Type N Experimental Buffer Treatment Project in Hard Rock Lithologies – Report to Policy

Approved by CMER – 27 February 2018

Study Report

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 the fact that the Type Np rule for western Washington was based on the results from few studies with limited scope and inference. As part of our evaluation, we assessed the Forest Practices Resource Objectives defined for key aquatic conditions and processes affected by forest practices outlined in the Forest Practice’s Habitat Conservation Plan (WADNR 2005; hereafter, FPHCP), Appendix N, Schedule L-1. Resource Objectives are intended to meet the overall performance goals, and consist of Functional Objectives, or broad statements of objectives for the major watershed functions potentially affected by forest practices, and Performance Targets, or measurable criteria defining specific, attainable target forest conditions and processes. In this study, we address Resource Objectives for heat/water temperature, large wood/organic inputs, and hydrology. We will specify the Functional Objectives and Performance Targets evaluated for each study response variable presented in the study results in #4 below. Note that not all study responses have corresponding Functional Objectives and Performance Targets in Schedule L-1, and for these we will identify applicable Resource Objectives and Critical Questions outlined in Schedule L-2 and/or the CMER Work Plan.

This effectiveness monitoring and research 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)

Finally, the overall study design 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 design was carried out 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, and CMER approved the entire final report in September 2017.

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

CMER designed an Effectiveness Study to evaluate clearcut harvest of lands managed for timber production with alternative riparian buffers on Type N Waters. We evaluated four experimental treatments including (1) an unharvested **Reference,** and clearcut harvest with three alternative riparian buffers that differed in the length of the riparian buffer in the RMZ: (2) **100% treatment**, (3) **Forest Practices (FP) treatment**, and (4) **0% treatment** (Table 1 and Figure 1).

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	Withheld from 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)	3

	radius buffers around Type Np intersections and headwater springs, consistent with current FP rules.[1]	
0%	Clearcut harvest throughout the entire Type Np RMZ	4

Where required, 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, specifically uppermost points of perennial flow (hereafter PIPs, which includes both the headwater spring and headwall seep sensitive site categories) and Type Np intersections. Unstable slopes required wider buffers of variable width along some channels. The 100% and FP treatments include riparian buffers throughout all or some of the RMZ (hereafter, buffered RMZ). The FP and 0% treatment include stream reaches that were clearcut, with removal of all standing trees, including non-merchantable timber, throughout some or all of the RMZ (hereafter, clearcut RMZ).

[1] In practice, 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%.

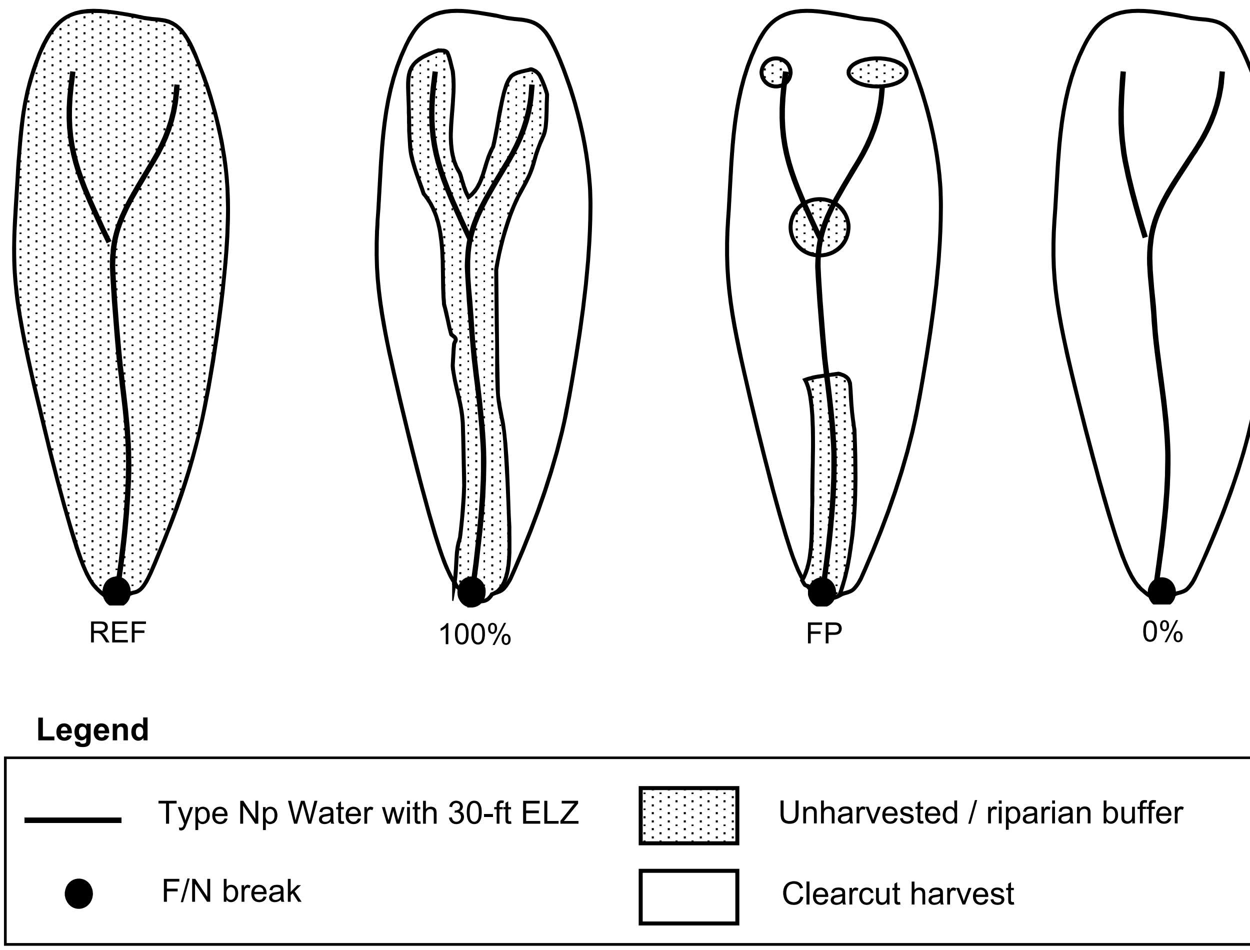

Figure 1. Schematic of the four experimental treatments included in the Type N Study. Treatments included unharvested reference sites (REF) and sites receiving a clearcut harvest with one of three riparian buffer treatments along the Type Np Water RMZ: two-sided 50-ft (15-m) riparian buffers of 100%,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

We collected 2-3 years of pre-harvest data 2006-2008 (Table 2). Timber harvest with riparian buffer treatments were applied July 2008 through August 2009. We collected two or more years of post-harvest data 2009-2011. We report on the findings from these periods here in the Findings Report. We have collected additional data from 2011 to the present (extended period). CMER is currently developing a separate final report containing the findings from the extended period and will convey results to the Timber, Fish and Wildlife Policy Committee (hereafter, Policy) in an additional findings report, tentatively expected in 2019. Policy may be interested in conducting future data collection beyond what has already been collected. The current CMER Master Schedule has line items and projected budgets associated with this work.

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	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

The study focused on the response of stream-associated amphibians and resources known to impact amphibian populations (i.e., water temperature, sediment, organic input, shade and channel structure), as well as exports to downstream fish-bearing (Type F) Waters (i.e., water temperature, sediment, organic/nutrient export, macroinvertebrate export, and discharge).

CMER designed the study to maximize the likelihood of detecting differences among treatments, if they existed. In order to accomplish this, we designed a landscape-scale study with sites located throughout western Washington and the south Cascades. We utilized an experimental Before-After Control-Impact (BACI) design and compared the response of sites to clearcut harvest with treatments that differed in the length of the RMZ buffered. We collected two or three years of pre-treatment (i.e., before treatment) data during 2006-2008. Landowners applied clearcut harvest treatments between July 2008 and August 2009. We collected two or more years of post-treatment (i.e., after treatment) data 2009-2011. In some instances, the riparian buffer along 100% and FP treatment streams was longer and/or wider than the minimum required under Forest Practices rules due to regulatory and/or logistical constraints. We maximized the treatment impact by applying the treatments on the scale of an entire Type N basin (i.e., study site), when possible. Less than the total basin area was harvested in four of 13 riparian buffer treatment sites. The unharvested area in two 100% treatment sites was 3.7 ha (9.1 ac) of a 28 ha (68 ac) basin, or 13% of the total, and 2.8 ha (6.9 ac) of a 26 ha (65 ac) basin, or 11% of the total. The unharvested area of two 0% sites was 0.4 ha (1.0 ac), or 2% of the total, and 2.1 ha (5.2 ac), or 15% of the total (see Final Report Chapter 3 – *Management Descriptions* for details). 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. Finally, we used the most appropriate sampling methods and statistical analyses available.

The null hypothesis, or expected result if there was no effect of clearcut harvest and no differences in response among riparian buffer treatments, is that the pre- to post-harvest change in the reference would not differ from the change in the 100%, FP or 0% treatments. Alternatively, where we anticipated a difference, we hypothesized that the change in the 100% treatment would differ the least from the reference, with a moderate difference between the reference and FP treatment, and the largest difference between the reference and 0% treatment.

The results of the Hard Rock Study inform the efficacy of current Forest Practices rules. The temporal scope of inference applies to the two year post-harvest interval. Overall, the 100% treatment was the most effective in maintaining pre-harvest conditions, followed by the FP and then the 0% treatment. We found more statistically significant changes, with greater magnitudes of change, in the 0% treatment than in the other buffer treatments. While the 100% and FP treatments had similar responses for several metrics, we also found responses that differed between the two treatments.

We present applicable results, with a focus on responses that differ from the reference, in a "Results" section and then discuss those results in terms of effectiveness in meeting Schedule L-1 Functional Objectives and Performance Targets in a "Conclusions" section. For all comparisons, results are as they relate to the reference except where otherwise stated.

Stand Structure and Tree Mortality Rates

The LWD/Organic Inputs Resource Objective addresses riparian stands. The Hard Rock Study reduces uncertainty for riparian stand condition with an evaluation of tree mortality and tree fall during the two years after harvest.

Functional Objective: Develop riparian conditions that provide complex habitats for recruiting large woody debris and litter.

Performance Targets: There are no Performance Targets specific to riparian condition for Type N Waters.

We can also indirectly inform the critical question regarding the frequency and distribution of windthrow in forest practices buffers on Type N Waters.

Critical Question: How do survival and growth rates of riparian leave trees change following Type Np buffer treatments?

Results:

- The greatest change in stand structure occurred in the treatments where riparian trees were completely removed to the stream edge (clearcut) and replanted with conifers (the 0% treatment and unbuffered portions of the FP treatment RMZs).
- Two year post-harvest tree mortality rates were higher in the FP buffered RMZs compared to unharvested reference sites and 100% treatment RMZs. Post-harvest tree mortality (% basal area/yr) in FP buffered RMZs was over four times greater than in unharvested reference RMZs ($P = 0.01$) and over two times greater than in 100% RMZs ($P = 0.09$). The mortality rate in the 100% RMZs was double the reference rate, but the difference was not statistically significant. The mortality (% basal area) in both the FP and 100% PIPs were significantly higher than the rate for the reference PIPs, eight ($P <0.01$) and four ($P = 0.05$) times higher, respectively.
- Stand structure as measured by trees per acre in the FP buffered RMZs was highly variable two years post-harvest. Most (~75%) stands had densities greater than 120 trees/acre, while a subset (~25%) had densities below 120 trees/acre.
- Windthrow was the primary cause of mortality and tree fall in both RMZ and PIP buffers. There was substantial variability in windthrow mortality among and within sites. We observed higher rates of windthrow in the RMZs of the coastal blocks (Willapa 1 and Willapa 2) than in sites located further inland in both the pre- and post-harvest periods.
- Higher tree mortality in PIP buffers was likely due to their exposed locations and vulnerability to windthrow.

Conclusions:

- Removal of streamside trees in the 0% treatment and unbuffered portions of the FP treatment returned these areas to the stand-initiation stage of development and is likely to have the greatest effect on the quantity, characteristics and timing of wood input.
- Unless the rates of tree mortality change significantly over time, FP and 100% RMZ buffers, which experienced low mortality, are likely to continue developing as single

cohort, conifer dominated stands. The future trajectory for the sub-set of buffer stands with higher mortality remains unclear. Since replanting is not required in these areas under Forest Practice rules, success of natural conifer regeneration will likely determine if these stands develop as multi-cohort conifer stands, or become dominated by broadleaf trees or shrubs.

- Results from the Hard Rock Study are consistent with the findings from the Westside Type N Buffer Characteristics, Integrity, and Function Project (BCIF) Study (Schuett-Hames *et al.* 2011). Post-harvest mortality rates in the FPB RMZs were similar, and both studies documented statistically significant increases in mortality in FPB RMZs compared to reference sites.

Wood Recruitment and Loading

The LWD/Organic Inputs Resource Objective addresses wood recruitment and loading. The study reduces uncertainty for instream wood through an evaluation of wood recruitment and loading in the two years following harvest.

Functional Objective: Develop riparian conditions that provide complex habitats for recruiting large woody debris and litter.

Performance Targets: There are no Performance Targets specific to wood recruitment and loading for Type N Waters.

Wood Recruitment Results:

- Two year post-harvest tree fall rates, as a percentage of standing stems, in the FP buffer RMZs and PIPs were >5 (P = 0.02) and 12 (P = 0.01) times greater than the comparable unharvested reference rates. Tree fall rates in the 100% treatment PIPs were 7 times (P = 0.03) greater than in reference PIPs; however, no significant difference existed between tree fall rates in the 100% treatment and reference RMZs.
- In the two years following harvest, in-channel wood recruitment experienced the greatest change in the clearcut RMZs and PIPs, with little additional wood recruitment to the stream because trees were removed as part of the harvest treatments.
- Two year post-harvest large wood recruitment rates (volume) from RMZs in the FP buffer and 100% treatment were somewhat greater than for reference RMZs (1.1 and 1.6 times, respectively), but the differences were not statistically significant.
- Large wood recruitment volume in the FP and 100% treatment PIP buffers was substantially greater than in the reference PIPs (12 and 19 times, respectively) and the differences were statistically significant (P = 0.08 and 0.04, respectively).
- Riparian buffers prevented input of logging slash into the stream from upland clearcut harvest. In these buffers, wood input was mostly due to windthrow.
- Ninety percent of trees recruited during the two year post-harvest period were suspended over the stream channel.

Wood Loading Results:

- The post-treatment change in the number of in-channel large wood pieces (>10 cm [4 in] diameter) differed between the reference and riparian buffer treatments (P <0.01).

We estimated a between-treatment average increase of 60% (P <0.001), 40% (P = 0.03) and 50% (P = 0.01) in the number of large wood pieces per stream meter in the 100%, FP and 0% treatments, respectively. The pattern for functional large wood (i.e., contributing to step formation, bank stability, or hydraulic roughness) was similar to that for total large wood (P <0.01).

- The post-treatment change in the number of in-channel small wood pieces differed between the reference and riparian buffer treatments (P <0.01). We estimated a between-treatment average increase of 60% (P = 0.05), 70% (P = 0.07) and 170% (P <0.0001) in the number of small wood pieces per stream meter in the 100%, FP and 0% treatments, respectively. The pattern for functional small wood was similar to that for total small wood (P <0.01).
- The only significant difference in numbers of wood pieces among the three buffer treatments was for total small wood, which had a greater post-harvest increase in the 0% than in the 100% (P = 0.01) and FP (P = 0.08) treatments. The increase in total small wood in the 0% treatment was 70% greater than in the 100% treatment and 60% greater than in the FP treatment.
- Greater than 75% of all wood pieces were classified as small. Small wood played a functional instream role in all sites, with approximately 50% of small wood pieces contributing to instream function, regardless of treatment.
- When in-channel windthrow and slash were considered in combination, the channel length covered (hereafter "wood-obstructed reaches") differed significantly among treatments (P = 0.001). In the first post-harvest year, wood-obstructed reach length in the 100%, FP and 0% treatments was estimated to be 3, 8, and 9 times greater than in the reference, and the FP and 0% treatments were significantly greater than in the reference (P <0.01).
- The proportion of wood-obstructed reaches in the post-harvest period increased with a decrease in the length of buffered RMZ, ranging from 8 to 25% in the FP treatment and 0 to 61% in the 0% treatment.
- We observed up to 5 times more large wood and up to 15 times more small wood in wood-obstructed reaches than in reaches that were not obstructed by wood. Ninety-one percent (91%) of all wood pieces in wood-obstructed reaches were classified as small wood (≤10 cm [4 in] diameter).
- Large wood pieces most frequently contributed to bank stability in both the pre- and post-harvest periods, except in wood-obstructed reaches in the post-harvest period where the predominant function was hydraulic roughness. Large wood in wood-obstructed reaches also spanned the channel more frequently than in reaches that were not obstructed by wood.
- Small wood was generally loose in the stream (e.g., not anchored in the stream and easily moved downstream during periods of higher flow) in both the pre- and post-harvest periods. In the post-harvest period, the proportion of small wood pieces that were loose declined, while the proportion of pieces that contributed to hydraulic

roughness increased. The proportion of pieces contributing to hydraulic roughness or spanning the channel was greater in wood-obstructed reaches.

Conclusions:

- Streams with buffers (FP buffered and 100% treatments) had increases in wood recruitment and loading over the two year post-harvest period.
- For streams with buffers, differences in wood recruitment were associated with levels of disturbance (mostly windthrow), including frequency and severity, regardless of treatment. Variability in stand structure associated with differences in post-harvest mortality has implications for future wood input and loading in the buffered streams, creating uncertainty about the ability of disturbed buffers to supply wood over the long-term.
- Future large wood recruitment from buffered RMZs and PIPs will depend on several factors, including existing recruitment potential (the density and size of the current stand), ingrowth of new trees, future silvicultural activities, and the magnitude and frequency of disturbances, such as wind, that cause tree mortality and wood input. In buffered RMZs without extensive mortality, future recruitment potential is good. For the sub-set of buffers with substantial wind mortality, wood recruitment rates were higher during the first two years after harvest, but the number of trees remaining in the stand were depleted. Uncertainty remains about the ability of these stands to regenerate and supply instream wood over the long-term.
- Future large wood recruitment from unbuffered (clearcut) RMZs in the FP and 0% treatments will require the establishment and development of a new forest stand. Over time, wood loading is likely to decrease as logging slash decays; however, these channels are likely to receive another pulse of logging slash during the next harvest. This process will result in an episodic wood input regime and changes in wood loading through time.
- We observed the greatest post-harvest increase in wood loading, especially small wood related to harvest of the streamside riparian stand (i.e., slash), as a result of harvest activity in the clearcut RMZs. In these reaches, equipment limitation zones (ELZs), in combination with additional rules intended to minimize wood input during harvest, did not prevent recruitment of logging slash to streams. However, our study streams had substantially less slash input than streams in some similar studies (e.g., Jackson *et al.* 2001).
- In clearcut stream reaches, there was very little additional large wood recruitment during the two years after harvest. Harvest of streamside trees eliminates potential future wood recruitment for an extended period, which will likely result in smaller and lower wood loading levels over longer periods (e.g., a harvest rotation). Uncertainty remains about the fate and persistence of logging slash, especially small wood, which decays at a much faster rate than, and does not provide the same opportunity for instream sediment storage as, large wood. In Type N basins with clearcut RMZs, replacement of large wood with smaller pieces will likely reduce long-term sediment storage capacity.

- We cannot evaluate whether this wood input regime meets the Functional Objective of providing complex habitats and developing riparian conditions for recruiting large wood through time with only two years of post-harvest study.
- Wood pieces suspended above the stream channel provides shade and cover and are expected to provide in-channel functions eventually as they decay and are recruited to the stream. Uncertainty remains about the timeframe for suspended pieces to fall into the channel.

Shade and Stream Temperature

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

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

Performance Targets:

- Shade – Westside, Type N Waters: shade available within 50 feet for and least 50% of stream length.
- Stream temperature – Water quality standards (WQS) – current and anticipated in next triennial review[2].

Chapter 7 also addresses the Schedule L-1 Priority research directive to “Test the cumulative effect (at basin scale) of the Westside Type N patch buffers in meeting temperature targets".

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.
- Before 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 (Ecology in review; Streams in the Extensive Study were not stratified by area, substrate or lithology; Figure 2). The pre-harvest maximum 7-

[2] 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).”

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] on page 40) 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 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):

- Shade, measured at 1 m above the stream, began an upward trajectory (increasing) in post-harvest year 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 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).

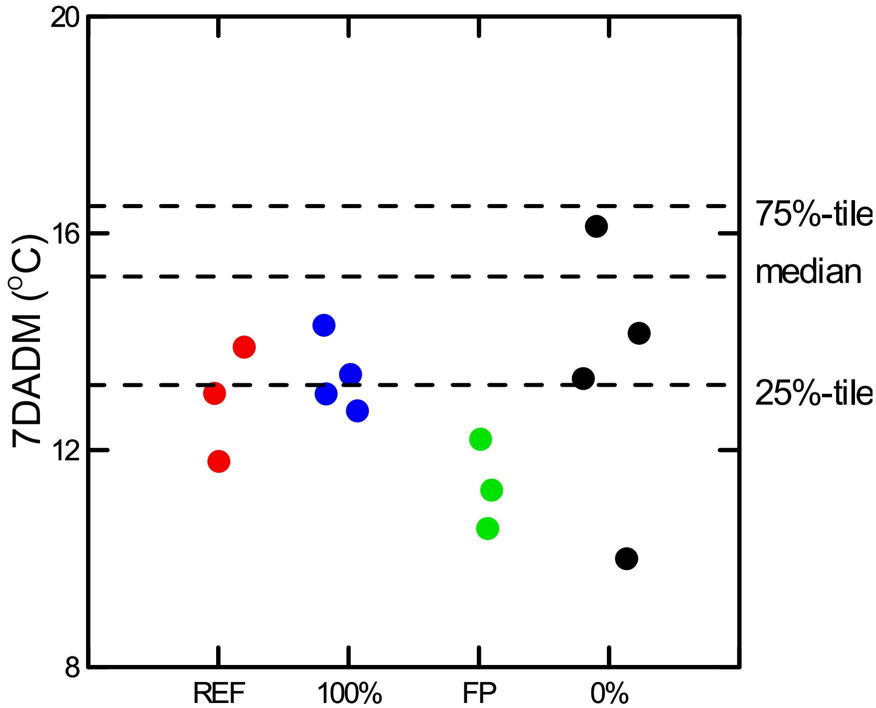

Figure 2. Pre-harvest seven day average daily maximum water (7DADM) temperature plotted by buffer treatment. Quartiles (dashed horizontal lines) from the westside Type Np Extensive Riparian Monitoring Study are shown for comparison. Note that the random sample of Type N Waters was not stratified by basin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

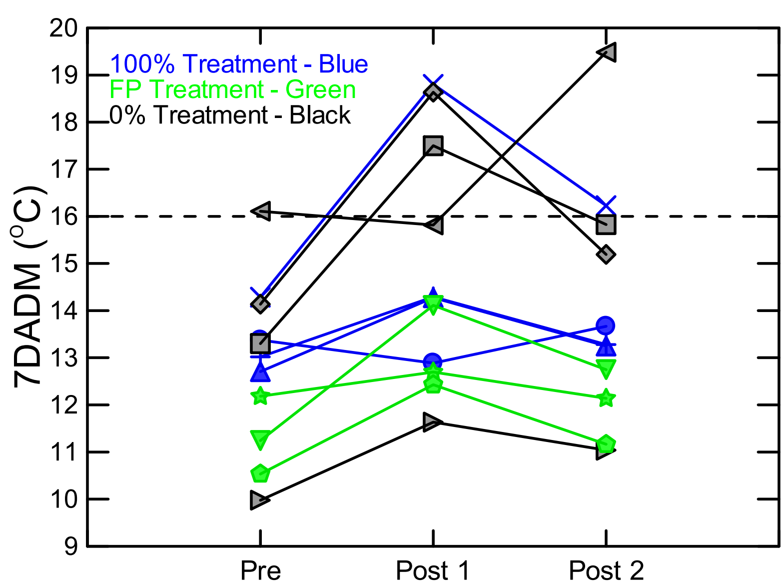

Figure 3. Seven day average daily maximum temperature for each site by year. Sites that were warmer than 13°C pre-harvest tended to warm to 16°C or more after harvest. Nine of the eleven harvested buffer treatment sites were cooler in Post 2 than Post 1.

Discharge

The Hydrology Resource Objective addresses discharge. We measured discharge in the Olympic and Willapa 1 blocks.

Functional Objective: Maintain surface and groundwater hydrologic regimes (magnitude, frequency, timing, and routing of stream flows) by disconnecting road drainage from the stream network, preventing increases in peak flows causing scour, and maintaining the hydrologic continuity of wetlands.

Performance Target:

> Peak flows – Westside: Do not cause a significant increase in peak flow recurrence intervals resulting in scour that disturbs stream channel substrates providing actual or potential habitat for salmonids, attributable to forest management activities.

Results:

- The change in total water yield was positive for all treated sites, with discharge increasing in proportion to the area of each basin harvested. We also observed treatment differences in water yield per unit area of harvest (i.e., specific discharge), with the 100% treatment exhibiting the smallest increase per unit area and the FP and 0% treatments exhibiting larger increases.
- Baseflow response (i.e., return interval [RI] <2 day) differed among buffer treatments, with baseflows decreasing in both 100% sites and significantly increasing in both 0% sites and the Willapa 1 FP treatment. Baseflow response in the Olympic FP treatment only increased significantly for the wetter portion of the baseflow period.
- For events with an RI between 2 and 7 days, which are likely to be associated with low to moderate intensity rainfall, specific discharge increased by 1.5 to 7 mm/day in all FP and 0% sites.
- Discharge increased for larger events (e.g., RI >7 day), but the effect size varied by block as well as treatment.
- We found no evidence of increased annual peak flows in the Willapa 1 sites or Olympic 100% site, but did observe peak flow increases in the Olympic FP and Olympic 0% treatments.

Conclusions:

- We evaluated changes in peak flow recurrence intervals in harvested streams and found no evidence of increased annual peak flows in the three riparian buffer treatment sites in the Willapa 1 block or the 100% treatment in the Olympic block. We did observe peak flow increases in the FP and 0% treatments in the Olympic block. For these sites, we conclude that the Performance Target for peak flows was not met, which can affect sediment transport and aquatic habitat.
- The difference in peak flow response between the two blocks may be due to differences in runoff generation processes (e.g., rain vs. rain-on-snow) with rain-on-snow in the Olympic block leading to increased peak flows. Our findings and literature suggest that, given the importance of rain-on-snow in peak flow generation,

prescription effectiveness related to peak flow is unlikely to be uniform across the landscape of interest.

Sediment

The Sediment Resource Objective addresses sediment.

Functional Objective: Provide clean water and substrate and maintain channel-forming processes by minimizing to the maximum extent practical the delivery of management-induced coarse and fine sediment to streams (including timing and quantity) by protecting stream bank integrity, providing vegetative filtering, protecting unstable slopes, and preventing the routing of sediment to streams.

We address streambed surface composition in the section on Stream Channel Characteristics. We did not evaluate coarse sediment transport.

Suspended Sediment Export

We estimated suspended sediment export (SSE) in the Olympic and Willapa 1 blocks.

Performance Targets: While there are a number of performance targets related to sediment, none of them are addressed specifically through our evaluation of suspended sediment export.

Results:

- Study sites appeared to be supply limited with respect to suspended sediment, both before and after harvest. Observed turbidity was below 3.1 NTU over 95% of the time. The study design was restricted to headwater basins underlain by relatively competent lithologies so we expected suspended sediment concentration (SSC) and annual estimates of SSE to be low.
- Eight storm events dominated suspended sediment budgets, which generally resulted in SSE spikes. These storm events typically occurred in late fall or early winter and any given event generally resulted in SSE spikes in only about half of the sites. Spike magnitude varied by storm, but did not vary significantly by treatment.
- We did not find strong relationships between changes in discharge and sediment export. Although discharge with RIs greater than 7 days increased in all treatment sites, we did not detect a significant change in SSE following harvest.

Conclusions:

- We conclude that the Functional Objective for sediment was met in our study sites, though we caution that these results are limited to streams underlain by competent lithologies.
- Overall, we failed to detect a significant effect of harvest on sediment, and were not able to detect a clear pattern regarding the relative effectiveness of buffer treatments at mitigating the effects of clearcut harvests on SSE. Delivery of management-induced sediment to streams appeared to be limited.
- Total annual SSE (2 to 108 tons/km^2/yr) was within the range of reported suspended yields for unmanaged small catchments, though up to 4 times greater than expected for sites dominated by competent lithologies. Yields tended to be higher in the Olympic block sites with the highest yields in the Olympic reference.

- Given the limited number of sites and paucity of sediment-producing storm events, the lack of a detectable relationship between changes in discharge and sediment export is not surprising.
- If there were harvest-related changes in SSE, they appear to have been small relative to the natural variability.

Other Sediment Processes

In addition to our more formal evaluation and analysis of suspended sediment export, we collected gross estimates of some additional sediment input metrics to help explain hypothesized changes in the amphibian response. Results from these components can reduce uncertainty related to the following:

Performance Targets:

- Road sediment delivered to streams – virtually no sediment delivered to streams from new roads.
- Stream bank/ELZ disturbance – Type N: ≤ 10% of the ELZ.

We evaluated the following metrics, which inform the Performance Targets:

(1) Road sediment – Though we did not design the study specifically to address the effectiveness of the rules to minimize road sediment delivered to streams, it does help inform the Road sediment delivered to streams Performance Target. We used the Washington Road Sediment Erosion Model (WARSEM; Dubé *et al.* 2004) to evaluate sediment delivery from road surface erosion.
(2) Sediment delivery related to windthrown trees – We estimated the proportion of windthrown trees that showed visible evidence of sediment delivery to the stream channel, which informs the Stream bank/ELZ disturbance Performance Target, and
(3) Stream-delivering surface erosion – We estimated the proportion of the stream length affected by bank erosion, which also informs the Stream bank/ELZ disturbance Performance Target. This response was evaluated only in the post-harvest period, so we can only examine differences in post-harvest erosion among buffer treatments and the reference.

Results:

- Our ability to detect changes in road-induced sediment was limited by the model we selected to evaluate this response; however, the model did predict a large spike in sediment input when one previously decommissioned road was reconstructed during harvest and then decommissioned within the same year. In this instance sediment increased from a pre-harvest level of 0.4 tons/year to 14.6 tons/year in the year in which harvest occurred. The model suggested that post-harvest sediment levels decreased back to pre-treatment levels after road decommissioning.
- We did not identify windthrow as a major driver in SSE. Although the number of windthrown trees per 100 m of channel ranged from 0 to 51 in the pre-treatment and 0 to 20 in the post-treatment period, most did not exhibit visual evidence of sediment delivery to the stream and we did not observe significant spikes in SSE during windthrow events.

- Stream-delivering surface erosion was documented at 11 of 17 study sites and was largely restricted to small areas of the streambank and it was unlikely that it measureably contributed to SSE. At the most severely impacted site, we found evidence of erosion adjacent to only 4.6% of the total stream channel length and we did not observe statistically significant differences in stream-delivering surface erosion among treatments ($\alpha = 0.05$). We did not observe mass wasting or landslide events at any study sites, and, on average, reference and buffer treatments visually exhibited a similar amount of exposed bank.

Conclusions:

- The method selected for evaluating road sediment inputs lacked the precision and temporal resolution needed to explain patterns in suspended sediment export (SSE), and was limited by its ability to predict only large changes in road sediment delivery.
- The likelihood of sediment delivery from windthrow decreases rapidly with increasing distance from the stream channel. As a result, in western Washington forests, windthrow is unlikely to be a significant source of sediment unless there is widespread windthrow of buffer trees growing immediately adjacent to the channel. This conclusion is consistent with the results of the BCIF Study.
- Though not explicitly examined, strict observence of ELZs, which restricted equipment disturbances within 30 feet of the stream, appeared to have prevented sediment inputs.

<u>Nutrient Export</u>

There are no Resource Objectives, Critical Questions, or Performance Targets that address nutrient export specifically. However, nutrients can be considered another terrestrially-linked input similar to litterfall. We assessed the quantity of instream nitrogen and phosphorus exported from Type N Waters for two reasons: 1) nutrient concentrations may affect instream productivity at the site level, thereby influencing the biotic response to harvest; and 2) excess nutrient loads can encourage increased accumulations of algal biomass, which may depress dissolved oxygen concentrations in coastal receiving waters.

Results:

- Mean total N and nitrate-N concentrations increased in all buffer treatment sites. This, along with greater annual discharge, increased N export after harvest. The magnitude of the increase ranged from 8.2 to 32.9 kg ha^{-1} yr^{-1} (7 to 358% increase) for total N, and from 6.3 to 30.0 kg ha^{-1} yr^{-1} (13 to 327% increase) for nitrate-N. These increases were greatest in the 0% treatment, intermediate in the FP treatment, and lowest in the 100% treatment.
- Total-P export in buffer treatments increased after harvest by 21 to 50%; however, we did not detect significant post-harvest differences in the concentration or export of total-P among the three riparian buffer treatments.

Conclusions:

- Higher post-harvest export of total-N and nitrate-N in all buffer treatments was correlated to the increase in annual runoff, which was correlated with the proportion of the watershed harvested and was similar to earlier studies.
- The implication, favorable or unfavorable, of the increase in N export on downstream receiving waters depends upon the N load delivered, the existing N load in the downstream waters, and the timing of delivery to the receiving waters.
- The increase in total-P export in buffer treatments was a function of the low pre-harvest exports, stable concentrations, and increased post-harvest runoff.

Stream Channel Characteristics

There are no Resource Objectives specific to Type N Water channel or stream characteristics outlined in Schedule L-1. There is, however, a Resource Objective and Performance Target related to stream channel characteristics in the CMER Work Plan.

Resource Objective (CMER Work Plan): Provide complex in- and near-stream habitat by recruiting wood and litter.

Critical Question (CMER Work Plan): How does stream-associated amphibian habitat respond to variation in inputs (e.g., sediment, litterfall, wood)?

We considered this critical question when designing our stream channel characteristic sampling methodology. Though there are specific Performance Targets for some measures of stream channel characteristics outlined for the LWD/Organic Inputs Functional Objective (i.e., pool frequency, and residual pool depth, Schedule L-1), during their review of the CMER work plan's Type N rule group, Policy determined that those performance targets were intended for Type F waters, not Type N Waters.

We evaluated the response of stream-associated amphibian habitat availability and quality based on the following: stream hydrology (wetted width, stream depth, dry length), bankfull width, channel units (pool, riffle, and step density and characteristics), and substrate (fines/sand, gravel/cobble, and boulder/bedrock).

Results:

- With the single exception of pool length, which increased in all three buffer treatments compared with the change in the reference (P = 0.03), channel characteristics in the 100% and FP treatments did not differ from the reference.
- We estimated the change in pool length in the reference to be less than the change in the 100% (P = 0.05), FP (P = 0.01) and 0% treatments (P = 0.04), with the within-treatment change in mean pool length estimated to be 12 to 20% greater in harvested sites than in the reference.
- The stream wetted width response differed among treatments (P = 0.03), with the pre- to post-harvest change in the 0% treatment estimated to be 0.3 m less than the change in all other treatments (P = 0.01, 0.01, and 0.04 for the reference, 100% and FP treatments).

- The bankfull width response also differed among treatments (P <0.001). Similar to the pattern we observed for stream wetted width, the pre- to post-harvest change in the 0% treatment was 0.4 m less than the change in the reference (P <0.001) and 0.5 m less than the 100% and FP treatments (P <0.0001 and <0.001, respectively).
- The response of the proportion of the channel rise attributed to steps also differed among experimental treatments (P <0.01). The pre- to post-harvest change was 16 to 17% less in the 0% treatment than the other treatments (P <0.01).
- Though not significant, we observed an increased proportion of the channel length dominated by fines and sand with a decrease in buffer length. Specifically, we estimated a 4%, 9% and 16% increase in the channel length dominated by fines and sand in the 100%, FP and 0% treatments, respectively.
- The dominant stream channel unit type differed between wood-obstructed reaches and those that were not obstructed. We noted an increase in the dominance of pools and steps and a decline in riffles in wood-obstructed stream reaches.

Conclusions:

- Changes in habitat availability and quality were apparent in all riparian buffer treatments, but were greatest in the 0% treatment.
- The rules provided for complex in- and near-stream habitat. We hypothesized that changes in stream channel characteristics were attributable to both large and small wood recruitment, which was greatest in the 0% treatment, and subsequent increases in channel roughness. Wood alters stream hydrology and restrict wetted width in logged streams by concentrating wood towards the channel margins. Wood and debris dams dominate pool formation and slow the rate of water discharge, increasing pool length.
- The changes in habitat quality were a result of increased sediment storage, particularly in the 0% treatment. Though the increase in stored sediment did not differ statistically between reference and buffer treatment basins, we hypothesize that the increase may be biologically meaningful. Increased sedimentation has been negatively associated with amphibian occupancy and density as a result of impaired feeding, specifically for tailed frog larvae grazers. Sediment may also fill interstitial spaces, eliminating critical microhabitats and reducing habitat complexity and cover. It may also impair respiration for larval stream amphibians. (See conclusions for Stream-associated Amphibians – with the single exception of giant salamanders in the FP treatment, we did not see a negative response to treatment for any amphibian taxa and treatment combination in the two years following harvest)
- The relative quality (contribution to stream-associated amphibian feeding and reproductive success) of wood-obstructed reaches is not known.
- Both large and small wood played functional roles in forming amphibian habitat. However, we do know what persistence and future recruitment of wood will be like or what the long-term impacts will be to habitat. The large amount of small wood input to streams during harvest of the RMZ (0% and portions of FP treatment) will

decay at a much faster rate than large wood, which forms larger instream structures with greater sediment storage capacity.

Litterfall Input and Detritus Export

The LWD/Organic Inputs Resource Objective addresses litterfall and detritus.

Functional Objective: Develop riparian conditions that provide complex habitats for recruiting large woody debris and litter.

Performance Target: At least 50% of recruitment available from within 50 ft, for westside Type N Waters.

The study reduces uncertainty about litterfall recruitment in the two years following clearcut harvest. This is the first CMER study to include an evaluation of litterfall as it relates to Type N riparian prescription effectiveness. Litterfall input and detritus export were variables of interest because of the potential for timber harvest to alter the quantity, composition, and timing of litterfall inputs, which may in turn affect the quantity and composition of the instream detritus and food availability to the biotic community. We assessed litterfall inputs and detritus exports in the Olympic and Willapa 1 blocks.

Results:

- Riparian tree removal in the clearcut RMZs of the 0% and FP treatments reduced post-harvest litterfall inputs and detritus exports in both treatments, while total litterfall inputs and detritus exports were slightly higher after harvest in the 100% treatment.
- Significant differences were noted only in the 0% treatment for deciduous litterfall and total leaf (deciduous plus conifer) litterfall ($P < 0.01$). Deciduous litterfall decreased from 0.51 to 0.05 g ash-free dry mass (AFDM) m^{-2} day^{-1} (91% decrease) and total leaf litterfall from 1.06 to 0.08 g AFDM m^{-2} day^{-1} (92% decrease) after harvest in the 0% treatment. Annual litterfall inputs continued to remain low in the 0% treatment at the end of the second post-harvest year.
- The decrease in litterfall inputs resulted in a significant decrease in instream detritus exports from the 0% treatment ($P \leq 0.04$), a response driven by a decrease in total, coarse, and fine particulate organic matter and wood. Total detritus export decreased from 517 to 247 g AFDM day^{-1} (52% decrease) after harvest in the 0% treatment.

Conclusions:

- Riparian buffers in the 100% and FP treatments maintained litterfall inputs that did not differ statistically from reference conditions, leading us to conclude that, based on this evaluation, the Functional Objective was met, at least initially, by the 50-ft RMZ and sensitive site rules. These riparian buffers may not maintain litterfall levels in the long-term, however, as standing trees in these buffers are prone to loss.
- A decrease in litterfall input from riparian canopy in the 0% treatment reflects the removal of all trees from that treatment. The result is a post-harvest reduction in the delivery of litter to the stream, at least in the short-term until plant communities are reestablished. This leads us to conclude that, based on this evaluation, the functional objective was not met in the 0% treatment.

- Riparian buffers in the 100% and FP treatments maintained detritus exports that did not differ statistically from reference conditions, but did not maintain detritus exports in the 0% treatment. A decrease in detritus export from the 0% treatment reflects the removal of all trees in that treatment and a decrease in litterfall inputs. The addition of slash and windthrow to the stream, however, may have increased detritus retention. Wood decreases water velocity and creates depositional areas where litterfall would be retained for consumption and fragmentation by microbes and macroinvertebrates.

Biofilm and Periphyton

There are no Resource Objectives, Performance Targets, or Critical Questions that address the production of biofilm (i.e., the assemblage of algae, diatoms, and cyanobacteria on benthic substrates) or periphyton (i.e., the algal component of biofilm). Biofilm forms the vast majority of microbial biomass in headwater streams and periphyton contributes to most of the primary production in headwater streams. Biofilm and periphyton have short life cycles, rapid reproduction, and are sensitive to changes in physical and chemical processes. They are valuable indicators of short-term environmental change and provide the primary food resource for tailed frog larvae and some macroinvertebrates important as food resources for stream-associated amphibians.

Results:

- We found no evidence of a post-harvest difference in biofilm (as measured by AFDM) among treatments.
- We found no evidence of a post-harvest difference in periphyton (as measured by chlorophyll *a*) among treatments.
- Wood from slash and windthrow was providing shade in clearcut reaches of the RMZ. We documented a bimodal distribution of cover values from densiometer results for sample locations in the clearcut RMZ (i.e., $<30\%$ for 58% of sample locations and $\geq 60\%$ for the remaining 42% of sample locations), where overhead canopy was removed as a part of the experimental treatment.

Conclusions:

- While we observed reductions in shade, increases in stream temperature, and increased nitrogen export related to the length of clearcut RMZ, we did not observe the increased algal production we expected.
- Ultimately, while we do not know what physical and/or biological processes are controlling algal production in our study streams, we have no evidence of a difference in the response of biofilm or periphyton production to buffer treatments. Other processes that may have countered an increase include sediment, water flow/scour, grazer consumption, and in-channel wood that contributes to stream shading.

Macroinvertebrate Export

There are no Resource Objectives, Critical Questions, or Performance Targets that address macroinvertebrates specifically, but we assessed the response of macroinvertebrate export from Type N Waters to evaluate the effect of harvest on food resources for stream-associated amphibians and downstream fish. Macroinvertebrate export has the potential to change after harvest with potential changes in leaf litter inputs and primary production. We examined export rates for total macroinvertebrates, functional feeding groups, and dominant taxa in the Olympic and Willapa 1 blocks.

Results:

- Total macroinvertebrate export (numbers and biomass per day) did not change in response to buffer treatments.
- We did not see a significant change in most functional feeding groups, however, the response varied. Export of collector-gatherer biomass increased in the FP treatment relative to the reference (P = 0.02). Collector-gatherer biomass increased from 14 to 58 mg day^{-1} (329% increase) after harvest in the FP treatment. Parasite, scraper, and Dixidae (Diptera) export decreased significantly relative to the reference (treatment x period <0.05) in two or more of the buffer treatments.
- Chironomidae and *Baetis* comprised much of the proportion of individuals exported both pre- and post-harvest, and *Baetis* comprised most of the biomass exported; however, neither changed in response to harvest.

Conclusions:

- Overall, there were no major reductions in macroinvertebrate export and no major shifts in functional feeding groups associated with riparian buffer treatments.
- A lack of response of biofilm and periphyton production to clearcut harvest in our buffer treatments may explain the lack of a consistent response in most functional feeding groups.

Stream-associated Amphibians

There are no Resource Objectives specific to stream-associated amphibians outlined in Schedule L-1. However, we used the response of stream-associated amphibians to alternative riparian buffer prescriptions on Type N Waters to evaluate the Schedule L-1 Overall Performance Goal of supporting the long-term viability of "other covered species," which includes stream-associated amphibians. There is also a Resource Objective and several Critical Questions for stream-associated amphibians outlined in the CMER Work Plan.

Resource Objective (CMER Work Plan): Provide conditions that sustain stream-associated amphibian population viability within occupied sub-basins.

Critical Questions (CMER Work Plan):

- Is stream-associated amphibian population viability maintained by the Type N prescriptions?
- What are the effects of three buffer treatments on stream-associated amphibians two years post-harvest?
- How do stream-associated amphibian populations respond to the Type N prescriptions over time?

The definition of population viability is the ability of a population to persist and avoid extinction. The rules do not designate a metric for evaluating amphibian population viability.

We used population density as an indicator of viability; however, to address amphibian population viability adequately, longer-term study is required.

Though we did not design the study to address occupancy or reproduction on the reach scale, we do have data that can inform the following additional Critical Questions:

- Do stream-associated amphibians continue to occupy and reproduce in the patch buffers?
- Do stream-associated amphibians continue to occupy and reproduce in ELZ-only reaches?

The forest practices-designated amphibians included in this study were Coastal Tailed Frog and three species of Torrent Salamanders (Olympic, Columbia, and Cascade). We also evaluated the response of two species of Giant Salamanders (Coastal and Cope's).

Results:

- The post-harvest change in stream network-wide larval Coastal Tailed Frog (*Ascaphus truei*) density differed among treatments ($P < 0.0001$). Density increased in intermediate treatments (i.e., 100% and FP) relative to both the reference and 0% treatment. We detected significant post-harvest increases in the 100% and FP treatments that were 4 ($P = 0.02$) and 8 ($P < 0.0001$) times greater, respectively, than the post-harvest change in the reference. The change in the 0% treatment did not differ statistically from the change in the reference, but did differ from the change in both the 100% ($P = 0.01$) and FP ($P < 0.001$) treatments.

- The post-harvest change in stream network-wide post-metamorphic Coastal Tailed Frog density differed among treatments ($P = 0.10$). We detected a post-harvest increase in the 0% treatment that was 6 times greater than the change in the reference ($P = 0.07$), an increase that was significantly greater than the change in the 100% and FP treatments ($P = 0.02$ and 0.03, respectively).

- We saw no difference in torrent salamander (*Rhyacotriton*) density among treatments using one method of determining density. However, when we applied another method where we included animals that were encountered in wood-obstructed reaches, we detected a post-harvest increase in torrent salamander density in the 0% treatment that was a 3 times greater than the change in the reference ($P < 0.01$).

- The post-harvest change in stream network-wide giant salamander (*Dicamptodon*) density differed among treatments ($P < 0.01$). Giant salamander density decreased by 82% in the FP treatment relative to the reference ($P < 0.001$), a decrease that was significantly greater than the change in the 100% and 0% treatments ($P < 0.01$ and $P = 0.02$, respectively). We did not note a significant change in density for any other treatment, including the reference.

- We found all genera in clearcut RMZs with wood-obstructed reaches covered by dense matrices of wood, organic debris (e.g., leaves and needles) and fine sediment. Densities in these reaches were sometimes quite high with values as high as 3, 20, and 6 animals per stream meter for tailed frog, torrent and giant salamanders, respectively.

- We observed egg masses for all three genera in harvested streams, including in the 0% treatment and in the wood-obstructed reaches of clearcut RMZs.

- We had no evidence of a treatment effect on body condition for any species, though we were unable to include tailed frog post-metamorphs in our analysis due to a small sample size.
- The density of focal FP-designated amphibians did not decline in any buffer treatment, including in the 0% treatment, where the July-August 7-DADMax increased by 3.2°C in the two years post-harvest.

Conclusions:

- The Type N prescriptions maintained tailed frog and torrent salamander density within occupied basins two years after harvest in all riparian buffer treatments.
- The very high densities of torrent salamanders observed in some wood-obstructed reaches explains the differing results that we obtained when we did and did not include density estimates from these reaches in our overall stream-network wide density analysis.
- Though it is not an FP-designated species, post-harvest conditions did not sustain giant salamander density within the FP treatment in the two years after harvest. The negative response of giant salamanders in the FP treatment is inconsistent with study findings for the other stream-associated amphibian species. Further, the lack of a statistically significant difference in the pre- to post-harvest change between the reference and the 0% treatment leads us to suspect that the response to the FP treatment may not be driven by treatment *per se*, but may reflect complex ecological interactions, including site-specific factors.
- In theory, body condition reflects an animal's energy reserves and can be associated with environmental characteristics such as habitat quality and prey availability. We did not observe an effect of treatment on body condition for any species.
- We used the presence of egg masses as a sign of reproduction. Although sample sizes were limited, we concluded that all genera continued to occupy and reproduce in stream reaches with buffered (i.e., patch buffer) and clearcut (i.e., ELZ-only) RMZs in the two years following harvest.
- Evaluation of a genetic response requires generational turnover of amphibian populations that will require a minimum of seven to eight years after treatment implementation. Consequently, we report the results from this component of the study separately. A report evaluating the response of measures of amphibian genetic diversity has been through CMER review and is currently in ISPR review. The genetics response can be used to inform further the degree to which meeting the overall Performance Goal of long-term viability is being met.
- An evaluation of a response of amphibian population viability to the Type N prescriptions will require study over a longer temporal scale that reflects reproductive success through time. Analysis of amphibian demographic data collected seven and eight years post-harvest (after one generational turnover) will provide our first opportunity for understanding the true impacts to long-term amphibian viability, though continued monitoring even beyond one generational turnover would be more informative.

Downstream Fish

The original research objectives for the fish component of the study were to: (1) evaluate the existing hypotheses on Cutthroat Trout (*Onchorhynchus clarkii clarkii*) at the upstream extent of fish use, (2) assess fish response to upstream timber harvest and different riparian buffer prescriptions, and (3) generate new information characterizing the ecology of headwater fish populations. Unfortunately, due to a variety of complications, inclusion of the fish component was only possible for six study sites located in the Olympics and Willapa Hills. We modified the study objective to focus on generating new information for Cutthroat Trout and their habitats at the extreme upstream extent of fish distribution in a case study involving these six study sites.

Results:

- We found cutthroat trout density to be relatively low in comparison with other studies.
- We found no relationships between total linear fish density and physical stream habitat characteristics, such as stream gradient and percent pool area.
- We observed patterns suggesting a positive relationship between age-0 fish density and increased percent pool area and lower stream gradient.
- We did not find any evidence that fish density was significantly correlated with either fish condition or growth.
- Cutthroat trout in the uppermost extent of fish distribution grew more slowly and were smaller on average, with a lower condition factor than those reported in other studies.

Conclusions:

- This work, while limited, documents the relatively low abundance and growth rate of cutthroat trout populations in headwater stream reaches at the extreme upstream extent of fish distribution in western Washington. We found that these habitats tended to support lower densities of fish than typically reported in the reviewed literature for headwater basins as a whole, and that the cutthroat trout in these habitats grew more slowly and were smaller on average with a lower condition factor than those reported in these studies. Our findings support the hypotheses of researchers such as Trotter (2000) who contend that fish in these habitats are living, "at or near the limit of available stream resources", be those resources food, space (habitat), or both.

Summary of Treatment Performance

We hypothesized that when the pre- to post-harvest change differed among treatments, change in the 100% treatment would differ the least from the reference, with a moderate difference between the reference and FP treatment, and the largest difference between the reference and 0% treatment.

<u>Results for the following metrics matched our hypothesis, where we observed the following statistically significant response related to reductions in the length of the RMZ buffered</u>:

- Increased tree mortality in the 100% and FP treatments
- Decreased shade

- Increased stream temperature (throughout the stream, that persisted throughout most of the year)
- Increased discharge (with an increase in the proportion of the basin area harvested)
- Increased nitrogen export
- The response of the following metrics also followed our predicted pattern, however, for these metrics the difference among treatments was not statistically significant:
- Decreased large wood recruitment
- Increased stored sediment

<u>For the following metrics, we observed a statistically significant response that differed from the change in the reference, but in these cases the responses did not differ among the buffer treatments</u>:

- Increased wood density (total and functional large wood, and functional small wood)
- Increased phosphorous export
- Increased pool length

<u>For the following metrics, we measured a significant difference only for the 0% treatment</u>:

- Decrease in stream wetted and bankfull channel widths
- Decrease in the proportion of channel rise attributed to steps
- Decrease in litterfall input
- Decrease in detritus export
- Increase in tailed frog post-metamorph density

<u>We observed a significant difference among treatments for the following metrics, however, in these instances the post-harvest response differed from our hypothesis and was not consistent among treatments</u>:

- Increase in total small wood in all three riparian buffer treatments, with the greatest increase in the 0% treatment and moderate increases in both the 100% and FP treatments
- Increase in stream length obstructed by wood (i.e., slash and windthrow) in both the FP and 0% treatments. The change did not differ between the FP and 0% treatments
- Increase in tailed frog larvae density that did not differ between the 100% and FP treatments
- Decrease in giant salamander density in the FP treatment only

<u>For the following response categories, there was an overall lack of statistically significant response</u>:

  - Sediment input and export
  - Biofilm and periphyton production

- Total macroinvertebrate export and most functional feeding groups

Any treatment response that differed from the change in the reference was evidence of a harvest effect. Overall, the response in the 0% treatment differed from the reference and the other buffer treatments most frequently. The magnitude of change also tended to be greatest in the 0% treatment.

B. What does the study not tell us?

One should consider a number of study limitations when interpreting and 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). One should not assume that the results apply equally to other lithologies. 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 can only be made to the two year post-harvest interval. Do not assume that the results are applicable over a longer period. One can only understand the scope of potential long-term response with longer-term monitoring. For example, there will be opportunities for continued ingrowth and stand development, windthrow from riparian buffers and associated in-channel wood recruitment, sediment delivery, or delayed response to the reproductive success of stream-associated amphibians, among others. Conversely, for metrics that changed from pre-harvest levels, we do not know how much time will be needed for recovery to pre-harvest levels.

Riparian Buffering/BMPs: Application of clearcut timber harvest included buffers for sensitive sites and unstable slopes, and followed other best management practices (BMPs), ultimately, influencing the level of buffering (width and length) in the FP treatment sites. CMER did not design this study to examine directly the influence of specific rules or BMPs, but rather to evaluate the overall influence of the FP buffer strategy as it is applied under real world circumstances. We do not know if the results for the FP buffers would have been different if only the minimum riparian buffers had been applied. We also do not know how frequently more than the minimum buffer length is applied across the managed landscape. Since the proportion of the stream length buffered in FP treatment sites was more than the minimum required under Forest Practice’s rules, some consistency in responses between the 100% and FP treatments may reflect the fact that the stream length buffered was more similar between these treatments than between the FP and 0% treatments. Furthermore, protection of unstable slopes resulted in wider riparian buffers along some portions of two of four 100% buffer treatment sites, although it should be noted that this study was designed to evaluate buffer length, not buffer width. Nonetheless, wider buffers in some 100% treatment sites may have resulted in a consistency of response between reference and 100% sites. Buffers along the FP treatments sites were 50 ft, as specified in the FPHCP. As stated above, and based on the results from sites with buffers 50 ft wide, it is very likely that sites containing buffered sections wider than 50 ft would still have experienced increases in stream temperature associated with shade reductions.

The following summarizes the limitations specific to particular responses:

- *Discharge.* Discharge changes associated with harvest are likely to be complex and extend over much longer timescales than those analyzed as part of this study. We do not know how flows will change over a longer period of time as the trees regrow. As a result, it is not possible to provide a comprehensive assessment of long-term treatment effectiveness.
- *Sediment.* We cannot draw major conclusions about the effectiveness of forestry activities on sediment processes at this time. Our ability to detect a treatment effect for the sediment component of the study was hampered by the limited number of sediment generating events, inconsistent harvest timing and sediment export across sites for a given storm event, and low site-scale replication (n = 2) of each treatment,. We may obtain a more definitive answer through analysis of the data collected through the extended period or through related research (e.g., the Type N Soft Rock).
- *Stream-associated amphibians.* We selected study sites based on specific criteria, including the presence of stream-associated amphibians. Sites chosen tended to have cooler pre-treatment stream temperatures than are typical of Type N Waters in western Washington (see Figure 2, which includes pre-harvest seven day average daily maximum water (7DADM) for our study streams compared with the quartiles for the same information from the Extensive Riparian Monitoring Study, which evaluated a random sample of Type N Waters that was not stratified by basin area, lithology, or other physical features. This creates some uncertainty around the application of results broadly across the westside managed landscape. The study cannot tell us if specific amphibian taxa would respond differently in Type N Waters with warmer pre-harvest temperatures. Additionally, since our methodology focused on instream sampling, potential impacts to post-metamorphic Coastal Tailed Frog and Coastal Giant Salamanders found terrestrially were not addressed in this study.
- *Downstream Fish.* Since the fish component was a series of case studies in a limited number of study sites (n = 6), we did not evaluate treatment effectiveness for downstream fish and our results have limited inference beyond the sites we sampled.
- *Pre-harvest Windthrow Event.* Interpretation of results, especially for riparian vegetation and wood, required consideration of the timing and severity of a windthrow event that occurred 1-4 December 2007. During this time, a series of storms caused extensive windthrow throughout western Washington. The storms resulted in extensive damage to forestlands along the Washington coast, leading us to add an additional, third year, of pre-treatment sampling for some response variables. We found that study sites assigned to all treatments were impacted, including references and riparian buffer treatments. Since we had the opportunity to collect additional pre-harvest data, our data reflect the broad range of disturbances that occur throughout the managed forestlands of western Washington.

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. They will generate data that can be used to determine if the resource objectives for heat/water temperature, LWD/organic inputs, sediment, hydrology and stream-associated amphibians (with the exception of terrestrial Dunn's and Van Dyke's Salamanders) 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 Hard Rock Study expanded on the knowledge gained in the BCIF Study, supplementing the results from the latter by increasing the sample of clearcut, 50-ft buffer and PIP buffer RMZ reaches. These results are particularly helpful in reducing the level of uncertainty in PIP buffer response, increasing the sample size and providing PIP reference data. Additionally, the Hard Rock Study included responses that were not incorporated in the BCIF study, including riparian-related inputs (light, litterfall, sediment, and wood) and the response of instream (amphibians, water temperature, and habitat) and downstream components (export of nutrients, organic matter, macroinvertebrates, and sediment; water temperature; and fish in the downstream fish-bearing reach). Findings through five years post-harvest are reported on in Schuett-Hames and colleagues (2011). A report on findings through 10 years post-harvest is in development.
- Type N Experimental Buffer Treatment Project in Soft Rock Lithologies Project [Soft Rock Study, underway]: This study was funded by Policy and the Board with the understanding that Hard Rock lithologies targeting cold streams inhabited by amphibians could potentially underestimate and/or mask impacts caused by forest practices on streams in soft rock lithologies uninhabited by amphibians. The Soft Rock Study will expand on the knowledge gained from the Hard Rock Study by evaluating 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 that replicates current Forest Practices rules (equivalent to the Hard Rock Study FP treatment; no alternative buffers are tested). Both the Hard and Soft Rock studies use a manipulative experimental design to compare effectiveness of riparian buffers with unharvested controls. Like the Hard Rock Study, the Soft Rock Study is limited to western Washington. It also does not evaluate the response of stream-associated amphibians, which are largely restricted to competent lithology types, fish, or litterfall. The Soft Rock Study will provide important confirmation of the effect of forest practices prescriptions on more erodible substrates that are potentially more sensitive to forest practices and that were not included in the Hard Rock Study.
- Buffer Integrity – Shade Effectiveness (Amphibians) Project [Shade Study, underway]: The Shade Study was intended to isolate the impacts of shade reduction from the impacts of potential increased sedimentation related to timber removal in the RMZ. This project examined the effects of shade reductions on stream-associated amphibians, water temperature, primary productivity, litterfall and macroinvertebrates.

This study can be used to supplement the findings for the Hard Rock Study, especially for results related to amphibian response to treatment.

- Amphibian Recovery Project [completed]: This project evaluated the effects of three buffer treatments on headwater streams throughout coastal western Washington. Riparian buffer treatments in this study differed from those included in the Hard Rock Study and included: (1) unthinned riparian buffers, (2) partial buffer, (3) buffer of non-merchantable trees, and (4) clearcut to the channel edge. The study included an evaluation of stream channel characteristics, wood loading, stream temperature, sediment, macroinvertebrates and stream-associated amphibians. One year of pre-harvest and three years (immediately post-harvest and two additional years beyond that) of post-harvest data were collected; not all metrics were evaluated in every post-harvest year. Fifteen study sites were included, but amphibians were not detected in all study sites so amphibian response was limited to a small sample size (e.g., prior to harvest Coastal Tailed Frogs were detected in only 5 of 15 sites). Since the treatments in the Amphibian Recovery Project were not designed to evaluate the current Forest Practices prescriptions for Type N Waters, direct comparisons of results between this and the Hard Rock Study are only available for what we call the 0% treatment (their clearcut RMZ treatment). Differences in sampling methodologies, especially as they relate to amphibians, must be noted. In particular, the Recovery project did not evaluate amphibian presence/abundance in stream reaches that were inaccessible due to post-harvest wood loading in the form of slash whereas the Hard Rock Study did. See Jackson and colleagues (2001; 2007) and Haggerty and colleagues (2004).

To address the effectiveness of westside riparian prescriptions in maintaining terrestrial salamander populations, CMER would need to complete the Van Dyke's Salamander Project:

- Van Dyke's Salamander Project [underway]: The Van Dyke's Salamander was the only FP-designated amphibian that was not addressed by another CMER study. This study will result in the development of sampling protocols for adequately evaluating Van Dyke's presence and abundance, and if warranted, include a BACI-type manipulative study to compare Van Dyke's populations between harvested and unharvested units. This study will address a gap in information from the Hard Rock Study, which did not include effectiveness of riparian prescriptions in maintaining FP-designated terrestrial amphibians (Dunn's and Van Dyke's Salamanders).

One additional amphibian-focused study that has the potential to inform riparian prescription effectiveness for westside Type N Waters is the Amphibians in Intermittent Streams Project.

- Amphibians in Intermittent Streams Project [planned]: This study will examine amphibian use of the non-fish-bearing stream segments having discontinuous perennial flow, conditions that often occur at or near the origins of headwater streams. It is intended to inform the efficacy of the westside riparian prescription in maintaining amphibian occupancy in intermittent reaches. Data from the Hard Rock Study may be able to inform the importance of completing this project.

These studies will not address the effectiveness of the riparian prescriptions for eastside Type N Waters, for which CMER needs to complete the ENREP Study (underway), Eastside Np Effectiveness Project (planned), and the Eastside Amphibian Evaluation Project (currently scheduled for FY22).

- Eastside Amphibian Evaluation Project [planned]: The Hard Rock Study focused entirely on managed landscapes in western Washington, because most FP-designated amphibians have westside distributions, and those with eastside distributions are believed to have little overlap with eastside managed landscapes. The Eastside Amphibian Evaluation Project is an occupancy study intended to address the distribution of FP-designated amphibians throughout eastern Washington, to determine if their distribution on eastside managed landscapes deserves larger study attention. This study will supplement the findings of the Hard Rock study by evaluating amphibians in eastern Washington.
- 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 include: (1) quantify the magnitude of change in stream flow, canopy closure, water temperature, suspended sediment transport and wood loading within eastern Washington RMZs following harvesting, and (2) evaluate the effects of these changes on downstream waters where possible. While the rule prescriptions are different for Type N Waters in eastern WA (cite WAC), this study will complement the Hard Rock Study by evaluating Type N prescription effectiveness in eastern Washington.
- Eastside Np Effectiveness Project [planned]: The Eastside Np Effectiveness Project will determine if and to what extent the riparian prescriptions for eastside Ns streams (non-fish-bearing seasonally dry) maintain Performance Targets and water quality with a particular focus on effects in downstream typed waters. 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 will 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. This study will complement the Hard Rock Study by evaluating Type N prescription effectiveness in eastern Washington.

Additional studies related to the Hard Rock Study include:

- Windthrow Frequency, Distribution, and Effects Project [planned]: Preliminary results of the BCIF Study indicated that windthrow mortality in westside Type N buffers was widespread. In response to this finding and supported by direction from Policy, the intent of the Windthrow Frequency, Distribution, and Effects Project is to include a windthrow assessment in existing Type N riparian projects. While assessments of windthrow mortality were included in both the Hard and Soft Rock Studies, it was not in response to this Project *per se* but findings from these studies may inform this Project as it is scoped.
- SAA Detection/Relative Abundance Methodology Project [completed]: This project was designed to evaluate and develop a standard sampling methodology for stream-associated amphibians (SAA) in headwater forest streams. Results from this study informed the sampling methodology for the amphibian component of the Hard Rock Study. See Quinn and colleagues (2007).

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

Opportunities exist to better inform Policy of the longer-term post-harvest impacts and recovery with data that have already been collected for the Hard Rock Study through eight years post-harvest (through 2016). 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. However, some reference sites have been or will be harvested for timber in the near future, making them unsuitable for use as references in the study. Opportunity may exist to establish new reference sites, or to use nearby references from the Soft Rock study, in lieu of harvested references for selected response variables, including stream temperature. 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. 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.

- ***What are the costs associated with additional studies?***

Analysis and report development through eight years post-harvest are a part of the current CMER 2017-2019 biennium budget. Costs estimates associated with additional study beyond eight years post-harvest are variable and dependent on which responses interest Policy and the Board. Budget placeholders exist in the CMER Master Schedule, including continued stream temperature monitoring (continuation of current monitoring with no break in data collection) and another round of sampling for riparian vegetation, stream channel characteristics, wood recruitment and loading, and stream-associated amphibian demographics and genetics currently projected for the 21-23 biennium. We estimated that monitoring of stream temperature through 2019, until references are lost, would cost an additional $150,000 in the 19-21 biennium. We estimated that stream temperature monitoring through 2024, using Soft Rock references, would cost an additional $907,000 distributed from FY20 through FY26. We estimated that another round of sampling for riparian vegetation, stream channel characteristics, wood recruitment and loading, and stream-associated amphibian demographics and genetics would be an additional $1,660,000. Modifying the specific responses included, as well as the number and timing of future sampling, affects the estimated budget.

- ***What will additional studies help us learn?***

Results from the extended study period through eight years post-harvest will provide additional information for understanding the effectiveness of the current Forest Practices rules and buffer alternatives in achieving resource objectives (including both functional objectives and performance targets). Additional long-term monitoring will provide a unique opportunity to evaluate the longer-term response of variables of interest to forest practices in a research backdrop where such studies are extremely rare for most variables (e.g., temperature, amphibians). Originally, it was proposed that this cover an entire harvest rotation (i.e., 30 to 40 years in western Washington). However, based on budget priorities, Policy and the Board settled on a two year post-harvest BACI study design and reserved the decision to allocate additional funds for future monitoring until after some study results were available upon which to base a decision. Future monitoring would allow us to monitor the rate of recovery of response variables that were significantly different from pre-harvest conditions in the years immediately post-harvest (e.g., stream temperature). It would also allow us to detect potential lag effects in response in those variables that did not reveal an immediate impact in the years immediately post-harvest (e.g., FP-designated stream-associated amphibians).

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

CMER anticipates development and approval of reports from the extended period (through eight years post-harvest) during the current biennium (2017-2019) and beginning of the following biennium (2019-2021), with transmission to Policy estimated for the 2019-2021 biennium. Timing of dissemination of findings to Policy for any potential future sampling would depend on the interest and priority, as well as the number of responses for which Policy is interested in continuing to monitor and the timing of that effort. The timeframe could be shorter or longer depending on the number of responses that Policy and the Board are interested in monitoring. We encourage Policy to consider the benefits of continued or additional future monitoring, in particular for riparian vegetation, wood recruitment and loading, stream temperature, shade, stream channel characteristics and amphibians.

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

Future monitoring beyond eight years post-harvest will reduce uncertainty associated with long-term trajectories of potential change. For example, in the case of stream-associated amphibians, no FP-designated species was negatively impacted in the two years immediately post-harvest. However, only a longer-term study of the impacts of clearcut timber harvest can provide guidance on the effectiveness of the current Forest Practices rules and their ability to achieve the overall Performance Goal (Schedule L-1) of long-term viability for populations of stream-associated amphibians listed under the FPHCP.

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?**

What is the scientific basis that underlies the rule, numeric target, Performance target or Resource Objective that the study informs?

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 between the finalization of the FPHCP in 2005 and now, see the chapters for the individual response metrics in the study report.

Large Wood: Wood is a key element in the creation and maintenance of instream and riparian habitat, trapping and storing sediment and organic material, stabilizing streambeds and banks, dissipating stream energy, forming pool habitat, providing cover, and serving as a food source for aquatic insects (Bisson 1987). The recruitment and retention of wood was a primary consideration for development of the leave tree requirements for RMZs. Forest Practices rules are intended to provide sufficient large wood recruitment to create, restore and maintain riparian and aquatic habitat for species covered under the plan. Rule buffer width for Type N Waters was largely determined by a study conducted by McDade and colleagues (1990), who found that 70% of instream wood from mature conifer forests had a source distance of 50 ft or less. The conclusion based on this finding was that between 35% and 70% of the potential large wood supply within each Type N network would be retained in streamside buffers where the Type N rules had been applied.

Shade: 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 may 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). It was anticipated that shade reduction along small clearcut streams in western Washington would 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. Further, based on the findings from three studies (Caldwell *et al.* 1991; Dent and Walsh 1997; Robison *et al.* 1999), downstream temperature effects that might negatively affect aquatic resources in Type S and F Waters were expected to be minimal. 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. Caldwell and colleagues (1991) concluded that shade reduction along small clearcut streams in western Washington would recover within five years.

Suspended Sediment: Protection measures in the FPHCP minimize the risk of accelerated surface erosion and modified hydrology by minimizing harvest-based disturbances (e.g., log yarding activities and other equipment use) in and around typed waters. Along Type N Waters, direct physical disturbance is minimized in RMZs with a combination of a two-sided 50-ft riparian buffer and a two-sided 30-ft equipment limitation zone (ELZ) throughout the unbuffered RMZ. The ELZ requirement was based on a combination of study results, including those of Kreutzweiser and Capell (2001) who found that measurable increases in fine sediment levels in streams adjacent to clearcut harvesting were minimal when there was careful use of equipment in streamside areas. Another study concluded that riparian buffers of 10 m alleviated chronic sediment delivery to streams from harvest-related erosion (Rashin *et al.* 1999).

Peak Flow: At the time of rule development, conclusions from research into the effects of forest practices on peak flows in the Pacific Northwest were variable. Some studies documented increased peak flows following timber harvest (Ziemer 1981; Hetherington 1987). Others found decreased peak flows (Cheng *et al.* 1975) or no change (Wright *et al.* 1990). The physical characteristics of a watershed, including topography, soils, geology and vegetation, all influence water routing, resulting in the conclusion that the response of peak flows to timber harvest would be watershed-specific. Forest Practices rules address timber harvest effects on peak flows through the rain-on-snow and green-up rules, the latter of which minimizes the effect of harvest by limiting the size and timing of clearcut timber harvest across the state.

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 outlined in Schedule L-1 of the FPHCP (Appendix N). While previous studies may have evaluated many of the metrics we included in this study as they relate to forestry practices, 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.

The BACI study design is very robust to the extent that it provides causal linkages between forest practices and impacts to instream and riparian habitats while producing a more precise estimate of measurable responses to forest harvest. The inclusion of variable buffer treatments, both more restrictive (100%) and less restrictive (0%) than the current rules, was established to provide a response curve along a gradient of buffer length.

We expanded on the knowledge base for many metrics included in the study. For example, our results further informed us about the baseline densities of stream-associated amphibians throughout managed forest landscapes in western Washington, and our BACI study design expanded on most previous studies that were largely retrospective. For example, previous observations had resulted in the conclusion that torrent salamanders were relatively rare on managed landscapes; in contrast, we found torrent salamanders to be the most abundant stream-associated amphibian species encountered both pre- and post-harvest.

We also expanded on the knowledge gained from other CMER studies, for example by supplementing the findings from the BCIF study by increasing the sample of riparian vegetation and wood recruitment from clearcut, 50-ft buffer and PIP buffer RMZ reaches. While most previous studies have focused on large wood (≥10 cm [4 in] diameter), small wood (<10 cm [4 in] diameter) is frequently abundant in smaller channels, where stream power is typically too low to transport wood downstream. Small wood in headwater provides functional roles (e.g., sediment storage) and influences channel morphology in the short-term, however, small wood decays more quickly than large wood so those functions will be lost without additional long-term wood recruitment. Our study is among a few that addresses the prevalence, characteristics and short-term function of small wood in headwater streams.

We are much more confident in many of our findings than previous studies because we were able to utilize new technology and sampling techniques that were not previously available to those studies, because of the duration and/or intensity of sampling, and because we were able to take advantage of more recent statistical methods. For example, a new statistical method allowed us to adjust counts of amphibians by estimates of detection without the need for marking individual animals, for less biased estimates of density than for those based on count data alone.

In relation to specific assumptions regarding FP treatment response specified in the 2005 FPHCP and listed above, we found the following:

Large Wood: The FPHCP rationale for large woody debris recruitment in Type Np Waters was based on existing information on source distances for wood recruitment (McDade *et al.* 1990), which indicates that approximately 70% of large wood from old-growth forests came from within 50 ft of the stream. Since between 50 and 100% of the Np stream length is buffered under FP rules for Type N Waters, it was estimated that the prescription would provide between 35 and 70% of potential large wood recruitment. We did attempt to validate the source distance curves since that was not an objective of this project, however, we did provide estimates of large wood recruitment pieces and volume in reaches with RMZ and PIP buffers. A separate study with an appropriate design will be necessary to validate the source distance curves for Np streams in western Washington forests.

Shade:

- Initial shade reductions were similar to the expectations in the HCP.
- Shade reductions did persisted and only began to recover after five years post-harvest.

Stream Temperature:

- The FPHCP does not define what a "small" temperature increase is, but average post-harvest increase was 1.2°C in both the FP and 100% treatments.
- Increases in stream temperature have lasted longer than expected (>5 years), through seven years post-harvest, to date.
- Temperatures did increase downstream of the harvest unit, but less so than further upstream. We monitored only 100 m downstream, so we cannot say at what point downstream a temperature increase may have dissipated.
- Stream temperature did increase, as expected, within the Type Np stream under the current rules (i.e., FP treatment), but the increases have been long lasting at most sites and have persisted in the immediate (100 m) downstream reach.

Suspended Sediment:

- Suspended sediment levels were generally low in these sites and we were not able to detect a treatment effects in any of the riparian buffer treatments, including the 0% treatment.
- The lack of measurable treatment response in all harvested sites supports the idea of ELZ effectiveness, but may also be the result of low statistical power or underlying lithology. The effectiveness of FP buffers with respect to suspended sediment will be better understood once data from the extended study period (through 8 years post-harvest) have been analyzed and results from the other Type N studies (e.g., Type N Soft Rock and Eastside Type N Riparian Effectiveness Projects) are available.

Peak Flows:

- Results from this study indicate that harvest can affect both peak flows and baseflow hydrology.

- We observed peak flow responses in harvested sites in the Olympic block, but not sites in the Willapa 1 block. Published literature and elevational differences between these blocks suggests that rain-on-snow is the most likely cause for the differential peak-flow response. Unfortunately, both the Olympic and Willapa 1 treatment sites fall outside of WDNR's mapped rain-on-snow zone. Therefore, although it cannot be definitively determined without actual snowmelt data, the results suggest the rain-on-snow rule (WAC 222-22-100(2)) is not being effectively applied in all portions of the state. Additional directed research and/or additional years of data may strengthen or weaken this conclusion.

Technical Implications and Recommendations:

New rule tools or field method development.

- We consistently had a difficult time detecting Coastal Tailed Frogs, especially post-metamorphs, in some sites. In one site, we encountered only a single post-metamorphic individual in a single year. The sparsity of data for this species at sites in which we know it occurred made it difficult to calculate density estimates, and made it impossible to include all of the detection covariates that we used in our estimates of detection for the other taxa. The result is that we are less certain in our density estimates for tailed frog. Exploration of alternative methods for detecting the species, including the viability of using tools such as environmental DNA (eDNA) for occupancy and abundance, may prove invaluable for future research and monitoring of stream-associated amphibians. We could address the question: How well and under what conditions does eDNA sampling accurately and consistently identify Coastal Tailed Frog presence in headwater streams, and can it be used effectively to estimate abundance?

Research/monitoring suggestions.

- Buffered versus unbuffered Np reach-scale effectiveness: An evaluation of within-stream variability and characteristics between buffered and unbuffered reaches and between wood-obstructed and unobstructed reaches may prove informative for understanding the effects of alternative riparian buffer prescriptions. For example, based largely on retrospective studies, stream-associated amphibians were thought to be mostly absent from areas lacking overstory canopy and covered with dense matrices of wood and stored sediment; however, we found all focal amphibians, and even evidence of reproduction in the form of egg masses, in wood-obstructed reaches filled with fines and organic debris. CMER could address reach-scale effectiveness, at least in part, with existing data from the Hard Rock Study. While continued monitoring could provide additional information about long-term trends. For example, even with forest practices rules intended to minimize slash input into streams, we still observed heavy slash loading in some stream reaches. Current and future evaluations could assess persistence of these wood-obstructed reaches through time and investigate overall stream coverage through time. Additional metrics could include differences in the structure and characteristics of different reach types, such as wood loading and function, water temperature, and hydrology, as well as amphibian use. We recommend an evaluation of reach-scale variability with existing data from this study, which could inform the utility of continued monitoring and/or future projects.

- Sensitive Site Effectiveness: We have the data needed to do at least a preliminary evaluation of the characteristics of sensitive sites before and after harvest, under varying buffer strategies (i.e., buffered and unbuffered). While we have sufficient data for some sensitive sites (i.e., side-slope seeps, Type Np intersections and headwater springs), our data for headwall seeps is lacking (N=10) and we did not have alluvial fans in any study sites. We can also evaluate amphibian use of sensitive sites and whether use and/or density differs from that in non-sensitive site reaches and buffers. We recommend an evaluation of sensitive sites with existing data from this study. Results from this evaluation could inform the need for additional investigation in the future.
- Side-slope and Headwater Seep Characteristics: During amphibian sampling, we collected data associated with side-slope and headwater seeps. Like the data that could answer questions about within-site and reach-scale variability within treated sites, these existing data could be used to answer the following questions:
    - What are the characteristics associated with the hydrologic footprints of seep areas and are they reflected in the forest practices definitions for side-slope and headwall seeps?
    - What is amphibian use of seeps, and what characteristics are associated with amphibian use?
    - How does the presence of seeps influence the basin-wide stream temperature response to clearcut harvest, if at all?

  We recommend an evaluation of these questions with the existing data from this study. Results of this examination could inform the utility of additional investigation in the future.

  - Disturbance and recovery trends over time: This study covered only the first two years after harvest as agreed to by CMER, and approved by Policy and the Board, as the minimum number of years needed to detect an impact. Policy has since approved the funding of additional post-harvest sampling for some metrics through eight years post-harvest, and additional monitoring depends on future support by CMER and Policy. To understand completely the impacts of the treatments on the managed landscape one would have to monitor the response for a longer period. A substantial amount of time and energy have been invested in this study to date, from study design to site selection, harvest treatment implementation and through data collection. While analyses of currently collected data through eight years post-harvest are underway, data collection at existing study sites over an even longer time would reduce scientific uncertainty about the duration of disturbance and the progress of recovery in Type N buffers and clearcuts. For example, for shade and temperature trends over time we suggest continuing with data collection at existing Hard Rock and Soft Rock study sites until 2019 and 2020, respectively. Additional data collection may be especially important for evaluating the time to recovery to baseline conditions for stream temperature, continued effects of windthrow and tree mortality in riparian buffers, ingrowth and stand development, as well as for evaluating potentially delayed responses for amphibians. Continued study for this and other related studies (see **What is the relationship between this study and any others that may be planned, underway,**

or recently completed?) would result in a more confident assessment of prescription effectiveness as we monitor response to treatments through a greater period.

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, both in context of the study results and other current scientific research. Such a review would be appropriate once the studies outlined under #5 are completed. They could propose changes to Performance Targets and/or new measures if appropriate. This recommendation is consistent with commitments already made by CMER and Policy in response to the Stillwater Sciences Independent Review of the "CMER adaptive management program review of science" (Stillwater Sciences 2009; CMER 2012). We recommend the following considerations:
    - 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.
    - Clarification is needed on whether some Performance Targets apply to Type N Waters. For example, it is unclear if the the Performance Target for In-stream LWD applies to Type N Waters.
    - Performance Targets for some metrics have yet to be developed. For example, there is an Overall Performance Goal in Schedule L-1 to support the long-term viability of covered species and a CMER Work Plan Resource Objective is to provide conditions that sustain stream-associated amphibian population viability within occupied sub-basins for covered-species. However, a definition of "viability" and metrics for evaluating viability are not provided in either document.
- Another specific recommendation is to reevaluate of the definitions for seep sensitive sites in the Forest Practices rules. We found that many of the hydrological features that we identified along the streams in our study sites that appeared to function as seeps did not meet the definitions under the current rules.

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

We discuss key aquatic Resource Objectives for all metrics in our responses to questions 4 (*"What does the study tell us?"*) and 6 (*"How much of an incremental gain in understanding to the study results represent?"*). Because of the complex nature of the rules surrounding stream temperature, 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.

The state surface WQS direct that:

- 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.
- Whenever 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.
- Whenever 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. This was done in Chapter 7 and includes the following relevant observations.

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

- The average increase in post-harvest 7-DADM 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.

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?

- 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) post-harvest 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.

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?

- 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 7-DADM temperatures exceeded 16°C for one of the four 100% treatment sites, none of the FP treatment sites and three of the four 0% treatment sites. 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.
- Three streams which were less than 16°C, the threshold criterion, pre-harvest exceed the criterion post-harvest (one-100%, two-0% sites; Figure 3). One 0% site was greater than 16°C pre-harvest and warmed after harvest. Our study streams were generally 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.

References

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby and T.D. Hofstra. 1987. Stream temperature and aquatic habitat: Fisheries and forestry interactions. Pages 191-232 *in* E.O. Salo and T.W. Cundy (eds.) *Streamside management: forestry and fishery interactions*, Contribution No. 75, Institute of Forest Resources, University of Washington, Seattle, WA.

Bisson, P.A. 1987. Large woody debris in forested streams in the Pacific Northwest: Past, present, and future. Pages 143-190 *in* E.O. Salo and T.W. Cundy (eds.) *Streamside management: forestry and fishery interactions*. College of Forest Resources, Univeristy of Washington, Seattle.

Brazier, J.R. and G.W. Brown. 1973. *Buffer strips for stream temperature control*. Research Paper 15, Forest Research Laboratory, School of Forestry, Oregon State University, Corvallis. 9 pp.

Brown, G.W. 1985. *Forestry and Water Quality*. 2nd ed. OSU Book Stores, Inc., Corvallis, OR.

Caldwell, J.E., K. Doughty and K. Sullivan. 1991. *Evaluation of downstream temperature effects of Type 4/5 waters*. Timber, Fish and Wildlife Final Report, Washington Department of Natural Resources, Olympia TFW-WQ5-91-004, Olympia, WA. 77 pp.

Cheng, J., T. Black, J. De Vries, R. Willington and B. Goodell. 1975. Evaluation of initial changes in peak streamflow following logging of a watershed on the west coast of Canada. *Water Resources Research* 25(3):449-456.

CMER. 2012. *Response to the Stillwater Sciences independent review of the CMER adaptive management program review of science*. Cooperative Monitoring, Evaluation, and Research Committee, Washington Department of Natural Resources, Olympia. variable pp.

Dent, L. and J. Walsh. 1997. *Effectiveness of riparian management areas and hardwood conversions in maintaining stream temperature*. Forest Practices Technical Report 3, Oregon Department of Forestry, Forest Practices Monitoring Program, Salem. 58 pp.

Dubé, K., W. Megahan and M. McCalmon. 2004. Washington road surface erosion model (WARSEM) manual. Washington State Department of Natural Resources, Olympia.

Haggerty, S.M., D.P. Batzer and C.R. Jackson. 2004. Macroinvertebrate response to logging in coastal headwater streams of Washington, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 61(4):529-537.

Hetherington, E. 1987. Carnation Creek, Canada - review of a west coast fish/forestry watershed impact project. Pages 531-538 *Proceedings of the Int. Assn. of Hydrological Sciences Forest Hydrology and Watershed Management Symposium*, Vancouver, BC.

Jackson, C.R., D.P. Batzer, S.S. Cross, S.M. Haggerty and C.A. Sturm. 2007. Headwater streams and timber harvest: Channel, macroinvertebrate, and amphibian response and recovery. *Forest Science* 53(2):356-370.

Jackson, C.R., C.A. Sturm and J.M. Ward. 2001. Timber harvest impacts on small headwater stream channels in the coast ranges of Washington. *Journal of the American Water Resources Association* 37(6):1533-1549.

Kreutzweiser, D.P. and S.S. Capell. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. *Canadian Journal of Forest Research* 31(12):2134-2142.

McDade, M., F.J. Swanson, W.A. McKee, J.F. Franklin and J. Van Sickle. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. *Canadian Journal of Forest Research* 20(3):326-330.

McIntyre, A.P., M.P. Hayes and T. Quinn. 2009. *Type N Feasibility Study*. A report submitted to the Landscape and Wildlife Advisory Group, Amphibian Research Consortium, and the Cooperative Monitoring, Evaluation, and Research Committee. Washington Department of Natural Resources, Olympia. 48 pp.

Quinn, T., M.P. Hayes, D.J. Dugger, T.L. Hicks and A. Hoffmann. 2007. Comparison of two techniques for surveying headwater stream amphibians. *Journal of Wildlife Management* 71(1):282-288.

Rashin, E., C. Clishe, A. Loch and J. Bell. 1999. *Effectiveness of forest road and timber harvest best management practices with respect to sediment-related water quality impacts*. Publication No. 99-317, Washington Department of Ecology, Environmental Assessment Program, Olympia. 118 pp.

Robison, G.E., J. Runyon and C. Andrus. 1999. *Oregon Department of Forestry cooperative stream temperature monitoring: Project completion report for 1994-1995*. Forest Practices Technical Report 2, Oregon Department of Forestry, Forest Practices, Salem. 47 pp.

Schuett-Hames, D., A. Roorbach and R. Conrad. 2011. *Results of the Westside Type N Buffer Characteristics, Integrity and Function Study Final Report. Cooperative Monitoring Evaluation and Research Report, CMER 12-1201. Washington Department of Natural Resources, Olympia, WA*. 93 pp.

Steinblums, I.J., H.A. Froehlich and J.K. Lyons. 1984. Designing stable buffer strips for stream protection. *Journal of Forestry* 82(1):49-52.

Stillwater Sciences. 2009. *Cooperative Monitoring, Evaluation, and Research Committee (CMER) review of science*. Final Report, Prepared by Stillwater Sciences, Seattle, Washington for Washington Department of Natural Resources, Olympia. variable pp.

Summers, R.P. 1982. *Trends in riparian vegetation regrowth following timber harvesting in western Oregon watersheds*. MS thesis, Oregon State University, Corvallis. 151 pp.

WADNR. 2005. *Forest Practices Habitat Conservation Plan*. https://www.dnr.wa.gov/programs-and-services/forest-practices/forest-practices-habitat-conservation-plan, Olympia, WA. variable pp.

Wright, K.A., K.H. Sendek, R.M. Rice and R.B. Thomas. 1990. Logging effects on streamflow: Storm runoff at Caspar Creek in northwestern California. *Water Resources Research* 26(7):1657-1667.

Ziemer, R.R. 1981. Storm flow response to road building and partial cutting in small streams of northern California. *Water Resources Research* 17(4):907-917.