, canopy + topographic density (CTD), and percent of catchment with wetland. Veldhuisen and Couvelier (2006) also found significant relationships between temperature response and elevation and channel gradient plus percent shade (however, their effects modifiers analysis included fully forested, clearcut, and debris flow streams). Several of the highly relevant publications reported temperature results from studies conducted in first-order, non-fish-bearing streams (Jackson et al., 2007; Janisch et al., 2012; Veldhuisen and Couvelier, 2006). Controls on water temperature in the extreme headwater reaches of a stream network are more variable than the dominant controls in larger downstream reaches (Jackson et al. 2007; Janisch et al, 2012), a factor that likely added to the variability in the response to treatment for this rule alternative.

3.6.6 Plan for Alternate Practice

Description of rule alternative: This alternative allows site-specific practices and is designed to provide flexibility for landowners. For the purposes of this rule analysis, this alternative encompasses practices not included in any of the other rule alternatives.

Multiple alternate practices were considered in the reviewed publications. Hardwood conversion (HWC), patch, perennial initiation point, non-merchantable, and site-specific buffers were evaluated in riparian shade studies (three of the seven studies were conducted in Oregon); only hardwood conversion, patch, and non-merchantable buffers were assessed in stream temperature studies (two hardwood conversion studies from Oregon). Hardwood conversion buffers followed state-specified rules for converting hardwood-dominated buffers to conifer (Allen and Dent, 2001; Dent and Walsh, 1997; Dent, 2001; Hunter, 2010). Patch buffers had 164- to 360-foot-long sections of forested buffer with the rest of the catchment clearcut (Janisch

et al., 2012; Wilk et al., 2010). Perennial initiation point buffers had a 56-foot radial buffer emanating from the point of perennial streamflow initiation (Schuett-Hames et al., 2012). Site-specific buffers were not well-defined, but were intended to "enhance and restore riparian areas" (Allen and Dent, 2001).

Effectiveness in protecting against decreases in riparian shade varied among the different alternate practices investigated (Figure 12). The most effective was the site-specific buffers, which had an average decrease in canopy density of 4.5%, but confidence in this finding is limited by a low number of sites (n=2). HWC buffers resulted in a 10% to 20% reduction of canopy density for small streams (Allen and Dent, 2001; Dent and Walsh, 1997; Dent, 2001; Hunter, 2012), whereas that of the only medium HWC stream surveyed had a reduction of 36% (Dent, 2001). The patch buffers decreased canopy density by 18%, on average (Janisch et al., 2012; Wilk et al. (2010) reported a 45% reduction in the same study, but using a smaller sample size). The perennial initiation point (Schuett-Hames et al., 2012) and non-merchantable tree buffers (Jackson et al., 2007) were not generally effective, with 30% and 58% reductions in canopy densities, respectively.

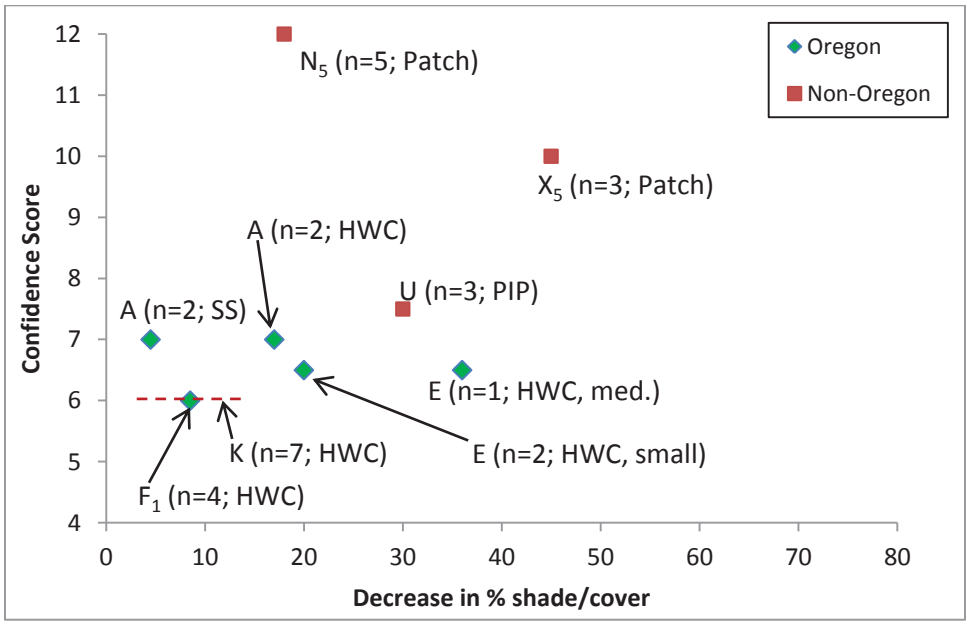

Figure 12. Decrease in shade for sites with alternate practices buffers.

Letter refers to publication ID (Table 2), n is the number of sites, and capitol letters in parentheses refer to: HWC=hardwood conversion; NT=nonmerchantable tree; PIP=point of initiation of perennial flow; SS=site specific plan; and Patch are buffers left in patches along sensitive reaches. Data from X- and Y-axes are listed in Table 2.

Only one patch buffer measurement location in all of the alternate practices studies appeared to prevent a PCW criterion exceedance: a patch buffer with an increase of 0.1 °C (Figure 13; Janisch et al., 2012), although their average temperature increase was 0.7 °C (n=5). Hardwood conversion buffers resulted in a wide range of temperature responses, spanning from a few sites that appeared to meet the PCW criterion (decrease in temperature of 1.8 °C; Hunter et al., 2012) to increases of more than 3°C (Dent and Walsh, 1997). Non-merchantable buffers were also not generally effective, with measured increases of 2.8 and 4.9 °C (Jackson et al., 2001).

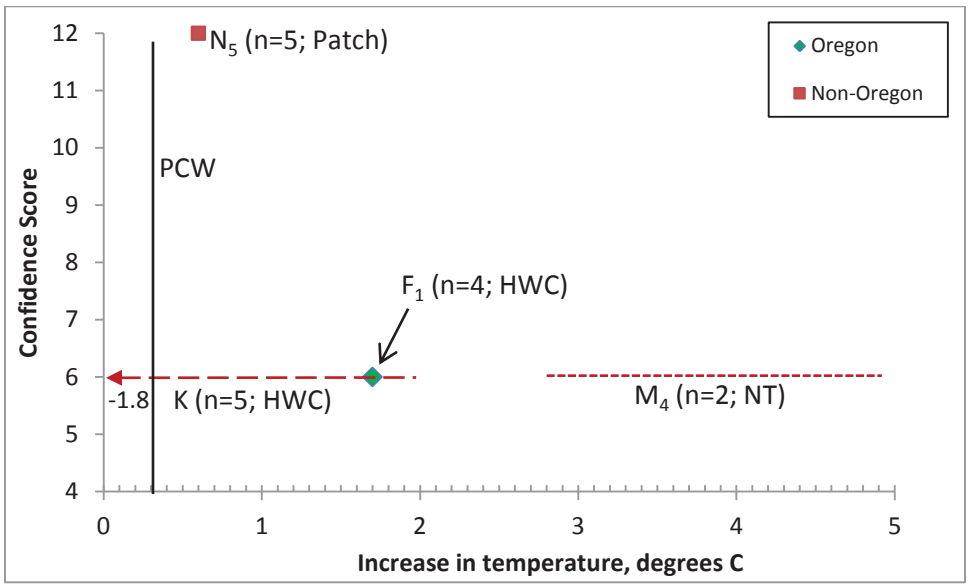

Figure 13. Increase in temperature for sites with alternate practices buffers.
Letter refers to publication ID (Table 2), n is the number of sites, PCW is the protecting cold water criterion, and capitol letters in parentheses refer to: HWC=hardwood conversion; NT=nonmerchantable tree; PIP=point of initiation of perennial flow; SS=site specific plan; and Patch are buffers left in patches along sensitive reaches. Dashed lines indicate a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths). Dashed lines with arrow heads and accompanying number indicate range extended beyond X-axis. Data from X- and Y-axes are listed in Table 2.

Information on specific alternate practices is too sparse to make a definitive assessment as to the true effectiveness of each. It appears that non-merchantable and perennial initiation point buffers did not meet the PCW criterion. HWC buffers, for which the greatest amount of information exists, along with site-specific and patch buffers, have the potential to protect against PCW exceedance. However, additional study is needed, with particular focus given to controlling for effects modifiers such that the design specifications necessary to provide adequate protection to the stream can be constrained.

3.6.7 One-sided Buffer

Description of rule alternative: This alternative maintains trees on south sides of streams.

Two different publications located at the same sites during the same time-frame examined three hardwood conversion units with limited openings on the south side of the stream (Dent and Walsh, 1997; Zwieniecki and Newton, 1999). Buffer widths ranged from 18 to 131 feet, and harvest units were between 1100 feet to nearly one mile in length.

Dent and Walsh (1997) described a 4% (range: 0-7%) decrease in cover at the sites post-harvest (Figure 14), but Zwieniecki and Newton (1999) reported no difference in shade post-harvest, though results were not separated by prescription. Considering the difference in results, the range of variability for shade measures and the low sample size, these results are relatively inconclusive.

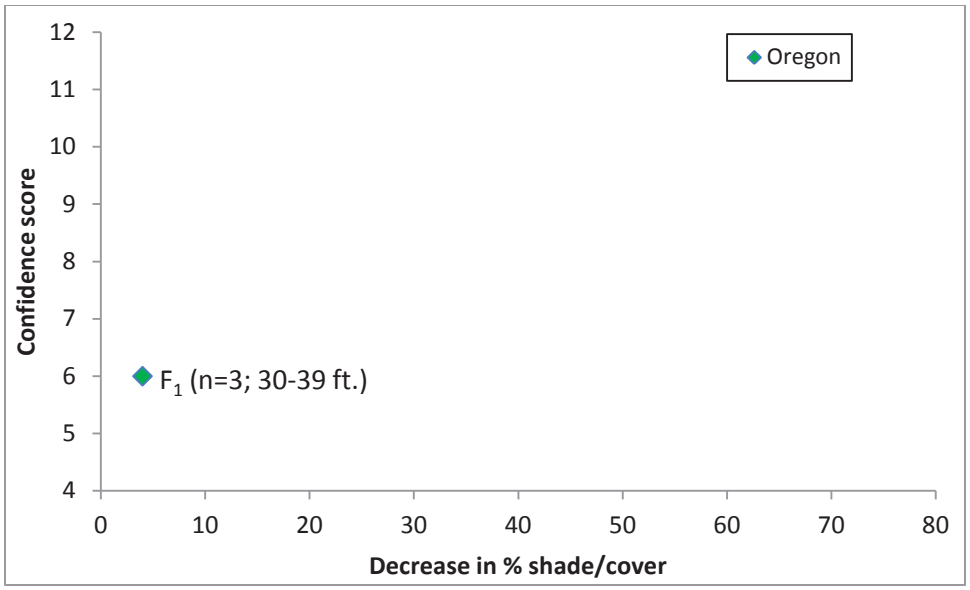

Figure 14. Decrease in shade for sites with south-sided buffers.
Letter refers to publication ID (Table 2), n is the number of sites, and distance is the width of buffer. Data from X- and Y-axes are listed in Table 2.

Despite small changes in cover, stream temperatures appeared to increase above the PCW criterion. Both publications showed an increase in stream temperature post-harvest: 0.7 °C (Figure 15; range: +0.07 to +2.6 °C; Dent and Walsh, 1997) and 0.5 °C (Zwieniecki and Newton, 1999; Table 2). Differences in results are likely due to differences in sampling method: both publications collected the 7 day moving mean maximum temperature, but sampling occurred in July and August for Zwieniecki and Newton (1999) and generally between July and early September for Dent and Walsh (1997). Regardless, sample sizes were low and results by individual site are not conclusive of a general trend of increase in temperature (Completed Tables A.6.2). Reanalysis of those data by Newton and Cole (2013b) suggest more confidence that warming occurred post-harvest.

These studies took into consideration stream characteristics, landscape position and stand characteristics such as buffer width and cover. Zwieniecki and Newton (1999) modeled behavior from multiple prescriptions using these effects modifiers; however, the sample size for one-sided buffers is too small to encompass the variability and compare differences between treatments in a statistical test.

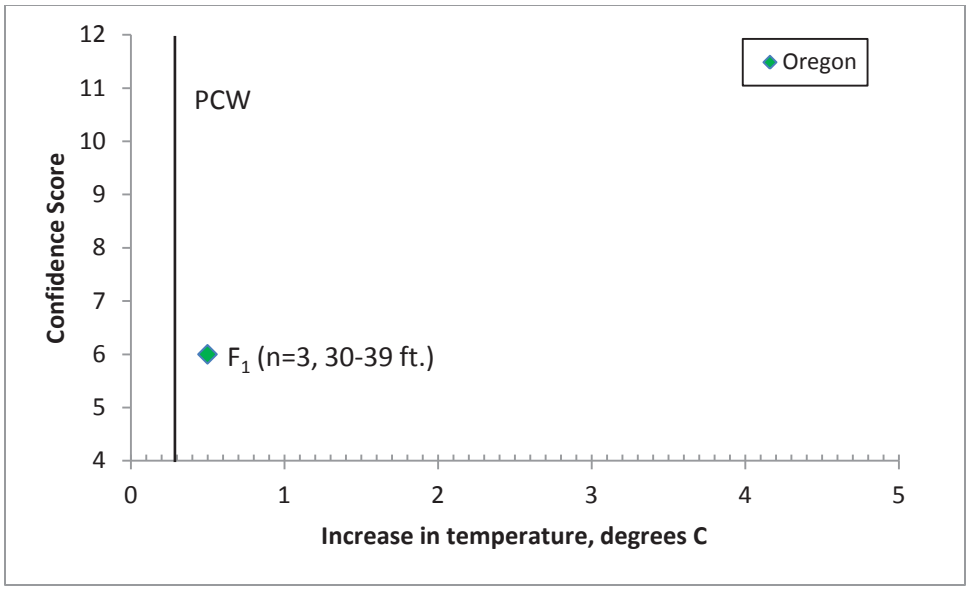

Figure 15. Increase in temperature for sites with south-sided buffers.
Letter refers to publication ID (Table 2), n is the number of sites, distance is the width of buffers, and PCW is the protecting cold water criterion. Data from X- and Y-axes are listed in Table 2.

3.7 Study Limitations and Knowledge Gaps

Although a relatively significant amount of information is available regarding stream temperature and riparian shade responses to forest management, the ability to identify emergent trends across studies is hampered by several factors. The primary limitation is the inconsistencies between study designs and analysis methodologies, particularly the adequate measurement of, and incorporation of, effects modifiers into the assessment. Deciphering observed differences in responses between similar buffer designs is extremely difficult if effects modifiers have not been controlled for in the study design and analysis. The generally low sample sizes (especially within buffer management types) and inconsistency in assessment of effects modifiers made traditional statistical models inappropriate, thereby making comparisons between studies challenging. Another study design-related limitation is that several studies collected a wealth of data but offered very little for inferring their results to other locations because they were essentially designed as a series of single-stream case studies rather than replicated sampling (Rashin et al., 1992; Dent and Walsh, 1997; Martin, 2004; Hunter, 2010).

A somewhat related limitation is the use of a variety of response metrics. This primarily applies to stream temperature studies where the time series of temperature data can be reduced or

averaged in many ways, but it also applies to shade studies where different methodologies for collecting and processing canopy density data generate different metrics, such as canopy density percent, global site factor, and canopy and topographic density. Results are more difficult to compare across studies when the measured response metrics are dissimilar.

A major finding of this SR effort is the lack of studies that were highly relevant to proposed rule alternatives other than the no-cut buffer. Twelve different studies (15 publications) investigated no-cut buffers of various widths compared to only four (7 publications) for the current FPA and only one (3 publications) for the current State Forests standards. Seven studies were highly relevant to the Alternative Practices rule alternative, but within that category the most studies related to any one specific alternative practice was three (hardwood conversion). Nine rule alternatives did not have any highly relevant studies. Studies ranked low relevance with respect to a rule alternative were generally more numerous across the rule alternatives. However, extracting rigorous information that is applicable to a rule alternative, from studies of low relevance to that alternative, is extremely challenging and highly prone to mischaracterization.

Several studies were not focused directly on the review questions of stream temperature or riparian shade response to forest management, and data relevant to this effort were not collected as a primary goal of the original study (e.g., Brosofske et al, 1997; Danehy et al., 2007; Jackson et al., 2007; Wilk et al., 2010). Though these studies were considered highly relevant to at least one rule alternative, sample sizes were small (Wilk et al., 2010), no pre-treatment data were collected (Brosofske et al., 1997), and their lack of relevance to the review question perhaps limited confidence in the findings.

4. Lessons Learned – External Scientists' perspective

Utilization of the systematic review process is still being tested and several lessons were learned that may help inform future review efforts.

First, the process employed in this systematic review was helpful in initiating conversation between the reviewers. The process included an initial review of four publications that were compared between reviewers. Comparing reviews resulted in conversation about terminology, discussion of how tables should be completed, and a shared understanding of

definitions. It would be useful for the four review papers to provide a spectrum of challenges and test the range of definitions so that reviewers are also better prepared.

As with any new process, methods can be developed but are not reliable until they have been tested. Time and resources on behalf of the reviewers may have been saved if definitions and tables were tested prior to engaging the reviewers. If there is a desire to standardize tables, it might also be useful to provide an example of the type of information to be collected in the table, possibly using an example of one of the papers not chosen for inclusion in the study.

The systematic review question is focused on meeting the information needs of policy-makers; however, few of the studies were conducted specifically to answer the question posed. The uniqueness of the studies made it challenging to compare data and to answer the systematic review question. As described in Study Limitations (Section 3.7), the vast difference in study designs made it challenging to objectively assess the study design and statistical methods. For example, sample sizes were frequently low; data on effects modifiers were often collected, but not always analyzed; if there were pre-treatment data, they were frequently only for one year, which may be adequate for assessing shade, but may not be adequate for assessing temperature.

The systematic review publication search and filter results were heavily balanced towards particular buffer management types (i.e., FPA, derived no-cut); therefore, it might have been advantageous to open up the review to studies outside of the region to provide some insight on those management types that had no studies of high relevancy. However, such an action would have made interpretation more challenging and transference to this region would likely be uncertain. Also, there were studies that fell into the category of "Plan for alternate practice" which cannot be easily compared to each other or any of the other buffer management types; therefore, there is too much variability in study designs to provide a strong basis for management decisions.

Finally, reading and understanding a study well enough to summarize it takes time. Results can be skimmed through and extracted relatively quickly, but to be able to understand the context of those results so that they can be compared to other studies takes more effort in reading and interpretation. For example, a temperature increase of 0.7 °C can be extracted looking at figures and tables, but management practice and effects modifiers need to be considered, as well as data collection and statistical analysis methods. Furthermore, once data have been gleaned

from a paper or report, additional time is needed to assess comparisons between studies, especially when methods are substantially different from each other. We recommend time be allowed for the reviewer to re-familiarize themselves with the papers prior to writing the report, as it will necessarily take some time from the review of the first papers to the time when writing must begin. Mechanisms for reducing this need for additional review should be considered.

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Appendix A. Protocol and Data Table format

This appendix presents the protocol as approved by the Board of Forestry on 6 March, 2013. Additions to the protocol are indicated by underlined, red font, with deleted text in ~~strikethrough~~. Reasoning behind substantial changes are clarified in subsection A.7.

For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?

Systematic Review Protocol

Oregon Department of Forestry, 2600 State St., Bld. D, Salem, OR 97310, USA.

A.1 Introduction

A.1.1 Background

Many Oregon streams support several cold-water fisheries (e.g. salmon, steelhead, cutthroat) which are important to the region's economy, culture, and recreational activities. These fish are thermally adapted to specific water temperature regimes for various life stages such as egg and smolt survival, spawning, and adult migration (Richter and Kolmes, 2005). These regimes are affected by several natural processes including direct exposure to sunlight, the transfer of heat from water to the air or stream bed, evaporation, water exchange with groundwater or the hyporheic zone, and others (Brown, 1969; Johnson, 2004). Of these factors, direct exposure to sunlight is a major contributor to maximum daily summer stream temperatures, and this exposure may increase following timber harvest (Brown and Krygier, 1970; Johnson, 2004; Sinokrot and Stefan, 1993). Therefore, maintaining riparian shade may serve as an effective tool for minimizing the increases in stream temperature during the summer months when maximum stream temperatures are observed (Johnson, 2004).

Oregon has enacted timber harvest regulations to maintain shade on streams following timber harvest (Oregon Department of Forestry, 2010). Timber harvest operations are considered in compliance with Oregon Department of Environmental Quality (DEQ) water quality standards (Oregon Department of Environmental Quality (ODEQ), 2004) if harvest operations comply with the Forest Practices Act (FPA; ORS 527.770). The Oregon Department of Forestry (ODF)

must establish best management practices and rules that will meet state water quality standards and periodically conduct studies to determine if the FPA effectively meets state water quality standards (ORS 527.765, 527.710).

ODF initiated its Riparian and Stream Function (RipStream) monitoring project in 2002 to assess the effectiveness of FPA and State Forests standards at complying with DEQ water quality standards for temperature. One of the temperature criteria examined was the Protecting Cold Water (PCW) criterion, which is designed to prevent warming of streams that are currently cold enough to protect fish. This criterion prohibits human activities such as timber harvest from increasing stream temperatures by more than 0.3 ºC at the point of maximum impact where: a). salmon, steelhead or bull trout are present; b) streams are designated as critical habitat for salmonids; or c) streams are necessary to provide cold water to a) (OAR 340-041-0028 (11)). An analysis of the pre and post-harvest data indicated that the PCW criterion was likely not being met at all study sites with FPA buffers (i.e., these sites frequently exhibited temperature increases greater than 0.3 ºC; (Groom et al., 2011b)). This finding of degradation has initiated an FPA riparian rule analysis process. The geographic scope of the findings of degradation are based on (Groom et al., 2011b), which studied streams in the Coast Range and Interior Geographic Regions of Oregon (as defined in OAR 629-635-0220). While the exact geographic extent of the rule analysis is yet to be determined, it will be limited to western Oregon. This limitation is due to the vegetation, climate and hydrologic characteristics of eastern Oregon being significantly different enough from those included in the RipStream study to preclude extending a rule to eastern Oregon. As part of this rule analysis process, stakeholders contributed 16 alternative methods of riparian management as options for meeting the PCW standard during future near-stream harvest operations. The Oregon Board of Forestry approved consideration of these 16 alternatives at their July 2012 meeting.

ODF is conducting this systematic review (SR) to fulfill a requirement of the rule analysis process: proposed rules must reflect available scientific information (ORS 527.714 (5)(c)). The SR will also serve to inform the decision on the geographic extent of the rule analysis process relative to the RipStream findings on FPA sufficiency. Therefore, this SR will, through evaluating a focused question, directly assist in evaluating the 16 alternative scenarios for riparian management and help inform ODF rule analysis process. However, this review will

not recommend which alternative is the best to choose, nor explicitly define a particular rule prescription.

A.1.2 Protocol for Systematic Review

Protocols provide a road map for how to conduct a systematic review of scientific literature relevant to a narrowly-defined question (Centre for Evidence-based Conservation, 2013). A systematic review seeks to answer this question with evidence, as opposed to the authors' interpretation of such evidence, from existing studies that are rigorously screened for quality and relevance to this question. The structured process provides for transparency concerning how studies are searched for, which ones are included in the review, and how they are analyzed. This structure also allows for a review to either be updated in the future, or completed by another party. Elements incorporated in a systematic review are outlined in Table A.1.

Table A.1 Elements described in a protocol for conducting a systematic review.

Elements	Brief explanation
Question	Focused, scientifically answerable question that guides search strategy and inclusion criteria
Search strategy	Methods (e.g., search terms and databases) to find studies pertinent to question
Inclusion criteria	Filters used to determine relevance of studies to question
Study quality and relevance assessment	Criteria used to determine strength of study methodology, and the relevance of study findings to the review question
Data extraction	Tables used for consistently recording data and meta-data from studies and associated reviewer notes
Data synthesis	Methods (quantitative, qualitative) used for synthesizing data with respect to the review question

A.1.3 Review partners

Numerous partners are helping to strengthen the quality of this systematic review. We obtained input on both the formulation of the review question and this protocol from a group of stakeholders, the external reviewers, and the RipStream External Review Team (RSERT). These groups included university, federal, forest industry, and state scientists; staff from the Oregon Departments of Forestry, Environmental Quality, and Fish & Wildlife; and nongovernmental organizations including Pacific Rivers Council. Similarly, a reference librarian from the Oregon

State Library assisted in refining the search strategy. Finally, ODF staff composed initial drafts of the protocol and question, and will coordinate the work of these partners and the completion of the final SR report. This protocol might be slightly modified during the review process if external reviewers find ways to improve it. Any changes to this protocol will be coordinated by ODF, and fully documented for transparency. All mentioned partners will have the opportunity to review the completed SR report.

ODF will use external scientists to conduct the review. These reviewers will first cross-check their work by reviewing a subset of studies (including assessing their study relevance, quality, and extracting the data). Each reviewer will then independently review half the remaining studies included in the review. After analyzing the articles, the reviewers will write a report synthesizing their analyses.

A.2 Objective of the Review

This systematic review is designed to provide scientific guidance, per Oregon Revised Statues 527.714 (5)(c), to the Oregon Board of Forestry in addressing the following rule analysis objective developed by the Board at their April 2012 meeting:

> ***Establish riparian protection measures for small and medium fish-bearing streams that maintain and promote shade conditions that insure, to the maximum extent practicable, the achievement of the Protecting Cold Water criterion.***

Small streams are defined as having average annual flows ≤57 L/s (2 cfs), and medium streams are defined as having flows >57 L/s (2 cfs) and ≤283 L/s (10 cfs; Oregon Department of Forestry, 2010). Fish-bearing streams are those for which anadromous, game, or threatened and endangered fish presence has been observed or modeled. Specifically, this review is designed to provide insight on the efficacy of the 16 rule alternatives that were approved by the Board at their July 2012 meeting (Table A.5.1). A secondary purpose is to inform the Board's decision on the geographic extent of the rule analysis process.

This review will represent a less-extensive effort than typical systematic reviews. Guidance from the Collaboration for Environmental Evidence (CEBC) suggests extracting primary data from all studies to complete a quantitative analysis (e.g., meta-analysis). We decided against conducting a meta-analysis due to the limited budget, time, and need for such an

extensive analysis. In addition, such an analysis is often not possible in natural resources due to differences in study methods and questions examined (Centre for Evidence-based Conservation, 2013). CEBC guidance suggests exploring all possible sources of data (including e.g., on-going or never-published studies) and contacting study authors to obtain primary data. As noted below, our search strategy and types of studies included in the review are well-defined, although they are not as extensive as suggested in the guidance. We decided to include studies that pass a certain level of rigor (i.e., peer-reviewed literature, manuscripts in review, and graduate theses), and governmental studies, the latter of which are likely the most relevant to the review questions. These decisions are expected to provide an adequate level of information while speeding up the review process and limiting expenditures; typical systematic reviews cost approximately $100,000 and take a year to complete (Collaboration for Environmental Evidence, personal communication, Oct. 2012).

A.2.1 Primary review question

Systematic reviews are designed to assess a body of literature through the lens of a focused question regarding the efficacy of active treatments, rather than a general topic of concern to policy or practice. The question should be value-free to the extent possible, answerable in scientific terms, and specify the subject, treatment, comparator, and outcome(s) of interest. The question is also important since it is used to generate terms used in the literature search and to determine relevance criteria.

The review question was developed by several partners in stages. ODF staff (T. Frueh, J. Groom, and M. Allen) developed a draft review question. The question was refined in consultation with the external reviewers, representative stakeholders, and RSERT to ensure the question's importance and appropriateness of scope for this review. The question was then further refined with ODF input. The review question is:

> ***For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?***

The elements of the question are based on the rule objective (see above) and the finding of degradation. The question is limited to western Pacific Northwest (e.g., wet, temperate

climates) since these areas might have similar-enough characteristics (i.e., vegetation, hydrology, climate) to provide insight on the effects of riparian buffers on stream temperature or riparian shade in western Oregon. The purpose of the rule objective is to protect stream temperature within the context of harvesting forests, thus the examination of the effects of near-stream forest management in the context of forest harvest operations.

Table A.2.2 Definition of components of the primary systematic review question.

Population	Small and medium streams in forest harvest operations in western PNW forests
Intervention	Riparian management areas (e.g., buffers) for protecting cold water or riparian shade
Comparator	Lack of forest harvest
Outcomes	Change in stream temperature or riparian shade

A.2.2 Secondary question

This review will evaluate differences between studies that might explain variations among study outcomes. These differences may be due to effects modifiers (see Section A.3.3 for more information on these modifiers), and this secondary question explicitly addresses the causes of these differences. To the extent that relevant information is available in reviewed studies, this secondary question will be addressed:

For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, how do effects modifiers (e.g., discharge, substrate characteristics, length of buffers, stream aspect), in combination with near-stream forest management, change stream temperatures or riparian shade?

A.3 Methods

A.3.1 Search strategy

An important aspect of systematic review is the use of a search strategy that specifies, *a priori*, how a comprehensive and unbiased sample of the literature will be searched. For this review, the search strategy was drafted by ODF staff and modified following input from external reviewers, RSERT, and Stakeholders. In addition, a reference librarian from the Oregon State Library guided its refinement using professional judgment and test searches. We decided to search as wide as possible, then use rigorous inclusion criteria to determine which studies to

include. All publications found in each searched source will be imported into bibliographical management software, except for internet searches from which the first 100 results will be reviewed for relevant publications. Results with indeterminate information (e.g., incomplete citation) or that are duplicates will be discarded. The source of each reviewed publication will be specified in the study inclusion table (Table A.6.1).

Search terms are divided into sets that represent an element of the review question. Terms within each set will be combined via Boolean operators (e.g., AND, OR) with those of each term within the other sets. These terms were determined via consultation with ODF partners, and by looking at a protocol of a similar SR (Bowler et al., 2008). Search terms (* indicates wildcard search term):

Set 1. Management activity

(*Forest* or wood* or tree*) AND (thin* or harvest* or clear* or cut* or remov* or regenerat*)

Set 2. Treatment/intervention

(Riparian or streamside or "stream-adjacent" or "near stream") AND (buffer* or reserve* or manage* or zone* or leave* or veg* or strip * or area or canopy or wood*)

Set. 3 Outcome

("stream temperature" or "water temperature" or shade or cover)

For every search, the following information will be documented:

- Date when search was conducted
- Database, search engines, websites, or professional network that was searched
- Exact search strings used

The following electronic resources will be searched:

- Scopus
- World Cat
- CAB Abstracts
- Tree Search: USDA Forest Service Research
- AGRICOLA: Ebsco

- Streamnet Library Columbia Basin
- WAVES Canada: Libraries of Fisheries and Oceans Canada

An Internet search will be performed using the following search engines:

- www.yahoo.com;
- www.bing.com;
- google.com;
- www.scholar.google.com; and
- www.dogpile.com.

The first 100 hits from each internet search will be examined for appropriate studies.

Because disciplines related to stream temperature use diverse study designs and have little consensus on key terms, the systematic search will be augmented with an *ad hoc* search to avoid omitting useful publications. In the ad hoc search, bibliographies and citation searches of included studies and any traditional reviews will be examined for relevant references. Additionally, email or phone queries concerning obscure studies will be sent to scientists and stakeholders (e.g., participating environmental NGOs) in the Pacific Northwest who study, or work with people who study, riparian buffers, stream temperature, or shading of streams.

Searches will also be carried out within the web pages of relevant associations and organizations including, but not limited to:

- the US Environmental Protection Agency;
- National Council for Air and Stream Improvement;
- Washington Dept. of Natural Resources/Cooperative Monitoring, Evaluation and Research Committee;
- Washington Dept. of Ecology/ Forest Practice Effectiveness Monitoring Program;
- California Dept. of Forestry and Fire Protection;
- British Columbia Ministry of Forests, Lands, and Natural Resource Operations;
- US Forest Service;
- Northwest Indian Fisheries Commission;
- Columbia River Inter-Tribal Fisheries Commission;
- Skagit River System Cooperative;
- Canadian Forest Service, Natural Resources Canada;
- Alaska Dept. of Natural Resources/Division of Forestry.

Finally, to capture theses and dissertations that are archived more recently (i.e., not located in regular library catalogs), the search will include catalogues of electronic graduate theses from research universities in the Pacific Northwest:

- Oregon State University;
- University of Oregon;
- Portland State University;
- University of California system;
- University of Alaska;
- University of Washington;
- Washington State University;
- University of British Columbia.

A.3.2 Study inclusion criteria

Study inclusion criteria are predefined to ensure an objective selection of the relevant literature. For this review, the studies must directly inform the primary review question in the context of the rule alternatives and rule objective. Only primary studies (i.e. studies with original data, not reviews or meta-analyses) will be included since we want to base the rule analysis on evidence, not authors' interpretation of the evidence. While peer-reviewed articles are the gold standard in science, we decided to include "gray literature" (i.e., articles that might have less rigor in either peer-review or research methods and analysis, e.g., government reports, graduate theses) and manuscripts in review because some of these studies are most relevant to the review question. It is a common requirement that agencies (e.g., ODF, Washington Dept. of Natural Resources) assess the effectiveness of their respective rules via studies, thus this gray literature is likely to be highly relevant to the primary review question. In addition, only studies that measure the effects of recent forest harvests, with near-stream areas managed for protecting water (i.e., similar to OAR 629-635-0100), on stream temperature or riparian shade will be included since these elements are essential to analyze the riparian rule objective that provides the impetus for conducting this study. Restricting studies to those of "recent" harvest is warranted due to the decline, with time, of adverse impacts of harvest on stream temperature and riparian shade (Hale, 2007; Johnson and Jones, 2000). The final inclusion criteria are:

- Studies must have proper controls with which to measure the effects of buffer treatments;
- Studies must have been conducted in sites with similar stream sizes and forest types (OAR 629-635- 0310); and
- Studies must have been located in similar forests as that of western Oregon.

Inclusion criteria are further detailed in Table A.6.1.

With these criteria in mind, inclusion will be determined initially on viewing the titles of articles. When titles provide insufficient information to ascertain consistency with inclusion

criteria, the ODF review coordinator will read abstracts to determine inclusion. Where there is still insufficient information to make a decision, an article's inclusion will be determined by reading the full text. Studies that meet all inclusion criteria will be reviewed by the external reviewers. For transparency, the fate (i.e., inclusion or exclusion), and basis for this decision, of each publication found in the search will be documented in Table A.6.1. If a thesis that meets all inclusion criteria and also has a peer-reviewed publication associated with it, only the peer-reviewed publication will be used in the review. For studies from which multiple publications are produced, all publications will be included in the review.

A.3.3 Potential effect modifiers

While studies may have very similar methods, they may show differences in the measured outcomes. These differences may be due to circumstances ("effects modifiers") that alter the outcomes. For example, two studies may have identical buffer widths, yet if they have different buffer lengths, they might exhibit different changes in stream temperatures. Thus, these effects modifiers are important to consider when synthesizing the extracted data. The role effects modifiers played in study outcomes will be assessed in Table A.6.2 and discussed in the narrative synthesis (Section A.3.6).

The following lists of effects modifiers were determined by: 1) modifying a list of effects modifiers in a systematic review similar to this review (Bowler et al., 2008); 2) examining a subset of studies to see what are considered important effects modifiers; and, 3) incorporating input from RSERT and other technical experts.

Factors of, or affecting, the riparian zone:

- Length, width of the riparian reserve
- Tree harvest in part or all of the riparian reserve
- Type of trees e.g. deciduous or non-deciduous
- Tree height, age, distance from edge
- crown height
- Tree density
- Residual stand composition
- Tree/basal area retention amount
- Other riparian vegetation: presence,% cover
- Aspect

- Method of vegetation or tree removal
- Clearcut vs. thin (outside of riparian reserve)
- Harvest on both sides or single side of riparian reserve
- Logs or slash left in stream
- Harvest on both sides or only one side of riparian reserve
- Time since harvest
- Windthrow

Factors of the stream:

- Stream width/depth
- Discharge
- Distance from stream/river source
- Groundwater-surface water interactions
- Connectivity to other streams
- Hyporheic flow
- Flow through, or from, a wetland or lake
- Continuity of flow (seasonally and longitudinally)
- Substrate
- Gradient
- Aspect
- Geology and soils

Additional factors affecting temperature or shade measurements:

- Time of year and season
- Latitude
- Elevation
- Precipitation: volume, rain vs. snow domination
- Potential for topographic shading
- Air temperature
- Cloudiness
- Accuracy and precision of instruments for, and frequency of, data acquisition

A.3.4 Data extraction strategy

When conducting a systematic review, it is important to extract both information about studies and their respective primary data. This information focuses the review on evidence instead of authors' interpretation of the evidence. The data extraction tables allow for objective and transparent extraction of this data. In addition, these tables will likely highlight gaps in our understanding. For this study, these data will be compiled in Table A.6.2 for each study. This table was developed by modifying those of (Bowler et al., 2008; Burnett et al., 2008), testing

with several studies, and with input from RSERT and stakeholders. Reviewers will also assess various components (e.g., bias, effects modifiers) that provide a more complete understanding of the context, relevance and relative strength of studies (Table A.6.2).

A.3.5 Study quality assessment and relevance

When synthesizing data from the studies, it is important to consider both the quality of each study and its relevance to the review question. For example, a study might have directly addressed the review question, yet was poorly conducted so as to provide little confidence in the study's results. Conversely, a study may have been conducted very well, yet has only weak relevance to the review question.

External reviewers will complete tables that enable quick, objective comparisons of studies. Table A.6.3 addresses the quality of studies by determining e.g., the rigor of their controls, and number of replicates. This table also determines study relevance by determining how close studies are geographically and in stream size to those of (Groom et al., 2011a). Table A.6.4 determines whether studies directly or indirectly addressed a rule alternative, ~~and a relative assessment of the effectiveness of buffer treatments at protecting cold water or shade~~. Additional reviewer notes that further illuminate study quality and reference (e.g., robustness of study measures, sources of bias, consideration of effects modifiers) are listed in Table A.6.2.

A.3.6 Data synthesis

To make sense of the information extracted and analyzed from the studies, a narrative synthesis will be composed. This synthesis will assess the differences and commonalities between riparian management scenarios used in studies and their respective outcomes. For each rule alternative, the synthesis will discuss:

- Number of studies that directly or indirectly address the alternative[4];
- The evidence from a suite of studies regarding the effectiveness of the alternative, including:

[4] Note that although several publications may be from a single study, this is clarified in the discussion of how many studies addressed an alternative. In addition, a single study may have several publications, each of which addresses a different alternative.

    - range of variation in metrics defining each alternative (e.g., buffer width, basal area retention)
    - range of variation in outcomes measured
    - degree of effectiveness at protecting cold water or riparian shade
- The role of effects modifiers in the stream temperature and riparian shade outcomes that were measured; and
- Significant gaps in our understanding.

The synthesis will also consider the magnitude of influence the effects modifiers had on results, for the full suite of studies. However, the synthesis will not recommend which rule alternative to adopt in the rule analysis process, nor explicitly define a particular rule prescription.

A.5 Rule alternatives

Table A.5.1 Recommended initial range of alternatives for riparian rule analysis on small and medium fish bearing streams.

Alternatives were generated from stakeholder and staff input. Proposed alternatives may be either regulatory or voluntary, except for the Oregon Plan (voluntary) and Plan for Alternate Practice (regulatory) alternatives. From http://www.oregon.gov/odf/Pages/board/BOF_072612_Meeting.aspx

Category	Alternative	Scientific Principle(s)
Variable retention buffer	**Current FPA:** Maintain current standard target prescriptions (no action)	Include no-action as comparison
	State Forests Standards: State Forest Management Plan riparian protection standards. Three (3) zone RMAs with varying retention standards established for multiple purposes including but not limited to maintaining shade.	Shade known key driver of stream temperature increases.
	Derived variable retention: Use collected data or literature to explore a variety of stand metrics versus shade outcomes (including but not limited to RipStream data).	Utilize RipStream and any other relevant monitoring or research data that links riparian stand conditions to shade.
	Large tree variable retention – Emphasizes retention of largest trees close to the stream in addition to a no-cut and variable retention buffer.	Increased riparian basal area linked to higher shade levels.
	Minimize gaps: Maintain existing standard targets but modify current spatial retention standards (basal area/1000 ft) to minimize shade gaps	Strategic RMA tree retention to minimize shade gaps.
	Basal-area retention by aspect: Increase basal area density retention targets on south-sided RMAs only	Aspect known to influence stream temperature and shade.
Shade standard	**Field-based shade standard**: Establish process to implement field-measured shade standard rather than managing for RMA stand metrics	Shade known key driver of stream temperature increases.
	Shade approach from Washington DNR method: Three (3) zone RMAs based on a combination of site index, shade and basal area retention standards with linkages to applicable temperature standards. Uses channel migration zones (CMZs) versus high water	Shade known key driver of stream temperature increases.

Category	Alternative	Scientific Principle(s)
	level in current Oregon FPA.	
	Shrub shade: Develop alternative to account for shade contribution from shrubs or other non-woody plants.	Sites with significant shrubs or other non-woody plants may allow greater tree removal while maintaining shade.
Hardwood contribution	**Hardwood sites**: Consider alternatives to account for conifer vs. hardwood-dominated riparian stands.	Hardwoods provide shade but conifer retention emphasis in FPA, does not account for sites poorly suited for conifers.
	Hardwood shade: Include hardwoods in basal area standard target.	Hardwoods provide shade but few count towards current retention targets in FPA.
No-entry buffer	**Derived no-cut buffer**: No-cut buffer as based on actual shade, temperature, buffer width data or literature (including but not limited to RipStream).	Increased riparian basal area and greater no-entry buffer widths linked to higher shade levels.
	No-cut aspect buffers: No-cut buffers on south-sided RMAs plus standard retention prescription everywhere else.	Aspect and buffer width have been linked to shade levels.
Other	**Oregon Plan**: Modify Oregon Plan voluntary measures to encourage location of wildlife leave trees within RMAs, both small & medium streams (voluntary alternative).	Increased riparian basal area linked to higher shade levels.
	Plan for alternate practice - Develop criteria to allow for site-specific RMA prescriptions and maintain flexibility while achieving rule objective (regulatory alternative).	Promotion and maintenance of shade can be achieved through a variety of approaches.
One-sided buffer	**(added during BOF meeting 7/26/12):** Riparian vegetation retained only along the southern portion of a stream	Aspect and buffer width have been linked to shade levels.

A.6 Data extraction and summary tables

Table A.6.1 Determination of inclusion of studies, found in the search for potentially relevant literature, in this review.

"Y" indicates a study meets that inclusion criteria, "N" indicates it does not meet that inclusion criteria. To be excluded from this systematic review, a study must not meet at least one inclusion criteria (note: in order to prevent spending time reading an entire article, searching for exclusion criteria within an article will stop after finding one, and thus a study might meet more of the inclusion criteria then are listed in this table). To be included in this review, a study must meet all of the inclusion criteria. Note: if an insufficient number of studies are found during the search process, this strict exclusion threshold may be re-examined.

Study	Inclusion criteria					
	Outcome[1]	Setting[2]	Intervention[3]	Study design[4]	Study type[5]	Geographic extent[6]

[1] ~~Measured~~ Reported (via at least one figure or table) primary measurements of stream temperature ~~or~~, riparian shade (or a proxy thereof), or insolation.
[2] Small and medium streams (i.e., with contributing areas or average annual flow less than 1.5 times the upper limit of medium stream defined in (ODF, 1994) (11250 ac.(45 km^2) and 15 cfs, respectively), or wetted width or bankfull width less than 1.1 times the maximum wetted width or bankfull width from (Groom et al., 2011a) (4.0 m and 8.7 m, respectively) in mountainous terrain with forests harvested less than five years before data collection of a study.
[3] Near-stream area managed for protection of cold water and/or riparian shade. Management prescription is clearly quantified (e.g., buffer width, basal area retention).
[4] Controls exist (either pre-treatment data, control sites, or reference sites)
[5] Peer-reviewed papers, government reports, manuscripts in review, and graduate theses, all of which must be primary studies that describe methods and contain primary data.
[6] A portion of the study must have been conducted in any of the following locations: parts of Oregon, Washington, and British Columbia west of the crest of the Cascades, the Siskyous of northern California, northwest British Columbia, southeast Alaska, or the coastal range of northern California.

Table A.6.2 Data to be extracted from each publication included in evaluating the review question "For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?"

Studies labeled with a. and b. will be evaluated by both reviewers in order to assess consistency of their respective work. All publications will be identified in the systematic search process except those for which the citation will be followed by a reference to its source in brackets.

Publication title and principal investigator(s)	
Study dates and study duration (# of years, dates within a year)	
Study location (watersheds, region/state, country), settings where riparian buffers were applied	
Ecosystem type; plant association group; type of forest	
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	
Research question(s), hypotheses, objectives	
Study design[1]	
Pretreatment data (yes/no), # of years of pretreatment data	
Details on management action(s) (e.g., ~~examples:~~ sizes and types of buffers; clearcut or thin on both or single sides of streams)	
Replications (if applicable)	
Nature of the outcome measures used, their relative importance and robustness[2]	
Sample sizes and results with estimates of variation[3]	
~~Location of results within article (e.g., specific tables & figures, text)~~	
Notes concerning study quality with evidence or reasoning behind the notes[4]	
Potential sources of bias or error	
Effects modifiers[5]	
Notes[6]	
Method references[7]	

[1] ~~Replicated sampling, replicated controls, sampling before and after treatment; unreplicated, controlled, sampling before and after treatment; unreplicated, uncontrolled, sampling before and~~

~~after treatment; unreplicated, controlled, sampling after treatment~~ Brief description of study design, e.g., BACI, # of sites, types of controls (pre-treatment, reference, upstream), site layout.

[2] Examples of outcome measures: stream temperature, basal area, riparian shade; relative importance refers to instances where a proxy is used (e.g., canopy cover for shade at stream surface), how representative is the proxy? Robustness refers to how well outcomes were measured (e.g., accuracy of measurements, frequency, sound method for measuring)

[3] For sample size, list with respect to particular results (e.g., "increase of X degrees (n=4)"); list specific results that are most pertinent to answering the question and help inform the rule analysis objective, referencing a figure or table where appropriate; include confidence limits, ranges, or standard deviations.

[4] Address study quality questions such as: Did authors adequately address fundamental processes? How well did they conduct their statistical analyses? Were biases addressed?

[5] Discuss how well, and which, effects modifiers were considered (see list of effects modifiers in Section A.3.3)

[6] Notes allows for additional insight reviewer may provide on study quality

[7] refers to references that are essential to understanding methods of an article.

Table A.6.3 Summary of information from each study that indicates its quality and relevance to the review question.

Study	Quality							Confidence Score*	Relevance			
	~~Duration~~ Sampling periods†	Pre-treatment[1] (yrs)	Study design[2]	$N_{replicate}$[3]	$N_{control}$[4]	$N_{samples}$ sites[5]	Statistically robust[6]		Geography[7]	Mountains[8]	Stream size[9]	Question/Objective[10]

† ~~The number of sampling seasons for which data were collected.~~ The number of time periods in which data were collected; a time period combines spring, summer, and fall if in same calendar year, and may be as short as one event (e.g., for shade measurements).

[1]Data collected before treatment with the number of years of pre-treatment data in parentheses (X=yes, blank=no)

[2]H=high=Replicated sampling, replicated controls, sampling before and after treatment; M=medium=unreplicated, controlled, sampling before and after treatment; L=low=unreplicated, uncontrolled, sampling before and after treatment or unreplicated, controlled, sampling after treatment (modified from (Fazey and Salisbury, 2002)). If mixture (e.g., some sites with and some sites without replicates), give mixed rating (e.g., L/M).

[3]~~Number of treatment replicates~~ $N_{replicates}$ refers the numbers of treatments with the same prescription (e.g., buffer width).

[4]Number of control replicates; add succinct description (e.g., "3 yrs. Post-treatment, treatment X"), knowing that greater detail is captured in Completed A.6.2.

[5]Number of ~~samples (i.e., total number of~~ sites; add succinct description (e.g., "3 yrs. Post-treatment, treatment X"), knowing that greater detail is captured in Completed Table A.6.2.

[6] ~~H=high= stream temperature autocorrelation dealt with, data not combined across sites without accounting for site differences; M=moderate= contains some features of High as applicable; L=low=statistical tests used (or not) but ignore site differences or autocorrelation~~ This category considers two questions: 1) Were the statistical analyses conducted appropriate for the data collected? And, 2) Did study authors adequately explore data (via analyses) to address study questions and objectives? H=high= yes to both questions; M=medium= yes to one question; L=low= no to both questions. Note that this category does not consider study design.

* Sum of quality points for sampling periods, study design, number of replicates, and statistically robust columns. Points are: H=3, M=2, L=1. for sampling periods;1, 2, and 3 for 1, 2, and ≥3 seasons, respectively; for number of replicates: 1, 2, 3 for 0, 2-3, and ≥4 replicates, respectively. If a rating is between two categories, then the points are between these two (e.g., L/M, or duration=1 or 2 years, then the points would be 1.5). [7]H=high= west of crest of Cascades in OR,

WA, BC plus the Siskyous (i.e., sites most similar to those in western Oregon); L=low=Coast Range of N. CA, Vancouver Island, NW BC, SE Alaska (i.e., sites somewhat similar to those in western Oregon).

[8]In mountainous terrain (X=yes, blank=no)

[9]H=high=small or medium streams as defined in either of (Groom et al., 2011b; ODF, 1994) (i.e., with contributing areas ~~less than~~ ≤ 7500 ac.(30 km^2), or average annual flow ~~less than~~ ≤ 10 cfs, or wetted width < ~~less than~~ 3.7 m ~~wetted width~~, or bankfull width < 7.9 m~~bankfull width~~); L= low = "near" medium size stream (i.e., contributing areas 7500 - 11250 ac. (30-45 km^2), or 10 - 15 cfs average annual flow, or 3.7 - 4.0 m wetted width, or 7.9 - 8.7 m bankfull width).

[10]H=high=study objectives or questions directly relate to review question; L=low= study has relevant data even though study objectives or questions are not directly related to review question.

Table A.6.4 Relevance of each study to each rule alternative as listed in Table A.5.1.

In relevance row, high relevance (H) indicates study directly addressed a particular rule alternative; low relevance (L) indicates study indirectly addressed a rule alternative; blank indicates did not address rule alternative. The effectiveness row gives a relative rating of how well a particular treatment prevented warming, or decrease in shading, of streams.

Study		Current FPA[1]	State Forests Standards[1]	Derived variable retention	Large tree variable retention	Minimize gaps	Basal area retention by aspect	Field-based shade standard[2]	Shade approach from WA DNR method	Shrub shade	Hardwood sites	Hardwood shade	Derived no-cut buffer	No-cut aspect buffers	Oregon Plan	Plan for alternative practice[3]	One-sided buffer
	Relevance[4]																
	~~Effectiveness~~[5]																
Total # studies (pubs.) High relevance[5]																	

[1] Standards are summarized in .
[2] This alternative involves measuring shade at a site, estimating how much shade would be left with removing certain trees, removing these trees, and re-measuring the resultant shade.
[3] Any other type of treatment that may have been studied.
[4] A study is considered directly relevant (H) if it provides quantitative data that addresses whether or not a particular design or prescription of a rule alternative is effective at preventing warming or maintaining shade. A study is considered indirectly relevant (L) if it provides information that can give some insight to effectiveness of a particular rule alternative.
[5] ~~Effective at preventing stream from warming or maintaining shade: ++= prevented warming; += reduced warming; - =resulted in maximal warming.~~
[5] Sum of all studies that are highly relevant for each rule alternative; parentheses indicates the total number of publications relevant for a particular alternative if different than the number of studies. See Table 2 for clarification of relationship between studies and publications.

A.7 Discussion of significant modifications to the protocol

The protocol was modified during the review process, and the majority of these changes were added for clarification. This section discusses changes to the protocol that were more than clarifications.

Section A.3.2 Study inclusion criteria: We decided to include peer-reviewed publications rather than the theses from which they were produced since the former tend to be stronger analyses presented in a more succinct manner. We also decided to include all publications from a study because they typically present different analyses and/or data (e.g., shade vs. temperature, looking at the data differently).

Table A.6.2: Footnote describing "study design" was modified to include more information. The previous method is addressed in the study design category of Table A.6.3.

Table A.6.3:

- The original footnote describing "statistically robust" considered studies that took regular (e.g., hourly) measurements of stream temperature, but did not consider shade or less-regular temperature measurements. The modified footnote addresses studies of any kind, given their particular study design.
- The "confidence score" category was added to give a relative scoring of the quality of each publication reviewed. The scoring method is developed based on objective criteria within this table, and minimizing using elements that confound one-another (e.g., part of the rating for study design incorporates whether or not there was pre-treatment data, thus the pre-treatment column is not included in the confidence score). Adding this score is important to help policy-makers judge the quality of information from a publication, as well as for graphing purposes.
- The "question/objective" category was added to clarify whether or not relevant evidence from a study was in the context of a study that is closely aligned with this review's primary question.

Table A.6.4:

- "Field-based shade standard" was clarified because it is easy to consider a study that measures shade before and after harvest as being highly relevant. However, the standard is meant to measure shade before, estimate what it will be by harvesting specific trees determined by shade measurements, then re-measuring shade.
- The Effectiveness row was eliminated after doing the evaluations and realizing there was no good, objective way to assess this; instead, summaries (e.g., mean, range) of

effectiveness data (e.g., increase in temperature, decrease in shade/cover) are pulled directly from a publication and entered in Table A.6.2 in the Sample sizes and results row.

Appendix B. Completed data extraction and study comparison tables

This appendix contains Tables A.6.2-4 completed by the reviewers. The completed version of Table A.6.1 is in Data Supplement 2, Lit_Search_Filter. xls.

Completed Tables A.6.2 Data to be extracted from each publication included in evaluating the review question "For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?"

Studies labeled with A. and B. will be evaluated by both reviewers in order to assess consistency of their respective work. All publications will be identified in the systematic search process except those for which the citation will be followed by a reference to its source in brackets. Note: footnotes are listed only following the first copy of this table.

Publication	A. (Allen and Dent, 2001)
Study dates and study duration (# of years, dates within a year)	Post 1998 but before 2001, not sure of exact dates
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Siletz, Tillamook, Nehalem, Lower Columbia, Necanicum, Clatskanie, and Alsea basins
Ecosystem type; plant association group; type of forest	Riparian areas are typically dominated by an alder overstory and a salmonberry/sword fern understory. Riparian conifer species typically include western hemlock, western red cedar, and/or Sitka spruce. Douglas-fir is more prevalent farther away from the stream. Soils are deep and well-drained. Average of 90 year old unharvested stands and 65 year old harvested stands (32-120 years and 35-125 years, respectively)
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Large (6), medium (10), and small (14) type F (fish-bearing) streams, and small type D (domestic water supply) streams Average of 16 ft bankfull width (5-37 ft)

Publication	A. (Allen and Dent, 2001)
Research question(s), hypotheses, objectives	"OBJECTIVES 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 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[1]	30 sites, 21 harvested and 9 unharvested; 22 of 30 were large industrial ownership Plot was established on both sides of the stream, 500-1000 ft. along stream, at least 100 ft from the end of the harvest unit, 100 ft wide on each side of stream (measured from average annual high water) All trees >6 inches DBH measured
Pretreatment data (yes/no), # of years of pretreatment data	No; used set of unharvested reference stands for comparison
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Operations conducted after January 1, 1998. • Harvest units with the same "prescription" on both sides of a stream. • 16 RMAs were managed with a no-cut buffer, 2 riparian conifer restoration, and 3 site-specific plan • All of the adjacent uplands in the Coast Range were clearcut to the buffer's edge (21 out of 21 sites) • Basal area retained on these study sites was in excess of what can result from a basal area

Publication	A. (Allen and Dent, 2001)
	prescription on small 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.
Replications (if applicable)	6 large, 10 medium, 14 small sites by stream type

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = shade using hemispherical photographs at every 100 feet at center of channel
	  • Relative importance = shade estimated using 1-Global Site Factor averaged along the length within a plot, GSF based on June 30
	  • Robustness = is an accurate measure
	
	• Measure = cover measured by densiometer
	  • Relative importance = tended to over-predict shade (ave 100%), especially at higher cover levels
	  • Robustness = measurement method is consistent so can be calibrated

Sample sizes and results with estimates of variation [3]	• Shade in 19 harvested = 51-89% (73% ave) and 9 unharvested = 72-95% (84% ave) (Figure 7, Table 7) • 92% of sites had >60% shade • Shade was lower on large streams, though not statistically robust (Table 8, Figure 9) • Average shade was lower in all RMA prescriptions over that of unharvested stands, but differed little between each other (10-13% lower than unharvested) (Figure 10) • No statistically significant relationship between buffer width and shade results (though small relationship) • Stream shade decreased by approximately 9.1% (-1 – 29.5%) for shrub only prescriptions, whereas is decreased by 2.5% in unharvested (-0.6 - 7.7%). (Table 10) • No relationship with aspect, gradient, floodprone width, tree height • Harvest conifer had lower shade than harvested hardwood (Figure 21), but statistical difference is not likely • There were no differences between basal area of sites with fair (40-60%, n=2) to moderate (60-80%, n=16) shade. 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, but

Publication	A. (Allen and Dent, 2001)
	no statistical difference. (Figure 25)
Notes concerning study quality with evidence or reasoning behind the notes[4]	They addressed the fundamental drivers of shade along with prescriptions and reported statistics in a reasonable manner. I am not certain of the stream size differences or when plots were measured relative to the June 30 GSF estimate. I am not clear on how stream size influences results for harvest prescription.
Potential sources of bias or error	Low sample sizes and not having pre-treatment data limits conclusions
Effects modifiers[5]	• They addressed many factors affecting the riparian zone, including: tree height, type of trees, basal area, understory vegetation, aspect. • They addressed some factors affecting the stream, including: stream width, gradient, aspect.
Notes[6]	Actual shade results would have been good to have besides just summary tables so that we can make conclusions for ourselves. This is especially important in the situation where there are frequently not statistical differences.
Method references[7]	n/a

Publication	B. (Allen and Dent, 2001)
Study dates and study duration (# of years, dates within a year)	Between 1998 and 2001, single event sampling at each site during the study period
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Oregon Coast Range (central to northern), Oregon, USA Basins include: Siletz, Tillamook, Nehalem, Lower Columbia, Necanicum, Clatskanie, and Alsea
Ecosystem type; plant association group; type of forest	Only a general description of conifer species associated with the Coast Range georegion is provided. Riparian conifers include: *Tsuga heterophylla*, *Thuja plicata, and Picea sitchenis* *Pseudotsuga menziesii* is more common away from the stream.

Publication	B. (Allen and Dent, 2001)
	Unharvested stands averaged 90-years old (32 to 120). Harvested stands averaged 65-years old (35-125).
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	14 small, 10 medium, and 6 large streams Average bankfull widths for harvested/unharvested: (10/7),(20/19), and (32/33) feet respectively
Research question(s), hypotheses, objectives	**Objectives:** 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:** 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 between riparian stand characteristics and shade?
Study design[1]	Replicated sampling, replicated controls, sampling after treatment
Pretreatment data (yes/no), # of years of pretreatment data	no
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	22 of 30 sites under large industrial ownership with remaining 8 split between small, private and federal ownership All treatment plots extended100-feet from the ordinary high water mark on each side of the

Publication	B. (Allen and Dent, 2001)
	stream and were 50 to 1000 feet in length. **<u>RMA prescriptions:</u>** No-cut Buffer Width (n=16) Riparian Conifer Restoration (n=2) Site Specific (n=3) Unharvested (n=9) **<u>Upland Prescriptions:</u>** Clearcut (n=21) Unharvested (n=9)
Replications (if applicable)	Questionable if these are considered replicates – not really treated as a replicated design
Nature of the outcome measures used, their relative importance and robustness[2]	Percent shade (measured by hemispherical camera along stream channel): relevant, robust
Sample sizes and results with estimates of variation [3]	30 sites, 21 harvested and 9 unharvested Harvested shade: 51 to 89 % - 2/3's of sites in 60 to 80 % range Unharvested shade: 72 to 95 % - 7 of 9 in 80 to 100 % range Average stream shade was 11 % less in unharvested stands than in harvested (84 versus 73 %, respectively) Differences relative to the unharvested sites by riparian management type varied little for

Publication	B. (Allen and Dent, 2001)
	the three prescriptions: Riparian Conifer Restoration (n=2): -13 % No-cut (n=16): -12 % Site Specific (n=3): -10 % Buffer width did not explain differences in shade (no values given, just a plot) States that harvested stands had greater blowdown, but also that shade was better explained by harvest than blowdown percent (Figure 17 is blacked out – additional quantification is not possible). Differences between measurements that captured understory and those that did not were greater at harvested sites (9.1 versus 2.5 %, on average).
Notes concerning study quality with evidence or reasoning behind the notes[4]	Sample sizes to compare difference in shade between riparian prescriptions are insufficient.
Potential sources of bias or error	Hemispherical photo analysis is sensitive to proper setup of camera. Error possible via resolution of camera and analysis algorithm. Bias introduced by intentionally eliminating sites with >75 % blowdown
Effects modifiers[5]	Effects modifiers such as topography/valley morphology, aspect, forest type and composition, and natural disturbances are addressed in this paper, but not used to adjust results of analysis pertaining to SR questions.
Notes[6]	The paper includes a section where a model to predict stream shade is developed. The analysis doesn't provide any additional insight on the treatment effects presented earlier in the paper, but does suggest that 65 % of the variability in stream shade can be explained by the variables Live Crown Ratio and Basal Area per Acre on the south side of the stream.
Method references[7]	

Publication	(Brazier and Brown, 1973)

Publication	(Brazier and Brown, 1973)
Study dates and study duration (# of years, dates within a year)	Not stated
Study location (watersheds, region/state, country), settings where riparian buffers were applied	• Oregon, USA • southern Cascades (Little Rock, Francis, and Reynolds Creeks) • Coast Range (Deer, Lake, Grant, Griffith, Savage, and Needle Branch) • All sites with the exception of Needle Branch located in National Forests (Umpqua for the Cascades and Siuslaw for the Coast Range); Needle Branch is industrially owned
Ecosystem type; plant association group; type of forest	primarily merchantable (stated "commercial") conifers comprising riparian forests but one site with young red alder and shrub vegetation
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	"small mountain streams" is only detail on size provided
Research question(s), hypotheses, objectives	OBJECTIVE (not stated directly, but inferred) 1. Examine buffer widths, buffer timber volume, and buffer canopy density effectiveness in protecting stream temperature increases following forest harvest
Study design[1]	• Stream temperature measurements "above and below" clearcut (exact locations/distances not provided) • Angular canopy density (aligned with maximum solar angle for July/August) measured on 100-feet intervals • Estimated commercial timber volume within buffer • Average buffer strip width through clearcut estimated •
Pretreatment data (yes/no), # of years of pretreatment data	No
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Clearcut with buffer strips of varying widths and species composition (although species effect not directly assessed)

Publication	(Brazier and Brown, 1973)
Replications (if applicable)	No

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Stream Temperature
	  • Relative importance = High
	  • Robustness = High (resolution for early-70's measurements?)
	• Measure = Angular Canopy Density
	  • Relative importance = High
	  • Robustness = Somewhat robust (user-subjectivity similar to densiometer)
	  •

Sample sizes and results with estimates of variation [3]	• Upstream-to-downstream temperature increases ranged from 0.6 to 5.0 C and followed a generally decreasing trend with increasing buffer width (n=11) • The lowest increase was found for both 60-foot and 100-foot buffers (a different 100-foot buffer had an increase of 2.2 C) • The maximum increase was for an eight foot buffer of young *Alnus rubra* saplings • Maximum angular canopy density of 80 % is achieved at a buffer width of 80 feet; 90 % of the maximum is achieved with a 55-feet wide buffer (n appears to equal 13, but no explanation given for additional data points; Figure 5)
Notes concerning study quality with evidence or reasoning behind the notes[4]	Strength of statistical relationship relating angular canopy density to buffer strip width questioned as regression assumptions do not appear to have been met and considerable scatter around prediction.
Potential sources of bias or error	• Did not account for aspect, buffer age (one buffer was young alder), distribution of vegetation types on each side of the buffer (at least one stream had no conifers on south side of the buffer), or understory composition
Effects modifiers[5]	Assessed the influence of buffer strip timber volume, buffer strip width, and angular canopy density as effects modifiers.
Notes[6]	.
Method references[7]	

Publication	(Brosofske et al., 1997)
Study dates and study duration (# of years, dates within a year)	2 years: 9 sites summer of 1993, 5 resampled in summer 1994; additional 6 sites summer of 1994 Summer = 1-2 weeks within window of end of June through August
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Washington – foothills of western Cascade Mountains, elevations 150-600 m
Ecosystem type; plant association group; type of forest	"Overstory vegetation at the study sites is comprised primarily of Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) and western hemlock (Tsuga heterophylla [Raf.] Sarg.), with occasional red alder (Alnus rubra Bong.), western red cedar (Thuja plicata Donn), and grand fir (Abies grandis [Dougl.] Lindl.). Ground vegetation is diverse, composed of both lowland and upland species."
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Width between 2-4 m
Research question(s), hypotheses, objectives	"Specific objectives of this paper are: (1) to characterize pre-harvest riparian microclimatic gradients from the stream to the upland; (2) to identify the effects of harvesting on these gradients; and (3) to describe the effects of buffer width and nearstream microclimate on stream microclimate."
Study design[1]	• Sampling at six 50 m stations along a 300 m transect perpendicular to the stream, only 1 measure at the stream center where water temperature was measured (no details to depth or method). Air, surface and soil temperatures were measured along with relative humidity, wind speed and solar radiation. Measures above the surface were 2 m from the surface. • Average dominant tree height between 25 and 50 m, canopy coverage 70-80%
Pretreatment data (yes/no), # of years of pretreatment data	5 sites with 1 week of pretreatment data

Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• 15 sites:
	  • 4 sites harvested/planted 1990-1991 with buffers of 12-23 m
	  • 5 sites have pretreatment (1993) and post-treatment (1994) data, with buffers 17-72

Publication	(Brosofske et al., 1997)
	m • 6 sites were cut 1-4 years before monitoring in 1994, 1 with no buffer and others 10-72 m Harvest was clearcut with buffer on all sites but one with no buffer.
Replications (if applicable)	None, unless considering spatial replication.
Nature of the outcome measures used, their relative importance and robustness[2]	Measures: air, surface, stream and soil temperatures, relative humidity, wind speed and solar radiation • Importance: Common microclimate measures, direct measures of microclimate • Robustness: Stream temperature measure was not explained in enough detail to make a determination of robustness.
Sample sizes and results with estimates of variation [3]	• No clear pattern in stream temperature at the sites. At the site with no buffer, stream temperature was higher than all other sites. • Regression between stream water temperature and microclimate variables showed no significant relationship between stream water temperature and wind speed, relatively humidity and solar radiation; intermediate effects of air and surface temperatures (R^2 = 0.20-0.70); and strong effects of soil temperature (R^2 = 0.75-0.98) (especially at pre-harvest sites) (Figure 9). • Soil temperature indicated no significant difference pre- vs. post-harvest within 50 m of the stream, though there was an increase in by 25% in soil temperatures outside of the buffer (Fig 3). • Increased air temperatures found within 50 m of the stream pre-harvest vs. post-harvest (difference of <1 degree C; approximately 22.5%) (Figure 2). • Solar radiation significantly higher (difference of ~0.1 kW/m^2) post-harvest during the day throughout the buffer (Figure 5).
Notes concerning study quality with evidence or reasoning behind the notes[4]	Many concerns around reliability of stream temperature data – no replication in the channel to determine whether the stream measure is characteristic, only 1-2 weeks of stream temperature data taken at just one window with no replication.
Potential sources of bias or error	Regressions of stream temperature vs. microclimate measures is straight-forward, though there was no indication of how time series effects were dealt with.

Publication	(Brosofske et al., 1997)
Effects modifiers[5]	• Direct comparisons: air temperature • Indirect comparisons: buffer width • Factors collected but not discussed: time since harvest, tree height, aspect
Notes[6]	Most of this study was focused on microclimate factors and they suggest at the end that a very wide buffer (≥300 m) may be necessary to reduce influence on all microclimate measures described in this study.
Method references[7]	
Publication	(Danehy et al., 2007)
Study dates and study duration (# of years, dates within a year)	15-day period in August 2003
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Coast Range, Oregon Elevations between 298 and 614 m
Ecosystem type; plant association group; type of forest	Douglas-fir dominant
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Small streams with bankfull width around 1-2 m "All but one site had base flow discharge of less than a liter per second, with treatment means ranging from 0.33 to 0.69 l/s (Table 1)."
Research question(s), hypotheses, objectives	"Our objectives were (1) to describe and compare the structure of diatom and macroinvertebrate assemblages in headwater streams, (2) to identify environmental factors associated with assemblage structure, and (3) to determine the extent these factors vary among harvest prescriptions (thinning and clearcutting)."
Study design[1]	• Stream temperature measures at four locations along each study reach for the same 15-day period using thermocouples inserted into the substrate (8 cm depth). • Hemispherical photographs taken at stream center at four locations along each reach after leaf out.
Pretreatment data (yes/no), # of years	None

Publication	(Brosofske et al., 1997)
of pretreatment data	
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• 6 mature – no harvest for at least 50 years; all second-growth • 7 thinned – target of ~200 trees/hectare (initially 500-750 trees/hectare); no harvest in 15 m buffer
Replications (if applicable)	6 spatial controls
Nature of the outcome measures used, their relative importance and robustness[2]	Thermal maxima (°C): • Importance: fairly commonly used measure therefore usually comparable • Robustness: uncertain due to the nature of this particular measure. Sensors were embedded within the substrate and there was no discussion of variation and how this compares to the typical variation observed for stream temperature measures. Thermal maximum minima (°C): • Importance: a method for standardizing across sites • Robustness: This value should be more robust than thermal maxima.
Sample sizes and results with estimates of variation [3]	Table 1: Mature Mean (SE) Thinned Mean (SE) Clearcut Mean (SE) ANOVA P 6 samples 7 samples 5 samples Thermal maxima (°C) 13.35 (0.40) 13.37 (0.59) 14.6 (0.55) 0.23 Thermal maximum minima (°C) 11.37 (0.26) 11.46 (0.48) 11 (0.88) 0.81
Notes concerning study quality with evidence or reasoning behind the notes[4]	Sample sizes are very small; therefore results could be biased. Statistics include clearcut samples, so results may be somewhat different for a comparison of mature vs. thinned stands.
Potential sources of bias or error	• Abiotic factors were assessed with a simple ANOVA, which is robust for three-way comparisons of this nature. • Not certain how time series were dealt with, nor how the four sampling locations at a site were compiled.
Effects modifiers[5]	Direct measures: woody debris, gradient, substrate, discharge, groundwater (springs and

Publication	(Brosofske et al., 1997)
	seeps), stream width/depth, morphology
Notes[6]	Cannot make direct comparisons of stream temperature findings in this study to most other studies because stream temperature was measured within the substrate to reduce influence of loss of surface flow and solar insolation on the sensor.
Method references[7]	

Publication	(Dent, 2001)
Study dates and study duration (# of years, dates within a year)	2 years, unknown dates but assume some time around 2008
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Study contained sites across Oregon. This review focused on data from the Coast Range, West Cascades and Interior regions.
Ecosystem type; plant association group; type of forest	• Coast Range: "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." • Interior: "Riparian areas on the westside of the valley are similar to those of the Coast Range with alder-dominated stands and patchy Douglas-fir. Conifers are more common in the riparian overstory on the east-side of the valley." • West Cascades: "The dominant riparian tree species are red alder, western hemlock, western redcedar, and Douglas-fir. Noble fir, white fir, grand fir and Pacific fir grow at higher elevations."
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Based on FPA standards: "small (< 2 cfs), medium (> 2cfs and < 10 cfs), or large (> 10cfs)" • Coast Range: 8 small, 2 medium, 4 large • Interior: 4 small, 5 medium, 3 large • West Cascade: 4 large
Research question(s), hypotheses, objectives	Overarching question: "Are the new (1994) forest practices regulations effectively maintaining and promoting riparian conditions that will achieve the desired future condition?"

Publication	(Brosofske et al., 1997)
	Specific questions: "1. Do estimates of average basal area that were used to craft the standard targets for basal area accurately represent mature riparian forests? 2. Do hardwoods dominate the near-stream area on all stream sizes? 3. How does the available basal area in riparian management areas compare to standard targets? 4. Are the 1994 forest practices riparian rules effective in maintaining potential sources of large wood recruitment for in-stream habitat as compared with pre-harvest condition? **5. Are the 1994 stream protection rules effective in maintaining stream shade as compared with pre-harvest condition?** 6. What are the trends in conifer regeneration within riparian areas?"
Study design[1]	• Pre-treatment data collected at 40 sites, 25 were visited 1year later after harvest. • "Riparian sample sites were 500 ft long by 100 ft wide, running parallel to the stream. The plot location was placed at a randomized distance from the bottom of the unit. The plot was located on the left side of the stream if both sides were to be harvested." • "Shade and cover were measured along five evenly spaced transects (one every 100 feet) starting at one end of the plot. Cover was measured with a convex densiometer at all five transects at midchannel and on both banks. Shade was measured with a Solar Pathfinder at the upstream, downstream, and middle transects."
Pretreatment data (yes/no), # of years of pretreatment data	1 year, 40 samples, 21 sites

Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Prescriptions: (see Table 2 for more detail on size-prescription combinations):
	  • Coast Range: 4 riparian conifer restoration, 1 standard target, 3 unknown, 6 not harvested
	  • Interior: 7 standard target, 2 no-cut RMA, 1 unknown, 2 not harvested
	  • West Cascades: 1 standard target, 2 no-cut RMA, 1 not harvested
	• Riparian Conifer Restoration (RCR) - conversion (maximum 500 feet long, can harvest all trees to within 10 feet of the stream and must replant conifers) and retention blocks (minimum 200 feet long, harvest depends on whether standard basal area target is met)
	• Standard Target – depending on region target, "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"

Replications (if applicable)	Replication by Geographic Region, stream size and prescription; therefore, no replicates to 2

Publication	(Brosofske et al., 1997)
	replicates.
Nature of the outcome measures used, their relative importance and robustness[2]	Cover: percent of sky covered by vegetation or topography • Importance: Frequently used as a surrogate for describing shade, though is not equivalent. This study drew the distinction between the two. • Robustness: Repeatability of +/- 10% is reasonable for method used. No reference to understory in the text makes it challenging to understand what was measured.
Sample sizes and results with estimates of variation [3]	• Reductions in cover of were seen in) (Figure 14): • 7 out of 9 small streams, 4 exceeded 10% (average of 12% reduction, significant p=0.03) • 4 of 7 medium streams, 2 exceeded 10% (average of 7% reduction) • 5 out of 8 large streams though the reduction was by <10% (average of 1% reduction) • "Cover in small streams before harvesting ranged from 83 to 95%, and after harvesting, ranged from 60 to 95% (Table 6)." • Cover was reduced the most (up to 36%) in narrower streams (<10 ft wide) (Figure 15). • "The two greatest reductions in cover (-36 and 34%) were observed on two out of four of the RCR sites (one medium stream and one small stream)."
Notes concerning study quality with evidence or reasoning behind the notes[4]	Number of replicates are low and number of samples are low, especially considering the diversity of sites and variability of measure. Not very conclusive evidence of effect or of no effect.
Potential sources of bias or error	Sites were not randomly selected. Not a large sample size considering variation.
Effects modifiers[5]	Direct comparisons of: stream width Indirect comparisons of: width of riparian reserve, hardwoods vs. conifers, tree/basal area retention, other riparian vegetation cover
Notes[6]	This study covers additional material regarding hardwood and conifer retention and density within the RMA (see study questions), but only one key question relevant to this review.
Method references[7]	ODF protocol: http://www.odf.state.or.us/internal.htm

Publication	(Dent and Walsh, 1997)

Publication	(Dent and Walsh, 1997)
Study dates and study duration (# of years, dates within a year)	July through September 1995 (Brush Creek study 1994-1996)
Study location (watersheds, region/state, country), settings where riparian buffers were applied	8 of 13 were in Coast Range; 5 of 13 were in "Interior" which is the Willamette Valley foothills and interior Umpqua basin
Ecosystem type; plant association group; type of forest	Not described
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	8 medium, 3 large and 2 small (in Coast Range: 5 medium, 1 large and 2 small; in Interior 2 large and 3 medium) Wetted widths ranged from 2 to 26 feet
Research question(s), hypotheses, objectives	Objectives: "Investigate stream and riparian characteristics which influence stream temperature. Test the effectiveness of riparian management areas and hardwood conversions in maintaining stream temperature at a site and a watershed level. Determine if riparian management areas and hardwood conversions maintain stream temperatures at or below the Department of Environmental Quality (DEQ) state standard for water quality."
Study design[1]	• 13 streams • "Stream temperatures were used from three stations on each stream: station 1, on the upstream boundary of the harvest unit; station 2, on the downstream boundary of the harvest unit; and station 3, 1000 feet downstream of the harvest unit" • "Temperature data were collected every 48 minutes using HOBO-temp monitoring thermistors."
Pretreatment data (yes/no), # of years of pretreatment data	none
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single	• 13 streams harvested with either a riparian management area (5 sites/3 sites Coast Range) or a hardwood conversion (8 sites/5 sites Coast Range) • "…three sites (2 sites coast range) harvested under the HWC rule were intentionally designed to limit openings on the south side of the streams." (i.e., buffer on one side of stream)

Publication	(Dent and Walsh, 1997)
sides of streams)	• Sites had "intact riparian condition 1000 feet upstream and 1000 feet downstream of the harvest unit, and harvesting conducted under the 1994 stream rules….Harvest units vary between 1100 feet to nearly one mile in length." • "Buffer widths varied from 18 feet to 131 feet."
Replications (if applicable)	13 sites
Nature of the outcome measures used, their relative importance and robustness[2]	7-day moving mean of daily maximum, minimum and average; diurnal fluctuation • Importance: widely accepted measure • Robustness: collection of measures appears to be accurate, though there are four streams with missing data at one station and two streams where the third station is considerably further downstream than the other sites (one 2.4 miles and seems like it should not be used for analysis)

Sample sizes and results with estimates of variation [3]	• Average increase in stream temperature from up to downstream station for the highest 7DMax period (July 31-Aug 6) was 2.5 °F for HWC and 2.1 °F for RMAs (Figure 3). Five changed by 1 °F or less (3 HWCs, 2 RMAs) and four changed by >3 °F (all HWCs) (Figures 3 and 4). Note that HWC one-sided had inconclusive results (2 sites with little change and one with substantial change). N=13
	• Of the four sites with <3 °F temperature increase, three had buffers designed to remove basal area for the north side of stream and leave more on south side of stream.
	• Change in canopy cover for the HWCs = -20 to +6% (Table 3). Change in RMAs = -18 - +9 %.
	• For 2 out of 6 comparisons, as buffer width increased, 7DMaximum and Average temperature increased (Table 4).
	• No statistically significant temperature differences between upstream and downstream of harvested stream lengths, based on an analysis of residuals from equations that account for distance from divide.
	• Analysis of the raw temperature data showed stream temperatures upstream significantly lower than either of the two stations downstream of the harvest unit (n=13?, Figure 6):
	  • approximately 2.5 °F for upstream to immediately downstream HWCs
	  • approximately 2.2 °F for upstream to 1000 feet downstream HWCs
	  • approximately 2.1 °F for upstream to immediately downstream RMAs

Publication	(Dent and Walsh, 1997)
	• approximately 1.5 °F for upstream to 1000 feet downstream RMAs • Diurnal fluctuation downstream of the harvest unit was 5.8 °F for intact riparian areas, 4.7 °F for RMAs and 7.5 °F for HWCs (Figure 7). • One example in Umpqua Basin showed increased 7DMax downstream of HWC two years post-harvest, 1.6 °F 1st year and 2.6 °F 2nd year, following a pre-harvest decrease in temperature of 1.5 °F (Figure 11).
Notes concerning study quality with evidence or reasoning behind the notes[4]	• Small sample sizes and a lot of variability that was not displayed on plots, therefore cannot make statistically robust comparisons. • No pre-harvest and no control. • There were concerns that measures of canopy cover were not accurate.
Potential sources of bias or error	Strong correlations between temperature and physical characteristics of the stream were not adequately addressed. Assumptions were made that all streams would retain the same trend in physical characteristics, therefore they did not need to be accounted for separately.
Effects modifiers[5]	Direct measures and correlation analysis of: width and length of buffer, cover/shade, stream flow, aspect, elevation, gradient, width and depth, substrate and distance from divide
Notes[6]	Qualitative study
Method references[7]	

Publication	(Gomi et al., 2006
Study dates and study duration (# of years, dates within a year)	Spring 1997 through summer 2002 (~5.25 years of data collection for most sites)
Study location (watersheds, region/state, country), settings where riparian buffers were applied	60 km east of Vancouver, British Columbia, Canada (UBC Malcom Knapp Research Forest)
Ecosystem type; plant association group; type of forest	Second-growth Tsuga heterophyla, Thuja plicata, and Psuedotsuga menziesii approximately 30 to 40 m in height and with 70 to 90 % crown closure
Stream size (avg. annual flow,	Mean bankfull widths range from 0.5 to 4.0 m

Publication	(Gomi et al., 2006
contributing area, HUC, avg. wetted width, etc.)	
Research question(s), hypotheses, objectives	OBJECTIVE "…evaluate headwater stream temperature response to clearcut logging with different riparian treatments based on a replicated paired catchment design."
Study design1	• Replicated paired catchment design with replication of the control and three treatment types • The control stream catchments had not been disturbed for 80 years and were forested with second-growth conifers • Treatments were 10 m stream buffer on each side of the stream and 30 m buffer on each side of the stream • Only 20 to 25 % of the total area adjacent to the stream was clearcut, with the exception of one "No Buffer" reach which was 53 % harvested, so as to reduce the effects of increased streamflow • Stream temperature was measured on 192-minute intervals at the downstream end of the cutblock or control reach • Harvesting occurred from April 1998 to January 1999 using a cable logging system • Used Generalized Least Squares regression, accounting for serial autocorrelation, to assess treatment effects
Pretreatment data (yes/no), # of years of pretreatment data	Yes, 1 year
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• 100 % harvest within units/blocks located immediately upgradient of the buffer • Harvest units tended to be linear in most cases with the long axis paralleling the stream • For all treatments, both sides of the stream were harvested
Replications (if applicable)	Control: n=3 10 m buffer: n=1 30 m buffer: n=2

Nature of the outcome measures used, their relative importance and robustness2	• Measure = Stream temperature (daily maximum, minimum, and mean)
	  • Relative importance = High
	  • Robustness = High

Sample sizes and results with estimates of variation 3	Text Section 3.3, Table 3, Figure 4-6 10 m buffer (n=1) • Up to 3 °C treatment effects for daily maximum temperature measured in first, second, and fourth years after harvest, with a slightly larger (3 °C) and more continuous and prolonged effect measured during the third year

Publication	(Gomi et al., 2006
	after harvest (this stream was noted to become discontinuous during low flows which could have been a factor in the third year, however mean discharge at the control was second highest of the post-treatment period in the third year) 30 m buffer (n=2) • Treatment effects were mostly less than 2°C for daily maximum stream temperature • Excursions beyond the upper 95 % prediction interval (~1°C) for the daily maximum treatment effects occurred only during summer months for one stream (D Creek) while they occurred more continuously for the other stream
Notes concerning study quality with evidence or reasoning behind the notes4	Despite a strong study design and analysis approach, this study is flawed in that some treatment reaches are downstream of other treatment reaches and/or tributaries directly affected by treatment harvests. The authors provide rationale for why they do not believe the effect of this factor is of significance in Section 4.3. However, this factor adds uncertainty to the overall results. Interpretation of results was difficult because of conflicting statistical significance hits for the "treatment effects" plots (Figures 4 and 5) and Table 4 that summarized summer "disturbances".
Potential sources of bias or error	• Potential for upstream treatment reaches introducing bias and/or variability to downstream treatment-control relationships during the post-treatment period • Did not account for channel width: for the no buffer streams, the 4 streams were split between wide channels and narrow, incised channels which likely influenced the large variability in the response to harvest • Drainage area differences between treatment types could confound comparison of effects magnitude by treatment type • Streamflow continuity was not accounted for: for the 10 m buffer stream, the channel was noted to become "a series of poorly connected or disconnected pools" which likely affected temperature dynamics relative to the spatially-continuous control stream
Effects modifiers5	• The effect of air temperature was assessed in Figure 6. • Impacted area % mainly controlled for with one exception • Drainage area was not intentionally controlled for but generally the same within treatments (with exception of one "No Buffer" stream having ~5 times larger drainage area) , but different across treatments
Notes6	This study was thoughtfully planned from both statistical design and statistical analysis perspectives. However, loss of treatment streams for the 30 m and 10 m buffer types resulted in less replication than planned which reduced the confidence in the findings for the management types most relevant to this Systematic Review. Additionally, the authors attempt to reduce the effect of increased groundwater contributions and associated temperature influences as a result of forest harvest make this study less applicable to real-world harvest situations.
Method references7	General least squares method fully-developed in text, but adopted from Watson et al. (2001)

Publication	(Groom et al., 2011a)
Study dates and study duration (# of years, dates within a year)	Entire study period from 2002 to 2008; temperature data collected July 1 – September 15; channel and riparian data 2 years pre-harvest and 2-years post-harvest within the study period
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Oregon Coast Range 33 sites: 18 private and 15 state forest land locations in Oregon's north and middle Coast Range
Ecosystem type; plant association group; type of forest	• Forests were ~50-70 years old; dominated by Douglas fir (*Pseudotsuga menzeisii*) and red alder (*Alnus rubra*); harvest or fire regenerated; lands primarily managed for timber production • One site had a 220 m long beaver pond
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Small streams - average annual flows ≤57 L/s Medium streams - average annual flows 57 – 283 L/s 1st – 3rd order streams
Research question(s), hypotheses, objectives	Objectives: "1. Identify site physical and vegetative factors, including shade, that relate to stream temperature change. 2. Determine the magnitude of stream temperature change that results from timber harvest. 3. Quantify riparian characteristics that predict shade retention after harvesting."
Study design[1]	• 2 years pre-treatment data and 5 years post-treatment with minimum reach length of 300 m • Two study reaches on all streams – unharvested control reach immediately upstream of treatment reach • Reach sizes varied with averages of: 276 m control, 684 m treatment • Temperature collected hourly from July 1 – Sept 15 each year at 3 stations per stream bracketing the up and downstream ends of each reach • Probe placement followed OWEB protocol – shaded where temperature was relatively constant, reliable summer depth and well-mixed water column • Channel data collected: wetted width, bankfull width, thalweg depth and stream gradient every 60 m • Vegetation data collected in four 152 x 52 m plots on either side of study stream in control and

Publication	(Groom et al., 2011a)
	treatment reaches; centered along reach
Pretreatment data (yes/no), # of years of pretreatment data	2 years pre-harvest for 31 sites
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	18 streams harvested according to FPA rules: RMAs are 15 m (small streams) and 21 m (medium streams) that are fish bearing, with a 6 m no cut zone; harvest in remaining RMA to a minimum basal area of 10.0 (small streams) and 22.9 (medium streams) m^2/ha 15 streams harvest according to FMP rules: RMAs are 52 m wide for all fish bearing streams, with an 8 m no cut zone; limited harvest allowed within 30 m of stream to create mature forest, but retain 124 trees/ha; additional tree retention of 25-111 conifer trees and snags/ha between 30-52 m
Replications (if applicable)	33 replicate streams; similar in site characteristics (Table 5)
Nature of the outcome measures used, their relative importance and robustness[2]	Stream shade: fish-eye photographs of canopy cover, middle of stream, 1 m above water, oriented north • Importance: widely considered representative of canopy shade, therefore important • Robustness: common method of measure whose accuracy is highly dependent on method of data collection and analysis; analysis method appears robust Daily maximum, mean, minimum and fluctuation stream temperature • Importance: direct measures from data logger • Robustness: used standard OWEB measurement protocol
Sample sizes and results with estimates of variation [3]	Gradient-Shade effects model was highest ranking model for Maximum, Mean and Diel Fluctuation, followed closely by six other mixed-effects models where shade was included as one of the parameters (Table 1). Minimum was explained equally well by nearly all variables. When shade was at a minimum (51%), predicted temperature increased for all parameters: ~2 °C for maximum, ~1.5 °C for fluctuation, ~1 °C for mean and ~0.25 °C for minimum (Figure 2).When shade at maximum (96%), predicted temperature decreased (0 - ¯1.0 °C, depending on temperature measure). n=119?

Publication	(Groom et al., 2011a)
	Longer reaches exhibit higher predicted temperature (0.5- 1 °C when maximum length was 1.83 km) (Figure 2). Though for private forests, predicted temperature was higher in shorter reaches, maybe in part because shade was lower in shorter reaches (Figure 5). Low gradient (0.75%) displayed an increase in temperature, whereas a steep gradient (approximately 15%) showed decreases in predicted temperature (Figure 2). Out of n=31 sites with pre- and post-treatment data, approximately 12 sites (i.e. 39%) observed increases and 5 sites observed decreases in predicted maximum temperature, 14 sites showed no difference (Figure 3). ** Note that this observation is based on plots and not data points, so observations are approximate. "Following harvest, Maximum temperatures at private sites increased relative to state sites on average by 0.71 °C (Table 6, coefficient of PP, 95% CI = 0.51, 0.92). Similarly, Mean temperatures increased by 0.37 °C (0.24, 0.50), Minimum temperatures by 0.13 °C (0.03, 0.23), and Diel Fluctuation increased by 0.58 °C (0.41, 0.75)." "Private post-harvest shade values differed from preharvest values (mean change in Shade from 85% to 78%, $n_{Private}$ = 18, df = 17, paired t = -3.678, p = 0.002); however, no difference was found for state site shade values pre-harvest to post-harvest (mean change in Shade from 90% to 89%, n_{State} = 15 df = 14, paired t = -1.150, p = 0.269)." Harvest practices on state forests led to the same average shade pre- and post-harvest generally ranging 80-95% (Figure 4). Shade in private forests in pre-harvest (approximately 72-92%) was generally higher than in post-harvest (approximately 50-87%). No evidence of difference in shade if one or both banks were harvested at private sites ($n_{SingleSide}$ = 4, $n_{TwoSides}$ = 14, df = 7.589, t = 1.978, p = 0.085). Sample size for single sided harvests was low.
Notes concerning study quality with evidence or reasoning behind	All results based on predicted change in temperature. Figure 3 shows the range in true values, therefore the range and/or a probability of exceedance may have been a more representative

Publication	(Groom et al., 2011a)
the notes[4]	measure of the likelihood of finding an increase in temperature. Statistical methods appear strong and predicted temperature is likely a good representation of observed temperatures at sites. A power analysis would have helped to determine the strength of the sample size. Biases were well addressed by analysis method.
Potential sources of bias or error	Understory shade may be under-represented by height at which stream shade measures were made.
Effects modifiers[5]	Direct consideration of: length and width of riparian reserve, tree height, basal area, harvest on one vs. both sides of riparian reserve, live crown ratio, aspect, gradient, elevation, and watershed area Indirect consideration of: harvest in part of the riparian reserve, understory, and windthrow
Notes[6]	
Method references[7]	Dent et al. 2008, Kaufmann and Robison 1998, Groom et al. 2011b

Publication	A. (Groom et al., 2011b)
Study dates and study duration (# of years, dates within a year)	33 streams in the Oregon Coast Range from 2002 to 2008
Study location (watersheds, region/state, country), settings where riparian buffers were applied	16 streams were oriented east-west 18 private and 15 state forest land locations in Oregon's north and middle Coast Range
Ecosystem type; plant association group; type of forest	Forests were ~50-70 years old, primarily managed for timber production. No beaver ponds or debris flows
Stream size (avg. annual flow, contributing area, HUC, avg. wetted	Small streams - average annual flows ≤57 L/s Medium streams - average annual flows 57 – 283 L/s

Publication	A. (Groom et al., 2011b)
width, etc.)	Wetted width, gradient, depth given in Dent et al. 2008
Research question(s), hypotheses, objectives	Primary study objective: "evaluate the effectiveness of private and state forest riparian rules and management strategies at meeting the state water quality stream temperature antidegradation standard in the Oregon Coast Range." Secondary objective: "determine a means for assessing the regulatory criterion with empirical stream temperature data in an analysis that conformed as closely as possible to regulatory language."
Study design[1]	Two study reaches on all streams – unharvested control reach and treatment reach 18 streams had a downstream reach, immediately downstream of the treatment reach that was not harvested Reach sizes varied with averages of: 276 control, 684 treatment, 288 downstream Spatial control – reach immediately upstream of the harvest unit that remained unharvested during the study Temperature collected hourly from July 1 – Sept 15 each year at 3-4 stations per stream bracketing the up and downstream ends of each reach Probe placement followed OWEB protocol – shaded where temperature was relatively constant, reliable summer depth and well-mixed water column A subset of streams temperature probes may have been downstream of reaches that some years exhibited spatially intermittent surface flow Two statistical analyses: 1) determined whether reaches exceeded Protecting Cold Water (PCW) rule for specific years; 2) assessed whether exceedances were management-related
Pretreatment data (yes/no), # of years	Temporal control - 2 years preharvest data for 26 sites, 1 year preharvest data at 7 sites

Publication	A. (Groom et al., 2011b)
of pretreatment data	
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	Treatment reach –clear-cut or thinned based on FPA or FMP riparian buffer width rules: 4 were small, no harvest <6 m, limited 7-15 m 14 were medium, no harvest <6 m, limited 7-21 m 6 were small, no harvest <8 m, limited 9-52 m 9 were medium, no harvest <8 m, limited 9-52 m Buffers widths averaged 40.4 m 26 clear-cuts, 7 partial cuts (all on state land) 17 harvested one bank (13 were state), 16 along both 10 sites non-fish bearing or unknown; though timber treatment same as fish-bearing regarding buffers
Replications (if applicable)	By stream size/prescription: 4 small/FPA, 14 medium/FPA, 6 small/FMP, 9 medium/FMP
Nature of the outcome measures used, their relative importance and robustness[2]	Primary measure: PCW year-pair exceedance comparisons of 7DAYMAX stream temperature • Relative importance: an interesting approach to standardizing data, though unclear how frequently pre-harvest data is replicated to create the year-pair comparisons. • Appears to be a relatively robust approach.
Sample sizes and results with estimates of variation [3]	Each site had 7-45 year-pair comparisons for a total of 614 comparisons for all three reach types (upstream, treatment, downstream) and three timings (pre-harvest, harvest, post-harvest) 24 of 33 sites had at least one PCW year-pair exceedance and 65 (11%) of reaches exceeded PCW Approximately 40% of exceedances occurred in treatment reaches, approximately 27% pre- to post-harvest (Figure 4).

Publication	A. (Groom et al., 2011b)
	Private forests - 40.1% probability that a preharvest to postharvest comparison of 2 years data will have temperature increase of >0.3 deg C (in discussion) State forests – 8.6% exceedance probability for treatment pre-to postharvest that was not statistically different than all other comparisons (3.7%) (in discussion)
Notes concerning study quality with evidence or reasoning behind the notes[4]	Statistical analysis was thorough, but results were fairly abstract. A better explanation of differing factors under the study period would have been appreciated – such as differences in air temperature. Could have benefited this review by providing some discussion of two-sided harvest vs. one-sided harvest or other parsing by buffer width.
Potential sources of bias or error	Authors did a good job at removing sources of bias or error.
Effects modifiers[5]	Modifiers directly considered in statistical analysis: discharge (i.e. size and a proxy for downstream in flow, gradient, width, width/depth ratios, and their substrate), ownership (i.e. buffer width and somewhat clearcut vs. partial cut, one bank vs. two banks).
Notes[6]	Not enough detail was given on Table 3. Would have been good to see plots of what the real data was for these sites so we could draw our own conclusions. Authors say: "We expect the magnitude of the temperature response to harvest will additionally be affected by factors such as channel gradient [Subehi et al., 2009], aspect [Gomi et al., 2006], treatment length, channel width, elevation [Arscott et al., 2001], channel substrate, wood storage [Kasahara and Wondzell, 2003], and subsurface hydrology [Story et al., 2003]." Seems like they have the data to look at some of these factors and should report how much the magnitude might change.
Method references[7]	Dent et al. 2008 for stream characteristics

Publication	B. (Groom et al., 2011b)
Study dates and study duration (# of years, dates within a year)	Data collected from July 1 to September 15 of 2002 through 2008; overall study duration was 6 years
Study location (watersheds,	northern and middle Oregon Coast Range, Oregon, USA

Publication	B. (Groom et al., 2011b)
region/state, country), settings where riparian buffers were applied	
Ecosystem type; plant association group; type of forest	Forests managed for timber production ranging from 50-70 years old
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Small (<57 l s^{-1} mean annual flow) and medium (>57 and ≤283 l s^{-1}); additional stream and riparian forest data provided in Dent et al. [2008]
Research question(s), hypotheses, objectives	**Primary:** "…evaluate effectiveness of private and state forest riparian rules and management strategies at meeting the state water quality antidegredation standard in the Oregon Coast Range." **Secondary: "…**determine a means for assessing the regulatory criterion with empirical stream temperature data in and analysis that conformed as closely as possible to regulatory language."
Study design[1]	Replicated sampling, control, sampling before and after treatment
Pretreatment data (yes/no), # of years of pretreatment data	Yes Minimum of 2 years pre-treatment record required initially, but probe malfunctions and premature harvest schedules led to 7 sites only having 1 year of pretreatment data For the actual analysis, only 1 pretreatment year was used at a time in their year-pair comparisons. This effectively made this a 1-yr pretreatment study.
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	Used both Forest Practices Act (FPA) buffers for private forests and the Northwest Oregon State Forest Management Plan (FMP) buffers for state forests. Within each of these categories, different no entry and limited entry buffer widths apply as a function of stream size classification. From Table 1, the no entry buffer was 0-6 m and 0-8 m slope distance for the FPA and FMP sites respectively. Limited entry buffers were 7-15 m on FPA sites with small streams, 7-21 m on FPA medium stream sites, and 9-52 m on FMP sites (regardless of stream size)

Publication	B. (Groom et al., 2011b)
	26 of the 33 treatment reaches were clearcut and 7 were partial cut 17 of the 33 were harvested on one bank only (of these 17, 13 were FMP sites) and 16 were harvested on both banks
Replications (if applicable)	FPA/Small: n=4 FPA/Medium: n=14 FMP/Small: n=6 FMP/Medium: n=9
Nature of the outcome measures used, their relative importance and robustness[2]	**Outcome Measure:** PCW stream temperature exceedances as 7-day moving mean of the daily max (7DAYMAX) **Relative Importance:** The 7DAYMAX is the regulatory standard so it is of high relative importance. **Robustness:** Based on the authors described data vetting procedure, combined with sensor accuracy (+/- 0.2° C), collection frequency (hourly), and QC checks with NIST thermometers, this outcome measure is regarded as robust.
Sample sizes and results with estimates of variation [3]	614 total year-pair comparisons, with between 7 and 45 generated at each study site In a raw assessment of all exceedances, the treatment reach of the pretreatment/postharvest year-pair category had the largest proportion of exceedances The mixed-effect effect model that best explained the differences in exceedances was the one that allowed for differences in FPA and FMP sites (the second best was the same but considered stream size as well) The probability of PCW exceedance was highest for the pretreatment/postharvest year-pair comparisons of FPA (private) sites (0.4 +/- 0.1) when all stream sizes were compared.

Publication	B. (Groom et al., 2011b)
	When stream size was considered, the point estimate probability of small FPA streams was higher than medium FPA streams (~0.55 versus ~0.38; it is not stated if this difference is statistically significant, but there is substantial overlap of 95% CIs as the small stream ranges from ~0.3 to ~0.78). When both streams sizes were considered, the probability of exceedance for all groups other than pre/post FPA was ~0.05 (+/-~0.05). Specific to the FMP sites, pre/post exceedance probability was 0.09 (no error estimate provided). Exceedances occurred for non-harvest comparisons (5 %).
Notes concerning study quality with evidence or reasoning behind the notes[4]	The study quality is high. Data from multiple sites were used, serial autocorrelation was accounted for, model selection was validated using post-hoc simulations, and overall finding was clearly distinguishable.
Potential sources of bias or error	Study sample size weighted more heavily to medium-size FPA streams which could potentially result in tighter prediction intervals for these sites relative to the others for the same level of variation. Choice in defining null model slope from year 2 in order to reduce Type II error rate produces conservative exceedance estimation. Incomplete seasonal data sets increased prediction intervals which further increased conservativeness (for those sites with incomplete data sets). More than half of the sites (17 of 33) were one-sided buffers only. This was not accounted for in the analysis and could bias the results.
Effects modifiers[5]	Stream size was directly considered. Ownership classification (state versus private) with differences in regulations (FMP versus FPA) essentially assessed the effect of buffer width.

Publication	B. (Groom et al., 2011b)
	Mixed effects Model 2 was designed to also pick up effects of differences in reaches (i.e. flow, gradient, width/depth ratios, and channel substrate).
Notes[6]	
Method references[7]	Sturdevant [2008]; Burnham and Anderson [2002]

Publication	(Groom et al., 2013)
Study dates and study duration (# of years, dates within a year)	Up to 4 years (2002-2005) pre-harvest, 2 years post harvest; temperature collected July 1 to September 15
Study location (watersheds, region/state, country), settings where riparian buffers were applied	North and middle Oregon Coast Range Mountains
Ecosystem type; plant association group; type of forest	Forests were ~50-70 years old; dominated by Douglas fir (*Pseudotsuga menzeisii*) and red alder (*Alnus rubra*); harvest or fire regenerated; lands primarily managed for timber production
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	"Small and Medium (<56 lps and 56 ≥ but < 280 Lps average annual flow, respectively) fish-bearing streams"
Research question(s), hypotheses, objectives	"This study is an example of a programmatic evaluation, as it examines the efficacy of forestry best management practices (BMPs, codified in the FPA) at meeting the numeric criteria across a geographic area." Specific goals: "evaluate the efficacy of state and private forest practices at meeting the numeric criteria; and evaluate the process of applying numeric criteria to field data from a study replicated and controlled both spatially and temporally."
Study design[1]	33 sites: 15 state forest and 18 privately owned forest • Two study reaches on all streams – unharvested control reach immediately upstream of treatment reach • Temperature collected hourly from July 1 – Sept 15 each year at 3 stations per stream

Publication	(Groom et al., 2013)
	bracketing the up and downstream ends of each reach
Pretreatment data (yes/no), # of years of pretreatment data	Up to 4 years pre-treatment
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	18 private streams harvested according to FPA rules: RMAs are 15 m (small streams) and 21 m (medium streams) that are fish bearing, with a 6 m no cut zone; harvest in remaining RMA to a minimum basal area of 10.0 (small streams) and 22.9 (medium streams) m^2/ha • 18 clearcut • 4 harvest on one bank, 14 harvested on both banks 15 state streams harvest according to FMP rules: RMAs are 52 m wide for all fish bearing streams, with an 8 m no cut zone; limited harvest allowed within 30 m of stream to create mature forest, but retain 124 trees/ha; additional tree retention of 25-111 conifer trees and snags/ha between 30-52 m • 8 clearcut, 7 partial cut • 13 harvest on one bank, 2 harvested on both banks
Replications (if applicable)	Up to 33 sites
Nature of the outcome measures used, their relative importance and robustness[2]	7DAYMAX water temperature data • Importance: a common measure; therefore important • Robustness: generally considered a strong, robust measure Station 3 7DAYMAX temperature as a function of Station 2's 7DAYMAX temperature • Importance: a predictive model, but based on data • Robustness: if the variability between sites is considered large, I would think there may be some question as so the robustness of the model (even if statistics are strong)
Sample sizes and results with estimates of variation [3]	Only 9 sites exceeded the 16 °C or 18 °C criteria (for their respective streams) (n=33, Table 1); 7 of which exceeded post-harvest at Station 3 (downstream-most station) and 2 of which did not exceed at Station 3, but exceeded at one of the two control stations (Figure 1). Of the 7 exceeding post-harvest, three exceeded pre-harvest and 4 did not exceed pre-harvest (Figure 1). Of the 4 that did not exceed pre-harvest, two exceeded upstream pre-harvest (Table 1)

Publication	(Groom et al., 2013)
	Of the 7 exceeding post-harvest, three had a statistically significant increase (1.2 °C or greater) and all were on private land. "The median (and maximum) temperature increase necessary to trigger a breach of the numeric criteria threshold at St. 3 was 2.5 °C (4.4 °C) and 3.6 °C (6.6 °C) for 16 °C and 18 °C thresholds, respectively."
Notes concerning study quality with evidence or reasoning behind the notes[4]	The primary effect considered was air temperature and the state vs. private forest rules. Other aspects of the stream that could affect stream temperature were not discussed. Especially important when looking at broader impacts are the effects occurring in the upstream extents of the watershed and the influence of cold-water (or warm-water) inputs to the stream (i.e. tributaries, hyporheic exchange). These things were not considered. Results that were focused on were the exceedances, but no comparisons of the number of sites without effects vs. with observed effects or no-effects vs. effects.
Potential sources of bias or error	Bias could be based on assumptions of similarities in groundwater inputs.
Effects modifiers[5]	Direct effects of: air temperature, riparian buffer widths Indirect effects of: one side vs. two sides of riparian reserve
Notes[6]	Has not yet been peer-reviewed. Frequency/number of exceedances was not described clearly enough to understand whether exceedance duration would be an issue.
Method references[7]	Groom et al. 2011a,b

Publication	(Hunter, 2010)
Study dates and study duration (# of years, dates within a year)	Summer months of 2003 through 2006 (4 years)
Study location (watersheds,	Western Washington (Olympic Peninsula and southwest Washington Coast Range)

Publication	(Hunter, 2010)
region/state, country), settings where riparian buffers were applied	
Ecosystem type; plant association group; type of forest	Riparian forests dominated by hardwoods (primarily *Alnus rubra* with some *Acer macrophyllium*), some conifers present
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Mean channel width ranged from 2.2 to 10.3 m (no designation defined, but assume bankfull width)
Research question(s), hypotheses, objectives	OBJECTIVES "…collect data that may help understand what effect hardwood conversion rules and alternate plans may have on water temperature."
Study design[1]	• Nine sites of varying buffer lengths, buffer widths, riparian forest composition, channel substrate, and valley segment type were studied (sites were actually chosen based on characteristics desired for a related silvicultural study) • Transects established on 25 m spacing beginning 50 m upstream of the harvest unit boundary and extending as far as 400 m downstream of the boundary when possible • Riparian conditions, canopy cover, channel dimensions, substrate, and streamflow, and stream temperature were measured at/along transects (or a subset of the transects) • Canopy cover was measured using hemispherical photography • Stream temperature was measured hourly on 75 m intervals (within buffer reach?) and at locations 50 m upstream and 50, 100, 200, and 400 m downstream of buffered harvest units during the summer months (beginning anywhere between mid-June to July 31 and ending after September 10 or the first high flow, whichever came first) • Forest harvesting occurred after 2 years of pre-treatment data was collected and continued for 2 years following treatment
Pretreatment data (yes/no), # of years of pretreatment data	Yes, generally 2 years
Details on management action(s) (e.g., sizes and types of buffers; clearcut or	• Clearcuts in upslope harvest units with a hardwood conversion buffer adjacent to the stream

Publication	(Hunter, 2010)
thin on both or single sides of streams)	• Final buffer configuration was different for each of the nine sites
Replications (if applicable)	

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Canopy Cover as a Global Site Factor (GSF) weighted for exposure aspect and solar angle (0 is fully shaded and 1 is no shade)
	  • Relative importance = High as metric is related to shade
	  • Robustness = High (measured directly and objectively)
	• Measure = Stream Temperature (only maximum of the daily maxima provided per year)
	  • Relative importance = High
	  • Robustness = High

Sample sizes and results with estimates of variation [3]	• 1 sample per treatment type
	• Within each treatment:
	  • Canopy cover measured annually at each transect (n varies by site)
	  • Annual maximum of daily maxima temperature reported for each sensor (n varies by site)
	• Results were variable based on treatment type
	• Typically, buffers where widths decreased below 10 m showed an increase in GSF of ~0.1 while wider buffers showed less change (0 to a few hundreths)
	• Stream temperature response varied and did not necessarily correspond to changes in mean GSF
	• Visually-notable increases in annual maximum of the daily maxima within or downstream of harvest unit were apparent for:
	  • two-sided buffers with widths less than 10 m at points on both sides
	  • a one-sided buffer with a mean width of 15 m and less overall width variability than others

Notes concerning study quality with evidence or reasoning behind the notes[4]	Quality measurements were made in this study. However, the design is poor for determining the effects of buffer management on stream temperature and shade (primarily because each treatment was essentially unique). Also, use of only the annual maximum of the daily maxima for each sensor location is problematic as the day of the annual maximum could differ spatially and a large amount of information is lost when a season of data are

Publication	(Hunter, 2010)
	reduced to a single number.
Potential sources of bias or error	• Buffer widths greater than 30 m were not measured, but categorically classed as 40 m buffers in plot of buffer width • Some sites had recent harvest units not associated with this study and with varying buffer widths located opposite (or nearly so) of the actual treatment unit
Effects modifiers[5]	Channel azimuth, buffer width, surface flow continuity, channel gradient, channel substrate, drainage area, and maximum elevation were all measured and reported.
Notes[6]	The outcome measures reported are of high relative importance and highly robust, however the variability in buffer configuration amongst sites essentially makes this a series of 9 case studies. Individually, the case studies do not provide the ability to allow statistically-grounded inferences beyond the actual study reaches. Additionally, the use of GSF to characterize canopy cover is good conceptually because it accounts for effects modifiers. However, this factor is not explicitly linked to stream temperature response in this study so it is difficult to interpret the significance of different magnitudes of change in GSF. Finally, the reduction and presentation of the stream temperature data in this paper creates difficulty in detecting treatment effects.
Method references[7]	

Publication	(Jackson et al., 2007)
Study dates and study duration (# of years, dates within a year)	Overall study conducted from 1998 through 2001 as annual summer surveys (4-year duration). Data specific to the SR question collected in summers of 1998, 1999, and 2001.
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Washington Coast Range –Willapa Hills (Palix and Willapa River drainages), Grays Harbor (Newskah Creek drainage), and southwest portion of Olympic National Forest (Humptulips River)
Ecosystem type; plant association group; type of forest	Commercial timber, 2nd-growth *Tsuga heterophylla* in riparian forest

Publication	(Jackson et al., 2007)
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Non-fish-bearing streams • Drainage areas range from 1.1 to 10.1 hectares • Mean active channel widths range from1.1 to 2.85 m
Research question(s), hypotheses, objectives	OBJECTIVE This paper sought to assess how timber harvest adjacent to first-order, non-fish-bearing streams changed canopy cover percentage for buffered streams and increased coverage by slash for unbuffered streams.
Study design[1]	• Before/After treatment design (no control used for the SR-specific measures, although full BACI used for other metrics) • Two treatment types: buffered (8-10 m two-sided buffer) and unbuffered • Measurements were made in a survey reach that was approximately 20 times the mean channel width (no measurement frequency within survey reach provided)
Pretreatment data (yes/no), # of years of pretreatment data	Yes, 1 year
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Unbuffered: clearcut to streambank • Buffered: 8 to 10 m two-sided buffer (one instance where buffer was nonmerchantable timber)
Replications (if applicable)	Four replications

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Canopy cover % for buffered streams
	  • Relative importance = High as metric is a good proxy for shade
	  • Robustness = Moderately robust (measured with spherical densiometer, subject to user-bias)
	• Measure = Logging slash coverage % for unbuffered streams
	  • Relative importance = Moderate (at least one study has associated this measure with protecting stream temperature increases after harvest, but, to my knowledge, the persistence of protection via this mechanism is not well-documented)
	  • Robustness = Low (assumed that it was visually estimated – no details were provided here or in Jackson et al. 2001)

Publication	(Jackson et al., 2007)

Sample sizes and results with estimates of variation [3]	• Canopy cover % was measured in 5 buffered streams (Table 4)
	  • Full buffer (n=3):
	  • pre-treatment=91%
	  • 1st summer post=30%
	  • 3rd summer post=41%
	  • Non-merchantable buffer (n=1) :
	  • pre-treatment=90%
	  • 1st summer post=65%
	  • 3rd summer post=10%
	  • Partial buffer (n=1) :
	  • pre-treatment=95%
	  • 1st summer post=not measured
	  • 3rd summer post=90%
	  • Mean buffer blowdown percent in the 3rd summer post-treatment (see sample sizes above):
	  • full=50%
	  • non-merchantable=44%
	  • partial=42%
	• Stream coverage by slash was measured in 7 unbuffered streams (Table 3)
	  • 1st summer post=46%
	  • 3rd summer post=25%

Notes concerning study quality with evidence or reasoning behind the notes[4]	The study authors advise caution in use of canopy cover % data as the value presented is an average of the study reach only and the streams as a whole had "patchy" buffers and blowdown within buffers. Further, neither canopy cover % or slash coverage % data were presented for the reference stream. This is particularly problematic for interpreting the results of the canopy cover % data as there was significant blowdown documented and it is therefore impossible to know what proportion of that blowdown may have occurred under fully forested conditions. There is also uncertainty regarding the spatial frequency of the canopy cover and slash cover measurements made within the study reach, so it is difficult to

Publication	(Jackson et al., 2007)
	assess how representative the reported values are of the reach.
Potential sources of bias or error	User-bias associated with spherical densiometer
Effects modifiers[5]	• Riparian buffer width was consistent for all survey reaches • High riparian tree density and associated high crown height and low live crown ratio was a factor in the low post-treatment canopy cover % values for the buffered streams (no stand density measurements provided however) • Blowdown prevalence resulted in increased understory light, which led to increased herbaceous vegetation growth near the stream that was "difficult to quantify"
Notes[6]	This study is unique and useful in that it focuses on small, 1st-order streams where relatively little work has been done to quantify the effects of shade on stream temperature. However, the canopy cover estimates are not completely representative of the entire stream and therefore may not be suitable for use as the basis of policy decisions.
Method references[7]	Jackson et al., 2001

Publication	(Jackson et al., 2001)
Study dates and study duration (# of years, dates within a year)	1998 through 1999, summer months
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Washington Coast Range –Willapa Hills (Palix and Willapa River drainages), Grays Harbor (Newskah Creek drainage), and southwest portion of Olympic National Forest (Humptulips River)
Ecosystem type; plant association group; type of forest	Commercial timber, 2nd-growth *Tsuga heterophylla* in riparian forest
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Non-fish-bearing streams • Drainage areas range from 1.1 to 8.1 hectares • Mean active channel widths range from1.1 to 2.85 m
Research question(s), hypotheses,	OBJECTIVE This paper sought to assess how timber harvest adjacent to small, non-fish-bearing streams

Publication	(Jackson et al., 2001)
objectives	affected stream temperature for buffered and unbuffered streams.
Study design[1]	• Replicated, before/after, control/impact design • Two treatment types: buffered (average total buffer width ranged from 15 to 21 m, with shortest single-sided buffer of 2.3 m) and unbuffered • Stream temperature was measured in either one or two locations within the study stream (specific locations unknown- see notes below)
Pretreatment data (yes/no), # of years of pretreatment data	Yes, 1 year
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• • Buffered: 8 to 10 m two-sided buffer (one instance where buffer was nonmerchantable timber)
Replications (if applicable)	Four replications

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Stream temperature (Daily Maximum)
	  • Relative importance = High
	  • Robustness = High

Sample sizes and results with estimates of variation [3]	Results values presented in text are different than in Table 3. Text values are presented in normal type and table values are presented in italics. • Buffered (n=3 streams): 2 streams warmed (+1.6 and +2.4 °C / *+2.0 and +2.6 °C*) and 1 stream cooled (-0.3 °C / *-0.5 °C*), mean change = +1.2°C / *+1.4 °C* • Non-merchantable buffer (n=1 stream with 2 measurement locations): Both measurement locations warmed (+3.7 and +6.6 °C / *+2.8 and +4.9 °C*)
Notes concerning study quality with evidence or reasoning behind the notes[4]	Lack of sufficient details within text reduces the overall utility of the results for the purposes of the SR. However, there is no evidence to suggest that the design and data acquisition were of low quality. The statistical analyses did not meet regression assumptions, which casts some doubt on the validity of the results (it is my experience that

Publication	(Jackson et al., 2001)
	this usually does not dramatically change the overall findings, but may change the magnitudes slightly).
Potential sources of bias or error	• It is unknown if each temperature logger is subjected to the same linear stream distance of treatment- this could play a role in the variability of results. • Potential error in interpreting change based on analysis of differences in regression slopes results from the fact that there is little to no overlap in temperature ranges between the pre- and post-treatment data. • Does not appear that regression assumptions were met in every case. • Serial autocorrelation was not accounted for in the regression analysis. • Aspect and steepness not accounted for in analysis (one of the sites had significantly lower slopes relative to the others; aspect variability is unknown)
Effects modifiers[5]	None of these are specifically accounted for, but may have influenced results: • Buffer width and length • Canopy cover % • Slash cover % (discussed) • Crown height • Riparian tree density • Near-stream herbaceous vegetation • Topography • Aspect
Notes[6]	The final analysis only assessed the influence of riparian management on stream temperature at 11°C. While this value was chosen to remain within limits of the regression relationship as best as possible, it obscures the fact that some of the streams would have much larger impacts if assessed at temperatures just a few degrees warmer (assuming, of course, that the relationships remained linear). The regression equations are provided so it is possible to compute treatment effects at other temperatures using the methodology of the paper. Also, no information is provided as to where the temperature loggers were located and if each was exposed to the same linear distance of treatment. Therefore, it is impossible to interpret what the measured magnitude of change is per unit length of treatment.

Publication	(Jackson et al., 2001)
Method references[7]	

Publication	(Janisch et al., 2012)
Study dates and study duration (# of years, dates within a year)	2001 through 2008 (study was not synchronous across all of the research catchment clusters) Data collection primarily in July and August
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Western Washington Coast Range– Willapa Hills and Capitol Forest areas
Ecosystem type; plant association group; type of forest	*Pseudotsuga menziesii*, *Tsuga heterophylla*, and *Alnus rubra* were dominant conifer and hardwood species Forests were even-aged within a catchment and stands ranged from 60 to 110 years old
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Drainage areas ranged from 1.9 to 8.5 hectares • Average July and August streamflow was 0.3 L s-1 • Mean bankfull width ranged from 0.4 to 2.3 meters
Research question(s), hypotheses, objectives	OBJECTIVES • Test if the temperature response to clearcut logging in small, headwater streams was the same as that documented for larger streams • Determine if either continuous or patch buffer strips resulted in smaller temperature responses than clearcut streams • Evaluate whether buffer design had an influence on how well the buffer mitigated temperature response HYPOTHESIS • Temperature increases would be large in clearcut streams, “small and non-significant” in continuously buffered streams, and intermediate in patch-buffered streams.
Study design[1]	• Before-After-Control-Impact

Publication	(Janisch et al., 2012)
	• Research catchment clusters had one reference and several treatments • Within clusters, some catchments were adjacent to each other and others were within the nearby vicinity • Treatments for each cluster occurred during the same year, but treatment timing varied across clusters • Calibration data was collected for 1 to 2 summers prior to treatment • Post-treatment data was collected for 2 summers after logging • Stream temperature was measured on half-hourly or hourly intervals at the most downstream location possible without being influenced by the buffer of the larger stream it was a tributary to
Pretreatment data (yes/no), # of years of pretreatment data	Yes, 1 to 2 summer seasons
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	Three management actions evaluated: • Clearcut entire catchment with no buffer • Continuous buffer - 10 to 15 m on each side of the stream with the rest of the catchment clearcut • Patch buffer – "portions of the riparian forest 50 to 110 meters long were retained in distinct patches…" with the remaining portion of the catchment clearcut
Replications (if applicable)	• Eight total clusters, but treatments were not balanced across clusters so cannot consider as true replicates • Occasional within cluster replication (two catchments maximum with same treatment)

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Canopy and Topographic Density (CTD; measured via hemispherical photography)
	  • Relative importance = High
	  • Robustness = High
	• Measure = Stream temperature (Daily Maximum)
	  • Relative importance = High
	  • Robustness = High

Publication	(Janisch et al., 2012)
Sample sizes and results with estimates of variation [3]	CTD (Section 3.1.1, p. 308) • Pre-treatment average for all streams = 94% • Reference did not change significantly in post-treatment period (n=8) • Patch buffer reduced to 76% (s.e. = 5.1; n=5), statistically significant • Continuous buffer reduced to 86% (s.e. = 1.7; n=10), not significant Mean Maximum Daily Stream Temperature Response (Table 2/Figures 3 and 4; * indicates statistically significant) • Patch buffer increased by 0.73*, 0.72, and 0.84 °C, respectively (n=5) • Continuous buffer increased by 1.06*, 0.89*, and 0.38** °C, respectively (n=6; **statistically significant until August 15th) Stream Temperature Response Correlations (Table 3) • Inverse relationship with CTD (not statistically significant) • Positive relationships with aspect cosine, length of surface flow, and wetland area (in increasing order; statistically significant)
Notes concerning study quality with evidence or reasoning behind the notes[4]	Overall study quality is high. Proximity of clusters allowed pre/post analysis of reference stream temperature series to ensure stationarity assumption was met. Statistical analyses accounted for serial autocorrelation and generally maximized potential of data. Small sample size restricted causal inference in correlation analysis.
Potential sources of bias or error	• Small sample sizes increase potential for Type II error in this analysis (false negative). • CTD determination was made with widely-spaced photographs relative to the stream size (40 to 80 m apart). • Unbalanced implementation of treatments across sites could introduce location/cluster bias (i.e. having two treatments at one site and one at the others means that if the response that the two-treatment site was uniform and different from the others, it would have a disproportionate effect on the overall result.
Effects modifiers[5]	The following effects modifiers were evaluated for correlation with magnitude of mean daily temperature responses for the first year following harvest (see Table 3):

Publication	(Janisch et al., 2012)
	• Elevation • Catchment Area • Aspect • Channel Gradient • Channel Length • Depth • CTD (total and only for wetted stream length upstream of temperature logger) • Wetland Area % Bankfull width and flow pereniality were also documented in the paper, but not used in the analysis. The theoretical influence of sediment size is addressed in the Discussion section, but not evaluated in the data. Variability in logging slash coverage in clearcut streams and windthrow in buffered streams is mentioned but was not accounted for in the analyses. Bedrock lithology was different between the two sites and could influence temperature response.

Publication	(Janisch et al., 2012)
Notes[6]	The overall temperature response for the small streams measured in this study was relatively small, particularly for the clearcut stream. Although the data analysis was well-planned, the results were not fully presented. Therefore, some facets of the results were not discernible. One point mentioned in the Discussion section was that within treatments the responses were highly variable. This is likely a function of the variability in streamflow generation processes and overall catchment heterogeneity at this scale and fits well with the representative elementary area concept (where these catchments are smaller than the threshold for stream temperature response). The management implication is that there is no one size fits all prescription to protect stream temperature at this scale. On the other hand, even the clearcut streams did not have a large temperature response (maximum increase measured on a single day was 3.6 °C).
Method references[7]	

Publication	(Kiffney et al., 2003)
Study dates and study duration (# of years, dates within a year)	November 1997 to October 1999
Study location (watersheds, region/state, country), settings where riparian buffers were applied	• 45 km east of Vancouver, British Columbia, Canada • UBC Malcom Knapp Research Forest – Maple Ridge • "Coast Range of the Pacific Coastal ecoregion"
Ecosystem type; plant association group; type of forest	• Coastal western hemlock biogeoclimatic zone • Dominant forest tree species: *Tsuga heterophyla*, *Thuja plicata*, and *Psuedotsuga menziesii* • Broadleaf riparian species: *Populus trichocarpa, Alnus rubra, Acer circinatum*, and *Rubus spectabilis* • Generally "second-growth, fire-initiated forest approximately 70 years old (mean height = 45 m)
Stream size (avg. annual flow, contributing area, HUC, avg. wetted	• 1st- and 2nd-order streams • Drainage areas range from 12 to 84 hectares

Publication	(Kiffney et al., 2003)
width, etc.)	• Summer baseflow discharge ranges from 0.03 to 3.2 L s^{-1}
Research question(s), hypotheses, objectives	RESEARCH QUESTIONS • How does riparian buffer width influence biota as a result of changes in light and water temperature? • "Was there a buffer width that had no detectable effect on these response variables?"
Study design[1]	• 13 stream reaches were included in the study • Each reach was designated as one of three different treatments (described below) or a control • Stream temperature was measured on hourly intervals (location not specified but see Gomi *et al.*, 2006 for additional details) • Photosynthetically-active radiation (PAR) was measured directly above the water surface at 6 to 9 "random locations within each study reach" once or twice a month
Pretreatment data (yes/no), # of years of pretreatment data	• None used in analysis although partial pre-treatment data was collected for stream temperature (temperature loggers for a subset of locations were lost in a storm; locations not lost had 1-year of pre-treatment data)
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Treatments were 10 m stream buffer on each side of the stream and 30 m stream buffer on each side of the stream • 100 % harvest within units/blocks located immediately upgradient of the buffer • Harvest units tended to be linear in most cases with the long axis paralleling the stream • For all treatments, both sides of the stream were harvested
Replications (if applicable)	Control: n=3 10 m buffer: n=3 30 m buffer: n=3

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Stream temperature (daily mean and maximum)
	  • Relative importance = High
	  • Robustness = High
	• Measure = PAR at water surface (June through November)
	  • Relative importance = High
	  • Robustness = Potentially high, but not enough detail given to ascertain

Publication	(Kiffney et al., 2003)

Sample sizes and results with estimates of variation [3]	Stream Temperature (Results text, p. 1066; Figure 3)
	• Actual sample sizes not given, but are assumed to be the number of days per season times the number of replications for a given treatment/control (only the first year post-harvest was used in the analysis)
	• For both mean and maximum daily temperatures, the seasonal mean was inversely proportional to the level of protection given to the stream (i.e. clearcut>10 m buffer>30 m buffer>reference) in winter, spring, and summer; it is important to note that not all differences between treatments were statistically significant; variability shown as 1 standard deviation of the mean is almost always larger than the difference between treatment types of the next level of protection
	  • The seasonal mean, mean daily water temperature for each treatment was significantly greater than the control for the winter, spring, and summer
	  • The seasonal mean, maximum daily water temperature for each treatment was significantly greater than the control in spring and summer
	  • For summer maximum daily temperatures, the mean for the clearcut was 4.8 °C higher than the control, the 10 m buffer was 3 °C higher, and the 30 meter was 1.6 °C higher (the response for the 30 m treatment was not statistically significant); however, there was no significant difference between the 10 m buffer and the clearcut or for the 30 m and 10 m buffers for this season
	
	PAR (Figure 2)
	• Actual sample sizes for PAR are unknown (see "Study Design" section for general numbers)
	• PAR was also inversely proportional to the level of protection given to the stream
	  • Clearcut PAR was 58 times, 10 m buffer was 15 times, and 30 m buffer was 5 times larger than Control (all statistically significant)

Notes concerning study quality with evidence or reasoning behind the notes[4]	The study quality is moderate. Without pre-treatment data at all of the sites, natural conditions unique to each treatment or control unit with potential to affect the outcome measures cannot be accounted for in the analysis. Therefore, some unknown degree of uncertainty is inherent in the results. Additionally, the PAR measurement methodology as

Publication	(Kiffney et al., 2003)
	presented is potentially not as strong as systematic measurements of shade proxies that are common in other studies (see note in section below for additional detail).
Potential sources of bias or error	• Potential for upstream treatment reaches to introduce heat to downstream treatment reach • Drainage area differences between treatment types could confound comparison of effects magnitude by treatment type • Two of the Control streams had substantially greater summer baseflow discharge than any of the treatments – this does not appear to be related to drainage area and could therefore be an indicator of larger groundwater contributions which would affect the temperature regime in these streams • The number of PAR measurements in each treatment reach varied from 6 to 9; it is unknown if the number of measurements was related to the length of the treatment reach; if not, representativeness would vary between treatment
Effects modifiers[5]	• Percent of drainage area harvested and stream length in treatment were mainly consistent with one exception for the clearcut treatment type • Total drainage area was not intentionally controlled for but generally the same within treatments (with exception of one clearcut stream having ~5 times larger drainage area); drainage areas were different across treatments • Aspect was essentially controlled for as all streams flowed north to south with one exception which flowed south to north • Elevation range, stream gradient, and summer baseflow discharge were also reported and could influence stream temperature
Notes[6]	This study provides useful data for understanding the marginal benefits of increasing levels of stream protection during forest harvest. Despite an apparent increasing trend of mean or maximum temperature with level of protection, the differences are not statistically significant and are therefore not a strong basis for making management decisions.
Method references[7]	See Gomi et al. (2006) for additional detail on management actions and general study design

Publication	A. (Martin, 2004)

Publication	A. (Martin, 2004)
Study dates and study duration (# of years, dates within a year)	1993-1996, during July and August
Study location (watersheds, region/state, country), settings where riparian buffers were applied	South Fork of Michael Creek drains into Michael Creek, which is a tributary to Lake Florence on Admiralty Island, Alaska
Ecosystem type; plant association group; type of forest	Spruce/hemlock forest in the lowlands and alpine vegetation in the highlands (max 4,800 ft elevation)
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	basin area is 2,532 acres (1,025 ha)
Research question(s), hypotheses, objectives	Evaluate buffer zone effectiveness in protecting water quality and fish habitat. Specific to this review: Examine the water temperature response to changes in riparian stand composition.
Study design[1]	• Partial-cut riparian buffers were retained, no buffers on ephemeral streams • Two buffer zone study areas (designated "upper' and "lower" study reaches; 1,600 ft [488 m] and 1,200 ft [364 m] long, respectively) were retained along a 2,800-ft (852-m) reach • A third zone 1000 ft long in a large tributary stream to the above reach • Water quality monitored 2-yrs pre and 2-yrs post harvest • Water temperature were monitored at five stations – upstream edge of harvested (control), downstream end of upper study reach, just upstream of tributary confluence on the tributary, the last two book ended the lower study reach • Unharvested control upstream of the two harvested reaches
Pretreatment data (yes/no), # of years of pretreatment data	Yes – 2 years pretreatment water quality; 1 year pre-treatment fish habitat; 1 year riparian conditions
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• buffer zone treatment included the retention of a 25-ft (7.6 m) wide no-cut zone adjacent to the stream, followed by a 41-ft (12.4 m) wide partial-cut zone, where 50 percent of the trees greater than 12 inches DBH were harvested • Road construction began during fall 1994 and continued during part of the 1995 logging

Publication	A. (Martin, 2004)
	season (i.e., March to November). Most of the timber in the basin was harvested during 1995, and all harvesting was completed by the end of the 1996 season. All timber harvesting adjacent to the study reaches was completed in late June of 1995.
Replications (if applicable)	2 reaches, but they were up/downstream of each other; 1 additional reach for shade study only

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = shade by spherical densitometer (canopy density)
	  • Relative importance = very commonly used measure. According to Allen and Dent 2001, the shrub layer may provide more shade.
	  • Robustness = robust measure, though may have a user bias (which would at least be consistent for the entire study)
	• Measure = average or maximum daily stream temperature from continuous monitoring stations
	  • Relative importance = adjusted for autocorrelation
	  • Robustness = seems like they adjusted for autocorrelation in a fair manner

Sample sizes and results with estimates of variation [3]	• N = 39 – 62 days of temperature data per station, per year • Shade (i.e. canopy density) before logging = 64-72% • Shade significantly reduced (24-38%) in all reaches (including control) post-harvest with greatest losses on the downstream end • Significant blowdown occurred throughout the buffer (up to 60%, with an average of 20%) • At the upstream reach - difference between average temperature at the upstream and downstream stations ranged from 0.06-0.07 ºC pre-harvest and 0.19-0.20 ºC post harvest; max similar (Fig 9) • At the downstream reach – difference between average temperature at the upstream and downstream stations was 0.23 ºC pre-harvest and 0.30-0.31 ºC post harvest; max similar (Fig 10) • Entire reach – difference between average temperature at the upstream and downstream station was 0.05 ºC pre-harvest and 0.43-0.44 ºC post harvest; max 18 ºC pre-harvest and 0.60-0.64 ºC post-harvest (Fig 11)
Notes concerning study quality with	• N was based on pseudoreplicates and so differences between prescriptions cannot be easily

Publication	A. (Martin, 2004)
evidence or reasoning behind the notes[4]	determined. • Control was downstream of logging and therefore is not a good control for stream temperature due to potential cumulative effects.
Potential sources of bias or error	Should provide some explanation for air temperature comparisons from year to year. Are the lack of substantial temperature differences in the downstream reach due to 1993 data exclusion?
Effects modifiers[5]	Indirect Modifiers: tree density, tree harvest in part of the riparian reserve – i.e. variable width, harvest on both sides with buffer, windthrow
Notes[6]	• Stream temperatures were generally cool - 13.2 ºC and 15 ºC • Upstream-downstream comparisons may not be valid due to significant changes in the tributary reach that enters halfway through the study reach. • Plots need to zoom in closer to the data range (i.e. minus outliers) for better review of data. • Better explanation needed for the anomalous temperature data, including the cause of the anomaly.
Method references[7]	

Publication	B. (Martin, 2004)
Study dates and study duration (# of years, dates within a year)	Total study period: 1993 through 2003, 11 years Temperature monitoring conducted from 1993-1996, 4 years
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Lake Florence/Michael Creek Watershed, Admiralty Island, Alaska, USA
Ecosystem type; plant association group; type of forest	Lowlands: Spruce/Hemlock Highlands: Alpine vegetation
Stream size (avg. annual flow, contributing area, HUC, avg. wetted	Study area is South Fork Michael Creek (SFMC) - 1025 ha

Publication	B. (Martin, 2004)
width, etc.)	
Research question(s), hypotheses, objectives	**<u>Objectives (temperature, riparian timber, habitat):</u>** 1) "Examine the water temperature response to changes in riparian stand composition." 2) "Compile data and examine changes in riparian stand conditions over time."
Study design[1]	Before and after treatment, control compromised
Pretreatment data (yes/no), # of years of pretreatment data	Yes, 2 years
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	15.5 % of lower watershed was harvested between 1994 and 1996 Partial cut riparian buffers retained along lower mainstem of SFMC. A 25-feet wide no-cut zone was located immediately adjacent to stream and then a 41-feet partial cut zone where 50 % of >12 inch DBH trees were harvested. Two buffers left on SFMC (upper and lower, 1600 and 1200 feet, respectively) and one on the lower 1000 feet of Rutherford Creek. Pre-treatment occurred in 1993 and 1994. Road construction started in 1994 and most of the harvesting occurred in 1995 (but some continued in 1996).
Replications (if applicable)	
Nature of the outcome measures used, their relative importance and robustness[2]	Riparian canopy density measured with a spherical densiometer, relevant, somewhat robust Stream temperature measured at hourly intervals, relevant, robust
Sample sizes and results with estimates of variation [3]	**<u>Riparian canopy density:</u>** Station 1 (n=9): mean decreased from 72 to 47 % (p-value=0.000) Upper Reach (n=15): …71 to 48 % (p-value=0.000) Middle Reach (n=7): … 66 to 40 % (p-value=0.014)

Publication	B. (Martin, 2004)
	Lower Reach (n=12): … 64 to 26 % (p-value=0.000) **<u>Temperature Response:</u>** *Upper reach*: daily mean temperature difference between the upstream and downstream extent of the reach increased from 0.06 and 0.07 C prior to harvest to 0.19 and 0.20 C in the postharvest years daily maximum temperature difference between the upstream and downstream extent of the reach increased from 0.06 and 0.08 C prior to harvest to 0.18 and 0.21 C in the postharvest years significant difference in daily mean and daily max using Tukey multiple comparison (alpha = 0.05) for preharvest/postharvest but not for within preharvest or within postharvest years *Lower reach:* daily mean temperature difference between the upstream and downstream extent of the reach increased from 0.23 C prior to harvest (1994 only) to 0.30 and 0.31 C in the postharvest years daily maximum temperature difference between the upstream and downstream extent of the reach increased from 0.22 C prior to harvest to 0.30 and 0.35 in the postharvest years significant difference in daily mean and daily max using Tukey multiple comparison (alpha = 0.05) for preharvest/postharvest but not for within preharvest or within postharvest years *Entire reach:* daily mean temperature difference between the upstream and downstream extent of the reach increased from 0.05 C prior to harvest (1994 only) to 0.43 and 0.44 C in the postharvest years

Publication	B. (Martin, 2004)
	daily maximum temperature difference between the upstream and downstream extent of the reach increased from 0.18 C prior to harvest to 0.60 and 0.64 in the postharvest years significant difference in daily mean and daily max using Tukey multiple comparison (alpha = 0.05) for preharvest/postharvest but not for within preharvest or within postharvest years
Notes concerning study quality with evidence or reasoning behind the notes[4]	Control reach was compromised by forest harvest activities upstream of the site. Even if control wasn't compromised, the treatment reach is significantly long enough that an upstream measurement point may not have the same temperature dynamics as the downstream reaches which could cause problems with interpreting changes along the full study reach.
Potential sources of bias or error	Data record truncation as a result of anomalous values likely affect ANOVA results (even though the data that was removed was done so to avoid artificially inflating variance). Harvesting upstream of control reach. Spherical densitometer subjectivity.
Effects modifiers[5]	
Notes[6]	Decrease in riparian canopy density is attributed to blowdown during winter following harvesting rather than a direct effect of harvest.
Method references[7]	

Publication	(Morman, 1993)
Study dates and study duration (# of years, dates within a year)	Summers of 1990, 1991, 1992
Study location (watersheds,	Northwest Oregon: primarily Coast Range

Publication	(Morman, 1993)
region/state, country), settings where riparian buffers were applied	Southern Oregon: Umpqua region and further south - Cascades and Siskyous
Ecosystem type; plant association group; type of forest	Primarily second-growth Mix of hardwood and conifer overstory, generally dominated by hardwood in the riparian area
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Class I and II waters Average high water level width – 40 feet in Northwest (9-151 feet) and 28 feet in Southern (5-88 feet)
Research question(s), hypotheses, objectives	"Are forest riparian resources being effectively protected by the Forest Practices Program?"
Study design[1]	• Surveyed: stream and riparian area widths, gradient, orientation, substrate, slope, pool depth, shade, conifer and hardwood overstory canopy, shrub cover, soil exposure, LWD, snags • Sample point and transect (6 ft wide) measures, stream surveys, timber cruises within 100 feet of stream • 29 units surveyed pre- and post-treatment • Shade measured by compass and densitometer from the mid-stream and at the same azimuth and aspect, expectation of a 10% measurement error.
Pretreatment data (yes/no), # of years of pretreatment data	Yes, one year
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Primarily clearcut harvests, mostly on private timber lands. • Northwest streams: average required RMA width: 82 feet (27-100 feet); 3 logged on both sides of stream • Southern streams: average required RMA width: 59 feet (25-100 feet); 6 logged on both sides of stream
Replications (if applicable)	1 year of pre-treatment data for 29 sites
Nature of the outcome measures used, their relative importance and	Aquatic solar shading: measured by densiometer • Importance: shade is a common measure

Publication	(Morman, 1993)
robustness[2]	• Robustness: there can be a 10% measurement error or greater View to sky: open sky above the aquatic area in all directions measured with densitometer • Importance: a measure of exposure that has not been used frequently or is well defended in the literature, but may be able to give a qualitative understanding shade • Robustness: densiometer measures have a large degree of error; exposure to sky does not necessarily relate directly to significant solar radiation reaching the stream
Sample sizes and results with estimates of variation [3]	Northwest Oregon aquatic shading (n=16): • Pre-treatment: 77% (10-99%) • Post-treatment: 62% (10-90%) Southern Oregon aquatic shading (n=13): • Pre-treatment: 81% (52-96%) • Post-treatment: 67% (37-96%) Some of the biggest decreases in shade (frequently >20%) occurred when both sides of the stream were logged (Figures 4 & 5). Northwest Oregon view-to-sky • Pre-treatment: 30 (100 – 3) • Post-treatment: 40 (100 – 6) Southern Oregon view-to-sky: • Pre-treatment: 29 (75 – 9) • Post-treatment: 40 (77 – 10)
Notes concerning study quality with evidence or reasoning behind the notes[4]	No statistical analysis of differences, nor power analysis allowing us to know if differences between pre- and post-harvest could even be different. There needs to be an explanation of the 10% and 96% shading results, especially the 10% site. Assuming it is the same site, it is important to understand why it would have been selected as representative of a Northwest Oregon forest stand. This site would be especially questionable if it has a view-to-sky of 100.
Potential sources of bias or error	Samples sizes moderate to low. Unclear whether there were statistical differences between groups.

Publication	(Morman, 1993)
Effects modifiers[5]	Direct measures of: hardwood vs. conifers, shrub densities, large wood (terrestrial and aquatic), riparian area widths, volume/retention, gradient, substrate, method of tree removal, elevation
Notes[6]	Good notes on conditions for each individual site so statistical analysis could be conducted and more information could be pulled from the document. For example, relationships between shading for Class I and Class II streams, 1-sided vs. 2-sided harvest, hardwood vs. conifer, etc.
Method references[7]	

Publication	(Newton and Cole, 2013a)
Study dates and study duration (# of years, dates within a year)	2002-2009, up to 7 years mid-June through mid-September each year
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Western Oregon – within a 200 km radius of Corvallis, OR
Ecosystem type; plant association group; type of forest	"representative of hardwood and conifer-dominated riparian areas at low/medium elevations"
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	250 – 400 ha basins
Research question(s), hypotheses, objectives	"This research asks whether a series of clearcuts with various buffer designs along small fish-bearing streams in western Oregon 1) leads to post-harvest changes in stream temperature, 2) results in cumulative warming downstream from harvested units independent of pre-harvest natural warming trends as flowing waters move toward lower elevation and warmer climates, and 3) leads to post-harvest changes in air temperature near the stream surface."
Study design[1]	"Reaches were 1800-2600 m long on each stream, divided into seven contiguous units of approximately equal length" composed of:

Publication	(Newton and Cole, 2013a)
	• Upstream control 250-500 m long • Three harvest units (250-400 m) alternating with three uncut units of comparable size Stream temperature measured two years prior to harvest activities, and for up to five years post-harvest: • Three or more thermistors placed at about 100-m intervals in each of the seven units along the entire reach length ("approximately 80 m below the upstream boundary of each unit, 30 m above the downstream boundary, and at an intermediate point equidistant between the upstream and downstream")
Pretreatment data (yes/no), # of years of pretreatment data	2 years stream temperature

Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Basin-wide management included: "three clearcut units of 10-20 ha [that] would span the stream with uncut units of comparable size between harvest units"
	• Harvest units were on both sides of the stream except in the designated buffer
	• Control was unharvested for five or more years
	• Buffers were:
	  • No tree – "merchantable trees were removed in the harvest unit, extending to the bank, leaving only shrubs; shrubs and other vegetation were chemically controlled beyond 3 m from the bank to facilitate regeneration"
	  • BMP – according to FPA for two-sided buffers with width depending on stream size (15-30 m)
	  • Partial – "buffers limited to all residual trees and shrubs within 12 m of the bank south of open water", for streams oriented north-south, a 9-12 m screen was left on both sides of stream

Replications (if applicable)	3 replicates of no tree, 4 replicates of partial cut, 5 replicates of BMPs
Nature of the outcome measures used, their relative importance and robustness[2]	Time series relationships of stream temperature daily means, minima, maxima, and diel fluctuations: • Importance: commonly used measures of temperature, generally good at exposing extremes, though reporting as a time series relationship removes the ability to detect

Publication	(Newton and Cole, 2013a)
	extremes and generalizes the data for the period of interest • Robustness: not enough information regarding collection method to evaluate measures, though generally robust if sensors installed properly; analysis method appears to be robust 7-day 24-hour moving mean maxima: • Importance: well accepted method for evaluating stream temperature • Robustness: similar comment as above regarding the measure; analysis method is robust but was only used qualitatively for this study
Sample sizes and results with estimates of variation [3]	• No tree • "Daily maxima (Figures 2-5) ($p < 0.0001$), and means ($p < 0.0078$), and diurnal fluctuations ($p < 0.0001$) were significantly greater post-harvest in all of the no-tree units on the three streams where that harvest occurred." (n=3) • "The no-tree units also showed significant decreases in summer minima ($p < 0.0439$) after harvesting" at 2 of the 3 sites. • "Changes above predicted values ranged up to 3.8° C for daily maxima (Table 2)." • BMP sites had mixed results – no change at one site, significant decrease in stream temperature means and minima post-harvest (though differences small) for one site, and significant increase in means, maxima (Figures 2 and 4) and diels at two sites (all ranges of differences in Table 2). Maximum change in maxima was 5.3 °C (Table 2). • Partial sites had mixed results (n=4) – one site had higher mean, minima, maxima and diel temperature post-harvest, maxima were lower post-harvest for 3 sites (up to 2.18 °C lower), lower diel fluctuations at two sites (up to 2.91 °C lower), and lower mean at one site (up to 0.59 °C lower) (Table 2, maxima in Figures 2-5). • Overall trend for the reach displayed increases in maxima post-harvest for 2 out of 4 sites (Figure 6) and for one other site if only one year post-harvest was considered. One site had lower maxima post-harvest (Figure 6). All other relationships were not significant. • Increases in 7DAY mean maximum temperature increased in the no tree units (n=3, generally by more than 1-2 °C), but smaller changes in partial and BMP sites, though changes could still be by 1 °C or more (Figure 7).

Publication	(Newton and Cole, 2013a)
Notes concerning study quality with evidence or reasoning behind the notes[4]	The opportunity for upstream harvest to increase temperatures in downstream uncut reaches makes downstream uncut reaches unfit to be true controls. Comparing differences between entry and exit temperatures may be able to account for some of the cumulative impacts; however, it is important to note that uncut reaches may display different results than a true control. Since temperatures could be warmer entering the uncut reach, there is more opportunity for a temperature decrease than in a true control reach. Evidence of this would be if the temperatures post-harvest cooled more than pre-harvest.
Potential sources of bias or error	Differences in air temperature from year to year can also influence stream temperature. This potential problem appears to be addressed in the pre-harvest data sets, but relationship of stream to air temperature post-harvest is not as clear.
Effects modifiers[5]	Direct effects: harvest one vs. two sides of stream, air temperature, width of riparian reserve, time since harvest, harvest on one or both sides of stream Indirect effects: harvest method, aspect
Notes[6]	Many of the reported results were not backed up with figures, though results could be partially interpreted from Table 2.
Method references[7]	

Publication	(Newton and Cole, 2013b)
Study dates and study duration (# of years, dates within a year)	Used data from earlier studies, newly collected data from mid-June to mid-September of 2008 and 2009, cover estimates in July 2009
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Oregon Coast Range and western foothills of the Oregon Cascades
Ecosystem type; plant association group; type of forest	Prior to harvest, riparian areas were dominated by hardwoods, primarily red alder and bigleaf maple (*Acer macrophyllum* Pursh), 12-27m tall.
Stream size (avg. annual flow, contributing area, HUC, avg. wetted	Small and medium sized streams Widths: 1.95- 4.16 m

Publication	(Newton and Cole, 2013b)
width, etc.)	
Research question(s), hypotheses, objectives	Revisit two previous studies (Zwieniecki and Newton 1999 and Dent 1995) to determine if increases in stream temperature and decreases in cover continue 14 and 17 years after harvest.
Study design[1]	Previous Dent study to present: • four streams at least 1,460 meters long • "reach included an 180-m harvested reach, an uncut reach 300-700 m long, an upper 90-m harvested reach, an uncut reach 100-300 m long, a lower 90-m harvested reach, and an uncut reach of about 300 m downstream of the lowest harvested area" • "Stream temperatures were monitored starting June or July and continuing through September or October for five summers" Previous Zwieniecki and Newton (Z&N) study: • 3 streams with reaches 490 m (Cascade Brush), 550 m (North Mill), and 790 m (Scheele) • 1 summer pre-harvest data (1994) upstream and downstream of harvest unit and first year post-treatment from June to September • Stream temperature collected 152 and 304 m downstream of harvest unit At both sites current: • Present study attempted to place thermistors close to original locations • Land points for plantation and buffer structure 4.6 m from bank on each side of stream at 15 m intervals in harvest units; at each point tallies of hardwood vs. conifer • Cover estimates (visual and densiometer) every 30 m centered midstream for harvested and uncut areas. Fisheye photographs taken within an hour of dusk or dawn when overcast. Cover estimates include conifer, hardwood and shrub 5 m on point; visual estimate of hemispherical cover; densiometer counts in four cardinal directions; and cover over stream by log, herbaceous vegetation and shrubs 5 m up and downstream of point.
Pretreatment data (yes/no), # of years	1 year pre-treatment for 3 streams

Publication	(Newton and Cole, 2013b)
of pretreatment data	
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	Previous Dent study: 1993 harvest with residual buffers (15 or 21 m wide depending on stream width, both sides) associated with clearcut harvesting, interspersed with no-tree buffers Previous Z&N study: 12 m buffer on the south side of stream (or some trees on both sides if stream runs north-south)
Replications (if applicable)	2 years for recent post-harvest (n=7) and 5 years immediately post-harvest for half of the sites (n=4)
Nature of the outcome measures used, their relative importance and robustness[2]	Time series relationships of daily mean, maximum and minimum summer stream temperature: • Importance: commonly used measures of temperature, generally good at exposing extremes • Robustness: not enough information regarding collection method to evaluate, though generally robust if installed properly Cover – not clear which measures of cover were used for comparison in which parts of the results • Importance: densiometer measures are a widely used method for estimating cover • Robustness: visual estimate can have a high degree of inaccuracy, not much explanation was given in how this was minimized to the extent possible
Sample sizes and results with estimates of variation [3]	No-tree buffers (n=4): • increased temperatures downstream of harvest units vs. upstream uncut in the 5 years post-harvest (Fig 2) • increased temperatures 16-17 years post-harvest downstream vs. uncut upstream, but not as high as immediately post-harvest time period • cover was similar immediately post-harvest to 17 years post-harvest Partial buffer (n=3): • first year post-harvest had significant warming below harvest unit vs. above harvest unit of means and maxima and minima for one site • one site had slight increase in temperature maxima first year post-harvest

Publication	(Newton and Cole, 2013b)
	• one site unchanged temperature first year post-harvest • no significant temperature differences vs. pre-harvest from 2008/2009 data collection efforts
Notes concerning study quality with evidence or reasoning behind the notes[4]	Beaver removal and damage of trees may influence results. Cover results from the Dent study area should have been reported here to be able to compare trends visually.
Potential sources of bias or error	No pre-harvest data for half of the sites. There are very small samples sizes with inconsistent sampling periods (1 year up to 4 years in a row).
Effects modifiers[5]	Directly measured effects: types of trees, basal area retention, residual stand composition, harvest on both or one side of stream, time since harvest, aspect Indirectly measured effects: width of buffers, stream width
Notes[6]	
Method references[7]	Dent 1995, Zwieniecki and Newton 1999, Strickler 1959

Publication	(Rashin et al., 1992)
Study dates and study duration (# of years, dates within a year)	Summer 1990- temperature was measured for 2 weeks at every location (measurement periods were not synchronous across sites)
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Coast Range, Puget Lowland, and Cascades ecoregions of Washington
Ecosystem type; plant association group; type of forest	Not stated
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Type 2 and 3 streams (Washington classification) • Average bankfull width ranged from 2.4 to 15.8 m • Discharge ranged from 4.3 to 128 L s^{-1} at downstream extent of study reaches
Research question(s), hypotheses, objectives	OBJECTIVES • "Determine the effectiveness of the BMPs (i.e. the RMZ rules) at maintaining water

Publication	(Rashin et al., 1992)
	temperatures at levels which meet the criteria for maximum allowable temperature established in state water quality standards." • "Determine the effectiveness of the BMPs at meeting water quality criteria pertaining to incremental increases in temperature." • "Evaluate the influence of various stream and riparian zone characteristics on BMP effectiveness."
Study design[1]	• This study is a series of 9 individual case studies for west-side streams (all attempts to synthesize data include east-side streams so those results are not directly applicable to this SR and are therefore not included in this table) • Study sites were recently harvested (2 years or less) catchments with buffers that conformed to Washington standards at the time of the study • Measured stream temperature at upstream and downstream extents of riparian buffers • Measured shade with spherical densiometer on 76-m intervals within existing buffer • Also measured a variety of other buffer characteristics with potential to act as effects modifiers (see list in Effects Modifiers row)
Pretreatment data (yes/no), # of years of pretreatment data	No

Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• The buffer types included one-sided and two-sided buffers adjacent to clearcut units (it is important to note that the one-sided buffers were only applied where one side of the stream was being harvested)
	• Buffer lengths varied from 385 to 825 m
	• Buffer widths ranged considerably:
	  • Mean buffer width (per side) varied from 9.1 to 17.4 m
	  • Minimum buffer width (per side) ranged from 1.5 to 7.6 m
	  • Maximum buffer width (per side) ranged from 15.2 to 30.1 m

Replications (if applicable)	

Nature of the outcome measures used, their relative importance and	• Measure = Stream temperature (difference in upstream and downsteam locations)
	  • Relative importance = High
	  • Robustness = High

Publication	(Rashin et al., 1992)

robustness[2]	• Measure = Canopy Cover (as measured by spherical densiometer)
	  • Relative importance = High
	  • Robustness = Moderate based on user-subjectivity

Sample sizes and results with estimates of variation [3]	Median of the maximum daily water temperature differential for: • 2-sided buffers ranged from 1.3 to 4.6 °C (Table 1; n=3) • 1-sided buffers ranged from 0.1 to 1.4 °C (Table 1; n=6) Mean canopy cover for: • 2-sided buffers ranged from 23 to 91 % (Table 1; n=3) • 1-sided buffers ranged from 52 to 97 % (Table 1; n=6)
Notes concerning study quality with evidence or reasoning behind the notes[4]	The study quality with regards to making inferences to temperature or shade response to buffer characteristics for west-side streams is generally low because no statistical analysis was performed for the desired subset of sites.
Potential sources of bias or error	Thermistors had a fairly crude accuracy of 0.5 °C. Measurement periods were asynchronous across sites and some were measured outside of the critical summer high temperature season.
Effects modifiers[5]	The following potential effects modifiers were measured: • Air temperature • Groundwater inflow as difference in upstream and downstream discharge • Stream discharge • Buffer length • Buffer width and width variability • Channel gradient • Aspect • Buffer tree count per unit area • Percent hardwood and conifer species in buffer • Harvesting within buffer • For one-sided buffers, the stand and buffer type on the opposite side of the channel was

Publication	(Rashin et al., 1992)
	noted Other potential effects modifiers that were not measured or documented: • Catchment geology • Beaver activity within or upstream of buffer reach
Notes[6]	This paper presents data for a series of 9 individual case studies for west-side streams. Summary tables of results and site characteristics as well as a brief text write-up of the results for each study stream are presented. The authors evaluate correlations of temperature response with buffer characteristics, but do so across both east- and west-side streams. Therefore, those results are not included in this table. The potential for extracting west-side data only and conducting multivariate analyses exists and may be a useful exercise for extending the utility of the study.
Method references[7]	

Publication	(Schuett-Hames et al., 2012)
Study dates and study duration (# of years, dates within a year)	2003 through 2008, sampling in three years (2004, 2006, and 2008)
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Western Washington western hemlock zone Includes Coast Range, Puget Lowlands, Cascades, and North Cascades ecoregions
Ecosystem type; plant association group; type of forest	Western hemlock zone
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Non-fish bearing perennial streams • Mean bankfull width ranged from 3.0 to 11.4 feet
Research question(s), hypotheses, objectives	OVERALL OBJECTIVES "Obtain an unbiased estimate of post-harvest conditions associated with the western Washington Type Np riparian prescriptions"

Publication	(Schuett-Hames et al., 2012)
	• "Evaluate the magnitude and duration of change in comparison to untreated reference sites" • "Identify site and stand attributes (covariates) that influence response" SPECIFIC QUESTIONS *Riparian stand response* "What are the characteristics of riparian stands after application of the westside Type Np riparian prescriptions?" "What is the magnitude and duration of change in riparian stands following application of the westside Type Np riparian prescriptions compared to un-harvested reference sites?" *Channel debris loading* "What amount of channel woody debris occurs in stream channels following application of the westside Type Np riparian prescriptions?" "What is the magnitude and duration of change in channel debris following application of the westside Type Np riparian prescriptions compared to untreated reference sites?" *Shade condition indicators* "How much shade to the stream channel is provided by riparian stands following application of the westside Type Np riparian prescriptions?" "What is the magnitude and duration of change in shade following application of the westside Type Np riparian prescriptions compared to untreated reference sites?"
Study design[1]	• Randomly selected 15 treatment sites from pool of Type Np (non-fish bearing, perennial) streams approved for harvest within the time constraints of the study • Each treatment site was paired with a nearby reference stream that did not have harvest activities within 100 ft • Treatment types contained a mixture of management types allowed for Np streams under Washington rules (details below) • The following metrics were measured: • *Riparian stand response:* live trees per acre and basal area per acre via a complete

Publication	(Schuett-Hames et al., 2012)
	census of all standing trees within 50 feet of the stream (3rd and 5th years only; 1st year was estimated using stand reconstruction procedure) • *Channel debris loading*: visually estimated total debris coverage over a 4-foot length of stream spanning the bankfull channel and centered on 50-foot intervals (3rd and 5th years only) • *Shade condition indicators*: % canopy cover was measured at systematic intervals beginning at a random point near the bottom of the survey reach using a spherical densiometer; measurements were made at waist-height facing upstream, downstream, and towards the left and right banks (4 measurements per station); understory plant shade was estimated visually in a 4-foot length of stream centered on the densiometer measurement station • Mann-Whitney non-parametric test used to compare means between treatment and reference sites
Pretreatment data (yes/no), # of years of pretreatment data	No
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	Treatment types: • 50-foot wide no-cut buffer on each side of the stream (50-ft buffer patches) • 56-foot radius no harvest around the perennial initiation point (PIP patches)
Replications (if applicable)	

Nature of the outcome measures used, their relative importance and robustness[2]	*Riparian Stand Response*
	• Measure = Live trees per acre
	  • Relative importance = Moderate- can be related to shade
	  • Robustness = High
	• Measure = Basal area per acre
	  • Relative importance = Moderate to High- can be related to shade and some management alternatives focus on basal area retention
	  • Robustness = High
	
	Channel Debris Loading

Publication	(Schuett-Hames et al., 2012)

	• Measure = Total debris cover
	  • Relative importance = High- debris shade has been related to protection against stream temperature increases
	  • Robustness = Moderate
	
	Shade Condition Indicators
	• Measure = Canopy Cover (as measured by spherical densiometer)
	  • Relative importance = High
	  • Robustness = Moderate based on user-subjectivity

Sample sizes and results with estimates of variation [3]	Statistical significance for the portions of the study referenced below was α=0.10
	
	Riparian Stand Response (for 50-ft buffer patches and PIP patches only)
	• 50-ft buffer patches (n=13):
	  • Approximately 88 less mean trees per acre in each of the three post-harvest measurement periods relative to the control (no data on baseline differences though) – mean basal area per acre was approximately 60 ft^2 less in the 3rd and 5th years after harvest (-57.6 and -64.3, respectively)
	  • there was a statistically significant decrease in live trees per acre between the 1st and 3rd year after harvest relative to the reference patch (-15 %)
	  • the basal area change between 2006 and 2008 was not significant relative to the reference
	• PIP patches (observational only, no statistics; n=3)
	  • Declining pattern of trees per acre and basal area per acre similar to 50-ft buffer patches but steeper decline (lost 50 % of the original density by the end of the 5-year study)
	
	Channel Debris Loading
	• The 50-ft (n=13) and PIP (n=3) buffer patches did not have significantly different total debris coverage than the reference in either the 3rd or 5th year post-harvest

Publication	(Schuett-Hames et al., 2012)

	• 3rd-year mean coverage was 25 (14), 25 (17), and 28 (15) %, respectively with standard deviation in parentheses
	• 5th-year was similar except PIP increased to 43 (11) likely as a result of windthrow
	
	Shade Condition Indicators (Tables 49, 50, and 51)
	• Mean total overhead cover % (standard deviation in parentheses; * indicates statistically significant difference from mean Reference value)
	  • Reference (n=14): 89 (4) / 93 (5) / 90 (5) for 1st, 3rd, and 5th years after harvest, respectively
	  • 50-ft buffer (n=13): 76 * (16) / 81* (20) / 81* (16)
	  •
	  • PIP buffer (n=3): 55 (21) / 65 (13) / 62 (21) (no statistical tests performed for PIP)
	
	• Mean channel % obscured by understory vegetation (number of samples is the same as above)
	  • Reference: 14 (8) / 13 (5) / 16 (17)
	  • 50-ft buffer: 29* (17) / 31* (2) / 35* (21)
	  • PIP buffer: 37 (26) / 30 (15) / 47 (38) (no statistical tests performed for PIP)

Notes concerning study quality with evidence or reasoning behind the notes[4]	The overall study quality is considered low to moderate. While the measurements, analysis, and presentation are all moderate to high quality, the absence of pre-treatment data in combination with relatively low sample sizes increases the likelihood of Type I and II errors.
Potential sources of bias or error	• Error associated with the uncertainty of not knowing pre-treatment conditions • Potential bias and/or error from visual estimation of channel debris coverage and channel coverage by understory vegetation
Effects modifiers[5]	• Catchment and channel geomorphology is likely an important modifier for these sites that cover a fairly-wide geographic area. • Vegetation type within the riparian buffers should also influence the results but was not factored into any of the analyses (although conifer versus hardwood % is available in the

Publication	(Schuett-Hames et al., 2012)
	report)
Notes[6]	The data collected in this study focuses on shade for non-fish bearing perennial streams. The paper presents a comprehensive dataset with respect to post-harvest shade for small streams covering the full range of physiographic conditions west of the crest of the Cascades in Washington. Critical data is presented in tables so that further analysis is possible.
Method references[7]	

Publication	(Steinblums et al., 1984)
Study dates and study duration (# of years, dates within a year)	Unknown, but shade measures collected during low-flow season
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Cascade Mountains of western Oregon
Ecosystem type; plant association group; type of forest	• Dominant at low elevations: Douglas-fir (*Psuedostuga menziesii*), western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) • Dominant at high elevations: noble fir (*Abies procera*), white fir (*A. concolor*), grand fir (*A. grandis*) and Pacific silver fir (*A. amabilis*)
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Unknown
Research question(s), hypotheses, objectives	Study environmental factors that affect buffer strip stability and stream shading
Study design[1]	• 40 buffer strips – 400-700 feet long • Measured independent variables - characteristics of the buffer strip (i.e. basal area, understory species, buffer width). • Measured shading by estimating canopy density with an angular canopy densiometer. Densiometer was placed in stream center, oriented south, on a 1.5 foot tripod.

Publication	(Steinblums et al., 1984)
	• Regression analysis was conducted to relate densiometer measures to independent variables.
Pretreatment data (yes/no), # of years of pretreatment data	None
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	Harvest occurred from 1 to 15 years prior to the study. Buffer widths ranged from approximately 25 feet to >140 feet (Figure 2).
Replications (if applicable)	28 shade-providing strips
Nature of the outcome measures used, their relative importance and robustness[2]	Angular canopy density: measured as shade with a densiometer • Importance: fairly common measure of shade • Robustness: concerns with reliability of densiometer data as results can range widely
Sample sizes and results with estimates of variation [3]	• Shade along streams with buffer strips that were considered "shade-providing" averaged 51% (15-87%; n=28). • In 12 strips bounded on south by uncut forest, shade averaged 62% (26-85%). • As buffer strip width increased, canopy density increased in a curvilinear fashion (Figure 2).
Notes concerning study quality with evidence or reasoning behind the notes[4]	No statistical analysis – focus was on determining regression equations.
Potential sources of bias or error	Densiometer measures can have a wide range of measurement error.
Effects modifiers[5]	Direct measures: buffer width, shrub density, aspect Indirect measures: time since harvest, elevation
Notes[6]	
Method references[7]	Relationship between canopy density and densiometer measurements: Brazier and Brown 1973

Publication	(Veldhuisen and Couvelier, 2006)

Publication	(Veldhuisen and Couvelier, 2006)
Study dates and study duration (# of years, dates within a year)	2001 through 2003, measurements made between June and September each year
Study location (watersheds, region/state, country), settings where riparian buffers were applied	• Headwater tributaries of the Skagit Basin • northwestern Cascade mountains, Washington
Ecosystem type; plant association group; type of forest	• Western Hemlock Climax Zone • *Tsuga heterophylla*, *Pseudotsuga menziesii*, *Thuja plicata*, and *Alnus rubra* were prevalent riparian species across all sites
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	• Non-fish bearing perennial streams • Bankfull width ranged from 0.9 to 4.2 meters • Wetted width ranged from 0.5 to 1.9 meters
Research question(s), hypotheses, objectives	OBJECTIVES • "Evaluate the role of riparian logging, shade, aspect and channel dimensions in influencing segment-scale temperature change"

Study design[1]	• Selected non-fish bearing perennial streams in the Skagit basin that were harvested within the past 10 years
	• Stream temperature monitoring strategy varied by year in the study
	  • temperature either measured at upstream and downstream extents of the treatment reach (2001 and 2002) or measured upstream/downstream extents plus intermediate points on 150 meter intervals within the treatment reach (2003)
	  • forested control stream segments were measured in 2002 and 2003
	  • bankfull channel widths measured at each temperature monitoring location in 2001 and 2002
	  • in 2003, shade (via spherical densiometer) and channel dimensions were measured at four evenly-spaced locations within each temperature measurement segment
	• Upstream forest and riparian management varied across sites (See Appendix 2, 3, and 4b)

Pretreatment data (yes/no), # of years of pretreatment data	No

Publication	(Veldhuisen and Couvelier, 2006)

Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	3 primary management categories:
	• Clearcut completely within the past 10 years
	  • For 2002, this category included 3 streams that were completely clearcut and 3 that originally had buffers <10 meters wide per side but had mostly blown down
	• Harvest with buffer within the past 10 years
	  • Buffer widths ranged from 6 to 30 meters on each side
	• Forested (mature)
	
	• 2 streams were put into a 4th category as they had been scoured by debris flows and were significantly different than the other categories

Replications (if applicable)	

Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = Stream temperature (instantaneous maximum temperature, maximum 7-day moving average of the daily maximum (7-DAD Max), and range of the daily maxima and minima during the period of the 7-DAD Max)
	  • Relative importance = High
	  • Robustness = High
	• Measure = Shade (as measured by spherical densiometer)
	  • Relative importance = High
	  • Robustness = Moderate

Sample sizes and results with estimates of variation [3]	• Mann-Whitney test for significant differences in temperature metric from 2002 (as measured at the bottom of the treatment reach; number of sites for forest = 5, buffer = 7, clearcut = 6, and debris flow = 2; significance level is α=0.10; Table 3)
	  • Instantaneous max: no significant difference for forested< buffer test, while forested<clearcut and buffer<clearcut were significant
	  • 7-DAD Max: no significant difference for forested< buffer; forested<clearcut and buffer<clearcut were significant
	  • 7-DAD Range: forested<buffer, forested<clearcut, and buffer<clearcut were all significant

Publication	(Veldhuisen and Couvelier, 2006)

	• Tested for differences "between temperature responses on north and south aspects" and found no differences for all treatment categories except debris flow streams (no data provided or details on analysis)
	•
	• Downstream minus upstream temperature differences were all positive (heating in the downstream direction) in 2002, but variable in 2003 (Figure 7)
	
	• Multiple regression analysis (Table 4)
	  • Shade, elevation, square root of channel gradient, and channel gradient were significant predictors of seasonal maxima (R^2=0.73) and 7-DAD maxima (R^2=0.77)
	  • 7-DAD range was best predicted by shade, square root of channel gradient, and channel gradient (R^2=0.72)
	  • No significant model was found for predicting change in maximum from upstream
	  • Bankfull width, wetted width, depth, and buffer width were not significant predictors in any of the models
	
	• Using all treatment types, mean shade % (i.e. canopy closure %) was found to asymptote at 90 % for buffers 25 meters or greater (this is based on a curve "fitted by eye" (Figure 8)) –however, no observable trend in no-cut buffer width and canopy closure
	
	• Shade % required to meet water quality criteria (either AA criteria or Core Rearing Standard) was inversely proportional to channel gradient up to gradients of 25 % (the relationship reaches somewhat of an asymptote beyond 25 to 30 % channel gradient; Figure 9)

Notes concerning study quality with evidence or reasoning behind the notes[4]	The study quality relative to the SR question is low. Flaws in the study design as described below limit the statistical power to allow strong reliance upon the results.
Potential sources of bias or error	• Use of sites with varying time since treatment management was employed. Even if constrained to a range of 10 years, this introduces uncertainty to the results and potentially low bias for temperature response in clearcuts.

Publication	(Veldhuisen and Couvelier, 2006)
	• Direct comparison of temperature metrics from downstream sensors only (as in Table 3) does not control for factors influencing stream temperature upstream of treatment unit. • The effects of hydroclimatic conditions by year were not assessed, likely because of the study design changing every year, so it is impossible to know what effect lower flows and warmer summers had on the temperature responses.
Effects modifiers[5]	Stream temperature modifiers assessed in analyses: Shade Elevation Channel gradient Bankfull width Wetted width Depth Buffer width Aspect Other modifiers documented but not assessed in analysis: Age of treatment Upstream management Others: Sensor placement relative to groundwater inflows, springs, or tributary junctions Buffer age Buffer species composition and density Discharge Flow continuity Climate/Air temperature
Notes[6]	While this study does not provide robust and defined results that warrants basing management decisions on, it does highlight the variability in stream temperature response encountered in very small headwater streams.
Method references[7]	

Publication	A. (Wilk et al., 2010)
Study dates and study duration (# of years, dates within a year)	2003-2006, data collected in 2003, 2005, 2006
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Western Washington – Willapa State Province in the Coast Ranges Regional Province
Ecosystem type; plant association group; type of forest	Managed previously logged and naturally regenerated second-growth coniferous forests of mostly western hemlock (Tsuga heterophylla), Douglas-fir (Pseudotsuga menziesii) and western redcedar (Thuja plicata), with vine maple (Acer circinatum) in the midstory. Some sites had dense patches of salal (Gaultheria shallon) in upland ground cover. Devil's club (Oplopanax horridus), salmonberry (Rubus spectabilis), western sword fern (Polystichum munitum) and redwood sorrel (Oxalis oregana) characterized streamside vegetation. Stand ages at the time of logging were 61–108 years.
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	1st and 2nd order streams Catchment size of 1.2 – 8.1 ha Bankfull < 3 m
Research question(s), hypotheses, objectives	"Understanding of alternative buffer designs in the maintenance of streamside small mammal communities by comparing the short-term treatment response of habitat, abundance and composition to measures from prelogging and to measures from uncut reference sites"
Study design[1]	• Reaches 80-480 m long • 1 year pretreatment and 2 years post-treatment • Replicated with controls • Vegetated forest stand data collected in four 3x3m quadrats in each of two 10x10 m plots on each side of stream 2-12 m from bank. Data collected include: basal area, QMD, and canopy with hemispherical photos 1.2 m above ground with fisheye converter and 20% mask of sky.
Pretreatment data (yes/no), # of years of pretreatment data	Yes = 1 year

Publication	A. (Wilk et al., 2010)
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	There were two experimental treatments of relevancy: (1) clearcuts with continuous buffer strips from a few to 20m each stream side (n = 7; one or two per cutblock), and (2) clearcuts with small patch (<0.6 ha in size) buffers left to protect sensitive streamside terrain (n = 3; in two of the cutblocks). Six unmanaged controls, one in each cutblock
Replications (if applicable)	Replicates of each method: 6 control, 7 strip buffer, 3 patch leave, 3 patch cut, 7 no buffer
Nature of the outcome measures used, their relative importance and robustness[2]	• Measure = change in habitat (understory – richness, evenness, diversity; forest – canopy closure, standing live trees, basal area) • Relative importance = describe habitat • Robustness = sampling methods are robust

Sample sizes and results with estimates of variation [3]	• Patch cut (n=3) and no buffer (n=7) had significantly different habitat than the control for all outcome measures listed above (Table 1)
	  • Patch leave (n=3) had significantly different understory richness and forest canopy closure than the control
	  • Canopy closure (%):
	  • strip buffer: -8.6 ± 3.5 (p=0.12)
	  • patch leave: -23.4 ± 8.7 (p>0.05)
	  • control: 0.2 ± 1.2
	  • Basal area (m2/ha):
	  • Strip buffer: -19 ± 4 (p=1)
	  • Patch leave: -17± 4 (p=1)
	  • Control: -10 ± 7

Notes concerning study quality with evidence or reasoning behind the notes[4]	Low sample sizes. Not entirely certain what statistical analysis method was used.
Potential sources of bias or error	Logging altered stream locations in some cases.
Effects modifiers[5]	Did not test modifiers besides width of riparian reserve, riparian cover, and windthrow
Notes[6]	No direct relationship to shade or temperature, more about plant community composition.

Publication	A. (Wilk et al., 2010)
	Focus of paper was on small mammals.
Method references[7]	

Publication	B. (Wilk et al., 2010)
Study dates and study duration (# of years, dates within a year)	2003 through 2006, 4 years
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Willapa State Province, western Washington State, USA
Ecosystem type; plant association group; type of forest	Northern edge of Coast Ranges Regional Province Naturally regenerated, second-growth coniferous forest (primarily *Tsuga heterophylla*, *Pseudotsuga menziesii*, and *Thuja plicata*)
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Catchment area: 1.2 to 8.1 hectares Reach lengths (source to confluence): 80 to 480 meters Bankful width: generally < 3 meters Mostly perennial, with one having a "dry, trickle bed"
Research question(s), hypotheses, objectives	**Objective:** "…provide a better understanding of alternative buffer designs in the maintenance of streamside small mammal communities by comparing short-term treatment response of habitat, abundance, and composition to measures from prelogging and uncut reference sites."
Study design[1]	Replicated sampling, replicated control, sampling before and after treatment
Pretreatment data (yes/no), # of years of pretreatment data	Yes, 1 year
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	#1: Clearcut, no buffer #2: Clearcut, with few to 20 meter buffer strip on both sides of stream #3: Clearcut, with small (<0.6 ha) patch buffers at sensitive streamside terrain

Publication	B. (Wilk et al., 2010)
	#4: "Unmanaged" control
Replications (if applicable)	Replication occurred primarily via 6 different study blocks (separated by ~10-80 kilometers) Within block replication minimal Specifics by treatment: #1 and #2: n=7 (1 or two per cut block) #3a: n=3 (2 blocks total?) #3b: n=3 (2 blocks total?) #4: 1 in each block (6 blocks total)
Nature of the outcome measures used, their relative importance and robustness[2]	Forest stand: canopy closure % (measured by hemispherical camera) - relevant, robust standing live trees (plot count)- indirectly relevant, robust Forest stand basal area (Spiegel Relaskop)- indirectly relevant, robust
Sample sizes and results with estimates of variation [3]	**#1- Clearcut, no buffer (n=7)** canopy closure*: -69.1 +/- 2.6 % (* = significant relative to change in control, alpha=?) standing live trees*: -518 +/- 115 trees ha^{-1} basal area*: -54 +/- 6 m^2 ha^{-1} **#2- Clearcut, with buffer strips (n=7)** canopy closure: -8.6 +/- 3.5 % standing live trees: -152 +/- 44 trees ha^{-1} basal area: -19 +/- 4 m^2 ha^{-1}

Publication	B. (Wilk et al., 2010)
	#3a- Patch leave (n=3) canopy closure*: -23.4 +/- 8.7 % standing live trees: -120 +/- 51 trees ha^{-1} basal area: -17 +/- 4 m^2 ha^{-1} **#3b- Patch cut (n=3)** canopy closure*: -67.2 +/- 3.9 % standing live trees*: -273 +/- 41 trees ha^{-1} basal area*: -38 +/- 4 m^2 ha^{-1} **#4- Control (n=6)** canopy closure: -0.2 +/- 1.2 % standing live trees: -109 +/- 87 trees ha^{-1} basal area: -10 +/- 7 m^2 ha^{-1}
Notes concerning study quality with evidence or reasoning behind the notes[4]	
Potential sources of bias or error	Typical error associated with these types of measurements
Effects modifiers[5]	
Notes[6]	Although this study was conducted within the geographical range of this SR and deals with riparian management, its usefulness is primarily linked to the possibility of correlating changes in riparian basal area with changes in canopy closure for this forest type. If the results were paired with stream temperature data, this study may have provided more useful information for addressing the SR questions.
Method references[7]	

Publication	(Zwieniecki and Newton, 1999)
Study dates and study duration (# of years, dates within a year)	July and August 1995

Publication	(Zwieniecki and Newton, 1999)
Study location (watersheds, region/state, country), settings where riparian buffers were applied	Western and northwestern Oregon
Ecosystem type; plant association group; type of forest	Low elevation sites
Stream size (avg. annual flow, contributing area, HUC, avg. wetted width, etc.)	Discharge ranged from 0.0004-0.022 m^3/km^2s (0.006 m^3/km^2s average) Depth ranged from 0.04-0.47 m (0.20 m average) Width ranged from 0.7-7.0 m (3.4 m average)
Research question(s), hypotheses, objectives	Hypothesis: "each stream has its own temperature signature reflecting its specific environment and flow pattern" Objective: "evaluates the direct effect on summer maximum stream temperature of various timber harvest units along forested streams with tree buffers of varying widths and arrangements; it also examines trends in the return to the temperature signature"
Study design[1]	• 14 forested streams • Temperature data collected at four or more continuous recording temperature monitors installed: immediately upstream and downstream of harvest unit boundary and 150 and 300 m downstream. • Stream depth, wetted width, gradient and cover were collected every 30 m within the harvest unit and within 300 m upstream and downstream of the harvest unit.
Pretreatment data (yes/no), # of years of pretreatment data	None
Details on management action(s) (e.g., sizes and types of buffers; clearcut or thin on both or single sides of streams)	• Clearcutting on one or two sides of the streams while leaving tree buffers of varying widths. • Some streams included natural and/or cleared overstory gaps. • Buffer width ranged from 8.6 to 30.5 m. • Harvest according to: Hardwood Conversion Rules, Best Management Practices, or experimental (one-sided (south) buffers of 12 m as part of Hardwood Conversion Rules.
Replications (if applicable)	3 Geographic Regions, 2 harvest prescriptions, 2 stream sizes resulted in none or one

Publication	(Zwieniecki and Newton, 1999)
	replication
Nature of the outcome measures used, their relative importance and robustness[2]	7-day moving mean maximum stream temperature • Importance: authors selected the warmest weather periods to find the highest temperatures that fish would have to tolerate • Robustness: measure is well-recognized and considered strong if the temperature data is collected appropriately Cover density: measured with a spherical densiometer • Importance: considered as a surrogate for shade • Robustness: measurement error is frequently a concern with densitometers, little explanation was given to describe methodology for reducing this potential error
Sample sizes and results with estimates of variation [3]	• Cover was 78% within harvest units and 83% above and below harvest units (n=14), though no significant differences. • Absolute water temperatures were 1.09 °C higher in the harvest unit (p=0.0005). • Temperature decreased by 0.69 °C in the first 150 m downstream of the harvest unit (p=0.08). • From top to bottom of entire study reach (upstream, within, downstream) temperature rose 0.55 °C (p=0.07). • Streams harvested on one side only appear to have smaller changes in temperature and quicker recovery, though sample size is low and no statistical analysis was conducted (Figure 3). • Hardwood Conversion Units look to have greater increases in temperature and slower recovery than BMP units, also no statistical analysis conducted (Figure 3).
Notes concerning study quality with evidence or reasoning behind the notes[4]	Conclusions regarding cumulative effects are neither well tested nor represented by the data. There is evidence of temperatures rising and then decreasing substantially downstream, but this does not equate to the term 'cumulative effects'. Also, the sampling window is short enough that cumulative effects over the season cannot be described. It is not completely clear how the different harvest management practices affected temperature – differences by harvest practice not clearly reported or discussed.

Publication	(Zwieniecki and Newton, 1999)
Potential sources of bias or error	Methods for deploying stream gages is not clearly defined.
Effects modifiers[5]	Direct measures: tree buffer width, density of cover, gradient, wetted width, stream depth Indirect measures: harvest on one or both sides of stream
Notes[6]	
Method references[7]	

Completed Table A.6.3 Summary of information from each study that indicates its quality and relevance to the review question. An X indicates the study incorporates this characteristic.

ID*	Study	Quality							Confidence score*	Relevance			
		Duration (years)	Pre-treatment[1] (yrs)	Study design[2]	$N_{replicate}$[3]	$N_{control}$[4]	N_{sites}[5]	Statistically robust[6]		Geography[7]	Mountains[8]	Stream size[9]	Question/Objective[10]
A	(Allen and Dent, 2001)	1	0	L	1-13	5	19	H	7	H	X	H	H
B	(Brazier and Brown, 1973)	1	0	L	0	11	11	M	5	H	X	H	H
C	(Brosofske et al., 1997)	1-2	1 yr., 5 sites	M	0	5	14	M	6.5	X	X	H	L
D	(Danehy et al., 2007)	1	0	L	6	6	7	M	7	X	X	H	L
E	(Dent, 2001)	2	1	M/L	0-6 /site type	18	18	L	6.5	H	H	H	H
F_1	(Dent and Walsh, 1997)	1	0	M/L	2-3/site type	11	11	L-M	6	H	H	M	H
G_2	(Gomi et al., 2006)	5	1-2	H/M	0-1	3	3	H	9.5	H	X	H	H
H_3	(Groom et al., 2011a)	6	2	H	14-17	18 (PF), 15 (SF)	18 (PF), 15 (SF)	H	12	H	X	H	H

I_3	(Groom et al., 2011b)	4 out of 6 year window	2 (31 sites)	H	14-17	18 (PF), 15 (SF)	18 (PF), 15 (SF)	H	12	H	X	H	H
J_3	(Groom et al., 2013)	Up to 6 years	Up to 4 years	H	14-17	18 (PF), 15 (SF)	18 (PF), 15 (SF)	H	12	H	X	H	H
K	(Hunter, 2010)	4	2-3	L	0	7	7	L	6	H	X	H	H
L_4	(Jackson et al., 2007)	4	1	M	0	4	4	L	7	H	X	H	L
M_4	(Jackson et al., 2001)	2	1	M	0	4	3 buffered 1 non-merchantable buffer	L	6	H	X	H	H
N_5	(Janisch et al., 2012)	4 to 5 per catchment cluster	1-2	H	4-9	CTD/Temp 8/6	CTD/Temp 10/6 continuous buffers 5/5 patch buffers	H	12	H	X	H	H
O_2	(Kiffney et al., 2003)	1	0	M	2	3	6	L	6	H	X	H	H
P	(Martin, 2004)	2	1-2	M	2	3	3	M	8	M	X	H	H
Q	(Morman, 1993)	3	1	L	0	29	29	L	6	H	X	L	H
R	(Newton and Cole, 2013a)	8	2	H	2	3	3	H	11	H	H	H	H
S_1	(Newton and Cole, 2013b)	2	0	L	3	4	4	M	7	H	H	H	H
T	(Rashin et al., 1992)	1	0	L	0	9	9	L	4	H	X	H	H

U	(Schuett-Hames et al., 2012)	3 out of 5 yrs	0	L	2-12	14 total, but 1 per treatment location	13 50-foot buffers 3 PIP buffers	L	7.5	H	X	H	H
V	(Steinblums et al., 1984)	1	0	L	0	12	28	M	5	H	H	H	H
W	(Veldhuisen and Couvelier, 2006)	3	0	L	0	5 for 2002 13 for 2003	2002/2003 Buffered=7 / 11	L	6	H	H	H	H
X_5	(Wilk et al., 2010)	2	1	M	2-6	6	10	H	9.5	H	X	H	L
Y_1	(Zwieniecki and Newton, 1999)	1	0	L	2-5	14	14	M	6.5	H	H	H/L	H

*Relates publications to ID for graphing purposes. Publications with the same subscript are from the same study (see Table 2).

[1]Data collected before treatment with the number of years of pre-treatment data in parentheses (X=yes, blank=no)

[2]H=high=Replicated sampling, replicated controls, sampling before and after treatment; M=medium=unreplicated, controlled, sampling before and after treatment; L=low=unreplicated, uncontrolled, sampling before and after treatment or unreplicated, controlled, sampling after treatment (modified from (Fazey and Salisbury, 2002)).If mixture (e.g., some sites with and some sites without replicates), give mixed rating (e.g., L/M).

[3]Number of treatment replicates; add succinct description (e.g., "9 sites, 3 yrs. Post-treatment, treatment X"), knowing that greater detail is captured in Table B2.

[4]Number of control replicates; add succinct description (e.g., "9 sites, 3 yrs. Post-treatment, treatment X"), knowing that greater detail is captured in Table B2.

[5]Number of samples; add succinct description (e.g., "9 sites, 3 yrs. Post-treatment, treatment X"), knowing that greater detail is captured in Table B2.

[6] H=high= stream temperature autocorrelation dealt with, data not combined across sites without accounting for site differences; M=moderate= contains some features of High as applicable; L=low=statistical tests used (or not) but ignore site differences or autocorrelation

*sum of quality points for duration, study design, number of replicates, and statistically robust columns. Points are H=3, M=2, L=1; for duration, points are 1, 2,3 for 1, 2, and ≥3 seasons, respectively; for number of replicates, points are 1, 2, 3 for 0-1, 2-3, and ≥4 replicates, respectively. If a rating is between two, then the points are between these two (e.g., L/M, or duration=1 or 2 years, depending on the site, then the points would be 1.5).

[7]H=high= west of crest of Cascades in OR, WA, BC plus the Siskyous (i.e., sites most similar to those in western Oregon); L=low=Coast Range of N. CA, Vancouver Island, NW BC, SE Alaska (i.e., sites somewhat similar to those in western Oregon).
[8]In mountainous terrain (X=yes, blank=no)
[9]H=high=small or medium streams as defined in either of (Groom et al., 2011b; ODF, 1994) (i.e., with contributing areas < 7500 ac.(30 km^2), or average annual flow < 10 cfs, or wetted width <3.7 m, or bankfull width < 7.9 m); L= low = "near" medium size stream (i.e., contributing areas 7500 - 11250 ac. (30-45 km^2), or 10 - 15 cfs average annual flow, or 3.7 - 4.0 m wetted width, or 7.9 - 8.7 m bankfull width)
[10]H=high=study objectives or questions directly relate to review question; L=low= study has relevant data even though study objectives or questions are not directly related to review question.

Completed Table A.6.4 Relevance of each study to each rule alternative as listed in Table A.5.1.

High relevance (H) indicates study directly addressed a particular rule alternative; low relevance (L) indicates study indirectly addressed a rule alternative; blank indicates did not address rule alternative.

Study	Current FPA[1]	State Forests Standards[1]	Derived variable retention	Large tree variable retention	Minimize gaps	Basal area retention by aspect	Field-based shade standard	Shade approach from WA DNR method	Shrub shade	Hardwood sites	Hardwood shade	Derived no-cut buffer	No-cut aspect buffers	Oregon Plan	Plan for alternate practice[2]	One-sided buffer
(Allen and Dent, 2001)		L				L					L	H	L		H	
(Brazier and Brown, 1973)	L	L	L	L			L	L				H		L	L	
(Brosofske et al., 1997)												H			L	
(Danehy et al., 2007)												H				
(Dent, 2001)	H									L	L	H			H	
(Dent and Walsh, 1997)	H									L					H	H
(Gomi et al., 2006)	L	L	L									H	L	L	L	
(Groom et al., 2011a)	H	H										L				L
(Groom et al., 2011b)	H	H				L	L				L					
(Groom et al., 2013)	H	H														
(Hunter, 2010)	L	L	L	L	L		L	L		L	L	L	L	L	H	L
(Jackson et al., 2007)	L	L					L	L	L			H	L	L	H	
(Jackson et al., 2001)	L	L										H			H	
(Janisch et al., 2012)	L	L				L	L	L				H	L	L	H	
(Kiffney et al., 2003)	L	L					L	L				H	L	L		
(Martin, 2004)			H									L				
(Morman, 1993)	L		H						L	L				L		L
(Newton and Cole, 2013a)	H								L					L	L	
(Newton and Cole, 2013b)			L		L	L			H	L	L					
(Rashin et al., 1992)	L	L	L	L	L	L	L	L		L	L	H	L	L	L	L
(Schuett-Hames et al., 2012)	L	L	L			L	L	L	L	L	L	H	L	L	H	

(Steinblums et al., 1984)	L											H				L
(Veldhuisen and Couvelier, 2006)		L	L				L	L				H			L	
(Wilk et al., 2010)												H			H	
(Zwieniecki and Newton, 1999)	H									L					H	H
Total # studies (pubs) High relevance**	4(7)	1(3)	2	0	0	0	0	0	1	0	0	12(15)	0	0	7(10)	1(2)

[1] Standards are summarized in (Groom et al., 2011b).
[2] Any other type of treatment that may have been studied.
[3] A study is considered directly relevant (H) if it provides quantitative data that addresses whether or not a particular design or prescription of a rule alternative is effective at preventing warming or maintaining shade. A study is considered indirectly relevant (L) if it provides information that can give some insight to effectiveness of a particular rule alternative.
[4] Effective at preventing stream from warming or maintaining shade: ++= prevented warming or maintained shade; += reduced warming or had a smaller decrease in shade relative to another treatment (indicated with ‘) or control (indicated with *), 0= no change; I= inconclusive; - =resulted in maximal warming or largest decrease in shade compared with other treatments. Note that effectiveness is only categorized where a study is highly relevant to a rule alternative.
**Sum of all studies that are highly relevant for each rule alternative; parentheses indicates the total number of publications relevant to a particular alternative if different than the number of studies. See Table 1 for clarification of relationship between studies and publications.

Appendix C. Data for Geographic Regions analysis.

Table C1. Data to compare effectiveness of different buffer prescriptions between ODF Geographic Regions for each study.

These data are illustrated in Figures 2 and 3 of the report.

Presc.[†]	Publication(s)[α]	Geog. Regions (# sites w/ prescr.)*	Conf. score	Outcome data comparison between Geog. Regions[††]
FPA	Dent, 2001	CR (1), I (6)	6.5	CR: Cover +4; I: Cover +2, -4, -6, -8, -16, -18
FPA	Dent and Walsh, 1997; Zwieniecki and Newton, 1999	CR (3), I (1)	6, 6.5	CR: Cover +8, -1, -18; Temp. 0.4, 1.8, 1.6 I: Cover +9; Temp. 1.6
FPA	Groom *et. al*, 2011a, b, 2013	CR (16), I (2)	12	NA
FPA	Newton and Cole, 2013a	CR (1), I (2)	11	CR: Temp. 1.3 I: Temp. -0.1, 0.6
FMP	Groom et. al, 2011a, b, 2013	CR (14), I (1)	12	NA
Variable Retention	Morman, 1993	CR (9), I (8)[αα]	6	shade 43' CR -32 I -9 shade 48' CR -20 I -22
Shrub shade	Newton and Cole, 2013b	CR (1), I (1), WC (1)	7	Temp. CR -0.3 I 1.2 WC 1.2
No-cut	Allen and Dent, 2001	CR (14)	7	NA
No-cut	Brazier & Brown, 1973	CR (7), I (4)[αα]	5	Cover 10' CR -24 I -61 Cover 50' CR 0 I -6, -3 Temp. 10' CR 9 I 7.5 Temp. 50' CR 3 I 2, 6
No-cut	Danehy et. al, 2007	CR (7)	7	NA
No-cut	Dent, 2001	I (1)	6.5	NA
No-cut	Steinblums *et. al*, 1984	I (18), WC (22)	5	NA
HWC	Allen and Dent, 2001	CR (2)	7	NA
HWC	Dent, 2001	CR (3)	6.5	NA
HWC	Dent and Walsh, 1997;	CR (2), I (2)	6, 6.5	CR: I

Presc.[†]	Publication(s)[α]	Geog. Regions (# sites w/ prescr.)*	Conf. score	Outcome data comparison between Geog. Regions[††]
	Zwieniecki and Newton, 1999			Cover: -10, -20; +6, -10 Temp.: 3.2, 1.7; 1.7, 0.4
South-sided	Dent and Walsh, 1997; Zwieniecki and Newton, 1999	CR (2), I (1)	6, 6.5	CR: Cover 0, -5; Temp. 0, 1.4 I: Cover -7; Temp. 0.1

[†]Type of buffer prescription, related as closely as possible to the rule alternatives. HWC (hardwood conversions) is considered under the "Plan for alternate practice" rule alternative.
[α] Note that many publications test several different prescriptions.
*Geographic Regions included in this analysis: CR = Coast Range; I = Interior; WC = West Cascade.
[††]All data are difference between post-harvest and control; cover/shade in %, temperature in °C. Note that data are compared only within a study since methods, and therefore data, might differ between studies. "NA" is for data that are not readily extractable from the publication [Groom *et al.* [2011a, b, 2013*]*, Steinblums *et al*. [1984]), or data are only from one Geographic Region.
[αα] Brazier and Brown (1973), and Morman (1993) each had internally comparable data for only a few buffer widths.

Appendix D. Draft report, with additions

This appendix includes the Draft Report and significant additions (i.e., Executive Summary, and Geographic ranges and physical settings) to this draft after it was completed. These documents were sent to stakeholders and technical experts in July 2013 for their review and comment (see Appendix E) since we wanted to both be more inclusive in the process of developing this report, and because their input strengthened the review. These documents are in this appendix for transparency and to provide context for their comments.

D.1 Draft Report

1. Draft Introduction

1.1 Background

Many Oregon streams support several cold-water fisheries (e.g. salmon, steelhead, cutthroat) which are important to the region's economy, culture, and recreational activities. These fish are thermally adapted to specific water temperature regimes for various life stages such as egg and smolt survival, spawning, and adult migration (Richter and Kolmes, 2005). These regimes are affected by several natural processes including direct exposure to sunlight, the transfer of heat from water to the air or stream bed, evaporation, water exchange with groundwater or the hyporheic zone, and others (Brown, 1969; f Johnson, 2004). Of these factors, direct exposure to sunlight is a major contributor to maximum daily summer stream temperatures, and this exposure may increase following timber harvest (Brown and Krygier, 1970; Johnson, 2004; Sinokrot and Stefan, 1993). Therefore, maintaining riparian shade may serve as an effective tool for minimizing the increases in stream temperature during the summer months when maximum stream temperatures are observed (Johnson, 2004).

Oregon has enacted timber harvest regulations to maintain shade on streams following timber harvest (Oregon Department of Forestry, 2010). Timber harvest operations are considered in compliance with Oregon Department of Environmental Quality (DEQ) water quality standards (Oregon Department of Environmental Quality (ODEQ), 2004) if harvest operations comply with the Forest Practices Act (FPA; ORS 527.770). The Oregon Department of Forestry (ODF) must establish best management practices and rules that will meet state water quality standards and periodically conduct studies to determine if the FPA effectively meets state water quality standards (ORS 527.765, 527.710).

ODF initiated its Riparian and Stream Function (RipStream) monitoring project in 2002 to assess the effectiveness of FPA and State Forests standards at complying with DEQ water quality standards for temperature. One of the temperature criteria examined was the Protecting Cold Water (PCW) criterion, which is designed to prevent warming of streams that are currently cold enough to protect fish. This criterion prohibits human activities such as timber harvest from increasing stream temperatures by more than 0.3 ºC at the point of maximum impact where: a)

salmon, steelhead or bull trout are present; b) streams are designated as critical habitat for salmonids; or c) streams are necessary to provide cold water to a) (OAR 340-041-0028 (11)). An analysis of the pre and post-harvest data indicated that the PCW criterion was likely not being met at all study sites with FPA buffers (i.e., these sites frequently exhibited temperature increases greater than 0.3 ºC; (Groom et al., 2011b)). This finding of degradation has initiated an FPA riparian rule analysis process (ORS 527.714(5)(a)). The geographic scope of the findings of degradation are based on (Groom et al., 2011a, 2011b), which studied streams in the Coast Range and Interior Geographic Regions of Oregon (as defined in OAR 629-635-0220). While the exact geographic extent of the rule analysis is yet to be determined, it will be limited to western Oregon. This limitation is due to the vegetation, climate and hydrologic characteristics of eastern Oregon being significantly different enough from those included in the RipStream study to preclude extending a rule to eastern Oregon. As part of this rule analysis process, stakeholders contributed 16 alternative methods of riparian management as options for meeting the PCW standard during future near-stream harvest operations. The Oregon Board of Forestry approved consideration of these 16 alternatives at their July 2012 meeting.

ODF is conducting this systematic review (SR) to fulfill a requirement of the rule analysis process: proposed rules must reflect available scientific information (ORS 527.714 (5)(c)). The SR will also serve to inform the decision on the geographic extent of the rule analysis process relative to the RipStream findings on FPA sufficiency. Therefore, this SR will, through evaluating a focused question, directly assist in evaluating the 16 alternative scenarios for riparian management and help inform the ODF rule analysis process. However, this review will not recommend which alternative is the best to choose, nor explicitly define a particular rule prescription.

1.2 Objective of the Review

This systematic review is designed to provide scientific guidance, per Oregon Revised Statues 527.714 (5)(c), to the Oregon Board of Forestry in addressing the following rule analysis objective developed by the Board at their April 2012 meeting:

Establish riparian protection measures for small and medium fish-bearing streams that maintain and promote shade conditions that insure, to the maximum extent practicable, the achievement of the Protecting Cold Water criterion.

Small streams are defined as having average annual flows ≤57 L/s (2 cfs), and medium streams are defined as having flows >57 L/s (2 cfs) and ≤283 L/s (10 cfs; Oregon Department of Forestry, 2010). Fish-bearing streams are those for which anadromous, game, or threatened and endangered fish presence has been observed or modeled. Specifically, this review is designed to provide insight on the efficacy of the 16 rule alternatives that were approved by the Board at their July 2012 meeting (Table A.5).

2. Draft Methods

This section summarizes the protocol for conducting the systematic review (for details of the methods, refer to Appendix A). Note that the tables to be completed by the reviewers are listed in Section A.6, whereas their associated completed forms are in Appendix B. The protocol was approved by the Oregon Board of Forestry at their meeting on 6 March, 2013, and was modified slightly during the review process.

2.1 Purpose of protocol for systematic review

Protocols provide a road map for how to conduct a systematic review of scientific literature relevant to a narrowly-defined question (Centre for Evidence-based Conservation, 2010). A systematic review seeks to answer this question with evidence, as opposed to the authors' interpretation of such evidence, from existing studies that are rigorously screened for quality and relevance to this question. The structured process provides for rigor and transparency concerning how studies are searched for, which ones are included in the review, and how they are analyzed. This process also allows for a review to be either updated in the future, or completed by another party.

2.2 Review partners

Numerous partners strengthened the quality of this systematic review. ODF staff composed an initial draft of the protocol, then obtained input on it from a group of stakeholders and the RipStream External Review Team (RSERT). These groups included university, federal,

forest industry, and state scientists; staff from the Oregon Departments of Forestry, Environmental Quality, and Fish & Wildlife; and nongovernmental organizations including Pacific Rivers Council. Similarly, a reference librarian from the Oregon State Library assisted in refining the search strategy. Finally, ODF coordinated the work of these partners, plus that of the external reviewers. All partners had the opportunity to provide input on:

- The protocol and question for this review;
- A draft list of publications to consider for inclusion in the review to assess if any studies were not found;
- A draft list of included publications to assess whether or not the inclusion criteria were appropriately applied;
- A draft of the completed SR report.

To minimize bias in the review, ODF hired external scientists to conduct the review. These reviewers first cross-checked their work by reviewing a subset of studies (including assessing their study relevance, quality, and extracting the data). Each reviewer then independently reviewed half the remaining studies included in the review. The protocol was modified during the review process, with alterations documented in Appendix A where the reviewers, in coordination with ODF, found ways to improve the protocol. After analyzing the articles, the reviewers collaboratively wrote this report synthesizing their analyses.

2.3 Review questions

Primary review question

Systematic reviews are designed to assess a body of literature through the lens of a focused question regarding the efficacy of active treatments, rather than a general topic of concern to policy or practice. The question should be value-free to the extent possible, answerable in scientific terms, and specify the subject, treatment, comparator, and outcome(s) of interest. The question is also important since it is used to generate terms used in the literature search and to determine relevance criteria.

The elements of this review's question are based on the rule analysis objective and the finding of degradation, and were developed by several partners in stages. ODF staff (T. Frueh, J. Groom, and M. Allen) developed a draft review question. The question was refined in

consultation with representative stakeholders and RSERT to ensure the question's importance and appropriateness of scope for this review. The question was then further refined with ODF input. The review question is:

> **For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?**

Secondary question

This review evaluated differences between studies that might explain variations among study outcomes. These differences may be due to effects modifiers (see Section A.3.3 for more information on these modifiers), and this secondary question explicitly addresses the causes of these differences. To the extent that relevant information is available in reviewed studies, this secondary question was addressed:

> **For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, how do effects modifiers (e.g., discharge, substrate characteristics, length of buffers, stream aspect), in combination with near-stream forest management, change stream temperatures or riparian shade?**

2.3 Search strategy

An important aspect of systematic review is the use of a search strategy that specifies, *a priori*, how a comprehensive and unbiased sample of the literature will be searched. We decided to search as wide as possible, then use rigorous inclusion criteria to determine which studies to include. All publications found in each searched source were saved in a database, except for internet searches from which the first 100 results were reviewed for relevant publications (this restriction follows CEBC guidance). Results with indeterminate information (e.g., incomplete citation) or duplicates were discarded. For every search, the following information is documented (see Data Supplement 1, SearchScoping.xls):

- Date when search was conducted
- Database, search engine, website, library, or professional contact that was queried
- Exact search strings used

2.4 Study inclusion criteria

Study inclusion criteria are predefined to ensure an objective selection of the relevant literature. For this review, the studies must directly inform the primary review question in the

context of the rule alternatives and rule objective. Only primary studies (i.e. studies with original data, not reviews, modeling, or meta-analyses) were included since ODF wants to base the rule analysis on evidence, not authors' interpretation of the evidence. While peer-reviewed articles are the gold standard in science, we decided to include "gray literature" (i.e., articles that might have less rigor in either peer-review or research methods and analysis, e.g., government reports, graduate theses) and manuscripts in review because some of these studies are most relevant to the review question. It is a common requirement that agencies (e.g., ODF, Washington Dept. of Natural Resources) assess the effectiveness of their respective rules via studies, thus this gray literature is likely to be highly relevant to the primary review question. In addition, only studies that measure the effects of recent forest harvests, with near-stream areas managed for protecting water (e.g., similar to OAR 629-635-0100), on stream temperature or riparian shade were included since these elements are essential to analyze the riparian rule objective that provides the impetus for conducting this study. Restricting studies to those of "recent" harvest is warranted due to the decline, with time, of adverse impacts of harvest on stream temperature and riparian shade (Hale, 2007; Johnson and Jones, 2000). The final inclusion criteria are:

- Studies must have proper controls with which to measure the effects of buffer treatments;
- Studies must have been conducted in sites with similar stream sizes and forest types as ODF's water classification of small and medium streams (OAR 629-635- 0310); and,
- Studies must have been located in similar forests as those of western Oregon.

Inclusion criteria are further detailed in Table A.6.1.

With these criteria in mind, inclusion was determined initially on viewing the titles of articles. When titles provided insufficient information to ascertain consistency with inclusion criteria, the ODF review coordinator read abstracts to determine inclusion. Where there was still insufficient information to make a decision, an article's inclusion was determined by reading the full text. Studies that meet all inclusion criteria were reviewed by the external reviewers. For transparency, the fate (i.e., inclusion or exclusion), and basis for this decision, of each publication found in the search are documented in Data Supplement 1.

2.5 Potential effects modifiers

Although studies may have very similar methods, they may show differences in the measured outcomes. These differences may be due to circumstances ("effects modifiers") that

alter the outcomes. For example, two studies may have identical buffer widths, yet if they have different buffer lengths, they might exhibit different changes in stream temperatures. Thus, these effects modifiers are important to consider when synthesizing the information extracted from studies. The role effects modifiers played in study outcomes is assessed using Table A.6.2 and are discussed in the narrative synthesis (Section 3).

2.6 Data extraction strategy

When conducting a systematic review, it is important to extract both information about studies and their respective primary data. This information focuses the review on evidence instead of authors' interpretation of the evidence. The data extraction tables allow for objective and transparent extraction of this data. In addition, these tables help to highlight gaps in our understanding. For this study, these data were compiled using Table A.6.2 for each study. This table was developed by modifying those of (Bowler et al., 2008; Burnett et al., 2008), testing data extraction with several studies, and with input from RSERT and stakeholders. Reviewers also assessed various components (e.g., bias, effects modifiers) that provide a more complete understanding of the context, relevance and relative strength of studies (Table A.6.2).

2.7 Study quality assessment and relevance

When synthesizing data from the studies, it is important to consider both the quality of each study and its relevance to the review question. For example, a study might have directly addressed the review question, yet was poorly conducted so as to provide little confidence in the study's results. Conversely, a study may have been conducted very well, yet has only weak relevance to the review question.

External reviewers completed tables that enable quick, objective comparisons of studies. Table A.6.3 addresses the quality of studies by determining e.g., the rigor of their controls, and number of replicates. A summary metric, Confidence Score, combines the various aspects that make for a high quality study. This metric is designed to help assess the quality of the information when looking at the effectiveness of a particular buffer type (e.g., Figures 1-12). This table also determines study relevance to the review question by determining how close studies are geographically and in stream size to those of (Groom et al., 2011a). Table A.6.4 determines

whether studies directly or indirectly addressed a rule alternative, and a relative assessment of the effectiveness of buffer treatments at protecting cold water or shade. Additional reviewer notes that further illuminate study quality and reference (e.g., robustness of study measures, sources of bias, consideration of effects modifiers) are listed using Table A.6.2.

2.8 Data synthesis

To make sense of the information extracted and analyzed from the studies, a narrative synthesizes the information collected in Completed Tables A.6.2-A.6.4 (Appendix B). This synthesis assesses the differences and commonalities between riparian management scenarios used in studies and their respective outcomes. For each rule alternative, the synthesis discusses:

- The number of studies that directly or indirectly address the alternative;
- The evidence from a suite of studies regarding the effectiveness of the alternative, including:
    - range of variation in metrics defining each alternative (e.g., buffer width, basal area retention)
    - range of variation in outcomes measured
    - degree of effectiveness at protecting cold water or riparian shade
- The role of effects modifiers in the stream temperature and riparian shade outcomes that were measured; and
- Significant gaps in our understanding.

The synthesis also examines the magnitude of influence the effects modifiers had on results.

3. Draft Results and Synthesis

3.1 Literature search and filter

In a search of studies relevant for this review, 1456 studies were identified, of which 25 met all criteria for inclusion in the review (see Table 1 and Data Supplement 2, LitSearchFilter.xls). Of studies excluded from the review, approximately 80% were rejected by reading the title, ~10-15% were rejected by reading the abstract, and the remainder required reading a portion of the complete text. When stakeholders and technical experts were asked to

provide input on the results of the literature search and filtering process, zero comments were received.

While we did not conduct an exhaustive process to evaluate the effort required to locate the 25 studies included in this review, we have some information that may be helpful in thinking about conducting a similar review. We only recorded the first type of search (e.g., database, reference) that found a study. We searched databases first, which found 1245 studies. Of these studies, nine were included in the review. Upon re-analysis, all of these studies were located by examining references of included studies or related review papers. In contrast, nine studies were found via only one search method: four unpublished studies were only found by contacting researchers (three studies were under review (Groom, 2013; Newton and Cole, 2013a, 2013b), and five studies were only found by searching agency websites (Dent and Walsh, 1997; Hunter, 2010; Martin, 2004; Morman, 1993; Veldhuisen and Couvelier, 2006).

Draft Table 1. Summary information on publications included in the review.

ID*	Study	Location (georegion)†	Pub. type††	Rel.?α	Buffer Prescriptions***	Effectiveness data (location of data, method of extraction if applicable)	Measurements	
							Temp.	Sh.
A	(Allen and Dent, 2001)	OR (CR, BM)	Gov't.	Y	14 no-cut buffers (20-70 ft.; 6-21 m), 2 riparian conifer restorations (RCR), 2 site-specific (SS) plans	Range in difference in shade (Table B1, excluding large stream and Blue Mtn. data, measured with respect to avg. forested shade) no-cut (n=14): -38 to -4%; RCR (-28, -6%), SS (-9, 0%)		X
B	(Brazier and Brown, 1973)	OR (CR, I(?))	Gov't.	Y	11 no-cut buffers (10-60 ft.; 3-18 m)	Range in change in canopy cover (Fig. 5; 10-60' buffers values compared with those at 100'): 0 to -60% Observed temp. change (Table 1) +0.6 to +5 ºC	X	X
C	(Brosofske et al., 1997)	WA (Cascades)	PR	N	14 no-cut buffers (26-141 ft.; 8-43 m)	Range in change in radiation (Fig. 8): 0 to +0.1 kW/m2		X
D	(Danehy et al., 2007)	OR (CR)	PR	N	7 no-cut buffers (49 ft.;15 m)	Change in temperature (Table 1, measured with respect to mean mature): 0.0 ºC Change in insolation (Table 1, measured with respect to mean mature; MJ/m2/day): uncut (+95 ±89), thinned (+137± 28)	X	X
E	(Dent, 2001)	OR (BM, CR, EC, I, S, WC)	Gov't.	Y	1 no-cut buffer (70 ft.; 21 m); 3 riparian conifer restorations; 7 standard Forest Practices Act (FPA) prescriptions.	Change in cover (averages for medium (M) and small (S) streams west of Cascade crest, Table 6): No-cut, medium (n=1): -2%; FPA: small (n=3): -9% (range -4 to -16), Med (n=4): -4.5% (range -18 to +4); RCR: small (n=2): -20% (-6, -34); Med. (n=1): -36%		X
F_1	(Dent and Walsh, 1997)	OR (CR,I)	Gov't.	Y	4 standard FPA prescriptions; 4 hardwood conversions (HWCs); 3 HWCs limiting openings on south side of streams	From Table 3 Rule / n / Avg. Change 7-D max., ºC (range) / Avg. change in cover, % (range) FPA / 4 / +2.4 (+0.6 to +3.3) / -0.5 (-18 to +9) HWC / 4 / +4.1 (+0.7 to +5.7) / -8.5 (-20 to +6) S. Side / 3 / +0.7 (+0.07 to +2.6) / -4 (0 to -7)	X	X
G_2	(Gomi et al., 2006)	BC	PR	Y	No-cut buffers (1 33 ft/10 m, 2 98 ft./30 m)	Mean (maximum) treatment effect summer maximum temp. (Table 3): 10 m: +1.0 (+4.1) ºC; 30 m: +0.2 (+1.4) ºC	X	

H_3	(Groom et al., 2011a)	OR (CR)	PR	Y	18 standard FPA prescriptions; 15 State Forest Management Plan (FMP) prescriptions	Avg. temp. change (text, p. 1626): FPA: 0.7 ºC (range -0.9 to +2.5 ºC); FMP: 0.0 ºC (range -0.9 to +2.3 ºC) Avg. change in shade (text p. 1627): FPA: -7%; FMP: -1%	X	X
I_3	(Groom et al., 2011b)	OR (CR)	PR	Y	18 standard FPA prescriptions; 15 State Forest Management Plan (FMP) prescriptions	% chance of exceeding 0.3 ºC FPA: 40; FMP: 9%	X	
J_3	(Groom, 2013)	OR (CR)	IR	Y	18 standard FPA prescriptions; 15 State Forest Management Plan (FMP) prescriptions	Number of sites exceeding 16 or 18 ºC criteria: 7	X	
K	(Hunter, 2010)	WA (Coast Ranges)	Gov't.	Y	7 hardwood conversions	Range in difference of mean GSF (pre-post, from text at each site): 0.03 to 0.13 Range in temperature changes (difference in temp. at upstream vs. downstream end of harvest unit, from figure for each site): -1.5 to +5.0 ºC.	X	X
L_4	(Jackson et al., 2007)	WA (Coast Ranges)	PR	N	3 no-cut buffers (7-69 ft.; 2-21 m); 2 nonmerchantable tree buffers	Change in cover (Table 4; average for both post-harvest years) no-cut: -54% (range: -15 to -78%); nonmerchantable tree: -58% (-35, -80%)		X
M_4	(Jackson et al., 2001)	WA (Coast Ranges)	PR	Y	3 no-cut buffers (7-69 ft.; 2-21 m); 2 nonmerchantable tree buffers	Range in change in temperature (Table 3) no-cut buffers: --0.5 to +2.6 ºC; nonmerchantable tree buffers: +2.8 to +4.9 ºC	X	
N_5	(Janisch et al., 2012)	WA (Coast Ranges)	PR	Y	6 no-cut buffers (33-49 ft.; 10-15 m); 5 patch buffers	Mean temperature disturbances (Figure 3b; range): no-cut: +0.7(0.0 to +1.9) ºC; patch: +0.6 (+0.1 to +1.2) ºC Change in canopy-topographic density (text p. 408), %: no-cut: -8; patch: -18	X	X
O_2	(Kiffney et al., 2003)	BC	PR	Y	No-cut buffers (3 33 ft./10 m, 3 98 ft./30 m)	Difference in PAR, µmol/m2/s (Fig. 2): 10 m: +78 ; 30 m: +8 Increase in maximum summer water temperatures with respect to control reaches (text p. 1066): 10 m: 3 ºC; 1.6 ºC	X	X
P	(Martin, 2004)	SE AK	Gov't.	Y	3 RMAs with inner no-cut (25 ft.; 8 m) & outer partial cut (41 ft.; 12 m)	Avg. change in shade (difference pre-post means for each reach, Table 3): -29% (-24%, -26%, -38%)		X
Q	(Morman, 1993)	OR (BM, CR, EC, I, SC, WC, S(?))	Gov't.	Y	29 Variable-retention RMAs (25-100 ft.; 8-30 m)	Average change in shade for NW and S streams (Table top of p. 17, weighted for number of samples): -15%		X
R	(Newton and Cole, 2013a)	OR**	IR	Y	3 standard FPA prescriptions	Average maximum change in temperature over the reach: +0.7 ºC (range: +0.3 to +2.0 ºC)	X	

S_1	(Newton and Cole, 2013b)	OR (CR,I)	PR	Y	4 shrub only buffers;	Average temperature differentials across 180 m shrub shade reaches: +1.6 ºC (range +0.6 to +2.7 ºC)	X	
T	(Rashin et al., 1992)	WA	Gov't.	Y	9 no-cut buffers (5-190 ft.; 1.5-58 m)	Range in median Max. water temp. differentials (Table 1): +0.1 to +4.6 ºC	X	
U	(Schuett-Hames et al., 2012)	WA (Cascades, Coast ranges)	Gov't.	Y	13 with ½ of length no-cut buffers (50 ft.; 15 m), ½ length cut to stream edge; 3 with radial no-cut buffers at point of initiation of perennial flow (PIP) (56 ft. (17 m) radius)	Average change in shade (Table 49; average of 3 years difference between mean value for patch type and that of reference) 1/2-length no-cut buffers: -29% (range -24% to -38%); PIP: -30% (range -28% to -34%)		X
V	(Steinblums et al., 1984)	OR (I, WC)	PR	Y	40 no-cut buffers (25-115ft.; 8-35 m)	Fig. 2: Range in change in cover (Fig. 2; measured with respect to value at 140'): 0 to -73%		X
W	(Veldhuisen and Couvelier, 2006)	WA (N. Cascades)	Gov't.	Y	9 no-cut buffers (16-105 ft.; 5-32 m)	Range in change in shade (Appendix 4A, Upr Childs, Red Dog, Full Sail, Anchor Stm., WhiteWash; 10-31 m): -3 to -33%; Range in change in temp. (2 (Powell, Savage), & 3(Long Tom, RoundAgain, SingleShot, Appendices 4B (Powell, RedDog, AnchorStm, Grisdale, Miller Pt.) ; comparing 7DAD max. for buffers located downstream of forest): +1.0 to +8.3 ºC	X	X
X_5	(Wilk et al., 2010)	WA (Coast Ranges)	PR	N	7 no-cut buffers (33-49 ft.; 10-15 m); 3 patch buffers	Difference in canopy closure (Table 1): no-cut: -9%; patch buffers (average of patch (cut) and patch (leave) since same sites): -45%		X
Y_1	(Zwieniecki and Newton, 1999)	OR (CR, I, WC)	PR	Y	6 standard FPA prescriptions; 5 hardwood conversions (HWCs); 3 HWCs limiting openings on south side of streams	For all prescriptions, no stat.sig. difference in shade; changes in temperature (differences between top and bottom of unit, averaged per prescription, from Fig.3) FPA: +1.3ºC; HWC: +1.3 ºC; S-sided HWC: +0.5 ºC	X	X

*Relates publications to ID for graphing purposes. Publications with the same subscript are from the same study (see Table 2).

† For studies located in Oregon, the Oregon Department of Forestry Georegions in which studies were completed is listed in parentheses; Georegions: CR=Coast Range; I=Interior; S=Siskyous; SC=South Coast; WC=West Cascades. Note: BM (Blue Mountains) and EC (East Cascades) are listed for informational purposes, although their data were not considered for this review.

** (Newton and Cole, 2013a): unclear in which georegion, but west of the crest of the cascades.

†† Gov't.=government report (including OSU research papers not published in peer-reviewed journal); PR=peer-reviewed; IR=in review.

ª Is the study's objective or questions directly relevant to this review's question?

***All forest harvests outside of buffers are clearcuts, except those of (Danehy et al., 2007) which were thinned from 200-300 down to 80 trees per acre.

Draft Table 2. Publications with overlap of data from the same study.

ID*	Study	Publications
1	W. Oregon	(Dent and Walsh, 1997; Newton and Cole, 2013b; Zwieniecki and Newton, 1999)**
2	BC	(Gomi et al., 2006; Kiffney et al., 2003)
3	RipStream	(Groom, 2013; Groom et al., 2011a, 2011b)
4	SW WA	(Jackson et al., 2001, 2007)
5	W. WA	(Janisch et al., 2012; Wilk et al., 2010)

* For each set of studies, a number identifies it; these numbers are the subscripts which appear in Table 1 and Figures 1-12.
** (Newton and Cole, 2013b) also included data from streams with different prescriptions and were not included in the previous two studies.

3.2 Summary of studies and management prescriptions

3.2.1 Summary of publications

Of the 25 publications reviewed, 10 were governmental reports, 13 were peer reviewed journal articles, and 2 publications were unpublished and in review (Table 1). Of the publications considered to have a high focus on the Systematic Review (SR) question, they were evenly divided among those providing measures of temperature and those measuring shade (Table 4). However, government reports more often provided measures of shade (90% of publications) and peer review / in review articles more often provided measures of temperature (91% of publications). Only four publications were considered to have a low relevance, or be indirectly related, to the SR question and they were all peer reviewed articles that primarily measured shade (Completed Table A.6.3).

Draft Table 3. Summary of publication measure and relevance to the primary review question.

High Relevancy	Temperature	Shade	Both	Total
Government	1	5	4	**10**
Peer Review	4	1	4	**9**
In Review	2	-	-	**2**
Sub-total	***7***	***6***	***8***	***21***
Low Relevancy				
Peer Review	-	3	1	**4**
Total	**7**	**9**	**9**	**25**

3.2.2 Study design variability

Though there are 25 publications selected for review, several of the publications have overlapping study designs and share data (Table 2). For example, all three of the publications by lead author Groom utilize the same temperature dataset from the same study design, but explore different relationships. Another example of shared study designs is when Wilk et al. (2010) collected habitat data for wildlife and Janisch et al. (2012) looked more directly at stream temperature response due to management. Other situations with shared study designs include reporting on shade in one publication and temperature in another or returning to old study sites (e.g. Jackson et al., 2001,2007; Newton and Cole 2013b) .

3.2.3 Geographical ranges and physical settings

Due to the rule analysis selection criteria, all publications were limited to georegions within or similar to western Oregon. These georegions were selected due to similarities in climate, vegetation, and topography. Vegetation composition was generally dominated by Douglas-fir (*Pseudotsuga menzesii*),with sub-dominants such as red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*), and several conifer species. All but one of the publications chosen for the review had study sites west of the Cascades in Oregon, Washington and British Columbia or in the Siskiyou Mountains and many were set in multiple georegions (Table 1). The remaining publication was of a study conducted in Southeast Alaska. At least 11 publications had study

sites in the Oregon Coast Range, 4 in the western Cascades and 5 in the Interior (i.e. Willamette Valley and central Umpqua Valley). Nine of the studies had sites in western Washington, the majority of which were in the Coast Range (60-70% of the publications).

3.3 Measurements

The primary systematic review question focuses on two factors associated with protecting core cold water habitat: 1) stream temperature and 2) riparian shade. Of the twenty-five publications reviewed, seven included only measurements of stream temperature, nine included only measures of riparian shade, and nine included measures of both stream temperature and riparian shade (Table 1). Stream temperature is a water quality parameter that can be measured directly using a number of sensing technologies; most commonly a thermometer, recording thermograph (a thermistor coupled with a data logging device), or, recently, fiber optics. Contrastingly, shade is difficult to measure directly because, for any given location, it changes both throughout the day and seasonally as a function of the position of the sun. Researchers have overcome this problem by using various measures of canopy density or light as proxies for shade (Davies-Colley and Payne, 1998).

All of the systematic review papers reporting stream temperature results collected time series of data measured at sub-daily intervals with recording thermographs. The duration of temperature data collection ranged from as little as two weeks (Danehy et al., 2007; Rashin, 1992) during the critical summer low flow period to year-round (Gomi et al., 2006; Kiffney et al., 2003). Measurement accuracy varied across studies for papers that actually reported such values, ranging from +/-0.2 to +/-1.0 °C. Resolution was only reported by Janisch et al. (2007) who had one sensor type with resolution of +/-0.16 and another with a resolution of 0.5 °C. As a frame of reference, most current sensors are advertised with +/-0.2 °C accuracy and 0.02 °C resolution. Many of the stream temperature analyses focused on relative differences between measurements made upstream and downstream of the riparian treatment before and after implementation such that measurement accuracy was not as critical as resolution in the statistical analysis. Notwithstanding, attention to reported measurement accuracy should be given when evaluating actual values of stream temperature extracted as a part of this systematic review.

326 Overhead canopy cover was measured with either a spherical densiometer (Dent, 2001;
327 Dent and Walsh, 1997; Martin, 2004; Morman, 1993; Schuett-Hames et al., 2012; Veldhuisen
328 and Couvelier, 2006; Zwieniecki and Newton, 1999) or via hemispherical photography (Allen
329 and Dent, 2001; Dent and Walsh, 1997; Groom et al., 2011b; Hunter, 2010; Janisch et al., 2012;
330 Wilk et al.,2010) while oblique canopy cover or angular canopy density (ACD) was measured
331 with an angular canopy densiometer (Brazier and Brown, 1973; Steinblums et al., 1984). Despite
332 the spherical densiometer being the most common device used to measure canopy cover,
333 measurements obtained are subject to user-bias (Davies-Colley and Payne, 1998). Hemispherical
334 photography is a less subjective means for quantifying canopy cover. However, multiple
335 methods were used to analyze the photographs making direct comparison of results across
336 studies difficult. Allen and Dent (1997), Groom et al. (2011a), and Hunter (2010) report
337 hemispherical photography results as a Global Site Factor (GSF), the ratio of direct and diffuse
338 energy at the point of the photograph to the total available direct and diffuse energy for that
339 latitude, longitude, and day of year; Janisch et al. (2012) reports a Canopy and Topographic
340 Density (CTD), a metric that, as its name implies, takes into account both the density of the
341 canopy and the topographic obscurance; Wilk et al. (2010) presents the photographic analysis
342 from the same study only as a canopy cover percent.
343 Photosynthetically active radiation (PAR; Kiffney et al., 2003) and solar insolation
344 (Brosofske et al., 1997; Danehy et al., 2007) are both measures that describe the amount of light
345 reaching a certain point. Direct measures of light are sensitive to subtle changes in cloud cover
346 and the position of the sun, a factor that was considered when evaluating the robustness of
347 outcome measures of light reported by Brosofske et al. (1997) and Kiffney et al. (2003). Danehy
348 et al. (2007) estimated total solar insolation indirectly using hemispherical photography.
349 The secondary review question focused on how effects modifiers interact with near-
350 stream forest management. In order to properly evaluate the influence of a particular effects
351 modifier, formal inclusion in the statistical analysis was necessary. The most commonly
352 evaluated effects modifiers were the length and width of the riparian reserve, stream width and
353 depth, and stream gradient (see Table 4 for a full list). A number of publications presented data
354 for variables that likely acted as effects modifiers without actually assessing their influence

statistically; most frequently, the types of trees, tree density, and stream/watershed aspect were reported but not evaluated (Table 4).

Draft Table 4. Information on effects modifiers.

First two columns list effects modifiers statistically analyzed for respective measure (i.e., column heading); number of publications for each effects modifier listed in parentheses. Effects modifiers from the protocol (Appendix A) that are not listed were not considered in any publications.

Temperature	**Shade**	**Measured & Reported but not used in analysis**
Length, width of riparian reserve (7)	Length, width of riparian reserve (10)	Types of trees (5)
Gradient (7)	Stream width/depth (6)	Tree density (5)
Stream width/depth (6)	Other riparian vegetation (5)	Aspect (5)
Aspect (4)	Gradient (5)	Tree/basal area retention (4)
Harvest on both or single sides of riparian reserve (4)	Discharge (3)	Time since harvest (4)
Canopy cover (4)	Substrate (3)	Discharge (4)
Discharge (3)	Gradient (3)	Length, width of riparian reserve (3)
Elevation (3)	Types of trees (2)	Logs or slash left in stream (3)
Air temperature (3)	Tree/basal area retention (2)	Windthrow (3)
Time of year (2)	Harvest on both sides or single side of riparian reserve (2)	Continuity of flow (3)
Substrate (2)	Logs or slash in stream (2)	Gradient (3)
Time since harvest (2)	Elevation (2)	Other riparian vegetation (2)
Types of trees (1)	Tree harvest in part of riparian reserve (1)	Canopy cover (2)
Residual stand composition (1)	Tree height, age (1)	Groundwater-surface water interactions (2)
Tree/basal area retention amount (1)	Crown height (1)	Elevation (2)
Other riparian vegetation (1)	Windthrow (1)	Air temperature (2)
Clearcut vs. thin (1)	Distance from stream source (1)	Tree height, age (1)
Distance from stream source (1)	Groundwater-surface water interactions (1)	Crown height (1)
Groundwater-surface water interactions (1)	Geology and soils (1)	Residual stand composition (1)
Flow through/from a wetland (1)	Time of year and season (1)	Method of tree removal (1)
	Air temperature (1)	Stream width/depth (1)

		Substrate (1)
		Geology and soils (1)

3.4 Statistical Analysis

Methods for analyzing temperature varied widely among the studies, dependent on the study design and measures selected for study. The majority of temperature studies included some type of statistical analysis of data, primarily analysis of variance (ANOVA) if differences between groups were considered by separating samples into groups prior to analysis (e.g. Dent and Walsh, 1997; Danehy et al., 2007) and regression analysis if the goal was to directly account for the effects of modifiers (e.g. Jackson et al., 2001; Veldhuisen and Couvelier, 2006; Groom et al., 2011b). A few of the studies used the measured data to develop predictive models to explore the importance of multiple effects modifiers, such as in Groom et al. (2011a,b; 2013) and Veldhuisen and Couvelier (2006). Autocorrelation of temperature time series data was addressed, but not consistently among the studies, which affected their statistical robustness score (Completed Table A.6.3).

Methods for analyzing shade were more consistent, with most of the studies conducting simple statistical tests of differences between either a control and the buffer type or a variety of buffer types. The exception tended to be if studies had too few samples for a statistical comparison or no control for comparison (e.g. Rashin et al., 1992; Martin, 2004; Hunter, 2010). For shade and cover studies, a sample was considered a control if it was collected pre-treatment or at a similar landscape unit at a nearby location.

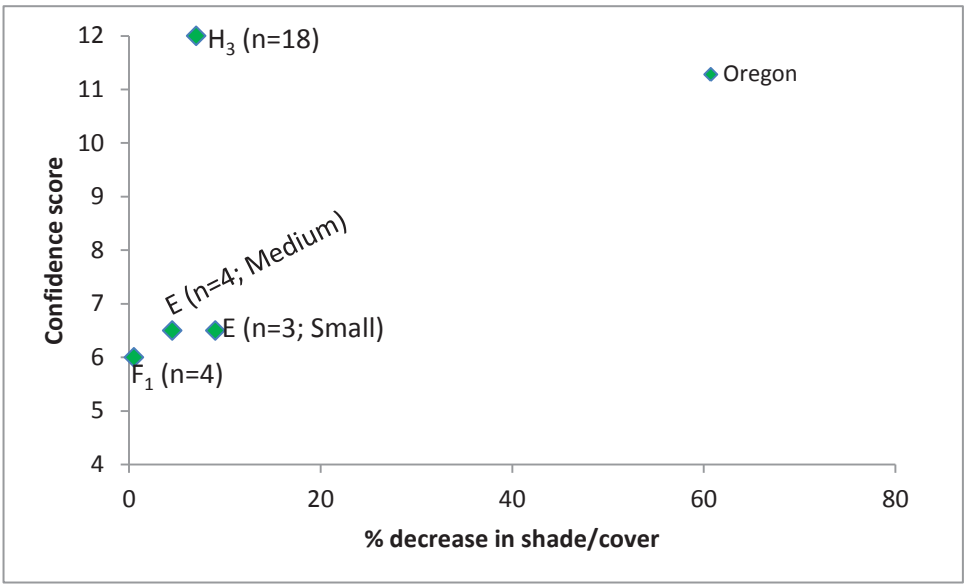
3.5 Rule Alternatives

Each reviewed paper was rated for relevance to the sixteen rule alternatives proposed by the Board of Forestry (Completed Table A.6.4). Seven of the sixteen rule alternatives had at least one highly relevant study (all had at least one study of low relevance). In the following sections, rule alternatives having highly relevant studies are discussed with respect to the range of variation in metrics defining each alternative, the range of variation in outcome measures, the degree of effectiveness at protecting against increases in stream temperature or riparian shade, and the overall confidence in the findings. Where applicable, the role of effects modifiers in influencing effectiveness is also addressed.

3.5.1 Forest Practices Act (FPA)

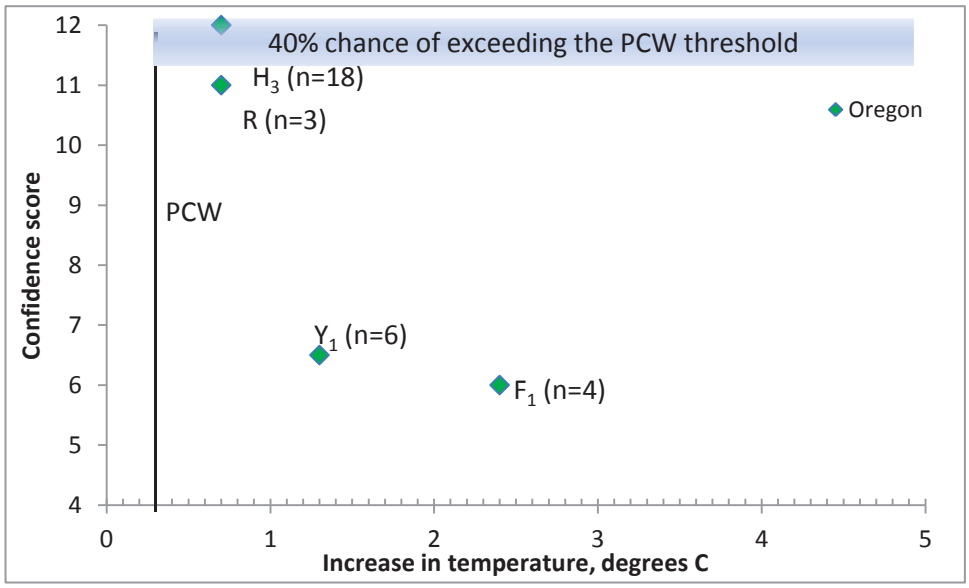
Seven publications covering five different studies were rated as highly relevant to describing changes to temperature and / or shade with harvest using FPA buffer management practices; nine publications were determined to have low relevance (Completed Table A.6.4). After leaving a 20 foot no-cut buffer, riparian buffers ranged from 20 to 130 feet, depending on the study (Dent and Walsh, 1997; Zwieniecki and Newton, 1999; Dent et al. 2001; Groom et al. 2011a,b; Groom 2013; Newton and Cole 2013a) . In some cases clearcut harvesting outside of the buffers occurred on both sides of the stream, but there were also cases were there was harvest on just one side of the stream. Tree retention within the buffer differs based on region, and though the majority of study sites were in the Coast Range, there were sites in the Interior and Western Cascades for all studies but those conducted by Groom et al. (2011a,b; 2013).

All studies reported an average decrease in shade or cover as a result of FPA management practices, regardless of whether it was a small or medium stream (Figure 1; Dent and Walsh, 1997; Dent et al. 2001; Groom 2011a). However, the change in shade ranged from a decrease of 18% to an increase of 11% (Dent and Walsh, 1997; Dent et al., 2001). Confidence in study design was low for the Dent and Walsh (1997) and Dent et al. (1999) studies, primarily due to low number of samples resulting in an inability to make robust statistical comparisons of the results. Due to the nature of the data collection method, there can be considerable error and thus variability in these measures leading to a wide range in results. Therefore, it is even more important to have larger sample sizes and differences in shade as low as 0.5% should be considered inconclusive.



Draft Figure 1. Decrease in shade for sites with FPA buffers.
Letter refers to publication ID (Table 1), n is the number of sites, and Small and Medium refer to stream size as defined in the FPA. Confidence score (a summary metric of study quality) is listed in Completed Table A.6.3; data on X-axis is listed in Table 1. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

Increases in temperature were also observed for all relevant studies, though the amount of increase varied (Figure 2). Groom et al. (2011a) and Newton and Cole (2013a) reported a temperature increase of 0.7 °C and there is high confidence that their results provide reliable information. Those studies with lower confidence in reported results had higher increases in their temperature: 1.3 °C (Zwieniecki and Newton, 1999) and 2.4 °C (Dent and Walsh, 1997). In all cases, the increase in temperature was greater than the PCW. Groom et al. (2011a) reported changes in temperature ranging from -0.9 to 2.4 °C, thus there is evidence that not all observed streams experienced an increase in temperature. Groom et al. (2011b; 2013) explored the probability of exceeding stream temperature criteria. The percent chance of a site managed using FPA rules exceeding the PCW rule was 40% and 7 out of 18 sites exceeded the 16 or 18 °C criteria for salmonids.

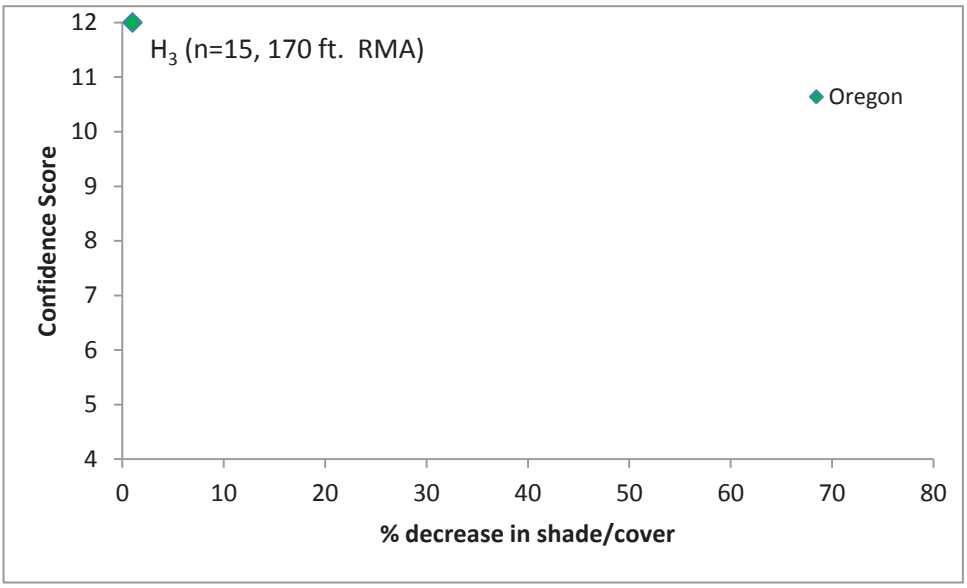


Draft Figure 2. Increase in temperature for sites with FPA buffers.
Letter refers to publication ID (Table 1), n is the number of sites, PCW is the Protecting Cold Water criterion , and Small and Medium refer to stream size as defined in the FPA. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

3.5.2 State Forest Management Plan (FMP)

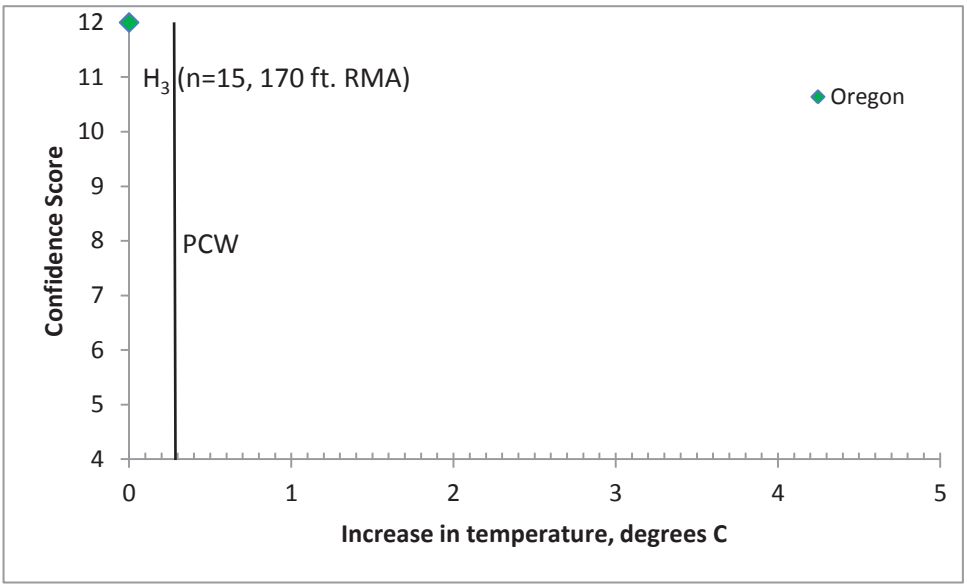
Three publications from one study (RipStream) contained highly relevant results of temperature and /or shade using the State Forest Management Plan (FMP) (Groom et al. 2011a,b, Groom et al. 2013); eleven publications were determined to have low relevance (Completed Table A.6.4). The highly relevant study was set in the Oregon Coast Range; therefore, all samples are from small and medium streams in a geographically similar area. Data was collected at 15 streams with a 25 foot no cut zone, limited harvest allowed within 100 feet of the stream to create mature forest with retention of 124 trees/ha, and tree retention of 25 to 111 conifer trees and snags/ha between 100 to 170 feet.

For the FMP sites of the RipStream study, shade comparisons were made pre- and post-harvest and there was no detectable change in shade post-harvest from pre-harvest conditions (mean decrease of 1%, n=15, $p = 0.269$) (Groom et al., 2011a). Shade pre- and post-harvest was between 80-95% for all sites.



Draft Figure 3. Decrease in shade for sites with FMP buffers.
Letter refers to publication ID (Table 1), n is the number of sites, and 170 ft. is the one-sided RMA (riparian management area) width. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

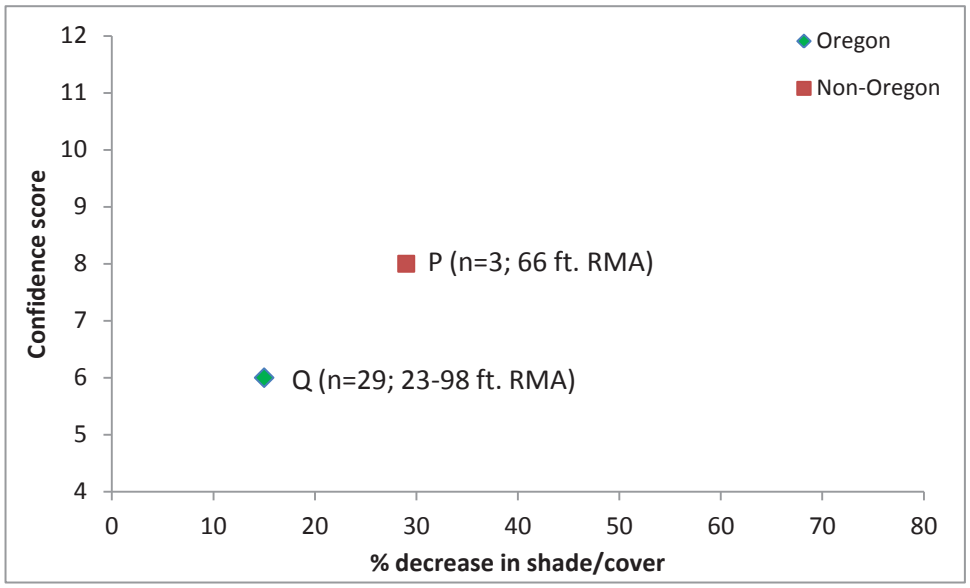
Findings from this study suggest there also are little to no noticeable changes in temperature using FMP practices. Changes in temperature were reported by looking at both change in temperature and probability of exceedances of criteria. Change in temperature at FMP sites was 0.0 °C (-0.9 to +2.5 °C) (Groom et al, 2011a). The chance of exceeding the 0.3 °C PCW criteria was found to be 9% and of the 15 sites, none exceeded the 16 °C or 18 °C criteria (Groom et al, 2011b; 2013). Strengthening the confidence in the results, data analysis for this study included measurement of effects such as discharge, length and width of the reserve, characteristics of the stand, landscape position and air temperature; therefore, taking into consideration a large number of the factors that have a high likelihood of influencing stream temperatures.



Draft Figure 4. Increase in temperature for sites with FMP buffers.
Letter refers to publication ID (Table 1), n is the number of sites, 170 ft. is the one-sided RMA (riparian management area) width, and PCW is the Protecting Cold Water criterion. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1. 9% change of exceeding PCW for sites with FMP buffers.

3.5.3 Derived Variable Retention

Two studies were highly relevant to the variable retention buffer rule alternative. Morman (1993) evaluated canopy density for twenty-nine variable retention buffers ranging from 25 to 100 feet in width in northwest and southern Oregon. Martin et al. (2004) measured stream temperature and riparian shade for three sites with 25-foot no-cut buffers and an additional 41-foot width of partial cut buffer in southeastern Alaska. The stream temperature control site was compromised, so only the shade data is considered in this synthesis. Six studies were considered to have low relevance to this rule alternative.



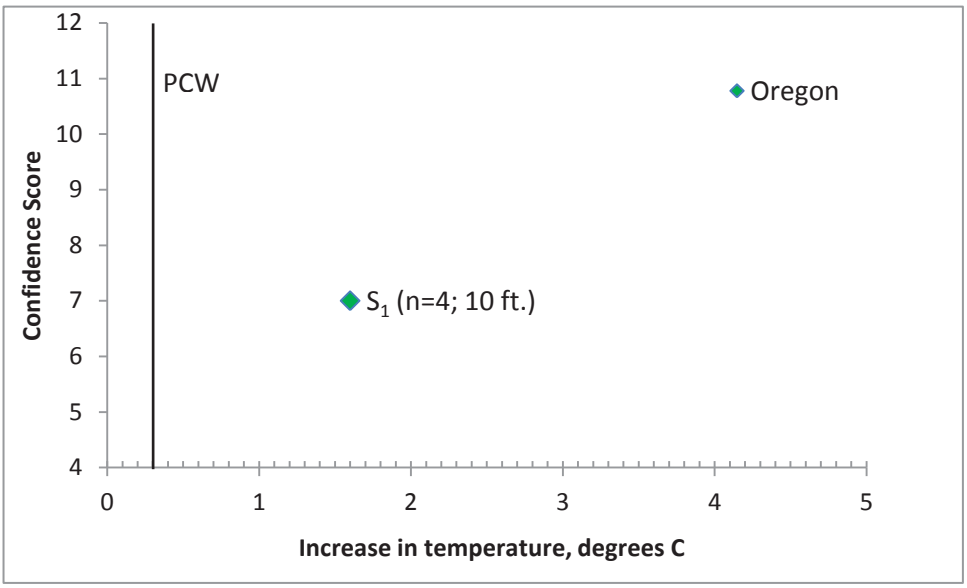
Draft Figure 5. Decrease in shade for sites with variable retention buffers. Letter refers to publication ID (Table 1), n is the number of sites, distance is the one-sided RMA (riparian management area) width. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

Both studies showed a decrease in shade where variable retention buffers were applied (Figure 5). Martin et al. (2004), who had a low sample size but a relatively sound study design, measured an average canopy density decrease of 29%. Morman (1993) used a larger sample size (29 sites) and found an average decrease of 15%. Morman's study evaluated the role of aquatic area width and hardwood versus conifers in relation to the amount of shade provided. However, despite the significantly larger sample size and assessment of effects modifiers, the confidence in the Morman study is lower than that of Martin et al. (2004)(Figure 5; Completed Table A.6.3). Additional data is required to definitively assess the effectiveness of this prescription at protecting stream shade.

3.5.4 Shrub Shade

Newton and Cole (2013b) provided highly relevant results for Shrub-Shade management practices by examining "no-tree buffers" (Completed Table A.6.4). In their study, different management practices were instituted along a length of stream where harvested and unharvested blocks lie adjacent to each other along the length of channel. Widths of the riparian reserve were

15 to 70 feet, depending on stream width, and interspersed with no-tree buffers along a harvested reach 600 feet long.



Draft Figure 6. Increase in temperature for sites with shrub shade buffers.
Letter refers to publication ID (Table 1), n is the number of sites, distance is the width of leaving shrubs, and PCW is the Protecting Cold Water criterion. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

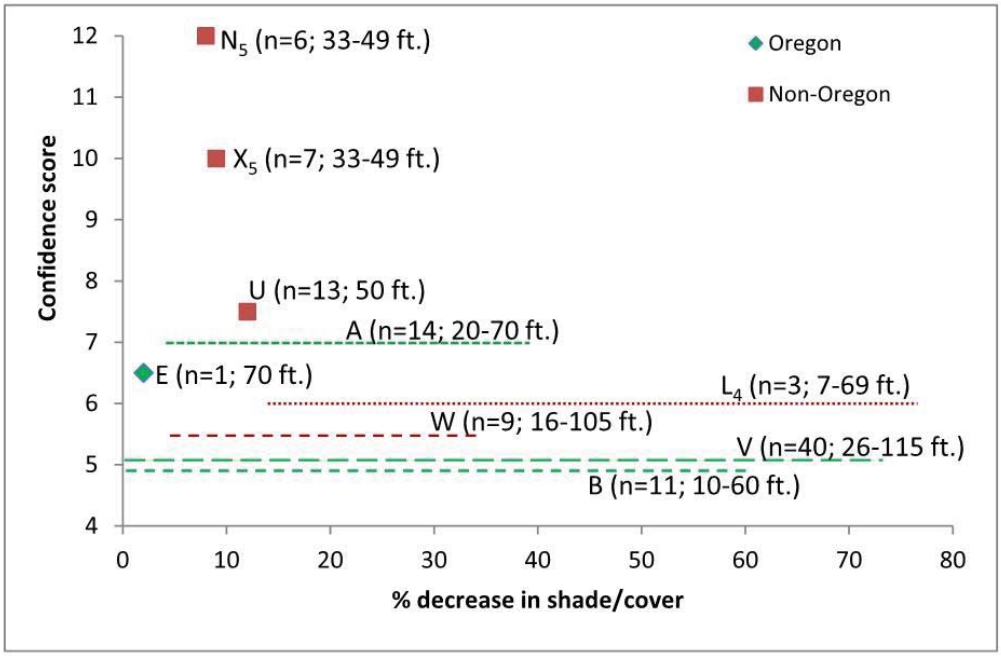
Stream temperature differentials increased in the no-tree buffers by an average of +1.6 °C (+0.6 to +2.7 °C) post-harvest (Newton and Cole 2013b; Figure 6). Effects considered when analyzing data include stand characteristics and some landscape characteristics, though sample sizes were low and the analysis method did not include formal statistical tests (they compared trendlines by site and year).

3.5.5 Derived No-cut Buffer

The no-cut buffer was the most frequently studied rule alternative; twelve studies (fifteen publications) were rated as highly relevant and an additional four publications had low relevance (Completed Table A.6.4). Nine of the highly publications presented data on riparian shade, while ten included stream temperature data. Four of the nine highly relevant riparian shade publications presented data collected in Oregon (Allen and Dent, 2001; Brazier and Brown, 1973; Dent, 2001;

and Steinblums et al., 1984). However, only two of the ten stream temperature publications presented data collected in Oregon streams (Brazier and Brown, 1973; Danehy et al., 2007).

No-cut buffer widths in highly relevant riparian shade studies ranged from 7 to 115 feet per side (Figure 7; Completed Table A.6.2). The effectiveness of the no-cut buffer in preventing an increase in shade varied considerably. The two publications with the highest confidence score, Janisch et al. (2012) and Wilk et al. (2010), found that a continuous buffer, ranging from 33 to 49 feet (10 to 15 m), resulted in a 10% decrease in canopy density (both publications originated from the same study). Similarly, Schuett-Hames et al. (2012) measured an average canopy density reduction of 12% across thirteen 50-foot no-cut buffers in western Washington.



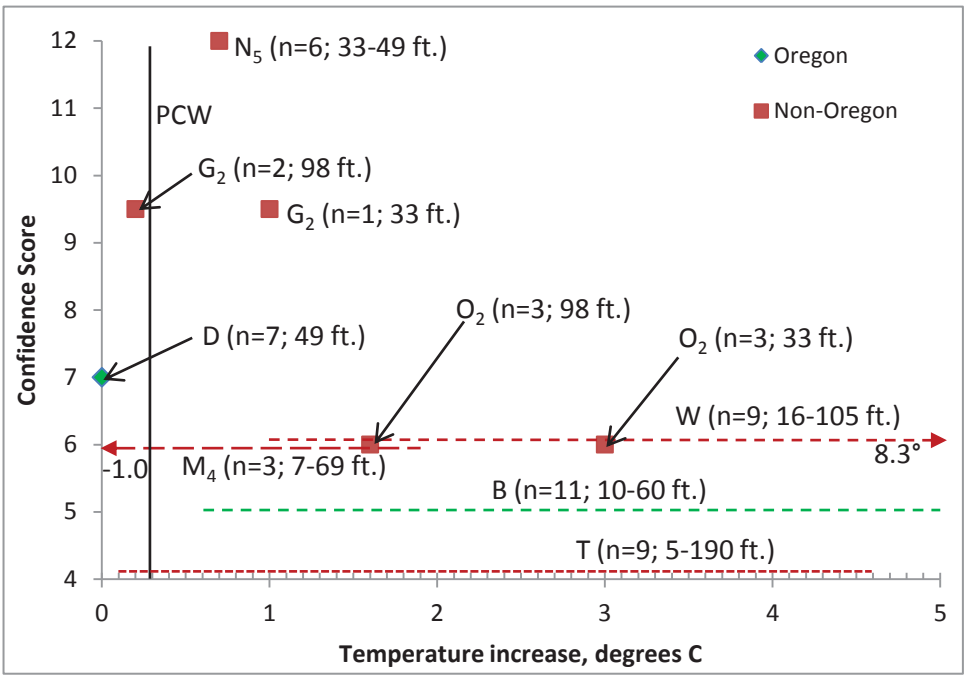
Draft Figure 7. Decrease in shade for sites with no-cut buffers.
Letter refers to publication ID (Table 1), n is the number of sites, and distance is the no-cut buffer width. Dashed lines indicate a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths). Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

Several studies included multiple buffer widths in their assessment of riparian shade (Allen and Dent, 2001; Brazier and Brown, 1973; Jackson et al., 2007; Steinblums et al., 1984; Veldhuisen and Couvelier, 2006). A positive relationship between angular canopy density and

buffer width was evident in the data of both Brazier and Brown (1973) and Steinblums et al. (1984) despite considerable variability amongst the responses at individual measurement locations. Kiffney et al. (2003) found that solar insolation (PAR) was approximately 5-times greater in the 33-foot buffer than in the 98-foot buffer. Contrastingly, no strong positive relationship between canopy density and no-cut buffer width was visually evident in the data presented by Allen and Dent (2001) or Veldhuisen and Couvelier (2006) (no regression performed for no-cut data only). Jackson et al. (2007) caution against use of their canopy cover data because of concern that the survey reach was not necessarily representative of the entire stream; therefore, their results are not included in this narrative assessment (see Completed Table A.6.2 for results).

No-cut buffer widths in highly relevant stream temperature studies ranged from 5 to 190 feet and, as with the riparian shade studies, responses to treatment were highly variable (see Figure 8 and Completed Table A.6.2). Three publications reported results where the temperature response to a no-cut buffer was less than the PCW criterion: the 98-foot buffer of Gomi et al. (2006), the49-foot buffer of Danehy et al. (2007), and one of the 26- to 33-foot buffers of Jackson et al. (2001). It should be noted that Danehy et al. (2007) measured temperature within the substrate and the Jackson et al. (2001) stream was significantly covered by blowdown. Gomi et al (2006) and Janisch et al. (2012) found that 33-foot and 33- to 49-foot no-cut buffers, respectively, resulted in an about a 1 °C increase in temperature over the study reach (these studies had the two highest confidence scores) while the 33-foot buffer of Kiffney et al. (2003) resulted in a 3 °C increase (a 1.5 °C increase was reported for their 98-foot buffer). Veldhuisen and Couvelier (2006) reported the largest temperature increase of all the highly relevant studies, an 8.3 °C increase in the maximum value of the 7-day moving mean of the daily maximum (buffer width unknown; it should also be noted that the forested controls had upstream-to-downstream increases ranging from +1.0 to +2.7 °C during the same monitoring period). The eleven sites of Brazier and Brown (1973) had a modest inverse relationship between temperature response and buffer width. The smallest differences in upstream-to-downstream temperature change (no information provided on the exact metric presented) were for a 60-foot and a 100-foot buffer (both had a 0.6 °C increase); however, one of the 100-foot no-cut buffers had a measured increase of 2.2 °C (note that although Brazier and Brown (1973) received a relatively

low confidence score, the temperature and buffer width data assessed here are considered robust).



Draft Figure 8. Increase in temperature for sites with no-cut buffers.
Letter refers to publication ID (Table 1), n is the number of sites, distance is the no-cut buffer width, and PCW is the Protecting Cold Water criterion. Dashed lines indicate a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths). Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

The publications reviewed showed that while no-cut buffers have the potential to protect against exceeding the PCW criterion, the generally implied notion that wider buffer widths provide better protection is not supported. The large degree of variability in the findings across studies limits confidence in pinpointing a specific no-cut buffer width that will be protective of the PCW criterion in all cases. The variability in magnitude of response is presumably related to the confounding role of effects modifiers in combination with the various buffer width treatments. Unfortunately, there was no consistency in evaluation of effects modifiers between studies. Janisch et al. (2012) found a significant correlation between mean daily temperature response and elevation, catchment area, aspect, channel gradient, channel length, depth, CTD,

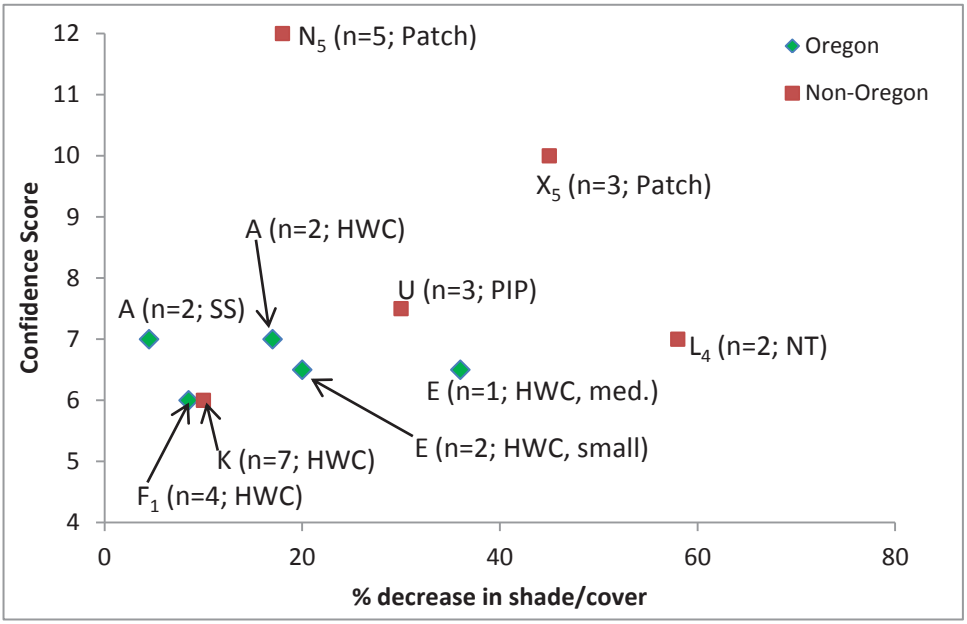
and percent of catchment with wetland. Veldhuisen and Couvelier (2006) also found significant relationships between temperature response and elevation and channel gradient plus percent shade but not for buffer width (however, their effects modifiers analysis included fully forested, clearcut, and debris flow streams). Several of the highly relevant publications reported temperature results from studies conducted in first-order, non-fish-bearing streams (Jackson et al., 2007; Janisch et al., 2012; Veldhuisen and Couvelier, 2006). Controls on water temperature in the extreme headwater reaches of a stream network are more variable than the dominant controls in larger downstream reaches (Jackson et al. 2007; Janisch et al, 2012); a factor that likely added to the variability in the response to treatment for this rule alternative.

3.5.6 Plan for Alternative Practice

Multiple alternative practices were considered in the reviewed publications. Hardwood conversion, patch, perennial initiation point, non-merchantable, and site-specific buffers were evaluated in riparian shade studies (three of the seven studies were conducted in Oregon); only hardwood conversion, patch, and non-merchantable buffers were assessed in stream temperature studies (two hardwood conversion studies from Oregon). Hardwood conversion buffers followed state-specified rules for converting hardwood-dominated buffers to conifer (Allen and Dent, 2001; Dent and Walsh, 1997; Dent, 2001; Hunter, 2010). Patch buffers had 164- to 360-foot sections of forested buffer with the rest of the catchment clearcut (Janisch et al., 2012; Wilk et al., 2010). Perennial initiation point buffers had a 56-foot radial buffer emanating from the point of perennial streamflow initiation (Schuett-Hames et al., 2012). Site-specific buffers were not well-defined, but were intended to “enhance and restore riparian areas” (Allen and Dent, 2001).

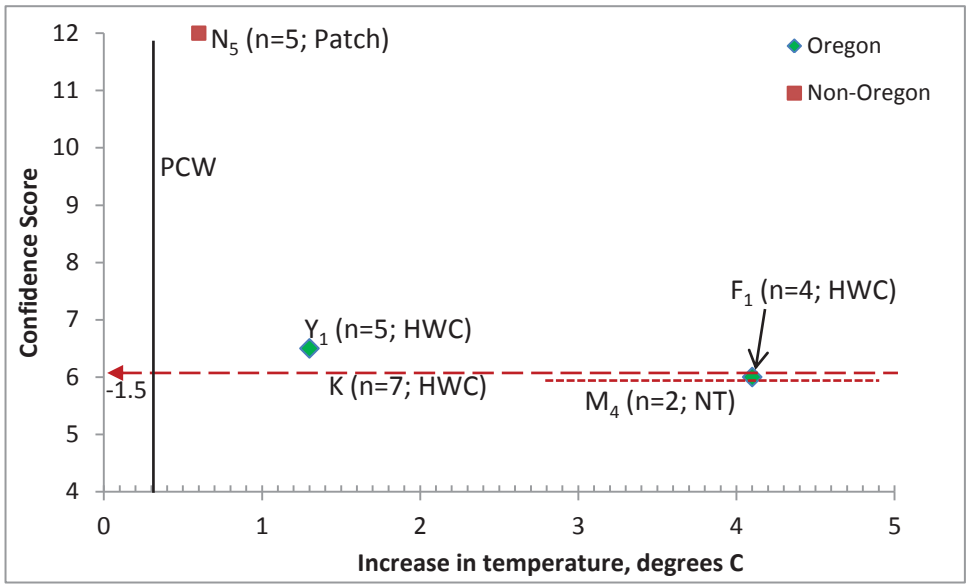
Effectiveness in protecting against decreases in riparian shade varied among the different alternative practices investigated (Figure 9). The most effective was the site-specific buffers, which had an average decrease in canopy density of 4.5%, but the confidence in this finding is limited by a low sample size (n=2). Hardwood conversion buffers resulted in a 10 to 20% reduction of canopy density for small streams (Allen and Dent, 2001; Dent and Walsh, 1997; Dent, 2001; Hunter, 2012), while the single medium hardwood conversion stream surveyed had a reduction of 36% (Dent, 2001). The patch buffers decreased canopy density by 18%, on average (Janisch et al., 2012; Wilk et al. (2010) reported a 45% reduction at the same study, but using a

smaller sample size). The perennial initiation point and non-merchantable tree buffers were not generally effective, with 30% and 58% reductions in canopy densities, respectively (Jackson et al., 2007; Schuett-Hames et al., 2012).



Draft Figure 9. Decrease in shade for sites with alternate practices buffers. Letter refers to publication ID (Table 1), n is the number of sites, and capitol letters in parentheses refer to: HWC=hardwood conversion; NT=nonmerchantable tree; PIP=point of initiation of perennial flow; SS=site specific plan; and Patch are buffers left in patches along sensitive reaches. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

Only one measurement location in all of the alternative practices studies prevented a PCW criterion exceedance, a patch buffer with an increase of 0.1 °C (Figure 10; Janisch et al., 2012); the average temperature increase for the patch buffers was 0.7 °C (n=5). Hardwood conversion buffers resulted in a wide range of temperature responses, spanning from a decrease in temperature of 1.5 °C (Hunter et al., 2012) to increases in excess of 5 °C (Hunter et al., 2012; Dent and Walsh, 1997). Non-merchantable buffers were also not generally effective with measured increases of 2.8 and 4.9 °C (Jackson et al., 2001).



Draft Figure 10. Increase in temperature for sites with alternate practices buffers. Letter refers to publication ID (Table 1), n is the number of sites, PCW is the protecting cold water criterion, and capitol letters in parentheses refer to: HWC=hardwood conversion; NT=nonmerchantable tree; PIP=point of initiation of perennial flow; SS=site specific plan; and Patch are buffers left in patches along sensitive reaches. Dashed lines indicate a range of outcomes for sites for which averaging is inappropriate (e.g., due to different buffer widths). Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

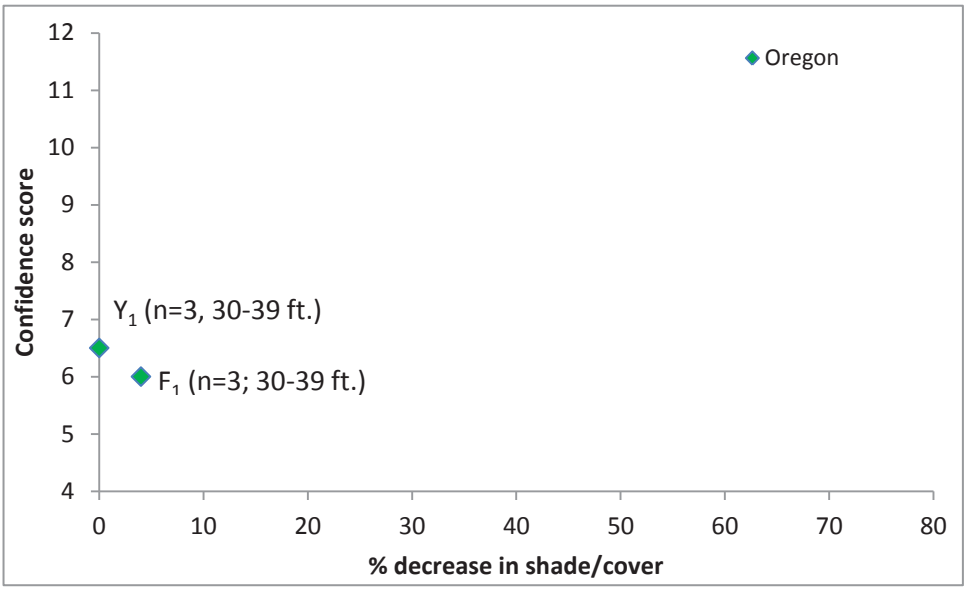
Information on specific alternative practices is too sparse to make a definitive assessment as to the true effectiveness of each. It appears that non-merchantable and perennial initiation point buffers did not meet the PCW. Hardwood conversion buffers, for which the greatest amount of information exists, along with site-specific and patch buffers have the potential to protect against PCW exceedance. However, additional study is needed, with particular focus given to controlling for effects modifiers such that the design specifications necessary to provide adequate protection to the stream can be constrained.

3.5.7 One-sided Buffer

Two different studies located at the same sites during the same timeframe describe three hardwood conversion units with limited openings on the south side of stream (Dent and Walsh,1997; Zwieniecki and Newton, 1999). Two of the three sites were in the Oregon Coast

Range. Buffer widths ranged from 18 to 131 feet and harvest units were between 1100 feet to nearly one mile in length; the sites were harvested according to 1994 stream rules.

Dent and Walsh (1997) described a 4% (0-7%) decrease in cover at the sites post-harvest, but Zwieniecki and Newton (1999) reported no difference in shade post-harvest. Considering the difference in results, the range of variability for shade measures and the low sample size, these results are relatively inconclusive.

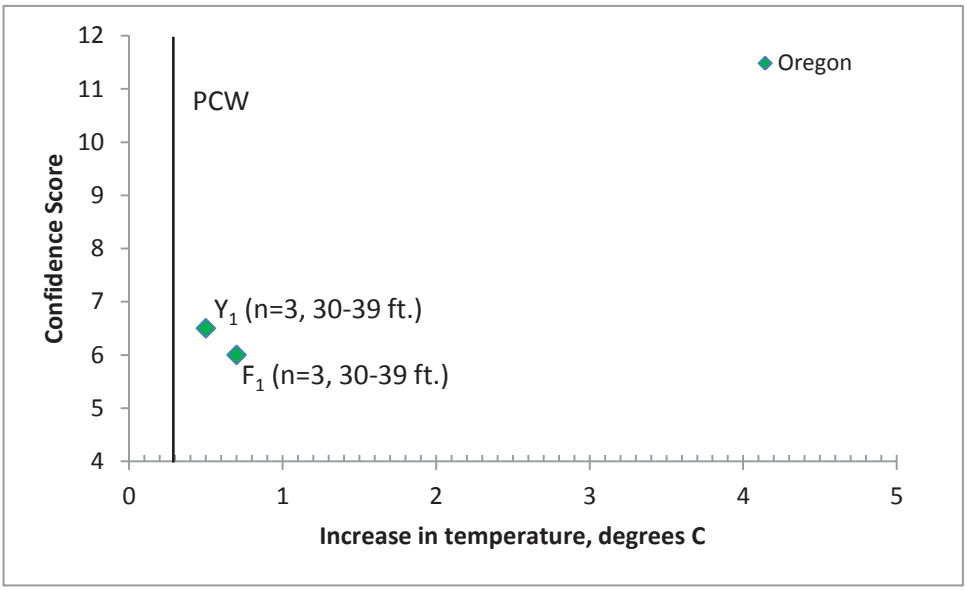


Draft Figure 11. Decrease in shade for sites with south-sided buffers.
Letter refers to publication ID (Table 1), n is the number of sites, and distance is the width of buffer. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

Despite small changes in cover, stream temperatures increased above the PCW criteria. Both studies showed an increase in stream temperature post-harvest: 0.7 °C (+0.07 to +2.6 °C; Dent and Walsh, 1997) and 0.5 °C (Zwieniecki and Newton, 1999; Table 1). Differences in results are likely due to differences in sampling method. Both studies collected the 7 day moving mean maximum temperature, but sampling occurred in July and August for Zwieniecki and Newton (1999) and generally between July and early September for Dent and Walsh (1997). Regardless, sample sizes were low and results by individual site are not conclusive of a general

trend of increase in temperature (Completed Tables A.6.2). Reanalysis of data by Newton and Cole (2013b) suggest more confidence that warming occurred post-harvest.

These studies took into consideration stream characteristics, landscape position and stand characteristics such as buffer width and cover. Zwieniecki and Newton (1999) modeled behavior from multiple prescriptions using the effects modifiers; however, the sample size for one-sided buffers is too small to encompass the variability and compare differences between treatments in a statistical test.



Draft Figure 12. Increase in temperature for sites with south-sided buffers.
Letter refers to publication ID (Table 1), n is the number of sites, distance is the width of buffers, and PCW is the protecting cold water criterion. Confidence scores (a summary metric of study quality) are listed in Completed Table A.6.3; data on X-axis are listed in Table 1.

3.6 Study Limitations and Knowledge Gaps

Although a relatively significant amount of information is available regarding stream temperature and riparian shade responses to forest management, the ability to identify emergent trends across studies is hampered by several factors. The primary limitation is the inconsistencies between study designs and analysis methodologies, particularly the adequate measurement and incorporation of effects modifiers into the assessment. Deciphering observed differences in

response between similar buffer designs is extremely difficult if effects modifiers have not been controlled for in the study design and analysis. A somewhat related limitation is the use of a variety of response metrics. This primarily applies to stream temperature studies where the time series of temperature data can be reduced or averaged in many ways but is also applicable to shade studies where different methodologies for collecting and processing canopy density data generate different metrics, such as canopy density percent, global site factor, and canopy and topographic density. Results are more difficult to compare across studies when the response metrics utilized are dissimilar. The generally low sample sizes (especially within buffer management types) and inconsistency in utilization of effects modifiers made traditional statistical models inappropriate, also making comparisons between studies challenging. Another study design-related limitation is that a several studies collected a wealth of data but offered very little for inferring their results to other locations because they were essentially designed as a series of single stream case studies (Rashin et al., 1992; Dent and Walsh, 1997; Martin, 2004; Hunter, 2010).

A major finding of this SR effort is the lack of studies that were highly relevant to proposed rule alternatives other than the no-cut buffer. Twelve different studies investigated no-cut buffers of various widths compared to only three for the current FPA and only one for the current State Forests standards. Seven studies were highly relevant to the Alternative Practices rule alternative, but within that category the most studies related to any one specific alternative practice was three (hardwood conversion). Nine rule alternatives did not have any highly relevant studies. Low relevance studies were generally more numerous across the rule alternatives. However, extracting usable information from low relevance studies is extremely challenging and highly prone to mischaracterization.

Several studies were not focused directly on the SR-related questions of stream temperature or riparian shade response to forest management and data relevant to this effort were collected indirectly (e.g. Brosofske et al, 1997; Danehy et al., 2007; Jackson et al., 2007; Wilk et al., 2010). Though these studies were considered highly relevant to at least one rule alternative, sample sizes were small (Wilk et al., 2010), no pre-treatment data was collected (Brosofske et al., 1997), and their lack of direct focus perhaps limited confidence in the findings.

4. Draft Lessons Learned – External Scientists' Perspective

Utilization of the systematic review process is still being tested and several lessons were learned that may help inform future review efforts.

First, the process employed in this systematic review was helpful in initiating conversation between the reviewers. The process included an initial review of four publications that were compared between reviewers. Comparing reviews resulted in conversation about terminology, discussion of how tables should be completed, and a shared understanding of definitions. It would be useful for the four review papers to provide a spectrum of challenges and test the range of definitions so that reviewers are also better prepared.

As with any new process, methods can be developed but are not reliable until they have been tested. Time and resources on behalf of the reviewers may have been saved if definitions and tables were tested prior to engaging the reviewers. If there is a desire to standardize tables, it might also be useful to provide an example of the type of information to be collected in the table, possibly using an example of one of the papers not chosen for inclusion in the study.

The systematic review question is focused on meeting the information needs of policy-makers; however, few of the studies were conducted specifically to answer the question posed. The uniqueness of the studies made it challenging to compare data and to answer the systematic review question. As described in Study Limitations, the vast difference in study designs made it challenging to objectively assess the study design and statistical methods. For example, sample sizes were frequently low; effects modifiers were often collected, but not always analyzed; if there was pre-treatment data, it was frequently only for one year, which may be adequate for assessing shade, but may not be adequate for temperature.

For a systematic review question as focused as it was for this study, it may have been more advantageous to search specifically for studies that could answer the management question posed. It is hard to understand whether or not the full spectrum of studies for a given buffer management type was explored, when there appeared to be a heavy balance towards particular buffer management types (i.e. FPA, derived no-cut). Also, there were studies that fell into the category of "Plan for alternative practice" which cannot be easily compared to each other or any of the other buffer management types; therefore, they are essentially not useful to this review.

Finally, reading and understanding a study well enough to summarize it takes time. Results can be skimmed through and extracted relatively quickly, but to be able to understand the context of those results so that they can be compared to other studies takes more effort in reading and interpretation. For example, a temperature increase of 0.7 °C can be extracted looking at figures and tables, but management practice and effects modifiers need to be considered, as well as data collection methods and statistical analysis methods. Furthermore, once this data has been gleaned from a paper or report, additional time needs to be made to assess comparisons between studies, especially when methods can be substantially different from each other. We recommend time be allowed for the reviewer to re-familiarize themselves with the papers prior to writing, as it will necessarily take some time from the review of the first papers to the time when writing must begin. Mechanisms for reducing this need for additional review should be considered.

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D.2 Additions to the draft report

Draft Executive Summary

Draft ES 1. Introduction

ES 1.1 Background

The Oregon Department of Forestry (ODF) has undertaken a systematic science review in support of a riparian rule analysis process to address concerns about Oregon Department of Environmental Quality (DEQ) stream temperature standards. Specifically, the Oregon Board of Forestry ("Board") made a decision in January 2012 that stream protections afforded to small and medium sized fish-bearing streams under the Forest Practices Act (FPA) were not likely

protective of the DEQ Protecting Cold Water (PCW) criterion. This criterion prohibits human activities such as timber harvest from increasing stream temperatures by more than 0.3 ºC at locations critical to salmon, steelhead or bull trout. This finding of degradation was due to scientific outcomes of the Oregon Department of Forestry (ODF) Riparian and Stream Function (RipStream) monitoring project. The geographic scope of the RipStream findings is limited to streams in the Coast Range and Interior Geographic Regions of Oregon (as defined in OAR 629-635-0220). While the exact geographic extent of the rule analysis is yet to be determined, it will be limited to western Oregon. This limitation is due to the vegetation, climate and hydrologic characteristics of eastern Oregon being significantly different enough from those included in the RipStream study to preclude extending a rule change to eastern Oregon. At their July 2012 meeting, the Oregon Board of Forestry approved consideration of 16 rule alternatives (contributed by stakeholders) for meeting the PCW standard during harvest operations.

ES 1.2 Objective of the Review

This systematic review is designed to provide scientific guidance to the Board on the efficacy of the 16 rule alternatives in addressing the following rule analysis objective developed by the Board at their April 2012 meeting:

> **Establish riparian protection measures for small and medium fish-bearing streams that maintain and promote shade conditions that insure, to the maximum extent practicable, the achievement of the Protecting Cold Water criterion.**

A secondary purpose of this review is to inform the Board's decision on the geographic extent of the rule analysis process.

Draft ES 2. Methods

A protocol for this systematic review was developed following guidance on conducting systematic reviews in the natural resource sciences. This protocol provided a road map for how to conduct the review of scientific literature relevant to the focused question:

> **For small and medium streams in the western Pacific Northwest, in or adjacent to forest harvest operations, what are the effects of near-stream forest management on stream temperature and/or riparian shade?**

The review seeks to answer this question with evidence, as opposed to the authors' interpretation of such evidence, from existing studies. These studies are rigorously screened for quality and relevance to this question. The protocol provides for rigor and transparency concerning how studies are searched for, which ones are included in the review, and how they are analyzed. This process also allows for a review to be either updated in the future, or completed by another party. Finally, the entire process of conducting the review allows for greater inclusion of review partners (e.g., stakeholders and technical experts). All steps of the review are fully documented for transparency and input from review partners. These partners (e.g., agency personnel, conservation stakeholders, industry experts) strengthened the quality of this systematic review.

To minimize bias in the review, ODF hired external scientists to conduct the review and write this report synthesizing their analyses. ODF coordinated the work of the reviewers and all other partners, and wrote portions of this report.

Draft ES 3. Results and Synthesis

The systematic search found 1,456 publications, of which 25 passed all the inclusion criteria for the review. Of included publications, 10 were governmental reports, 13 were peer reviewed journal articles, and two documents were unpublished and in review. Since several of the publications are from the same study, these 25 publications represent 19 distinct studies. The publications were divided between those measuring shade only (7), temperature only (7), or both (9).

ES 3.1 Geographical ranges and physical settings

Due to the geographically-focused review question, all publications were limited to areas within, or similar to, Oregon west of the crest of the Cascade Range. Considered in terms of ODF Geographic Regions: twelve publications had study sites in the Coast Range, two in the Western Cascades, and eleven in the Interior.

To gain insight on geographic extent of the rule analysis, effectiveness of buffer prescriptions were compared between ODF Geographic Regions. Analysis could not discern a pattern of effectiveness being different in any particular Geographic Region for the various

buffer prescriptions. The inability to discern a pattern may be influenced by the small amount of data available for robust comparisons.

ES 3.2 Rule Alternatives

Each publication in this review was rated for relevance to the sixteen rule alternatives proposed by the Board. Seven of the sixteen rule alternatives had at least one highly relevant study (i.e., the study provides quantitative data that addresses the effectiveness of a particular prescription of a rule alternative at protecting stream temperature or shade). In contrast, nine rule alternatives had no studies that were highly relevant to them. All rule alternatives had at least one study of low relevance. Eleven studies were highly relevant to more than one rule alternative. Only rule alternatives that had highly relevant studies are included in this analysis because they provide evidence of buffer effectiveness. The nine rule alternatives without highly relevant studies are not examined because they lack evidence concerning their ability to protect cold water and shade in western Oregon.

Only two classes of rule alternatives had studies that were high quality and were clearly effective at protecting cold water: Derived Variable Retention (which includes State Forest Management Plan [FMP] as a particular prescription) and No-cut buffers. For the FMP, the only study considered had a high confidence score (a measure of study quality), and protected both shade (average change in shade: -1%) and temperature (average change in temperature: 0.0 °C). Another specific prescription of a variable retention buffer, the Forest Practices Act (FPA), was assessed. All averaged data from each of the four FPA studies ranged for change in % shade between -0.5 and -9%, yet none of those with temperature data met the PCW standard. Confidence scores for these studies ranged from low to high. Of the other two variable retention prescriptions tested, the only one that had some sites that appeared to protect shade was based on the ODF riparian rules from before 1994. However, the average change in shade was -19% and the confidence score was low (temperature data were not collected for this study).

The No-cut buffers were the most-extensively studied (12 studies) of all the rule alternatives. Nearly all studies that examined shade had some sites wherein shade was protected, and their confidence scores ranged from low to high. However, it should be noted that many of the studies included a wide range of buffer widths and thus their data could not be averaged in a

meaningful way. Four of seven studies that measured stream temperatures had some sites that met the PCW standard, three of which had a range of buffer widths.

Three other rule alternatives were assessed for their effectiveness at protecting cold water and/or shade. The shrub shade alternative had a low quality study with three sites, and came close to, but did not achieve, the PCW standard. Similarly, the south-sided buffers had one study of low quality with three sites. The results show this buffer was protective of shade, and came close to, but did not achieve, the PCW standard.

The final rule alternative, plan for alternate practices, acts as a catch-all for riparian management prescriptions that did not fit into other rule alternatives. As such, it includes six different prescriptions analyzed in seven studies. Two prescriptions (undefined "site specific" plans, and hardwood conversions (HWC) following each of Washington and Oregon's rules) had sites wherein shade was protected (low to medium confidence scores), and only Washington's HWC (low confidence score) had some sites wherein the PCW standard was met.

ES 3.3 Summary

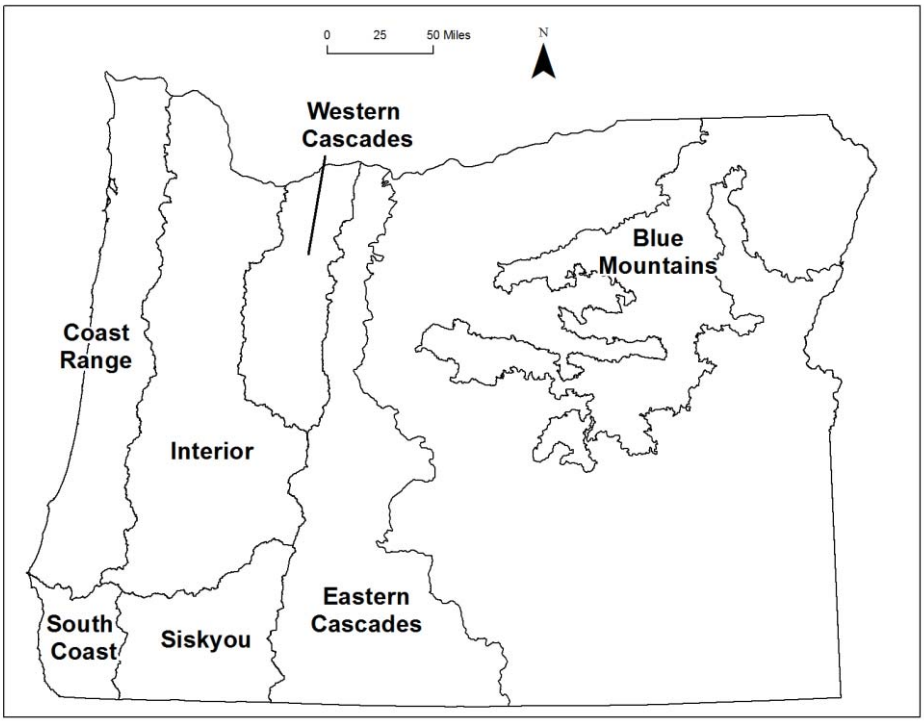
This review provides two key components that inform the Riparian Rule Analysis:

1. Nineteen studies have assessed the effectiveness of riparian buffers to protect cold water or shade in forest harvest operations in the Pacific Northwest. These studies vary widely in both their designs and their quality.
2. The evidence from this suite of studies only supports two classes of rule alternatives as effective in meeting the Protecting Cold Water standard:
    A. Variable retention buffers (including State Forest Management Plan)
    B. No-cut buffers

3.2.3 Draft Geographical ranges and physical settings

Due to the selection criteria for this review, all publications were limited to areas within, or similar to, Oregon west of the crest of the High Cascades. These areas were selected due to their similarities in climate, vegetation, hydrology, and topography with those from the study (Groom *et. al*, 2011b) that initiated this rule analysis. Vegetation composition was generally dominated by Douglas-fir (*Pseudotsuga menzesii*), with sub-dominants such as red alder (*Alnus*

rubra), big-leaf maple (*Acer macrophyllum*), and several conifer species. All but one of the publications chosen for the review had study sites west of the Cascades in Oregon, Washington and British Columbia or in the Siskiyou Mountains, and many were set in multiple ODF Geographic Regions (per OAR 629-634-0220; Table 1, Figure 1). The remaining publication was conducted in Southeast Alaska. Twelve publications had study sites in the Oregon Coast Range, two in the western Cascades and eleven in the Interior (i.e., most of the Willamette Basin and upper Umpqua Basin). Nine studies had sites in western Washington, the majority of which were in the Coast Range (60-70% of the publications).



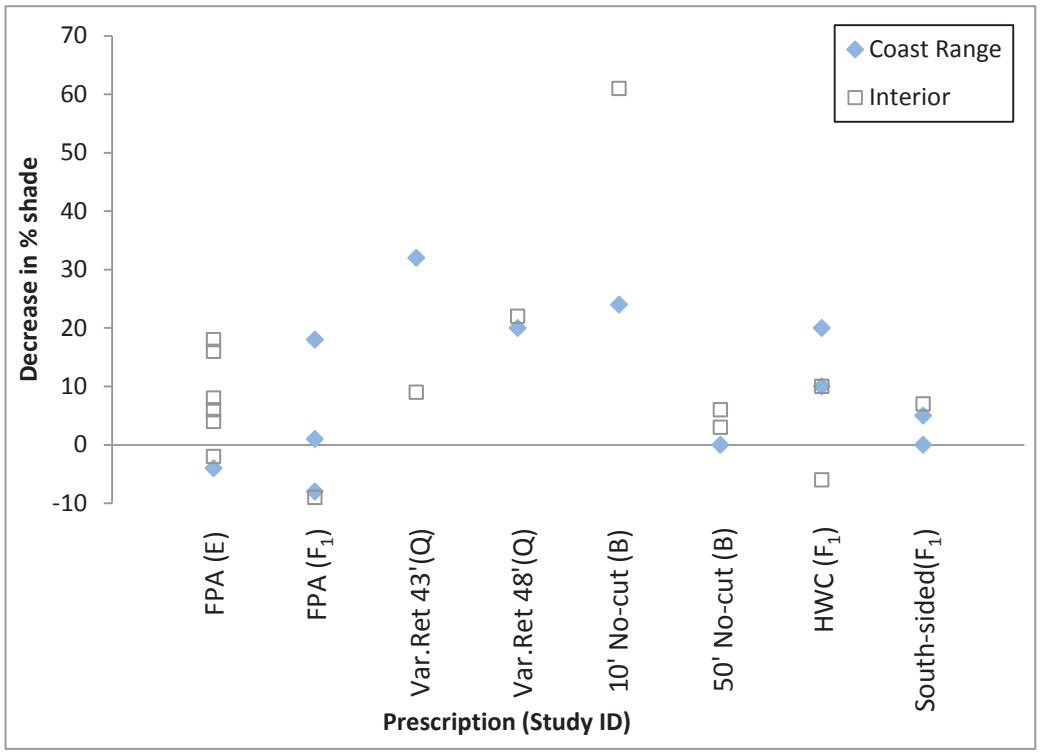
Draft Figure 1b. Oregon Department of Forestry Geographic Regions.

A secondary purpose of this systematic review is to inform the Board's decision on the geographic extent of the rule analysis process. Overall, most sites studied are located in the Coast Range (n=82), followed by Interior (n=47), and West Cascades (n=23; no data were found in the South Coast or Siskyou Geographic Regions). However, data are only comparable between Geographic Regions when data assess the same buffer prescription from the same study conducted in more than one Geographic Region. Thus, there are many fewer data available for

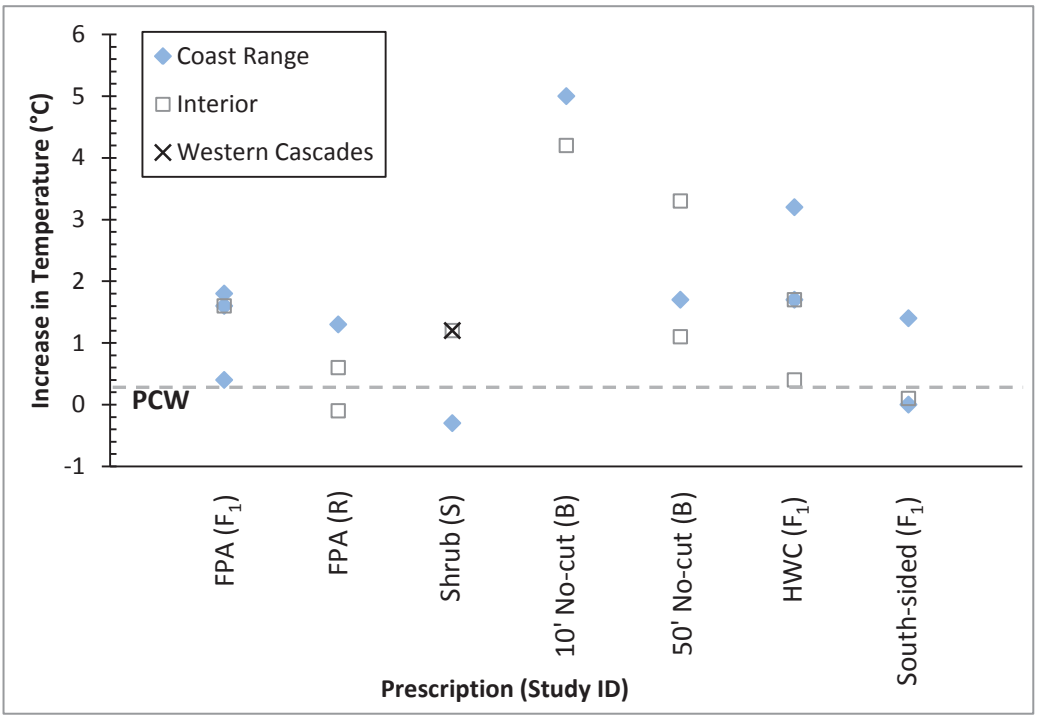
comparison (15 combinations of temperature or shade data for specific rule prescriptions and studies from different Geographic Regions; Figures 2, 3). Whereas data from publications are included in this analysis regardless of their confidence score, it is worth noting:

- Most comparisons are from studies with low confidence scores (<7);
- Although the Coast Range and Interior are the only Geographic Regions with sites (n=31 and 5, respectively) from studies with high confidence scores (≥10), only two of these sites are comparable between Geographic Regions; and,
- All of the Western Cascades sites are from studies with low confidence scores, and most of these sites are not comparable with those of another Geographic Region.

To gain insight on regional differences in buffer effectiveness, changes in shade and temperature are plotted with respect to prescriptions from various studies in Figures 2 and 3, respectively (Appendix C). No clear picture emerges when comparing prescription effectiveness between Geographic Regions for any given study. This lack of clarity is partly due to insufficient data with which to make robust comparisons: no comparisons between Geographic Regions for a buffer prescription have more than two sites for each Geographic Region and study. In addition, no clear pattern presents itself by what data do exist. The Coast Range appeared to have greater change in shade or temperature with buffers in seven comparisons with those of Interior, whereas the latter appeared to have greater change in shade or temperature with buffers in four instances (Figures 2, 3). Four comparisons of these two regions appeared to have buffers with similar changes in shade or temperature. The only Western Cascades site assessed had the same impact as Interior, both of which were larger than the Coast Range (Figure 3).



Draft Figure 2b. Decrease in shade for each Geographic Region.
Each symbol represents data from one site for a particular rule prescription from a particular study. The symbol type denotes the ODF Geographic Region: blue diamonds are Coast Range sites, hollow squares are Interior sites. Prescriptions are: FPA = Forest Practices Act; Var.Ret = Variable Retention; 10' and 50' are for No-cut buffers of 10 and 50 feet, respectively; HWC = hardwood conversion; South-sided = buffers retained on southern side of streams. Letter in parentheses denotes study ID: E=Dent, 2001; F_1=Dent and Walsh, 1997; Q= Morman, 1993; B=Brazier and Brown, 1973(Table 1).



Draft Figure 3b. Increase in temperature for each Geographic Region.

Each symbol represents data from one site for a particular rule prescription from a particular study. The symbol type denotes the ODF Geographic Region: blue diamonds are Coast Range sites, hollow squares are Interior sites, and "x" is a Western Cascades site. Prescriptions are: FPA = Forest Practices Act; Shrub = shrub shade; 10' and 50' are for No-cut buffers of 10 and 50 feet, respectively; HWC = hardwood conversion; South-sided = buffers retained on southern side of streams. Letter in parentheses denotes study ID: F_1=Dent and Walsh, 1997; R=Newton and Cole, 2013a; S=Newton and Cole, 2013b; Q= Morman, 1993; B=Brazier and Brown, 1973(Table 1). The dashed line labeled PCW is the Protecting Cold Water criterion.

Appendix E. External comments, and responses to these comments, on draft report and associated additions

This appendix documents comments from external reviewers (e.g., conservation organizations, agency personnel, industry experts) on the draft report plus its additions (Executive Summary and Geographic Ranges and Physical settings; see Appendix D), and the associated responses from both the Department and the External Scientists hired to conduct the review.

E.1 External comments, and responses to these comments, on the draft report

Liz Cole, Senior Faculty Research Assistant, OSU/FERM

Line #	Comment/modification	ODF Response	External Reviewer Response
	Report needs to be proof read for spelling and grammatical errors. Examples, *macrophyllium* instead of *macrophyllum*, *menzesii* instead of *mensiezii*, *sitchenis* instead of *sitchensis*, "between" is for comparison of two items, use "among" for more than two items, and use "were" not "was" with data, which is the plural form of datum.	Agreed.	Thank you for catching these errors. We made edits to the document.
318-326	The authors include the importance of accuracy and resolution and indicate that it should be considered. I could not find where they reported the accuracy and resolution for the studies they extracted. (I was expecting that information in either Table 1 or Appendix B.) They also suggest that resolution is more critical for the statistics of upstream and downstream comparisons. Both accuracy and resolution need to be considered, and many scientists (myself included) often fail to address that in scientific publications. For example, accuracy of	For external reviewers to respond.	We agree with the reviewer that this is an important consideration. Due to the inconsistencies in reporting accuracy and resolution in the literature reviewed, we determined that the best way to caution readers about the results would be to call their attention to the potential error in measures in

Line #	Comment/modification	ODF Response	External Reviewer Response
	many thermistors is 0.2° C. An upstream thermistor reads 12.0° C, meaning the "true" reading lies between 11.8° and 12.2° C. A downstream thermistor reads 12.4° C, with the "true" reading between 12.2° and 12.6° C. The difference between the thermistors is 0.4° C, which exceeds the PCW, but the "true" reading of both could be 12.2° C. The accuracy of the thermistors is especially important for some of the older studies which utilized less accurate thermistors.		this section (3.3) of the review document. When reported in the publication, we included these data in Table A.6.2 of Appendix B. We removed sentence suggesting resolution being more important than accuracy for upstream/downstream comparisons as this statement is fraught with assumptions.
401	There are no sites in west Cascades, revise sentence accordingly.	No comment	Revised
433	Did Groom also report the chances of exceeding the criteria prior to harvest? If so, that should be included. If not, then that should be addressed.	Out of scope for this review.	A statement was made in the text about the exceedance results, but the information cannot be presented on the plot because values are different.
448-9	I realize that we mix English and metric measurements in regards to stream temperature rules. Are the rules for conifer stocking and snags in English or metric?	Change to all English units for this sentence (i.e., 50 trees/acre and 10-45 snags/acre)	Changed to English units.
500	There is a difference between a "shrub" buffer and a "no-tree" buffer. A no-tree buffer may or may not have shrub shade over the stream, and that may make a difference in the amount of light reaching the stream. I would suggest mentioning that distinction. Newton and Cole (2013b) reported on a no-tree buffer that lacked shrub cover in places, as indicated in the paper.	Would be good to mention difference between shrub and no-tree	We have added text to the paragraph explaining that "no-tree" does not necessarily mean "shrub".
516	Newton and Cole did report formal statistics on the trend	Defer to external reviewers.	Text has been altered to account

Line #	Comment/modification	ODF Response	External Reviewer Response
	line comparisons		for the regression analysis.
655	Newton and Cole (2013a) also tested the one-sided (called partial) buffer. Results were confounded with those units being downstream of harvested units with significant warming after harvesting. However, on three of the four streams, there were no significant differences in daily maxima after harvesting.	Since post-harvest data for partial buffer sites are confounded due to units being downstream of other harvested units (i.e., they lack appropriate controls), it is not scientifically valid to compare post-harvest daily maxima results with those from pre-treatment.	Agreed with ODF. We chose not to include the results in the review.
843	Citation is Western Journal of Applied Forestry 2013 28(3):107-115.	No comment.	Change made.

Josh Seeds, Nonpoint Source Pollution Analyst, ODEQ

Line #	Comment/modification	ODF Response	External Reviewer Response
	The table of summary information is a nicely usable summary.	Agree.	Glad it is helpful
	The tabular format for comparing relevance, effects modifiers addressed, etc. , is also brilliant.	Glad it is helpful.	Thank you
	The graphs comparing BMP effectiveness with study	Glad it is helpful.	Glad they are helpful

Line #	Comment/modification	ODF Response	External Reviewer Response
	quality are extremely helpful for understanding the results of the studies, how they compare, and quality-based weighing of information.		
	Is there a way to show which buffer sizes had which effects in the studies that looked at a wide range of widths (Figures 7, 8, & 10)?	Some of the studies provide the data with which to plot this, some do not. Extracting all these data is beyond the scope of this report	Agreed with ODF.
	A table of rule alternatives, number of studies addressing each, and the support for each would be a good addition to the report. It would be a nice way to see which ideas would really be a large-scale experiment and which we already have some idea of performance and how good that performance is at meeting PCW/maintaining shade.-> table with columns such as: 1.Rule Alternative 2.# of Publications Addressing Alternative 3.Quality of Studies 4. Effectiveness of Alternative According to Pubs (1 column for shade, 1 for temp)	Completed Table A.6.4 has the first two components, Table 1 has the fourth component and it is recommended that it include the 3rd component. However, the report's figures (1-12) show this information, and thus such a table is not warranted.	Agreed with ODF. Information is being supplied in other tables.

Maryanne Reiter, Hydrologist, Weyerhaeuser Co.

Line #	Comment/modification	ODF Response	External Reviewer Response
3	The first line of the introduction focuses the report on	No comment.	Added intro sentence

Line #	Comment/modification	ODF Response	External Reviewer Response
	salmonids and temperature. Consider a broader introduction about how stream temperature plays a key role in structuring the composition of biotic communities in aquatic ecosystems and how it also influences the rate of chemical processes (DO, etc.). Then let the audience know that this report is specifically on temperature and salmonids because that is what the DEQ standards address.		conveying these points.
7-11	This paragraph describing thermal regimes could be strengthened. I would indicate that a stream's thermal regime results from daily and seasonal variations in the rate of thermal energy transfer between a stream and its environment. As the paragraph is written (e.g., line 8) it implies that thermal energy transfer is one way. Also note that they use the term 'heat' when indicating thermal energy. Heat is the transfer of thermal energy between 2 objects of different temperatures.	-line 8: add "to and" before "from" -Physicists refer to the flow or transfer of heat (P.A. Tipler, 1982, Physics, p.493), so fine as is, or could replace with "thermal energy".	Changed language to account for more general transfer of energy between the stream and its environment as suggest. Changed heat to thermal energy.
12-13	Note that maintaining shade as an effective tool for minimizing stream temperature during the summer applies to certain sized streams where localized stream temperature patterns can be influenced by the near-stream environment, especially where vegetative canopies are able to substantially shade the stream. For larger streams/rivers, shading is not an effective of a tool in controlling maximum stream temperatures.	While this may be true, the part about large rivers is not germane to this review, which focuses only on small and medium streams.	This is a good point and is discussed later in the paper.
27	This line indicates that the streams the PCW target are those that are "currently cold enough to protect fish". Suggest something more reflective of the target of the PCW, i.e., prevent anthropogenic temperature increases	Agree	Agreed. We revised the text.

Line #	Comment/modification	ODF Response	External Reviewer Response
	for streams containing salmon.		
353	When the authors use the term "riparian reserve" I immediately think of a federal definition. Is there a better term for riparian areas that do not invoke a federal perspective?	Use either "riparian buffer" or "riparian management area"	We changed it to riparian management area.

Jeff Light, Hydrologist, Plum Creek Timber Company

Overall, I believe this was a thorough and objective effort to find published scientific information that is relevant to analysis of the rule alternatives. I only have one edit to suggest: On page 22, line 432, the Draft SR authors state that Groom (2013; in prep) reported "…7 out of 18 sites exceeded the 16 or 18C criteria for salmonids." This is in a sentence discussing FPA rule effectiveness for achieving temperature standards. I checked the reviewer summary of this publication (page 98 of the Draft SR), and found that only 2 sites that exceeded numeric criteria might be associated with harvest. Please verify this and revise accordingly.

ODF Response	External Reviewer Response
A more accurate portrayal: "The percent chance of a site managed using FPA rules exceeding the PCW rule was 40% and 7 out of 18 sites (four of which exhibited a potential harvest signal) exceeded the 16 or 18 °C criteria for salmonids.	Text has been altered to provide clearer details.

Greg Haller, Conservation Director, Pacific Rivers Council

General Comments

While we recognize that direct solar input is the primary driver of water temperature, it is not the only factor. Stream temperature is not simply a result of shade. Rather, it is a result of interplay between numerous factors, including composition of the streambed substrate and the length of time surface water flows through it, the influence of groundwater, elevation and stand-type. Many of these

factors may be influenced by changes in management, but many may not. Without an understanding of these factors, understanding the relationships involved in water temperature may prove elusive. Advantageous management and policy is nearly impossible to realize without fully understanding the relationships. We urge the investigation team to broaden the scope of their review to include these additional factors. Only after considering all pertinent factors can prudent decisions about riparian buffers occur.

Compared to Washington forest practices, the riparian buffer regulations in Oregon Forest Practices Act are far weaker, as evidenced by the poor condition of many of the streams and rivers flowing through private forestlands in Oregon and the presence of ESA-listed Coho salmon. As such, we are very concerned about any proposal that would further weaken requirements for riparian buffers. On the other hand, we welcome discussion about how to strengthen riparian buffer requirements and this investigation provides valuable insight into the possible effects of any alteration to the existing buffer regime.

With that said, we would like to reiterate our thanks to those that helped make this investigation a reality. Attached are our specific comments regarding this review. We urge the investigation team to incorporate these suggestions into the review so that the final edition is as thorough and scientifically sound as possible.

Line #	Comment/modification	ODF Response	External Reviewer Response
167 – 173; 229 - 231	**Reviewers should more thoroughly vet possible studies prior to including or excluding them in this investigation. Reading the abstracts to determine suitability would benefit the study.** The protocol for systematic review (section 2.1) states that reviewers "rigorously screened" studies for quality and relevance to the question the study sought to answer. However, reviewers based their decision to include or exclude a study based initially on the title and, only if uncertainty remained, did they investigate the abstract or read the section of the full text. The report states, "approximately 80% were rejected by reading the title." Reading the titles alone does not ensure rigorous screening. Reviewers should more thoroughly investigate possible studies for inclusion to ensure that no relevant information is omitted. At the very least, the abstracts should be read to ensure relevant studies are included.	Since the search was very wide (i.e., 1,456 publications), titles of numerous publications were found that were obviously not relevant (e.g., they were in a different geography, or they were on a subject not at all related to forestry and riparian buffers). In addition, the list of all included and excluded studies was sent on March 18, 2013 to all stakeholders (including Greg Haller) for their input as to whether or not we either mis-applied the inclusion criteria, or missed a publication.	Though we were not included in this part of the review, we understand the necessity of ODF screening protocol.

Line #	Comment/modification	ODF Response	External Reviewer Response
291 - 295	**Including studies from other regions would benefit the review and supplement the findings.** Within the Western Oregon forests, there are smaller regions and forest stands with differing characteristics. Eastern Oregon forests may better represent some of these stands. Studies of inland forests should not have been automatically eliminated from the investigation.	ODF staff decided that the unique combination of hydrology, latitude, and vegetation in W. Oregon limit relevance of studies from other regions to effectiveness of riparian management in forestry settings of W. Oregon.	Though the regional scope is too limited to provide guidance to other parts of the state, the review should be highly relevant to the western Oregon region.
303 - 307 354 – 356 592 - 600	**Considering other factors would contribute to a more thorough and possibly accurate investigation.** The investigation on page 17 only looked at two factors: shade and temperature. However, temperature is not simply a function of shade. Numerous other factors that impact stream temperature should have been considered, including substrate composition, stand-type and the influence of groundwater. Other studies identified factors that play an integral role in determining the stream temperature. Those factors should have been considered more consistently throughout the investigation. Temperature is a result of interplay between numerous factors, not simply shade. While it is very difficult to fully evaluate the impact of so	ODF agrees that other factors (including those listed by Mr. Haller) affect stream temperature. However, the main purpose of this review was to test outcomes for temperature associated with shade. To fully address effects modifiers is beyond the scope of this document.	We clarify why the scope was limited in the introduction (see Reiter comment for line 3 and corresponding response). We also include more information about other causes of high stream temperature (see Frissell #2). Additionally, while applying process-based understanding is important to developing management policies, this is not the stage at which such additional analysis would be fruitful. We encourage and expect that ODF will evaluate the short-list of alternatives with respect to known

Line #	Comment/modification	ODF Response	External Reviewer Response
	many variables, they should at least be considered and possibly discussed. These factors have the possibility of drastically influencing the findings, making them valuable to include.		temperature-driving processes when that time comes.
466 - 469	**The factors not discussed in other studies should be mentioned.** The Groom et al, 2011 study discussed an array of other factors, which could have a large impact on the findings. The lack of these other factors in the other studies should be mentioned at least briefly to make clear if there were any circumstances that could possible alter the outcome that were not discussed.	For external reviewers to respond.	The circumstances that could alter the outcome would be unique for each study and there are a large number of potential effects modifiers. To speculate on that for each study would be too cumbersome for this review. If there was something obvious of note, it is captured in the A.6.2 tables that provide information for each study and were likely incorporated into the main body of this review.

Line #	Comment/modification	ODF Response	External Reviewer Response
327 - 334	**More emphasis should have been placed on identifying studies that relied upon hemispherical photography.** Seven studies relied upon densitometers to determine overhead canopy cover. These tools are notorious for their inaccuracy and their tendency for bias. Relying upon less subjective means for quantifying canopy cover would be ideal. While PRC recognizes that densitometers are a common method of measuring canopy closure, a concerted effort to locate studies using other means would be beneficial. While this may prove difficult, it would greatly strengthen the reliability of the findings.	While this type of photography may be more accurate than densiometers, we decided to include all publications that met all the minimum requirements. Had there been numerous studies that used hemispherical photography, they would have played a more prominent role in this review. However, they did not exist in sufficient numbers to warrant excluding data collected with densiometers.	Agree with ODF comment.

Line #	Comment/modification	ODF Response	External Reviewer Response
379 - 380	**The lack of control group needs to be addressed regarding the reliability of the findings.** At least three studies did not have a control group. The reliability of the findings of those studies is suspect when there is not a control group to compare against the findings. The lack of control groups and the unreliability of other control groups could drastically influence the findings, potentially making these studies far less trustworthy. In addition, using the pre-treatment site as a control may bias the results. The pre-treatment areas may have been previously degraded by human activities, influencing the shade and temperature data. Information regarding the pre-treatment area is necessary to evaluate the findings of those studies. Without a comprehensive understanding of the properties of the pre-treatment sites, it is not possible to understand the results of the treatments.	The sentence needs to be re-worded since these studies did have controls (or they would not have been included in the study; in fact, a different publication was originally included, but later excluded due to lack of control). The scope of this review considers how interventions affect the existing shade and temperature regime, not historic temperature or shade ranges.	The sentence has been adjusted to clarify circumstances where statistical analyses were not conducted.
374 - 376	**Autocorrelation of temperature time series data for all the studies would be very beneficial.** This information would allow for higher statistical robustness, strengthening the findings and making this a more reliable	While autocorrelation of temperature time series data provides more robust findings, to exclude studies because they lack this autocorrelation would potentially exclude evidence that still has value, especially given there are so few studies that were	Agree with reviewer, though this cannot be done because requiring autocorrelation would dramatically reduce the number of studies available for review.

Line #	Comment/modification	ODF Response	External Reviewer Response
	review.	included.	
385 - 386	**The nine alternatives lacking a highly relevant study should be addressed.** While those nine alternatives lacked a highly relevant study, a brief discussion of them would strengthen the study. It would be very beneficial to give the reader at least some cursory knowledge regarding those alternatives so people know what options did not have any scientific basis. Also, very little background was provided regarding the specifics of each alternative. Understanding what each alternative entails is essential to comprehending the study's findings. Thus, the study should discuss the logistics of each option prior to delving into the findings.	Text can refer to Table A.6.4 for readers that want to know which rule alternatives were not included, and Table A.6.1 defines every rule alternative. It would be good to add a sentence at the beginning of each sub-section in Section 3.5 to ensure the reader understands clearly the alternative considered.	A sentence was added to the beginning of each sub-section in Section 3.5 to help describe the rule alternatives. We have also added a list of rule alternatives that did not have highly relevant studies to the intro to Section 3.5.
398 - 400	**It should be made clear which studies only had harvest on one side of the waterway compared to the studies that had harvest on both sides.** Having harvest on one side of the stream has the possibility of biasing the results. The investigation should clarify whether study areas had one or both sides harvested. Discussing the possible impact on the results of those studies would provide insight into the results. The	For external reviewers to respond.	While this might increase clarity concerning the outcomes measured, adding the clarification would be difficult because some studies do not report it, some report it but not which side of the stream and/or stream orientation, and thus drawing conclusions is beyond the scope of this report.

Line #	Comment/modification	ODF Response	External Reviewer Response
	possible inconsistency in the findings due to this factor is highly relevant and deserves some discussion.		
410 - 412	**It is very important to have large sample sizes and consider differences in shade less than 0.5% inconclusive.** The investigation team is correct that larger sample sizes are very important. They help to mitigate some of the factors that can bias the results. Considering the unreliability of the densitometers, it is good to consider slight changes in shade inconclusive.	Agree	Agree
425 - 426	**Discussion of the reasoning for the confidence scores is needed.** The confidence scores of these studies is a highly relevant factor. Understanding why some studies had high scores and why other had low scores would be very useful for understanding the studies and findings as a whole. While the study briefly mentioned the confidence scores, the basis for of these figures is worth discussing.	Agree, add to discussion the why and what of the figures in a paragraph following line 391.	Agree that confidence scores need to be thoroughly explained. They are explained in section 2.7 and now in a footnote with the first of the results figures.
450 - 453	**Discussing the pre-harvest and post-harvest conditions would benefit the investigation.** There was no detectable change in the shade conditions. However, there was between 80-95% shade coverage to begin	For external reviewers to respond.	Description of the site conditions can be found in Tables A.6.2. for speculation to other types of stream conditions.

Line #	Comment/modification	ODF Response	External Reviewer Response
	with. While this study may be sound, it is worthwhile to discuss the stand conditions before and after treatment, as this type of management on other streams may have a greater impact if there was less shade before treatment.		
462 - 463	**The change in temperature should be discussed in more detail.** The change in temperature was quoted to be zero degrees yet there was a range of -0.9 to +2.5° C. This range is quite large, justifying a more in-depth explanation. If it were a matter of statistical relevance, stating such would benefit the study's results.	Discussing the range of variation, and the cause of it, for every study included in this review is beyond the scope of the review.	Agree with ODF. For discussion of each individual study, see A.6.2. tables.
498 - 499	**A plan for accruing additional data should be created.** The investigators did a great job at identifying the need for additional data on this topic. We strongly agree with that conclusion. As such, we would urge the accumulation of additional evidence to answer the remaining questions on this topic.	Outside the scope of the Systematic Review but will be retained for future use in the pending Monitoring Strategy update.	Agree with ODF
597 - 600	**The results from studies in extreme headwater reaches of streams must not be considered highly relevant.** The extreme headwaters are much more	While "extreme headwaters" likely exhibit more variable stream temperature regimes, we decided that drawing a line between these reaches and those downstream could	Agree with reviewer comment, but as described by ODF, it was too challenging to determine which studies fell

Line #	Comment/modification	ODF Response	External Reviewer Response
	variable in their temperatures. As such, those results are likely far more biased because of other unreported factors. These stream reaches are not highly relevant due to the possible bias in the results. While these results should be included, too much reliance on them is detrimental to the results.	not be done consistently-, and defensibly-, enough for this review. Namely, sufficient information is not consistently provided within study descriptions to classify the streams in question according to ODF regulatory standards.	into that category. The referenced sentence points out this variability and the caution for interpretation is implied.
614 - 616	**More research is needed to test this finding.** The "most effective" buffer still resulted in a decrease in the canopy density. Moreover, it had a lower confidence score than other studies. Due to the lack of confidence, reliance on this study is misplaced.	Outside the scope of the Systematic Review but will be retained for future use in the pending Monitoring Strategy update.	We agree. An important goal of this work was to identify the remaining gaps in knowledge. The text does not suggest disproportionate reliance on this study and states clearly that the confidence for the study is low.
711 - 720	**Identification of additional studies for inclusion is needed.** While we understand the difficulty in identifying and characterizing studies for inclusion, additional studies would be extremely beneficial to increase the confidence in these findings. Studies addressing all alternatives would be ideal. More information in general would strengthen the investigation greatly.	While including more studies could be helpful, we still need to include only studies that help answer the review question. Part of the purpose for this review is to uncover what we don't know.	We agree with ODF. An important goal of this work was to identify the remaining gaps in knowledge.

Chris Frissell, Ph.D., Consulting Research Ecologist and Freshwater Conservation Biologist for Mary Scurlock, Policy Analyst, M. Scurlock and Associates

1. Introduction

In general this is a well-executed and well-written report that clearly describes and directly responds to a specific charge from the Oregon Department of Forestry and the Oregon Board of Forestry. It's good to see a highly professional and transparent approach taken to literature review. On the other hand, the results do highlight inherent limits of the Systematic Review framework that reduce the scope for inference and useful interpretation of available research.

In the following comments I identify a handful of issues that could be more clearly addressed in the report and constitute potential limitations of the approach. However, in my view these shortcomings are inherent in the research question posed and in the available science, with further constraints imposed by the Systematic Review framework. That is, resolving these could somewhat improve the veracity of this report, but will likely not substantively change its conclusions and implications.

The most important conclusion of this report should not be lost on its agency sponsors: ***for the vast majority of the 16 alternative riparian management approaches identified by the Board of Forestry, existing empirical science is adequate to address only a small handful of them***, namely those for which some equivalent measures have been implemented on the ground by way of past state and federal rules. On its face the "Systematic Review" method is profoundly unsuited to address the potential outcomes of newly proposed management schemes, because few or no empirical studies have tested the specific treatments called for. Secondly, for the handful of riparian management approaches for which the "SR" method is suited at all, ***the results rest on a very small number of studies were conducted with adequate methods and designs***.

ODF Response	**External Reviewer Response**
Agree that most of the rule alternatives have few-to-no studies that address them.	Agree
The purpose of this SR is to see what science exists with which to assess the effectiveness of proposed rule alternatives, which the review accomplishes. ODF agrees that this information needs to be bolstered by additional analyses to address the potential	Though the SR method has its limitations, the goal is to find a way to narrow down the scope of information quickly and effectively in a resource-friendly manner. Ideally, funding would be available to conduct a broader, more inclusive review, but we

ODF Response	External Reviewer Response
outcomes of proposed rule alternatives; these analyses will be conducted outside this review.	believe the SR method is a reliable and strong substitute for the more labor-intensive efforts.

Somewhat less problematic but still limiting is the third lesson: even among the few studies that meet these requirements, researchers reported different methods and metrics, so that the equivalency of results is conditional and the ability to draw inferences is further narrowed. The authors of this report have done a thoughtful job of respecting this condition, while not allowing it to unduly limit inference.

ODF Response	External Reviewer Response
ODF agrees that research methods and metrics differed between studies, and that Drs. Czarnomski and Hale did a thoughtful job of respecting these differences.	Thank you.

2. Problem of Equivalency of Changes in Shade and Water Temperature

A conceptual premise underlying this report is that shade and stream temperature are directly related, and that canopy shade from riparian vegetation is the primary determinant of maximum stream temperatures. This presumption does not originate in the report itself, but in the conception of the questions the report was commissioned to address. The authors have taken care to avoid embracing this premise outright as an analytic matter in two ways: 1) canopy shade and stream temperature are treated separately as response variables, that is, in parallel analyses, and 2) "effects modifiers" are considered as covariates, to the extent this is possible with available data from the sources studies.

Considerable attention has been paid in the scientific literature to the point that shade reduction is not the only means by which logging can alter stream temperature. In addition to changes in channel structure, sediment conditions, and streambank erosion and reduced vegetative stability following logging, canopy reduction across a watershed or catchment surface can affect shallow groundwater thermal regimes. Pollock et al. (2009) found that post-logging temperature increases in Washington streams corresponded to catchment-wide extent of recent logging more strongly than to extent of logging or canopy reduction in riparian areas that would directly affect stream surface shade (See also Moore et al. 2005). Pollock et al. (2009) suggest that landslides and debris

flow-induced changes to channel conditions (namely, reduced hyporheic interchange and flow storage), as well as groundwater warming may explain logging-related stream warming. Bourque and Pomeroy (2001) reported a similar correlation with catchment-wide extent of logging in New Brunswick, such that stream warming was unrelated to riparian forested buffer width. Janisch et al. (2012) reported that small headwater streams in logged catchments warmed more if they drained a larger area of wetlands. More extensive wetlands would likely correspond to more extensive areas of near-surface groundwater, as well as open water surface, within these catchments.

In several of the above studies, a major causal mechanism for stream warming appears to have been the warming of near-surface groundwater in response to logging and subsequent soil warming with catchment-wide canopy reduction. While Janisch et al. (2012) pointed out that post-logging catchments may release more groundwater to streams because evapotranspiration is reduced, the temperature of shallow groundwater (2.5 m or less from the soil surface) can increase with soil warming under open land cover conditions in summer (Pluhowski and Kantrowitz 1963, Hewlett and Fortson 1982, Glazik 1987, and other sources cited in Rhodes et al. 1994). Therefore, under certain landscape conditions, logging could increase upland groundwater elevations and expose more near-surface groundwater to warming, at the same time it exposes the soils to greater warming because of canopy loss. The result is likely to be increased discharge of warmer water to streams in spring and summer months as a common result of catchment-wide logging. This may or may not be masked by larger fluxes in daily maximum surface stream temperature that are more directly influenced by riparian canopy condition, although groundwater warming should still be evident as increased daily minimum and median stream temperature. Surface temperature of small streams in the Oregon Cascades recovered about 15 years after logging of their catchments (Johnson and Jones 2000); this corresponds with the time commonly needed for regeneration of canopy shade along small channels in western Oregon, but also for canopy recovery over upland soils, hence the presumed return of extensive vegetative thermal buffering of soil and shallow groundwater. Roads may also intercept and divert groundwater to surface and near surface flow paths where it is more vulnerable to heating before it is delivered to streams (Gucinski et al. 2001).

Landforms and soils in the catchment likely determine the vulnerability of groundwater to warming following canopy reduction. In very steep and highly dissected terrain, especially where soils are well-drained and slope-bench wetlands absent, very little near-surface groundwater may be present for a long enough residence time to experience post-logging warming. In moderately sloping, gently sloping, and wetland-rich terrain, extensive near-surface groundwater is present within the soil depths where it is vulnerable to

warming, and the spatial and temporal duration of vulnerability may increase as a result of post-logging reductions in evapotranspiration.

From a regulatory viewpoint, the important take-home message of these observations is that regulating canopy shade cannot be presumed sufficient to protect all streams from logging-related summer temperature increases. This point contradicts a basic premise of this Systematic Review, and is not illuminated or disclosed by the review because 1) studies demonstrating the effects were deemed of inappropriate design for further consideration *a priori*, and 2) for the studies included, the analysis assumes that stream temperatures in "control" streams, where riparian areas were not logged, represent baseline conditions, whether their temperatures increased, decreased, or remained stable during the study interval. In fact, groundwater-mediate warming of control streams could bias the observed effect of riparian logging on canopy-mediated stream temperature downward, because the study baseline also warms.

ODF Response	**External Reviewer Response**
It is inaccurate to state the studies demonstrating watershed-wide effects were deemed inappropriate *a priori*. For example, had Pollock et al. (2009) provided data collected within 5 years of harvest (instead of binning into <20 years since harvest), their publication would have been included in this review. The reason 5 years was chosen as a cutoff is to provide a conservative timeframe in which to measure impacts of harvest on stream temperature before shade from vegetation growth recovers to nearly the same as that pre-harvest (Hale, 2007; Johnson and Jones, 2000).	It is important to recognize that this review question is purposefully limited in scope and that does place boundaries on use of conclusions from this report. You provided a helpful literature review and we have incorporated a few sentences describing the limitations in the introduction and in section 3.3. We also included more effects modifiers regarding site history.

From an analytic point of view, this problem could be checked by a more thorough review of catchment conditions of the study streams, including changes caused by logging, roads, fire, or other extensive disturbances within 15 years prior to and during the interval of the temperature study cases. In particular the conditions in control stream catchments are of concern, but also it is important that catchment conditions in treatment streams be similar to the controls within the 15-20 year period prior to the onset of the experimental study. Ideally they should all be free of extensive canopy and vegetative, or hydrologic perturbations within the two

decades prior to the study, but where such events have occurred, then they should be evenly distributed amongst control and treatment catchments. A retroactive, but only partial, means of analytically accounting for any known differences would be to include catchment history variables in the analysis of "effects modifiers."

Additional Analysis Needed. The question of how closely shade relates to stream temperature is briefly and qualitatively considered in the report in the context of the few studies considered that measured both factors in the field. I would suggest the authors consider a formal analysis of this question by extracting the data from each study in this report that reported both change in shade and change in temperature following logging treatments, aggregate the data and quantitatively evaluate their correlation. If change in shade and change in temperature are reasonably well-correlated across the studies, then focusing stream protection policy on riparian shade may be a useful approach. If not, than a more robust policy approach to stream thermal protection is called for. As other researchers have pointed out in prior studies, residuals around the shade v. temperature relation could be usefully examined against covariates ("effects modifiers") to help assess what other ecosystem features play a role in keeping water cool, and therefore require protection (such as base flow, see Arismendi et al. 2012, 2013).

ODF Response	**External Reviewer Response**
Extracting all the shade and temperature data from studies with both datasets is beyond the scope of this report.	We agree that the review question would be better answered with such an approach; however, this effort is outside of the scope of this report. An important goal of this work was to identify the remaining gaps in knowledge and there may be some merit to additional data analysis in future stages of the Rule Analysis.
Change in shade and change in temperature have been well-correlated across studies previously (Groom et al., 2011; Holtby and Newcombe, 1982; Johnson and Jones, 2000; Johnson, 2004), and thus we did not undertake this correlation.	See above

3. Assumption that Shade and Temperature are Not Equivalent only for Eastern Oregon

Given the global presumption that shade and stream temperature are equivalent and correlated metrics, as discussed above, it is not readily apparent as a scientific matter why studies from eastern Oregon, or any other region of forested, coldwater streams, were

excluded from the set of studies to be considered for this report. Unless other hydrologic, geomorphic, or high-resolution vegetative or microclimatic factors are critical to determining stream thermal regimes relative to canopy shade, then studies from forested mountain regions of eastern Oregon, Eastern Washington, and northern California should be useful to include in the scope. If the so-called "effects modifiers" are so different for these regions that stream thermal dynamics are fundamentally different, this should be demonstrable through specific data or analysis. We know that covariates of stream thermal regime vary widely within streams and within regions, hence it appears most likely the context of "effects modifiers" is a complex and overlapping functional domain that spans all of the regions.

ODF Response	**External Reviewer Response**
The Board of Forestry declared a finding of degradation based on a study of 33 sites in western Oregon. In addition, they limited the rule analysis (i.e., the basis for this SR) to western Oregon, and agreed to only include studies located in forests similar (i.e., with similar hydrology, vegetation characteristics, and latitude) to western Oregon.	No additional comment

4. Simplification of "Effects Modifiers"

The complex and systemic problem of covariate causal factors determining stream thermal regime is considered in this report in terms of "effects modifiers," at least where some data are available in the studies deemed to be in scope. However, it is already well-established that such covariates can have large quantitative and qualitative influence over how streams respond to changes in canopy shade or other single factors (e.g., Arismendi et al. 2013). Therefore, I remain concerned that the results presented in this report could misrepresent reality if "effects modifiers" are not given more systematic and exhaustive treatment. For example, if because of undocumented reasons of geomorphology or groundwater hydrology a "control" stream is more sensitive to climate forcing than neighboring streams used as "treatments" in a riparian logging study, then the control's greater sensitivity could result in overestimation of baseline temperatures and underestimation of potential effects of canopy shade if post-treatment years are warmer and sunnier. Conversely, treatment streams that are thermally buffered by unexamined geohydrologic factors will show less response to canopy reduction that would other streams, or in some cases may actually cool post-logging if groundwater discharge and baseflow increases result form extensive vegetation reduction in the catchment.

There is no easy solution to this problem, particularly when relying on past studies that unevenly documented or failed to consider geohydrologic and other variation among study streams. In the future, different study designs, such as designs that measure how downstream thermal profiles vary in response to changes in riparian vegetation, or what percentage of a stream length exceeds some maximum temperature threshold, and larger sample sizes are likely to shed more light on the question of thermal impacts and sensitivity. Moreover, better tracking of upland treatments is needed in logging studies-- not just consideration of whether riparian zones were wide or narrow, thinned or unthinned, continuous or patchy, but also the logging alteration of upland areas, including total catchment area logged over time, and proportion of wetland area logged

Implications of scientific limitations for policy: Need to tier the limits of response to effectively protect stream resources. Meanwhile, we are stuck with studies that do not adequately account for this complexity, and forced to draw what inference we can to inform policy. But recognizing these scientific limitations is vital to framing policy in a way that will actually result in resource protection**.** There are many reasons why a riparian logging treatment in stream A might have a lesser, or a greater effect, in stream B. Until we have sufficient scientific understanding and field information to explain those reasons and classify streams reliably in terms of their probable response, the only way to assure resource protection will be to assume all streams could behave like the most sensitive streams in the record. For this reason, I suggest this problem is best suited to an analytic approach such as quantile regression (e.g., Bryce et al. 2010), which emphasizes the limits of response, rather than the mean response to an independent or treatment variable. Embracing this kind of approach, whether nested within the Systematic Review context or another, could much more effectively advise policymakers on what steps are needed to effectively achieve resource protection on a regional or state-wide basis.

ODF Response	**External Reviewer Response**
The Board of Forestry will have to determine the degree of certainty to use if they choose to modify the riparian rule.	The unique conditions for each study and large number of potential effects modifiers that are not necessarily explained in the original paper make it too cumbersome to speculate on that for each in this review. If there was something obvious of note, it is captured in the A.6.2 tables that provide information for each study and were likely incorporated into the main body of this review. We agree that the method for modifying the riparian rule needs to take into account the uncertainty and unknowns.

5. Hazards of Data Extraction Apart from Authors' Knowledge

One endemic risk with the SR method, or any other means of meta-analysis, is that the specific limits of data could be compromised when data are "lifted" from the original published source and applied in a somewhat different analytic context. This concern is acknowledged in the report, and as far as I can discern the authors have done a conscientious and careful job of respecting the limitations of each study design and data set. This is less difficult in this instance because only a small number of studies provided the data for the vast majority of the analysis.

6. Absence of Studies Directly Relevant to Many Alternatives

The fundamental shortcoming and fact of life disclosed by this report is that existing field research is largely unsuited for addressing the vast majority of the management alternatives under consideration by the Board. While it did not take a study to determine this, hopefully this result will underscore that ***an entirely different approach will be necessary to assess potential environmental effects of unstudied riparian treatments.***

ODF Response	**External Reviewer Response**
This SR is designed to answer questions relating to assessing effectiveness of riparian buffer prescriptions that have been tested in the western Pacific Northwest. It was not designed to exhaustively explore new buffer alternatives but to understand the scientific underpinnings of the proposed alternatives scoped with input from stakeholders as directed by statute for the rule analysis process. The Board made a decision in July 2012 that the range provided by the 16 alternatives being considered was acceptable.	We agree that the Board will have to have a different approach for decision-making where there is no available information on the effects of a particular rule alternative.

In the past, simulation modeling using heat budget and related models has been used to compare stream thermal outcomes under different management scenarios. One potential value of the present report is that that vetted data from the studies reported here could provide the empirical basis for calibrating a stream temperature simulation model. If the model proves robust to the studies reviewed here, and simulates their outcomes with acceptable precision, then it could be turned to evaluating some of the other riparian management alternatives proposed by the Board.

ODF Response	External Reviewer Response
The SR was not designed to provide a single answer of which rule alternative is best (in fact, the protocol explicitly states that no recommendation will be made of which alternative to select). Instead, the SR was designed to provide information on the current state of knowledge of the effectiveness of various riparian management strategies. Additional analysis will likely be necessary to fully flesh-out rule alternatives.	An important goal of this work was to identify the remaining gaps in knowledge. This seems like an appropriate topic for new research.

While a stepwise improvement over past modeling that has often been weakly grounded in empirical data, this modeling approach is not without problems and risks because it assumes stationarity (Milly et al. 2008) and uniformity of groundwater, surface water, and canopy shade effects even though various treatments may in fact affect these factors and their relationships differently. For example, a south-side-retention only alternative might retain a significant fraction of shade over the stream channel, but expose a large area of riparian area and associated wetlands to increased solar insolation, affecting near-surface groundwater temperatures.

7. Conclusions

In sum, from a policy point of view the limitations of the available research present two fundamental alternatives if the Board is to ensure that its rulemaking has a rational scientific basis:

- it will have to settle on ***fewer potential alternative management strategies*** and invest substantially greater resources in carefully designed and executed scientific field tests of outcomes of implementing them in the field;
- it must ***adopt a conservative protection strategy*** that ensures resource conditions are maintained or improving for even the most sensitive waters.

ODF Response	External Reviewer Response
Outside the scope of the Systematic Review but will be retained for future use in the pending Monitoring Strategy update	Agree with ODF

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Jeff Lockwood, Fisheries Biologist, NOAA/NMFS

The systematic review focuses quite a bit on the two Groom et al. publications, and they do seem highly relevant. One caution though, as you may have heard from others (but perhaps the systematic review authors have not) there is a question whether at least some of the sites studied had trees cut down to the minimum required buffer widths. My understanding is that EPA reviewed the raw data and found that the median widths of the non-cut areas were larger than the minima. Without having reviewed the data myself, what I have heard from EPA is that the median widths for no cut buffers along the treated portions of designated treatment reaches were 80' and 64', respectively, for the right and left stream banks, on private lands and no cut zones were154' and 131', respectively, for the right and left stream banks on state forest lands. If this is true, this suggests that the effects observed do not necessarily correlate with the minimum buffer sizes on private and state lands; in other words, the shade and temperature changes could have been larger if the minimum buffers were implemented.

ODF Response	**External Reviewer Response**
The Forest Practices Act and State Forest Management Plan have both a no-cut width and a requirement to leave a certain amount of basal area of (conifer) trees within the riparian management areas (RMAs). The RMA width includes this no-cut width. Forest harvest operators tend to meet basal area requirements by leaving sufficient trees within the RMA immediately adjacent to the no-cut area. That is, the RMA beyond the 20' is generally not thinned but the clearcut may extend into the RMA to a distance where the basal area requirements are met. This practice facilitates the operational ease of harvest, and effectively creates no-cut buffers around streams that vary in width according to the riparian tree size, density, and composition. There is no evidence in this study that operators left more basal area than that required under the respective rules. Therefore, there is no evidence suggesting that the shade and temperature outcomes from RMAs in the study differ from those of RMAs harvested to the minimum of each respective rule.	Agree with ODF response.

E.2 External comments, and responses to these comments, on additions to the draft report (Executive Summary, and Geographic ranges and physical settings)

Mike Newton, Professor Emeritus – Silviculture, Dept. of Forest Engineering, Resources, and Management/Oregon State University

When I look at these summaries, I suddenly realized that there were no data from streams that had no harvesting whatever along them. I am certain that there are occasionally exceedances in virgin streams, especially those with alder riparian cover. This is a statistical matter. Intuitively, this would put somewhat wider boundaries on the spread of comparisons with the PCWS (*editor's note: PCWS refers to Oregon Dept. of Environmental Quality's Protecting Cold Water Standard)*. In our work, there was substantial year to year variation before harvests that lead to uncertainty as to baseline warming trends.

ODF Response	**External Reviewer Response**
The SR protocol explicitly only includes studies that had treatments (i.e., forest harvest with some type of buffers around streams). In addition, the SR addresses how well studies controlled for background variation by using different types of controls. Groom et al. (2011b) specifically examined rates of PCW exceedances along unharvested streams (within the past 40+ years) and found a background exceedance rate of 5% when comparing two years of temperature data. However, many other studies did include pre-treatment temperature data with which to more accurately assess the treatment effect, even though the studies did not focus on the PCW.	Agree with ODF

I will maintain my concern that adherence to the PCWS is meaningless unless one considers the biological rationale for it. Water warmed returns to equilibrium in the reaches it flows into. Heat does not accumulate apart from equilibration with the environments into which it flows. None of this work was allowed to consider fish despite a rich literature showing that fish benefit from increased

primary production. thus my concern about all its findings for lack of biological relevance. To me, being a biological scientist requires asking questions that are germane to the biology rather than the politics of regulation. This study, conducted with precision and intensity, was great statistically, but failed biologically for having not asked the relevant question. So the scores are A+ and F.

ODF Response	**External Reviewer Response**
This comment is outside of the analysis' scope. The Board of Forestry made a decision on degradation based on the statutory obligation that ODF forest practices must meet DEQ water quality standards. We acknowledge the concern about biology. However, the analysis and the review are not and never have been focused on biology, rather on the addressing the Board's decision on degradation and subsequent need to have scientific backing for proposed rule alternatives.	Agree with ODF. We recognize that the SR question was purposefully limited, thus results must also be considered in light of the question that was addressed.

Jeff Lockwood, Fisheries Biologist, NOAA/NMFS

I am concerned that the executive summary (and perhaps the document it is summarizing - I did not check) is not accurately summarizing the "protecting cold water" criterion. The executive summary says this about the criterion in the first paragraph:

"This criterion prohibits human activities such as timber harvest from increasing stream temperatures by more than 0.3 ºC at locations critical to salmon, steelhead or bull trout."

What is missing is the concept that each source does not get a 0.3 ºC increase, it is the whole watershed. According to subsection (a) of OAR 340-041-0028 (11) [Protecting Cold Water], "This provision applies to all sources taken together at the point of maximum impact where salmon, steelhead or bull trout are present…."

If there are multiple streams in a watershed that are allowed to warm by 0.3 ºC, the cumulative temperature increase downstream obviously could exceed this value. I recommend you correct this in the executive summary, and in the main document if necessary.

ODF Response	External Reviewer Response
Modification made in document.	Agree with modification

Jeff Light, Hydrologist, Plum Creek Timber Company

Line #*	Comment/modification	ODF Response	External Reviewer Response
GR	Change "west of the crest of the High Cascades" to "west of the Cascade Mt. Crest"	Fine.	Agree
GR	What are metrics for temperature in Figure 3b? 7-day max?	The studies used different temperature metrics, the details of which are found in Table 1 of the draft report (which is Table XX in the final report).	No comment
GR	What do you conclude from this with respect to the ability to extrapolate RipStream findings beyond the coast range?	This report does not make recommendations.	While the report does not extrapolate results, the synthesis shows that various buffer configurations in other Geographic Regions also do not always appear to meet the PCW standard. Added language to point out that the SR did capture apparent PCW exceedances for the FPA in the Interior Geographic Region.
ES	For the Executive Summary, I expect the way things are worded in a few places will lead to immediate questions from BOF members or others, and I'm curious what your responses will be to: 1. In the no-cut buffers discussion (line 94) you state: "Four of seven	An explicit part of the systematic review's protocol was that the review would not include recommendations, including which buffer type or specific prescription is best at protecting cold water. Guidance will likely be based on additional data analysis.	No comment

Line #*	Comment/modification	ODF Response	External Reviewer Response
	studies that measured stream temperatures had some sites that met the PCW standard, three of which had a range of buffer widths." This means that the PCW was not met in 3 of seven studies, and some sites in the four that did meet the PCW did NOT meet the PCW. What guidance will you offer on these different outcomes? 2. Your final conclusion (line 112) "The evidence from this suite of studies only supports two classes of rule alternatives as effective in meeting the Protecting Cold Water standard: • Variable retention buffers (including State Forest Management Plan) • No-cut buffers The variable retention buffers were so widely variable, and the State FMP buffers included cases with only one side of the stream harvested, so how will you respond when someone asks "which buffer is best"? Same question for no-cut buffers; they range from 10-ft to super wide. And there is a 20-ft no-cut in the FPA buffers which did		

Line #*	Comment/modification	ODF Response	External Reviewer Response
	not *always* meet the PCW. Which is best?		
	A key conclusion that I read in the RipStream SER is that it is hard to guarantee a stream won't warm by 0.3C no matter how wide the buffer. This I think reflects that the change is too small to attribute to harvest – rather it could be driven by many other things. This point is important - I believe it should be in the Executive Summary. It will give the BOF a healthy dose of caution with the notion that they can 'cure' the problem with riparian management.	For a buffer prescription to meet the PCW criterion (i.e., not warm by more than 0.3°C), it does not need to meet this criterion in 100% of the cases. An example of this was found in Groom *et al.* (2011b) for State Forest Management Plan (FMP) buffers wherein the probability of meeting this criterion (91%) was not statistically different than streams without harvest, and thus these buffers are considered by ODEQ to meet the PCW.	We explain in the report that modifiers may affect results, but that the modifiers in each of the studies were too varied (and descriptions of how they were incorporated into the study design and analysis was not always available) to be incorporated into this analysis. However, the one commonality between the studies is that they test the effect of harvest. We agree with ODF regarding their comments of how the PCW criterion is met.

* GR refers to Geographic Regions Analysis; ES refers to Executive Summary.

Maryanne Reiter, Hydrologist, Weyerhaeuser Co.

For the Geographic scope document, the location described in line 2 is awkward. Maybe something simpler like Oregon west of the Cascade Crest, I don't know if is necessary to call it the high Cascade Crest, since crest implies the top of the range. A map of the study sites you used with your georegions would be good. I realize your georegions don't encompass WA or SE AK. You could use Ecoregions as a proxy to show they are similar in climate, etc.

ODF Response	External Reviewer Response
-Concerning high cascade crest, wording changed. -A map of all study sites would be unwieldy to make and overly	Agree with ODF. An additional problem to creating the map is that exact study locations would be challenging to identify.

busy to include in the report.	

The georegion distinction will be important in interpreting what changes need to occur if one of the options chosen is more BA *(editors note: BA refers to basal area)* since the Coast medium streams require 120 sq ft BA per 1000 while W.Casc/Interior require 140. Would this difference in BA be enough to create difference in shade and temperature?

ODF Response	**External Reviewer Response**
Addressing a difference in basal area causing a difference in shade and temperature is beyond the scope of this review. Additional data analysis may address this.	Agree with ODF

Another question I have in the georegion document is about the interpretation of Brazier and Brown. I looked at their 1973 publication and could not find change in shade, but rather ACD *(editors note: ACD stands for angular canopy density)* for the harvested reach. Likewise with temperature, how was a change arrived at? Sorry if that is a late in the game question.

ODF Response	**External Reviewer Response**
-Angular canopy density (ACD) measures canopy cover, and cover should be included in axis title. Change in ACD is measured by subtracting the value measured at a buffer with that for 100 foot buffers. -Brazier and Brown (1973) report observed temperature change in Table 1. They measured this change as the difference in temperature between the upstream and downstream ends of the harvest unit.	Agree with ODF

In Fig. 3b of the georegion document it has in the legend a Q for the Morman study, but I did not see a Q in the figure.

ODF Response	**External Reviewer Response**

-Mistake corrected.	No comment

In the executive summary I feel the list at the end that indicates there are two only choices to meet the PCW need some caveats. The "Variable retention buffers (including State Forest Management Plan)" needs to indicate it is not just the buffer, but harvest strategy as well. The Ripstream data clearly shows that harvest strategy, that is, the number of sides of a stream harvested matters. Whether by plan or chance, it appears the State predominantly only harvests 1 side at a time as compared to private forest lands and this appears to influence whether the PCW is met or not. When 2 sides were harvested on state lands (n =2) the increases in temperature were 1.21 and 2.11 deg C, indicating there could be concern over 2-sided harvest on State lands. For private lands there were only 4 sites with 1-sided harvest; for those sites increases ranged from 0.03-0.53 deg C. It makes sense that leaving intact forest on one side of the stream can influence the thermal environment of the stream through shading and amelioration of microclimate.

ODF Response	**External Reviewer Response**
Harvesting one bank instead of two may influence shade levels at a stream and impact stream temperature changes. The two sites selected are not necessarily indicative of two sided buffers on State streams impacting temperatures. In the Groom et al. 2011 paper in Forest Ecology and Management, the third figure displays observed changes in temperature and predicted changes. The predicted changes were generated from a statistical model that examined all sites. The conditions at a particular site would cause that site to have a different temperature response than another site. Some variables in the statistical model did not change across years (e.g., stream gradient, length of the harvested reach). Other variables changed more frequently. Shade was measured once pre-harvest and once post-harvest. The change in the treatment reach temperature was summarized for each summer, as it was for the upstream control. If the stream banks were contributing greatly to the change in shade, and that change in shade was causing up to a 2^0 C, we would have expected to see	We agree with the reviewer that there may in fact be confounding variables that led to the results found in the RipStream study. The difference between one-sided and two-sided harvest may be a contributing variable to difference in stream temperature between the two management practices. Because we were unable to compare one-sided vs. two-sided harvest more universally for this systematic review, we do not want to draw conclusions based on number of sides harvested. However, it is worth noting that there are contributing factors that may influence stream temperatures and we have added language to the summary to that effect.

a large drop in shade for these sites. Instead the two sites exhibited a 5% and a 2% drop in shade – not a lot compared to other sites. For both sites we see agreement between the observed and predicted temperature change values. This is particularly true for the site that increased by > 2^0 C. If there wasn't a large change in shade, how did the model predict the change in temperature? The only other variable that changes with frequency was the temperature change in the upstream control reach. Therefore, the increase in temperature in the treatment reach was likely not due to a change in shade, but rather in the temperature of the control reach. The site that increased in temperature by 1.21^0 C had two distinct observations and predictions in the pre-harvest years. This indicates that the upstream control reach temperature behavior changed in that time period. The observed post-harvest treatment reach temperature changes were close (slightly greater than) the predicted values, indicating that the match wasn't perfect but that knowing the control reach temperature change assisted in approximating the post-harvest response.	

Mary Scurlock, Policy Analyst, M. Scurlock and Associates

First, as I understand it the additional piece relating to buffer efficacy between geographic regions does not appear to address the question raised by Chris Frissell in the comments I submitted - i.e. whether available information supports the implicit but unsupported assumption that stream thermal dynamics are actually significantly different between regions. ("If the so-called "effects modifiers" are so different for these regions that stream thermal dynamics are fundamentally different, this should be demonst rable through specific data or analysis.")

ODF Response	External Reviewer Response
The Board made a decision in March 2013 approving the proposed systematic review only considering geographic regions west of the Cascade Crest (i.e., western Oregon). ODF staff support this decision since eastern Oregon has significantly different riparian vegetation and resulting shade responses to silvicultural prescriptions, and shade is the primary control on stream temperature examined in this review. Other effects modifiers are assumed to be similar between georegions in western Oregon.	The SR protocol was developed by ODF and vetted by stakeholders prior to our involvement with the project. We therefore have no additional comment.

The new section focuses instead on assessing whether available studies are adequate to demonstrate the relative efficacy of the same buffer prescriptions between regions, stating that: "data are only comparable between Geographic Regions when data assess the same buffer prescription from the same study conducted in more than one Geographic Region." This would seem to set up an unrealistically and un-necessarily narrow standard for probative studies. Although, technically, few -- if any -- of the identified studies used exactly the same specific buffer prescription, these prescriptions nonetheless produced end results that are comparable enough for them to be evaluated statistically. Therefore, the notion that identical buffer prescriptions have to be used to make any comparative study useful is false. Arguably, setting the proposed narrow standard is simply a way to stave off all relevant science and inference until some distant future when every possible option has been measured in a systematic study. But that has never happened, and it is unreasonable to expect it ever will happen. I submit that the definition of relevant science should not be narrowed to a single simplistic experimental paradigm. (Wasn't this a tactic long-used by the tobacco industry that is now being used to try to discredit science on climate change?)

ODF Response	External Reviewer Response
Our premise is that when trying to compare two quantities, it is essential that they be obtained in nearly the same way, especially when conducting a field science such as stream temperature monitoring wherein environmental variability is large. Methods of study design and data collection vary greatly between these	Add to ODF response that, for the scope of this SR, the statement in question is true. Comparison across studies would require analysis outside of our scope.

studies, thereby rendering a statistical comparison difficult and invalid.	

Although the implication of this section is that there is not enough information to make inter-regional comparisons, on the other hand it would seem just as possible that the fact that "no clear picture emerges when comparing prescriptions' effectiveness" is not be due to lack of data, but to the fact that there simply isn't much of a difference in the underlying thermal processes at work.

ODF Response	**External Reviewer Response**
It's true that there may not be much difference in buffer efficacy between georegions examined in this review, as the pattern suggests (this is stated in the report). However, we cannot state that with a high degree of confidence due to the paucity of data (this is also stated in the report).	Agree with ODF

It seems to me that we should be interested in all studies that shed light on 1) the scientific basis for the different rule prescriptions we have, which vary between regions (i.e. are they based on empirically demonstrable differences in the physical processes at work?), and in; 2) the actual efficacy of the rules we are using in Eastern Oregon with respect to the prevention of management-induced stream warming.

ODF Response	**External Reviewer Response**
We agree that we should be interested in all studies that shed light on the scientific basis for different rule prescriptions, which is why we conducted this rigorous, evidence-based review of studies that directly relate to this suite of rule alternatives in western Oregon. We believe the extensive search and filter process, wherein 1,456 studies were assessed for relevancy to the review question, captured all the studies relevant to the review question. For the second point, eastern Oregon is not part of this review. We note the interest in assessing stream warming in eastern	Studies frequently do not provide enough information about the effects modifiers (which are sometimes surrogates for processes at work) to allow for a thorough review of all the contributing factors at play in a given site. Conclusions were drawn from the literature where possible, keeping in mind what data on effects was available for the majority of the publications. Most of this information could not be easily compiled, thus it can be found in reviews of individual studies in the Appendix.

Oregon for the upcoming revision of the Monitoring Strategy.	We received comments from other reviewers about effects modifiers. One example of our response can be found in Greg Haller's comments on lines 303-307; 354-356; and 592-600.