Type N Experimental Buffer Treatment Project in Hard Rock Lithologies: Phase II Extended Monitoring

Answers to Six Questions from the CMER/Policy Interaction Framework Document

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Type of Product in Review:
Prospective Answers: ☐ Charter ☐ Scoping Document ☐ Study Design
Retrospective: ☐ Completed Pilot/Study Phase ☒ Completed Final Study Report

Brief Description:

This study was designed to evaluate clear-cut harvest of lands managed for timber production with alternative riparian buffers on Type N Waters. We included four experimental treatments including (1) an unharvested **Reference** (n = 6), and clear-cut harvest with three alternative riparian buffers that differed in the configuration of the riparian buffer in the RMZ: (2) **100% treatment** (n = 4), (3) **Forest Practices (FP) treatment** (n = 3), and (4) **0% treatment** (n = 4). Note that one reference (i.e., the in the Willapa 2 block) was originally assigned to the FP treatment, but harvest was delayed. Consequently, it was used as a second reference until its harvest in 2016 when it became an FP site for some analyses. The percent of Np stream buffered in the FP sites were 55%, 62%, 73%, and 100% (the latter being the length of the Np buffer in the delayed FP treatment that was not applied until 2015).

The 100% and FP treatments included riparian buffers throughout all or some of the riparian management zones (RMZ) (hereafter, buffered RMZ). The FP and 0% treatment included stream reaches that were not buffered (i.e., hereafter, clearcut RMZ). Unstable slopes required buffers wider than the minimum two-sided 50-ft buffers specified under FP rules, resulting in variable width buffers in some sites.

Pre-harvest data were collected from 2006 – 2008 (**Table 2**). Timber harvest with riparian buffer treatments were applied July 2008 through August 2009. We collected two to nine years of post-harvest data, depending upon the variable, from 2009-2017. Here, we report on the findings for metrics that were evaluated through nine years post-harvest (**Table 2**). For a report on the response of all metrics evaluated through two years post-harvest see McIntyre *et al.* 2018.

The results of this study will inform resource managers of the efficacy of current Forest Practices rules, including how landowners can continue harvesting wood resources while protecting important headwater habitats and associated species and meeting resource objectives outlined in the FP HCP (Schedule L-1, Appendix N) "Overall Performance Goals" which states that Forest

Practices, either singly or cumulatively, will not significantly impair the capacity of aquatic habitat to:

a) support harvestable levels of salmonids;

b) support the long-term viability of other covered species; or

c) meet or exceed water quality standards (WQS) (protection of designated uses, narrative and
numeric criteria, and antidegradation)."

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 Hard Rock Study was to evaluate the effectiveness of a range of RMZ prescriptions for Type N Waters, including the current rules, in maintaining key aquatic conditions and processes. Specifically, we evaluated whether the riparian buffer prescriptions for Type N Waters met the overall Performance Goals to support the long-term viability of stream-associated amphibians and meet or exceed WQS.

   This effectiveness monitoring and research study addresses one of the key questions that drives adaptive management, namely, "*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).

3. **Was the study carried out pursuant to CMER scientific protocols (i.e., study design, peer review)?**

   Yes. The study was implemented according to the CMER and Independent Scientific Peer Review (ISPR) approved study design (including sampling methodologies, statistical methods, and study limitations). SAGs (RSAG and LWAG), CMER, and ISPR reviewed and approved all study chapters. CMER approved the entire final report in July 2021.

4a. What will the study tell us?

Here, we report on the findings for metrics that were evaluated through nine years post-harvest (summer 2017; **Table 2**). Stream temperature and cover were monitored through summer 2019. These data will be analyzed and presented to Policy in November 2021. The response of all metrics evaluated through two years post-harvest was reported in McIntyre *et al.* 2018.

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 Proposed 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									
Wood Recruitment/Loading	x	x	x	x	x			x			x									
Stream Temperature/Cover	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
Discharge/Turbidity	x	x	x	x	x	x	x	x	x	x	x	x								
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									
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									

* Stream-associated Amphibian Genetics sampling in 2015 and 2016 was the first post-harvest sampling for this response, with the report completed in 2019.

Stand Structure and Tree Mortality Rates

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 stand condition for Type N Waters.

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

Results:

- The greatest post-harvest change in stand structure in the RMZ was related to clearcut timber harvest / treatment implementation, which included the removal of all trees in the 0% treatment RMZ and unbuffered portions of the FP treatment RMZ.

- Windthrow was the dominant tree mortality agent in riparian buffers.

- The highest tree mortality was observed in the first two years post-harvest, then decreased over time.

- In the RMZs, the highest tree mortality rates and greatest reductions in density and basal area occurred in the FP treatment, where cumulative mortality eight years post-harvest was 51% of initial basal area and 50% of initial density. This compared to a cumulative mortality of 24% of basal area and 30% of density in the 100% RMZs and 16% of basal area and 20% of density in the reference RMZ.

- Differences in mean tree mortality among treatments were most pronounced in the points of perennial flow (PIPs) (compared to mortality in the RMZ), with the greatest post-harvest mortality in the FP treatment PIPs (56% of basal area and 68% of density), followed by the 100% treatment (43% of basal area and 49% of density) and reference (9% of basal area and 15% of density).

Conclusions:

- In general, post-harvest changes in stand structure in the 100% treatment were intermediate between FP and reference; more similar to the reference in the RMZs, but more similar the FP in the PIPs.

- 100% and FP buffers with chronic mortality rates (<5%/yr) appear on track for development as single-cohort stands. Tree regeneration is widespread in RMZs having mortality rates >5%/yr, so most of these may likely develop as two-cohort stands.

Wood Recruitment and Loading

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:

- A pulse of large wood (≥10 cm [4 in] mid-point diameter and consisting of small diameter tops, branches, and broken stems) was recruited to streams in unbuffered reaches of the FP and 0% treatments during harvest. Because riparian trees were removed during harvest there was little to no additional opportunity for large wood recruitment in unbuffered reaches during the post-harvest period.

- In the buffered RMZs of the 100% and FP treatments, windthrow-associated tree fall was the primary agent driving increased large wood recruitment to channels. Large wood recruitment in the 100% and FP treatment buffers was greatest in the first two years after harvest and decreased over time.

- Most recruited large wood pieces (>80%) were suspended above the active stream channel.

Wood Loading Results:

- We observed substantial increases in in-channel large and small wood (<10 cm [4 in] diameter) densities in all buffer treatments in the two years post-harvest.

- The greatest increase in in-channel small wood in the two years post-harvest was estimated as a 176% increase in the 0% treatment, a 69% increase in the FP treatment and a 58% increase in the 100% treatment. Small wood during this period was comprised largely of logging slash from timber harvest of the streamside trees in the RMZ.

- Densities of small wood pieces continued to increase in the FP and 0% treatments through five years post-harvest. Small wood densities in the FP and 0% treatments no longer differed from the reference eight years post-harvest, and exhibited marked declines between five and eight years post-harvest.

- The greatest increase in in-channel large wood in the two years post-harvest was estimated as a 66% increase in the 100% treatment. We also observed a 44% and 47% increase in the FP and 0% treatments during the same period.

- From two to eight years post-harvest, in-channel large wood density continued to be higher in the FP treatment (41% increase relative to the reference), but remained relatively stable in the 100% and 0% treatments.

Conclusions:

- 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 (<5% of live trees/year), future recruitment potential is high. 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 riparian stands that had high wind mortality in the first two years post-harvest to regenerate and supply instream wood over the long-term.

- Similarities in both small and large wood densities within or over the bankfull channel between the 100% treatment and reference both five and eight years post- harvest provides some evidence of a balance between input and export over this period.

- In clearcut RMZs of FP and 0% treatments, harvest of streamside trees eliminates potential future wood recruitment for an extended period, which may likely result in smaller and lower wood loading levels over longer periods (e.g., a harvest rotation). Future large wood recruitment from clearcut RMZs will require the establishment and development of a new forest stand.

- In the clearcut RMZs, equipment limitation zones (ELZs) and additional rules intended to minimize wood input during harvest did not prevent recruitment of logging slash to streams.

- In the 0% treatment, wood loading is likely to decrease as logging slash decays. Although, these channels are likely to receive another pulse of logging slash during the next harvest, loss of large wood and replacement with smaller pieces of logging debris over time will likely reduce long-term wood volume and sediment storage capacity.

- Wood pieces suspended above the stream channel provide shade and cover and are expected to provide in-channel functions eventually as they decay and are recruited to the stream.

- The post-harvest increase in mortality and wood input and reduction in density and basal area in the buffered FP RMZs and PIPs are consistent with the results of the same prescriptions in the earlier Westside Type N Buffer Characteristics, Integrity and Function Study.

- The response of wood input and loading will continue for decades and our results provide only a portion of the view of longer patterns and trends.

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 at least 50% of stream length. (Note that this is a self-fulfilling target for the FP treatment.)

Stream temperature – Water quality standards (WQS) – current and anticipated in next triennial review.

Chapter 4 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".

Results:

- We observed a post-harvest reduction in site average of all shade metrics in all buffer treatments. Canopy closure at 1m decreased 10% in the 100% treatment but declined 32% in the FP treatment and 87% in the 0% treatment by the third post-harvest year. After nine years, canopy closure at 1m in the FP and 0% treatments was 15% and 27% below pre-harvest values relative to the reference sites (REF), respectively.

- Mean shade values generally reached a minimum around the fourth post-harvest year in the 100% and FP treatments. None of the buffer treatments showed increases in mean shade (all metrics) until roughly the fifth post-harvest year. See Table 4-6 and Figure 4-2 in the final report for more detail.

- Slash and understory vegetation provided shade, especially in unbuffered stream reaches, compared to measurements taken 1 m above the water surface. However, despite there being little change in shade at the water surface in the 100% treatment, water temperature increased post-harvest.

- The seven day average daily maximum stream temperature (7DADM) never exceeded 16°C in the unharvested REF sites and in the pre-harvest period in the buffer treatment sites only one site (CASC-0%) exceeded 16°C. After harvest the 7DADM at four sites exceeded 16°C in at least one year (**Figure 2**). Of these four sites, three were in the 0% treatment and one in the 100% treatment. Two of these four sites, WIL1-0% and WIL3-100%, were relatively warm (>15°C in one or more in one or more years) prior to harvest and only these two sites exceeded 16°C for more than one post-harvest year.

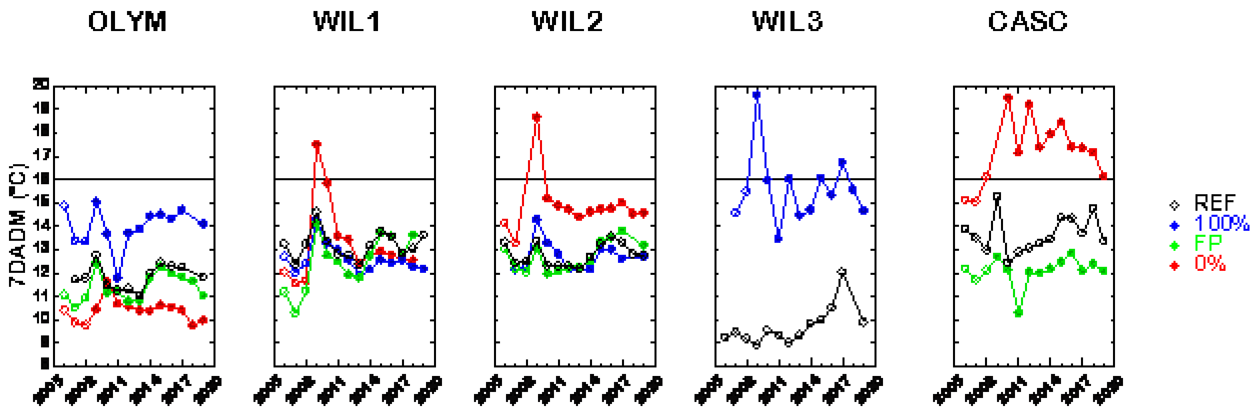

Figure 2. Highest annual seven-day average daily maximum temperature for each site by year. Unfilled symbols = Unharvested condition. Filled symbols = Post-harvest.

- The seven-day average temperature response (Δ7DTR) increased post-harvest in the Buffer Treatment location[1] and at the F/N break in all buffer treatments (P <0.05). There was no difference between the 100% and FP treatments (P >0.05), while the increase in both the 100% and FP treatments was less than in the 0% treatment (P <0.05).

- In the Buffer Treatment locations, the Δ7DTR increased by 1.1°C in the 100% treatment after harvest and declined to pre-harvest temperatures in the third post-harvest year (**Figure 3**). In the FP treatment, Δ7DTR the temperature response ranged from 0.5 to 1.2°C and changed little during the nine years post-harvest. Δ7DTR in the 0% treatment increased by 3.8°C in the first year after harvest and declined to 0.8°C after nine years. Variability among sites is illustrated by the 95% confidence intervals about the mean response in Figure 3 (see Appendix Table 4-17 for the tabulated results).

[1] The Buffer Treatment location is the downstream extent of clearcut harvest in a Type N basin. Where clearcut harvest was implemented throughout the entire Type N basin, the Buffer Treatment and F/N break locations align. Where the Type N basin was not harvested in its entirety due to landowner or regulatory constraints (see Ch. 2 – *Study Design*) the Buffer Treatment location is upstream of the F/N break.

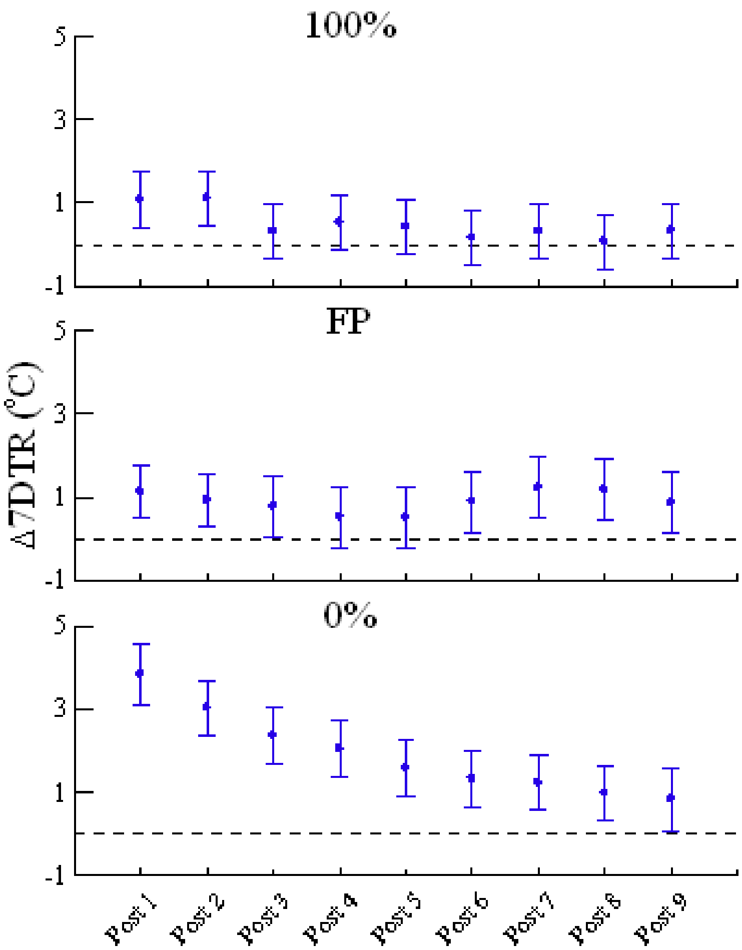

Figure 3. Pairwise comparisons of each post-harvest year to the pre-harvest period for the seven-day average temperature response (Δ7DTR) measured at the buffer treatment locations. Estimated means and 95% confidence intervals are presented.

- The calculation of the Δ7DTR involved several complex statistical procedures to account for natural background variability (e.g., warm vs. cool summer temperatures). This is the best estimate of the average change in stream temperature due to harvest.

- The 7DADM values, which do not account for natural variability, show a similar response. Table 4-11 of the report includes the 7DADM for each site and year plus the post-harvest change in the 7DADM for each site to illustrate the variability among sites within and across treatments. The mean within treatment post – pre-harvest difference in the 7DADM in the reference sites never exceeded 1.0°C. This illustrates the background variability in stream temperature in unharvested forest streams. In contrast, the mean post – pre-harvest difference in the 100% treatment was 2.4°C in Post 1 (2009) but never exceeded 1.0°C (similar to the REF treatment) in later years. The mean difference in the FP treatment exceeded 1.0°C immediately after harvest then again in Post 6–9 (2014–2017), while the mean difference in the 0% treatment was 5.3°C initially, then decreased over time to 0.9°C at Post 9.

- Immediately post-harvest the greatest change in temperature occurred during the July–August period, but in the later years summer temperature responses moderated while spring and fall temperatures were elevated at most locations in all sites.

- Temperature increases within the harvest unit decreased at locations downstream of the harvest unit where the stream had flowed through approximately 100 m of unharvested forest or buffers wider than 50 ft (i.e., a reach within a Type F fish-bearing stream buffer).

Conclusions:

- None of the three buffer treatments were effective at preventing reductions in effective shade nor in preventing increases in stream temperature, although there were substantial differences among the treatments in terms of the magnitude and duration of temperature changes.

- Post-harvest reductions in effective shade and/or canopy closure were of similar magnitude to other studies with comparable buffer treatments (Janisch *et al.* 2012; Schuett-Hames *et al.* 2012; Schuett-Hames and Stewart 2019).

- Shade reductions in the FP treatment roughly met the expectations in the FP 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 daily stream temperature.

- The 100% treatment was most effective in terms of the magnitude (1.1°C) and duration (at pre-harvest levels by Post 3) of the temperature increase. The 0% treatment was least effective with a 3.8°C increase in Post 1 and steady decrease to 0.8°C increase by Post 9. The FP treatment was in the middle with an initial increase of 1.1°C but was still elevated by 0.9°C at Post 9.

- Both the 100% and FP treatments resulted in smaller increases in water temperature than the 0% treatment, but temperature increases in the 100% and FP treatments did not differ from each other. The FP treatments that were substantially wider than 50 ft. and with longer buffers approaching 100% may have contributed to the lack of difference.

- Even small reductions in shade (e.g., 11% in effective shade) lead to measurable increases in stream temperature in the 100% treatment.

- The primary driver of post-harvest stream temperature increases was the loss of riparian cover from harvest and post-harvest windthrow within the buffer. However, anecdotal evidence from this study suggests that basin aspect may have influenced the magnitude of change and there was one instance (CASC-FP) where hyporheic flow probably mitigated some or all of the higher temperatures in a well-shaded downstream reach. This is consistent with recent scientific literature, but their effect cannot be tested directly in this study.

- The estimated mean temperature response in the 100% buffer treatment was at or below 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)) for five of the nine post-harvest years. The mean response in the FP and 0% treatments were 0.5°C or greater for the entire post-harvest period. See the Pre vs. Post pairwise comparisons of Δ7DTR in Appendix Table 4-17 for estimated mean response by year along with associated confidence intervals.

- The analysis of variance estimated an increase in the mean annual seven-day average temperature response ($P < 0.05$) as low as 0.8°C (see Appendix Table 4-17 in final report). The minimum detectable change was largely a function of the variability of the temperature response across sites within a treatment and the number of sites within each treatment in the study. The reader should review Table 4-11 in the final report for a sense of the post-harvest temperature change in individual sites relative to those of any or all reference sites.

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:

- Results from the eight-year monitoring period were similar to those from the two-year analysis, though the extended monitoring period was useful for illustrating seasonal treatment effects and the relationship between treatment effects and estimated monthly precipitation.

- On average, discharge increased 1 to 18 mm/yr for each percent of the watershed harvested in the OLYM-FP and OLYM-0% in the wetter Olympic block, exhibiting the largest increases.

- Baseflow response differed among buffer treatments[2]. Baseflows decreased in the 100% treatment and significantly increased in the 0% treatment. Baseflow also increased significantly in WIL1-FP. Baseflow response in the OLYM-FP only increased significantly for the wetter portion of the baseflow period.

- In the Olympic block, absolute change in water yield increased with storm magnitude, while it reached its maximum at some point between the 2-day and 7-day recurrence intervals (RI) in the Willapa 1 block.

[2] Baseflow was defined as specific discharge less than the median (i.e., 2-day RI). In the Pacific Northwest, these are non-storm discharges.

- Discharge increased for larger events (e.g., RI >7 day), but the effect size varied by block as well as treatment. Large increases were only observed in the OLYM-FP and OLYM-0%.
- We found no evidence of increased annual peak flows for sites in the Willapa 1 block or the OLYM-100%. Increases in the OLYM-0% were within our margin of error, but peak flow increased in the OLMP-FP.

Conclusions:

- The frequency and timing of specific discharge (stream flow per unit area) was affected by harvest in all six treatment basins; and the magnitude of change varied with harvest treatment, weather, and climate. Although not measured, the are consistent with the hypothesis that discharge changed because of changes in evapotranspiration associated with harvest.
- We found no evidence of increased annual peak flows in the three riparian buffer treatment sites in the Willapa 1 block or the OLYM-100%. We did observe peak flow increases in the OLYM-FP and OLYM-0%, but the increases in the OLYM-0% decreased with event magnitude and were within our margin of error. For the OLYM-FP, we conclude that the Performance Target for peak flows was not met.
- The difference in peak flow response between the Olympic and Willapa 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 in the two higher elevation sites. 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.

<u>Sediment</u>

<u>Functional Objective</u>: 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.

<u>Suspended Sediment Export</u>

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

<u>Performance Targets</u>: 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:

- Results from the eight-year monitoring period were similar to those from the two-year analysis.

- 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.
- SSE did not correlate well with discharge even though large amounts of suspended sediment were exported in individual sites during late fall or early winter storm events. The lack of SSE synchronization to storms suggests that sediment inputs were stochastic and not inherently related to the treatments.
- Although sediment transporting flows did increase in the OLYM-FP and OLYM-0%, we did not see an increase in SSE in the OLYM-0% and could not tie increases in the OLYM-FP back to the harvest treatment.

Conclusions:

- We conclude that the Functional Objective for sediment was met in our study sites, though we caution that the suspended sediment analysis was not definitive, and these results are limited to streams underlain by competent lithologies.
- We were not able to detect a clear pattern regarding the relative effectiveness of buffer treatments at mitigating the effects of clearcut harvests on SSE, but delivery of management-induced sediment to streams appeared to be limited.
- Total annual SSE 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 OLYM-REF and OLYM-100%.
- 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.

Nitrogen Export

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 exported from Type N Waters for two reasons: 1) nitrogen concentrations may affect instream productivity at the site level, thereby influencing the biotic response to harvest; and 2) excess nitrogen loads can encourage increased accumulations of algal biomass, which may depress dissolved oxygen concentrations in coastal receiving waters.

Results:

- In the initial two-years post-harvest, mean total nitrogen (total-N) and nitrate nitrogen (nitrate-N) concentration and export increased in all buffer treatment sites. The magnitude of the increase varied among sites. Export ranged from 8.2 to 32.9 kg/ha/yr (7 to 358% increase) for total-N and 7.3 to 30.0 kg/ha/yr (13 to 327% increase) for nitrate-N. The estimated change, relative to the reference sites, was greatest in the 0% treatment, intermediate in the FP treatment, and lowest in the 100% treatment.

- Total-N export declined between the first two years post-harvest and approximately seven and eight years post-harvest at three sites and increased slightly at three sites, while nitrate-N export declined at four sites and increased slightly at two sites. Only one of the sites had recovered to pre-harvest export rates eight years post-harvest. There was no consistent response in nitrogen concentration and export to buffer treatment.

Conclusions:

- Total-N and nitrate-N concentration and export increased at all sites immediately after harvest, with the greatest change in the 0% treatment and the smallest in the 100% treatment. Concentration and export were less obvious and not apparently related to buffer treatment seven and eight years after harvest.

Stream Channel Characteristics

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 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:

- The change in stream wetted width was, on average, 0.3 m less in the 0% treatment in the two years post-harvest and 0.4 m less in the eight years post-harvest. The average change in bankfull width was 0.4 m less in the 0% treatment in the two years post-harvest and 0.7 m less in the eight years post-harvest.

- We found evidence that the percentage of fines and sand-dominated stream channel was greater in buffer treatments. Only the 0% differed from the other treatments in the two years post-harvest, a difference that was sustained eight years post-harvest. However, an increase in fines and sand was also evident in the FP treatment in eight years post-harvest.

- We noted a decrease in the proportion of channel rise attributed to steps in the 0% treatment. We attribute this difference to wood accumulations associated with slash input in RMZs lacking riparian buffers.

- Observed differences in wetted and bankfull widths, the proportion of sand and fines-dominated stream length, and the proportion of channel rise attributed to steps did not result in significant differences in the densities or characteristics of stream channel units, including cascades, riffles, pools or steps, among treatments.

Conclusions:

- Changes in stream channel characteristics may be associated with the increase in in-channel wood, specifically instream inputs of both large and small wood attributable to harvest, which was greatest in the 0% treatment.
- Concentrations of harvest-related wood towards stream channel margins, especially in the clearcut RMZ, may have restricted stream and bankfull widths.
- Though we detected no change in the densities of stream channel units (i.e., cascades, riffles, pools, steps), we did note changes in overall habitat availability (e.g., narrower stream wetted channel and bankfull widths) and quality (e.g., increased fines and sand) in all riparian buffer treatments. These changes were greatest in the 0% treatment. Amphibian occupancy and density have been negatively associated with sediment, which can impair feeding, specifically for tailed frog larvae, and fill interstitial spaces, eliminating critical microhabitats and reducing habitat complexity and cover. It may also impair larval respiration.
- Both large and small wood played functional roles in forming amphibian habitat.
- The relative quality (contribution to stream-associated amphibian feeding and reproductive success) of wood-obstructed reaches is not known.

<u>Stream-associated Amphibians</u>

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

<u>Critical Questions</u> (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 rules do not designate a metric for evaluating amphibian population viability (i.e., the ability of a population to persist and avoid extinction). We used population density during the study period 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 CMER Work Plan 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 (i.e., unbuffered RMZ)?

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) not covered by the FPHCP.

Results:

- Results for all density estimates are presented as the within-treatment pre- to post-harvest change after controlling for temporal changes in the reference over the same period.

- Eight years post-harvest, we observed a severe decline in stream network-wide Coastal Tailed Frog larval density in all three buffer treatments (65%, 93%, and 84% decline in the 100%, FP, and 0% treatments, respectively) that was consistent with the results in the lower Np reach (97%, 97%, and 89% decline, respectively). This pattern was not evident in the first two years post-harvest.

- We observed a 71% and 97% decline in post-metamorphic Coastal Tailed Frog density in the 100% and FP treatments, respectively, in the eight years post-harvest. We also estimated a 60% decline in the 0% treatment; however, there was statistical uncertainty in the direction of this effect. These declines, evident only in the stream network-wide assessment, were not evident in the two years post-harvest.

- A 64% decline in torrent salamander density was observed in only the FP treatment in the eight years post-harvest, while an increase (198%) was observed in torrent salamander density in the 0% treatment in the two-years following harvest.

- While giant salamander density declined (64%) in the FP treatment in the two years post-harvest, there was no difference in the change in density among treatments in the eight years post-harvest.

- We observed very high densities of torrent salamanders (as high as 37 animals/stream meter) in some wood-obstructed (i.e., slash filled) reaches in the two years post-harvest. However, there was not a difference in densities of torrent salamander between wood-obstructed reaches and similar reaches that were not obstructed by wood in the seven and eight years post-harvest.

- Overall, we did not detect a substantial or consistent treatment effect for metrics of genetic diversity (i.e., genetic diversity and clustering) for the three species tested in this study, i.e., Coastal Tailed Frog, and Cope's and Coastal Giant Salamander (Spear *et al.* 2019). However, when evaluating treatment effects using genetic metrics a temporal lag frequently exists, unless the effects are extreme (Hoban *et al.* 2014). Therefore, follow up genetic monitoring of additional generational turnover is necessary to evaluate the longer-term impacts of harvest on genetic diversity and geneflow and future potential implications for amphibian abundance. We have genetic evidence that Coastal Tailed Frog populations are operating on a spatial scale larger than the Type N basin sizes we included in our study (Spear *et al.* 2011; Spear *et al.* 2019).

- Our carbon (^{13}C) and nitrogen (^{15}N) isotopic signatures comparison of stable isotope data collected eight years post-harvest indicated that Coastal Tailed Frog larvae were ingesting primarily biofilm. The post-metamorphic Coastal Tailed Frogs, torrent salamanders and giant salamanders all exhibited stable isotope values that suggested a diet of aquatic predators and shredders, and terrestrial spiders.

- 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 torrent or giant salamanders; however, sample sizes for Coastal Tailed Frogs were too small for analysis.

Conclusions:

- Based on the substantial declines observed for Coastal Tailed Frog in all buffer treatments eight years post-harvest, we conclude that the retention of a riparian buffer did not moderate the effects of harvest, particularly for larval Coastal Tailed Frog. Larval tailed frogs declined similarly in all buffer treatments, suggesting that factors related to harvest but not directly linked to riparian buffer length influenced the observed response.

- We observed a moderate decline in torrent salamander density in the FP treatment; however, we did not include torrent salamanders in our genetic analysis so we cannot attest to the spatial extent of gene flow for these species in our study sites. However, Emel and colleagues (2019) evaluated landscape genetics for two species of torrent salamanders, finding that the Columbia Torrent Salamander had a relatively restricted geographic range and significantly lower average within-population genetic diversity than the Southern Torrent Salamander (*R. variegatus*).

- 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 and reflects the spatial scale at which the species operate. Analysis of amphibian demographic data collected seven and eight years post-harvest (after one generational turnover) provided our first opportunity for understanding the true impacts to long-term amphibian viability. Continued monitoring of amphibian densities necessary to determine whether populations continue to decline, stabilize, or recover through time has been approved to start next fiscal year (FY22) and will provide the information necessary to evaluate if future evaluations might also be valuable

4b. What will the study not tell us?

In general, when applying these results, or those from any study, one should consider the pre-harvest physical setting (e.g., amphibian populations, stream temperature, riparian shade, lithology, aspect), applied harvest prescription(s) (timing, buffer locations, dimensions, density), and time elapsed since harvest.

Experimental studies, like this, select sites to meet specific criteria so the observed post-treatment effects (e.g., amphibian density, stream temperature) are more likely to be due to the treatment than to inherent differences among the study sites. Although this increased the statistical power of the study by reducing variability in response, only a segment of the population (Np streams underlain by competent lithologies) was studied.

The range of experimental treatments may also limit the scope of inference if these differ from forest practices in use by landowners. This study manipulated the proportion of channel with a two-sided 50-ft wide buffer, with three buffer treatments that were equally-spaced along the same axis, thereby allowing for interpolation between treatments. In practice, only the 0% buffers were relatively uniform, while the 100% varied widely in width and the FP sites varied from 55 – 100% of stream length buffered. Input from several CMER reviewers suggest that variability in FP buffers in practice may be even greater than that seen in this study because entire Np basins may be harvested over multiple years, rather than in a single entry.

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 (personal communication, P. Pringle September 2005, formerly Washington Department of Natural Resources).
The transferability of the study findings to other Type N basins must be done carefully because the physical characteristics, management history, and harvest intensity among Type N basins, across the landscape, are highly variable. Therefore, extrapolating the study across the landscape requires knowledge of the physical and environmental variability among headwater basins to provide a spatial context for inference.

Temporal Scope of Inference: The temporal scope of inference should be relatively reliable for the first 10 years after harvest for basins with similar characteristics.

<u>*The following summarizes the limitations specific to particular responses*</u>:

- *Discharge*. Discharge changes associated with harvest complex and extend over much longer timescales than those analyzed as part of this study. This study was able to document relatively short-term (~ 8 year) changes in discharge following harvest, but we do not know how flows will change over a longer period as the trees regrow or what the effects will be under specific extreme events (e.g., drought). 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 from the data collected in this study. Our ability to detect a suspended sediment treatment effect was hampered by the short pre-treatment period relative to the number of sediment generating events, lack of synchronous sediment export across sites for a given storm event, and low site-scale replication (n = 2) of each treatment. While the turbidity measurements indicated a lack of chronic suspended sediment export before or after harvest, this study could not address whether the frequency or magnitude of sediment producing mass-wasting events changed following harvest, and mass-wasting has been shown to be the largest driver of sediment export in relatively competent headwater basins like these.

- *Stream-associated amphibians.* We selected study sites based on specific criteria, including the presence of focal stream-associated amphibians. This study does not 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.

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?

Opportunities exist to better inform Policy of the longer-term post-harvest impacts and potential for recovery for stream-associated amphibians. Proposed extended monitoring (Phase III) will focus on addressing Overall Performance Goals, Resource Objectives and key questions specific to the response of stream-associated amphibians across study sites 14 years following harvest. A Schedule L-1 Overall Performance Goal is supporting the long-term viability of "other covered species," which includes stream-associated amphibians. Additionally, a Resource Objective outlined in the CMER Work Plan is to provide conditions that sustain stream-associated amphibian populations within occupied sub-basins. Finally, Critical Questions in the CMER Work Plan also address whether stream-associated amphibian population viability is maintained by the Type N prescriptions and how stream-associated amphibian populations respond to the Type N prescriptions over time.

Results from data collection through 2017 and outlined in this report (Phase II) indicate a delayed negative response to harvest for some stream-associated amphibian species in some treatments. Results for the eight years post-harvest indicated a substantial decline in Coastal Tailed Frog densities in all buffer treatment sites in the eight years post-harvest. There was also a delayed decline detected for torrent salamanders in the FP treatment. Based on these findings, the FP Board approved Phase III monitoring for stream-associated amphibians beginning in the 21-23 biennium.

The following relevant studies are either planned, underway or recently completed. For more information comparing specifics between this and listed projects, see the answers to the CMER Six Questions for Policy for the Phase I Report.

<u>Planned Studies:</u>

- Van Dyke's Salamander Project (a literature review was completed, not scoped)
- Amphibians in Intermittent Streams Project (currently being scoped)

- Eastside Amphibian Evaluation Project (not scoped)
- Windthrow Frequency, Distribution, and Effects Project (currently being scoped)

Underway Studies:

- Analysis of temperature data from 2017-2019 from this study (November 2020 CMER presentation).
- Type N Experimental Buffer Treatment Project in Soft Rock Lithologies Project [Soft Rock Study] currently approved by CMER.
- Eastside Type N Riparian Effectiveness Project [ENREP Study]

Completed Studies:

- Westside Type N Buffer Characteristics, Integrity, and Function Project [BCIF Study]
- Buffer Integrity – Shade Effectiveness (Amphibians) Project [Shade Study]
- Amphibian Recovery Project
- SAA Detection/Relative Abundance Methodology Project

Study PIs and LWAG proposed a Phase III amphibian monitoring in two consecutive years beginning in the 21-23 biennium, which was recently approved for funding by the FP Board. Two years of Phase III sampling are recommended because natural annual variability in amphibian populations is high and counts for some species were small and/or zero for some study sites and years, especially during Phase II monitoring. This was the case for Coastal Tailed Frog, for which we observed the most substantial declines in all buffer treatments in post-harvest years seven and eight. Including at least two years of amphibian monitoring during each sample period helps account for the effect of natural variability in our estimate of treatment response and increases our chances of obtaining adequate sample sizes at all study sites. Two years of additional monitoring is also supported by the loss of some reference sites, which will result in a decreased precision in our treatment estimates. With additional Phase III amphibian monitoring we are confident that we will provide a more robust assessment of amphibian response to Forest Practices Rules in Western Washington than has previously existed.

Budget estimates and proposed timing for Phase III amphibian monitoring across Type N Hard Rock study sites:

Field monitoring/ Data organization		**Field monitoring/ Report writing**	**Complete report writing/ CMER/ISPR review**		**Total**
FY22	**FY23**	**FY24**	**FY25**	**FY26**	
$130,000	$412,000	$349,000	$82,000	$20,000	$993,000

Note that the suitable sampling season for focal amphibian species is June to September, which spans fiscal years. The budget accounts for the spread of funding required for field sampling over 3 fiscal years (FY22-24).

Phase III monitoring for amphibians is currently proposed and on the CMER MPS to begin in FY22, with project completion (final report approval and delivery to TFW Policy) scheduled for FY 25 or FY26.

Additional study will inform whether current or alternative riparian buffers: (1) support the long-term viability of "other covered species," which includes stream-associated amphibians, (2) provide conditions that sustain amphibian populations within occupied sub-basins, and (3) inform how amphibian populations respond to the Type N prescriptions over time.

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 conservation 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 studies related to riparian ecological processes, habitat needs of covered species and forest management effects on larger streams. 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. Based on the findings of McDade and colleagues the HCP concluded 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.

We did not attempt to validate the source distance curves as a part of this study. We did provide estimates of large wood recruitment pieces and volume in reaches with RMZ and PIP buffers with a maximum source distance of 50 feet.

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 the 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).

In this study, we found that initial shade reductions were similar to these predictions. However, reductions in canopy closure persisted, with mean treatment values continuing to decline through four years post-harvest and only beginning to increase after five years post-harvest. Only the 100% treatment returned to pre-harvest conditions by Post 9.

<u>Stream Temperature</u>: 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.

As anticipated, stream temperature did increase within the Type Np stream under the current rules (i.e., FP treatment), however, the increases have been longer lasting than expected. The FPHCP does not define what a "small" temperature increase is, but the highest mean post-harvest increase in both the FP and 100% treatments was 1.1°C and was 3.8°C in the 0% treatment. Increases in average stream temperature in the FP and 0% treatments have lasted longer than expected (>5 years), and neither treatment had returned to pre-harvest levels at nine years post-harvest. Contrary to expectations based on the rational for the HCP, temperatures did increase downstream of the harvest unit at some FP and 0% sites after flowing a short distance through an unharvested forest or wider (>50 ft) buffer but not in the 100% sites. We also did not monitor the cumulative effects of temperature increases from multiple Type N streams flowing into receiving Type F waters.

<u>Suspended Sediment</u>: 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 intended to be 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 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).

In this study we found that suspended sediment levels were generally low in these sites and we were not able to detect a treatment effect in any of the riparian buffer treatments, including the 0% treatment. The lack of a 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.

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.

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.

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 can provide 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 protective (100%) and less protective (0%) than the current forest practice rules, was established to provide a response curve along a gradient of buffer length. The length of the study and an evaluation of responses of metrics through up to nine years post-harvest expands on the timeline relative to other similarly rigorous studies, and is especially important for metrics such as the stream-associated amphibians for which a delayed response would be anticipated.

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 in 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 stand characteristics and wood recruitment from clear-cut, 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 more confident in many of our findings than previous studies because we were able to utilize new analytical approaches 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.

If not already done so within the answers to the six questions above, provide the technical implications/recommendations resulting from the study.

<u>Technical Implications and Recommendations:</u>

New rule tools or field method development.

- We consistently had a difficult time detecting Coastal Tailed Frogs, especially post-metamorphs, for some sites both pre- and post-harvest. 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, for post-metamorphs in particular. 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: 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. 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. Additional data collection will be especially important for evaluating the time to recovery to baseline conditions for stream-associated amphibians and provide a more confident assessment of prescription effectiveness over 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.
    - 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 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.

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