Findings Report

Chapter 7. Stream Temperature and Shade

Type N Experimental Buffer Treatment Project in Hard Rock Lithologies

11 May 2018

The results from this study are found in the following Study Report:

McIntyre, A.P., M.P. Hayes, W.J. Ehinger, S. Estrella, D. Schuett-Hames and T. Quinn (technical coordinators). 2017. Effectiveness of Experimental Riparian Buffers on Perennial Non-fish-bearing Streams on Competent Lithologies in Western Washington. Cooperative Monitoring Evaluation and Research Report CMER XX-XXX, Washington State Forest Practices Adaptive Management Program, Washington Department of Natural Resources, Olympia, WA.

CMER/Policy Interaction Framework Six Questions

1. **Does the study inform a rule, numeric target, Performance Target, or Resource Objective?** Yes.
2. **Does the study inform the Forest Practices Rules, the Forest Practices Board Manual guidelines, or Schedules L-1 or L-2?** Yes.

The objective of the Type N Experimental Buffer Treatment Project in Hard Rock Lithologies (Hard Rock Study) was to evaluate the effectiveness of the current westside riparian management zone (RMZ) prescriptions for Type N (non-fish-bearing) Waters in maintaining key aquatic conditions and processes affected by Forest Practices. Specifically, we evaluated whether the riparian buffer prescription for Type N Waters met the following overall Performance Goals, namely: (1) to support the long-term viability of stream-associated amphibians and (2) to meet or exceed water quality standards (WQS).

CMER ranked the Hard Rock study as the highest priority based on the potential high risk to aquatic resources (CMER work plan 2005 - 2017) and because the Type Np rules for western Washington were based on the results from only a few studies with limited scope and inference. We assessed the Forest Practices Resource Objectives defined for key aquatic conditions and processes described in the Forest Practice’s Habitat Conservation Plan (WADNR 2005; hereafter, FPHCP), Appendix N, Schedule L-1. Resource Objectives are consist of Functional Objectives, or broad statements of objectives for the major watershed functions, and Performance Targets, or measurable criteria defining specific, attainable targets. This findings report addresses Resource Objectives for heat/water temperature only as requested by the TFW Policy Committee.

The Hard Rock study addresses one of the key questions that drives adaptive management:

> *“Will the rules produce forest conditions and processes that achieve resource objectives as measured by the performance targets, while taking into account the natural spatial and temporal variability inherent in forest ecosystems?*” (FPHCP, Appendix N, Schedule L-1)

The overall study addressed CMER Work Plan Critical Questions derived from Schedule L-1, including:

- Are riparian processes and functions provided by Type N buffers maintained at levels that meet Forest Practices (FP) Habitat Conservation Plan (HCP) Resource Objectives and Performance Targets for shade, stream temperature, large wood recruitment, litterfall, and amphibians?
- How do other buffers compare with the FP Type N prescriptions in meeting Resource Objectives?
- How do Type N riparian prescriptions affect water quality delivered to downstream Type F/S waters?

3. **Was the study carried out pursuant to CMER scientific protocols?**

Yes. The study was implemented according to the CMER and Independent Scientific Peer Review (ISPR) approved study design (including sampling methodologies, statistical methods, and study limitations). SAGs (RSAG and LWAG), CMER, and ISPR reviewed all of the study chapters and their associated findings. CMER approved the final report in September 2017.

4. **A. What does the study tell us?**

We evaluated the performance a clearcut harvest with one of three riparian buffer strategies relative to unharvested reference sites. The experimental treatments are described below in Table 1 and Figure 1. Riparian buffers were two-sided 50-ft (15-m) minimum leave-tree buffers. In addition, 56-ft (17-m) radius buffers were required around some sensitive sites, (PIPs, which includes both the headwater spring and headwall seep sensitive site categories) and Type Np intersections. All sites had a two-sided 30-ft (9-m) equipment limitation zone (ELZ) along the entire Np channel.

The riparian buffer along some 100% treatment streams was wider than the 50 feet width intended. due to regulatory and/or logistical constraints (e.g., unstable slopes or intersection with another riparian buffer). The FP streams were buffered along 55-73% of the perennial length.

We utilized an experimental Before-After Control-Impact (BACI) design. We maximized the treatment impact by harvesting the entire Type N basin (i.e., study site), when possible. Since the response of stream-associated amphibians was a primary variable of interest, we only included study sites where the species was known to occur, which restricted sites to those underlain by competent (i.e., hard rock) lithologies.

We collected pre-harvest temperature data continuously since mid-2006 (Table 2). Timber harvest occurred July 2008 through August 2009. We continued to monitor stream temperature and shade because of widespread increases in stream temperature noted immediately after harvest. These data will be reported in a separate document due in draft form September 2018.

<u>Shade and Stream Temperature</u>

The Heat/Water Temperature Resource Objective addresses shade and stream temperature.

<u>Functional Objective</u>: Provide cool water by maintaining shade, groundwater temperature, flow, and other watershed processes controlling stream temperature.

<u>Performance Targets</u>:

- <u>Shade</u> – Westside, Type N Waters: shade available within 50 feet for and least 50% of stream length.
- <u>Stream temperature</u> – Water quality standards (WQS) – current and anticipated in next triennial review[1].

Shade and Stream Temperature Results-First two years post-harvest:

- Type Np stream lengths (and percent of Np stream buffered) in the FP sites were 1050 m (62%), 325 m (73%), and 822 m (55%).
- We observed a significant post-harvest reduction in all shade metrics in all buffer treatments. Effective shade and canopy closure measured 1 m above the water surface were reduced 10% and 5%, respectively, in the 100% treatment, 36 and 27%, respectively, in the FP treatment, and 72% and 78%, respectively, in the 0% treatment.
- Slash and understory vegetation can provide shade, especially in unbuffered stream reaches, compared to measurements taken 1 m above the water surface. However, in spite of there being no significant (P >0.05) change in shade at the water surface in the 100% and FP treatments, water temperature increased post-harvest in both treatments.
- Pre-harvest streams in this study were cool compared to the random sample of western Washington Type Np streams on industrial forestland sampled in the Westside Extensive Study (Figure 2) (Ecology in review). Streams in the Extensive Study were not stratified by area, substrate, lithology or amphibian presences as the Hard Rock streams were. The pre-harvest maximum 7-day average daily maximum (7DADM) water temperature ranged from 10.0-16.1°C, with a median value of 13.0°C in the eleven harvested streams in this study. Only one stream exceeded 16.0°C pre-harvest. In comparison, the 7DADM in the random sample ranged from 8.6 – 23.7°C, with a median water temperature of 15.2ºC.
- The 7DADM at four sites exceeded the 16°C threshold criteria (see description of water quality standards [WQS] below) in at least one of the two post-harvest years (Figure 3). These were the four warmest sites pre-harvest and included one 100% treatment site and three 0% treatment sites.
- The average post-harvest increase in the 7DADM temperature, measured at the Buffer Treatment locations (the lowermost monitoring location on each stream that represented the buffer treatment), was 1.2ºC in the 100% and FP treatments and 3.2ºC

[1] The Forests and Fish Report was established in 1999 while revisions were being proposed to the state's water quality standards. This performance objective provides direct support for Forests and Fish Report's Overall Performance Goal: "c) Meet or exceed water quality standards (protection of designated uses, narrative and numeric criteria, and antidegradation)."

in the 0% treatment. The post-harvest increase in 7DADM in the three FP treatment streams ranged from 0.4 to 2.3°C.

- Further downstream at the F/N break, the magnitude of the 7DADM increase was 0.7°C, 1.2°C, and 2.9°C in the 100%, FP, and 0% treatments, respectively.
- Post-harvest increases in 7DADM were significant ($P < 0.05$) in all buffer treatments at the Buffer Treatment location and at the F/N break. There was no significant difference between the 100% and FP treatments, while the increase in both the 100% and FP treatments was significantly less than in the 0% treatment.
- Significant ($P < 0.05$) increases in the maximum daily stream temperature, averaged by month, were detected over a broad seasonal range at most sites and in all buffer treatments, typically occurring from early spring through the fall in both post-harvest years.
- Small (<1.0°C), but significant ($P < 0.05$), increases in the 7-day average minimum daily water temperature were noted in all buffer treatments, most frequently for the July-August period.

Shade and Stream Temperature Results-Years three through eight post-harvest (data not included in the report):

- In all three buffer treatments shade, measured at 1 m above the stream, declined through the first four years post-harvest then began an increasing in fifth year post-harvest 5.
- Mean monthly summer water temperatures, seven years after harvest, were significantly ($P < 0.05$) greater than pre-harvest levels at two of the four 100% treatment sites (one site >1.0°C), two of three FP sites (one site >1.0°C), and all four 0% sites. In addition, spring and fall temperatures were significantly higher at all 11 treatment sites.
- At seven years post-harvest mean monthly summertime water temperatures measured at downstream locations where the stream had flowed through approximately 100 m of unharvested forest (i.e. a reach within a Type F fish-bearing stream buffer or an unharvested forest) were significantly ($P < 0.05$) warmer at five of the six treatment sites (1-FP site, 4-0% sites). Summer temperature was significantly cooler only at the 100% treatment site. Spring and fall temperatures were higher at five of the six sites.

Conclusions:

- None of the three riparian buffer treatments were effective at preventing statistically significant changes; e.g., reductions in shade and increases in stream temperature.
- The immediate post-harvest reductions in effective shade and canopy closure were consistent with the intensity of buffer treatments and were of similar magnitude to the BCIF study (Schuett-Hames et al. 2011) and the Type 5 study (Janisch et al. 2012).
- Shade reductions in the FP treatment roughly met the expectations in the Forest Practices HCP. (The HCP expectations are in terms of angular canopy density. We used a densiometer and canopy photos.)

- Consistent with reductions in shade, we observed increases in the maximum and minimum daily stream temperatures and diel ranges across all buffer treatments.
- Both the 100% and FP treatments resulted in significantly (P <0.05) smaller increases in water temperature than the 0% treatment, but temperature increases in the 100% and FP treatments did not differ significantly (P >0.05) from each other.
- Even small reductions in shade (e.g., <10% in effective shade) lead to measureable increases in stream temperature (e.g., in the 100% treatment).
- The estimated increase for each buffer treatment is greater than the 0.3ºC increase allowable in the WQS for waters which are at or above the assigned temperature criteria (WAC 173-201A-200(1)(c)(i)). This magnitude of increase would trigger a Tier II antidegradation review to determine if the warming is necessary and in the overriding public interest (see and WAC 173-201A-320).

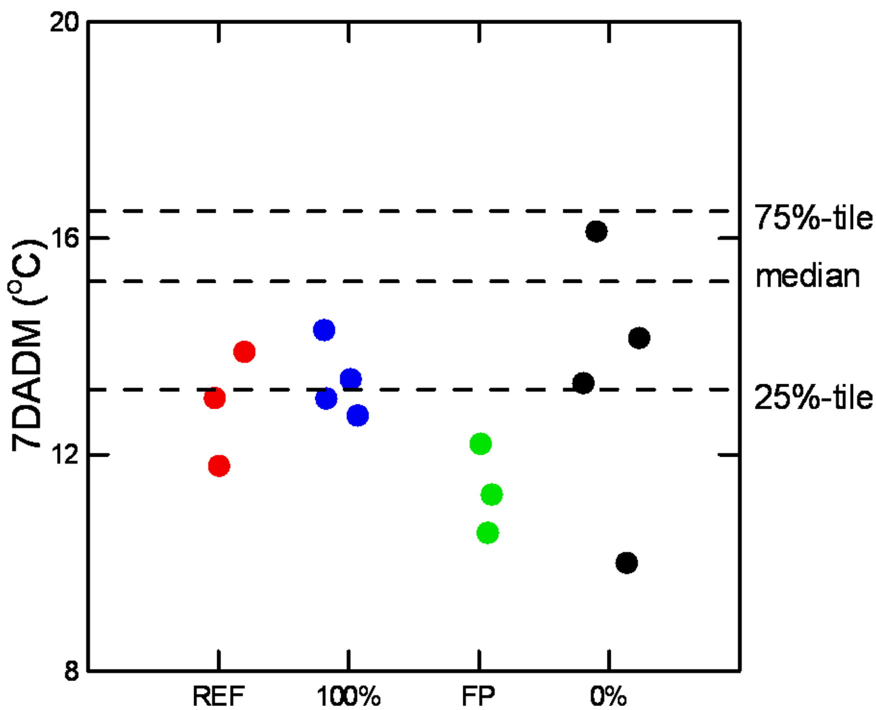

Figure 2. Pre-harvest seven day average daily maximum water (7DADM) temperature plotted by buffer treatment. Quartiles (dashed horizontal lines) from the westside Type Np Extensive Riparian Monitoring Study are shown for comparison. The random sample of Type N Waters was not stratified by basin area, lithology, or amphibian presence.

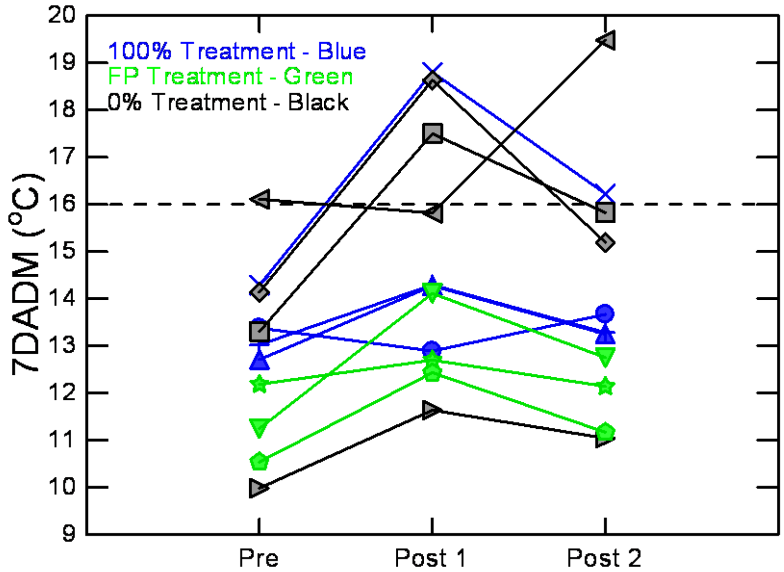

Figure 3. Seven-day average daily maximum temperature for each site by year. Sites that were warmer than 13°C pre-harvest tended to warm to 16°C or more after harvest. Nine of the eleven harvested buffer treatment sites were cooler in Post 2 than Post 1.

Summary of Treatment Performance

None of the buffer treatments prevented shade loss or increased stream temperatures after harvest. The 100% and FP performed similarly with respect to temperature and the 0% warmed significantly more than either the 100% or FP.

B. What does the study not tell us?

The study sites and buffer treatments did not include all possible combinations of physical conditions, stand conditions, and harvest. One should consider these when generalizing the results.

Spatial Scope of Inference: The spatial scope of inference is limited to Type N basins dominated by competent lithologies, which comprise approximately 29% of western Washington Forests and Fish-regulated lands (P. Pringle, personal communication, September 2005, formerly Washington Department of Natural Resources). Additional considerations include the fact that all sites, including references, were located in second-growth forests and ranged from approximately 12 to 53 ha (30 to 130 ac). See McIntyre and colleagues (2009) for a summary of the site selection process.

Temporal Scope of Inference: The temporal scope of inference is limited. The results from the extended monitoring through fall 2017 will be in a report due in fall 2018.

Riparian Buffering/BMPs: First, buffering of unstable slopes resulted in some 100% treatment sites having buffers much wider than 50 feet along at least a portion of the perennial length. This has no effect on the analysis of treatment effects at the Buffer Treatment locations because the stream above these locations always matched the intended treatment (i.e., 50-ft buffers).

Second, the presence of sensitive sites resulted in buffering of 55, 62, and 73% of the Type N length in the three FP sites, i.e., more than the 50% minimum required. Shorter (e.g., 50%) buffers would likely result in greater shade loss and higher water temperature.

Third, harvest in this study was done on both side of the stream. Anecdotal information from landowners suggests that harvest is not typically done on both sides of Type N streams simultaneously but that harvest could be separated by months to years. If so, this could lessen the impact to shade and stream temperature to an unknown degree.

Table 1. Description of four experimental treatments included in the Type N Study and the sample size for each treatment. All study sites are located on lands managed for timber production.

Treatment	Description	Sample size (n)
Reference	No harvest during study period	6
100%	Two-sided 50-ft (15-m) no-harvest riparian buffer along entire Type Np RMZ, with 56-ft (17-m) radius buffers around Type Np intersections and uppermost points of perennial flow (i.e., PIPs).	4
FP	Two-sided 50-ft (15-m) no-harvest riparian buffer along at least 50% of the Type Np RMZ, with 56-ft (17-m) radius buffers around Type Np intersections and headwater springs, consistent with current FP rules.[2]	3
0%	No buffer	4

[2] The length of the buffer in the three FP treatments was greater than the minimum 50% required under Forest Practices rules, equaling 55%, 62%, and 73% of the perennial Type N channel.

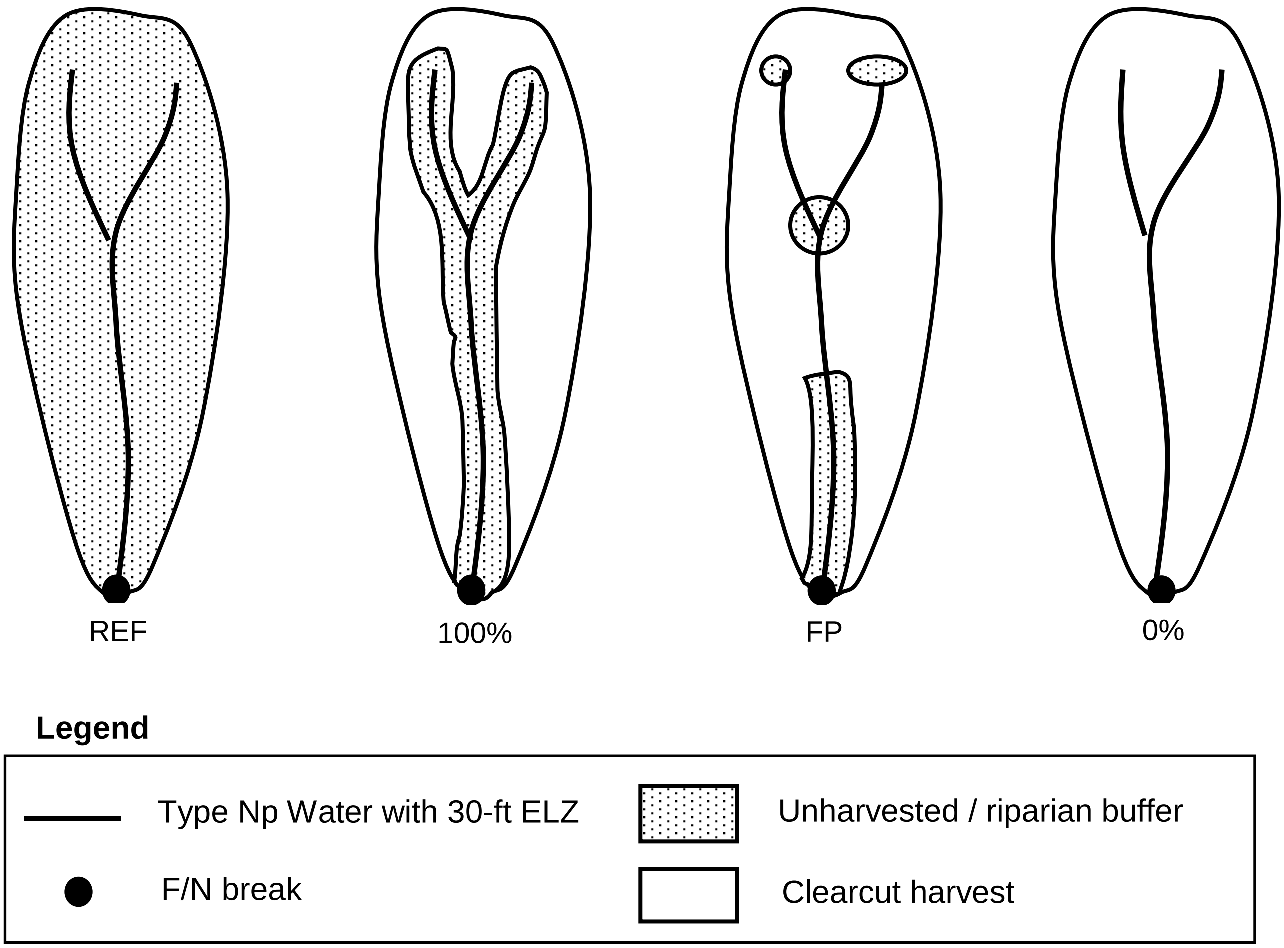

Figure 1. Schematic of the four experimental treatments included in the Type N Study. Treatments included unharvested reference sites (REF) and sites receiving a clearcut harvest with one of three riparian buffer treatments along the Type Np Water RMZ: two-sided 50-ft (15-m) riparian buffers of 100%, Forest Practice (FP), and 0%. All streams had a two-sided 30-ft (9-m) equipment limitation zone (ELZ).

Table 2. Timeline of data collection and report development for past, current and potential future work related to the Type N Hard Rock Study.

	Sampling Period and Year																			
	Pre-harvest			**Harvest**	**Post-harvest**		**Extended**								**Future Potential Extended Work**					
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Stand Structure/Tree Mortality		x	x	x	x			x			x					x				
Wood Recruitment/Loading	x	x	x	x	x			x			x					x				
Stream Temperature/Cover	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Discharge/Turbidity	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Nutrient Export	x	x	x	x	x	x					x	x								
Sediment Processes	x	x	x	x	x															
Stream Channel Characteristics	x	x	x	x	x			x			x					x	x			
Litterfall Input/Detritus Export	x	x	x	x	x	x														
Biofilm/Periphyton	x	x	x	x	x															
Macroinvertebrate Export	x	x	x	x	x	x														
Amphibian Demographics	x	x	x	x	x					x	x						x	x		
Amphibian Genetics	x	x	x							x	x*									
Downstream Fish	x	x	x	x	x															
Trophic Pathways	x	x	x	x	x						x									
Two year post-harvest report							x	x	x	x	x	x								
"Extended" post-harvest report												x	x	x			x	x	x	x
Amphibian Genetics reports				x	x	x						x*								

* Stream-associated Amphibian Genetics sampling in 2015 and 2016 was the first post-harvest sampling, with the report developed in 2017

5. What is the relationship between this study and any others that may be planned, underway, or recently completed?

The results from the Hard Rock Study, BCIF Study, Soft Rock Study, Shade Study, and Amphibian Recovery Project are expected to provide a thorough assessment of riparian prescription effectiveness for westside Type N Waters. These data can be used to determine if the resource objectives for heat/water temperature are being met.

- Westside Type N Buffer Characteristics, Integrity, and Function Project [BCIF Study, completed]: The BCIF Study evaluated the magnitude of change in riparian stand conditions, tree mortality, shade and LWD recruitment when prescriptions were applied on a reach-scale at sites selected from a random sample of forest practice applications. The shade results are most pertinent to Chapter 7.
- Type N Experimental Buffer Treatment Project in Soft Rock Lithologies Project [Soft Rock Study, underway]: The Soft Rock Study will evaluate the post-harvest changes in riparian stand conditions, buffer tree mortality, LWD recruitment, shade and stream temperature, and nutrient and sediment export from westside Type N basins with sedimentary lithologies. This study differs from the Hard Rock study in that it includes only study basins underlain with sedimentary lithologies and includes only one riparian buffer treatment equivalent to the Hard Rock Study FP treatment. Both the Hard and Soft Rock studies use a BACI experimental design to compare effectiveness of riparian buffers with unharvested controls.
- Eastside Type N Riparian Effectiveness Project [ENREP Study, underway]: The ENREP study will determine if, and to what extent, the eastside riparian prescriptions are effective in achieving Performance Targets and WQS, particularly as they apply to sediment and stream temperature. Study objectives are to quantify the magnitude of change in stream flow, canopy closure, water temperature, suspended sediment transport and wood loading in eastern Washington Type Np streams.
- Eastside Ns Effectiveness Project [planned]: A literature review will inform a field study to examine the effect of riparian prescriptions on Ns streams on downstream Type Np and F Waters. Responses may include in-channel wood loading, channel stability, and downstream water quality (temperature, turbidity, and sediment) and quantity, stream channel stability and magnitude and frequency of scour.

- ***Feasibility of obtaining more information to better inform Policy about resource effects.***

The CMER budget for the current biennium includes funding for analyses of these data and report writing. Future and continued data collection is possible if interest exists at Policy and the Board. To date, only one reference site has been harvested, one is currently being harvested, and two are expected to be harvested during calendar year 2019. Due to regulatory constraints, it is unlikely that the remaining two reference sites would ever be harvested. This is a unique long-term data set evaluating applicable riparian buffer treatments in a BACI-designed study. Value exists in continued monitoring of treated sites for interpretation of the longer-term trajectory of change.

What are the costs associated with additional studies?

Analysis and reporting of results through eight years post-harvest are included in the CMER 2017-2019 budget. Budget placeholders are in the CMER Master Schedule for continued stream temperature monitoring at a cost of $150,000 in the 19-21 biennium.

What will additional studies help us learn?

Additional monitoring in this study allowed us to estimate the rate of change of riparian shade and stream temperature over time. This is of interest because neither shade nor temperature has returned to pre-harvest levels in any of the treatments.

- ***When will these additional studies be completed (i.e., when will we learn the information)?***

A draft analysis of the extended data is due September 2018.

- ***Will additional information from these other studies reduce uncertainty?***

Yes. Future monitoring beyond eight years post-harvest will reduce uncertainty associated with long-term trajectories of shade and stream temperature.

6. **What is the scientific basis that underlies the rule, numeric target, Performance Target, or Resource Objective that the study informs? How much of an incremental gain in understanding do the study results represent?**

<u>*What is the scientific basis that underlies the rule, numeric target, Performance target or Resource Objective that the study informs?*</u>

RMZ requirements for Type N Waters were developed to maintain important ecological processes and provide levels of large wood, shade and other riparian functions adequate to meet conservations objectives (FPHCP, Chapter 4d – Rationale for the Plan). The management approach for westside Type N riparian prescriptions employs a patch-cut strategy, where a portion of the riparian stand in a Type N basin RMZ may be clearcut, providing that sensitive sites and at least 50% of the perennial stream length is buffered with a two-sided 50-ft buffer. The underlying assumptions of the current rule prescriptions for Type N Waters were based on limited experimental research studies related to riparian ecological processes, habitat needs of covered species and forest management effects on larger streams (FPHCP). The following information is based on that found in Chapter 4d of the FPHCP. For discussions that include relevant literature published since the FPHCP was finalized in 2005 see the chapters for the individual response metrics in the study report.

<u>Shade</u>: Riparian forests and the shade they provide are key factors affecting the thermal regime of aquatic ecosystems (Brown 1985), reducing incoming solar radiation and moderating water temperatures. Reductions in streamside shade alter the thermal regime of a stream (Beschta *et al.* 1987). Based on these findings from two studies (Brazier and Brown 1973; Steinblums *et al.* 1984), it was anticipated that riparian buffers retained on Type N Waters under Forest Practices rules would maintain between 50% and 75% of the pre-harvest Angular Canopy Density (ACD). Shade reduction along small streams in western Washington were expected to recover within five years, due to the rapid growth of understory vegetation (Summers 1982; Caldwell *et al.* 1991).

Stream Temperature: The FPHCP concluded that there was a reduced risk of temperature impacts to Type N Waters compared with Type S and Type F waters and that temperature increases within buffered reaches of the RMZ would be small. Temperature effects downstream of the harvest unit were expected to be minimal, based on the findings from three studies (Caldwell *et al.* 1991; Dent and Walsh 1997; Robison *et al.* 1999). Based on the findings of one study (Summers 1982), if temperature increases associated with timber harvest did occur in Type N Waters, recovery to pre-harvest levels was expected to be rapid.

How much of an incremental gain in understanding do the study results represent?

This study provides a substantial gain in understanding of the degree to which Type Np Forest Practices rules meet the Resource Objectives and Performance Targets. While previous studies may have evaluated stream temperature and shade, the Hard Rock Study provides results in context of the specific Forest Practices rules for riparian prescriptions required on Type N Waters in western Washington.

Technical Implications and Recommendations:

New rule tools or field method development.

- Year round monitoring, a solid study design (BACI), and multiple reference sites enabled us to detect even small changes in temperature using modern statistical techniques.

Research/monitoring suggestions.

- Forestry works over long time periods. Monitoring and evaluation recognize this.

Suggested rules/board manual sections to review/revise.

- We agree with the suggestion in the BCIF Study Findings Report (Schuett-Hames *et al.* 2011) that CMER and Policy should review and potentially revise some of the Type Np Performance Targets for westside and eastside Type N Waters.
    - Performance Targets for some metrics were tied to the objective of providing 50% of the riparian function available within 50 feet of the stream, and are more closely related to compliance targets than Performance Targets *per se*. For example, shade and litterfall Performance Targets merely restate the prescriptions, so if the harvest is done in compliance with the rules, the Performance Target will be met, at least immediately following harvest.
    - Schedule L-1 specifies that there will be idenfication of timelines for Performance Targets that can be met within short, mid- and long-term time periods, a process that has not yet occurred, but that is likely very important for evaluating the effectiveness of rules through time.

Evaluation of whether key aquatic Resource Objectives (Schedule L-1) are being met.

The rules for stream temperature are complex, especially as they are related to the state surface water quality standards (WQS). We provide additional information and discussion here regarding the degree to which state WQS were or were not met.

Heat/Water Temperature. The Schedule L-1 Performance Target for stream temperature is to meet the state surface WQS (Chapter 173-201A WAC). The WQS for stream temperature include:

(1) A threshold 7-day average daily maximum (7-DADM) temperature determined by the designated uses for that water body.
(2) Limits for warming that apply when waters are both cooler and warmer than the threshold criteria.
(3) Anti-degradation criteria designed to protect waters which are colder than the threshold criteria and that is triggered by a human-caused increase of 0.3°C or greater.

<u>The state surface WQS direct that:</u>

- Human actions alone or in combination are not allowed to cause or contribute to the exceedance of the threshold criteria. These include an annual 7-DADM of 12°C for Char spawning and rearing and 16°C for core summer salmonid habitat, which are the most common threshold criteria applied within lands subject to the forest practices HCP. Non-fish bearing tributaries are protected with the same annual threshold criteria as the fish-bearing waters into which they flow.
- When a waterbody is naturally at or above the threshold criteria, human activities, considered alone or in combination, cannot raise the temperature by more than 0.3°C.
- When a waterbody is cooler than the threshold criteria, an increase of 0.3°C or greater would trigger the need to determine if the action (warming due to implementing the Type Np rules in this case) is necessary and in the overriding public interest (required by the Antidegradation rules). If it is so determined to be necessary and in the overriding public interest, nonpoint sources could cumulatively raise temperatures by a maximum of 2.8°C or up to the threshold criteria, whichever is more stringent.

Interpretation of the WQS is the responsibility of the Washington State Department of Ecology, but the first step is a scientifically credible estimate of the post-harvest temperature change. Chapter 7 provides these estimates and includes the following relevant observations.

<u>Did the application of the Type Np rules cause temperatures to exceed the standard that would trigger a Tier II water quality antidegradation review?</u>

- The average increase post-harvest at the Buffer Treatment locations was 1.2, 1.2, and 3.2°C in the 100%, FP, and 0% treatments, respectively. This is greater than 0.3°C in all buffer treatments.
- Warming in excess of 0.3°C, calculated on a monthly basis, occurred throughout the spring to fall period at most of the monitoring locations.
- Statistically significant ($P < 0.05$) warming occurred at our downstream monitoring stations (placed 100 m or more downstream of the harvested portion of the site.
- Results indicate neither the Type N rules, nor the other two buffer treatments, were effective in preventing warmer stream temperatures. Water temperature remains significantly elevated at most sites seven years after harvest.

<u>Assuming a greater than 0.3°C warming due to the Type Np rules were to be found to be both necessary and in the overriding public interest by the Department of Ecology under the Antidegradation rules, would the warming be greater than the 2.8°C allowed cumulatively for nonpoint sources?</u>

- This criterion applies to all sources of warming by non-point sources (e.g. forestry, agriculture, commercial and residential development) throughout a waterbody, and so cannot be directly informed by this study alone.
- The average (across both post-harvest years) increase at the lower end of the buffer treatment was 1.2°C in the 100% and FP treatments and 3.2°C in the 0% treatment.
- This indicates that a single Type Np basin harvested in conformance with the 100% or FP treatment would not cause warming in excess of the allowed 2.8°C for at least the first two years post-harvest but the 0% treatment would.
- Results also indicate that warming was observed approximately 100 m downstream. Four of the six sites showing treatment effects of 0.4°C or less while the other two remained elevated 0.9°C and 1.6°C as an average response over the two year post-harvest period. This suggests some potential for cumulative increases in downstream temperature in watersheds where adjacent Type Np streams are harvested over a short period. The results also suggest that for many streams the risk of exceeding 2.8°C will be quite low.

<u>Did the application of the Type Np rules cause temperatures to exceed the threshold criteria (e.g. 12°C or 16°C), or to exceed the increment for warming (0.3°C) allowed for waters naturally warmer than the assigned threshold criteria?</u>

- The threshold standard was an annual 7-DADM of 16°C at all but one of the Hard Rock study sites.
- Pre-harvest the 7-DADM temperature exceeded 16°C only at the CASC-0% site.
- Post-harvest three streams which were less than 16°C pre-harvest exceeded 16°C post-harvest (one-100%, two-0% sites; Figure 3). The CASC-0% site was greater than 16°C pre-harvest and warmed after harvest.
- The 7-DADM at the remaining seven buffer treatments sites (3-100% sites, 3-FP sites, 1-0% site) was less than 14.3°C.
- The average (across both post-harvest years) post-harvest increase in 7DADM at the lower end of the buffer treatment was 1.2°C in the 100% and FP treatments and 3.2°C in the 0% treatment.
- Our study streams were relatively cool but these results suggest that streams in the warmer range of those tested in this study may be at risk of exceeding the threshold criterion after harvest.
- In addition, the greater than 0.3°C warming observed in each of the Hard Rock study buffer treatments strongly suggests the incremental warming allowance for waters that are naturally warmer than the assigned threshold may also occur.

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