

1 **Riparian Characteristics and Shade Response Experimental Research Study**
2 **Draft Study Design**

3
4 **INTRODUCTION**

5
6 The effect of timber harvest on stream temperature is a key issue for meeting water quality standards in
7 Washington State. Increases in stream temperature following timber harvest can alter stream
8 ecosystem processes and trophic dynamics, and cause stress and mortality of aquatic species, including
9 threatened and endangered fish species (Beschta et al. 1987, Bryant and Lynch 1996, Myers and Bryant
10 1998). Protecting stream temperature is a priority of the Washington Forest Practices Rules and is
11 directly related to the [Forests and Fish Report](#) (FFR 1999) and [Forest Practices Habitat Conservation Plan](#)
12 (Schedule L-1, Appendix N; FPHCP 2005) performance goals for meeting state water quality standards.
13 Removal of shade is strongly associated with increases in stream temperature (Brown 1969, Johnson
14 and Jones 2000, Danehy et al. 2005, Moore et al. 2005).

15
16 Washington's forest practices rules include requirements for retention of riparian buffers along streams
17 to help maintain stream shade following timber harvest in adjacent uplands. The regulations include no-
18 harvest buffers of varying width. In some cases, these no-harvest buffers can be combined with adjacent
19 riparian buffers in which some amount of timber harvest (thinning) is allowed. In total, the forest
20 practices rules allow for over 90 different riparian buffer configurations, the majority of which remain
21 untested regarding their effects on stream shade. This study will conduct a field experiment to examine
22 stream shade response to a range of riparian harvest treatments similar to those permitted under
23 Washington's forest practices rules.

24
25 **Problem Statement**

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27 Washington's forest practices regulations include riparian prescriptions that incorporate stream-
28 adjacent no-harvest buffers of varying width. The rules include no-harvest buffers that can be used
29 alone or in some cases applied in combination with adjacent buffers of varying width within which some
30 amount of harvest (thinning) is allowed. Field research is particularly limited examining the combined
31 effect of stream-adjacent no-harvest zone width and adjacent-stand harvest intensity (i.e., thinning
32 density) on stream shade. This study will address a key question about how shade could be affected by
33 using forest thinning as a riparian management tool.

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35 **Purpose**

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37 The purpose of this study is to evaluate how stream shade responds to a range of riparian harvest
38 treatments of varying intensity within multiple environments common to commercial forestlands
39 covered under the Forest Practices Habitat Conservation Plan (FPHCP 2005).

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41 For the purposes of this study, stream shade (effective shade, *ES*) is defined as the fraction of total
42 possible solar radiation blocked from reaching the stream surface for the period 1 June to 1 September
43 for solar altitudes 40° or greater. Note that solar altitude refers to the sun angle relative to the horizon.
44 This experimental design is intended to isolate the effects of the riparian harvest treatments on stream
45 shade assuming a common stream azimuth (east-west and north-south), latitude/longitude, and portion
46 of the solar cycle. Thus, this study is not intended to evaluate the mean treatment response across all
47 possible scenarios. Rather, stream azimuth, latitude/longitude, time of year, and time of day will be
48 standardized across all the study sites (described in more detail in the Methods section).

49 **Objectives**

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- 51 1. Estimate stream shade response to a range of riparian harvest treatments that combine
52 different stream-adjacent no-harvest zone widths and adjacent-stand harvest intensities (i.e.,
53 thinning treatments or clear-cut).
54 2. Examine how stand composition and structure characteristics influence stream shade response
55 to the riparian harvest treatments.

56

57 **Critical Questions**

58

- 59 1. How does stream shade respond to riparian harvest treatments with different stream-adjacent
60 no-harvest zone widths and adjacent-stand harvest intensities?
61 2. How does stream shade response to the riparian harvest treatments vary among ecoregions
62 where commercial timber harvest commonly occurs?
63 3. What are the important patterns, trends, and relationships between stand characteristics and
64 stream shade response to the riparian harvest treatments?

65

66

67 **LITERATURE SUMMARY**

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69 A full literature review was completed within the approved scoping document (Hicks 2018) for this
70 project. The following section provides a brief summary of that literature review, including references
71 for relevant, recently completed Cooperative, Monitoring, Evaluation, and Research committee (CMER)
72 research projects.

73

74 Shade provided by riparian vegetation is generally the single most important variable influencing
75 summer water temperature for perennial streams in forested environments (Brown 1969, Johnson and
76 Jones 2000, Danehy et al. 2005, Moore et al. 2005). Harvest of riparian trees can reduce canopy cover
77 and shade, thereby increasing the amount of solar radiation reaching the stream (Brazier and Brown
78 1973, Moore et al. 2005, Ehinger et al. 2018). Reductions in canopy shading of more than 6-10% have
79 been associated with measurable increases in stream temperature (>0.2 °C; Wilkerson et al. 2006,
80 Groom et al. 2011b, Guenther et al. 2014, Bladon et al. 2016, Witt et al. 2016, Ehinger et al. 2018,
81 Raulerson et al. 2020, Roon et al. 2021). Forestry regulations commonly establish riparian buffer zones
82 along streams in which harvest is restricted to minimize shade loss and other adverse environmental
83 effects.

84

85 The amount of stream shade provided by a riparian buffer is related to the width, tree density, and
86 height of the trees in the buffer (DeWalle 2010) and the intensity and configuration of tree harvest
87 (thinning) within the buffer. Understory vegetation, standing dead trees, and topography can also be
88 important contributors to stream shade. Removal of more than about 25-30% of standing trees or basal
89 area within a riparian buffer is associated with reduced stream shading and increased stream
90 temperature (Wilkerson et al. 2006, Boggs et al. 2016, Roon et al. 2021).

91

92 Evidence suggests that wider riparian buffers provide more opportunity for thinning within the buffer
93 without causing a significant loss of canopy cover or increase in stream temperature (Wilkerson et al.
94 2006, Groom et al. 2011a, Groom et al. 2011b, Groom et al. 2018). Adding a stream-adjacent no-harvest
95 zone within the buffer may increase the ability to thin adjacent stands at higher intensities with minimal

96 or no loss in stream shading (Park et al. 2008, Teply et al. 2014). The no-harvest zone width necessary to
97 prevent shade loss depends on the intensity of the adjacent harvest zone thinning treatment.
98 The effectiveness of riparian buffers for maintaining shade and stream temperature is also a function of
99 riparian stand characteristics immediately following harvest, along with the changes that occur over
100 succeeding seasons. Stand characteristics, including species composition, basal area, tree density, tree
101 height, and live crown ratio can influence stream shading (Allen and Dent 2001, Dent et al. 2008,
102 DeWalle 2010, Groom et al. 2011b). In general, stream shading is positively correlated with basal area,
103 tree density, and tree height, but the importance of individual variables depends on site conditions, such
104 as stream orientation (DeWalle 2010, Groom et al. 2011b). Therefore, the effectiveness of riparian
105 harvest rules for maintaining stream shade varies based on stand characteristics, location, and time
106 since harvest.

107

108 **METHODS**

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110 **Study Area and Site Selection**

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112 The study area includes riparian forest stands along Type Np (non-fish-bearing perennial) and Type F
113 (fish-bearing) streams occurring on non-federal lands managed under the FPHCP within the Northwest
114 Coast, West Cascades, Okanogan, and Canadian Rocky Mountains ecoregions in Washington State
115 (Figure 1; WADNR 2007). Specifically, field study sites will be selected according to the following criteria:

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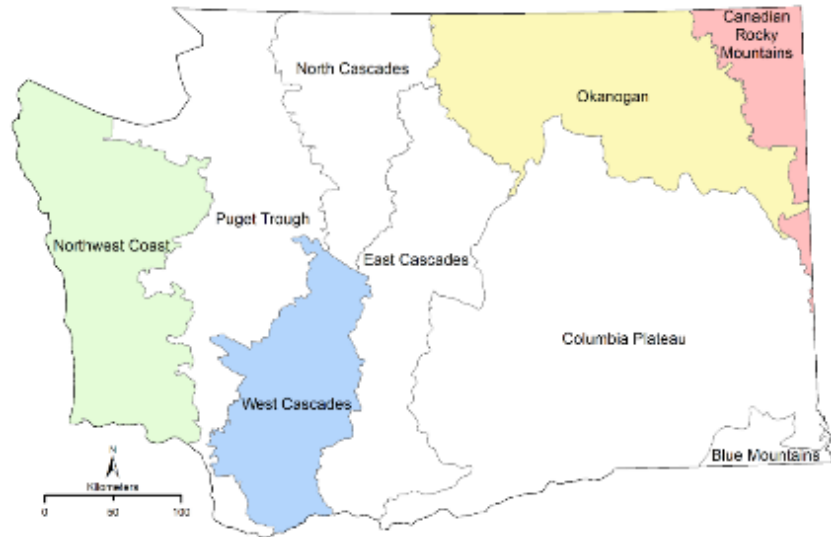
- 117 1) Within the Northwest Coast, West Cascades, Okanogan, or Canadian Rocky Mountains ecoregions in
118 Washington State (Figure 1).
- 119 2) Riparian stands of harvest age.
- 120 3) Washington Department of Natural Resources (WADNR) Site Classes II and III (FFR 1999; Table 1).
- 121 4) Type Np or Type F streams with bankfull widths from 5 to 25 feet.
- 122 5) Local topography does not completely obscure solar radiation penetration to the stream for more
123 than 10% of the solar period that will be evaluated in this study (the solar period evaluated in this
124 study is described later).

125

126 The first four criteria represent the geographic regions, stand age range, and site conditions where
127 timber harvest most commonly occurs on non-federal forest lands in Washington state ([Forest Practices
128 Application Review System, FPARS](#)).

129

130 The ecoregion boundaries were initially developed by the U.S. Environmental Protection Agency and
131 refined by Washington Natural Heritage Program scientists (WADNR 2007). Each ecoregion is
132 characterized by a distinct biophysical environment, including climate, landform, soils, hydrology, and
133 vegetation. Ecoregions provide a useful framework for distributing study sites across a range of
134 geographic regions and environments in western and eastern Washington.



135
 136 Figure 1. [Ecoregions of the Pacific Northwest in Washington State](#) (WADNR 2007). Study sites will be
 137 located in the Northwest Coast, West Cascades, Okanogan, and Canadian Rocky Mountains ecoregions.
 138 Site classes (FFR 1999; Table 1) provide an indication of site productivity and tree growth. The average
 139 total tree height that has been or will be attained at a given age is known as the “site index” (McArdle
 140 1961). Site indices are grouped into five broad site classes: Site Class I, Site Class II, Site Class III, Site
 141 Class IV, and Site Class V. Study sites will be located within Site Classes II and III, where the majority of
 142 commercial timber harvest occurs in Washington ([Forest Practices Application Review System, FPARS](#)).

143
 144
 145 Table 1. Washington Department of Natural Resources site class definitions based on site potential tree
 146 height (FFR 1999). Study sites will be located within Site Classes II and III (in bold).

Region	Site Class	Site Potential Tree Height (feet)
Western Washington	I	200
	II	170
	III	140
	IV	110
	V	90
Eastern Washington	I	130
	II	110
	III	90
	IV	70
	V	60

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 148
 149 Five study sites will be established in each of the four selected ecoregions, for a total of 20 study sites
 150 statewide. Potential study sites will be initially identified in a GIS platform. Potential study sites also may
 151 be identified by querying the Washington Department of Natural Resources [Forest Practices Application
 152 Review System \(FPARS\)](#) for approved Forest Practices Applications (FPAs) for stands that meet the
 153 selection criteria and will be harvested during the timeframe of the study. Based on this screening,
 154 landowners with potential study sites will be contacted to solicit participation in the study.

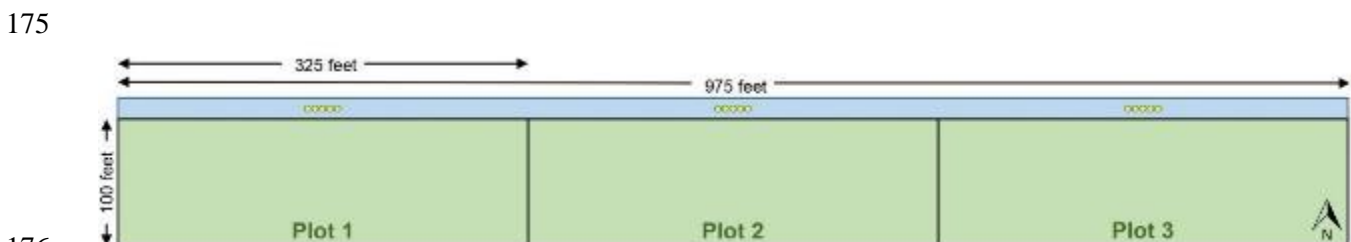
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156 The GIS screening will produce a site visitation list for each of the four ecoregions. The site list order will
157 be randomized and sites will be visited sequentially. Sites will be disqualified if field inspections conclude
158 that they do not meet the selection criteria. Site visitations will continue in random order until five
159 qualifying sites have been identified within an ecoregion.

160
161 During inspection of potential study sites, a subset of the two most dominant tree species will be
162 sampled for height and age. Tree age may be derived from tree cores or stand establishment date
163 records provided by the landowner. Only sites that meet the selection criteria and can be verified as
164 meeting the criteria for Site Classes II or III will be included in the study (as defined by “site potential
165 tree height” in FFR 1999; Table 1).

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167 **Study site layout**

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169 Three experimental plots each measuring 325 feet by 100 feet will be established along one side of the
170 selected stream at each study site (Figure 2). The plot dimensions, configurations, number of photo
171 points, and photo point spacing were designed to ensure that shade measurements (hemispherical
172 camera viewshed) for a given plot will not be influenced by areas outside of the plot for solar altitudes
173 of 40° or greater from 1 June to 1 September (Figures 3a and 3b). Solar altitude refers to the sun angle
174 relative to the horizon.



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176
177 Figure 2. Experimental plot dimensions and layout for this study. Yellow circles represent hemispherical
178 photo point locations (five per plot). This figure represents an east-west stream orientation with the
179 treatment bank assigned to the south.

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181
182 The treatment plot dimensions, configuration, and photo point locations (Figure 2) in this study are
183 based on the maximum shadow length for riparian trees from 1 June to 1 September for solar altitudes
184 40° or greater. Shadow length was calculated using <https://www.suncalc.org/> for the following
185 parameters:

- 186
- 187 • Tree height: 125 feet (based on expected maximum tree height for harvested stands).
 - 188 • Northernmost latitude in Washington State (~49° N, the latitude where maximum shadow
189 lengths occur within the state).
 - 190 • Photo points located 5 feet from the bankfull edge of the stream/stream-adjacent plot
191 boundary (see Figures 3a and 3b).

192
193 Note: Photo point spacing greater than 7.5 feet would capture shade sources originating from outside
194 the treatment plot, inhibiting our ability to isolate the treatment effects on effective shade. For this
195 reason, we have limited the number of photos to 5 per plot with 7.5-foot spacing.

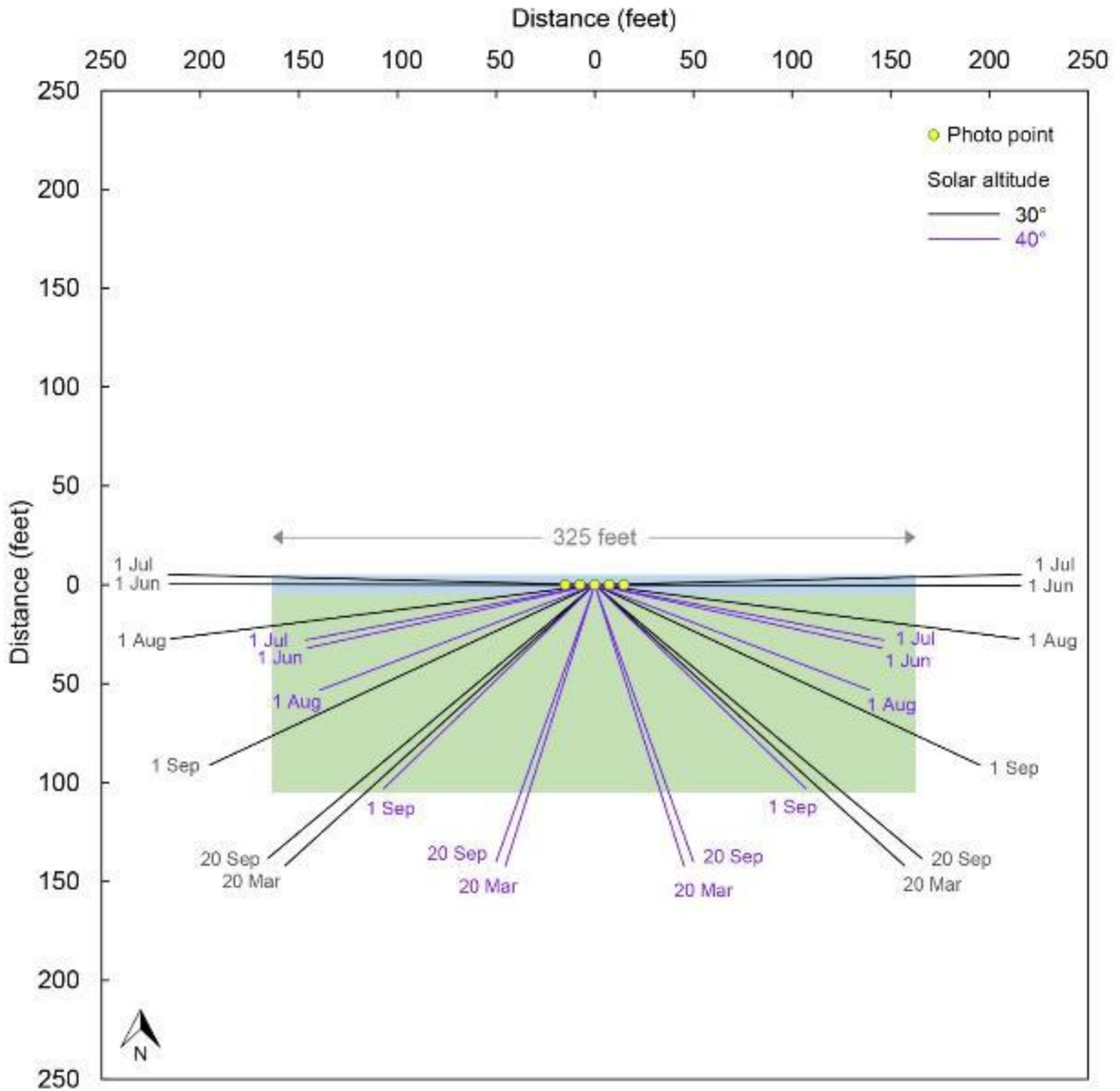
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197 Plot boundaries will be initially drafted in a GIS platform and finalized and staked in the field. The plot
198 boundary nearest to the stream will be located as close as possible to the bankfull width boundary
199 (defined later) while ensuring a straight boundary line.
200

201 Five hemispherical photo points will be established for each plot. The photo points will be located at a
202 consistent distance from the plot boundary at a manageable water depth (~<1 foot deep), to be
203 determined after study sites are selected. If, during site selection, the photo point locations are found to
204 be obstructed (e.g., by log jams, deep pools), then the entire 975-foot reach will be shifted by 25-foot
205 increments in the upstream or downstream direction (determined by coin flip), until a useable
206 configuration is determined or the site is rejected.
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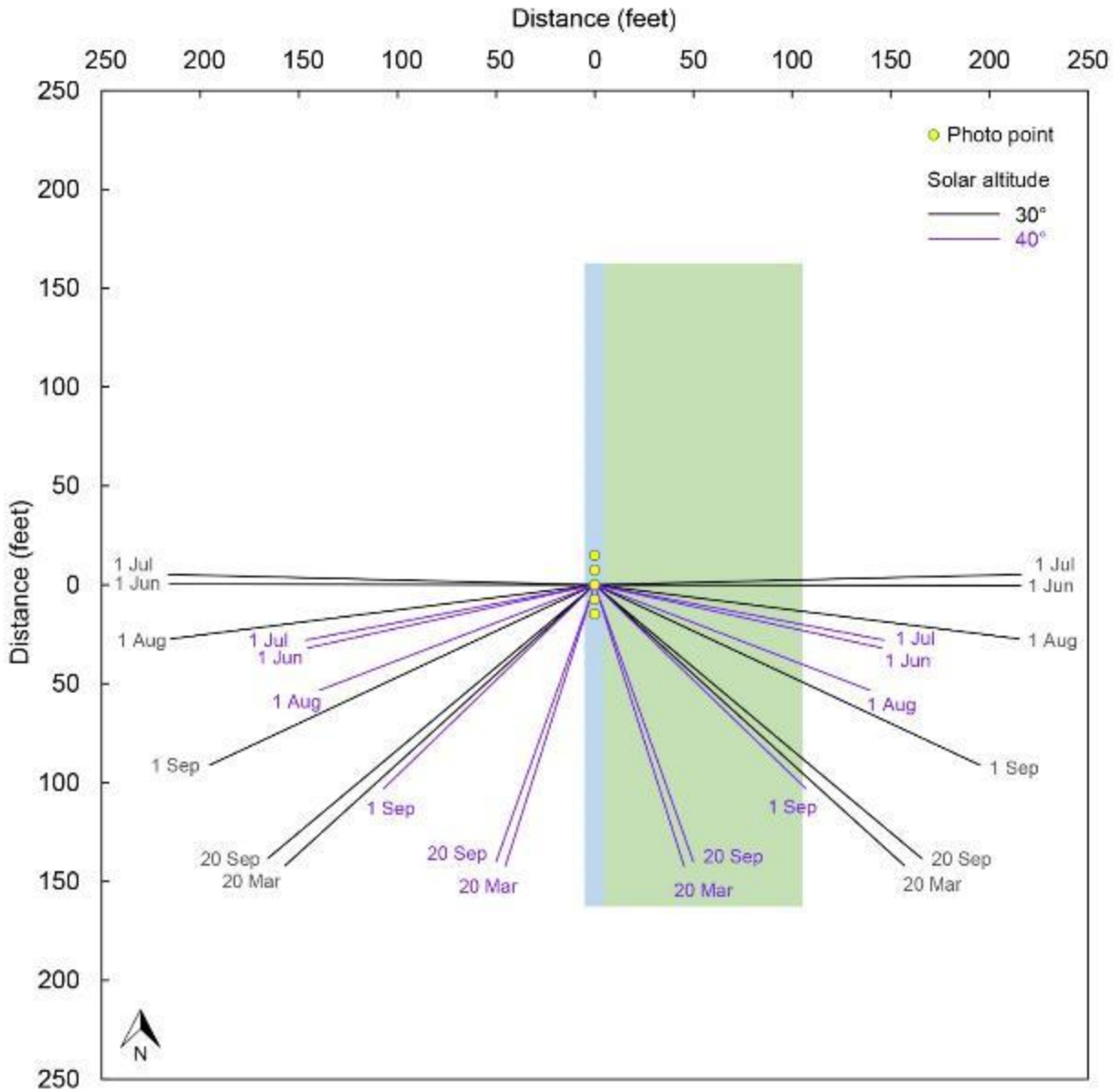
208 Photo points will be spaced 7.5 feet apart, with the middle photo point centered on the long edge of
209 each plot (Figure 2). Photo point locations will be recorded with GPS coordinates and monumented with
210 rebar driven into the streambed. The location of each monument, and the distance and compass
211 bearing from the monument to the in-stream photo point will be recorded so that photo points can be
212 duplicated later as necessary.
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 221 Figure 3a. Shadow length by date for 125-foot tall trees at ~49° N latitude for solar altitudes of 30° and
 222 40° from the vantage of the central photo point (<https://www.suncalc.org/>). The green shaded area
 223 represents a single experimental plot measuring 325 feet by 100 feet. The blue shaded area represents
 224 an adjacent east-west oriented stream measuring 10 feet wide. Plot size and photo point spacing are
 225 based on solar altitudes of 40° or greater from 1 June to 1 September to ensure that shade
 226 measurements will not be influenced by areas upstream or downstream of the plot.

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 232 Figure 3b. Shadow length by date for 125-foot tall trees at ~49° N latitude for solar altitudes of 30° and
 233 40° from the vantage of the central photo point (<https://www.suncalc.org/>). The green shaded area
 234 represents a single experimental plot measuring 325 feet by 100 feet. The blue shaded area represents
 235 an adjacent north-south oriented stream measuring 10 feet wide. Plot size and photo point spacing are
 236 based on solar altitudes of 40° or greater from 1 June to 1 September to ensure that shade
 237 measurements will not be influenced by areas upstream or downstream of the plot.

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245 **Pre-harvest data collection**

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247 *Site attributes*

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249 After the plot boundaries are marked and before the harvest treatments are implemented, site attribute
250 data including bankfull width, bankfull depth, channel confinement ratio, stream reach slope, stream
251 reach azimuth, plot slope, plot aspect, and understory vegetation conditions will be collected (Table 2).

252

253

254 Table 2. Site attribute data and methods included in this study.

Attribute	Methods/equipment
Bankfull width	WFPB 2004
Bankfull depth	WFPB 2004
Channel confinement ratio	WFPB 2004, 2011; Beechie and Imaki 2014
Stream reach slope	Clinometer
Stream reach azimuth	GPS survey/GIS
Plot slope	Clinometer GIS
Plot aspect	GPS survey/GIS
Understory vegetation cover	Ranking system and oblique digital photos

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256

257 **Bankfull width** and **bankfull depth** will be measured for each plot according to the methods described in
258 the [Washington Forest Practices Board Manual, Section 2](#) (2004). Specifically:

259

260 **Bankfull width** is the lateral extent of the water surface elevation perpendicular to the channel
261 at bankfull depth. Bankfull width will be identified as the edge of the channel that corresponds
262 to the start of the floodplain. Indicators include: a berm or other break in slope from the
263 channel bank to a flat valley bottom, terrace, or bench; a change in vegetation from bare
264 surfaces or annual water-tolerant species to perennial water-tolerant or upland species; and a
265 change in the size distribution of surface sediments (e.g., gravel to sand).

266

267 **Bankfull depth** is the average distance from the channel bed to the estimated water surface
268 elevation at bankfull flow. Bankfull depth will be measured after the edges of the bankfull
269 channel are determined. A measuring tape will be stretched across the channel perpendicular to
270 the direction of flow, and secured at the bankfull edges on both sides of the channel. With the
271 measuring tape extended across the channel, the bankfull width will be divided into 10 evenly
272 spaced sections. Depth measurements will be taken with a surveyor's rod at the center of each
273 section. The average bankfull depth will then be calculated by dividing the sum of all depth
274 measurements by the number of measurements (i.e., 10).

275

276 **Channel confinement ratio** (valley confinement ratio) will be measured at the center of each plot to
277 provide an indicator of channel form and topographic shading (Table 2). Channel confinement ratio will
278 be determined by measuring the width of the entire valley floor from hillslope to hillslope and
279 comparing this value to the bankfull width of the stream (WFPB 2004, 2011, Beechie and Imaki 2014).

280

281 **Stream reach slope** will be measured in the field from the upstream boundary to the downstream
282 boundary of the study reach (Table 2). **Stream reach azimuth** will be determined in GIS using GPS
283 coordinates of the upstream and downstream study reach boundaries.

284 **Plot slope and aspect** will be measured across the plot mid-line running perpendicular to the stream-
 285 adjacent boundary (Table 2). Aspect will be determined using coordinates from a GPS survey. Additional
 286 topographic information for each site may be derived in GIS depending on the availability of LiDAR data
 287 and digital elevation models.

288
 289 **Understory vegetation cover** will be defined as all vegetation (herbaceous and woody) occurring
 290 between 3.3 feet (1 meter) above the streambed (based on hemispherical photo elevation, described
 291 below) and below the overstory (defined as trees that would potentially be considered for harvest).
 292 Understory vegetation cover will be ranked as low, medium, or high for each plot (Table 2). This ranking
 293 will be based on observations from the central photo point associated with each plot (Figure 2). Specific
 294 ranking methods will be further described in the data collection plan.

295
 296 Before the harvest treatments are implemented, a set of four oblique digital photos will be taken from
 297 the central photo point associated with each plot (Figure 2) to provide a visual record of site attributes,
 298 including understory vegetation cover (Table 2). Four photos will be taken from each point at 90°
 299 intervals (upstream, downstream, left bank, and right bank).

300
 301 *Stand characteristics*

302
 303 After the plot boundaries are marked and before the harvest treatment implementation, all standing
 304 trees ≥ 4 inches diameter at breast height (dbh; 4.5 feet above ground surface) occurring in a plot will be
 305 tallied and marked with a unique identification number (100% inventory). The identification number,
 306 **species, condition (live or dead), dbh, tree height, height to live crown base, and maximum crown**
 307 **radius** will be recorded for all trees (Table 3).

308
 309
 310 Table 3. Stand composition and structure characteristics included in this study.

Stand characteristics	
Tree species	Basal area (feet ² per acre)
Tree condition (live or dead)	Tree height (feet)
Tree diameter (dbh, inches)	Live crown ratio (percent)
Tree density (trees per acre)	Maximum crown radius (feet)

311
 312 **Harvest treatment implementation and hemispherical photo collection sequence**

313
 314 Stream shade (i.e., effective shade, *ES*) will be estimated for 10 riparian harvest treatment combinations
 315 using hemispherical photography methods (Rich 1990, Valverde and Silvertown 1997, Groom et al.
 316 2011a). For the purposes of this study, effective shade (*ES*) is defined as the fraction of total possible
 317 solar radiation blocked from reaching an east-west or north-south oriented stream during the period
 318 from 1 June to 1 September for solar altitudes 40° or greater, or:

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 320
$$Effective\ shade = \frac{J_1 - J_2}{J_1}$$

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 322 where J_1 is potential solar radiation flux (un-attenuated by riparian vegetation and topography) and J_2 is
 323 solar radiation flux at the stream surface (camera elevation) during the period from 1 June to 1
 324 September for solar altitudes 40° or greater (Cristea and Janisch 2007).

325 Figure 4 provides a diagram of the harvest treatment and hemispherical photo collection sequence that
326 will be applied in the three experimental plots at each study site. The first step of the harvest sequence
327 will be to clear-cut the upland harvest unit to the edge of a 100-foot stream-adjacent no-harvest zone
328 (upland edge of each experimental plot). The upland edge of the 100-foot no-harvest zone will then
329 become the upland plot boundary for all subsequent harvest treatments. Levels of adjacent-stand
330 harvest intensity (i.e., moderate thinning, heavy thinning, clear-cut) will be randomly assigned to each
331 plot. Different levels of stream-adjacent no-harvest zone width will be implemented sequentially in time
332 within each plot (Figure 4, steps 'a'). Hemispherical photographs will be taken after the implementation
333 of each level of the no-harvest zone width (Figure 4, steps 'b'). This will allow all 10 treatment
334 combinations plus the pre-treatment condition to be applied at a single site (Table 4). If possible, the
335 harvest treatments and associated photo collection will occur between 1 June and 1 September to
336 coincide with the primary leaf-on period for deciduous vegetation in the study region. For a given site,
337 treatments will be applied to the plots within a short time period (e.g., ≤ 10 days). This will provide
338 consistency in site conditions and greatly reduce the possibility of non-treatment events (e.g.,
339 windthrow, understory growth) occurring during the harvest and hemispherical photo collection
340 sequence.

341
342 Based on the initial 100% stand inventory, harvest trees will be identified and color marked on the bole
343 and stump to indicate which trees to remove at every treatment interval. Thinning treatments will be
344 applied according to Curtis's Relative Density summation formula (RD_{sum} ; Curtis 2010).

$$345 \quad RD_{sum} = 0.00545415 \times \sum (d_i^{1.5})/area$$

346
347 Where d_i is the diameter of an individual tree and summation is over all trees ≥ 4 inches dbh within a
348 given harvest zone.

349
350 The tag number of each harvested tree at each treatment interval will be recorded so that stand
351 characteristics (e.g., basal area by species) can be computed for the harvest and no-harvest zones for
352 each interval. Thinning will be from below and implemented so that tree crowns are spatially distributed
353 as uniformly as possible. Following each harvest treatment interval, trees may be felled and removed
354 from site, or left on the ground and limbed (as necessary), depending on what is most operationally
355 feasible at a given site. Limbing of down trees will only be necessary in locations where limbs contribute
356 to the effective shade of the stream (intersect with the hemispherical camera viewshed) for the solar
357 period analyzed in this study.

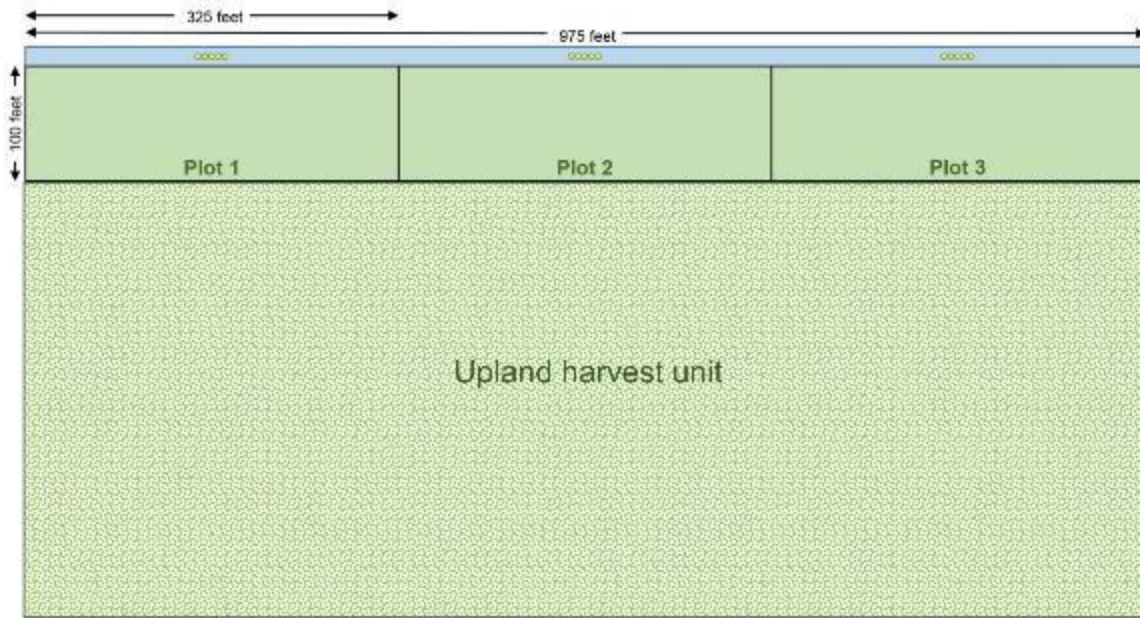
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359 After each thinning treatment, follow-up inspections will be conducted to ensure that all trees marked
360 for harvest were felled and to determine if any limbing of down trees is needed to meet the study
361 design requirements. Additionally, any unintended tree falling or damage that occurred during the
362 harvest activities will be recorded by tree tag number.

363
364 Hemispherical photos will be taken at each photo point for all five treatment intervals for a total of 75
365 photos per site (5 photos per plot \times 5 treatment applications \times 3 plots; Figure 4). Hemispherical photos
366 will be taken using a digital SLR camera equipped with a circular fisheye lens attached to a leveled tripod
367 and oriented to north. Photographs will be taken when no direct sunlight is visible, at pre-dawn, post-
368 sunset, or under an evenly overcast sky. The camera lens will be positioned at 3.3 feet (1 meter) above
369 the streambed. This will reduce the influence of shading by low-lying vegetation and the streambank
370 (i.e., reduce the influence of non-treatment factors on effective shade among study sites). At each photo
371

372 point, multiple images will be taken using different exposure levels. The camera settings will be
373 programed to take a series of images from -6 to 0 at 1-stop exposure value (EV) intervals to ensure that
374 light conditions do not interfere with shade characterization during photo processing (described later).
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(1a) Pre-treatment

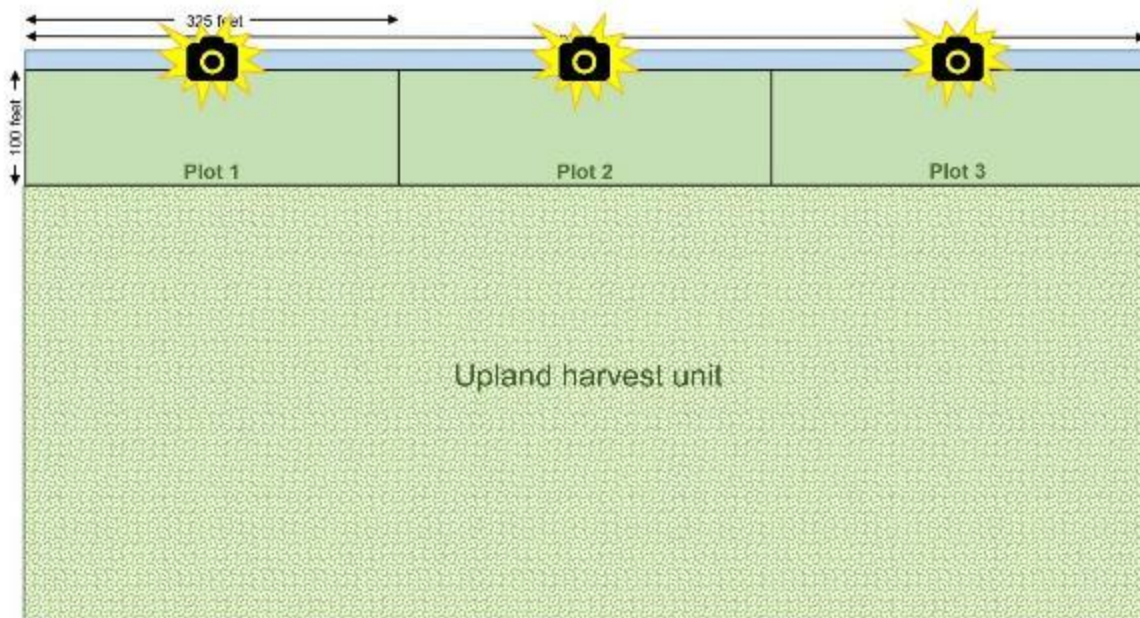
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(1b) Pre-treatment

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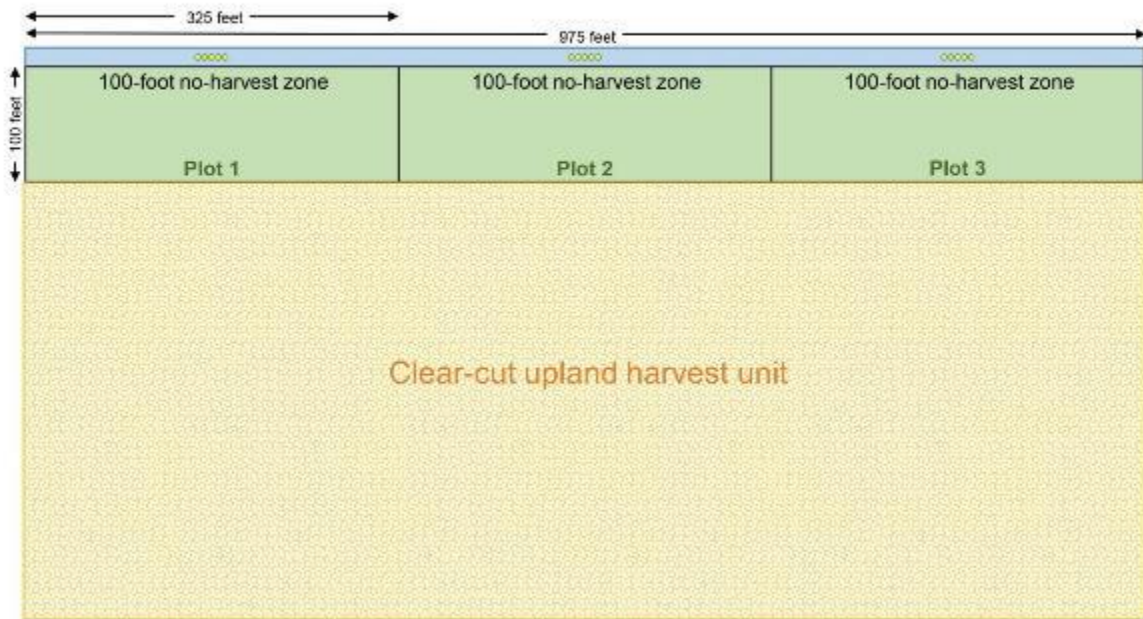
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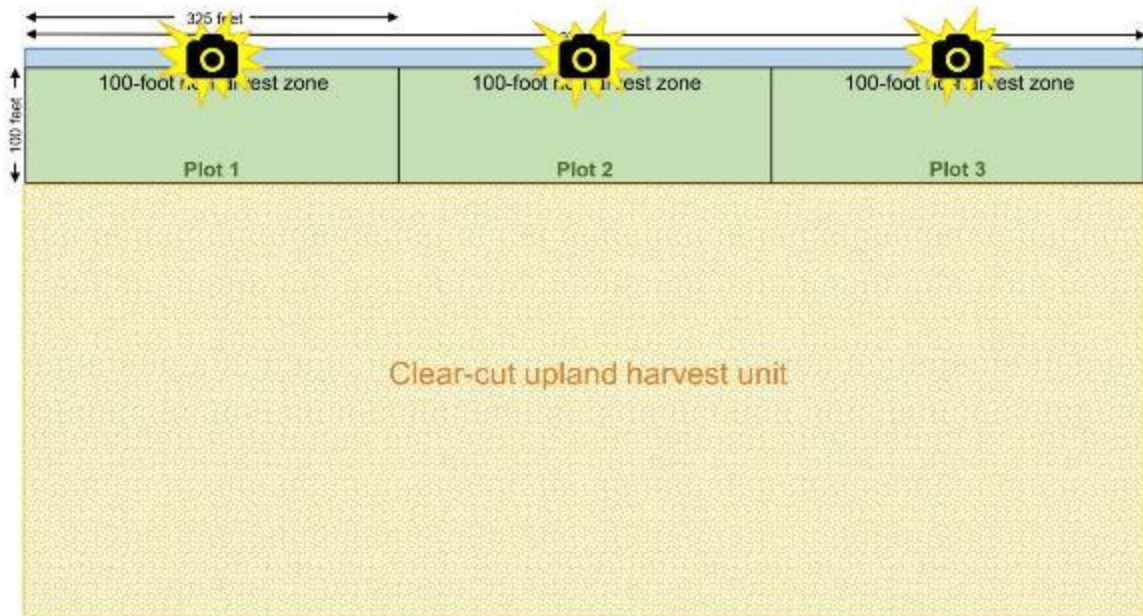
Figure 4 (continued on next five pages). The harvest treatment/hemispherical photo collection sequence used to implement the 10 harvest treatments in this study. Yellow dots represent hemispherical photo points. Camera icons represent the collection of hemispherical photos from all five photo points for each plot. Levels of adjacent-stand harvest intensity (i.e., moderate thinning, heavy thinning, clear-cut) will be randomly assigned to each plot. Moderate thinning = Curtis's Relative Density (RD) 40; Heavy thinning = Curtis's Relative Density (RD) 20.

(2a) Clear-cut the upland harvest unit to the edge of a 100-foot stream-adjacent no-harvest zone



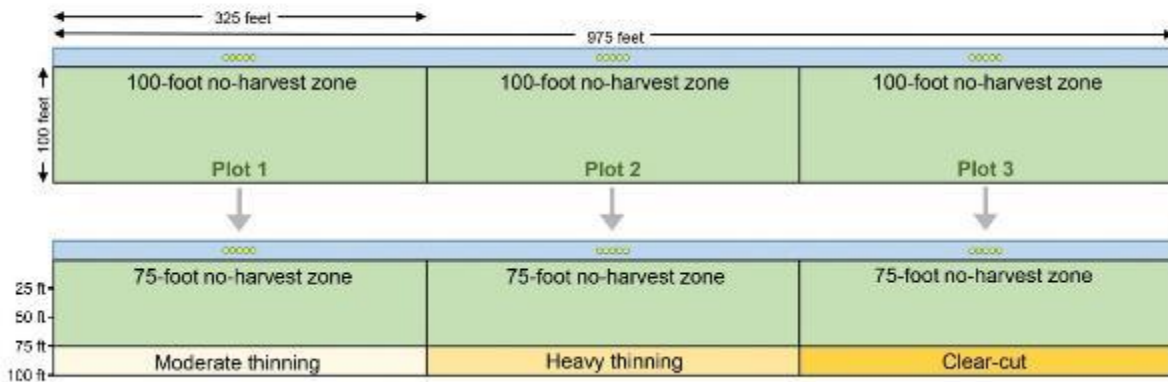
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(2b) Clear-cut the upland harvest unit to the edge of a 100-foot stream-adjacent no-harvest zone



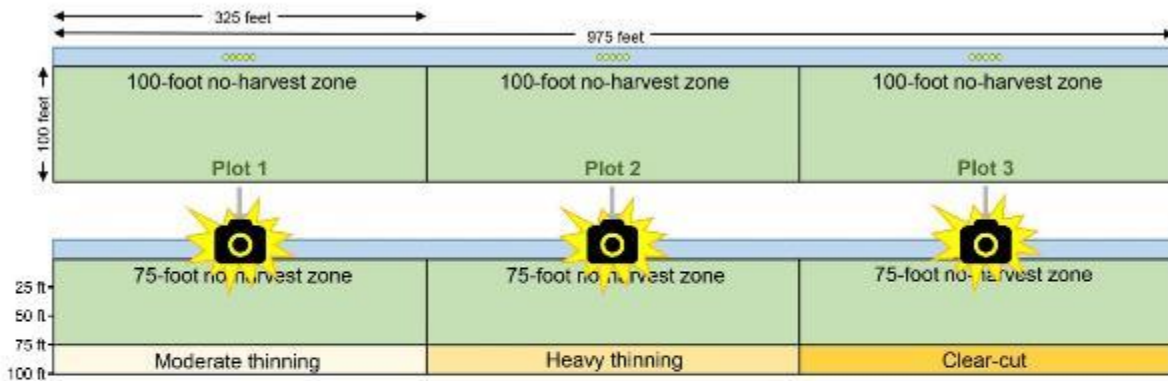
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(3a) Harvest to the edge of a 75-foot wide stream-adjacent no-harvest zone



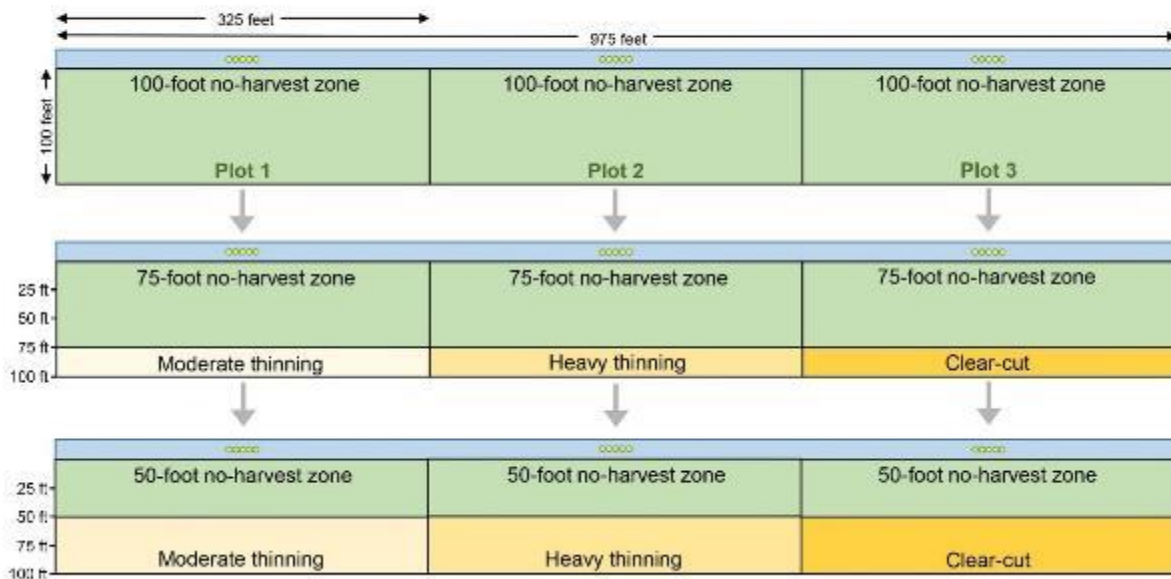
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(3b) Harvest to the edge of a 75-foot wide stream-adjacent no-harvest zone



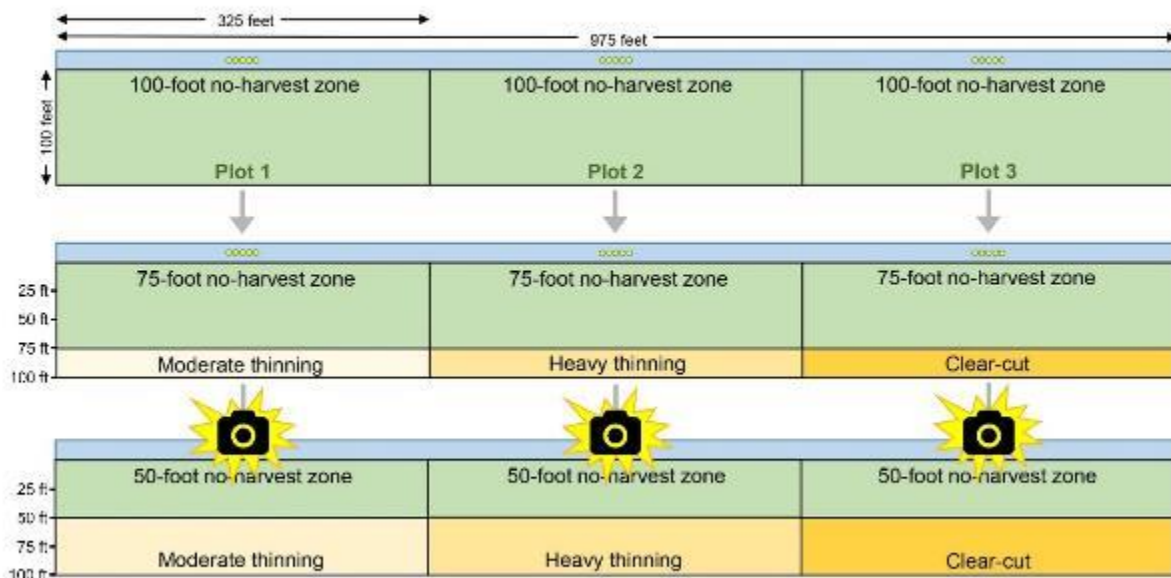
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(4a) Harvest to the edge of a 50-foot wide stream-adjacent no-harvest zone



442

(4b) Harvest to the edge of a 50-foot wide stream-adjacent no-harvest zone



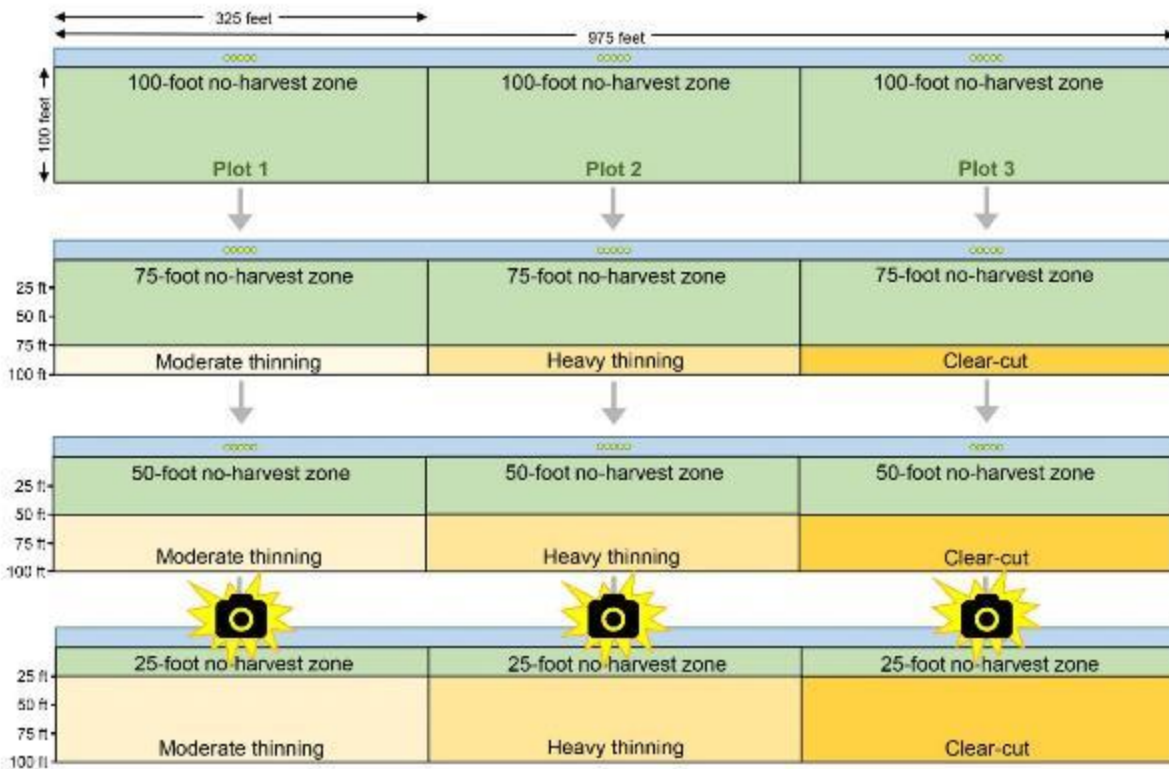
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(5a) Harvest to the edge of a 25-foot wide stream-adjacent no-harvest zone



448
449

(5b) Harvest to the edge of a 25-foot wide stream-adjacent no-harvest zone



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471

472 Table 4. The 10 riparian harvest treatment level combinations included in this study. Thinning treatment
 473 levels will be applied based on Curtis’s Relative Density summation formula (RD; Curtis 2010).

Adjacent-stand harvest intensity (thinning or clear-cut)			
Stream-adjacent no-harvest zone width (feet)	Moderate thinning (Curtis’s Relative Density 40)	Heavy thinning (Curtis’s Relative Density 20)	Clear-cut (Curtis’s Relative Density 0)
25	X	X	X
50	X	X	X
75	X	X	X
100†			X

474 †The data for this treatment will be analyzed separately.

475

476

477 **Sample Size**

478

479 Five study sites containing three experimental plots will be established within each of the four
 480 ecoregions, for a total of 20 sites statewide (Table 5). This study will produce 40 treatment
 481 level/ecoregion combinations. However, for statistical estimation purposes, the Linear Mixed-effects
 482 Model (LMM) analyses described below will not include the 100-foot no-harvest buffer width with a
 483 clear-cut “thinning” level beyond. The range of treatment levels and sample size is expected to capture a
 484 treatment effect within the bounds of this study. Additionally, the total sample size of 20 sites
 485 represents what may be attainable given the known challenges and limitations with site selection based
 486 on previous CMER studies.

487

488

489 Table 5. Number of replicates (sample size, *n*) for each treatment type and level per ecoregion. The pre-
 490 treatment condition will be measured for every plot (*n* = 15 per ecoregion).

Adjacent-stand harvest intensity (thinning or clear-cut)			
Stream-adjacent no-harvest zone width (feet)	Moderate thinning (Curtis’s Relative Density 40)	Heavy thinning (Curtis’s Relative Density 20)	Clear-cut (Curtis’s Relative Density 0)
25	5	5	5
50	5	5	5
75	5	5	5
100†	0	0	15

491 †The LMM analysis will not include this treatment level.

492

493

494 **Hemispherical photo post-processing and analysis**

495

496 Hemispherical photos will be post-processed and analyzed using [Hemisfer software](#). Photo pixel
 497 thresholding will initially be performed using the automated thresholding function in Hemisfer. If the
 498 automated thresholding function is deficient, manual thresholding procedures will be tested and
 499 implemented consistently. For example, pixel thresholding may use color band weighting using -100%
 500 green, +100% blue, and adjusting the red as needed around +20%.

501

502 Effective shade will be calculated for each photo according to the equation on page 10. For additional
503 information, please see the [Light Regime](https://www.schleppi.ch/patrick/hemisfer/help.php?t=rad) section of the Hemisfer software user guide
504 (<https://www.schleppi.ch/patrick/hemisfer/help.php?t=rad>).

505
506 The solar period selected for this study includes: (1) the time period when stream heating is generally
507 greatest, (2) the leaf-on period for deciduous trees and shrubs in the study region, and (3) allows for
508 experimental plot dimensions that can be practicably implemented in the field (based on maximum
509 shadow lengths; Figures 3a and 3b). Shorter time periods of interest may be analyzed within this portion
510 of the solar cycle (e.g., from 15 July to 15 August for solar altitudes 40° or greater). Figures 3a and 3b
511 provide guidance for determining which time intervals (sun altitude and azimuth) are appropriate based
512 on the plot size in this study. Note that harvest implementation may occur outside of the 1 June to 1
513 September window if leaf-on conditions are met.

514

515

516
517 The 20 sites selected for this study will likely include a mix of unique stream orientations (azimuths) in
518 the field. The amount of solar radiation reaching a stream depends not only on the amount of shade
519 provided by vegetation and topography, but also on the stream orientation. That is, even if canopy cover
520 and other shade sources were held constant, solar inputs/stream shade could vary depending on stream
521 orientation.

522

523 Additionally, effective shade can vary depending on which side of the stream the treatments are
524 implemented. For example, based on solar geometry alone, an exactly east-west oriented stream will
525 receive more solar inputs from the south than the north. Therefore, removal of riparian trees on the
526 south bank would be expected to result in a greater shade reduction than if the same riparian harvest
527 treatments were implemented on the north bank, all other site conditions being equal. Note that the
528 actual treatment bank direction will likely vary among the study sites depending on the cooperating
529 landowners' harvest plans. Effective shade potential also varies by latitude due to solar geometry.

530

531 To eliminate the influence of the non-treatment variables of stream orientation, treatment bank
532 direction, and latitude/longitude, these variables will be standardized during photo post-processing and
533 analysis (Figure 5). Using the Hemisfer photo analysis software, hemispherical photos will be analyzed
534 for the central latitude/longitude in Washington (47.3826, -120.4472) and for (1) east-west oriented
535 streams with the treatment bank assigned to the south; and (2) north-south streams with the treatment
536 bank assigned to the east. Note, for north-south orientations, an east-facing treatment bank was
537 selected for purposes of consistency, but effective shade values are expected to be similar to a west-
538 facing treatment bank.

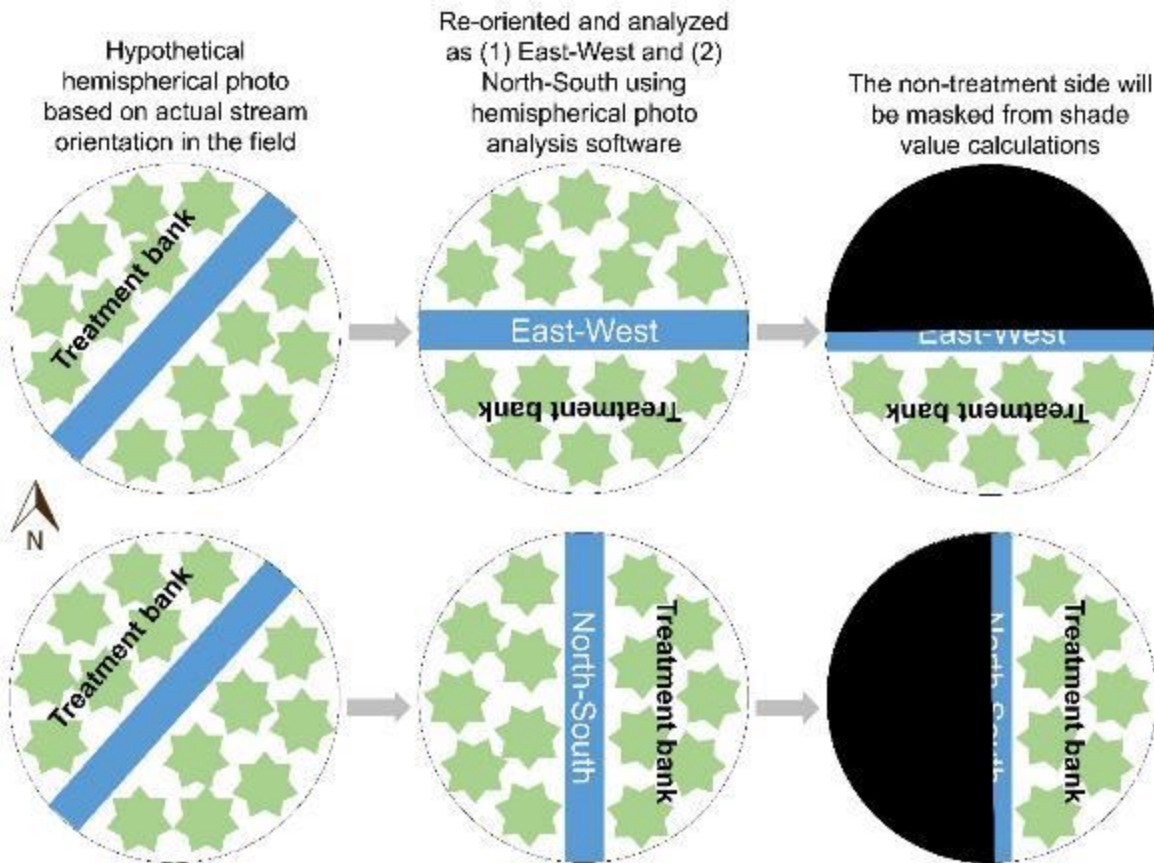
539

540 East-west (with south-facing treatment bank) and north-south (with east-facing treatment bank) stream
541 orientations will be used for this study because they represent the end-points for the range of stream
542 orientations where riparian harvest treatments are likely to have the greatest effects on effective shade.
543 It is important to target the maximum range of effective shade effects because this study is taking place
544 within a forestry regulations context. Other stream orientations/treatment bank assignments are less
545 relevant for the purposes of this study. For example, east-west streams with the treatment bank
546 assigned to the north are not prioritized because this scenario is expected to have the minimum effect
547 on effective shade due to harvest treatments, and therefore is less relevant in a rule-making context.

548

549 The untreated side (180°) of the stream will be excluded (masked) from effective shade value estimates
 550 (Figure 5). This will further reduce non-treatment influences and isolate the effects of the treatments on
 551 effective shade. That is, any variation among sites due to the untreated side of the stream will be
 552 removed from the analysis. For example, conditions on the untreated side of the stream are expected to
 553 vary among sites in terms of tree density, tree height, tree species, time since last harvest, previous
 554 planting strategy, etc. It will be important to reduce non-treatment influences as much as possible to
 555 better understand the harvest treatment effects on effective shade.
 556

557 The above hemispherical photo post-processing and analysis procedures are necessary because this
 558 study aims to estimate the *change* in effective shade due riparian harvest treatments relative to the pre-
 559 harvest condition. Actual effective shade values (*ES*) are less important than the values for *change*
 560 in effective shade (ΔES) due to the treatment, all other variables being equal. These procedures will help
 561 ensure that any shade signal we detect is related to the treatment response, and not non-treatment
 562 variables.
 563
 564



565 Figure 5. Example of stream orientation and treatment bank assignment that will occur during
 566 hemispherical photo analysis. This procedure will standardize estimates of effective shade by (1) east-
 567 west and (2) north-south stream orientations. The non-treatment bank will be masked from shade
 568 estimate calculations.
 569

573 As previously stated, five hemispherical photos will be taken for each treatment level (Figures 2 and 4).
574 After post-processing each hemispherical photo by the above methods, effective shade values will be
575 computed as the **mean** of the five photos taken at each plot for each treatment level.
576

577 **Analysis**

578 The main analysis response variable will be the difference, or change in, effective shade (ΔES) caused by
579 changes in the riparian stand due to the nine different treatment level combinations (three no-harvest
580 zone widths [the 100-foot no-harvest distance will be excluded] and all three thinning levels) and the
581 original pre-harvest plot-level effective shade values. All effective shade values will be calculated for
582 both east-west and north-south stream orientations and a common latitude/longitude (described
583 above). The treatment level combination values will be subtracted from the original effective shade
584 values to control for the initial differences in shade among sites.
585

586 Stream azimuth normalization will be addressed during hemispherical photo post-processing and
587 analysis described above.
588

589 Difference in effective shade (ΔES) will be computed as:
590

$$591 \Delta ES_{hijk} = ES_{hijo} - ES_{hijk}$$

592 where h = ecoregion (1 through 4), i = study site (block, 1 through 5), j = plot (1 through 3), and k =
593 treatment (0 through 4, where 0 = pre-treatment and 1 through 4 are the sub-plot treatments).
594

595 This study design may be represented as either a split-plot design with blocking or a strip-plot design
596 with blocking. Either design is an option as we cannot randomize the order in which the buffer widths
597 are adjusted, within or across subplots. In a split plot design, plots each receive one level of treatment
598 and sub-plots within the plots receive all levels of a second treatment. For the split-plot design we would
599 have plot-level thinning with the different no-harvest zone widths serving as sub-plots. The plots
600 themselves will occur in blocks (sites), similar to the “Hard Rock” study (McIntyre et al. 2018). Every site
601 will contain three plots, with the set of plots receiving all of the thinning treatment levels. Because of
602 this structure, the shade values for subplots within plots and plots within sites are not independent.
603 Measurements within a site may tend to be more similar than those among sites, and measurements
604 within a plot may be more similar than those from other plots.
605

606 Strip plots are statistically structured differently in that each plot receives one treatment (thinning) level
607 and then the other treatment (no-harvest buffer width) is applied perpendicularly across all plots. The
608 assignment of the levels for each treatment type should be randomized. For this study, we would have
609 effect estimates for three thinning levels (excluding 100 feet), each distance level, and their interactions
610 (width-thinning combination). A random effect is assigned for each site and treatment type nested
611 within site. The precision of estimates for no-harvest zone treatment levels from the split-plot design
612 would be sacrificed for improving the precision of interactions of the treatments in the strip-plot design.
613 We believe this trade-off is worthwhile as our main interest is in estimating the treatment interactions;
614 therefore, we anticipate using the strip-plot design for the analysis.
615

616 The study design differs from a classic strip-plot design in that, within the analysis, some considered
617 models will include an additive or interaction effect with a factor for ecoregion (with four levels). The
618

620 model set will additionally include other explanatory variables as covariates in addition to the treatment
621 and random effects variables associated with the strip-plot portion of the design.

622
623 Given that the data will be normally distributed and not fully independent due to the strip-plot design
624 with blocking, the data will be analyzed using a Linear Mixed-effects Model (LMM). The LMM will
625 account for nested non-independence with random effects parameters as well as produce all of the
626 needed estimates. The model will have a random effect for site, for plot nested within site, and for
627 thinning treatment nested within site. The fixed-effects variables will include ecoregion, the levels for
628 both treatments, and all interactions among them. As described below, we will be addressing the study
629 proposal by constructing and comparing the relative performance of several forms of the strip-plot
630 model, some with additional covariates and some without. From previous CMER research, we know that
631 *ES* may be modeled as a beta distribution and ΔES is likely to be approximately normally distributed.

632
633 The treatment combination for the 100-foot no-harvest buffer with clear-cut thinning beyond will be
634 analyzed separately using a LMM with the same shade-change response variable, a single random effect
635 for site, and no treatment fixed effects. The purpose of this analysis is to provide estimates of the
636 difference in shade between a 100-foot no-harvest buffer and the initial shade values.

637
638 The study design allows for three types of analyses that could inform shade-predictive equations:

639
640 1. **Determine how treatments affect shade** (Objective 1, Critical Questions 1 and 2). The LMM,
641 described above, will capture this analysis. Because the LMM can incorporate certain stand
642 metrics as well, it will provide shade-predictive equations. The LMM will be used to obtain
643 estimates (mean and 95% confidence interval) for each of the analyzed treatment level
644 combinations. This output will be provided graphically. This level of analysis will address
645 Objective 1 and Critical Question 1.

646
647 Further, the analysis will test whether including ecoregions in the model improves model fit by
648 comparing models that do and do not include the ecoregion variable (see Model Selection,
649 below). Contrasts will be examined to statistically compare different treatment level
650 combinations and treatment level combinations by area (Critical Question 2). The main
651 limitation is that the study design and analysis will provide predictive capabilities only for no-
652 harvest zones of 25, 50, and 75 feet, and for thinning out to 100 feet with no-harvest zones of
653 25, 50, and 75 feet. The design will not provide information about thinning treatment levels for
654 riparian buffers other than 100 feet wide, such as buffers with a 25-foot stream-adjacent no-
655 harvest zone and an adjacent 25-foot wide thinning zone (total buffer width of 50 feet). The
656 design also will not provide information for thinning treatment levels in the absence of a
657 stream-adjacent no-harvest zone.

658
659 2. **Determine how stand metrics post-harvest relate to changes in shade** (Objective 2, Critical
660 Question 3). The experimental layout offers many conditions against which shade changes will
661 be evaluated. This will be captured using a LMM where change in shade is the dependent
662 variable and the independent variables are continuous site metric variables (e.g., those listed in
663 Table 2 and Table 3). The findings may be relevant for creating predictive shade responses given
664 specific stand conditions.

665
666 3. **Determine how treatments affect stand metrics.** Do plots with different initial stand metrics
667 change in predictable or similar ways to the same suite of treatments? This information could be

668 useful for developing stand-specific or ecoregion-specific prescriptions. Multivariate analyses
669 (e.g., MANOVA, nMDS) along with univariate analyses will be used to quantify and visualize the
670 change in variable associations with different treatments.
671

672 During analysis, we will look for interactions among pre-harvest shade, ecoregion, and treatment.
673

674 Contrasts are comparisons of combinations of treatment means. The CMER “Hard Rock” (McIntyre et al.
675 2018) and “Soft Rock” (in review) studies used contrasts extensively for conveying results. As an
676 example, the LMM output will be used to examine how the change in shade for moderate thinnings with
677 50-foot no-harvest zones differed between ecoregions 2, 3, and 4 relative to ecoregion 1. This sort of
678 comparison approach will be used to address Critical Question 2 and others.
679

680 Assumptions:

681 Due to multiple treatments being applied within individual plots, the order of the within-plot treatments
682 cannot be randomized. This requires an assumption that the results would have been the same had
683 randomization occurred (see *Project Risk Analysis* below for more details).
684

685 The LMM assumptions will be tested following tests described in Pinheiro and Bates (2000). If the
686 assumptions are violated we will strive to correct them.
687

688 *Model Selection*

689 Classic split-plot and strip-plot designs are typically introduced as occurring in an industrial, laboratory,
690 or agricultural setting where there is a relatively high degree of control over environmental features.
691 This study will be conducted in a far less controlled setting. The study site selection procedure attempts
692 to exert some control over the more serious conditions that would affect outcomes, but certainly no
693 two sites will be the same. We can exert further control over the analysis by statistically controlling for
694 site features by including them as covariates in the analysis model. If they are important, they will assist
695 with overall model fit and provide us with greater confidence in model estimates of treatment effects.
696 However, we have uncertainty about the degree to which different possible covariates are needed in
697 the model.
698

699 The wildlife sciences have addressed the issue of model uncertainty by performing model selection by
700 having researchers develop, *a priori*, a suite of models to test and compare using model AIC, or Akaike’s
701 Information Criterion, scores (Burnham and Anderson 2002). Each model represents a sensible
702 hypothesis about how the system at hand may function. See Zuur (2009) for a description of an
703 approach for applying these techniques to LMMs. An AIC-based model selection approach protects
704 against overfitting models with uninformative variables by penalizing models for the number of
705 variables that they include. Similarly, by developing a set of models *a priori* and avoiding fitting all
706 possible models, we avoid data dredging. Model comparisons convey the performance of each model
707 relative to other models. We can assess how well certain covariates improve model fit relative to models
708 without them and determine the information gain of our top supported model(s) relative to a model
709 that has little information, such as an intercept model. If two or more models perform well (low AIC
710 scores that are nearly equal) then we consider the set as each may be informative in its own way.
711 Analyses of model AIC values also allow for the assignment of model weights, which represent the
712 probability that a model is the best of the set of considered models. For Analyses 1 and 2 we will create
713 a suite of models prior to analysis that contain different covariates that may assist in accounting for
714
715

716 inter-site differences. Aside from an intercept model, we anticipate that for Analysis 1, all models will
717 include the core model structure for the strip-plot design.

718
719 *Site attributes*

720
721 Site attributes including plot slope and aspect, stream channel azimuth and slope, bankfull width, and
722 channel confinement ratio will be tabulated and summarized using descriptive statistics for each plot
723 and each site (Table 2). This will provide additional information about the study sites, as well as the
724 amount and type of variation within and among study sites. Site attribute data will also be available for
725 use as covariates in shade-change analyses to control for site features not related to riparian stand
726 metrics.

727
728 *Stand characteristics*

729
730 Stand composition and structure data (Table 5) will be used to help account for changes in shade in
731 response to the treatments, variation in shade response among ecoregions, and the magnitude of model
732 variance. Stand data will be used to control for site-specific conditions. Stand data will also be
733 investigated independently of the LMM in relation to shade and treatment level combinations.

734 ***

735
736 All data will be post-processed and compiled in a database that can be queried to inform future
737 questions about stream shade response to different riparian harvest treatments and for additional
738 portions of the solar cycle. For example, analyses may be performed for shorter time intervals of
739 interest within the primary study period, such as 15 July through 15 August for solar altitudes of 40° or
740 greater. Figures 3a and 3b provide guidance for determining appropriate time intervals based on plot
741 size.

742
743 **QUALITY ASSURANCE AND QUALITY CONTROL**

744
745 The following quality assurance and quality control procedures will be implemented to ensure accurate
746 data collection, recording, and analysis.

747
748 *Harvest treatment application and field data collection*

- 749
- 750 • Field inspections will confirm that sites meet the site selection criteria.
 - 751 • If possible, the same field staff will be used to inventory and mark trees for harvest to provide
752 consistency across the thinning treatments.
 - 753 • Harvest inspections will be conducted for each treatment interval to ensure that all trees
754 marked for harvest were cut and to record any unintended tree falling or damage.
 - 755 • Boundary markers will be inspected and re-established as needed following each harvest
756 interval to correct for any disturbance by harvest crews and equipment.
 - 757 • Prior to field data collection, field staff will be provided with written instructions for all data
758 collection procedures and hands-on training with all procedures and equipment.
 - 759 • Field data sheet templates will be provided that list the type, units, and sequence of data to be
760 collected.

- 761 • Plot boundaries and photo point locations will be measured and confirmed by at least two field
762 staff before any data collection occurs. Plot boundaries will be inspected and corrected as
763 necessary after each harvest treatment.
- 764 • Sampling equipment including hemispherical cameras and tripods will be tested each day before
765 data collection begins to ensure proper operation. If any sampling equipment malfunctions
766 during data collection, field staff will note what data may have been affected and pause data
767 collection until a replacement is issued or the equipment is repaired. Any potentially affected
768 data will be re-measured and re-recorded.
- 769 • Trampling of understory vegetation by field staff will be avoided prior to and during all
770 photograph collection intervals, especially along and near the stream.
- 771 • Field staff will be instructed to take detailed notes and photographs to document any
772 anomalous situations.

773

774 *Data post-processing and analysis*

775

- 776 • Exploratory graphical analyses will be conducted to determine if any individual measurement
777 values are clear outliers due to measurement or recording errors. If an outlier is found, the field
778 datasheets, photos, and notes will be consulted to determine whether the data can be
779 corrected or if it needs to be eliminated from the analysis.
- 780 • Erroneous results and how they are addressed will be documented and described in the final
781 study report.
- 782 • As time and budget allows, a sub-sample of hemiphoto images will be analyzed by two separate
783 observers to assess whether there are significant differences in shade estimates due to
784 individual observer determinations for photo exposure and threshold settings.
- 785 • Statistical model assumptions will be checked. Models will be modified if they fail assumption
786 checks.
- 787 • All data analysis procedures will be documented and explained in the final report.

788

789 **PROJECT RISK ANALYSIS**

790

791 There are constraints and risks inherent to most experimental research that occurs in forested
792 environments. This section describes potential problems for data collection and analysis, as well as
793 contingencies for addressing these problems.

794

795 *Study scope*

796

797 The inference of our study results will extend to all riparian stands of harvest age occurring on non-
798 federal lands managed under the FPHCP within the Northwest Coast, West Cascades, Okanogan, and
799 Canadian Rocky Mountains ecoregions in Washington State; located within verified Site Classes II and III;
800 along Type Np and Type F streams with bankfull widths from 5 to 25 feet; and receiving harvest
801 treatments according to the prescriptions described within this document.

802

803 This study is intended to provide information in a relatively short timeframe and for a relatively low cost.
804 This sets limits on the sample size and number of treatments that can be included in the study. For
805 example, this study will include 10 riparian harvest treatment level combinations with intervals that are
806 expected to have a measurable difference in shade. However, these 10 treatment level combinations do
807 not include all possible treatments of interest (e.g., additional stream-adjacent no-harvest zone widths).

808 The findings may be interpolated within the range of the treatments but cannot be extrapolated outside
809 of that range with great confidence (e.g., predict the difference in shade for a 50-foot wide 100%
810 thinning buffer at RD 60). The 10 harvest treatment level combinations included in this study will inform
811 existing information gaps and will be sufficient to fulfill the objectives of this study.

812
813 The primary study period selected for this study (1 June – 1 September for solar altitudes 40° or greater)
814 encompasses the time period when stream heating is generally greatest, the leaf-on period for
815 deciduous trees and shrubs in the study region, and allows for experimental plot dimensions that can be
816 practicably implemented in the field. The study does not focus on other periods that may be of interest,
817 such as early morning or late afternoon/evening (i.e., solar altitudes <40°). Including solar altitudes <40°
818 in this study would require much larger plot sizes than could be practicably implemented in the field. For
819 example, analyzing east-west streams for solar altitudes 30° or greater would require each plot to
820 measure 460 feet by 100 feet, for a total site length of 1,380 feet (Figure 4a). Additionally, the area of
821 each plot would increase from about 0.75 acre to about 1 acre, increasing the costs, resources, and time
822 needed for stand inventories and harvest activities. Thus, the study design optimizes the information
823 gained for the primary period of interest within the logistical constraints for field implementation.
824 However, results from this study will be compiled and made available in a public database that can be
825 queried to inform other questions about stream shade response to riparian harvest treatments for
826 different portions of the solar cycle. Figures 4a and 4b provide guidance for determining what time
827 intervals can be accurately assessed based on the plot size used in this study.

828 *Study design assumptions*

829
830 A proper split-plot or strip-plot design requires a randomization of plot-level treatments (the thinning
831 intensity inside the plot) and the within-plot treatments (the stream-adjacent no-harvest zone widths).
832 The harvest sequence, however, does not allow randomization of the within-plot stream-adjacent no-
833 harvest zone width order. The design must proceed with each plot starting with a 100-foot, then 75-
834 foot, then 50-foot, then 25-foot no-harvest zone width. Based on this study design, there must be an
835 assumption that the order of the no-harvest zone width will not appreciably affect observed responses.
836 That is, it must be assumed that not randomizing the no-harvest zone width order will result in findings
837 that would match a study where the harvest order could be randomized. Because this design cannot
838 randomize the order of no-harvest zone widths within a plot, the results may be confounded by some
839 unanticipated aspect of harvest or site response that is due to harvesting the plots in that order. This
840 assumption can be partially supported by planned data collection methods, which will allow field crews
841 to identify which individual trees were correctly harvested or unintentionally felled. If we verify that
842 virtually all trees are removed as intended, this supports the assumption that the treatment level order,
843 if randomized, would not have produced different results.

844 845 *Site availability and sample size*

846
847 Lack of available sites is one possible limitation to this study. It may be difficult to identify an adequate
848 number of sites that match the selection criteria in areas where there are willing landowners or from
849 approved Forest Practices Applications (FPAs) that will be harvested during the study period. Further,
850 there is a small possibility that landowners may later choose not to harvest certain areas if timber
851 markets are not favorable.

852
853 To increase the number of potential sites, sites containing discontinuous plots (plots that do not share a
854 boundary) could be considered for inclusion in the study, as long as the site layout does not introduce
855 any unintentional biases that could affect outcomes.

856
857 If five qualifying sites cannot be identified in one or more ecoregions, other options will be considered,
858 such as: adding more sites in a subsequent year, continuing the study with fewer than five sites in an
859 ecoregion, adding more sites to another ecoregion, removing an ecoregion from the study, substituting
860 one of the four selected ecoregions with another relevant ecoregion in Washington, or adjusting the site
861 selection criteria to include more sites. The study will include at least four sites per ecoregion and will
862 only adjust site selection criteria if the criteria changes are carefully considered.

863 *Variation in site conditions*

864
865 Natural variation across the landscape creates variability in conditions across study sites. This variation
866 can produce confounding factors that limit the ability to identify trends and relationships for variables of
867 interest. Site variability will be reduced in this study by selecting sites within specified ecoregions that
868 have similar biophysical environments. Data will be analyzed according to ecoregion. Site variability will
869 also be reduced by using well-defined site selection criteria. Note: Reducing variability across sites will
870 reduce the range of variation over which conclusions can be drawn. It will improve study precision but
871 decrease the scope of inference.

872
873 During the analysis phase, stream orientation will be standardized across sites. The treatment bank will
874 be assigned to the south to estimate shade for east-west stream orientations, and to the east to
875 estimate shade for north-south stream orientations. Note that stream orientation will be assigned
876 during the photo analysis phase and is independent of actual stream orientation in the field. This step
877 will ensure that shade response to the treatments is not influenced by differences in stream orientation
878 across sites.

879
880 Variation in understory vegetation (e.g., shrub/sapling cover and height) and topographic shading across
881 sites may make it difficult to identify shade response due to the overstory harvest treatments. The
882 before/after treatment design and short duration of the harvest sequence ensures that there will be
883 minimal change in understory vegetation and topographic shading between treatments occurring in a
884 given plot, helping to isolate the treatment effect. Hemispherical photos will be taken at 3.3 feet (1
885 meter) above the streambed to further reduce the influence of low-lying vegetation and channel
886 topography on shade response to the treatments. Likewise, restricting the shade analyses to solar
887 altitudes $\geq 40^\circ$, will reduce the influence of shorter vegetation and sources of topographic shade (e.g.,
888 streambank) that fall below the zone of analysis. The primary focus is the change in effective shade due
889 to overstory harvest treatments.

890
891 *Study implementation/harvest logistics*

892
893 There are potential challenges with study implementation and harvest logistics due to the constraints of
894 the study design. First, landowner schedules for the upland clear-cut may not coincide with the leaf-on
895 conditions required for this study, so this constraint ideally will be addressed during the site selection
896 process. Second, the study design requires that the plot harvest sequence and hemispherical
897 photograph collection occur within a short timeframe (e.g., ≤ 10 days), so a large amount of coordination
898 will be needed between field crews and cutting crews. Cutting crews may have idle periods while field
899 crews are on site taking photographs at the designated intervals and appropriate times of day (when the
900 sun is not in view of the camera lens). An independent cutting crew will be hired and funded through
901 this project to apply the within-plot harvest treatments to help alleviate these logistical constraints.

902

903 Ideally, the riparian harvest treatments at a given site will occur during the same timeframe as the
904 adjacent upland harvest. This will minimize operational constraints such as re-opening access roads,
905 mobilizing harvest crews and equipment, or potential damage to newly planted seedlings. This will also
906 minimize the likelihood of windthrow and other disturbances occurring during the harvest and data
907 collection sequence. For each individual site, harvest within the experimental plots will be restricted to a
908 short time period (e.g., ≤ 10 days) to minimize the occurrence of uncontrolled factors during the harvest
909 sequence.

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911 If possible, the same personnel will be used to conduct stand inventories and mark trees for harvest to
912 provide consistency across all sites. A site selection and data collection plan (including Standard
913 Operating Procedures [SOPs]) will be developed to ensure the consistency and quality of data and to
914 identify and minimize logistical constraints.

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951 Tentative budget – subject to change

Budget Task	FY 22	FY 23	FY 24	FY 25
Westside Sites				
Site Selection (Westside)	\$39,415			
Layout plot and harvest zone boundaries, collect stand inventory data	\$42,240			
Mark Trees for thinning treatments	\$54,690			
Tree cutting within plots		\$75,985		
Compliance of tree cutting		\$7,500		
Data collection: Site attribute data		\$21,600		
Data collection: Photo Collection		\$55,840		
Eastside Sites				
Site Selection (Eastside)		\$40,278		
Layout plot and harvest zone boundaries, collect stand inventory data		\$22,803	\$30,244	
Mark Trees for thinning treatments		\$18,083	\$27,124	
Tree cutting within plots			\$97,515	
Compliance of tree cutting			\$7,500	
Data collection: Site attribute data			\$21,600	
Data collection: Photo Collection			\$58,129	
Photo processing, data analysis, and report writing				
Photo processing			\$25,000	
Data QA/QC, process, analyze, and summarize site attribute data			\$40,000	
Final report writing and review			\$40,000	
Final report revisions				\$20,000
Total FY Estimated Budget	\$136,345	\$242,089	\$347,112	\$20,000

952 **Total Estimated Project Budget: \$745,546***

953 ***It is assumed landowners will cover upland harvesting costs and removal of logs.**

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