Stream-Associated Amphibian Response to Manipulation of Forest Canopy Shading – Report to Policy

Approved by CMER – 27 November 2018

Study Report

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

MacCracken, J.G., M.P. Hayes, J.A. Tyson, and J.L. Stebbings. 2018. *Stream-Associated Amphibian Response to Manipulation of Forest Canopy Shading*. Cooperative Monitoring Evaluation and Research Report CMER #16-1600, 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 overarching objective of the *Stream-Associated Amphibian Response to Manipulation of Forest Canopy Shading Study* (Shade Study for short) was to evaluate the effectiveness of different shade levels in maintaining key aquatic conditions and processes affected by Forest Practices in Type N (non-fish-bearing) Waters. We evaluated that objective largely based on stream-associated amphibian (SAA) response in a 50-m reach-level context, which is where this study differs from the Hardrock Study, which focused on basin-level SAA response. In particular, we evaluated whether different shade levels met the overall Performance Goals of supporting the long-term viability of SAAs.

The Shade Study falls under the Type N Amphibian Response Program, which CMER ranked as third highest in priority based on potential risk to aquatic resources (CMER Work Plans 2005 to 2017-2019). When this study was considered, the Type N rule for western Washington was based on few studies with limited scope and inference. As part of our evaluation, we assessed the Resource Objectives defined for key aquatic conditions and processes affected by Forest Practices identified in the Forest Practices Habitat Conservation Plan (FPHCP, WADNR 2005; Appendix N, Schedule L-1).[1] The intent of the Resource Objectives was to meet the Performance Goals. Resource Objectives include Functional Objectives (broad statements of major watershed functions potentially affected by Forest Practices) and Performance Targets (measurable criteria defining specific, attainable target forest conditions and processes). In this study, we address Resource Objectives for heat/water temperature, and hydrology. We specify the Functional Objectives and Performance Targets evaluated for each study response variable presented in the study results in Question #4 below. Not all study responses have corresponding Functional Objectives and Performance Targets in Schedule L-1; for these, we identify applicable Resource Objectives and Critical Questions outlined in either Schedule L-2, the CMER Work Plan, or both.

[1] https://www.dnr.wa.gov/publications/fp_hcp_31appn.pdf?sustyx14.

This effectiveness monitoring and research study informs one of the key questions driving the Forests and Fish Adaptive Management Program:

> *"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:

- *What are the effects of various levels of shade retention on the stream-breeding SAAs?*
- *Is there an optimum level of shade retention?*

3. **Did the investigators carry the study out pursuant to CMER scientific protocols?**

Yes. We carried out the study according to the CMER and CMER approved study design (including sampling methodologies, statistical methods, and study limitations). The study design did not go through Independent Scientific Peer Review (ISPR) because the process of ISPR review of study designs was not in place at the time the Shade Study was developed. LWAG, CMER, and ISPR reviewed the report and its associated findings, and CMER approved the entire final report in November 2018.

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

Overall, the Intermediate Shade treatment was the most effective in maintaining conditions closest to that of Reference reaches and provide some benefits of increased irradiance to stream productivity. Both Low and No Shade treatments were less effective in maintaining those same conditions. Differences between Low and No Shade treatments were complex and difficult to identify; in short, we could not confidently identify a response difference between Low and No Shade treatments. Variation in the SAA and, secondarily, the temperature response pattern made site-specific conditions a suspect for contributing to variability.

Longview Fibre, in cooperation with CMER, designed this Effectiveness Study to evaluate the response of Type N waters to reductions riparian shade in 50-m stream reach treatments. We evaluated three experimental treatments representing levels of increasingly reduced shade: (1) Intermediate, (2) Low, and (3) No Shade levels (Table 1). One of the goals of the study was to isolate the impacts of shade reduction without the potentially confounding impacts of other responses during harvest (e.g., sedimentation). So, this study addressed a reduction in the Riparian Management Zone exclusive of upland harvest. We paired each of 25 experimental 50-m reaches receiving one of three treatments with one 50-m unmanipulated Reference reach located 50-90 m upstream.

The study focused on SAA response, but also on resources known to impact SAAs (i.e., shade, water temperature) as well as exports to downstream reaches (i.e., detritus, macroinvertebrates, water temperature; Table 2). We designed the study to detect differences over the manipulated shade reduction gradient. To this end, we utilized: 1) sites across a broad geographic footprint (western Washington and northwestern Oregon; Figure 2), and 2) a manipulative Before-After Control-Impact (BACI) design to compare how reaches responded to different levels of shade reduction while controlling for temporal variation. We blocked sites in the analysis to reduce variability (Figure 2), for a total of three blocks in each region. Data collection in the Olympic region was staggered relative to the remaining regions by two years (Table 2) because early in implementation, the Forest Service disallowed the use of several of the original sites targeted for the two more severe shade reduction treatments. We randomly assigned streams in each block to one of the three aforementioned shade reduction treatments.

Table 1. Treatments in the Shade Study. We applied treatments at the time of deciduous tree leaf-off in the fall, but the value for the Intermediate, Low and No Shade treatments during the leaf-on data collection season.

Treatment	Description	Sample size (n =)
Reference	Vegetation unmanipulated during study period. Note that each reference reach was paired with one of the above-mentioned treatment reaches	25
Intermediate Shade	Vegetation removal was intended to reach 70% overhead stream cover; the actual value attained was ± 3 SE	8
Low Shade	Vegetation removal was intended to reach 30% overhead stream cover; the actual value attained was 61% ± 3 SE	9
No Shade	Vegetation removal was intended to reach 0% overhead stream cover; the actual value attained was 40% ± 4 SE	8

Table 2. Data collection timeline for the Shade Study. Data collection in the Coast and Cascade (black **x**s) and Olympic (red **x**s) Regions. Note the Olympic Region time-stagger.

Regions								
	Coast & Cascade		Pre-harvest		Harvest	Post-harvest		
	Olympic				Pre-harvest		Harvest	Post-harvest
Variables		**Year**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Vegetation Cover			x	x	x (x)	x (x)	(x)	(x)
Light (as Photosynthetically Active Radiation)			x	x	x (x)	x (x)	(x)	(x)
Water Temperature			x	x	x (x)	x (x)	(x)	(x)
Biofilm/Periphyton			x	x	x (x)	x (x)	(x)	(x)
Stream Drift (Detritus & Macroinvertebrate Export)			x	x	x (x)	x (x)	(x)	(x)
Amphibians	Abundance		x	x	x (x)	x (x)	(x)	(x)
	Body Condition		x	x	x (x)	x (x)	(x)	(x)
	Growth		x	x	x (x)	x (x)	(x)	(x)

We collected two years of pre-treatment data, applied shade reduction (harvest) treatments, and collected two or more years of post-treatment data. We intentionally made treatments local-scale using a 50-m reach length. Since the response of SAAs was the primary objective, we only included sites where SAAs occurred, though not all SAA species were present at all study sites (Figure 2). Finally, we used the most appropriate sampling methods and statistical analyses available.

The null hypothesis was that the pre- to post-treatment change would not differ among shade reduction treatments. Alternatively, if we expected a difference among treatments, we hypothesized that the greatest reduction in shade (the No Shade treatment) would differ the most from unmanipulated Reference reaches, with progressively less difference at progressively lower levels of shade reduction (Low and Intermediate Shade treatments).

Results of the Shade Study inform the efficacy of particular levels of shading that inform the design of current Forest Practices rules. The temporal scope of inference applies to the two-year post-harvest interval, and the spatial scope of inference applies to stream reaches 50-m in length.

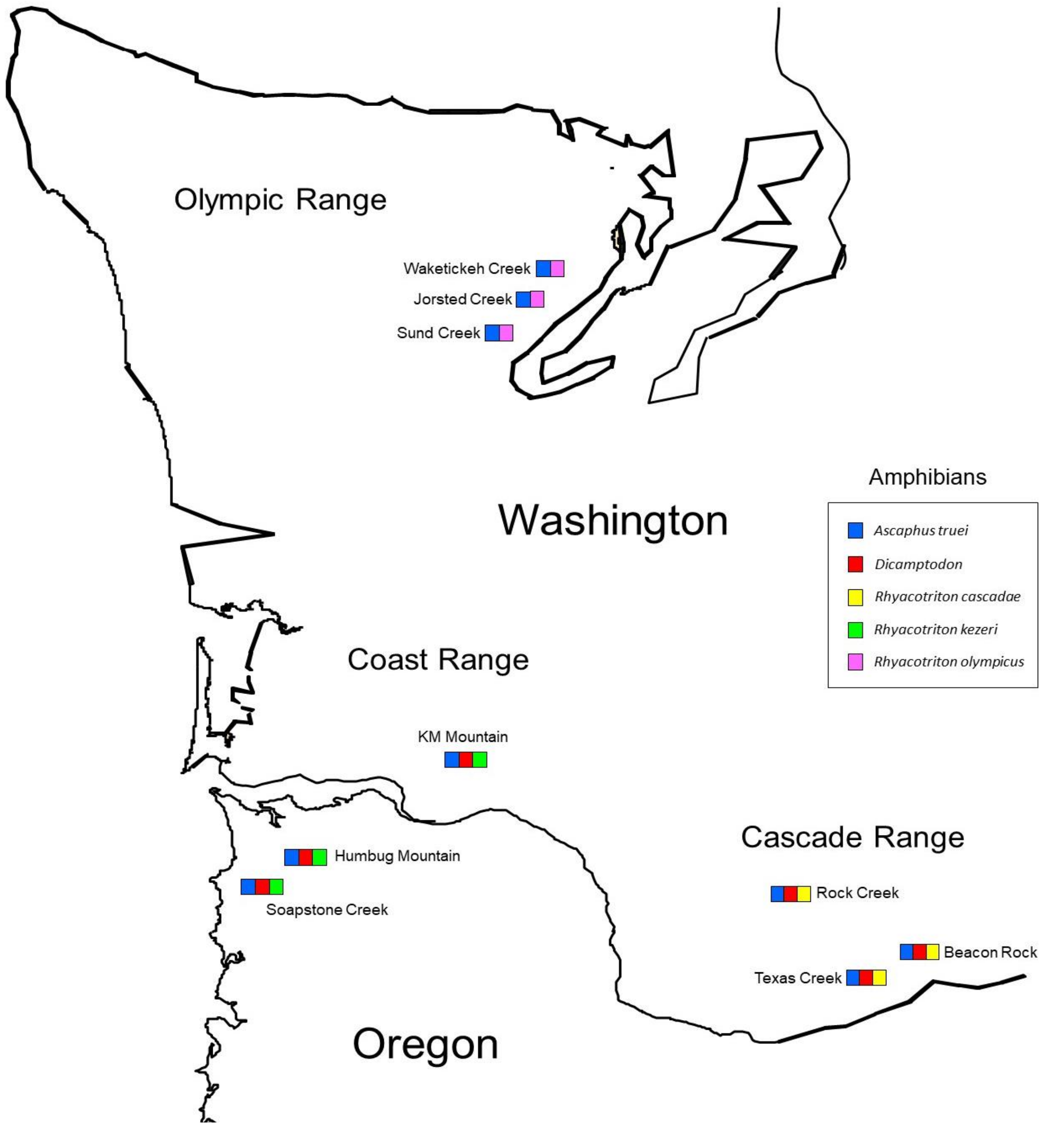

Figure 1. Location of the nine Shade Study blocks in the three regions of western Washington and northwest Oregon. We color-code and list alphabetically the species of stream-breeding amphibians (Amphibians in legend) by their scientific names: *Ascaphus truei* (Coastal tailed frog); *Dicamptodon* (giant salamanders; comprises two species, *D. copei* and *D. tenebrosus*); *Rhyacotriton cascadae* (Cascade torrent salamander); *Rhyacotriton kezeri* (Columbia Torrent salamander); and *Rhyacotriton olympicus* (Olympic torrent salamander).

Here, we present here applicable results, focusing on responses that differ from Reference reaches in a "Results" section. We then discuss the 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.

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 at least 50% of stream length.
- Stream temperature – Water quality standards (WQS) – current and anticipated in next triennial review.[2]

Shade and Stream Temperature Results:

- With the application of shade reduction treatments, we observed a significant progressively increasing decline in shade metrics over the shade reduction gradient. Pre-treatment, mean canopy cover at the stream surface was ≥ 92% in all reaches at all sites. Post-treatment, mean canopy cover declined an average of 19%, 36%, and 57%, respectively, in the Intermediate, Low, and No Shade treatments. In contrast, canopy cover increased an average of 5% in reference reaches post-treatment, thus post-treatment canopy cover in the reference reaches averaged ≥97% in contrast to the treatment reaches at an average of 77%, 61%, and 40%, respectively.
- Coincident with shade reductions, we observed an increase in photosynthetically active radiation (PAR) over the same gradient. Pre-treatment, mean PAR values at the stream surface ranged from 27 to 47 μmols m^{-2} sec^{-1} among treatments, variation that was not significant. Post-harvest, we found a near uniform increase in the mean PAR value across the shade reduction gradient from the Intermediate through the No Shade treatments. The magnitude of change was a rough doubling of PAR with each increased shade reduction treatment level.
- Examining temperature, the size of the change (the effect size) was a small non-significant increase (~0.5ºC) in the mean 7DADM for the Intermediate Shade treatment. However, we saw progressively larger temperature changes in the Low and No Shade treatments, both of which were large enough to be significant. Their magnitude was, respectively, 2.2ºC and 2.5ºC. However, the difference in the temperature change between the No and Low Shade treatments (0.3ºC) was not significant. However, not all stream reaches in any treatment or regional block surpassed the annual summer maximum 7DADM temperature criteria assigned to these waters. Figure 6B of the Final Report, illustrates the pre- and post-treatment means and the standard errors of those means that are the basis of this effect size information.

[2] At the time of Forests and Fish Report completion (1999), 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)."

- The temperature change patterns in the seasonal mean maxima were similar to those for the 7DADM data except that a significant difference (estimated at 1.4ºC) existed between the Low and No Shade treatments. Here, the temperature change in the Intermediate Shade treatment was also a small (~0.5ºC) non-significant increase in the seasonal mean maximum; the Low and No Shade treatments also had larger significant changes, in this case, 1.5ºC and 3.2ºC, respectively. Figure 6A of the Final Report, illustrates the pre- and post-treatment means and the standard errors of those means that are the basis of this effect size information.
- After treatment, we saw small, non-significant increases in the median 7DADM in both Reference (0.1ºC) and Intermediate Shading Level Treatment (1.1ºC) reaches, but no change in the mean for the absolute maximum in those same reaches. In contrast, we observed increases in both the medians of the 7DADM (1.2ºC and 1.1ºC, respectively) and absolute maxima for both Low and No Shade Level Treatment reaches; post-treatment, all median values for these two treatments were ≥16.0°C (Range: 16.0-18.0°C for both metrics examined).

Conclusions:

- Treatments achieved a remarkably uniform shade reduction gradient.
- Consistent with reductions in shade, we observed increases in water temperature for the No and Low Shade treatments. However, not all stream reaches in any treatment or regional block surpassed the annual summer maximum 7DADM temperature criteria assigned to those waters.
- We identified stream warming at a 50-m scale, but we found temperature variability, implying that some stream reaches are more sensitive to shade removal than others.
- We observed corresponding increases in PAR with greater shade reduction. However, unlike the temperature response, we observed significant increases in PAR across the entire shade reduction gradient, including the Intermediate Shade treatment.
- The Intermediate Shading treatment saw no clearly identifiable increases in water temperature pre-to-post treatment, and water temperature conditions in that treatment most closely approximated that of Reference reaches.
- Estimated post-treatment temperature increases in the Low and No Shade treatments were greater than the 0.3ºC increase allowable in the WQS for waters at or above the assigned temperature criteria (WAC 173-201A-200(1)(c)(i)). In addition, applications of shade reduction to a level equivalent to that in the Low and No Shade treatments in magnitude 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) for waters that are below the assigned temperature criteria prior to harvest. Low and No Shade treatments also warmed from below 16ºC criterion pre-treatment to above it post-treatment at several sites, a response not permitted under the state WQS.

<u>Biofilm and Periphyton</u>

No Resource Objectives, Performance Targets, or Critical Questions address the production of biofilm (i.e., the mix of microorganisms, slimy extracellular matrix, and fine detritus on stream substrates) or periphyton (i.e., the primary-producing segment of biofilm). In headwater streams, biofilm is typically most of the instream biomass, and periphyton contributes most primary production. Organisms in biofilm and periphyton have short life cycles (reproduce rapidly); and so respond rapidly to relatively small changes in physical and chemical processes. Consequently, they are useful indicators of short-term environmental change. They are also the primary food resource for tailed frog larvae and selected macroinvertebrates; the latter themselves are important food resources for SAAs.

Results:

- We observed increases in biofilm accumulation following shade reduction treatments in all three shade reduction treatments.
- Increase in biofilm accumulation in all shade reduction treatment levels were similar in magnitude.

Conclusions:

- The shade reduction gradient resulted in the expected increase in biofilm in all stream treatments.
- The basis of the increase in biofilm is unclear.

Detrital Drift (Export)

No Resource Objectives, Critical Questions, or Performance Targets specifically address detrital drift or export, but we assessed detrital drift from study reaches to evaluate the effect of shade levels on detrital production. Detrital export has the potential to change with reduction in levels of shade (analogous to harvest levels) due to changes in detrital input sources. Detritus is an important food resource for some macroinvertebrates (gatherers [e.g., net-spinning caddisflies] and shredders [e.g., selected stoneflies]).

We examined two categories of detrital drift, Coarse Particulate Organic Matter (CPOM) and Fine Particulate Organic Matter (FPOM). Material in the CPOM category consisted of deciduous leaves, conifer needles, wood, and other vegetation (bark, cone fragments, florets); whereas the FPOM category consisted of organic fragments often too small to identify their source. We described rates of detrital drift as mass per unit of flow (g/m^3) and mass per unit of time (g/day).

Results:

- We observed declines in CPOM in g/m^3 in all shade reduction treatments, but the decline was significant in only in the No Shade treatment.
- We did not see any significant treatment changes in CPOM measured as g/day (figure not shown).
- We did not record any significant treatment changes in FPOM measured either in g/m^3 (not shown) or in g/day (Figure 8). However, the decline in FPOM in the No Shade treatment measured in g/day was close to significant.

Conclusions:

- The reduction in detrital drift in the No Shade treatment was the only evidence of a difference among treatments.
- Reduction in CPOM or FPOM drift agrees with a reduced input source from riparian overstory canopy.

Macroinvertebrate Drift (Export)

No Resource Objectives, Critical Questions, or Performance Targets specifically address macroinvertebrates, but we assessed the response of macroinvertebrates exported from shade reduction treatments to evaluate the effect of shade levels on food resources for SAAs. Macroinvertebrate export has the potential to change with shade reductions, especially if different levels of shade translate into different levels of detrital input and instream production. The latter are important food resources for macroinvertebrates.

We described rates of drift for total macroinvertebrates and five functional macroinvertebrate feeding groups (filtering collectors, gathering collectors, predators, scrapers, shredders)[3] in units of mass per unit of flow (g m^{-3}) and units of mass per unit of time (g day^{-1}). We also described total macroinvertebrate drift as the number of individuals per unit of flow (individuals m^{-3}) and individuals per unit of time (individuals day^{-1}).

Results:

- We found no significant differences in filtering collectors among treatments, regardless of measurement mode.
- We found a significant increase in gathering collectors in the Low Shade treatment regardless of the measurement mode.
- We found a significant decline in predator macroinvertebrates in the No Shade treatment measured as mass per unit of flow but as mass per unit of time.
- We found a significant increase in scraper macroinvertebrates, but only in the Intermediate Shade treatment measured as mass per unit of time. Scraper response in the Intermediate Shade treatment measured as mass per unit of flow revealed a pattern that was not quite significant.
- We found a significant decline in shredder macroinvertebrates, but only in the No Shade treatment measured as mass per unit of flow.
- We found no significant post-treatment changes in total macroinvertebrates measured as mass per unit of flow or mass per unit of time.
- We found a significant decline in total macroinvertebrate drift measured as individuals m^{-3} exclusively in the No Shade treatment.

Conclusions:

- Macroinvertebrate responses generally had ecologically robust explanations.
- The decline in predators and shedders in the No Shade treatment supports the decline in total macroinvertebrates in the No Shade treatment. Fewer numbers means fewer prey (shredders, which are frequent prey, were common) and the No Shade treatment had the lowest resource base for shredders (mostly CPOM).

[3] Functional feeding group is a basic practical method of classifying macroinvertebrates via their generalized feeding mode; classification labels for group types are largely self-explanatory. Filtering collectors are macroinvertebrates that filter the stream water column for microorganisms and consumable organic material. Gathering collectors are macroinvertebrates that typically gather microorganisms and consumable organic material from the water column, but do not filter it. Predators are macroinvertebrates that specialize in consuming other macroinvertebrates. Scrapers are macroinvertebrates that scrape biofilm and consumble organic material from the substrate. Shredders are macroinvertebrates that shred Coarse Particulate Organic Material (CPOM – see Detrital Drift section) into consumable form.

- The increase in scrapers in the Intermediate Shade treatment is consistent with the increased food resource for scrapers, which is biofilm.
- The causative mechanism for the significant increase in gatherers in the Low Shade treatment is unclear.

Stream-associated Amphibians (SAAs)

Resource Objectives specific to SAAs are lacking in Schedule L-1. However, we used the response of SAAs to different shade levels 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 SAAs. The CMER Work Plan also outlines one Resource Objective and two Critical Questions that address SAAs in context of shade.

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

Critical Questions (CMER Work Plan):

- *What are the effects of various levels of shade retention on the stream-breeding SAAs?*
- *Is there an optimum level of shade retention?*

The generic definition of population viability is the ability of a population to persist and avoid extinction. Current rules do not identify a metric for evaluating amphibian population viability. In this study, we used abundance, body condition and growth as surrogate indicators of viability. This study was relatively short (two years in each of pre- and post-treatment) and generation times for SAAs are relatively long (>10 years), so adequately addressing amphibian population viability would require longer study.

We corrected all abundance (count) data for detection probability and obtained growth data for individuals contained in plastic tub enclosures placed in the stream in which substrate conditions approximating those of the stream.

The forest practices-designated amphibians 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) that are not forest practices-designated.

Results:

- We observed a significant increase in giant salamander abundances in the No Shade treatment, and an increase in Cascade and Olympic torrent salamander abundances in the Intermediate Shade treatment. We also found a significant decline in Olympic torrent salamander abundance in the Low Shade treatment. We found no significant differences among treatments for Coastal tailed frog larvae or adults and Columbia torrent salamander.
- We observed a significant increase in body condition for larval Coastal tailed frog in the Low Shade treatment, and a significant decrease in body condition for the Cascade torrent salamander in the Low Shade treatment. We found no clear differences in body condition for adult Coastal tailed frogs, Columbia torrent salamanders, and giant salamanders in any of our treatments. Data asymmetries between reference and

treatment reaches and small sample sizes prevented determination of body condition for Olympic torrent salamander.

- We observed a significant increase in growth rates for Coastal tailed frog larvae, and Columbia and Olympic torrent salamanders in the No Shade treatment; and for the Cascade torrent salamander in the Intermediate Shade treatment. We found no significant discernable changes in giant salamander growth.

Conclusions:

- We found no consistent patterns in the response of SAAs, complicating interpretation.
- Some SAA responses were consistent with expectations linked to shade reductions. In particular:
  - The increase in giant salamanders in only the No Shade treatment agrees with giant salamanders responses to clearcut harvest in small streams with gradients >9% (Murphy et al. 1981), a gradient range similar to most streams in the Shade Study.
  - The responses for two of three torrent salamanders agree with torrent salamander data for other variables correlated with shade, including buffer width (Stoddard and Hayes 2005) and stand age (Steele et al. 2003, Kroll et al. 2008).[4] These include the positive responses in the Intermediate Shade treatment (Cascade torrent and Olympic torrent salamanders for abundance and/or growth), and the negative responses in the Low Shade treatment (Cascade and Olympic torrent salamanders for either abundance, body condition, or growth).
  - The positive body condition response of Coastal tailed frog larvae to the Low Shade treatment is consistent with the intermediate positive (hump-shaped) response to bankfull width observed in another study (Kroll et al. 2008), for which an intermediate level of shading would be expected.
- However, other SAA responses more difficult to explain. These include:
  - The significant increase in Coastal tailed frog growth in the No Shade treatment in the absence of changes in growth in the Low and Intermediate Shade treatments.
  - The significant increase in Columbia and Olympic torrent salamander growth in the No Shade treatment when we also saw no significant change in growth in the Low Shade treatment.

  These seemingly inconsistent responses merit brief comment. First, all these responses relate to growth, which as noted earlier, we evaluated in enclosures. Because enclosures often had somewhat higher temperatures when compared with our stream data, we cannot confidently exclude an enclosure effect. Second, in one case, that of the Columbia torrent salamander, pre-treatment growth for the No Shade treatment was very negative in contrast to the other treatments, so opportunity for a positive response would be intrinsically high. Both issues may contribute to the patterns. For these reasons, we have less confidence in the SAA growth data than the abundance and body condition data.

[4] Kroll et al. (2008) found a quadratic (hump-backed) relationship to stand age.

- Considering all SAAs collectively, we observed more positive and fewer negative responses in the Intermediate Shade treatment than in the No and Low Shade treatments.
- The only two significant negative results both occurred in the Low Shade treatment (Olympic torrent salamander [abundance] and Cascade torrent salamander [body condition]). This may imply some unrecognized distinctive state for most streams in that treatment.
- The highly variable pre-treatment conditions of measured parameters among treatments may help explain lack of uniformity in anticipated responses. We have already pointed out the extremely low pre-treatment growth rate in the Columbia torrent salamander. A second example is the low body condition value for Coastal tailed frogs in the Low Shade treatment. We believe the low value provided greater opportunity for a significant positive response to that treatment. Conversely, we also expect that high pre-treatment values for some parameters would prevent identifying a significant positive response if conditions were close to the upper end of the response range for that parameter for that species.

Summary of Treatment Performance

- We achieved an unambiguous shade reduction gradient that was roughly uniform in its decreasing shade increments.
- That shade reduction gradient translated strongly to a light gradient based on PAR.
- The shade reduction gradient also translated to increases in temperature. However, the increases in temperature were only significant in the two treatments with the most reduced shade (Low and No Shade treatments). However, not all stream reaches in any treatment or regional block surpassed the annual summer maximum 7DADM temperature criteria assigned to those waters.
- The light gradient translated strongly to a biofilm production gradient, which we originally thought might reflect a shift to autotrophy, but data from the Trask study in Oregon suggest that a large heterotrophic response that increases biofilm productive without a significant autotrophic response is also possible.
- The shade/canopy reduction gradient also translated to declines in CPOM and FPOM in the No Shade treatment.
- Several changes in macroinvertebrate production appeared to track aforementioned shade reduction gradient-induced changes. In particular, the decline in predators and shredders in the No Shade treatment paralleled the decline, respectively, in total macroinvertebrates and CPOM in that treatment, reflecting their respective food resource bases. Further, the increase in scrapers in the Intermediate Shade treatment paralleled the increase in biofilm in that treatment, also its food resource base.
- Some SAA responses are consistent with expectations linked to shade reduction gradient-induced changes. In particular, increase in giant salamanders exclusively in the No Shade treatment; the positive responses for two of three torrent salamanders in

the Intermediate Shade treatment, and the negative responses in the Low Shade treatment; and the positive response of Coastal tailed frog in the Low Shade treatment.

- Considering macroinvertebrates and amphibians collectively, we observed more positive and fewer negative responses in the Intermediate Shade treatment than in the No or Low Shade treatments.
- Selected changes or lack thereof among macroinvertebrates and SAAs lack a clear ecological explanation. Many of these instances have in common that pre-treatment levels of each group may have strongly influenced the opportunity for a response.
- We designed this field experiment to distinguish among levels of shade reduction, not to identify the precise basis of the responses. However, if Policy desires, some data from the Shade Study would lend themselves to identifying a potential basis of responses. For example, we could use stream temperature data from relatively proximate treatment and reference reaches to determine the potential degree of groundwater influence. This could suggest whether that influence contributed to the variability in individual streams by examining amphibian and macroinvertebrate response and better understand a potential basis for some of the reach to reach variation in temperature responses we observed.

B. What does the study not tell us?

One must consider selected limitations when interpreting and generalizing study results.

Spatial Scope of Inference: Spatial scope of inference is limited to Type N streams with competent lithologies which may comprise about 29% of Forests and Fish jurisdictional lands in western Washington.[5]

Inference is limited to 50 meter reaches of generally east-west oriented 1-3rd order Type Np streams in dense (>96% overhead cover) second growth conifer forests, which have cool initial water temperatures (<14°C 7DADM) prior to harvest.

We did not test whether increasing light levels through traditional buffer harvesting or in combination with harvesting the uplands would have yielded similar results.

Temporal Scope of Inference: Results can only be interpreted for headwater stream conditions in the two years following harvest. One can only understand the scope of long-term response with longer-term monitoring. The results may not apply over more extended periods, a condition potentially suggested by the impending Hard Rock Phase 2 results. For example, opportunities for delayed responses (positive or negative) of SAAs and temperature may exist.

The following summarizes the limitations specific to particular responses:

- *Stream-associated amphibians.* We selected study sites based on specific criteria, including the presence of SAAs. This creates 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.

[5] Patrick Pringle, personal communication, September 2005, formerly Washington Department of Natural Resources.

We focused on instream sampling, so we did not address the potential impacts to the terrestrial life stages of Coastal tailed frog and giant salamanders.

The distribution of torrent salamander species is region-specific; one of each of the three species we addressed occurs in only one region. As a result, each torrent salamander species had one third of the full treatment reach complement.

Giant salamanders did not occur in the final streams selected for the Olympic block, and so these sites were excluded in the analysis of giant salamander response to treatment.

- *Shade levels.* Our operational post-treatment cover values (mean and standard error of the mean) were 77% ± 3 SE, 61% ± 3 SE, and 40% ± 3 SE, respectively for the Intermediate, Low, and No Shade treatments. We do not currently understand whether a threshold exists in shade translated as cover level that will function similarly to the Intermediate Shade treatment other than the fact that we know it is > 61% ± 3 SE.

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

We expect the results from this study and the Amphibian Recovery Project, and the BCIF, Hard Rock, and Soft Rock Studies will provide a thorough assessment of riparian requirements for westside Type N Waters. Collectively, they will generate data useful to determine if the resource objectives for heat/water temperature, LWD/organic inputs, sediment, hydrology and SAAs[6] are being met.

- Amphibian Recovery Project (ARP) [completed]: This project evaluated the effects of three buffer treatments on headwater streams in coastal western Washington. Riparian buffer treatments in this study included: (1) unthinned riparian buffers, (2) partial buffer, (3) buffer of non-merchantable trees, and (4) clearcut to the channel edge. The study included evaluation of stream channel characteristics, wood loads, stream temperature, sediment, macroinvertebrates and SAAs. One year of pre-harvest and three years of post-harvest data were collected on 15 sites; not all metrics were evaluated in every post-harvest year. No pre-treatment screening for amphibian presence was done; amphibians were detected at few study sites. Hence, small sample size limited amphibian response (e.g., only five sites had Coastal tailed frogs pre-harvest). The treatments in the ARP were not designed to evaluate the current Type N prescriptions and methods between it and Shade and Hard Rock studies differed, so comparisons of results among studies are limited to general contrasts, largely to each study's most severe treatment. In particular, the ARP did not evaluate amphibian detectability or amphibian presence/abundance in stream reaches that were inaccessible due to post-harvest wood loading in the form of slash. The former was done in both Shade and Hard Rock studies and the latter was done in the Hard Rock study. See Jackson and colleagues (2001; 2007) and Haggerty and colleagues (2004).
- 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 BCIF Study provided basic data on riparian stand condition in a sample of clearcut, 50-ft buffer and PIP

[6] Except for Dunn's and Van Dyke's salamanders.

buffer RMZ reaches. BCIF evaluated the shade potential via densiometer-measured canopy cover, which permits direct cover comparison with the Shade Study cover data. PAR was not measure in BCIF. Schuett-Hames and colleagues (2011) reported BCIF findings through five years post-harvest. A report on the 10-year post-harvest findings is in development.

- Type N Experimental Buffer Treatment Project in Hard Rock Lithologies Project [Hard Rock Study, Phase 1 completed, Phase 2 underway]: The Hard Rock Study evaluated the magnitude of change in SAA and macroinvertebrate response, flow, riparian stands, shade, temperature, and wood for three buffer prescriptions applied on a basin-scale at sites selected from a random sample of Type N basins. 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 increased PIP sample size, reducing the level of uncertainty in evaluating PIP buffer response. The Hard Rock Study included responses 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). The Shade Study expands comparisons of cover via the measurement of PAR, and PAR-specific comparisons are possible because both Shade and Hard Rock measure canopy cover using the same methods. Findings through two years post-harvest are reported in McIntyre and colleagues (2018). 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]: Policy and the Board funded this study 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. The Shade Study also uses an experimental design, but its treatment design is local scale (50-m reaches), whereas the Hard and Soft Rock Studies both address a basin scale (Type N basins). Like the Shade and Hard Rock Studies, the Soft Rock Study is limited to western Washington. The Soft Rock Study also does not evaluate the response of SAAs (largely restricted to competent lithologies), fish, or litterfall. The Shade and Hard Rock studies both evaluate SAAs, but only Hard Rock evaluates fish and litterfall, though the Shade study evaluates the CPOM, the instream component of litter. Comparison of shade as cover between Shade and Soft Rock studies is possible since both studies used the same methods to evaluate cover. The Soft Rock Study will provide important information on 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.

- Extensive Riparian Status and Trends Monitoring Program-Stream Temperature. Phase I: Westside Type F/S and Type Np Monitoring Project [Westside Study, in review]. This study used a probability-based sampling design to sample stream temperature and canopy closure on Type F/S (fish-bearing) and Type Np (non-fish-bearing perennial) streams on land regulated under the Forest Practices Rules in western Washington. Stream temperature and canopy closure were measured over the summer of 2008 and 2009. For each stream type, cumulative distribution function (CDF) plots are presented, along with the estimated 25%-tile, median, and 75%-tile CDF values, for maximum summer stream temperature, the seven-day average maximum stream temperature (7DADM), and canopy closure (shown in the table below).

Stream Type	Metric	25%-tile	Median	75%-tile
F/S	Canopy closure	39%	78%	96%
	Maximum temperature	16.0 °C	18.7 °C	20.4 °C
	7DADM	15.4 °C	18.1 °C	19.5 °C
Np	Canopy closure	73%	93%	98%
	Maximum temperature	14.0 °C	16.2 °C	17.3 °C
	7DADM	13.2 °C	15.2 °C	16.5 °C

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

Opportunities may exist to better inform Policy of threshold shade and cover levels needed to maintain SAAs and stream temperatures. We did not identify the mechanism of response variability in the Shade Study. However, an opportunity exists to try to identify causal mechanisms of temperature and amphibian response based on covariate data collected during the study and the possibility of evaluating within-reach variability related to differing covariate conditions.

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

A budget for an assessment of potential causal mechanisms for the observed response in stream temperature and SAAs from the Shade Study is not part of the current CMER 2017-2019 biennial budget. This effort is likely to initially cost ≤$60,000. However, if the assessment identifies one or more key variables that explain significant aspects of SAA response, a formalized field effort targeting those variables may ultimately be justified.

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

The aforementioned covariate assessment may help us learn whether pertinent variables explain a significant proportion of SAA and temperature responses. If that is the case, those variables should be important to include in future studies that examine SAA and reach-specific temperature responses to forest practices.

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

If Policy is interested in the aforementioned approach, and directs that funding be allocated to the effort, the initial assessment could be completed in the next biennium (2019-2021), including review and transmission to Policy. Timing of dissemination of findings to Policy for any potential future effort would depend on the findings of the initial assessment and interest and priority.

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

Identification of any variable that significantly reduces variability in SAA and water temperature treatment responses will reduce uncertainty. It is not clear if such variables would be identified or whether this reduced uncertainty would likely affect the overall adaptive management response by policy makers.

5. 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 shade, large wood, 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 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 Introductory Section to the Shade Study report.

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 in the short term (Appendix N). Previous studies have evaluated several of the metrics we included in this study as they relate to forestry practices, but the Shade Study provides results in context of relatively precise levels of reduced canopy cover at a small (50-m) reach scale in Type N waters over a broad geography (western Washington and northwestern Oregon). This was done while minimizing the impacts of other responses commonly associated with forest practices that can confound the effects of reducing canopy, such as ground disturbance from equipment and upland forest harvest and subsequent sedimentation. Our intentional use of directional felling of riparian canopy by hand in shade reduction treatments and the lack of concurrent upland timber harvest minimized the effects of sedimentation via substrate disturbance so we could more clearly study responses due to shade reduction.

Our use of a BACI study design enabled strong inference by causally linking treatments (shade reduction) to impacts (physical and biotic [SAA-focused] responses in instream and riparian habitats). We intentionally included a range of shade reduction treatments to establish a response curve to the gradient in shading.

We expanded on the knowledge base for several metrics included in the study. For example, our results informed us about post-treatment water temperature, macroinvertebrate, and SAA changes at a small reach scale in managed forest landscapes of western Washington and northwestern Oregon, where previous studies had addressed these features at larger scales. Our thinking was that if we could identify impacts at small reach size, all else being equal, they would likely be more evident at larger reach sizes. Additionally, our BACI study design expanded on the previous studies, most of which were retrospective, and as consequence, had less inferential strength.

We also expanded on the knowledge gained from other CMER studies, for example by supplementing the findings from the Hard Rock study by downsizing temperature and SAA responses from a basin- to a small reach-scale and coupling specific levels of shade reduction (measured as canopy cover) to specific levels of PAR.

We are more confident in our findings than some previous studies because we were able to utilize new technology and sampling generally not previously available to those studies, and because of the duration and/or intensity of sampling. For example, we used detection-corrected counts of amphibians for less biased estimates of abundance instead of 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:

<u>Stream Temperature:</u>

- The FPHCP does not define what a “small” temperature increase is, but average post-treatment increase was 2.2°C and 2.5°C in the Low and No Shade treatments, where the absolute 7DADM temperatures increased, respectively, to 16.0°C and 16.5°C. These treatments had canopy cover values that averaged, respectively, 61% ± 3 SE and 40% ± 4 SE. Given the rather small length of the reach (50 m), this mean temperature increase is impressive. Additionally, while confidence levels all exceeded the 0.3°C Tier II Antidegradation trigger value for needing to demonstrate the warming is necessary and in the overriding public interest, and seven reaches exceeded the 2.9°C allowance for all nonpoint sources combined, not all stream reaches in any treatment or regional block surpassed the annual summer maximum 7DADM temperature criteria assigned to those waters.
- The magnitude of the temperature increase in the Low Shade treatment is similar to that observed for the FP buffer in the Hard Rock study.

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

New rule tools or field method development.

- The enclosures we used are promising for selective monitoring of SAA larval stages, but need further evaluation for effectiveness. About two thirds of our enclosures had elevated temperatures. Temperature elevation was slight (in the 1ºC range), but enough to create a mismatch to actual stream temperatures and potentially slightly boost growth rates in the cool-temperature requiring SAAs. One should experiment with both different enclosure materials and greater perforation of enclosure walls to increase stream flow to limit or prevent enclosure temperature elevation. Second, we found larval torrent salamanders, especially the small size classes, capable escape artists. Juvenile torrent salamanders can use capillarity to adhere to smooth surfaces and are remarkably mobile on vertical and even inverted surfaces.

Experimentation with complex inverted lips to the enclosure that prevent capillary adhesion may solve this problem.

Research/monitoring suggestions.

- Contrasting the thermal profile of streams with varying groundwater versus surface water input is not currently a focal part of CMER's Work Plan though a ground water temperature interaction question does exist. We suspect it contributed to the variability in response in this study. Identification of streams dominated by surface water is likely to increase in importance because of the progression of climate change and the potential differential resource protection needs those streams may require. Policy should be encouraged to examine this issue.

Suggested rules/board manual sections to review/revise.

We concur with the suggestion from 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 Shade Study results and other current scientific research. Such a review would be appropriate once the studies outlined under the section labeled "What is the relationship between this study and any others that may be planned, underway, or recently completed?" are complete. They could propose changes to Performance Targets and/or new measures as appropriate. This recommendation is supported by 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 Performance Targets simply restate the prescriptions, so if harvest is rule compliant, the Performance Target will be met, at least immediately post-harvest.
- Schedule L-1 specifies that timelines for Performance Targets can be identified that are met within short, mid- and long-term time periods, a process that has not yet occurred, but likely critical for evaluating the effectiveness of rules through time.
- Performance Targets for some metrics are not yet developed. For example, 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 SAA population viability in occupied sub-basins for covered species. However, "viability" remains undefined and metrics for its evaluation are nowhere provided.

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

We discuss key aquatic Resource Objectives for metrics in our responses to questions 4 (*"What does the study tell us?"*) and 5 (*"How much of an incremental gain in understanding to the study results represent?"*).

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