EASTSIDE RIPARIAN SHADE/TEMPERATURE PROJECT

CMER Monthly Science Session
December 18, 2012

EFFECTIVENESS OF RIPARIAN MANAGEMENT ZONE PRESCRIPTIONS IN PROTECTING AND MAINTAINING SHADE AND WATER TEMPERATURE IN FORESTED STREAMS OF EASTERN WASHINGTON

Purpose of Talk

- Describe Study
- Project History
- Results Overview
- Conclusions
- Questions

Outline

- Background
- Key Questions and Objectives
- Study Design
- Site Selection and Installation
- RMZ Layout and Harvest
- Field Measurements and Results
- Conclusions
- Review Comments Considerations

Study Background

- Study Premises
- Shade Rules
- Bull Trout Overlay Map

Study Premises

- Stream temperature function of multiple processes
  - direct solar radiation
  - long wave radiation
  - conduction
  - convection
  - evaporation

Study Premises

- Stream temperature function of multiple processes

- Direct solar radiation
  - Primary contributor to daily maximum summer stream temperature
  - Has most direct response to forest harvest

Study Premises

- Canopy closure and shade over stream minimizes stream temperature heat flux during the summer months
- Removal of shade can lead to stream temperature increases
- Washington Forest Practices established to minimize stream temperature increases by application of minimum shade rule

Shade Rules

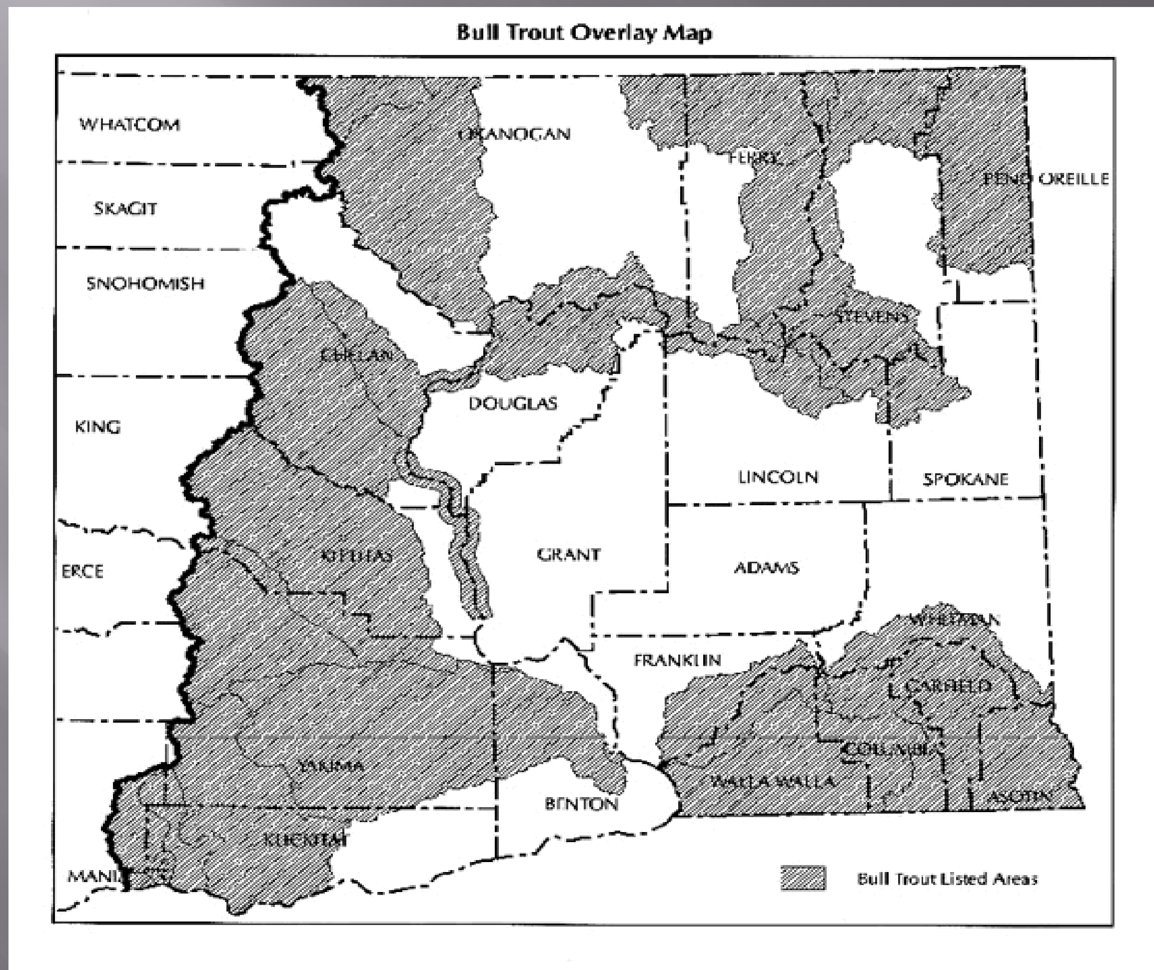
Minimum shade rules for fish bearing streams of Eastern Washington

- Applied within 75 ft of bankfull width or CMZ
- Differ inside or outside of the mapped bull trout overlay (BTO)

"All Available Shade Rule" within the BTO

"Standard Rule" applies outside of BTO

Bull Trout Overlay Map



Shade Rules

All Available Shade Rule (ASR)

- all trees providing shade must be retained

Standard Rule (SR)

- provides for varying canopy closure requirements depending on elevation and water quality standards following nomograph

Both rules have prohibit harvest within a 30 foot wide core zone have similar tree density and basal area retention

Assumptions for the Rules

- Standard Rule is inadequate to maintain the cold water temperatures required by bull trout of streams situated within the BTO.

- Retention of all available shade within 75-ft is sufficient to prevent harvest-related increases in stream temperatures.

Outline

- Background
- Study Purpose
  - Study Questions
  - Study Objectives

Study Question

Does the All Available Shade Rule provide the shade and temperature protection intended by the rule, and is it more effective , or not, than the Standard Shade Rule?

Questions Addressed Using Companion Solar Study

- Does removing trees that don't qualify as "all available shade" affect solar energy reaching the stream?
- Is canopy closure, as defined by the densiometer methodology used in the All Available Shade Rule, an adequate surrogate for the attenuation of solar energy to the stream needed to prevent stream temperature increases?
- What are the circumstances under which increases in solar energy to the stream significantly influence stream temperature?

Primary Study Objectives

- Quantify and compare differences of the ASR and SR rule
    - Post-harvest canopy closure and effective shade
    - Stream temperature effects

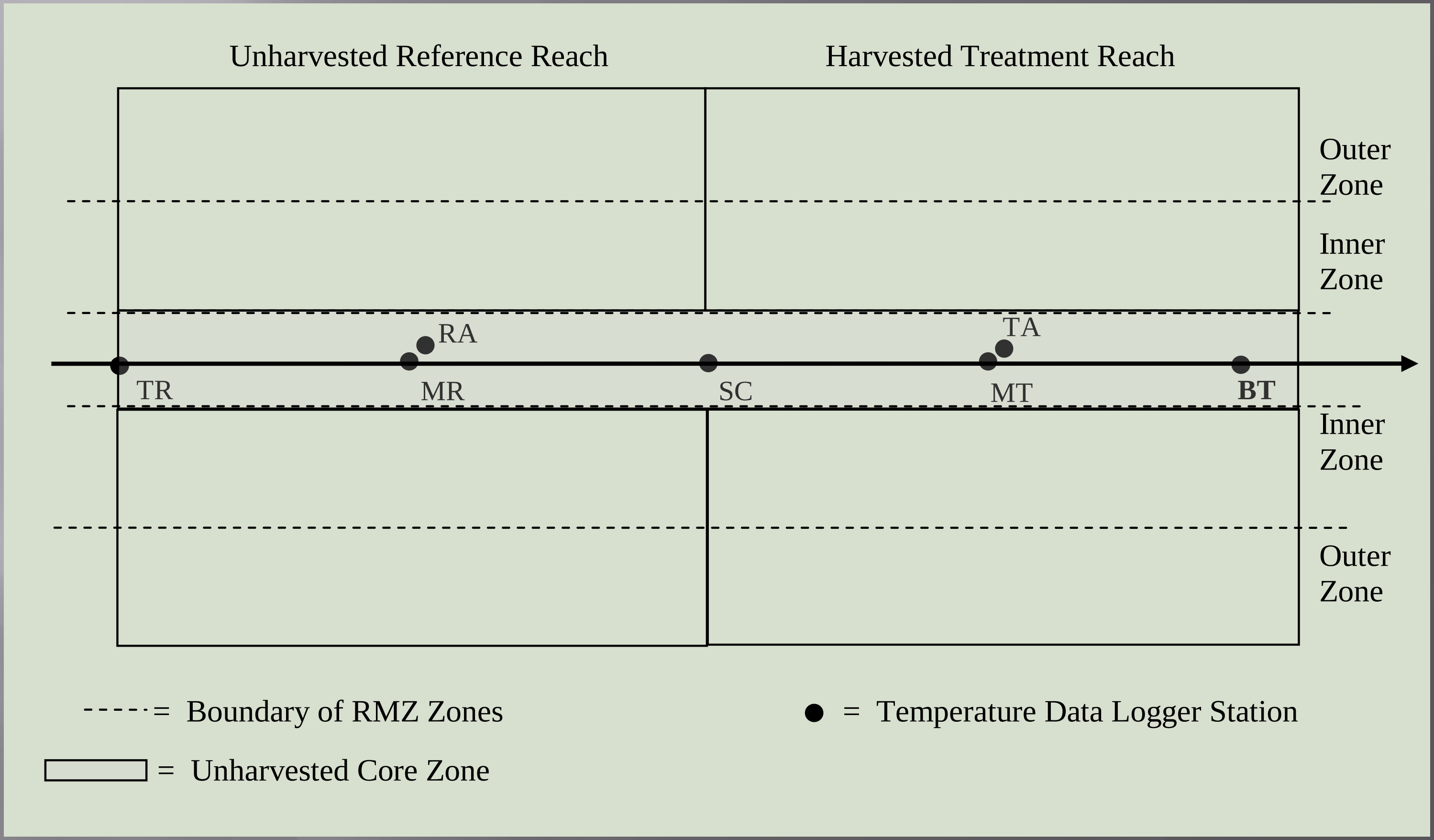
Outline

- Background
- Purpose
- Study Design
    - BACI
    - Site Configuration
    - Measurement Stations

BACI Design

- Before/after, control/impact experimental design
  - Untreated upstream 300 m reach provides control (reference) for immediately downstream 300 m impact (treatment) reach
  - Measure temperature for 2 years pre-harvest and 2 years post-harvest
  - No management within 200 feet of the stream in reference reach during course of study
- Prescriptions randomly assigned *

Study Site Configuration



Outline

- Background
- Purpose
- Study Design
- Site Selection and Installation
  - Selection Criteria
  - Search for Sites

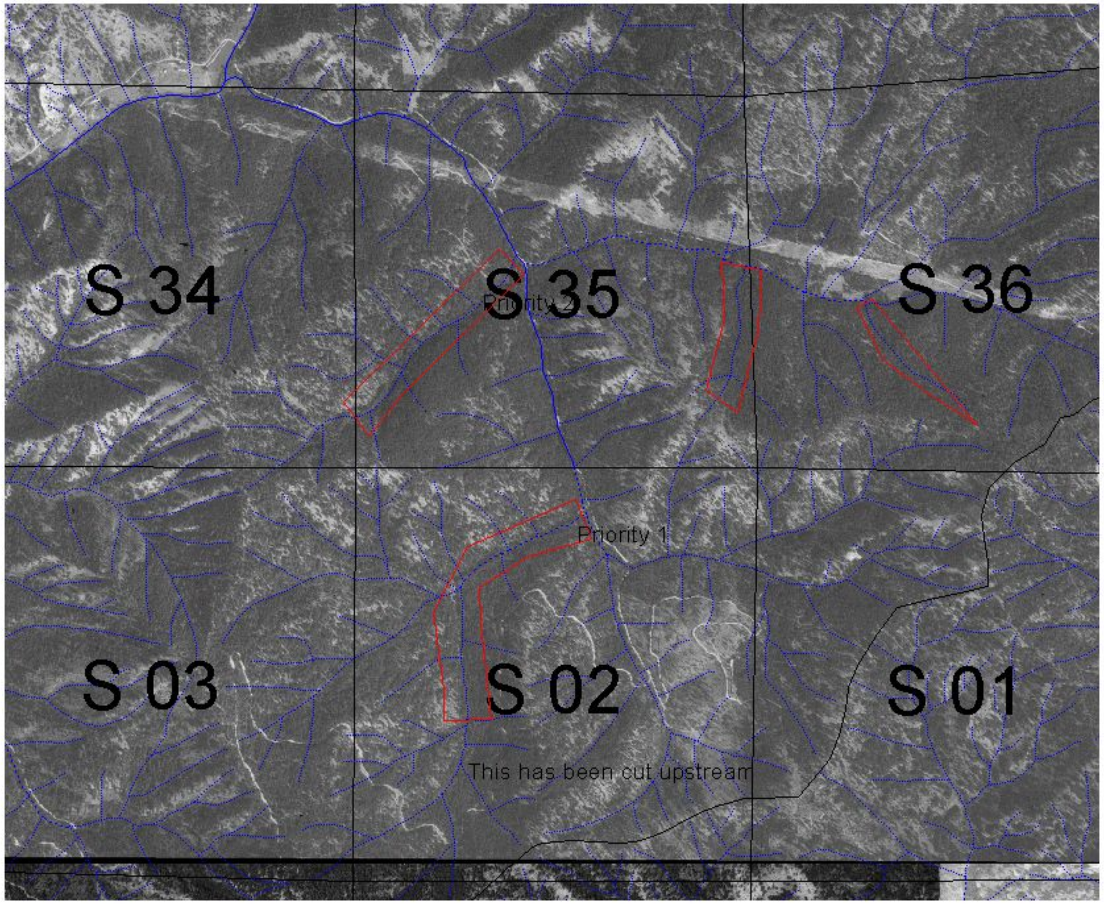
Site Selection

- Begin in 2003 with original goal of establishing 40 study sites
- Criteria established to minimize confounding factors
    - 13 physical and biological conditions
    - Stream size, wetlands, tributary input, forest conditions, roads, harvest history, seasonal flows

Search for Sites

- Initially solicited landowners for sites
- Assisted in identifying suitable areas
- 116 candidate site areas identified
- Contacted landowners
- Conducted field feasibility

Search for Sites



Site Selection

- Of the 116 sites, over ½ of them excluded
  - inadequate basal area for permitting harvest
  - included presence of extensive wetlands and beaver ponds
  - wide channel migration zones
  - extensive dewatered areas for extended periods
  - extensive road networks in riparian area

Site Selection

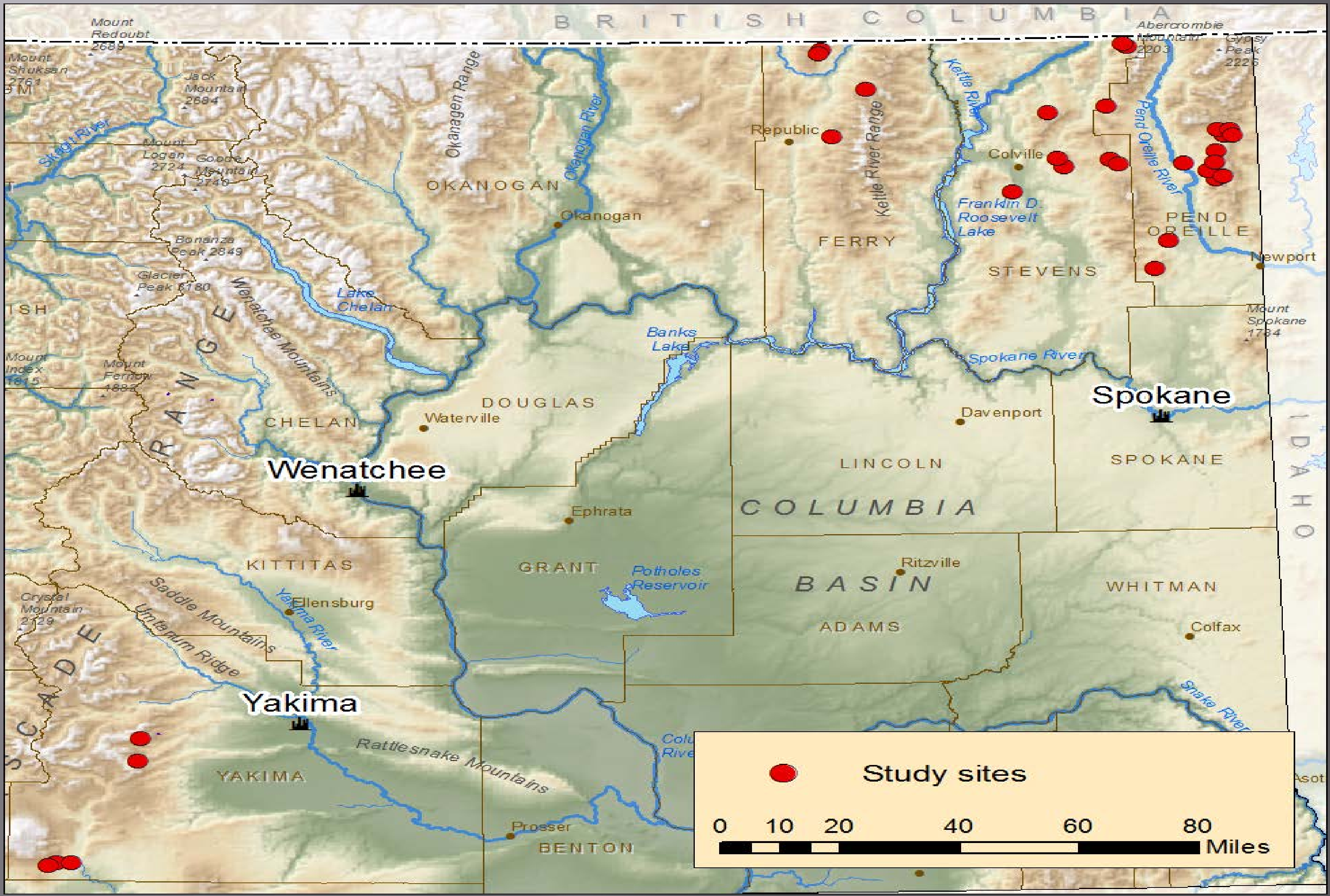
Because of the difficulty in attaining sites that met the entire suite of criteria, CMER agreed to broaden some criteria

- Channel Widths
- Tributary Inflow
- Wetland / Seeps
- Roads
- Discontinuous Flow

Site Selection

- The list of 116 sites was reduced to 45 that met the revised study design criteria
- Stream temperature and canopy conditions were monitored in 45 sites for at least 1 year
- 45 was reduced to 37 due to logistical considerations and permitting issues
- 37 reduced to 30 due to changes in harvest plans and permitting issues

Study Sites



BRITISH COLUMBIA
OKANOGAN
Okanogan
Republic
Kettle River Range
Kettle River
Colville
Franklin D. Roosevelt Lake
FERRY
STEVENS
PEND OREILLE
Pend Oreille River
Newport
Lake Chelan
Banks Lake
Spokane River
Spokane
DOUGLAS
Waterville
CHELAN
Wenatchee
Wenatchee Mountains
Davenport
LINCOLN
SPOKANE
COLUMBIA
Ephrata
GRANT
KITTITAS
Potholes Reservoir
BASIN
Ritzville
ADAMS
WHITMAN
Colfax
Ellensburg
Yakima River
Saddle Mountains
Umtanum Ridge
Yakima
YAKIMA
Rattlesnake Mountains
Prosser
BENTON
Snake River
IDAHO
Study sites
0 10 20 40 60 80
Miles

Outline

- Background
- Purpose
- Study Design
- Site Selection and Installation
- RMZ Layout and Harvest
  - Consistent Rules Application
  - Maximize “Harvest”
  - Follow-up QA/QC

RMZ Layout

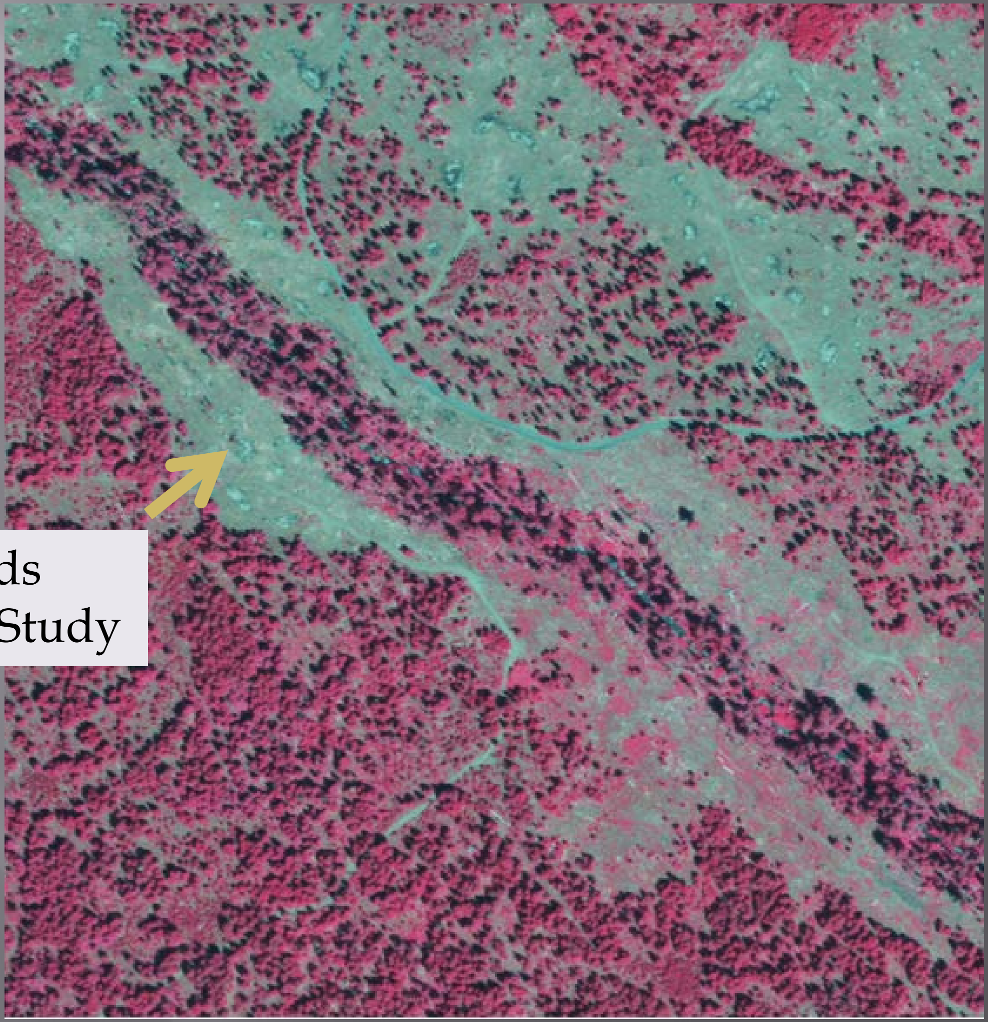
- Research staff laid out all RMZ prescriptions
- Prescriptions were interpreted consistently and sites were laid out to the fullest extent of the Forest Practice Rules.
- Communication with sale layout staff to ensure logging feasibility and appropriate tree and boundary marking strategies.
- Documentation for FPA submittal

RMZ Layout

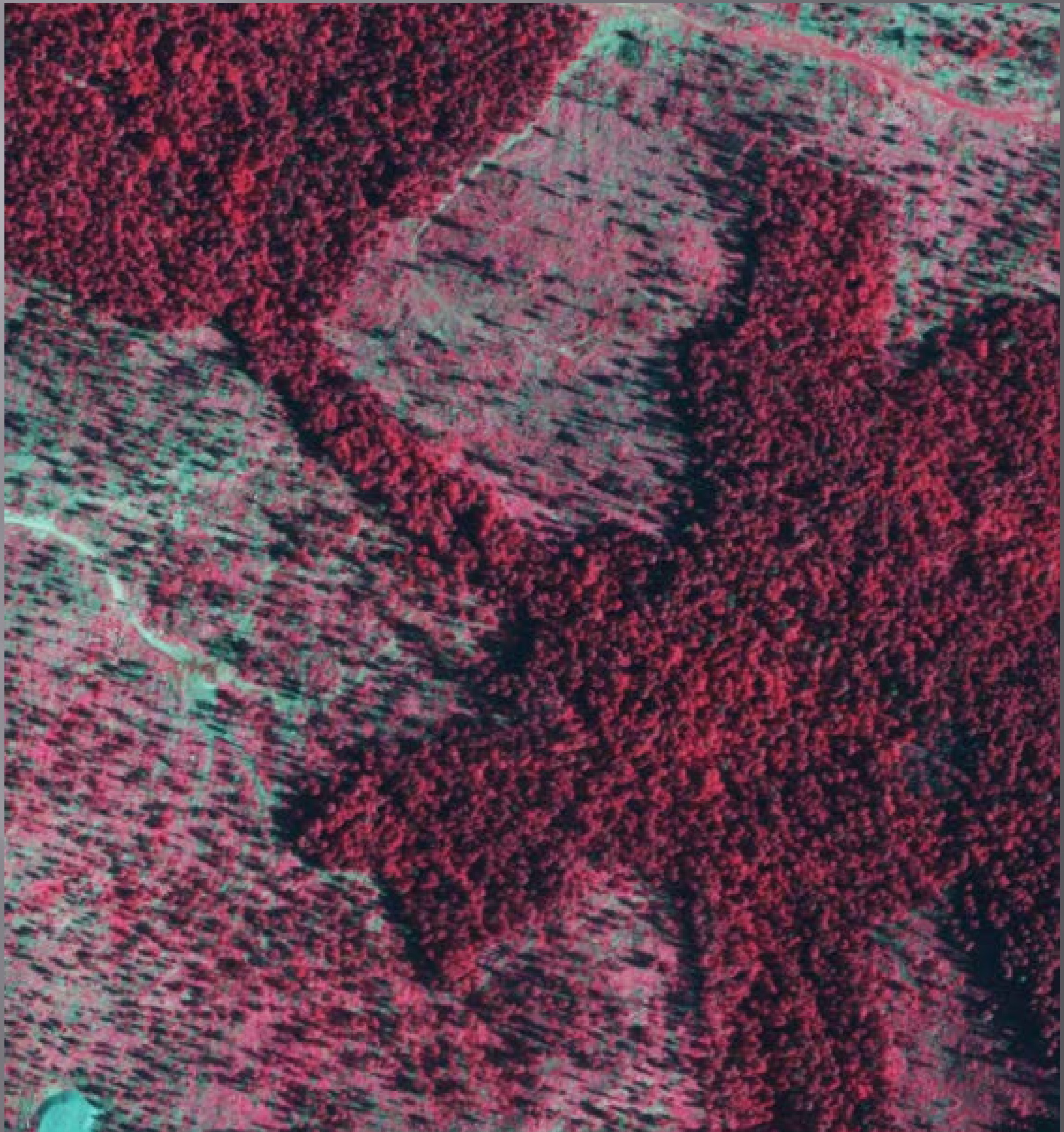
Harvest Treatments

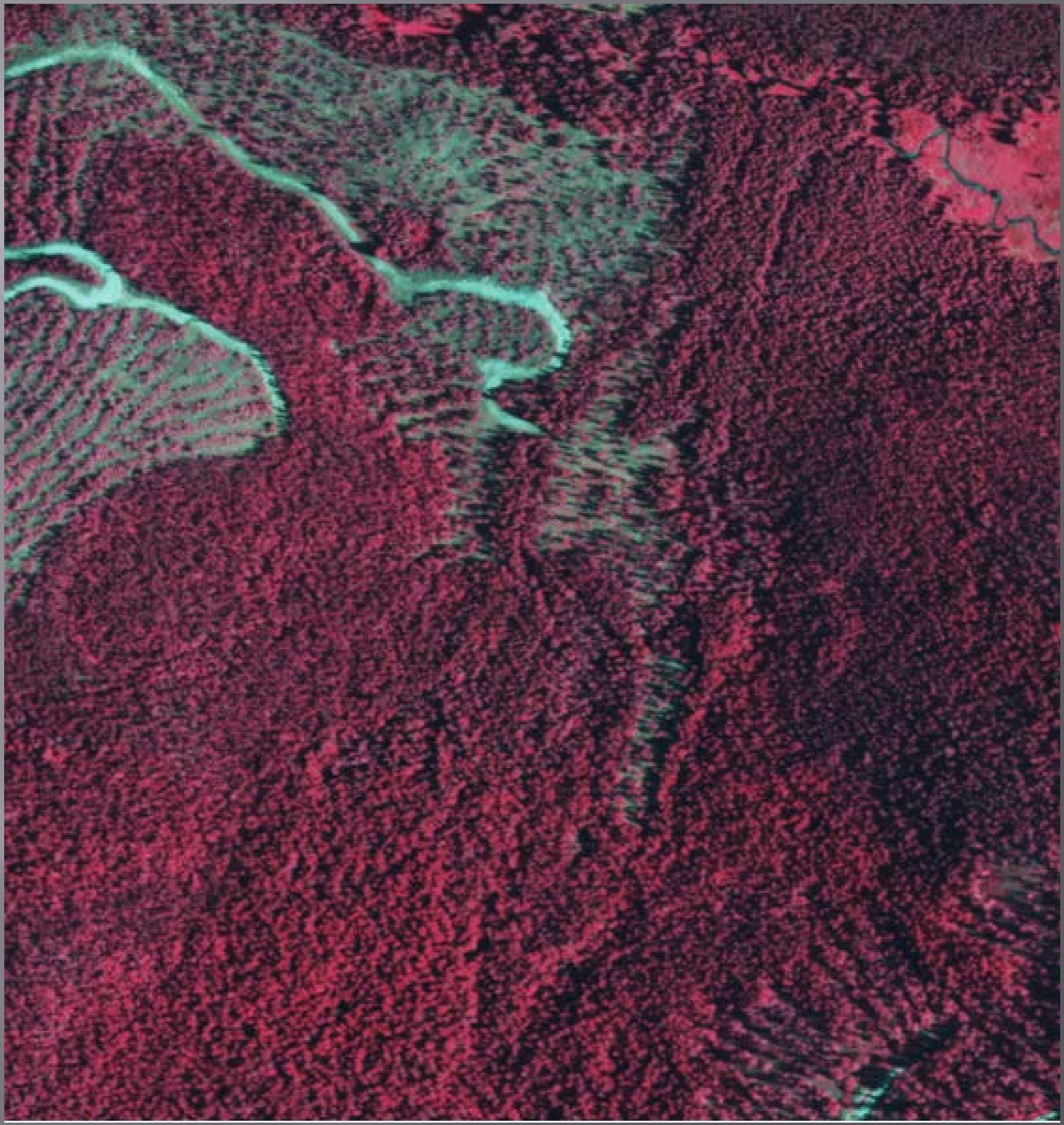
- Consistent adherence to rules and application of treatment
- Included post-harvest QA/QC
- Treatment in the uplands outside of the RMZ varied
  - 6 even age
  - 17 uneven age
  - 4 sites no harvest
  - 3 sites no harvest on one side

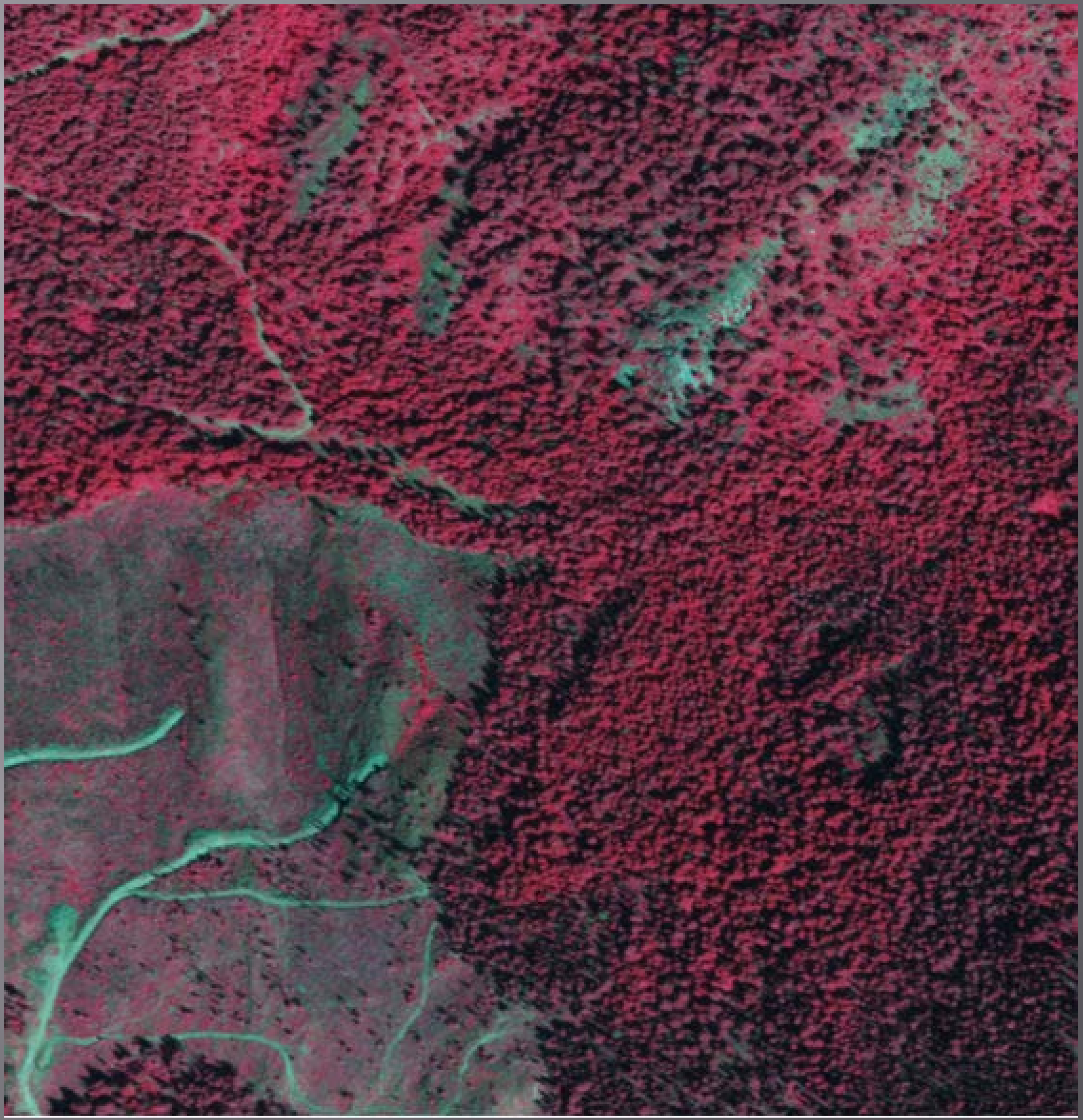
Harvest Treatments



Reference Uplands
Harvested After Study







Outline

- Background
- Purpose
- Study Design
- Site Selection and Installation
- RMZ Layout and Harvest
- Field Measurements
  - Channel and basin attributes
  - Forest stand attributes
  - Canopy closure and effective shade
  - Upland tree contribution to shade
  - Stream and air temperature

Channel and Basin Attributes

- Channel attributes
  - Wetted width
  - Bankfull width
  - Channel gradient
  - Dominant / subdominant substrate
- GIS Derived
  - Site elevation
  - Reach azimuth
  - Basin area
- Stream discharge
  - upstream end of the reference reach
  - boundary between the reference and treatment reaches
  - lower end of the treatment reach

Channel and Basin Attributes
All Sites

Attribute	Reference Reach	Treatment Reach
Basin Area (ac) *	1,732 (2108)	1,792 (2106)
Elevation (ft) *	3,382 (626)	3,305 (614)
Streamflow (ft^3/s)	0.5 (0.8)	0.5 (0.8)
Channel Gradient (%) *	8.4 (3.9)	7.6 (3.4)
Gravel (%)	53 (26)	53 (22)
Azimuth	39 (31)	39 (31)
Bankfull Width (ft)	9.5 (5.1)	9.9 (4.6)

Channel and Basin Attributes
Treatment Reach

Attribute	**ASR**	**SR**
Basin Area (ac)	2,085 (2750)	1,457 (966)
Elevation (ft)	3,354 (706)	3,248 (509)
Streamflow (ft^3/s)	0.6 (0.9)	0.5 (0.7)
Channel Gradient (%)	6.8 (2.7)	8.5 (4.0)
Gravel (%)	58 (10)	46 (29)
Azimuth	43 (32)	35 (30)
Bankfull Width (ft)	9.3 (4.6)	10.6 (4.7)

Riparian Stand Attributes

- 12 strip plots (6 on each side of the stream)
- Plot is 10 feet wide and extends out 130 feet
- All standing trees tallied separately for the core, inner, and outer zone
  - Species
  - dbh (to nearest inch)
  - tree height
  - height to live crown
- Each plot sampled within two years before and after harvest
- Windthrow, tree mortality, harvest, and felling accounted for in post-harvest samples

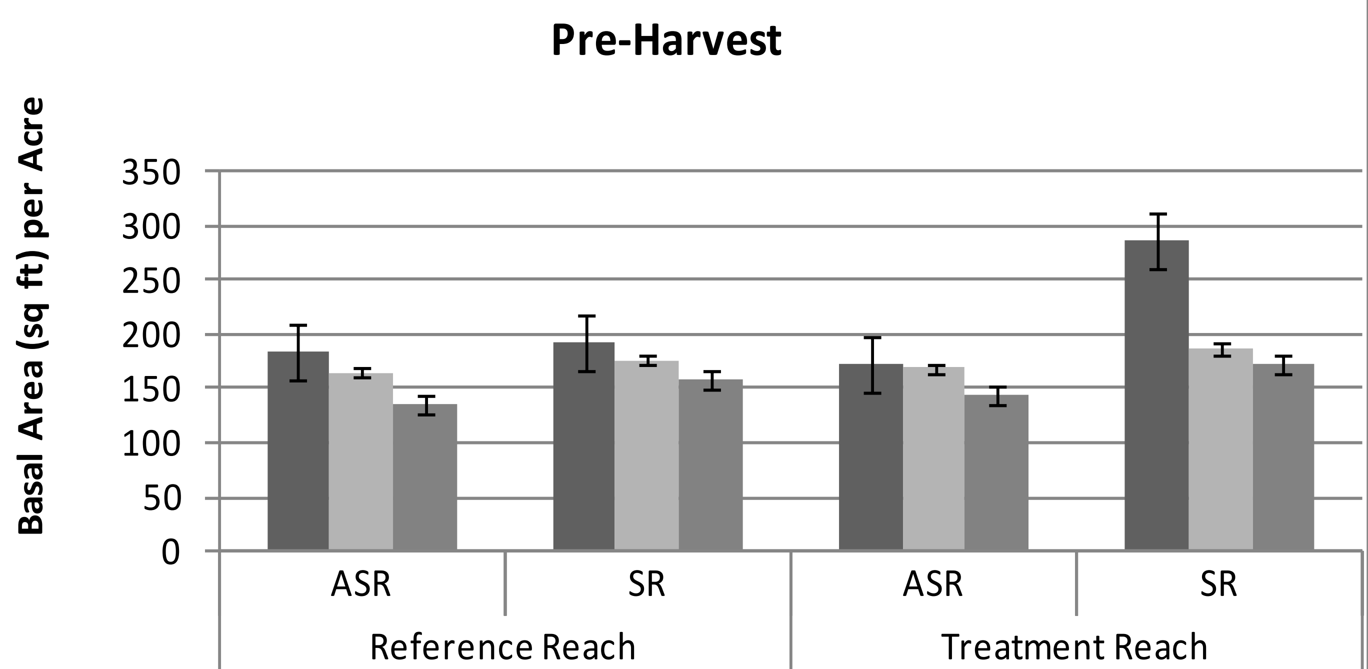
Pre Harvest
Riparian Stand Attributes

Treatment and Reference Reach Comparisons

Attribute	Reference Reach	Treatment Reach
Basal Area (ft^2/ac)	190 (69)	205 (69)
Trees / Acre	221 (90)	237 (88)
Mean Tree Diameter (in)	13 (3)	13 (3)
Live Crown Ratio	57 (6)	55 (8)
Tree Height (ft)	72 (7)	73 (8)

Pre Harvest
Riparian Stand Attributes

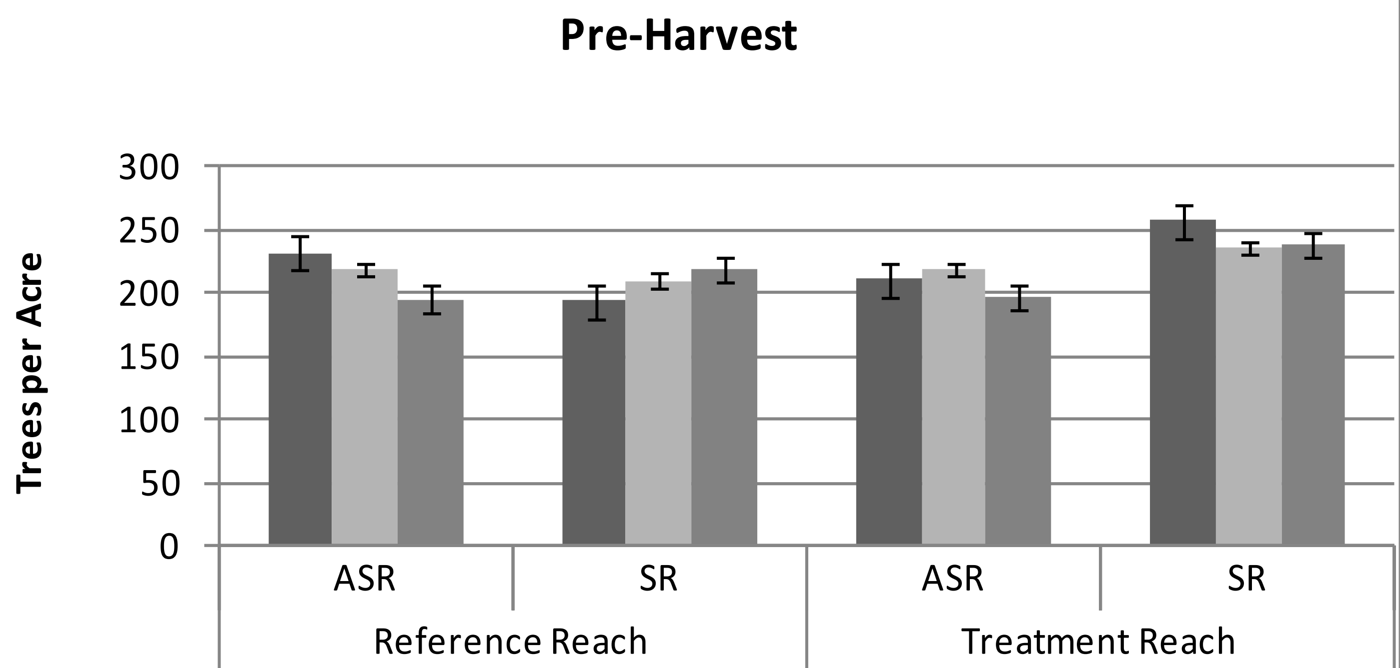
Basal Area



	Reference Reach ASR	Reference Reach SR	Treatment Reach ASR	Treatment Reach SR
Core	184	192	173	287
Inner	166	177	169	187
Outer	135	159	144	172

Pre Harvest
Riparian Stand Attributes

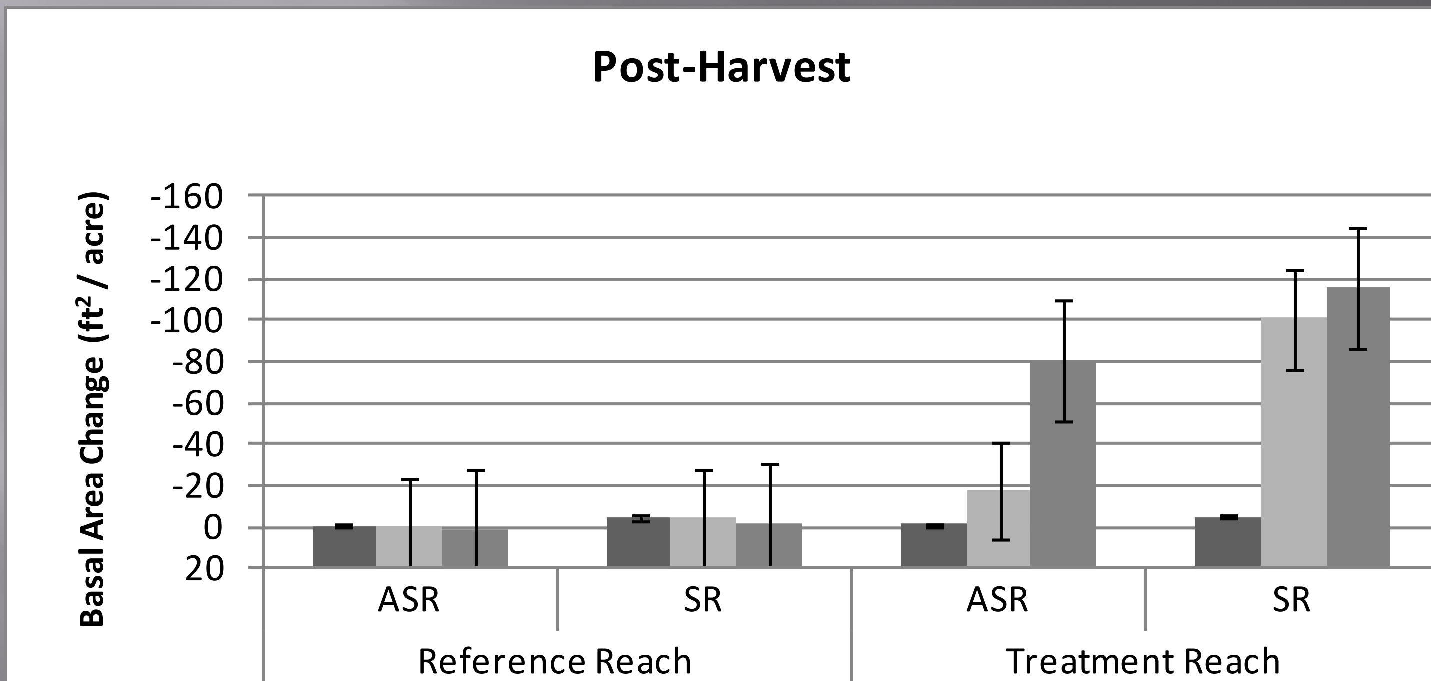
Tree Density



	Reference Reach ASR	Reference Reach SR	Treatment Reach ASR	Treatment Reach SR
Core	232	194	211	257
Inner	220	210	220	235
Outer	196	218	198	239

Riparian Stand Harvest Effects

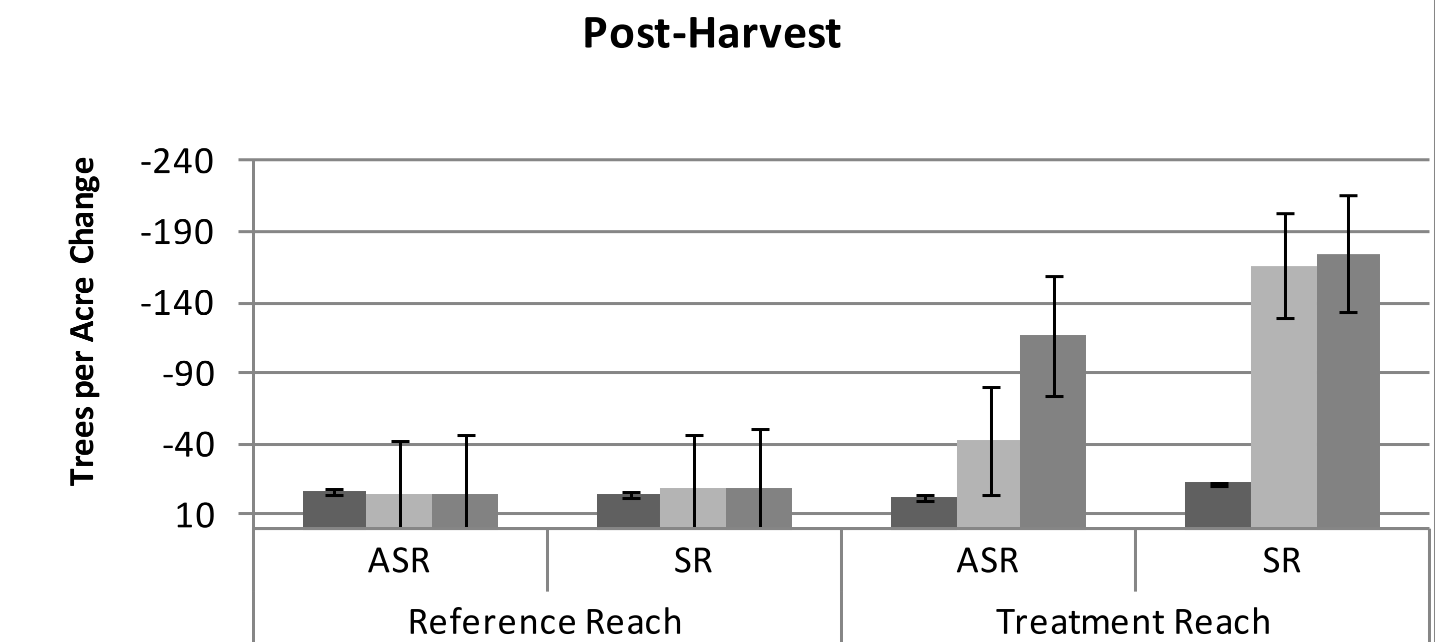
Basal Area



	Reference Reach ASR	Reference Reach SR	Treatment Reach ASR	Treatment Reach SR
Core	-0.5	-4.3	-1.1	-4.8
Inner	-0.2	-4.4	-17.1	-100.4
Outer	1.7	-1.6	-80.5	-115.2

Riparian Stand Harvest Effects

Tree Density

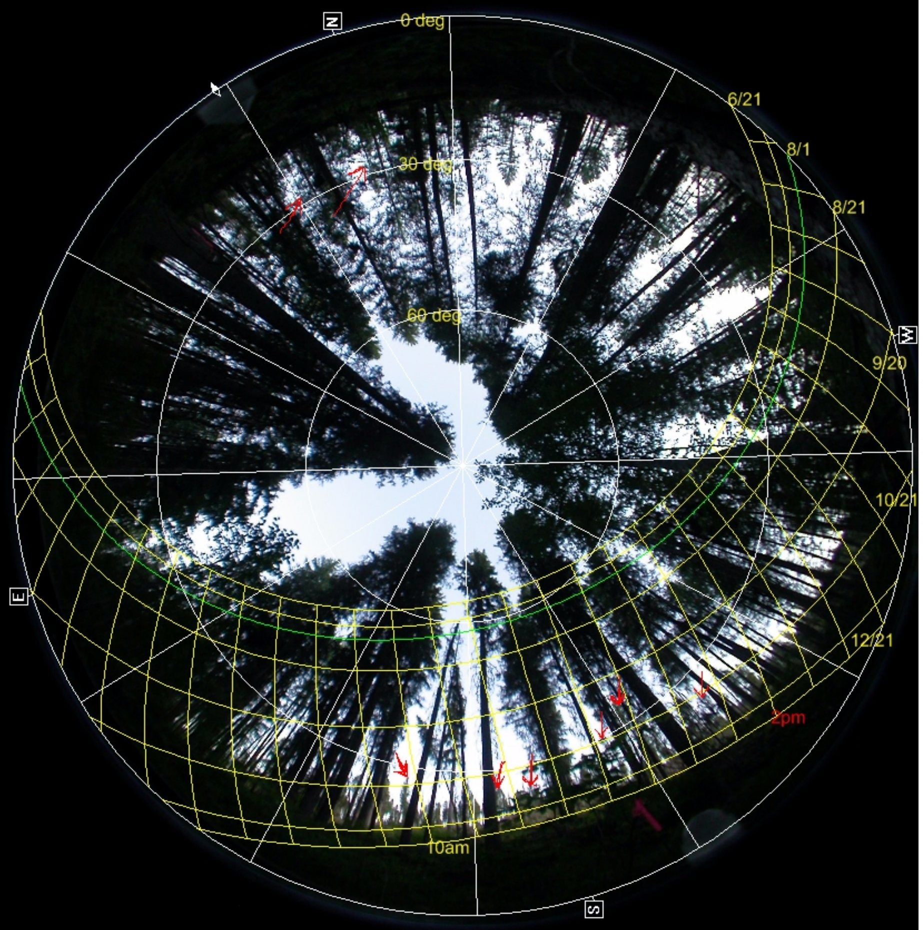


	Reference Reach ASR	Reference Reach SR	Treatment Reach ASR	Treatment Reach SR
Core	-7.2	-5.3	-2.8	-12.2
Inner	-5.5	-8.6	-42.4	-166.5
Outer	-4.5	-8.5	-116.3	-174.9

Canopy and Shade Measurements

- Measured at 25 m increments within the center of the wetted channel
- Repeated measures following timber harvest completion at same location
  - *Canopy closure (using densiometer and hemiview)*
  - *Effective Shading (Hemiview)*

Canopy and Shade Measurements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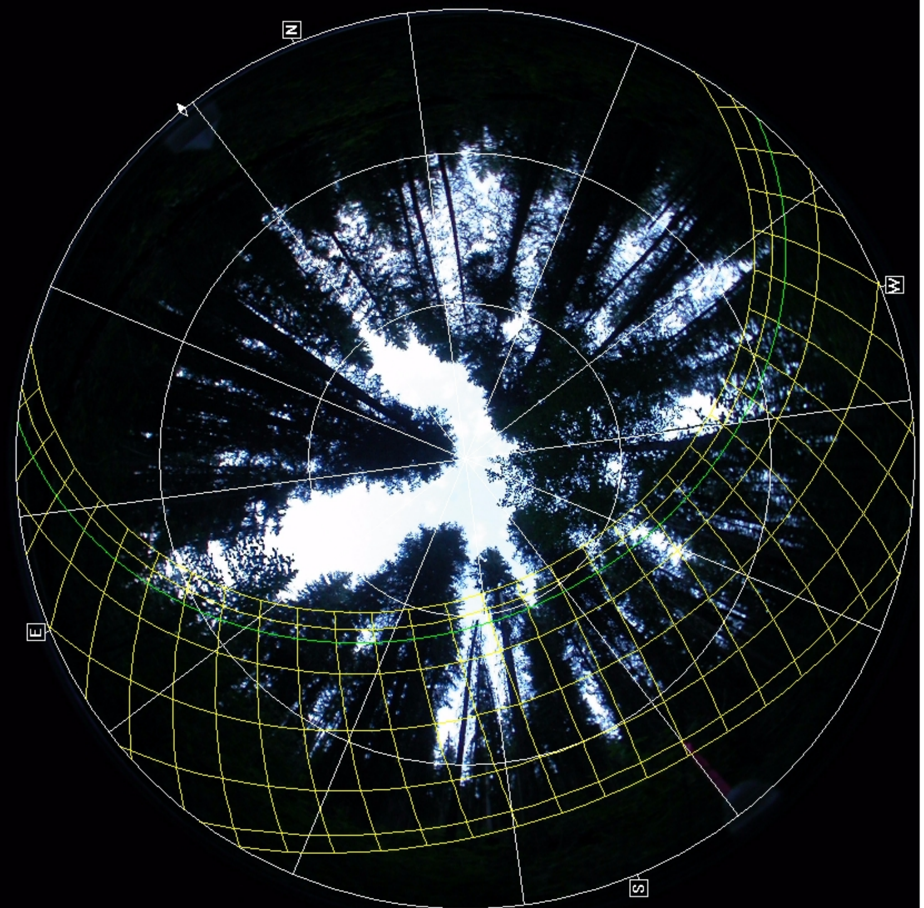
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Canopy and Shade Sites Prior to Harvest

Attribute	**Reference Reach**	**Treatment Reach**
Shade (%)	93 (2)	93 (2)
Canopy Closure (%)	88 (7)	88 (6)
Solar Attenuation (%)[a]	90 (5)	91 (4)
Solar Radiation (W/m^2) [a]	69 (39)	63 (35)

[a] Solar attenuation and radiation values are from McGreer et al. (2011) and were collected in the ASR sites only.

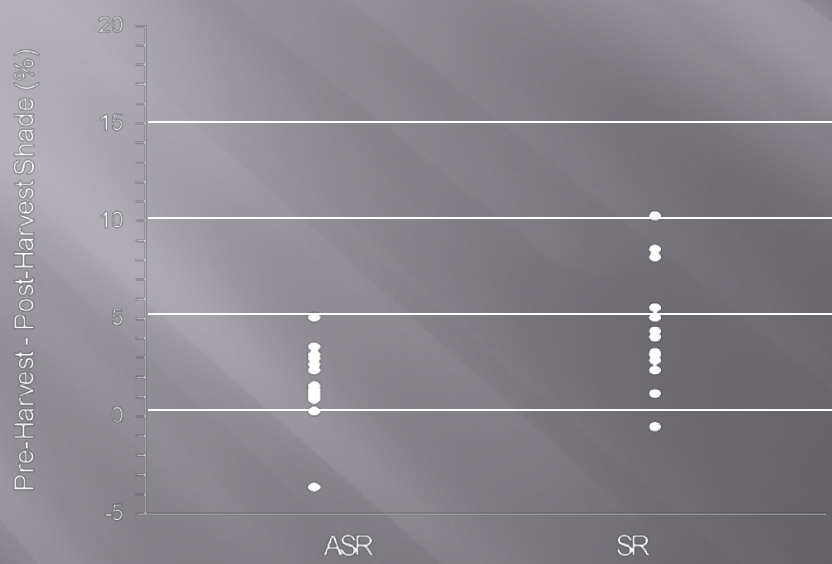
Canopy and Shade Prior to Harvest Treatment Reach

Attribute	ASR	SR
Shade (%)	93 (1)	93 (2)
Canopy Closure (%)	87 (6)	89 (6)
Solar Attenuation (%)[a]	91 (4)	
Solar Radiation (W/m^2) [a]	63 (35)	

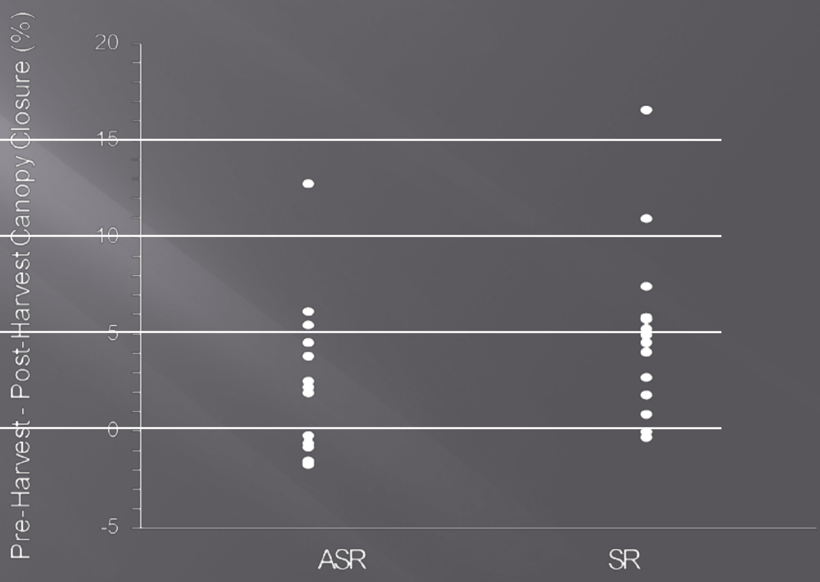
[a] Solar attenuation and radiation values are from McGreer et al. (2011) and were collected in the ASR sites only.

Canopy and Shade Harvest Effects

Shade



Canopy Closure



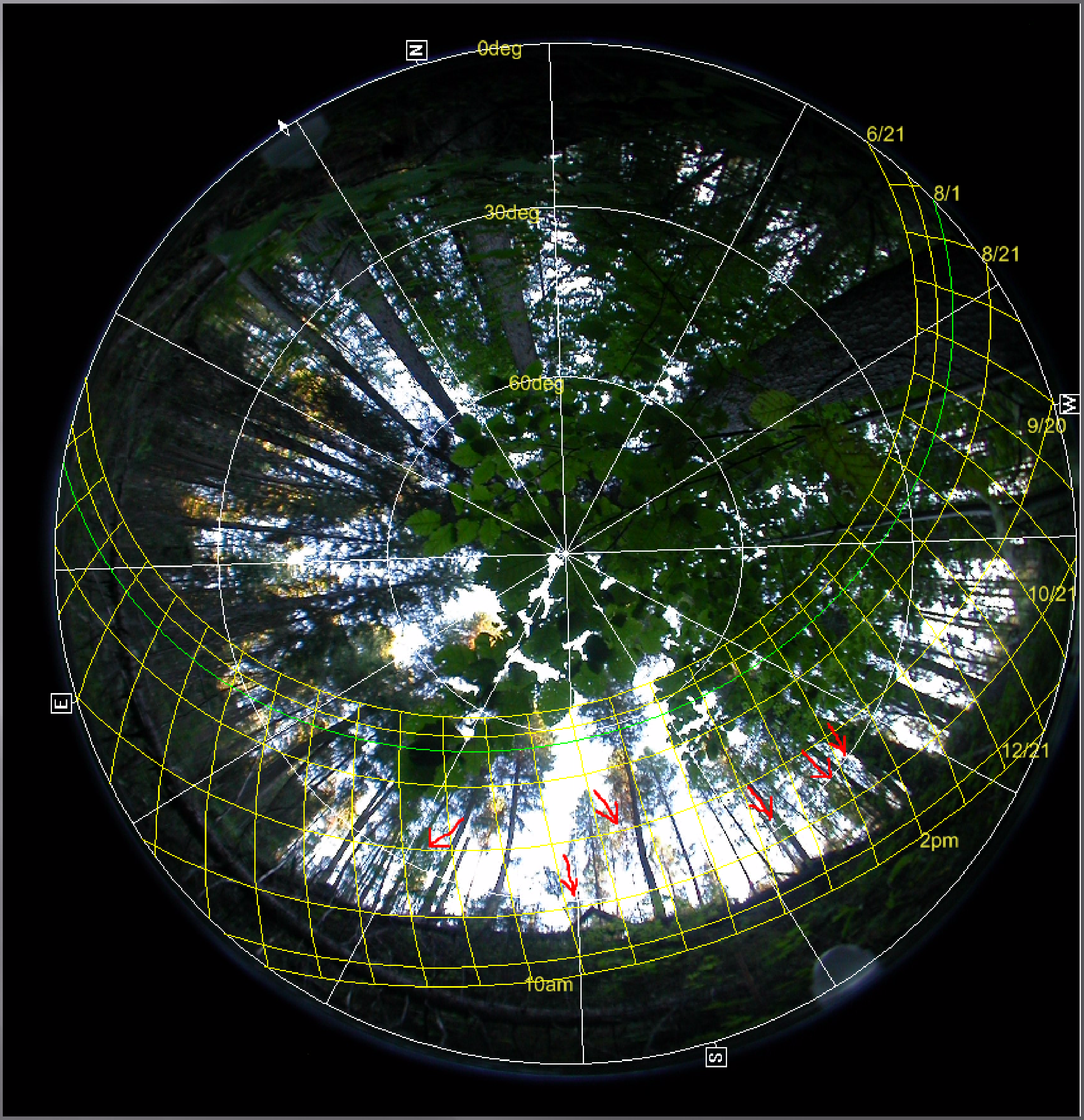
Influence of Retained Upland Trees on Shade

All RMZ treatments were harvested (or trees at least felled) to the fullest extent allowable under the Forest Practice Rules.

Upland harvest treatments varied between the sites.

Upland trees contributing to shade were identified

- 6 two-sided RMZ only harvest sites
- 2 one-sided RMZ-only harvest sites.
- 17 standard operational upland harvests sites



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Influence of Retained Upland Trees on Shade

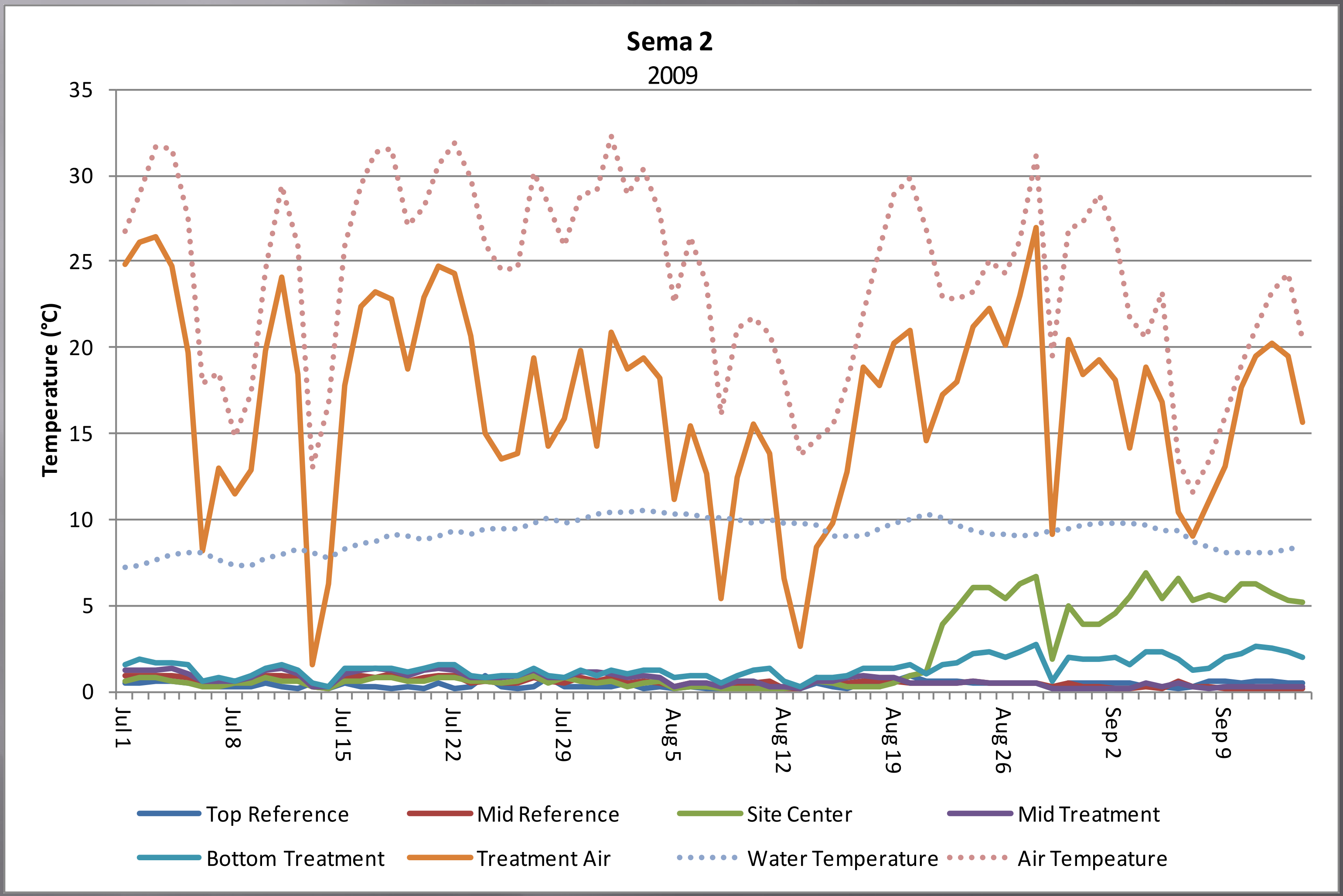
Average contribution of upland trees to effective shade per study site was calculated as < 1%.

No difference between RMZ only harvest and sites harvested under standard upland harvests operations (two-sample $t = 0.224$, $p = 0.821$).

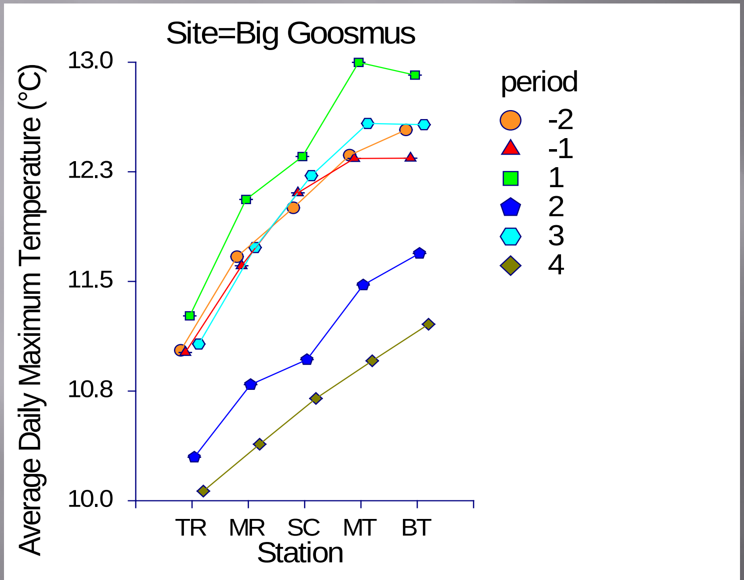
Stream and Air Temperature

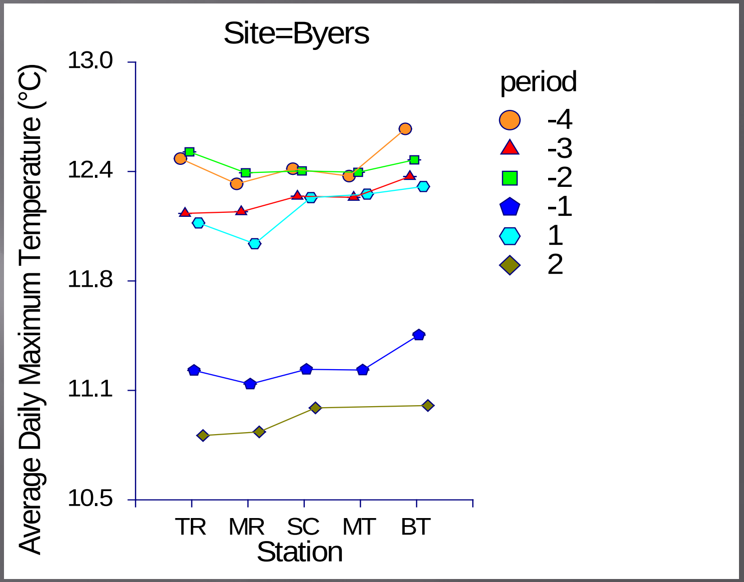
- Continuous temperature recorders at 150-m intervals throughout site
- 30 minute recording interval
- Air temperature dataloggers midpoints of the reference and treatment reaches, suspended 2-m over the stream channel.
- Daily time series extracted from each datalogger
  - Maximum
  - Mean
  - Minumum
- Measured for at least two summers before and two summers after riparian harvest

Stream Temperature Initial Screening



Stream Temperature Longitudinal Patterns





Stream Temperature
Site Specific Analysis

- Relationships between upstream and downstream temperatures and how they vary across years and harvest status were assessed with generalized least squares regression using daily time series for study site calibration following methods described by Gomi et al. (2006).

Stream Temperature
Site Specific Analysis

Data analysis included the following steps:

(1) establishment of regression relations between upstream and downstreeam temperatures for the pre-treatment periods to develop predictions (calibration)

(2) calculation of the differences between observed and predicted temperatures for both pre-harvest and post-harvest periods

(3) testing of the statistical significance of the differences between observed and predicted temperatures for the post-harvest periods, and

(4) analysis of the daily and seasonal variations of postharvest differences between observed and predicted temperatures, which provide estimates of the effects of the treatments.

Calibration Regressions

- Pre-harvest regression relations were developed for the daily maximum, mean, and 7 day maximum moving average stream temperatures at each treatment reach as a function of the corresponding values at the bottom of the upstream reach reference reach.
- Generalized least squares (GLS) regression was used to account for residual autocorrelation, using the implementation in the software package R.
- The error term was modeled as an autoregressive process

Calibration Regressions

The fitted model was:

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t$$

y_t - temperature at the bottom of a treatment reach on day *t*

x_t - corresponding temperature at the bottom of the upstream reference reach

β_o and β_1 - coefficients to be estimated by regression,

ε_t - error term (residual) modeled as an autoregressive process of order "*k*"

Calibration Regressions

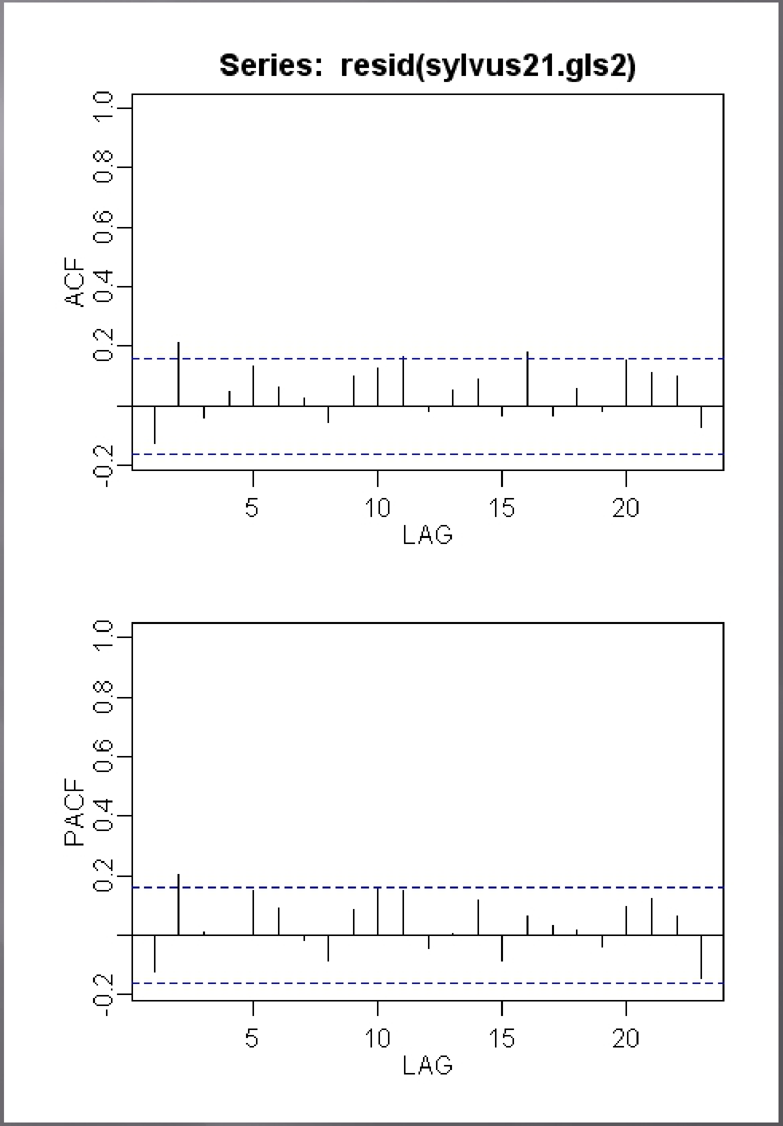
ε_t is an error term modeled as an autoregressive process of order "*k*"

$$\varepsilon_t = \rho_1 \varepsilon_{t-1} + \rho_2 \varepsilon_{t-2} + \dots\dots\dots. + \rho_k \varepsilon_{k-1} + u_t$$

ρ_i -> autocorrelation between error terms at a lag of "i" days,
ε_{t-i} -> error term "i" days before day "*t*", and
u_t -> random disturbance, assumed to be normally distributed with constant variance.

Order *k* was determined by examining partial autocorrelation functions (PACF) and plots of the pre-treatment residuals and retaining only the terms with statistically significant partial autocorrelation coefficients.

Calibration Regressions



Treatment Effect

The treatment effect on a given day in the post harvesting period (T_e) was estimated as

$$T_e = y_t - \hat{y}_t$$

Where y_t and $\hat{y}_t$ are the observed and predicted temperatures on day t

Treatment Effects => observed – predicted in treatment reach during the post-harvest period

Post harvest predicted values did not take the autoregressive error structure into account

Reference Variability
Background Response

- Similar pre-treatment calibration regressions were fitted for the reference reach
- Background responses => observed – predicted in reference during the post-harvest period
- Background response was computed to identify the variability in the cooling and warming rates in the absence of a treatment
- Establish the magnitude of post-harvest changes needed to clearly demonstrate a direct cause and effect linkage to riparian harvest treatment

Results of the Regression Analysis

- Significant ($p < 0.05$) residual autocorrelation in the pre-harvest regression was found for all streams in both the treatment and reference reaches.

- For maximum stream temperature, residuals were autocorrelated up to order 3 in both the treatment and reference reaches.

- Fits were relatively good for all temperature variables, where all r^2 values exceeded 0.75 with $p < 0.01$ in both the reference and treatment reaches in all study sites.

- Background responses and treatment effects most strongly expressed for daily maximum temperature

Evaluation of Treatment Effects and Background Responses

(following Gomi et al. (2006) and Watson et al. (2001)

First remove the autocorrelation from the residuals to provide and estimate of random disturbances:

$$\hat{u}_t = (y_t - \hat{y}_t) - \hat{\rho}_1(y_{t-1} - \hat{y}_{t-1}) - \hat{\rho}_2(y_{t-2} - \hat{y}_{t-1}) - \ldots - \hat{\rho}_k(y_{t-k} - \hat{y}_{t-k})$$

Where u_t is an estimate of the random disturbance on day t and p_i is and estimate of the lag i autocorrelation coefficient for the GLS regression fit.

Evaluation of Treatment Effects and Background Responses

- Under the null hypotheses of no riparian management treatment effect (true in the case of the control reaches), the distributions of the residuals and disturbances should be the same in both the calibration and test periods.

Evaluation of Treatment Effects and Background Responses

- Under the null hypotheses of no riparian management treatment effect (true in the case of the control reaches), the distributions of the residuals and disturbances should be the same in both the calibration and test periods.
- Two-sample Kolmogorov-Smirnov test for the distribution of disturbances between the pre-treatment period and each post – treatment year.
- The test does not require normality or equality of variance.

Background Responses

- Daily background responses ranged from -1.7 °C to 2.6 °C, with averages for the study sites ranging from - 0.3 °C to 0.5 °C with a mean of 0.0
- Seasonal mean DMAX background response ranged from -0.6 ° to 0.9 °C with a mean of 0.0
- 10 sites had daily background responses exceeding 1.0 °C, and these occurred during less than 1% in all days sampled
- 34 of the 98 seasonal means in 17 different study sites exceeded an absolute value of 0.2 °C, the established accuracy of the Tidbit data loggers.

Background Responses

- Fewer than 5% of the deviations in the remaining 9 sites were less than 1.0 °C in absolute value.
- These results suggest that pre-harvest regressions are reasonably stable and should provide a basis for indentifying post harvest treatment effects that exceed 0.3 °C in the majority of the sites. And

Background Responses

- The Komolgorov-Smirnov test indicated significant change between the calibration and test periods 19 of the 30 study sites
- More than 95% of the DMAX stream temperature background responses were less than 0.5 °C; over 98% of the background responses were less than 1.0 °C
- Suggest that site-specific pre-harvest regressions provide a basis for identifying post-harvest single daily maximum temperature responses in the treatment reaches as small as 0.5 °C.

Regression Analysis
Magnitude and Significance of Treatment Effects

- Treatment effects in daily maximum stream temperature ranged from -2.3 °C to 2.0 °C.
- Mean site treatement effects ranged from - 0.7 °C to 0.5 °C
- Mean DMAX treatment effects exceeded 0.2 °C in at least one sample period in 15 of the 30 study sites.
- Mean treatment effects exceeded 0.7 °C in only one site during one season and exceeded 0.5 °C in six additional sites
- The Komolgorov-Smirnov test indicated significant change between the calibration and test periods 21 of the 30 study sites

Regression Analysis
Magnitude and Significance of Treatment Effects

- Mean daily maximum temperature effects
  - 0.2 °C for SR
  - 0.0 °C for ASR
- Background responses
  - - 0.1 °C for SR
  - 0.1 °C for ASR

- In the first two sample periods following harvest, treatment effects were statistically significant during at least one year for 6 SR sites and 5 ASR sites despite what appeared to be only slight differences in mean predicted versus observed DMAX temperatures in many cases.

			Reference							Treatment				
		PL	**Post 1**	**Post 2**	**Post 3**	**Post 4**	**Post 5**		**PL**	**Post 1**	**Post 2**	**Post 3**	**Post 4**	**Post 5**
		All Available Shade Rule												
Bacon		0.3	**-0.1**	**-0.2**	**-0.2**	**-0.2**	**-0.2**		0.2	**0.0**	**0.0**	**0.1**	0.0	0.0
Clark		0.4	0.2	**0.2**					1.3	0.2	0.4			
Cole		0.4	0.0	0.0					0.3	0.1	0.0			
Dry Canyon		0.7	**-0.5**	-0.3	-0.6	0.2			0.2	**-0.1**	**0.1**	**0.2**	**0.1**	
Floedelle		0.8	**0.3**	**0.4**					0.7	-0.2	**-0.3**			
Long Alec		1.1	0.4	0.4	0.2				0.9	-0.1	-0.3	**-0.1**		
Lotze		0.3	**-0.1**	0.0	0.1				0.3	**0.2**	**0.2**	0.0		
Mill		0.4	**-0.2**	0.1	0.1	0.0	-0.1		0.5	**0.5**	0.2	0.1	0.0	**0.4**
Moses		0.4	-0.1	-0.2					0.6	**-0.1**	0.0			
NF Foundation		0.3	0.0	**0.1**	**0.2**				0.3	-0.1	-0.1	0.1		
Sanpoil		0.7	-0.1	0.1	**-0.3**				0.6	**0.7**	0.2	0.3		
Seco		1.3	0.1	0.2	0.3	0.1			1.4	**-1.1**	**-0.2**	**-0.4**	**-1.2**	
Sema 1		1.1	-0.2	0.1					0.6	0.0	0.2			
Sema 2		1.0	0.4	0.2					1.2	0.6	0.3			
SF Ahtanum		0.3	0.0	0.1	0.0				0.4	0.0	0.0	0.1		
Tungsten		0.4	**0.9**	**0.4**	**0.8**	0.1			0.7	-0.1	**0.2**	0.1	0.2	
		Standard Rules												
Big Goosmus		0.5	0.0	**-0.2**	0.1	-0.2			0.5	0.2	**0.4**	0.0	0.2	
Byers		0.4	**0.2**	**0.2**					0.3	-0.1	-0.2			
Dorchester		0.3	**-0.2**	**-0.1**	-0.1	-0.1			0.2	**0.2**	**0.2**	**0.3**	**0.1**	
Dry Creek		1.0	-0.1	0.1	**0.4**	**0.5**	**0.5**		1.1	0.2	**0.8**	-0.4	0.2	-0.4
EF Cedar		0.2	0.0	-0.1	0.0	-0.1			0.2	**0.1**	**-0.1**	**0.1**	**0.1**	
EF Cedar Trib		0.3	0.0	-0.1	-0.1	-0.2			0.3	**0.2**	0.1	-0.2	0.0	0.1
Heel		0.7	0.1	0.3	-0.3				0.2	**-0.1**	**-0.2**	0.0		
Little Goosmus		1.2	**-0.5**	**-0.5**	-0.1				1.6	-0.5	-0.1	0.2		
Middle		0.3	0.0	**-0.1**					0.2	**0.2**	**0.2**			
Prouty		0.2	0.0	**0.1**	-0.1	**-0.1**			0.6	**0.6**	**0.6**	**0.5**	0.3	
Sema 3		0.4	0.1	0.0					0.8	0.3	0.0			
Sema 4		0.4	**-0.2**	**-0.3**	-0.2	**-0.3**			0.4	**0.4**	**0.5**	**0.6**	**0.4**	
SF Dairy		0.7	-0.3	0.1	**-0.3**	-0.1			0.6	0.1	0.2	0.2	0.1	
Sylvus		0.2	0.0	**-0.1**	**-0.4**	**-0.6**			0.3	**0.2**	**0.2**	**0.6**	**0.4**	

Significance of Treatment Effects

- More than 90% of the DMAX stream temperature responses were 0.5°C or less; over 98% of the background responses were less than 1.0 °C.
- Measures of reference variability suggest that deviations of as much as ±0.5 °C are likely to occur even with no timber harvest impacts.
- Study site mean temperature responses exceeded the 95% regression prediction limits in only two sites ; both exceeded the limit by 0.1 °C.
- These results are similar to those observed for background responses in the reference reaches, suggesting that the range and variability in temperature responses were similar to the background responses observed in the reference reaches.

- Changes are minor and mostly beyond the accuracy of the thermographs

Pooled Evaluations

No relationship among canopy, shade, covariate data and stream temperature treatment effects

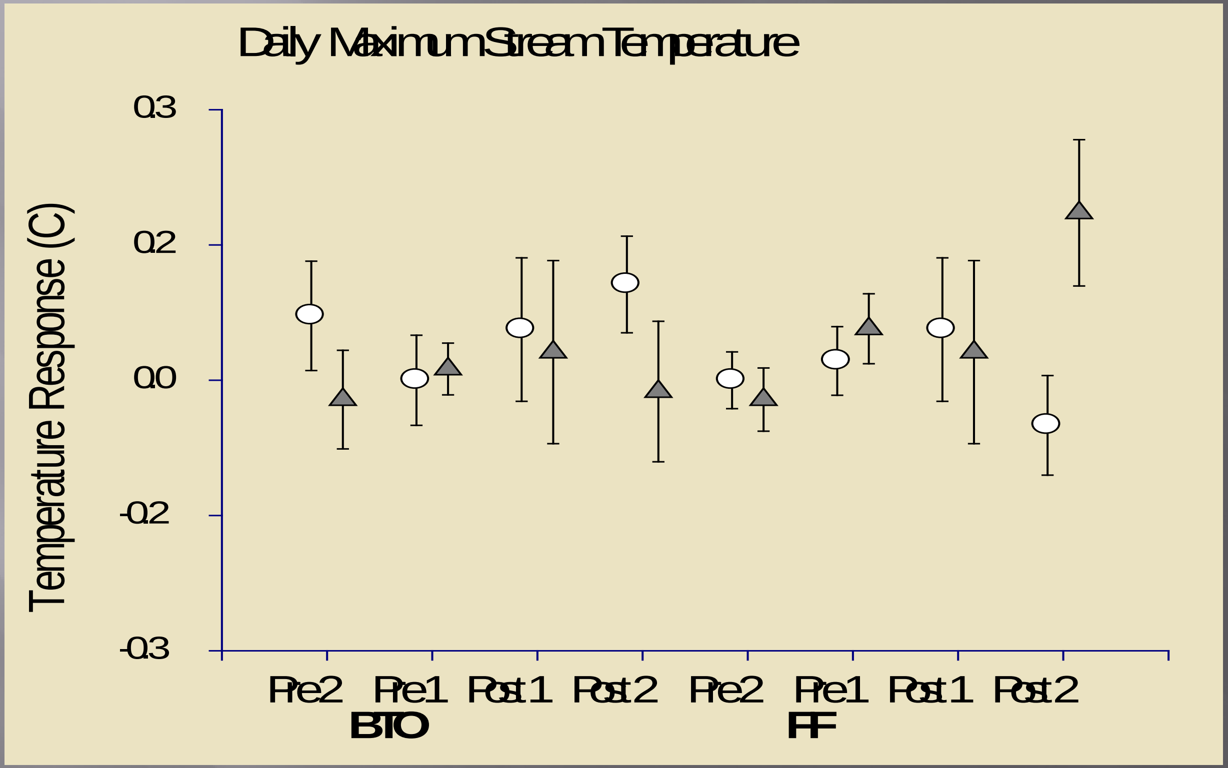
No relationship among shade, canopy, and changes in stand conditions

Pooled Evaluations

Three-way analysis of variance having two levels of prescriptions (ASR, SR), two levels of reach (Reference, Treatment), and four levels of sample period (Pre_1, Pre_2, $Post_1$, $Post_2$).

No significant three-way interaction among prescription, reach, and sample periods ($F_{3, 220} = 0.434$, $p = 0.697$), nor was there significant two-way interactions among prescription and sample period ($F_{3, 220} = 0.33$, $p = 0.804$) or among reach and sample period ($F_{3, 220} = 1.57$, $p = 0.198$).

Pooled Evaluations



Pooled Evaluations

Main interest in the analysis was the three-way interaction among the prescription, reach, and sample period factors (i.e. was there a significant post-harvest response in the treatment reach?).

Results indicate there is no treatment effect for either prescriptions and there were no significant differences in the treatment effects between prescriptions.

	Background Response			Treatment Effect		
Site	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
	All Available Shade Rule					
Bacon	-0.1	-0.4	0.0	0.0	-0.1	0.2
Clark	0.2	-0.3	0.8	0.3	-0.7	1.7
Cole	0.0	-0.3	0.2	0.1	-0.3	0.4
Dry Canyon	-0.4	-1.1	0.1	0.0	-0.2	0.4
Floedelle	0.4	0.0	0.8	-0.3	-0.6	0.1
Long Alec	0.4	-0.5	2.6	-0.2	-1.2	0.6
Lotze	-0.1	-0.4	0.4	0.2	-0.3	0.6
Mill trib	0.0	-0.6	0.6	0.4	-0.3	1.1
Moses	-0.1	-0.5	0.1	0.0	-0.4	0.4
NF Foundation	0.1	-0.2	0.5	-0.1	-0.3	0.2
Sanpoil	0.0	-0.9	1.3	0.5	-0.2	2.0
Seco	0.2	-0.6	1.3	-0.7	-1.5	0.2
Sema 1	0.0	-1.6	1.3	0.1	-1.0	0.7
Sema 2	0.2	-1.3	2.5	0.4	-0.8	1.1
SF Ahtanum	0.0	-0.3	0.3	0.0	-0.4	0.2
Tungsten	0.6	0.0	1.3	0.1	-0.5	0.9
Mean	**0.1**	**-0.6**	**0.9**	**0.1**	**-0.6**	**0.7**
	Standard Rule					
Big Goosmus	-0.1	-0.6	0.5	0.3	-0.4	1.7
Byers	0.2	-0.2	0.4	-0.1	-0.4	0.3
Dorchester	-0.1	-0.3	0.3	0.2	-0.2	0.5
Dry Creek	0.0	-1.0	1.0	0.6	-0.7	1.4
EF Cedar	0.0	-0.3	0.4	0.0	-0.5	0.3
EF Cedar Trib	-0.1	-0.3	0.2	0.2	-0.5	0.6
Heel	0.2	-0.9	1.0	-0.2	-0.6	0.2
Little Goosmus	-0.5	-1.1	0.1	-0.3	-1.7	1.0
Middle	-0.1	-0.3	0.1	0.2	0.0	0.4
Prouty	0.1	-0.4	0.4	0.6	-0.1	1.5
Sema 3	0.0	-0.4	0.7	0.2	-0.8	1.0
Sema 4	-0.2	-0.8	0.3	0.4	-0.2	1.0
SF Dairy	-0.1	-0.9	0.4	0.1	-0.3	0.5
Sylvus	-0.1	-0.4	0.2	0.2	-0.1	0.5
Mean	**-0.1**	**-0.6**	**0.4**	**0.2**	**-0.5**	**0.8**

Discussion

- Effectiveness at maintaining shade
- Prescription Effectiveness at Maintaining Shade
- Relationships Among Shade and Riparian Characteristics
- Stream Temperature Response to Harvest
- Magnitude of Harvest Effects
- Variability in Longitudinal Stream Temperature Patterns
- Applicability Across Eastern Washington Forested Streams
- Potential Confounding by Broadened Selection Criteria
- Experimental Design and Data Analysis

Conclusions

- ASR limited the decrease in shade to 1% on average, with a maximum decrease of 4%. Under the SR, shade was reduced by an average of 4%, with a maximum decrease of 10%.
- We found no relationship among pre-harvest to post-harvest change in shade and incoming solar radiation in the ASR sites.
- Examination of 16 ASR and 14 SR study sites using a BACI study design revealed small increases in summer stream temperature following timber harvest.
- Large variations were observed both reference variability and treatment effects, and hence, the differences between prescriptions are not great enough to be statistically significant.
- Changes in canopy closure, shade, and stand attributes did not account for the variations observed in stream temperature responses, suggesting that processes not directly related to timber harvest were responsible for the variations observed in stream temperature following timber harvest.
- Study results suggest that both the All Available Shade Rule and the Standard Rule are both likely to maintain stream temperatures similar to control conditions.