Effectiveness of Experimental Riparian Buffers on Perennial Non-fish-bearing Streams on Competent Lithologies in Western Washington – Phase 3 (Fifteen Years after Harvest)

Executive Summary

Headwater streams are largely understudied relative to their frequency in the landscape, constituting approximately 65% of the total stream length on forestlands in western Washington. As a result, understanding how forest practices affect riparian ecosystems is critical. We evaluated the effectiveness of riparian forest management prescriptions in maintaining key aquatic conditions and processes affected by Forest Practices for small non-fish-bearing (Type N) headwater stream basins underlain by competent, "hard rock" lithologies (i.e., volcanic or igneous rocks) in western Washington ~~(see Chapter 1 – *Introduction* in this report)~~. We compared current prescriptions to two alternatives, one with longer riparian leave-tree buffers and one without buffers. The current effort is part of a long-term effectiveness study that evaluated ~~We looked at~~ the magnitude, direction (positive or negative), and duration of change for riparian-related inputs and response of instream and downstream components.

As a part of the broader, inclusive study, ~~W~~we evaluated riparian processes affecting in-channel wood recruitment and loading, stream temperature and shade, discharge, suspended sediment export, nutrient export, channel characteristics, and stable isotopes (McIntyre et al. 2018, 2021). To evaluate biological response, we selected stream-associated amphibians as a ~~key~~ response variable because they are one of the important biotic resources for protection in non-fish-bearing streams. The results of the study were intended to inform the efficacy of current Forest Practices

Commented [AM1]: Reviewers, this is new text. We previously indicated that we would draft the ES once reviewers commented. Now was a good time to add. Note that this is a copy and paste of relevant material from the Phase II ES. Any changes to what was in the Phase II are in track changes.

(FP) 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 Habitat Conservation Plan (FP HCP; Schedule L-1, Appendix N). More broadly, amphibians have experienced declines in local abundance and range contractions as a result of habitat loss and degradation, disease, and competition with introduced species. Stream-associated amphibians are frequently the dominant vertebrates in and along non-fish-bearing headwater streams.

In the current effort, we used the same Before-After Control-Impact (BACI) study design as in our prior efforts to examine how steam-associated amphibians responded to riparian buffer treatments. ~~Amphibians have experienced declines in local abundance and range contractions as a result of habitat loss and degradation, disease, and competition with introduced species. Stream-associated amphibians are frequently the dominant vertebrates in and along non-fish-bearing headwater streams.~~ We collected ~~a minimum of two~~three years of pre-harvest data from 2006 until harvest began in 2008, and post-harvest data in 2009 and 2010 (Post 1 & 2), 2015 and 2016 (Post 7 & 8), and 2022 and 2023 (Post 14 & 15) ~~from 2009 (one year post-harvest) through 2016 or 2017, depending on the response variable (i.e., up to nine years post-harvest; see Chapter 2 – *Study Design* in this report)~~. Study sites included 17 Type N stream basins located in managed second-growth conifer forests across western Washington in three physiographic regions (Olympic Mountains, Willapa Hills and Southern Cascades). Sites were restricted to Type N basins ranging from 12 to 54 ha (30 to 133 ac) underlain by relatively competent lithologies, primarily volcanic flow rocks and breccias, and that were known to support Coastal Tailed Frog (*Ascaphus truei*) and Olympic, Columbia, or Cascade Torrent Salamanders (*Rhyacotriton olympicus*, *R. kezeri*, or *R. cascadae*).

We evaluated four experimental treatments, including an unharvested **Reference** (i.e., withheld from harvest~~; n = 6~~) and three alternative riparian buffer treatments with clearcut harvest: **100% treatment** (a two-sided 50-ft [15.2-m] riparian buffer along the entire Riparian Management Zone [RMZ~~; n = 4~~]); **FP treatment** (a two-sided 50-ft [15.2-m] riparian buffer along at least 50% of the RMZ, consistent with the current Forest Practices buffer prescription for Type N streams [n = 3]); and **0% treatment** (clearcut harvest throughout the entire RMZ~~ [n = 4]~~). The timber harvests and associated riparian buffer treatments were implemented between October 2008 and August 2009.

In the two years post-harvest we estimated an increase in larval Coastal Tailed Frog density in the FP treatment compared to the pre-harvest period, after controlling for temporal changes in the reference; however, ~~by~~ seven and eight years post-harvest we estimated substantial declines in larval density in all buffer treatments that further declined 14 and 15 years post-harvest. In the two years post-harvest, post-metamorphic tailed frog density declined in the 100% treatment but increased in the 0% treatment. However, ~~by~~ seven and eight years post-harvest we again estimated substantial declines in density in the 100% and FP treatments, whereas the change in density in the 0% treatment no longer differed from that of the reference. ~~-~~Fourteen and 15 years post-harvest, we estimated a strong decline in all buffer treatments relative to the reference, but that change was largely driven by an estimated increase in post-metamorphic tailed frog density in the reference. We estimated an increase in torrent salamander density in ~~the 0%~~all buffer treatments in the two years post-harvest~~; by~~. However, seven and eight years post-harvest ~~this the~~ increases ~~was~~ were no longer evident in ~~the 0%~~any of the buffer treatments~~ although we~~

~~estimated a decline in the FP treatment relative to the 100% treatment~~. Fourteen and 15 years post-harvest, we estimated a decline in torrent salamander density in the FP and 0% treatments. Finally, for giant salamanders we estimated a~~n~~ ~~initial~~ decline in density in the FP treatment that persisted into 14 and 15 years post-harvest. ~~in the two years post-harvest, however, by eight years post-harvest we had no evidence of a difference for any treatment. Our~~ We note that the study was designed to evaluate treatment effects, not the mechanisms behind potential changes in amphibian ~~abundance~~densities. However, stream temperature, overstory canopy, wood loading, sediment retention, flow dynamics, stream morphology, and nutrients all have been associated with amphibian ~~abundance~~densities, and the changes we documented in these metrics following timber harvest (McIntyre et al., 2018, 2021) ~~likely explain some or all~~many ~~of the~~are likely associated with changes we observed in amphibian ~~abundances~~densities. Our results to date provide evidence of a negative and sustained effect of timber harvest on stream-associated amphibians in harvest units located on hard rock lithologies. However, without a landscape effort to evaluate occupancy throughout western Washington, we are unable to evaluate the long-term consequences at broader spatial scales. Understanding landscape trends would complement our understanding of FP-designated amphibian response at the scale of a single Type N basin.

Introduction

Washington State enacted the Forests and Fish Law in July 2001 (WFPB, 2001). This ~~law~~law was largely motivated by the listing, and potential further listings, of salmon in Washington State under the federal Endangered Species Act (ESA; US Fish and Wildlife Service, USFWS 1999), and the hundreds of stream segments with compromised water quality under the §303(d) of the federal Clean Water Act (CWA).The Forests and Fish Law, negotiated among federal, state, tribal and county governments, and private forest landowners, was intended to improve and increase protection of riparian habitat on non-federal forestlands in Washington State (hereafter, Forest Practices rules; USFWS 1999). Forest Practices rules were designed to meet four Performance Goals: (1) provide compliance with the ESA for aquatic and riparian-dependent species; (2) restore and maintain riparian habitat to support a harvestable supply of fish; (3) meet the requirements of the CWA for water quality, and; (4) keep the timber industry economically viable in the state of Washington.

At the time of Forest Practices negotiations, few studies had addressed the efficacy of riparian buffers along non-fish-bearing, perennial “headwater” streams (or Type Np Waters), which comprise more than 65% of the total stream length on forestlands in western Washington (Rogers & Cooke, 2007). Furthermore, ~~existing~~ previous studies tend~~ed~~ to be retrospective (e.g., Bisson et al., 1996; Raphael et al., 2002) or lack the statistical power needed to ~~fully~~ inform whether Forest Practices ~~for effects on~~affect aquatic resources of interest (e.g., Jackson et al., 2001; O'Connell et al., 2000). The objective of the Type N Experimental Buffer Treatment Study in Hard Rock Lithologies (hereafter, Hard Rock Study) was to evaluate the effectiveness of the ~~current~~ westside riparian management zone (RMZ) rules for Type Np Waters in maintaining key aquatic conditions and processes affected by Forest Practices. This study was intended to address the key question (WADNR, 2006, FPHCP, Appendix N):

Commented [S(2]: From Joe: Revise to say increase protection of, there were already protections of riparian in place in 1999 when the law was passed.

Commented [RO3R2]: Added increased protection.

Commented [HB4]: The should be verbatim from FFLaw. May be include the RCW reference.

Commented [RO5R4]: Since this is a green comment, and we heard from a different reviewer that they wanted specific text, I used their suggestion. Since the RCW is pretty long, I am not sure exactly what you are after. “to be managed consistent with sound policies of natural resource protection “ is one quote that meets a similar intent, but I will go with Joe’s suggestion for now.

Commented [Q(6]: is it statistical power of study design?

Commented [RO7R6]: Accepted edit

Commented [Q(8]: what is a key aquatic conditions and processes.

Commented [AM9R8]: This is verbatim from Schedule L1. We are not going to rewrite or define.

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? [1]

In the Hard Rock Study, we compared unharvested references to the current Forest Practices buffer prescription (FP treatment) and to experimental treatments that did not retain a riparian buffer in the RMZ (0% treatment) and that retained a riparian buffer throughout the entire RMZ (100% treatment). We provided information relevant to evaluating whether these riparian buffer prescriptions met the Performance Goals to provide compliance with the ESA for aquatic and riparian-dependent species and met the requirements of the CWA for water quality. We also evaluated whether buffer prescriptions met the Resource Objectives (i.e., key aquatic conditions and processes affected by Forest Practices) for large wood inputs, organic inputs, and hydrology from the Forest Practices Habitat Conservation Plan (FPHCP; WADNR, 2006, Appendix N). In addition, we provided methods and data needed by the Washington State Department of Ecology to help determine compliance with water quality standards. The study commenced in 2006 and included up to three years of pre-harvest data collection (depending on the response variable). Treatment implementation occurred over~~s were implemented~~ over a period of 14 months~~.~~ in 2008 and 2009. Post-harvest data were collected for up to ~~nine~~ 15 years following harvest. Post-harvest sampling frequency and duration depended on the response variable. Results for Phase I of the study, comparing the response among treatments up to three years following harvest, were reported in McIntyre ~~and colleagues~~et al. (2018). Results for the Phase II of the study, comparing the response among treatments up to 11 years following harvest, were reported in McIntyre et al. (2021).

Amphibians are often considered among the vertebrate groups most susceptible to environmental modification. ~~and, because of their~~Due to limited dispersal abilities, dual life histories, and explicit microhabitat and physiological requirements (Lawler et al., 2010), they are frequently preferred for monitoring environmental conditions (Wake, 1991; Welsh & Ollivier, 1998). Worldwide ~~A~~amphibian populations are declining in local abundance and demonstrating range contractions because of disease, competition with introduced species, ~~and~~ habitat degradation and conversion, and sensitivity to climate change effects including increased temperatures and duration and severity of droughts ~~-~~(Sparling et al., 2001; Stuart et al., 2004).

Pacific Northwest headwater streams support stream-associated amphibians ~~abundances that arepopulations that are more abundant~~in greater abundances than ~~those found greater than~~ in larger, fish-bearing river systems (see Richardson & Danehy, 2007). ~~. Fish densities decline in smaller streams, offering amphibians a refuge from fish predators common in higher-order streams (Richardson & Danehy, 2007). In fact,Also, stream-associated amphibians often~~ replacinge fish as the dominant vertebrate predators in these systems ~~in and along headwater streams~~ (Burton & Likens, 1975; Bury et al., 1991). In fact, amphibians ~~and~~ may be up to ~~. In headwaters of the Pacific Northwest, aquatic amphibians are estimated to be~~ ten times more

[1] Each Resource Objective consists of (1) a Functional Objective, or broad statement of objectives for the major watershed functions potentially affected by Forest Practices, and (2) a series of Performance Targets, or measurable criteria defining specific, attainable target forest conditions and processes.

Commented [S(10]: From Joe Murray: Resource objectives and performance targets should be stated here in the document.

Commented [OBRA(11R10]: I don't think it makes sense to do a copy and paste of schedule L-1 into this document because it will decrease the readability. I think we should maintain the reference to it that Qui ...

Commented [S(12]: From Joe Murray: There is no footnote at the bottom of the ...

Commented [AM13R12]: I see a footnote...

Commented [Q(14]: really need a figure here showing treatments

Commented [AM15R14]: Figure 1 shows the treatments. Added reference.

Commented [HB16]: I don't think that all the amphibs are listed under the ESA. I ...

Commented [AM17R16]: It is ESA compliance under the HCP.

Commented [S(18]: From Joe Murray: What are the response variables?

Commented [RO19R18]: In this report it is just amphibians. Phase I and II has a ...

Commented [S(20]: From Joe Murray: What are the response variables?

Commented [RO21R20]: In this report it is just amphibians. Phase I and II has a ...

Commented [AJK22]: I suggest a couple of citations from the last 5-8 years and not ...

Commented [RO23R22]: Wes, take a crack at this one. We could probably add ...

Commented [AJK24R22]: That works…3-4 citations across the last 15-20 ...

Commented [WB25R22]: Review.

Commented [Q(26]: densities per sq meter? stream lenght, need units

Commented [RO27R26]: This is a broad statement in the introduction and ...

abundant than salmonid fishes in headwater streams (Bury et al., 1991). Stream-associated amphibian species may be uniquely adapted to the physical conditions of headwater streams (Kiffney et al., 2003) such ~~. Some of the specific headwater habitat attributes important to amphibians, such~~ as substrate composition (Dupuis & Steventon, 1999; Grialou et al., 2000; Stoddard & Hayes, 2005) and ~~water~~stream temperature (Bury, 2008; Pollett et al., 2010). Stream-associated amphibians may be particularly predisposed to large variations in population size or local extirpation because of disturbance, including timber harvest (Sparling et al., 2001; Stuart et al., 2004). Although the inferential quality of published studies varies, stream-associated amphibians may respond negatively to forest practices (Kroll 2008). ~~, are affected by~~ T~~t~~imber harvest and associated activities (Araujo et al., 2013; Grizzel & Wolff, 1998; Jackson et al., 2001; Janisch et al., 2012; Johnson & Jones, 2000; Moore et al., 2005) can modify abiotic ~~and~~ components of headwater streams. ~~Stream-associated amphibians may be particularly predisposed to large variations in population size or local extirpation because of disturbance, including timber harvest (Bury & Corn, 1988; Fagan, 2002).~~ Once extirpated, opportunities for recolonization from adjacent headwater streams may be restricted by larger channels in downstream reaches (Lowe & Bolger, 2002; Richardson & Danehy, 2007) or gaps in overhead canopy (Cecala et al., 2014) that form barriers to dispersal due to unfavorable physical conditions.

~~For example,~~ Corn and Bury (1989) found that Coastal Tailed Frogs occurred with higher frequency in unlogged watersheds. Steele et al. (2003) reported reduced numbers of Cascade Torrent Salamander (*Rhyacotriton cascadae*) in young forests (i.e., recent clearcuts to 24-year old) compared with mature forests (i.e., 25 to 60 years old). Jackson et al. (2007) found that giant salamander and Coastal Tailed Frog populations declined in the several years immediately following timber harvest. Olson and Ares (2022) found reduced densities of giant and torrent salamanders five years after a second forest thinning. Conversely, others have not detected a correlation between amphibian abundance and forestry activities, including for Coastal Giant Salamander and Coastal Tailed Frog (Murphy & Hall, 1981; O'Connell et al., 2000).

One of three Overall Performance Goals for the Forest Practices Habitat Conservation Plan (FPHCP) is to support the long-term viability of designated stream-associated amphibians, including Coastal Tailed Frog (*Ascaphus truei*); and Olympic (*Rhyacotriton olympicus*), Columbia (*R. kezeri*) and Cascade (*R. cascadae*) Torrent Salamanders (hereafter, FP-designated amphibians; Schedule L-1). ~~One~~ A Resource Objective under the Type N Riparian Prescription Rule Group is to "P~~p~~rovide conditions that sustain SAA (i.e., stream-associated ~~FP-designated~~ amphibian) population viability within occupied sub-basins" (CMER Work Plan 2025).

Though the ~~original study~~Phase I effort included ~~supported~~ only two years of post-harvest sampling, ~~significant~~ the responses to harvest for some variables (e.g., stream temperature) led the Forest Practices Board to support continued post-harvest monitoring beyond those two years~~.~~ in a Phase II effort. ~~Continued monitoring in~~ Phase II monitoring allowed ~~us to~~ evaluation of~~e~~ response variable trajectories over a longer time post-harvest and provided the opportunity to detect ~~of response variables~~ trends in responses. ~~including those that that changed immediately after harvest, such as for~~ ~~e.g.,~~ ~~stream temperature, and those that to detect potential lag effects for those for which a significant did not change response was not detected in the two years following harvest (e.g., stream-associated amphibians).~~ ~~Results through nine years post-harvest are reported herein.~~

Commented [Q(28]: gaps in overhead canopy work how? heat? light? or what

Commented [WB29R28]: Agreed, please expand, maybe directly call out large clearcut areas if that is the case.

Commented [AM30R28]: The study cited did not evaluate the mechanism for the difference only that movement was less across gaps in canopy.

Commented [Q(31]: better define what we mean by population viability.

Commented [AM32R31]: This is from Schedule L1 and the CMER Work Plan. We have been advocating for consideration of what this means for 20 years but it is not up to us as authors of this report to define "long-term" or "viability" in context of the AMP. As such, all we can do is convey the performance goals and provide the study results.

Commented [RO33]: Is this Schedule L-2 or CMER workplan? Would be good to cite this since it is not Schedule L1.

Commented [RO34R33]: Viable population – A population that is of sufficient size and distribution to be able to persist for a long period of time in the face of demographic variations, random events that influence the genetic composition of the population, and fluctuations in environmental conditions, including some catastrophic events.

Results from Phase II ~~suggested~~ indicated a ~~delayed~~ decline in larval Coastal Tailed Frog densities (-65% to -93%) 7- and 8-years post-harvest in the 100%, FP and 0% treatments that were not apparent ~~in the~~ 2-years~~two years~~ post-harvest (i.e., Phase I). ~~There was also a~~Also, we estimated a ~~delayed~~ negative response for torrent salamanders ~~estimated~~ in the FP treatment (-65%) ~~.~~that was not apparent 2-years post-harvest. In response to the Phase II amphibian results, the Adaptive Management Program supported monitoring to evaluate continued trends in stream-associated amphibian densities through 15-years post-harvest. This Phase III effort ~~inform~~ provides information about spatial and temporal variation in ~~whether~~ amphibian densities across the study sites. ~~at study sites stabilized, continued to decline, or recovered over time.~~

~~Despite the fact that~~Although ~~Though~~ Coastal and Cope's Giant Salamanders (*Dicamptodon tenebrosus* and *D. copei*, respectively) are not FP-designated amphibians, we included them in our study. We included ~~because~~ Cope's Giant Salamander because it is one of only two ~~is one of only two~~ instream-breeding amphibian species distributed throughout our entire study area, and thus an important part of the ~~and, for this reason, was included in the amphibian~~ genetics component of the study (Spear et al., 2011; Spear et al., 2019); we included ~~Furthermore,~~ ~~Since Cope's a~~e~~nd C~~Coastal Giant Salamanders ~~were included~~ because ~~they are~~it is ~~it is are extremely~~ difficult to differentiate from Cope's Giant ~~Salmander~~Salamander in the field (Foster & Olson, 2014; Good, 1989; Nussbaum, 1970, 1976)~~, and hybridization is known to occur (Spear et al., 2011; Spear et al., 2019), so Coastal Giant Salamander had to be included by defaul~~. ~~we included both species.~~ ~~Like~~Similar to the other FP-designated amphibians, changes in giant salamander populations may reflect changes in the environment.

~~There is substantial~~Substantial uncertainty exists regarding the effectiveness of the FPHCP buffer strategy for Type Np streams ~~as it relates~~ ~~relative~~ ~~to impacts on the~~for maintaining stream-associated ~~amphibians~~amphibian populations. To address ~~these uncertainties,~~ this question, we used a basin-scale approach to compare changes in stream-associated amphibian densities ~~and body condition~~ in response to ~~buffering strategies that varied in proportion of stream length buffered eight years post-harvest. Treatments~~ clearcut timber harvest with alternative riparian buffer treatments: ~~including~~ no buffering (0% treatment), partial buffering using the FPHCP prescription (FP treatment), and complete buffering (100% treatment). Though Phase I and Phase II efforts included genetic and ~~We also evaluated the response of Coastal Tailed Frog and Cope's and Coastal Giant Salamander genetics. Genetic~~ stable isotope monitoring ~~provides a complementary approach~~ to complement our demographic monitoring, ~~and can provide additional information on a population's~~the current Phase III effort included only an evaluation of stream-associated amphibian demographic response to ~~disturbance.~~ treatment.

Commented [HB35]: Please include the statistical significance of these estimates.

Commented [RO36R35]: The Bayesian statistics used to generate these estimates do not produce p-values so there is no threshold of statistical significance. The closets analog to statistical significance is the credibility intervals and the fact that they do not overlap a 0% change which suggests that there is a meaning difference and high confidence in the direction of that difference.

Commented [JM37]: How did the removal of slash from the streams to inventory amphibians influence populations?

Commented [AK38R37]: How would this possibility be ascertained?

Commented [RO39R37]: Slash sampling had a very small footprint in our basin and slash was returned to the stream after it was removed. I agree our study is not designed to answer this question and the introduction is not really the place to get at this kind of thing.

Commented [DM40]: Red

If you are using "population viability" as your metric for assessing effectiveness, yo ...

Commented [AM41R40]: This is from Schedule L1 and the CMER Work Plan. We have been advocating for consideration of ...

Commented [DM42R40]: I understand, but the reader expects you will address viability given the way this is worded. ...

Commented [AJK43R40]: Or…just use the word persistence.

Commented [AM44R40]: See our edits.

Commented [Q(45]: this is repetitive with material above and provides a clearer verbal definition of treatment types

Commented [AM46R45]: Since we are relying on previously approved language above, we will leave as is.

Methods

Study Sites

Site Selection

The inclusion of stream-associated amphibian species as a response variable placed important constraints on site selection for the Hard Rock Study (**Table 1**). Six of the seven Forest Practices (FP)-designated amphibians occur exclusively (n = 5) or largely (n = 1) in westside forestlands of Washington State. We selected sites in western Washington that supported Coastal Tailed Frog (*Ascaphus truei*) and Olympic, Columbia, and Cascade Torrent Salamanders (*Rhyacotriton olympicus*, *R. kezeri*, and *R. cascadae*).[2] Although Coastal (*Dicamptodon tenebrosus*) and Cope's (*D. copei*) Giant Salamanders are not FP-designated amphibians, we included them in the study because they co-occur with FP-designated species throughout the study area and Cope's Giant Salamander, along with the Coastal Tailed Frog, were appropriate for evaluating amphibian genetic responses (Spear et al., 2019). The site selection process is outlined elsewhere (McIntyre et al. 2009).

We limited site selection to the three westside physiographic regions with the greatest number of FP-designated amphibians (Olympic Mountains, Willapa Hills and Southern Cascades south of the Cowlitz River; Jones et al., 2005). We limited sites to those less than 1,067 m (3,500 ft) and 1,219 m (4,000 ft) elevation in the Olympic and South Cascade physiographic regions, respectively, because FP-designated amphibians rarely occur above 1,219 m (4,000 ft) elevation in Washington State and the upper elevation limit declines with increasing latitude (Dvornich et al., 1997). We did not impose an upper elevation limit in the Willapa Hills because the maximum elevation (Boisfort Peak: 948 m [3,110 ft]) is within the range of all amphibian species. We limited sites to those with a slope between 5% and 50% (3 and 27 degrees) that encompasses the range of stream gradients within which FP-designated amphibians are typically found (Adams & Bury, 2002). We included only sites composed of competent lithology, or those that could potentially be competent depending on weathering and age (as identified by Patrick Pringle, formerly with WADNR), because some FP-designated amphibians tend to occur more frequently on these types of lithology (Dupuis et al., 2000; Wilkins & Peterson, 2000). Finally, since Coastal Tailed Frogs rarely reproduce in small first-order basins in western Washington (Hayes et al., 2006), we restricted site selection to include second-order streams (Strahler, 1952). However, we later relaxed the stream order criteria to include first- to third-order streams to obtain the desired number of study sites.

To maximize the influence of the buffer treatments and to reduce confounding effects, we designed the study so that harvest units would encompass the entire Type N basin when possible. We also wanted harvest unit size to represent operational forest practices (McIntyre et al., 2009). Interviews with landowners revealed that the typical minimum unit size was about 12 ha (30 ac);

Commented [HB47]: Were the stream order sites balanced among treatments? For example were there more third-order reaches at the FP treatments sites than the REF sites. Would this make any difference for any of the species, If so, please discuss in Discussion/Conclusions.

Commented [RO48R47]: We added stream order to table 2. Thanks,

Commented [JM49]: Most basins are harvested with more than one entry. Perhaps you should say that.

Commented [AJK50R49]: We are describing what was done to implement the treatments here. Multiple entries were not required to harvest the individual units.

[2] The remaining three Forest Practices-designated amphibians not covered in our study include the Rocky Mountain Tailed Frog (*A. montanus*), and Dunn's (*Plethodon dunni*) and Van Dyke's (*P. vandykei*) Salamanders. Rocky Mountain Tailed Frog could not be included because it occurs exclusively in southeastern Washington, an area not included in our study. The two plethodons were not included because they breed and lay eggs on land, and have no free-living (i.e., aquatic) larval stage. Thus, they require different sampling techniques than the focal species in this study.

maximum harvest unit size is limited by Forest Practices to 49 ha (120 ac; WFPB, 2001). Thus, sites were limited to basins within that range.[3] Subsequently, we relaxed the criterion to include basins up to 54 ha (133 ac) to obtain the desired number of study sites. ~~To ensure that downstream fish response[4] was not confounded by other management activities, we required at least 75 m (246 ft) of stream below the upstream extent of fish distribution (F/N break) that lacked an incoming tributary.~~

Inclusion of study sites relied on commitments that landowners manage them according to treatment specifications (i.e., harvest layout and timing). We requested that landowners commit to completing timber harvest and associated buffer treatments between April 2008 through March 2009. We limited sites to those with at least 70% of the basin area with stands between 30 and 80 years of age at the time of harvest, because the average minimum stand age at the time of clearcut harvest is 30 years and harvest of stands over 80 years is infrequent in Washington State. Finally, because multiple ownership of the same study site would greatly complicate the coordination and implementation of treatments, we limited sites to those for which more than 80% of the Type N basin had a single landowner.

Selection of study sites began in June 2004 and continued through August 2006. We used a Geographic Information System (GIS) in ArcMap (ESRI, 2004) to identify Type Np basins meeting geographic range, elevation, stream gradient, lithology and stream order site selection criteria (see McIntyre et al. 2009). We conducted on-site surveys to validate lithology type, stream gradient and stand age. For those meeting site selection criteria, we conducted surveys to establish amphibian occupancy. On-site electrofishing surveys were conducted between December 2005 and June 2006 to verify the location of the F/N break (WFPB, 2002). Field surveys revealed inaccuracies in the hydrology layer used to determine stream order, so we relaxed our criteria to include a few first- and third-order sites for which we had already determined FP-designated amphibian presence.

Table 1. Site selection criteria and associated limits by category for the Hard Rock Study, 2004–2006.

Category	**Criterion**	**Limit**
FP-designated amphibian presence	Geographic range	Olympic Mountains, Willapa Hills, and South Cascade south of the Cowlitz River physiographic regions of Washington State
	Elevation	<1,067 m (3,500 ft) for the Olympic region
		<1,219 m (4,000 ft) for the South Cascade region
		No limit for the Willapa Hills region
	Stream gradient	5–50% (3–27 degrees)

[3] Unless an exception is granted after review by an interdisciplinary science team.
~~[4] Downstream fish response was only included through the two years following harvest and included only 6 of the 17 study sites. Results are reported in McIntyre et al. 2018.~~

Commented [JM51]: Commercial thinning is a harvest. On high site ground stands are thinned at 25 years of age. This is especially true if a stand was pre commercially thinned at a young age.

Commented [RO52R51]: Good point. I added text to clarify that the 30 year mark is when clearcut harvest starts which is the type of harvest that was implemented here. This should help reduce confusion around commercial thinning.

Commented [HB53]: Kroll et al, 2008 found a relationship between frog occupancy and stand age. If occupancy was affected then density could have been. Did all of the treatment sites have similar stand ages. Please discuss in discussions/conclusions

Commented [AK54R53]: Technical reports do not include discussions of every possible factor that may have been associated with estimated responses.

The analysis includes a site-specifc random effect, which accounts for variation among harvest units not captured by the main treatment effects.

Commented [JM55]: So were these basins completely harvested as stated above?

Commented [RO56R55]: This is now addressed in a new table 3 that provides more information about the harvest and buffers at the study sites.

Category	Criterion	Limit
	Lithology	Competent (or any lithology that could potentially be competent, i.e., potentially producing long-lasting large clasts or coarse grain sizes)
	Stream order	Second-order stream basins
Fish presence	Stream network	Minimum of 75 m (246 ft) of stream between the F/N break and nearest downstream tributary intersection
Landowner/operational considerations	Type N basin size	12–49 ha (30–120 ac)
	Stand age	30–80 years old
	Harvest timing	Buffer treatments: harvest Apr 2008–Mar 2009; References: no harvest
	Area owned	>80% owned by single landowner

Experimental Treatments

We established four treatments: three buffer treatments with clearcut harvest and riparian buffers of variable length, and a reference (i.e., control) with no timber harvest (**Table 2; Figure 1**):

1) **Reference** (REF~~, n = 6~~): unharvested reference with no timber harvest activities within the entire study site during the study period,

2) **100% treatment** (100%~~, n = 4~~): clearcut harvest with a no-harvest riparian leave-tree buffer (i.e., two-sided 50-ft [15.2-m]) throughout the RMZ,

3) **Forest Practices treatment** (FP~~, n = 3~~): clearcut harvest with current Forest Practices no-harvest riparian leave-tree buffer (i.e., two-sided 50-ft [15.2-m]) along ≥50% of the RMZ, and

4) **0% treatment** (0%~~, n = 4~~): clearcut harvest with no riparian leave-tree buffer retained within the RMZ.

Table 2. Sample size of each treatment by period and reporting phase. Phase I - McIntyre et al. 2018, Phase II - McIntyre et al. 2021, Phase III – this report.

Treatment Code	Sample size in Phase I & II	Sample size in Phase II	Sample size in Phase III		
	Post 1 & 2	Post 7 & 8	Post 1 & 2	Post 7 & 8	Post 14 & 15
REF	6	6	6	6	3
100%	4	4	4	4	4
FP	3	3	4	4	3
0%	4	4	4	4	4

Commented [HB57]: Please don't delete these because they indicate the strength of inferences.

Commented [RO58R57]: Added a new table to help convey sample size across the study.

Commented [JM59]: Why remove the n-number of sites. It helps the reader know the sample size.

Commented [AM60R59]: Because the number of sites in the various categories changed through time (e.g., FP treatment that was a reference until the current report period). Adding N here is misleading, the reader must refer to the greater description provided below.

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Commented [RO61]: Wes, table formats are not quite right. Check Phase 2 report for example (remove vertical lines).

Clearcut harvest was applied throughout the Type Np basin in sites with a riparian buffer treatment and, except for the length of the riparian buffer in the RMZ, harvest followed Forest Practices rules. Buffer width of 50 ft (15.2 m) is the horizontal distance from the bankfull channel. In all treatments, a 30-ft (9.1-m) equipment limitation zone (ELZ) was maintained along all Type Np and Ns (i.e., seasonal) Waters (WAC 222-30-021(2)), and no harvest activities were conducted on any potentially unstable slopes (WAC 222-16-050 (1)(d)). In the 100% and FP treatment sites, RMZ buffers were required for the five categories of sensitive sites WAC 222-16-010): side-slope[5] and headwall[6] seeps, headwater springs[7], Type Np intersections[8] and alluvial fans[9]. Riparian buffers on headwall and side-slope seeps require a 50-ft (15.2-m) no-harvest buffer around the outer perimeter of the perennially saturated area. Riparian buffers on Type Np intersections and headwater springs require a 56-ft (17.1-m) radius no-harvest buffer centered on the feature. No harvest is allowed within alluvial fans.

We identified all Type Np and Ns Waters and the locations of all sensitive sites according to Forests and Fish rules. All features were mapped in the field using Trimble Global Positioning Systems (GPS), which were differentially corrected using Pathfinder Office software and integrated into GIS (ArcMap).

The buffered length of the streams in FP treatment sites was determined by FP rules, which require a two-sided, 50-ft (15-m) wide buffer along a minimum of 50% of the length of the Type Np stream. Non-fish-bearing streams <1,000 ft (305 m) and ≥1,000 ft require a minimum of 300-ft (91-m) and 500-ft (152-m) length riparian buffer, respectively, located directly upstream of the F/N break, with additional riparian buffers centered on sensitive sites. All study sites were ≥1,000 ft (305 m), requiring a minimum 500-ft (152-m) length buffer. The configuration of the riparian buffer on a Type Np Water is subject to stream dendritic patterns and the number and location of sensitive sites. To determine the configuration at our sites, we located sensitive sites in the field 12 June to 1 November 2006. The application of FP rules at the four FP treatment sites resulted in riparian buffer lengths of 55%, 62%,73% and 97%. In addition, due to regulatory and/or logistic constraints (e.g., buffers required on unstable slopes and downstream fish-bearing waters), 2 to 15% of the basin area was not harvested in four riparian buffer treatment sites (specifically, OLYM-100%, WIL-100%-1, WIL-0%-2, and CASC-0%).

Commented [JM62]: Good.

Commented [HB63]: There were three treatments and I see four %s. Could one be the REF? If so, indicate such and discuss the possible effects of the different lengths on results

Commented [RO64R63]: Good catch Harry! There are 4 FP sites in this phase of the study because one of the references was harvested under FP rules. We corrected the oversight.

Commented [HB65]: If % harvested effects responses, and the higher % harvested sites cause increased responses, the FP sites have a relative headwind compared to the 100% & 0% treatments. Thia should be acknowledged and discussed in the discussion and conclusions.

Commented [AJK66R65]: This type of variation is incorporated in the statistical models for the giant and torrent salamanders.

[5] A seep with perennial water at or near the surface throughout the year, located within 100 ft (30.5 m) of a Type Np Water, on side-slopes greater than 20%, connected to the stream channel via overland flow, and characterized by loose substrate and fractured bedrock, excluding muck.
[6] A seep with perennial water at or near the surface throughout the year, located at the toe of a cliff or other steep topographical feature at the head of a Type Np Water, connected to the stream channel via overland flow and characterized by loose substrate and/or fractured bedrock.
[7] A permanent spring at the head of a perennial channel and coinciding at the uppermost extent of perennial flow.
[8] The intersection of two or more Type Np Waters.
[9] An erosional landform consisting of a cone-shaped deposit of water-borne, often coarse-sized, sediments.

Site Identification and Blocking

Though 35,957 Type Np basins were identified within our geographic scope of interest (Olympic Mountains, Willapa Hills and Southern Cascades physiographic regions), only 17 basins remained for inclusion in our study after selection criteria were applied and landowner and timber harvest constraints were considered. Sites consisted of first-, second- and third-order Type Np stream basins located in managed second-growth forests on private, state, and federal forestlands across western Washington. Stands were 30 to 80 years old and dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). Sites were in areas dominated by competent lithology types (largely basaltic) with average Type Np channel gradients ranging from 14 to 34% and catchment areas ranging from 12 to 54 ha (30 to 133 ac). Cumulative stream lengths ranged from 325 to 2,737 m (1,066 to 8,980 ft; **Table 3**). Sites were located along tributaries of the Clearwater, Humptulips and Wishkah Rivers in the Olympic physiographic region (n = 4); the North, Willapa, Nemah, Grays, and Skamokawa Rivers, and Smith Creek in the Willapa Hills physiographic region (n = 10); and the Washougal River and Trout Creek in the South Cascade physiographic region (n = 3; **Figure 2**).

Commented [JM67]: This is a very small sample of hand picked sites. It appears unlikely that the study captured the variability across the landscape in the geographic scope of interest.

Commented [RO68R67]: The site selection criteria are accurately stated and include sites across geographic regions. Sample sizes are also clearly stated.

Commented [AJK69R67]: The study plan was reviewed by ISPR and approved by CMER. We are past the point of objecting to how sites were identified and which populations they may or may not be representative of.

Commented [JM70]: Were some of these forests third growth?

Commented [RO71R70]: Could we say re-growth? I am not sure we know the full harvest history of all the sites, but third growth seems possible.

Commented [AJK72R70]: None of the sites had been harvested twice previously.

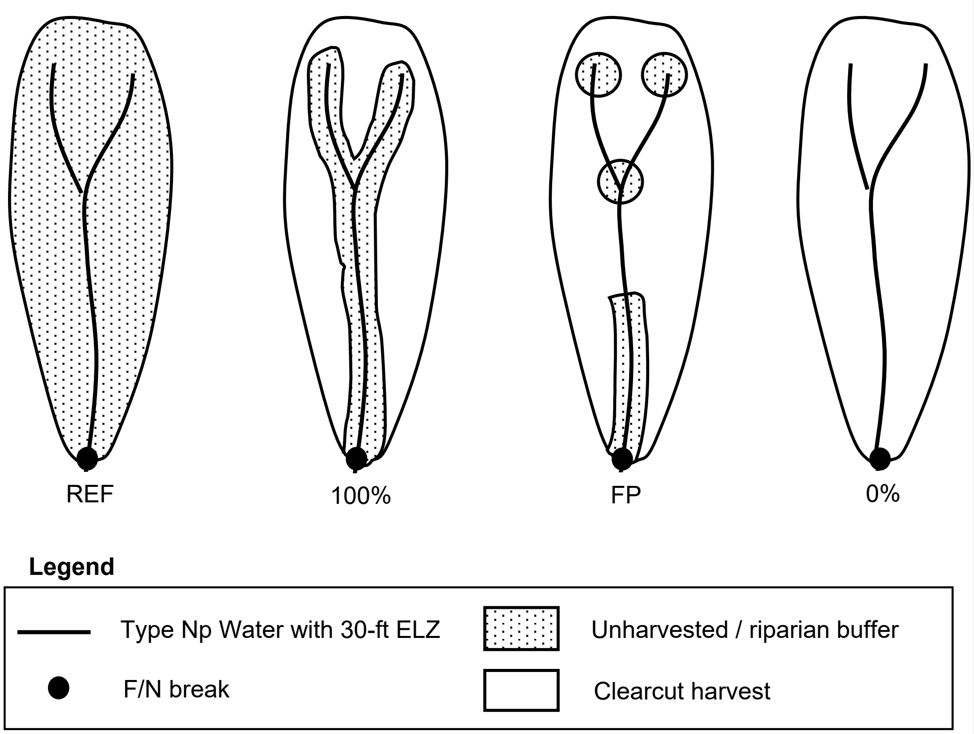

Figure 1. Schematic of the four experimental treatments included in the Hard Rock Study.

Treatments included unharvested references (REF) and sites receiving a clearcut harvest with one of three, two-sided 50-ft (15.2 m) buffer treatments along the Type Np Water riparian management zone (RMZ): 100% of the stream length buffered (100%), ≥50% of the stream length buffered (Forest Practice, FP), and no buffer (0%). FP and 100% treatments include 56-ft (17.1-m) radius buffers around Type Np intersections and the uppermost extent of perennial flow. All streams are protected by a two-sided 30-ft (9.1-m) equipment limitation zone (ELZ).

We blocked (grouped) study sites geographically within each physiographic region (i.e., Olympic, Willapa Hills, and South Cascade) to account for spatial variability (e.g., regional differences) and assigned sites within each block to one of the four treatments. In the Phase I and Phase II analyses, we included five blocks: one block in the Olympics, three blocks in the Willapa Hills, and one block in the South Cascades. Under the original study design, the intent was to have each of the four treatments (i.e., three buffer treatments and unharvested reference) represented in each block. However, in application this did not work as designed (see McIntyre et al. 2018 for details). Nonetheless, we ~~originally~~ randomly assigned treatments when possible based on the premise of one treatment per each of the five proposed study blocks. In practice, we ended up with some incomplete blocks and some blocks with more than one treatment type represented. As such, in the current analysis, we ~~simplified the~~consolidated sites in blocks~~blocking~~ ~~to be based on~~by physiographic region ~~only~~ to control for regional variation, including the fact that the three species of torrent salamanders are distributed regionally, with distributions that do not overlap ~~between regions~~ (**Table 3**). Study site codes used throughout this report are based on the geographic block and treatment.

Although ~~original~~ treatment assignment occurred at random when possible, we were unable to assign some treatments to particular sites. For example, unharvested references were assigned only to public ownership lands because private landowners would not agree to exclude sites from harvest for the duration of the study. Conversely, federal regulations prevented application of buffer treatments on National Forest sites. As a result, only state forestlands (Washington Department of Natural Resources) were available for the full complement of treatment assignments.

Given these constraints, we randomized treatment assignments within blocks to the extent possible, as follows:

Olympic (~~N~~n = 4): Treatments were randomly assigned to the four sites in this physiographic region, yielding a single a block with one each of the four treatments (OLYM). Riparian buffer treatments were implemented in accordance with the Study Plan and on schedule.

Willapa Hills (n~~N~~ = 3): Ten sites were available in the Willapa Hills region. Eight were distributed across the coastal region; two were located south and east of these. Not all sites in what is now the Willapa Hills (WIL) Block were randomly assigned to a treatment as landowner and other study considerations restricted specific site by treatment combinations (see McIntyre et al. 2018 for a full description). Of the eight coastal sites, two located on state lands were randomly selected as unharvested reference sites. ~~The original assignment of treatments considered overall study objectives including the evaluation of fish response in the downstream Type F Waters included only in Phase I. As such, we created two blocks, each with four sites, from the coastal region. Of these, only five sites (four on state forestland and~~

Commented [JM73]: Considering the number of type n basins I would think you would try to better understand the variability rather than minimize it.

Commented [RO74R73]: Spatial heterogeneity often influences the response variable due to environmental factors that are not directly measured. By including geographic blocks as a random effect, you allow the model to account for these unmeasured factors without needing explicit covariates for every source of variability. A random effect for geographic blocks also adjusts for non-independence by estimating and partitioning variance attributable to the blocks. I appreciate where you are coming from and suggested a modification of “minimize” to “account for” to better convey the intent.

Commented [HB75]: While blocking is a good strategy it sets up and increased likelihood that buries the any treatment by block interaction. If treatments changed rank from one block to another, or one treatment changed substantially from one block to another, then we could be missing the ...

Commented [RO76R75]: I am a little confused by this comment. AJ PLEASE REVIEW. Block is used as a random effect to account for spatial variability. There is n ...

Commented [AK77R75]: The main effect we are estimating in a BACI analysis is the year*treatment interaction term. Blocking allows us to account for the type ...

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~~one on private land) were suitable for evaluating downstream fish responses (i.e., they had the required 75 m downstream reach necessary for evaluating fish response, which was included only in the evaluation through Post 2, see McIntyre et al. 2018). To ensure one complete block representative of all treatments was available to evaluate the downstream fish response, we assigned treatments to sites as follows. First, the site on private land was assigned a buffer treatment. Of the four state-owned sites, two were randomly chosen as unharvested reference sites and randomly assigned to one of the two coastal Willapa Blocks, Willapa 1 (WIL1) and Willapa 2 (WIL2).~~ The remaining ~~two state~~six state and ~~-owned sites and the~~ privately owned sites ~~suitable for evaluating fish response~~ were randomly assigned to one of the three buffer treatments ~~to complete assignment in the WIL1 block. All sites in WIL1 were suitable for assessing export variables.~~such that there were two of each treatment across the sites. ~~For the~~The two remaining sites were on state lands and ~~in the Willapa Hills,~~ located south and east of the ~~eight~~ coastal sites. ~~, o~~One of these was assigned the reference treatment due to biological constraints (presence of marbled murrelet habitat) and the other was assigned the 100% buffer treatment due to slope instability which would have prevented application of the other experimental buffer treatments. Due to unfavorable economic conditions, harvest of one of the FP treatment sites was postponed, so it served as a second reference in this block until harvest in January 2016. This site represents a FP treatment in the Phase III analysis. ~~. In Phase III, all Willapa sites were consolidated into a single block.~~ Two reference sites ~~in the Willapa block~~ were harvested in 2020 and were excluded from the Phase III analysis.

~~The remaining coastal state-owned reference site was grouped with the remaining three coastal sites, which were randomly assigned to one of three buffer treatments to form a second block in the coastal Willapa Hills. Due to unfavorable economic conditions, harvest of the FP treatment site in this block was postponed, so it served as a second reference in this block until harvest in January 2016.~~

~~For the two remaining sites in the Willapa Hills, located south and east of the eight coastal sites, one was assigned the reference treatment due to biological constraints (presence of marbled murrelet habitat) and the other was assigned the 100% buffer treatment due to slope instability. In Phase III, all Willapa sites were consolidated into a single block. Two reference sites in the Willapa block were harvested in 2020 and were excluded from the Phase III analysis.~~

South Cascade (~~N~~n = 3): Three sites were included in the South Cascade (CASC) block. One was in the Gifford Pinchot National Forest and could only be assigned the reference treatment. We assigned buffer treatments randomly to the two remaining sites, FP and 0%.

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~~For Phases I and II,~~ Reference and treatment sites were distributed across federal, state and private timberlands for Phases I and II as follows: two references located on national forestlands, three on state lands, and one on private land; three 100% treatment sites on state lands and one on private land; two FP treatment sites on state lands and one on private land; and two 0% treatment sites on state lands and two on private lands (**Table 3**). References located on federal national forestlands may have been subjected to a different management history, including extent and frequency of harvest. However, their inclusion as references allow~~s~~ed us to account for temporal variation of forested stands in western Washington in the absence of active timber harvest. ~~Overall, four references were located on state and private lands actively managed for timber production. For Phase III, one of the Willapa references located on private land was harvested during the winter of 2015 and was included in subsequent analysis as an FP site. Two additional references located on state land were harvested in 2020 and excluded from the Phase III analysis.~~

Table 3. Treatments, site codes, and physical characteristics of study sites used in the Hard Rock Study. Type Np Length is the cumulative length of all perennial, non-fish-bearing tributaries in the study basin. Bankfull Width (BFW) is the mean of the mainstem channel in the pre-harvest period. An asterisk (*) indicates sites that were not included in Post 14 & 15 treatment response. A caret (^) indicates that WIL-FP-2 was included as an FP treatment in Phase III report because it was harvested in 2016.

Commented [JM78]: "... may have been subjected to a different management history ... in the absence of timber harvest.." Should the words "may have been" changed to were?

Commented [AJK79R78]: We are not aware of the specific management histories of stands on federal land.

Site Code	Ownership	Area (ha[ac])	Length (m[ft])	Elevation (m[ft])	Stream Order	Gradient (%)	Lithology	BFW (m[ft])	Aspect
OLYM-REF	USFS	54 (133)	2,737 (8,980)	163 (535)	3	18	Basalt flows and flow breccias	2.6 (8.5)	N
WIL-REF-1*	Private	16 (41)	816 (2,677)	228 (748)	2	18	Basalt flows and flow breccias	1.2 (3.9)	SE
WIL-REF-2*	State	12 (30)	589 (1,932)	200 (656)	2	19	Basalt flows and flow breccias	1.3 (4.3)	SW
WIL-REF-3	State	37 (92)	2,513 (8,245)	241 (791)	3	14	Basalt flows	1.7 (5.6)	SW
CASC-REF	USFS	50 (122)	1,080 (3,543)	601 (1,972)	2	21	Tuffs and tuff breccias	2 (6.6)	N
OLYM-100%	State	28 (68)	1,949 (6,394)	72 (236)	3	27	Tectonic breccia	2 (6.6)	NE
WIL-100%-1	Private	26 (65)	1,257 (4,124)	22 (72)	3	21	Basalt flows and flow breccias	1.8 (5.9)	SW
WIL-100%-2	State	31 (76)	1,029 (3,376)	198 (650)	2	18	Basalt flows and flow breccias	1.9 (6.2)	SW
WIL-100%-3	State	23 (58)	1,359 (4,459)	351 (1,152)	2	19	Basalt flows	2.1 (6.9)	SE
OLYM-FP	Private	17 (41)	1,070 (3,510)	277 (909)	3	25	Basalt flows and flow breccias	1 (3.3)	SE
WIL-FP-1	State	15 (37)	325 (1,066)	197 (646)	1	19	Basalt flows and flow breccias	1.3 (4.3)	SW
WIL-FP-2^	State	19 (48)	653 (2,142)	183 (600)	2	34	Basalt flows and flow breccias	1.9 (6.2)	W
CASC-FP	State	26 (64)	822 (2,697)	450 (1,476)	2	16	Andesite flows	1.5 (4.9)	E
OLYM-0%	Private	13 (32)	637 (2,090)	233 (764)	2	31	Basalt flows and flow breccias	1.6 (5.2)	W
WIL-0%-1	Private	28 (69)	1,525 (5,003)	87 (285)	3	16	Terraced deposits	1.9 (6.2)	NE
WIL-0%-2	State	17 (42)	933 (3,061)	159 (522)	2	21	Basalt flows	2.4 (7.9)	E
CASC-0%	State	14 (36)	420 (1,378)	438 (1,437)	1	29	Andesite flows	1.7 (5.6)	SE

Table 4. Summary of harvest implementation at riparian buffer treatment sites including Np s~~S~~tream length, buffered stream length within the harvested basin~~ buffer lengths~~, percent of stream length buffer~~ed percentages~~, and ~~proportion~~ percent of basin harvested. A caret (^)

indicates WIL-FP-2 was included as an FP treatment in Phase III report because it was harvested in 2016. At two sites some portion of the Type N stream immediately upstream of the F/N break was not included in the harvest due to required buffers on the downstream F reach, including 50 m of stream at the WIL-0%-2 site and 35 m of stream at the CASC-0%

Site Code	Stream length (m[ft])	Buffer Length (m[ft])	Length Buffered %	Basin Harvested %
OLYM-100%	1,949 (6,394)	1,680 (5,512)	86	43
WIL-100%-1	1,257 (4,124)	1,078 (3,537)	86	89
WIL-100%-2	1,029 (3,376)	1,029 (3,376)	100	72
WIL-100%-3	1,359 (4,459)	1,339 (4,393)	100	80
OLYM-FP	1,070 (3,510)	663 (2,175)	62	87
WIL-FP-1	325 (1,066)	236 (774)	73	94
WIL-FP-2^	653 (2,142)	638 (2093)	97	81
CASC-FP	822 (2,697)	456 (1,496)	55	91
OLYM-0%	637 (2,090)	0 (0)	0	100
WIL-0%-1	1,525 (5,003)	0 (0)	0	100
WIL-0%-2	933 (3,061)	0 (0)	0	98
CASC-0%	420 (1,378)	0 (0)	0	85

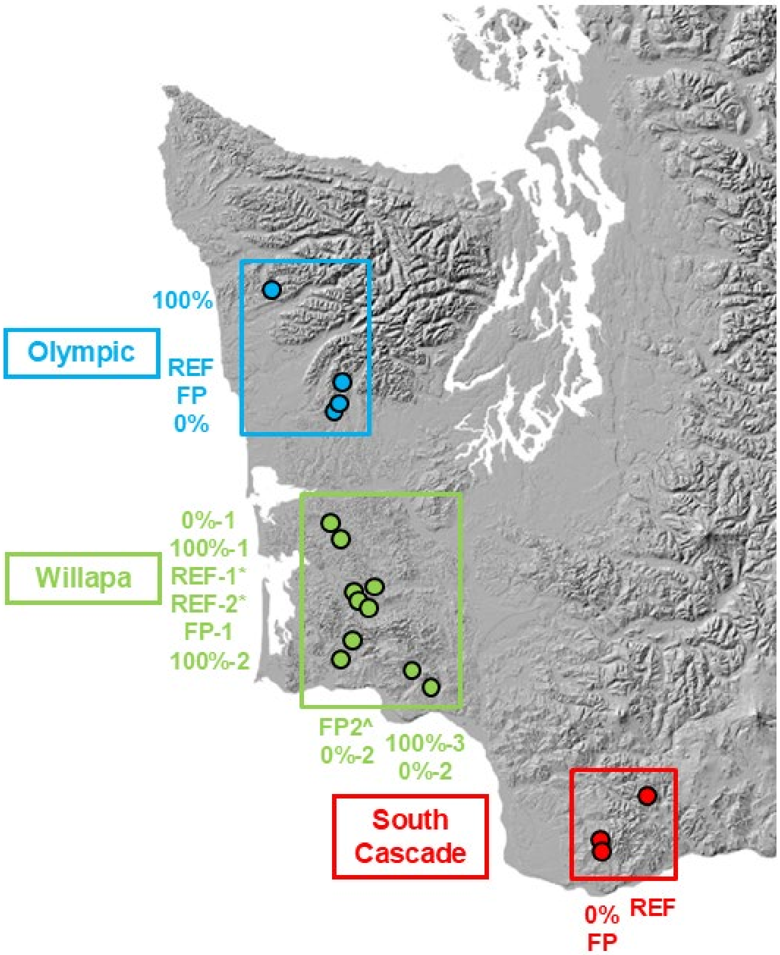

Figure 2. Distribution of study sites and treatments for the Hard Rock Study, 2006–2023. Sites are grouped (blocked) geographically (color coded). REF is the reference treatment (unharvested control) and 100%, FP, and 0% are the 100%, Forest Practices (≥50%) and 0% riparian buffer treatments, respectively.

Unanticipated Disturbance Events

The initiation and structural development of natural and managed forests are shaped by disturbances (Dale et al., 2005). Disturbance processes in Pacific Northwest forests include avalanches, debris-flows, disease, fire, flooding, insects, volcanic activity, and wind (Agee, 1993; Fetherston et al., 1995; Franklin et al., 2002). With 17 study sites and data collected over 17 years, disturbance other than timber harvest was expected to impact some study sites over the course of investigation. Two major disturbances occurred during the study: an extensive windthrow event in December 2007 that affected multiple study sites and a wildfire in October 2009 that affected two buffer treatment sites in the South Cascade block (see McIntyre et al. 2018, **Chapter 4** – *Unanticipated Disturbance Events*). In response to the December 2007 windthrow event, we collected data in an additional pre-treatment year (summer 2008) so that estimates of amphibian densities estimated the variation for the full pre-treatment study period, including post-windthrow and pre-harvest. The fire was extinguished with water from fire engines and helicopter bucket drops by 14 October 2009. No bulldozers or fire retardants were used, and the fire had no impact on future management.

Study Timeline

Pre-harvest sampling across all study sites began in 2006. Harvest timing and duration varied among study sites. Harvest at the first site to be treated began in July 2008. Harvest was completed at most treated sites by August 2009. (**Table 5**). Two references were harvested in 2020 and were excluded from the Phase III analysis. The WIL-FP-2 site was originally assigned the FP treatment, but harvest was delayed until January 2016, between the Post 7 & 8 sample years. For the Phase II analysis, we included ~~it~~this site as a reference and did not include data reflecting the post-harvest state in the statistical analysis. We included ~~it~~this site as a fourth FP treatment for Post 14 & 15. In the current analysis, we included the data from the pre-harvest period and then included data collected after harvest in 2016 as Post 1, and sampling in 2022 and 2023 as Post 7 & 8. This decision produces a more balanced design (four replicates of the FP treatment).

Table 5. Harvest timeline and periods of analysis. An asterisk (*) indicates sites that were not included in Post 14 & 15 treatment response. A caret (^) indicates that WIL-FP-2 was included as an FP treatment in Phase III report because it was harvested in 2016~~was harvested in 2016 and was included as an FP treatment in Phase III~~.

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<table>
<tr><th>Site Code</th><th>2006 2007 2008
Pre-harvest Period</th><th>2009 2010
Phase I</th><th>2015 2016
Phase II</th><th>2022 2023
Phase III</th></tr>
<tr><td>OLYM-REF</td><td rowspan="7">Pre 3, Pre 2, Pre 1</td><td rowspan="7">Post 1 & Post 2</td><td rowspan="7">Post 7 & Post 8</td><td>Post 14 & Post 15</td></tr>
<tr><td>WIL-REF-1*</td><td rowspan="2">-</td></tr>
<tr><td>WIL-REF-2*</td></tr>
<tr><td>WIL-REF-3</td><td rowspan="4">Post 14 & Post 15</td></tr>
<tr><td>CASC-REF</td></tr>
<tr><td>OLYM-100%</td></tr>
<tr><td>WIL-100%-1</td></tr>
</table>

WIL-100%-2 WIL-100%-3				
OLYM-FP WIL-FP-1 WIL-FP-2^ CASC-FP		Pre-harvest	Post 1	Post 7 & Post 8
OLYM-0% WIL-0%-1 WIL-0%-2 CASC-0%		Post 1 & Post 2	Post 7 & Post 8	Post 14 & Post 15

Scope of Inference

The temporal scope of inference is the 0-15 years post-harvest. The spatial scope of inference is limited to Type Np basins dominated by competent lithologies, which comprise approximately 30~~29~~% of western Washington FPHCP-covered lands (P. Pringle, personal communication, September 2005, formerly Washington Department of Natural Resources). The spatial scope of the study reflects ~~other constraints as well, including those associated with~~additional constraints including basin size, stand age, and the presence of stream-associated amphibians (see **Section 2-4.** Site Identification and Blocking). Results should be applied with caution to Type N streams outside the selection criteria. ~~A similar study on sites representing more erodible, soft-rock lithologies is also in progress~~~~was completed (Ehinger et al. 2021). In combination, the two studies will allow for broader inferences about FP rule effectiveness.~~

In FP treatment sites, buffer lengths ranging from 55 to 97% of the non-fish-bearing stream length exceeded the minimum required under Forest Practices rules. This factor may contribute to greater similarity between the responses in the 100% and FP treatments compared to that in the 0% treatment. This study was designed to evaluate responses to buffer length. However, the same rules that influenced buffer *length* in the FP treatment sites also affected buffer *width* in some 100% treatment sites. Specifically, in some 100% treatment sites, unstable slopes required buffers wider than the 50 ft minimum, which may have reduced effects of harvest (see McIntyre et al. 2018, Chapter 3 – *Management Prescriptions*).

Three aspects of this study support inference about effects of harvest to Type N streams in western Washington. First, the geographic scope is large, encompassing multiple sites in western Washington and the southern Cascade Range. Second, the duration of the study exceeds that of most other large-scale studies of forest practices effectiveness in the Pacific Northwest. ~~It~~This study include~~sd~~ two to three years of pre-harvest sampling and as many as nine years of post-harvest sampling. In contrast, the current FP prescription for Type Np Waters is based on little research and monitoring. Finally, we use a BACI design, capitalizing on pre- and post-harvest data to distinguish between responses to treatments and other sources of temporal variation.

Amphibian Sampling and Density Estimation

Data were collected at 17 study sites consisting of Type N headwater basins located in competent lithologies (largely basaltic) across western Washington. We evaluated the response of amphibian densities and body condition among reference and treatment sites in a BACI-designed study (see Chapter 2–*Study Design* in this report). We compared amphibian populations in Type Np reference basins (n = 6) to the response in basins with clearcut harvest and one of three riparian buffer treatments in the RMZ: 100% treatment (two-sided riparian buffer along the entire length of the Type Np stream network; n = 4), FP treatment (two-sided riparian buffer along at least 50% of the Type Np stream length, according to current Forest Practices Rules; n = 3), and 0% treatment (clearcut harvest to the stream edge with no riparian buffer; n = 4).

We used two standard amphibian sampling methods: light-touch ~~(conducted at systematically identified locations throughout the entirety of the Type N stream network),~~ and rubble-rouse. ~~(restricted to the 200 m stream reach immediately upstream of the F/N break, i.e., the point of last known fish use).~~ We conducted light-touch and rubble-rouse amphibian surveys diurnally

Commented [AJK80]: Approximately is for 15, 20,25%, etc…29% is too precise to call approximate.

Commented [HB81]: This caution needs to be emphasized in the conclusions and recommendations.

Commented [AJK82R81]: Why? The paragraph states clearly what the spatial and temporal scope of inferences are for the study.

Commented [WB83]: Soft Rock is complete (Ehinger et al. 2021)

Commented [RO84R83]: Good catch. Thanks!

Commented [JM85]: Together the two studies are a small sample. This would be a good place to state the total number of sites in both studies.

Commented [WB86R85]: Small is a relative term, it might be good to state that these 2 studies had 18 treatment sites in total and maybe how that compares to other studies addressing timber harvests in headwater streams.

Commented [RO87R85]: Aimee, we are only really reporting on one study in th ...

Commented [AM88R85]: Deleted ...

Commented [DM89]: A table would ...

Commented [RO90R89]: Added

Commented [DM91]: Identify which ...

Commented [RO92R91]: We added ...

Commented [AJK93]: This characteri ...

Commented [RO94R93]: AIMEE, ...

Commented [RO95R93]: Could also ...

Commented [AM96R93]: Good idea. ...

Commented [DM97]: Yellow ...

Commented [AJK98R97]: Why? It ...

Commented [AM99R97]: This ...

between 0700 and 1900 hours during the summer low-flow period, generally July through October.

Light-touch Sampling

Researchers commonly use ~~the~~ light-touch ~~method~~methods (Lowe & Bolger, 2002) for headwater amphibians in the Pacific Northwest to establish occupancy or abundance (Quinn et al., 2007; Russell et al., 2004; Steele et al., 2003). Light-touch sampling was chosen as a well-established method that has less impact on habitat than other standard amphibian sampling approaches (Quinn et al., 2007). ~~Light~~A modified light-touch sampling was used to provide count data over an extensive area of the stream network. We conducted stream network-wide light-touch surveys in Pre 3, Pre 2, Pre 1, Post 1, Post 2, Post 7, and Post 8. In a single effort across multiple days in a single site, ~~W~~we ~~visually~~ actively searched for amphibians as we sampled from down- to upstream, turning all moveable surface substrates small cobble-sized or larger (≥64 mm) and within the ordinary high-water mark (WFPB, 2001). We returned substrates to their original position and took care to preserve in-channel structures (e.g., steps). We sampled all study reaches, including those lacking surface water flow, from the F/N break and upstream to each PIP (i.e., uppermost point of perennial flow).

We conducted light-touch sampling along a subset of the stream channel network that included the contiguous 200 m (656 ft) of stream immediately upstream of the F/N break, as well as additional reaches located throughout the remainder of the stream channel network (**Figure 3**). For basins with a cumulative stream length less than 800 m, we surveyed a minimum of 50% of the stream length. For basins with a cumulative stream length greater than 800 m, we surveyed a minimum of 25% of the stream length. Additional reaches were surveyed in 20 m (66 ft) stream segments (i.e., two consecutive 10 m [33 ft] sample reaches, hereafter, sample intervals) distributed throughout the remainder of the mainstem channel (i.e., upstream of the contiguous 200 m sample reach) and spaced 20 m apart for shorter streams and 60 m apart for longer streams. In Pre 1, light-touch sampling was restricted to the 200 m upstream from the F/N break and to the 30-m long plots used for the estimation of detection probability (see **Section 0.** ~~*3*~~ D~~D~~etection Estimation).

Commented [JM100]: How did the rubble-rouse sampling influence populations. Did populations colonize the slash in the stream after the clear-cut harvest? How much time elapsed between the harvest and the rubble-rousing survey?

Commented [RO101R100]: We sampled a small enough proportion of the basin with rubble-rouse that we don't think it had an effect on the populations. We saw high densities of amphibians in slash that was reported on in Phase I and Phase II. We did not conduct additional sampling using rouble-rouse in slash in Phase III. Phase I rubble-rouse occurred 1 and 2 years after harvest, Phase II occurred 7 and 8 years post harvest.

Commented [HB102]: I'll bet this got tiresome in a hurry.

Commented [RO103R102]: 😆

Commented [HB104]: of

Commented [RO105R104]: Added missing word. Thanks

Commented [DM106]: Yellow
Add this to rubble-rouse and the shorter reaches (mostly FP and 100%) receive 100% or length disturbed by sampling. Discussion

Commented [AM107R106]: This is not relevant to rubble rouse, and thanks to your comments we did notice that we included rubble rouse information in the intro to this section which no longer applies and that we deleted.
A stand alone rubble rouse effort was not a part of Phase III sampling or reporting.

We also added more information on the level of effort for sampling and follow up on it again in the discussion.

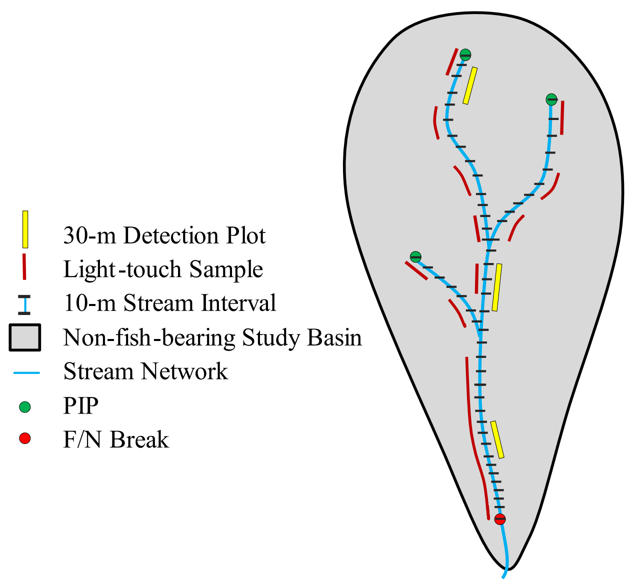

Figure 3. Sampling schematic of study basin with layout of light-touch single pass and 30 m multi-pass detection plots, from the F/N break and upstream along all tributaries to the PIP.

Detection Estimation

Starting in Pre 1, we incorporated a multi-pass light-touch sampling methodology in 30-m long plots (hereafter, detection plots). We sampled these plots in addition to the standard light-touch surveys of sample intervals, though detection plot locations sometimes overlapped with the locations of sample intervals. This approach allowed us to adjust our amphibian light-touch counts for detection probability, accounting for spatial and annual variation in detection in our estimates of stream network-wide amphibian abundance (McIntyre et al., 2012). We chose a 30-m plot length to maximize the ~~likelihood~~ probability of detecting focal amphibian taxa (Quinn et al., 2007).

We ~~randomly~~ located detection plots randomly and stratified plots by buffer type (buffered, unbuffered, reference) and stream order (first- and second-/third-order; Strahler 1952; **Table 6**). We established new plot locations each year. In some instances, we were not able to sample the entire 30-m plot length (e.g., due to wood obstructions); however, we required at least 15 m of

Commented [JM108]: What kind of obstructions?

Commented [RO109R108]: Added wood to clarify that the obstructions are composed of wood.

surveyed length for each plot. We surveyed each detection plot on three separate occasions, concurrent with our stream network-wide light-touch surveys. Our goal was to conduct repeat surveys on consecutive days. One day was considered enough time to reduce the possibility of a behavioral response that would ~~impact~~ influence amphibian detectability on subsequent surveys, while minimizing the chance of amphibian movement into or out of the plot between surveys (McIntyre et al., 2012). ~~We accomplished our goal 90.2% of the time; however, due to schedules and other activities that limited site accessibility (e.g., road closures),~~ In some cases, more than ~~1~~one day ~~did fall~~fell between repeat visits. However, we met our goal for the majority of passes (>75%), and ~~no more~~did not allow more than eight days ~~passed~~to pass between surveys for any plot and year (<3 % of passes). ~~for the remaining 9.8% of surveys. Specifically, there were two days between surveys for 1.1% of passes, 4 days for 6.5% of passes, 5 days for 1.7% of passes, 6 days for 0.2% of passes and 7 days for 0.4% of passes. During Phase III we accomplished our goal 74% of the time with 6 days between surveys for 14% of passes, 7 days for 9% of passes, and 8 days for 3% of passes.~~ One sampler conducted each survey~~,~~ and, to reduce potential surveyor bias, repeat surveys were conducted by different samplers. We counted animals and returned them to the channel at their location of capture. We included the animals detected during our first visit in our summaries of individuals encountered during stream network-wide light-touch sampling. We recorded stream temperature at the beginning of the plot (accuracy ± 1°C).

Commented [DM110]: Yellow, Do you have a reference to support this assumption?

Commented [AM111R110]: We added reference to our own work where we applied these methods and assumptions. The publication of this in the peer-reviewed literature provides some support for the reasonableness of these assumptions.

Table 6. The number of 30-m detection plots sampled by treatment, buffer and year. All plots in Pre 1 reflect reference conditions since buffer treatments had not yet been applied.

Buffer Type	Pre-harvest	Post-harvest					
		Post 1	Post 2	Post 7	Post 8	Post 14	Post 15
Reference	37	20	24	21	17	20	22
Buffered	0	27	19	21	24	17	18
Unbuffered	0	18	13	14	16	15	13

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Obstructed Reach Rubble-rouse Sampling

In Post 1 & 2 and Post 7 & 8, we ~~were not able to~~could not sample some stream reaches that were obstructed by downed trees or logging slash that prevented access to the stream or ~~made it impossible to see~~restricted visibility under cover objects. During these years, we conducted a more intensive rubble-rouse sampling on a subset of stream meters when 5% or more of the total stream network length for a basin was obstructed. Doing so allowed us to account for densities in obstructed reaches in our stream network-wide estimates of amphibian ~~abundance~~ density (See Density Estimation section and McIntyre et al. 2018, Chapter 15 – *Stream-associated Amphibians*). In Post 14 & 15 no sites had 5% or greater obstructed stream length.

Animal Processing

During ~~both~~ light-touch and rubble-rouse sampling, we captured amphibians by hand or with a dip net and identified each to species and life stage: larva (including individuals undergoing metamorphosis for Coastal Tailed Frog), neotene (for giant salamanders) or post-metamorph. We considered giant salamanders neotenic when they were >50 mm snout-vent length, had a shovel or rectangular shaped head, protruding eyes, and short, bushy gills. We considered salamanders post-metamorphs if they lacked external gills and a tail fin. We measured snout-vent and total lengths to the nearest 1 mm, weighed them using OHAUS® 120 g hand-held scales (rubble-rouse sampling only), and released them at the point of capture. We followed animal handling guidelines for the use of live amphibians in field research (Beaupre et al., 2004). To minimize the risk of spreading infectious diseases, we sanitized all sampling and personal equipment that came into contact with amphibians or streams when traveling between watersheds.

We collected small tissue samples ~~for all taxaf~~from~~or~~ some amphibians~~. Our target sample size was 40 samples per site for Coastal Tailed Frog~~ for use in genetic diversity (Coastal Tailed Frog and giant salamanders only; Spear et al., 2011; 2019) and stable isotope analyses in Phases I and II (McIntyre et al., 2018; 2021). We also collected tissue samples from ~~all~~ giant salamanders for the purpose of genetic differentiation between the species~~, and in use in our genetic diversity and stable isotopes analyses~~. ~~The exception was for sites in the Olympic Block, where we detected only Cope's giant salamander in the pre-harvest period, so we used a sample size of 40 per site in the post-harvest period. Since we did not include torrent salamanders in our analysis of genetic diversity, our target sample size for this taxon was 10. In general, w~~We collected tissue samples from ~~all~~ individuals as they were encountered until ~~our~~ minimum sample sizes ~~was~~ were met (target samples sizes were 10 samples for stable isotopes analysis and 40 for the genetic analysis). After that point, we collected tissue samples from the first individual encountered in each 10-m sample interval so that samples were distributed equally throughout the stream network. We collected tail tissue from ~~all~~ salamanders and Coastal Tailed Frog larvae and toe clips from post-metamorphic Coastal Tailed Frogs. We did not collect tissue from animals with injuries (e.g., missing part of tail or limb). We used sterilized dissecting scissors to remove tissue and placed samples in 1.5-ml ethanol-filled sample vials. Animals were immediately released at the point of capture. Samples were kept on ice for transport from the field to the lab, where they were immediately placed in a freezer.

Species Observations

We summarized amphibian species observations by site and year, since not all taxa were detected in every site or year. We did not include animals from the 3-m obstructed rubble-rouse plots since we conducted those surveys in the post-harvest period only. We noted observations that confirmed occupancy for a species in the rare case that an individual was detected only in obstructed plots or incidentally.

Density Estimation

We calculated Coastal Tailed Frog densities for larvae and post-metamorphs separately due to differences in body structure, habitat requirements, and diet. We considered individuals in the process of metamorphosis to be larvae. We combined the counts of Coastal and Cope's Giant Salamander for analysis because they are difficult to differentiate because they can hybridize (Spear et al., 2011). We also combined the three species of torrent salamanders into a single group for analysis because the range of each single species by itself only spans a small number of study sites. This assumes that ecology and response to disturbance among torrent salamander species is similar, an assumption based on the fact that the species were only relatively recently

Commented [JM112]: How did this influence the populations?

Commented [RO113R112]: We took very small clips of larval fins using sterilized scissors. We don't believe this influenced the populations.

Commented [Q(114]: why is this present tense and not past?

Commented [Q(115]: what is a physical requirement? Habitat requirments

Commented [RO116R115]: Changed to habitat identified as distinct (Good & Wake, 1992) and the three species ~~use habitats similarly~~occur in similar habitats (Jones et al., 2005).

We used a modified double-sampling design (Pollock et al., 2002) whereby we estimated stream network-wide density by applying detection probability estimates derived from a subset of 30-m detection plots to animal counts collected throughout the study site using the light-touch method. To ~~do this~~deploy this design, we delineated reaches throughout the entirety of each study site, so that the entire stream length of every study site from the F/N break and upstream to the PIP along every tributary was assigned to one combination of two covariates, which included stream order (first-order or second-/third-order) and buffer type (reference, buffered, or unbuffered). Hereafter, we refer to these reaches as single-pass reaches. The upstream and downstream limits of each single-pass reach were defined as the point at which either one of the two covariates changed (e.g., went from first- to second-order or from buffered to unbuffered). The number of single-pass reaches at a site ranged from 2 to 23.

We field-verified the stream order (Strahler, 1952) for each single-pass plot by walking the channel network one time in the pre- (2006) and one time in the post-harvest (2010) period. We obtained stream temperature for each single-pass plot from the StowAway TidbiT thermistors (Onset Computer Corporation, Bourne, MA) or from handheld thermometers. Temperature sensors were spaced from the F/N break to the PIP on the mainstem channel as well as on side tributaries, just upstream from the confluence with the mainstem. Data were collected at 30-minute intervals. During Phase I and II, we calculated stream temperature for each single-pass plot as the average temperature recorded by the nearest sensor during the period between 0800 and 1700 hours on the day, or days, that sampling occurred. During Phase III, we used handheld thermometers to obtain stream temperature in the plot at the time of sampling. ~~The purpose of~~ S~~s~~tream temperature data ~~collection~~ collected during Phase III ~~was to enable us~~allowe us to adjust detection and density estimates by temperature.

We calculated stream network-wide amphibian density for each study site and year as a linear density (count/30 m) in five steps: (1) estimating detection probability at the 30-m detection plot level (Royle, 2004); (2) dividing observed counts in all single-pass reaches by the detection probability estimated for each different combination of covariates (stream order, stream temperature and buffer type); (3) calculating the mean density within a site for each combination of stream order and buffer type by adding all adjusted counts and dividing by the total stream length for each combination, then normalizing to 30 m; (4) calculating the stream network-wide weighted mean of adjusted single-pass reach-level densities based on total stream lengths for each stream order and buffer type combination; and (5) adjusting linear density to incorporate the mean density from 3-m obstructed plots, when applicable, and based on the obstructed length by site and post-harvest year. The constituent ~~habitat types~~categories included as sampling strata were stream order, buffer type, and obstructed/unobstructed reach.

We used data obtained from the detection plots to estimate detection probabilities using the *N*-mixture model approach of Royle (2004). Specifically, we used a Poisson mixing distribution and a log-link function for the abundance model and a logit-link function for the detection model. We note that, unlike in the post-harvest analysis, we did not perform adjustments for detection probability to our counts for tailed frogs (steps 1 and 2 above). Zero counts in several basins led to unstable estimates of detection probability. Therefore, adjustments for detection probability were performed for torrent and giant salamanders only. The mean model (i.e., the model for the expected value) for torrent salamander and giant salamander abundance included covariates for stream order, year, buffer type, and the buffer type × year interaction, along with a basin-specific random intercept. The detection model for these two taxa contained covariates for stream order, stream temperature, year and buffer type. In the abundance model, buffer type was defined by the post-harvest state and was constant across all years (i.e., reference, buffered and unbuffered for all single-pass reaches located in the reference, 100% and 0% treatments, respectively, and buffered or unbuffered for plots located in the FP treatment). The interaction term (buffer type × year) accounted for the buffer treatment application. For the detection model, buffer type for all study sites was defined as a reference condition during the pre-harvest period but took the post-harvest state during the post-harvest period.

We fit all *N*-mixture models within a Bayesian framework using the WinBUGS (Spiegelhalter et al., 2003) software package called from R (R Development Core Team, 2010) using package R2WinBUGS (Sturtz et al., 2005). We assessed convergence using the Gelman-Rubin statistic (Gelman et al., 2004) and visual inspection of the chains and used posterior predictive checks to check for consistency between the model and the data.

We used estimates obtained from the *N*-mixture model in detection plots to predict detection probabilities for all single-pass plots, across all basins and years, using the appropriate covariate data. We accounted for the uncertainty in the detection probability estimates in our adjusted density estimates (McIntyre et al. 2018, Chapter 15 – Stream-Associated Amphibians, Appendix 15-A). We did not have the replicated count data for Pre 3 and Pre 2 needed to estimate detection probability, so we based estimates for detection probabilities for those years on data collected in Pre 1. We justified this approach based on the fact that: (1) all pre-harvest years are in the reference state; (2) relevant covariate data were collected during Pre 3 and Pre 2; and (3) detection probability estimates for Post 1 & 2 were close for all species. We conducted a sensitivity analysis by fitting the Before-After Control-Impact (BACI) model without Pre 3 and Pre 2 data and comparing results to the full analysis. Across all species, the results were sufficiently similar that we felt comfortable including the Pre 3 and Pre 2 data, which provided better precision on our estimates due to larger sample sizes.

We calculated estimates of amphibian linear density from the adjusted single-pass plot-level abundance values by considering the adjusted counts as coming from a stratified random sample. The constituent habitat types included as sampling strata were stream order, buffer type, and obstructed/unobstructed reach. We estimated the length of the obstructed stratum separately for all post-harvest years. We calculated separate estimates for each basin by year. We calculated the amphibian linear density for stratum *h* in basin *i* in year *j* as follows:

$$\tilde{N}_{ijh} = C \cdot \frac{\sum_k \tilde{N}_{ijhk}}{\sum_k c_{ijhk}} \qquad \textbf{(Eq. 1)}$$

where: *k* indexes plot,

$\tilde{N}_{ijhk}$ is the adjusted plot abundance,

c_{ijhk} is the plot length, and

C = 30 m.

We calculated the weighted abundance estimate for basin *i* in year *j* as follows:

$$\tilde{N}_{ij} = \sum_{h} w_{ijh} \cdot \tilde{N}_{ijh} \qquad \textbf{(Eq. 2)}$$

where: $w_{ijh} = l_{ijh}/l_{ij}$, with l_{ijh} = stratum network length, and
l_{ij} = total stream network length.

~~Water~~Stream Temperature

We measured ~~water~~stream temperature at 30-minute intervals using Hobo TidbiT MX2203 data loggers (Onset Computer Corporation, Bourne, Massachusetts) during the summer of 2023 to support our interpretation of amphibian density response. At each site, we installed a TidbiT where ~~there was~~ sufficient water depth and flow existed to keep the instrument ~~to keep it~~ submerged near the basin fish end point. We attached TidbiTs to iron rebar driven into the streambed. We used zip ties to suspend the thermistor in the water column and leaned woody debris on the rebar to protect the sensor from direct sunlight and detection (vandalism). Portions of these streams were very shallow (<3 cm), especially near ~~channel initiation~~PIPs, and some sensors were installed very near the streambed surface. ~~Water~~Stream temperature was summarized as the maximum 7-day average daily maximum (7-DADMax) for each site. Stream ~~Water~~ temperature change was not statistically analyzed. We did not sample stream temperature consistent with the study design used to evaluate stream temperature treatment effects consistent with Phases I and II. As such, these data are considered supplementary to the amphibian analysis and are not appropriate for use in any comparative analyses of stream temperature response to treatment. Prior to Post 15 (2023), ~~water~~ stream temperature monitoring was conducted by Washington State Department of Ecology (McIntyre et al., 2021, Chapter 4 – *Stream Temperature and Cover)*.

Statistical Analysis

We designed this study to evaluate differences in the magnitude of change (post-harvest – pre-harvest) among treatments at the site scale. We evaluated the effect of clearcut timber harvest with three variable-length riparian-buffer treatments relative to an unharvested control (reference). We used a Before-After Control-Impact (BACI) design whereby we established baseline conditions across study sites, implemented harvest at buffer treatment sites and monitored the response after harvest. The BACI design allowed us to compare harvested sites to their pre-harvest baseline conditions and unharvested references. ~~An advantage of this~~This design ~~is that it~~ controls for the effect of large-scale temporal variation (e.g., annual environmental variability) by establishing relationships between the control (i.e., unharvested reference) and impact (i.e., buffer treatment) sites in the pre- versus post-harvest periods (Smith, 2002), allowing us to adjust for environmental variation when estimating the impact of forest practices on post-harvest responses.

Randomization during site selection, when possible, helped prevent a systematic bias in the comparison of treatment effects. However, with smaller sample sizes there may be some bias in the sites to which treatments were assigned by chance.

Commented [HB117]: From 2009 through 2016 the OLYM-FP was consistently the coolest and WIL-FP-1 the warmest. This change in 2023 when CASC-FP became warmest. This , along with the taxa differences in Table 5, indicate that treatment responses among sites changed through time. In particular for frog density recovery, generalized conclusions across all sites do not indicate where recovery may or may not, or to what degree, have happened--that is where the treatments have or not have worked. Please discuss this in Discussions and Conclusions for each of the three amphibs.

Commented [AK118R117]: Yes, treatment effects were allowed to vary with time because a BACI design was approved in the study design.

Commented [DM119]: Yellow Assigning treatment categories given the variability in both buffer length and width within categories is questionable. The Ref and CC are only categories with consistent level of buffer/or not. The FP and 100% are essentially same cat, with variation in ...

Commented [AJK120R119]: Treatments have operational variability, that is just the way field trials of this type work out. Its variation that is accounted for by the site-specific random effects.

Commented [JM121]: Does this make the site selection non-random?

Commented [RO122R121]: We're conveying that there was an attempt at randomization but not possible across all sites due to landowner constraints (e.g., private timber could not commit to allowing ...

Commented [DM123]: Arm waving!

Commented [AM124R123]: We're conveying that there was an attempt at randomization but not possible across all sites due to landowner constraints (e.g., private timber could not commit to allowing ...

The statistical models used for the analysis of the BACI design include a blocking term, which groups sites geographically to increase precision, and a year term to account for inter-annual environmental variability. The model error term represents experimental error, which captures several sources of variation, including within-site sampling variability, measurement error, site × time interaction, and site × treatment interaction. The latter two terms correspond to the variation in the year effect by basin~~,~~ and the variation in treatment effect by basin, respectively. Other sources of variation are also included in the experimental error.

We used generalized linear mixed effects models to evaluate the pre- versus post-harvest changes for each treatment type (McDonald et al., 2000). The analysis focused on estimating mean treatment effects in each of three post-harvest time periods: 1-2 years, 7-8 years, 14-15 years. For each response, the models contained block and site random effects, as well as fixed effects for year to account for interannual variation. The models were further parameterized with terms for all combinations of treatment and post-harvest period. Post-hoc contrasts were used to estimate treatment effects for each post-harvest period. We examined pairwise contrasts for six combinations of references and buffer treatments, namely: REF vs. 0%, REF vs. FP, REF vs. 100%, 0% vs. FP, 0% vs. 100%, and FP vs. 100%.

The analyses of density produce results on the natural log (ln) scale. We exponentiated the difference in the natural logs of post- and pre-harvest values to give an estimate of the proportional change in density on its original scale. Therefore, a back-transformed result equal to 1 equates to no change in the average pre- and post-harvest estimates. A value between 0 and 1 equates to a result in the post-harvest period that is less than the average in the pre-harvest period. A value greater than 1 equates to a result in the post-harvest period that is more than the average in the pre-harvest period. For example, estimates of 0.5 and 1.5 equate to a 50% decrease and a 50% increase from pre- to post-harvest, respectively. We present contrast estimates in the text of the results for estimates for which the 95% credible interval does not include 1.

In cases where low amphibian counts led to numeric instability in maximum likelihood estimates from the GLMM, we fit the model using Bayesian methods. All Bayesian models were fit using JAGS (Plummer, 2003) called from the R programming environment. We specified Gaussian priors for all parameters, and performed sensitivity checks to verify that conclusions were consistent across a range of vague priors. Posterior mean estimates, contrasts, and 95% credible intervals were used to summarize results from all Bayesian analyses. We note that p-values are not available from the Bayesian analysis.

Basin-level density estimates for ~~both~~ torrent and giant salamanders were adjusted for imperfect detection (~~*reference where this was* described~~Density Estimation section) using estimates of detection probability from fitted N-mixture models (Royle, 2004). We propagated detection probability uncertainty into our generalized linear mixed model analysis using multiple imputation (Little & Rubin, 2019). Specifically, we used the following steps to account for this uncertainty:

1. Draw a sample *s* from the posterior distribution of the fitted N-mixture model.
2. Calculate detection probabilities using sample *s* and covariate data for each single-pass light touch sample.

Commented [HB125]: This is a near fatal flaw in the study design. Testing the site x time and site x treatment interactions against the remaining experimental error could provide much more fine grained understanding of where the treatments work or do not work. At least discuss this in the discussion and conclusions as a likely possibility that was not tested in this model. Could this still be done with these data, possibility looking at other covariates measured, to explain why some sites responded differently from the same treatment?

Commented [AJK126R125]: The BACI experimental design posits a statistical model in which the year*treatment effect is the focus of inference.

Also, we note the BACI design was part of the Type N Hardrock Study from the onset, and has gone through ISPR review and was approved by CMER.

Commented [AJK127]: …see what I mean…Jay can help provide a few sentences about how "evidence" or "support" are evaluated within a Bayesian framework.

Commented [RO128R127]: We lean on the credible intervals and if the contrasts overlap 0% change or not. We embolden contrasts that do not encompass a 0% change and put them in the text of the results.

Commented [HB129]: Do you still plan to do this?

Commented [RO130R129]: Added the section where this is described in greater detail.

3. Adjust observed counts by dividing by the calculated detection probabilities in step 2; aggregate the adjusted counts to obtain basin-wide density estimates, by year.
4. Fit the generalized linear mixed model to the basin-wide density estimates in step 3 and record contrast estimates and standard errors.
5. Repeat steps 1-4 *S* times.
6. Calculate the mean of the squared standard error over the *S* samples for each contrast; calculate the variance of contrast mean estimates over the *S* samples. Sum these two quantities.
7. Calculate the sample average over all *S* contrast mean estimates.

The square root of the sum in step 6 is an estimate of contrast standard error that incorporates both experimental error and uncertainty in the estimated detection probability. This value was used to calculate 95% confidence intervals. Due to the use of multiple imputation, we do not report p-values for either the torrent or giant salamander results. The generalized linear mixed model in step 4 was fit in R using the glmmPQL function in package MASS (Venables & Ripley, 2002).

Results

Summary of Amphibian Species Observations

In the Phase I and II efforts, we made 21,194 amphibian observations using light-touch and rubble-rouse techniques in the lower Np reach, of which 98% were focal amphibians (i.e., Coastal Tailed Frog, torrent salamanders, and giant salamanders; McIntyre et al., 2021). As a part of the Phase III effort, we made an additional 4,818 observations for focal amphibians through our light-touch and triple pass efforts. Of those, 480 were Coastal Tailed Frog, 2,951 were torrent salamanders, and 1,387 giant salamanders. In the pre-treatment period, we detected Coastal Tailed Frog in 15 of 17 sites, and torrent and giant salamanders in all 17 sites (**Table 7**). In Post 14 & 15, we detected Coastal Tailed Frog in 10 of 15 sites, torrent salamanders in 13 of 15 sites, and giant salamanders in all 15 sites that were included in the Phase III comparison (**Table 7**).

Table 7. Focal amphibian taxa detected during stream network-wide light-touch for all study sites and periods (pre-harvest, post-harvest [Post 1 & 2; Post 7 & 8, and Post 14 & 15]). ~~Filled circles (■)~~ Shaded cells indicate where a focal taxa was detected for a site and period and empty ~~circles (■)~~cells indicate where a taxa was not detected. An asterisk (*) indicates sites not included in Post 14 & 15 treatment response. A caret (^) indicates that WIL-FP-2 was included as an FP treatment in Phase III report because it was harvested in 2016.

Site Code	Coastal Tailed Frog				Giant Salamanders				Torrent Salamanders			
	Pre	Post 1 & 2	Post 7 & 8	Post 14 & 15	Pre	Post 1 & 2	Post 7 & 8	Post 14 & 15	Pre	Post 1 & 2	Post 7 & 8	Post 14 & 15
OLY-REF												

Commented [Q(131]: this is the first use of the word "focal" need to define?

Commented [RO132R131]: Added definition of focal species in parenthes

Commented [JM133]: What is a focal amphibian?

Commented [RO134R133]: Coastal Tailed Frog, Giant Salamanders, Torrent Salamanders

Commented [AM135]: The symbols keep getting mucked up. We'll have to find different symbols or shaded cells for the final draft.

Commented [WB136R135]: Done. Can easily change shading darker if preferred.

Commented [HB137]: The differential response of tailed frogs for all time periods shows a site x treatment interaction for both the FP and 100% treatments that was buried in the error term of the model. Ditto, but not so strong for Torrents. It seems that there should be some relationship between density and occupancy suggesting that the FP & 0% treatments worked well as some sites and less well at others. Are we not trying to ...

Commented [AJK138R137]: Within the experimental design, the goal of the analysis is to determine average effects (an ...

Commented [HB139]: Note here for Frogs: there is large precipitation (stream flow, temperature?) difference between the ...

Commented [AJK140R139]: Differences between the Olympics and Cascades not accounted for by the main treatment effect ...

Commented [JM141]: Filled and empty circles look the same. The circles look like squares.

Commented [RO142R141]: Agreed, we were having formatting issues that have been fixed for the final draft.

WIL-REF-1*				*				*				*
WIL-REF-2*				*				*				*
WIL-REF-3												
CASC-REF												
OLY-100%												
WIL-100%-1												
WIL-100%-2												
WIL-100%-3												
OLY-FP												
WIL-FP-1												
WIL-FP-2^												
CASC-FP												
OLY-0%												
WIL-0%-1												
WIL-0%-2												
CAS-0%												

Density

Coastal Tailed Frog Larvae

Mean annual larval tailed frog densities ranged from 0.0 to 3.1 in the pre-harvest period, 0.0 to 4.5 in Post 1 & 2, 0.0 to 1.2 in Post 7 & 8, and 0.0 to 2.3 in Post 14 & 15 (**Figure 4**). We found evidence that treatments differed in the magnitude of change over time (**Table 8**; **Figure 5**; **Table 9**).

Commented [HB143]: Also note that densities ticked (toward recovery?) up from Post 14 to 15 for all treatments other than FP—indicating again something other than the buffers are effecting the results. Please discuss in the results and conclusions.

Commented [AM144R143]: We know there is a lot of annual variability in amphibian densities/demographics, which is why we chose a sampling design that includes multiple sample years in any given period. The interaction in the model is a "period"*treatment interaction. Year is included in the model but the analysis compares change between periods.

In Post 1 & 2, we estimated the between-treatment comparison for the 100% treatment and the reference to be 1.61 (approximate 95% credible interval: 1.08, 2.41) or in other words a +61% (approximate 95 % credible interval +8%, +141%) change in mean density compared to pre-harvest period after controlling for temporal changes in the reference. Likewise, for the FP treatment we estimated a +72% (approximate 95% credible interval +9%, +171%) change in density compared to the change in the reference.

In Post 7 & 8, we estimated a -58% (-82%, -1%), -94% (-99%, -66%), and -75% (-93%, -8%) change in density in the 100%, FP, and 0% treatments, compared with the change in the reference.

In Post 14 & 15, we estimated a -71% (-86%, -41%), -95% (-99%, -68%), and -70% (-86%, -37%) change in density in the 100%, FP, and 0% treatments, compared with the change in the reference.

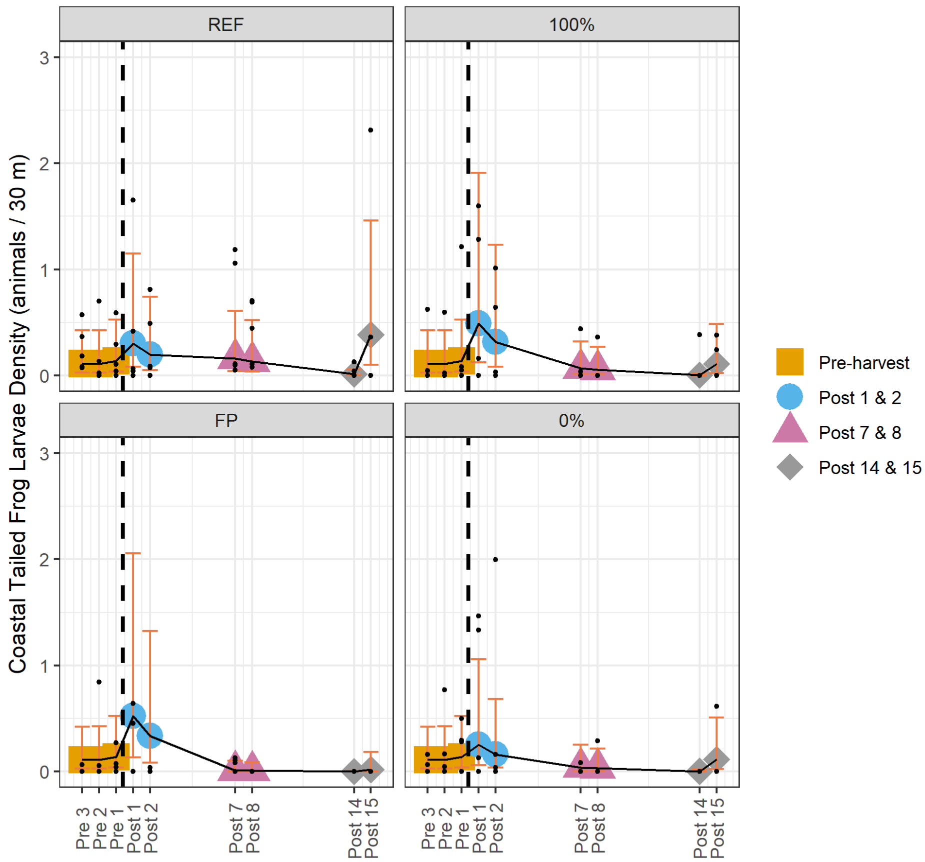

Figure 4. Mean larval Coastal Tailed Frog density (animals/30 m) by sample year. Vertical colored lines show approximate 95% credible intervals. Vertical dashed lines show the timing of harvest at buffer treatment sites. Site means are dots; treatment means are colored symbols. To ensure a y-axis scale that highlights the variability and is consistent among panels, points are not shown for ~~We removed~~ three points [for WIL-FP-1 in Pre 3 (3.10), Post 1 (3.80) and Post 2 (4.47).] ~~so that the y-axis scale would support comparisons among treatment point~~

estimates.

Commented [HB145]: Where is the data used to locate each of the density observations (site specific) within a post year? It would be informative to look at this, and may be assign a code to each site o better understand if one site is having a disproportionate impact on the treatment means. That is, the buffer treatments may be working well a some sites and not so well at others.

Commented [AK146R145]: Here, distinguishing between the observational units (the sampling plots) and experimental units (the basins where the treatments were applied) is helpful. The study is designed to make inference on the experimental units.

Commented [Q(147]: i would rescale these figure to show the bottom end at larger scale

Commented [JM148R147]: I agree.

Commented [AK149R147]: I understand the notion of including the data from the individual sites but doing so creates acres of white space...and the symbols for your point estimates are confusing given the scales of the CRIs.

Commented [OBRA(150R147]: Revised scale of y-axis

Commented [HB151]: The large CI difference between post 14 & 15 REF is suspect. Did the population densities change that much in one year? Is one site causing this? Please discuss.

Commented [OBRA(152R151]: In Post 14 larval frog density estimates were 0.003637169 and in Post 15 they were 0.1103474 animals per / 30 meters. The Olympic Reference Basin had higher densities in 15 than in 14. We average across two consecutive years to estimate change b ...

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Table 8. The within-treatment estimate of the proportional change and 95% credible intervals (CI) for mean larval Coastal Tailed Frog density between the pre-harvest period and Post 1 & Post 2, Post 7 & Post 8 and Post 14 & Post 15.

Treatment	**Estimate (CI)**		
	Post 1 & 2	**Post 7 & 8**	**Post 14 & 15**
REF	2.03 (1.69, 2.44)	1.22 (0.97, 1.54)	0.58 (0.37, 0.91)
100%	2.58 (2.09, 3.18)	0.79 (0.51, 1.23)	0.31 (0.18, 0.55)
FP	2.66 (2.08, 3.41)	0.31 (0.12, 0.83)	0.13 (0.05, 0.36)
0%	1.85 (1.34, 2.56)	0.61 (0.32, 1.19)	0.32 (0.18, 0.56)

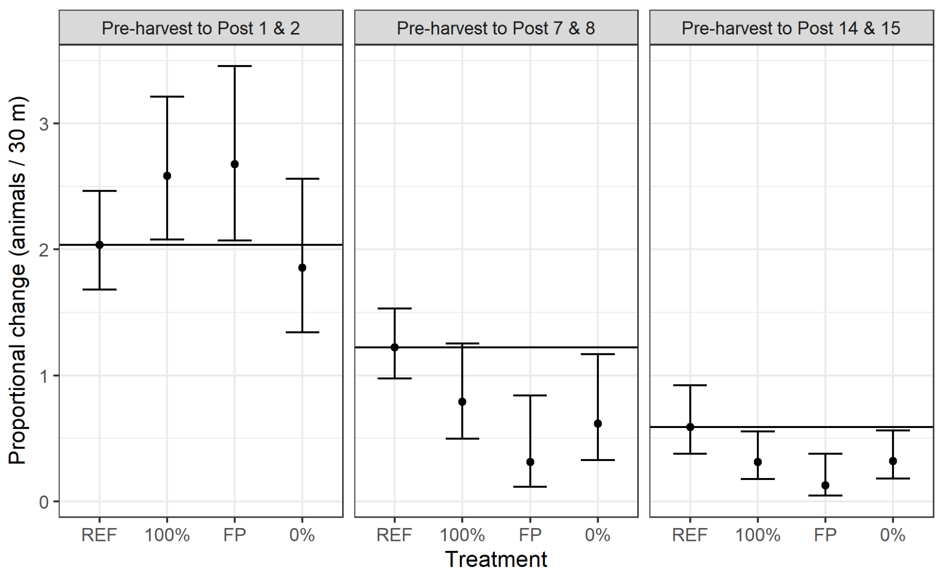

Figure 5. The within-treatment estimate of the proportional change and approximate 95% credible intervals for mean larvae Coastal Tailed Frog density between the pre-harvest and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15. A horizontal line placed at the reference treatment (REF) value indicates the estimated temporal change under reference conditions.

Table 9. The between-treatment comparison of the proportional change and approximate 95% credible intervals (CI) of the estimates for mean larval Coastal Tailed Frog density. Contrasts with credible intervals that do not overlap 1 are emboldened. The first treatment listed in each paired comparison is the treatment with fewer trees remaining in the RMZ buffer.

Commented [HB153]: Please explain the relationship between the REFs in this table and those in table 15.

Commented [RO154R153]: This table shows the pre to post treatment change in larval coastal tailed frog density in the reference by period. Table 15 shows the 7-DADMax for each site by year. I am not sure exactly what you are getting at, but this is not part of our analysis. We are sticking to a CMER approved study design focused on a ...

Commented [aa155]: Reformat so th ...

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Contrast	Estimate (CI)		
	Post 1 & 2	Post 7 & 8	Post 14 & 15
100% vs. REF	**1.61 (1.08, 2.41)**	**0.42 (0.18, 0.99)**	**0.29 (0.14, 0.59)**
FP vs. REF	**1.72 (1.09, 2.71)**	**0.06 (0.01, 0.44)**	**0.05 (0.01, 0.32)**
0% vs. REF	0.83 (0.44, 1.58)	**0.25 (0.07, 0.92)**	**0.30 (0.14, 0.63)**
0% vs. FP	0.48 (0.23, 1.02)	3.87 (0.38, 39.02)	6.12 (0.81, 46.26)
0% vs. 100%	0.52 (0.25, 1.05)	0.60 (0.13, 2.78)	1.04 (0.37, 2.88)
FP vs. 100%	1.07 (0.60, 1.91)	0.16 (0.02, 1.27)	0.17 (0.02, 1.25)

Coastal Tailed Frog Post-metamorphs

Mean annual post-metamorphic tailed frog densities ranged from 0.0 to 2.2 in the pre-harvest period, 0.0 to 2.5 in Post 1 & 2, 0.0 to 0.7 in Post 7 & 8, and 0.0 to 1.7 in Post 14 & 15 (**Figure 6**). We found evidence that treatments differed in the magnitude of change over time (**Table 10**; **Figure 7**; **Table 11**).

In Post 1 & 2, we estimated the between-treatment comparison for the 100% treatment and the reference to be 0.37 (approximate 95% credible interval: 0.20, 0.68) or in other words a -63% (approximate 95 % credible interval -80%, -32%) change in mean density compared to pre-harvest period after controlling for temporal changes in the reference. Likewise, for the comparison of the 0% treatment and the reference we estimated a +343% (approximate 95 % credible interval +79%, +993%) change in density. We also estimated a +522% (+66%, +2229%) change in density in the 0% treatment compared with the FP treatment and a +1112% (+354, +3137%) change in density in the 0% treatment compared to the 100% treatment after adjusting for pre-harvest differences among the treatment sites.

In Post 7 & 8, we estimated a -88% (-96%, -64%), ~~and~~ -91% (-98%, -63%) and -75% (-93%, -8%), change in density in the 100%, ~~and~~ FP and 0% treatments compared with the change in the reference.

In Post 14 & 15, we estimated a -98% (-99.6%, -93%), -97% (-99.6%, -82), -85% (-97%, -36%) change in density in the 100%, FP, and 0% treatments, compared with the temporal change in the reference. We also estimated a +781% (+16%, +6601%) change in density in the 0% treatment compared with the change in the 100% treatment.

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Commented [HB165]: I don't understand how significant differences show here when there were none in Figure 4. Please explain in the discussion.

Commented [RO166R165]: Pair-wise contrasts are calculated from the output of the statistical model. They are related to the within-treatment estimates, but they are not as simple as no overlap of within-treatment credible intervals. In other words, its reasonable to expect that the estimates would appear offset from one another but can still ...

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Commented [JM167]: Gridlines would this table.

Commented [WB168R167]: Or at least adjust the widths

Commented [RO169R167]: Fixed the widths. Thanks.

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Commented [JM170]: How did you control for temporal change?

Commented [O(171R170]: Using the BACI statistical framework.

Commented [Q(172]: what does "full" mean here

Commented [RO173R172]: I don't see the word full here. This must be misplaced ...

Commented [AJK174]: What about the 0%?

Commented [RO175R174]: Good catch

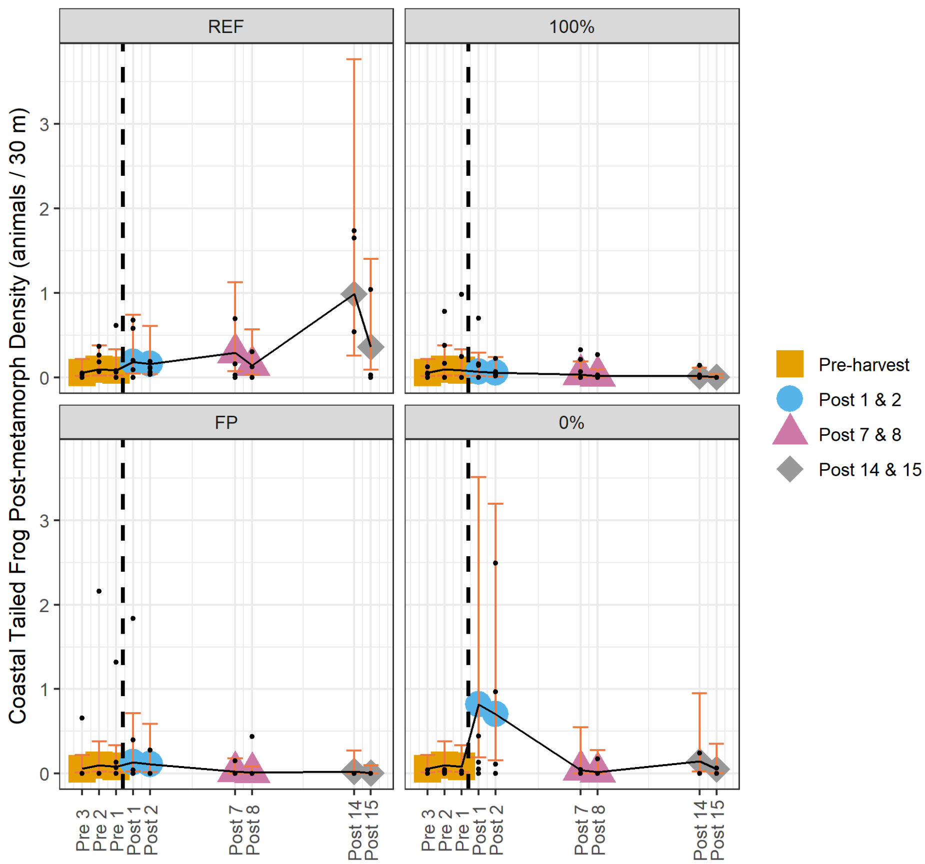

Figure 6. Mean post-metamorphic Coastal Tailed Frog density (animals/30 m) by sample year. Vertical colored lines show approximate 95% credible intervals. Vertical dashed lines show the timing of harvest at buffer treatment sites. Site means are dots; treatment means are colored symbols.

Table 10. The within-treatment estimate of the proportional change and approximate 95% credible intervals (CI) for mean post-metamorphic Coastal Tailed Frog density between the pre-harvest period and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15.

Treatment	Estimate (CI)		
	Post 1 & 2	Post 7 & 8	Post 14 & 15
REF	2.19 (1.49, 3.22)	2.6 (1.79, 3.77)	7.65 (5.57, 10.51)

Commented [HB176]: The large CI and density differences between post 14 & 15 REF are suspect. Did the population densities change that much in one year? Was 2023 a hot/dry year? More importantly it looks like one site was substantially different than the others for post 14. This looks like a treatment by site interaction that, if it has occurred, weakens the confidence and inferential ability of Table 10 results. This needs discussion in the discussion and conclusions section.

Commented [AJK177R176]: If one harvest unit responded differently compared to other harvest units in a treatment group, that reduces the precision around the treatment effect for that group. However, reduced precision does not, by default, "weaken the confidence and inferential ability" of the analysis.

Commented [AM178R176]: Annual variation in amphibian densities are common and that is why we included multiple sample years in each period.

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100%	1.33 (0.94, 1.87)	0.91 (0.52, 1.6)	0.99 (0.48, 2.04)
FP	1.85 (1.02, 3.34)	0.78 (0.36, 1.68)	1.28 (0.49, 3.35)
0%	4.62 (2.93, 7.27)	0.98 (0.31, 3.09)	2.93 (1.37, 6.26)

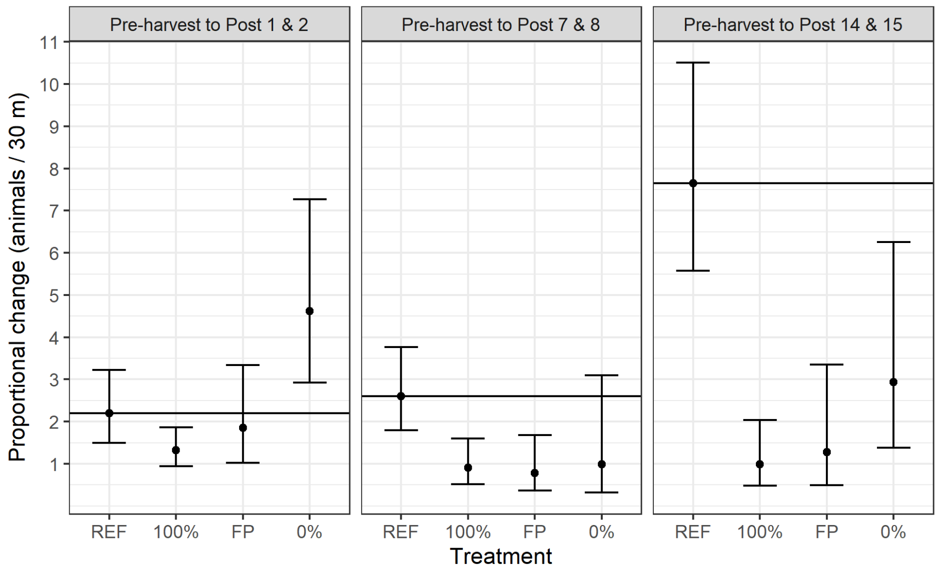

Figure 7. The within-treatment estimate of the proportional change and approximate 95% credible intervals for mean post-metamorphic Coastal Tailed Frog density between the pre-harvest and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15. A horizontal line placed at the reference treatment (REF) value indicates the estimated temporal change under reference conditions.

Table 11. The between-treatment comparison of the proportional change and approximate 95% credible intervals (CI) of the estimates for mean post-metamorphic Coastal Tailed Frog density. Contrasts with credible intervals that do not overlap 1 are emboldened. The first treatment listed in each paired comparison is the treatment with fewer trees remaining in the RMZ buffer.

Contrast	Estimate (CI)		
	Post 1 & 2	Post 7 & 8	Post 14 & 15
100% vs. REF	**0.37 (0.20, 0.68)**	**0.12 (0.04, 0.36)**	**0.02 (0.004, 0.07)**
FP vs. REF	0.71 (0.25, 2.05)	**0.09 (0.02, 0.37)**	**0.03 (0.004, 0.18)**
0% vs. REF	**4.43 (1.79, 10.93)**	0.14 (0.02, 1.31)	**0.15 (0.03, 0.64)**
0% vs. FP	**6.22 (1.66, 23.29)**	1.59 (0.11, 22.11)	5.26 (0.49, 56.32)
0% vs. 100%	**12.12 (4.54, 32.37)**	1.17 (0.10, 13.14)	**8.81 (1.16, 67.01)**
FP vs. 100%	1.95 (0.61, 6.25)	0.74 (0.13, 4.33)	1.67 (0.16, 17.54)

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Commented [HB179]: Post harvest changes are similar for the three treatments but the REF is a big outlier showing a relatively large change post 14&15. This indicates poor stationarity for the reference site that reduces certainty about the treatment responses. Please discuss this somewhere including the possibility of variable treatment responses among sites.

Commented [AM180R179]: We acknowledge that our estimates for post metamorphic tailed frogs are less reliable for a variety of reasons that are presented in the discussion already (e.g., we know we are not capturing terrestrial individuals in our basin-wide estimates), which is why we caution against relying on results for post metamorphic tailed frogs.

Commented [HB181]: It looks like the 0% treatment is not statistically different from the REF post 14 &15 in Figure 6 and Table 8 but not Table 9. Why?
Also, Figure 6 indicates for Post 14&15 0% vs 100% are not different but Table 9 indicates they are.

Commented [AK182R181]: Within a Bayesian framework, statistical significance is not the basis for making inference.

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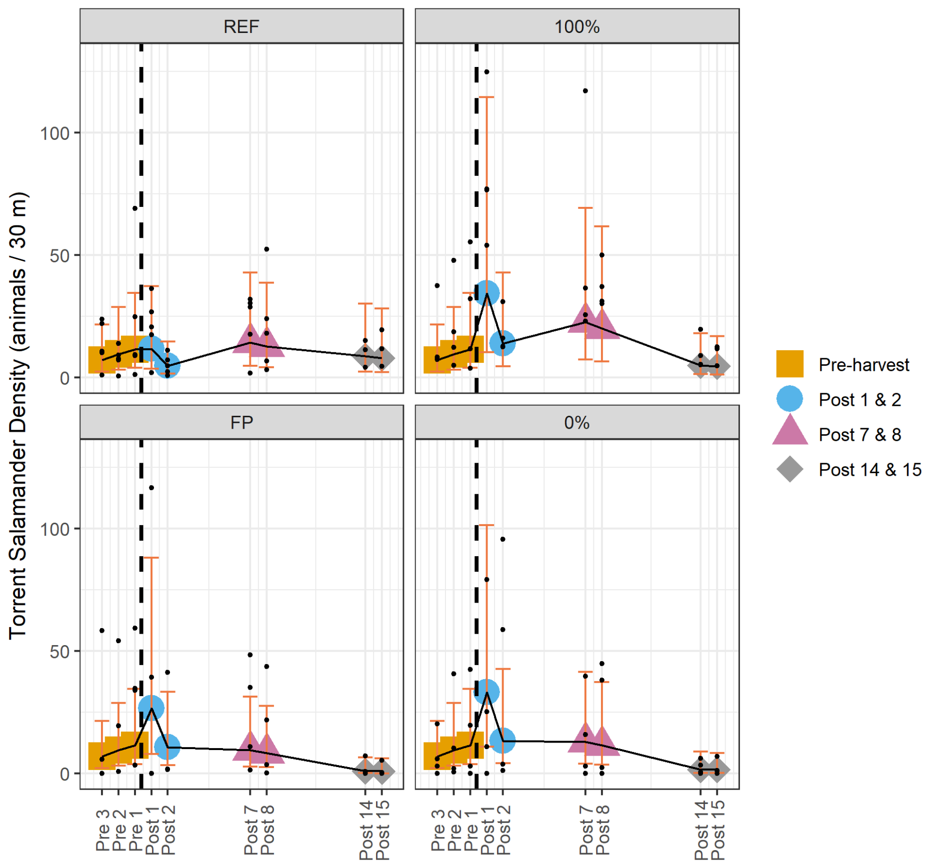
Torrent Salamander

Mean annual torrent salamander densities ranged from 0.0 to 69.0 in the pre-harvest period, 0.0 to 171.0 in Post 1 & 2, 0.0 to 117.0 in Post 7 & 8, and 0.0 to 19.7 in Post 14 & 15 (**Figure 8**). We found evidence that treatments differed in the magnitude of change over time (**Table 12**; **Figure 9**; **Table 13**).

In Post 1 & 2, we estimated the between-treatment comparison for the 100% treatment and the reference to be 2.96 (approximate 95% credible interval: 1.42, 6.18) or in other words a +196% (approximate 95 % credible interval +42%, +518%) change in mean density compared to pre-harvest period after controlling for temporal changes in the reference. Likewise, we estimated a +130% (+19%, +343%), +187% (+36%, +502%), and -75% (-93%, -8%) change in density in the 100%, FP, and 0% treatments, compared with the change in the reference.

In Post 7 & 8, we estimated a -58% (-79%, -15%) change in density in the FP treatment compared with the change in the 100% treatment.

In Post 14 & 15, we estimated a -88% (-98%, -38%) and a -80% (-95%, -18%) change in density in the FP and 0% treatments compared with the change in the reference.



Commented [OBRA(183]: Rescaled y-axis to 130

Figure 8. Mean Torrent Salamander density

(animals/30 m) by sample year. Vertical colored lines show approximate 95% credible intervals. Vertical dashed lines show the timing of harvest at buffer treatment sites. Site means are dots; treatment means are colored symbols. To ensure a y-axis scale that highlights the variability and is consistent among panels, points are not shown for one FP site (WIL-FP-1) in Post 1 (170.98).

Table 12. The within-treatment estimate of the proportional change and 95% credible intervals (CI) for mean torrent salamander density between the pre-harvest period and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15.

Treatment	Estimate (CI)		
	Post 1 & 2	**Post 7 & 8**	**Post 14 & 15**
REF	0.80 (0.43, 1.48)	1.46 (0.86, 2.49)	0.90 (0.43, 1.88)
100%	2.36 (1.28, 4.37)	2.30 (1.31, 4.03)	0.52 (0.24, 1.14)
FP	1.83 (1, 3.37)	0.97 (0.50, 1.9)	0.11 (0.02, 0.51)
0%	2.29 (1.27, 4.13)	1.32 (0.68, 2.56)	0.18 (0.05, 0.67)

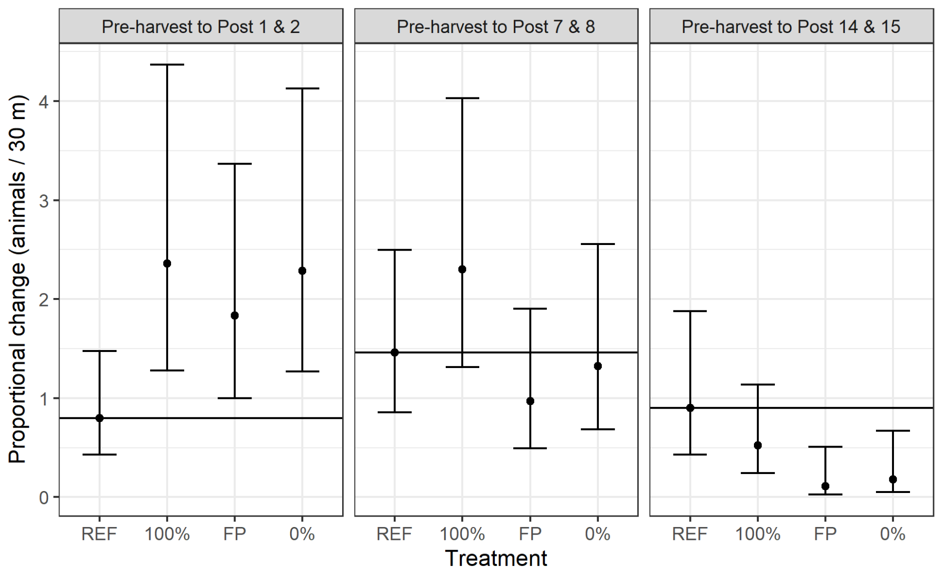


Figure 9. The within-treatment estimate of the proportional change and approximate 95% credible intervals for mean torrent salamander density between the pre-harvest and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15. A horizontal line placed at the reference treatment (REF) value indicates the estimated temporal change under reference conditions.

Table 13. The between-treatment comparison of the proportional change and 95% credible intervals (CI) of the estimates for mean torrent salamander density. Contrasts with credible intervals that do not overlap 1 are emboldened. The first treatment listed in each paired comparison is the treatment with fewer trees remaining in the RMZ buffer.

Contrast	Estimate (CI)		
	Post 1 & 2	**Post 7 & 8**	**Post 14 & 15**
100% vs. REF	**2.96 (1.42, 6.18)**	1.57 (0.82, 3.02)	0.58 (0.23, 1.48)
FP vs. REF	**2.30 (1.19, 4.43)**	0.66 (0.32, 1.39)	**0.12 (0.02, 0.62)**
0% vs. REF	**2.87 (1.36, 6.02)**	0.90 (0.43, 1.89)	**0.20 (0.05, 0.82)**

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Commented [RO185R184]: Yes, to one page. We are waiting for some final formatting until final approval. We are opting not to add grid lines because we are using a standard table format.
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0% vs. FP	1.25 (0.58, 2.67)	1.36 (0.58, 3.19)	1.63 (0.24, 11.21)
0% vs. 100%	0.97 (0.45, 2.09)	0.57 (0.27, 1.23)	0.35 (0.08, 1.44)
FP vs. 100%	0.78 (0.43, 1.41)	**0.42 (0.21, 0.85)**	0.21 (0.04, 1.07)

Giant Salamander

Mean annual giant salamander densities ranged from 0.2 to 33.9 in the pre-harvest period, 0.2 to 21.3 in Post 1 & 2, 1.6 to 54.4 in Post 7 & 8, and 0.0 to 13.0 in Post 14 & 15 (**Figure 10**). We found evidence that treatments differed in the magnitude of change over time (**Table 14**; **Figure 11**; **Table 15**).

In Post 1 & 2, we estimated the between-treatment comparison for the FP treatment and the reference to be 0.35 (approximate 95% credible interval: 0.17, 0.72) or in other words a -65% (approximate 95 % credible interval -83%, -28%) change in mean density compared to pre-harvest period after controlling for temporal changes in the reference. Likewise, we estimated a +266% (+78%, +649%) change in density in the 0% treatment compared to the FP treatment and a -62% (-92%, -26%) change in density in the FP treatment compared to the 100% treatment after adjusting for pre-harvest differences among the treatment sites.

In Post 7 & 8, we estimated a -53% (-77%, -7%) change in density in the FP treatment compared with the change in the reference.

In Post 14 & 15, we estimated a -81% (-94%, -43%) change in density in the FP treatment compared with the change in the reference and a -76% (-92%, -26%) change in density in the FP treatment compared with the change in the 100% treatment.

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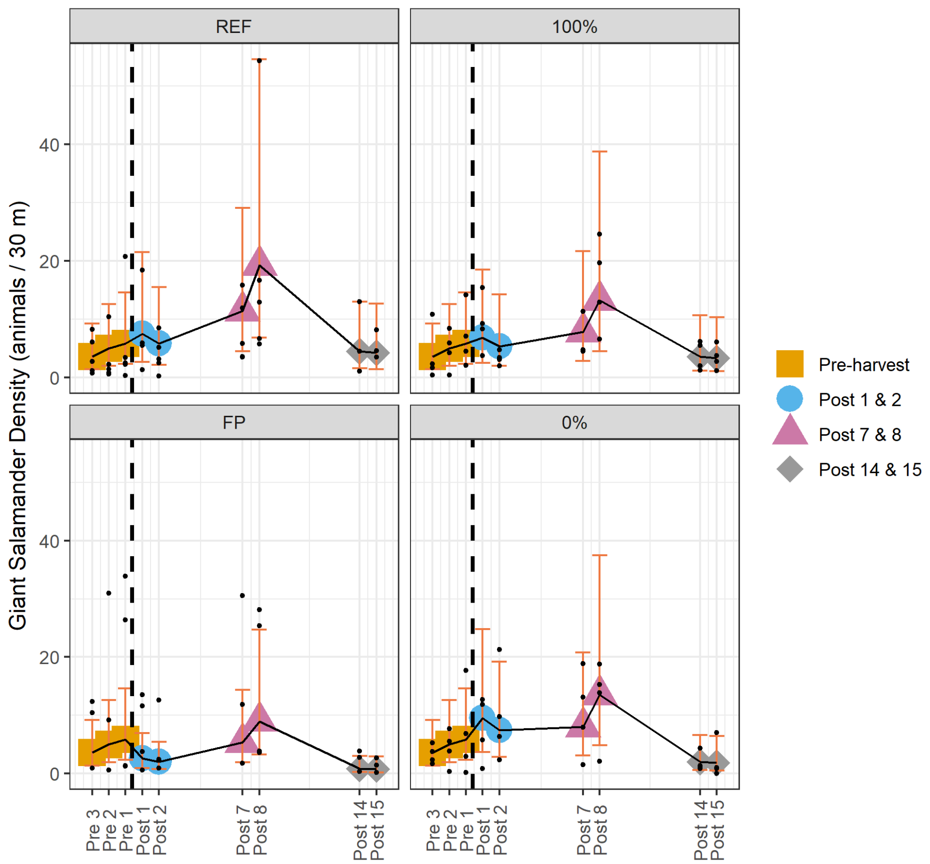

Figure 10. Mean giant salamander density (animals/30 m) by sample year. Vertical colored lines show approximate 95% credible intervals. Vertical dashed lines show the timing of harvest at buffer treatment sites. Site means are dots; treatment means are colored symbols.

Table 14. The within-treatment estimate of the proportional change and 95% credible intervals (CI) for mean giant salamander density between the pre-harvest period and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15.

Treatment	**Estimate (CI)**		
	Post 1 & 2	**Post 7 & 8**	**Post 14 & 15**
REF	1.41 (0.72, 2.76)	3.15 (1.69, 5.87)	0.93 (0.44, 1.95)

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100%	1.28 (0.66, 2.50)	2.16 (1.09, 4.31)	0.74 (0.34, 1.60)
FP	0.49 (0.25, 0.94)	1.47 (0.78, 2.74)	0.18 (0.06, 0.48)
0%	1.79 (0.98, 3.26)	2.21 (1.14, 4.27)	0.41 (0.17, 1.02)

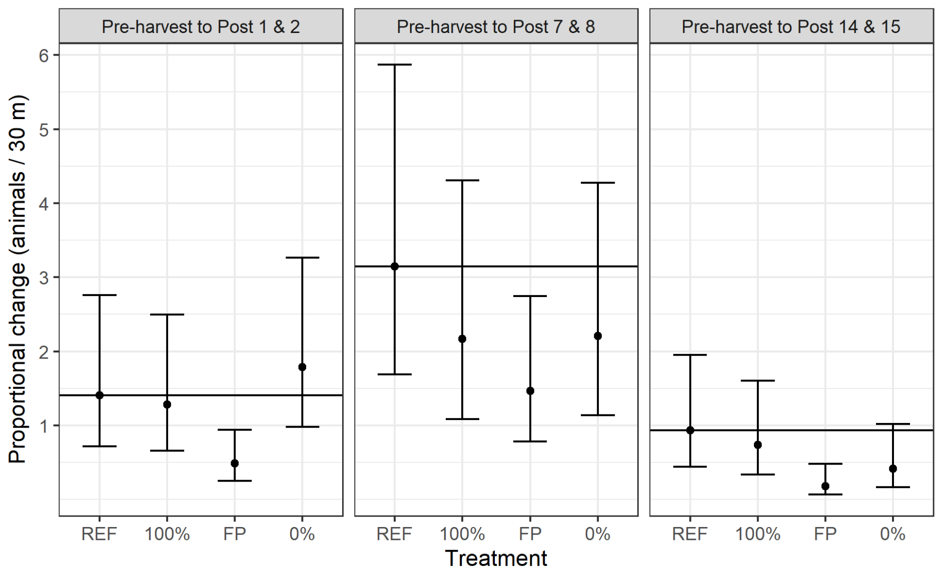

Figure 11. The within-treatment estimate of the proportional change and approximate 95% credible intervals for mean giant salamander density between the pre-harvest and post-harvest periods Post 1 & 2, Post 7 & 8 and Post 14 & 15. A horizontal line placed at the reference treatment (REF) value indicates the estimated temporal change under reference conditions.

Table 15. The between-treatment comparison of the proportional change and 95% credible intervals (CI) of the estimates for mean giant salamander density. Contrasts with credible intervals that do not overlap 1 are emboldened. The first treatment listed in each paired comparison is the treatment with fewer trees remaining in the RMZ buffer.

Contrast	**Estimate (CI)**		
	Post 1 & 2	**Post 7 & 8**	**Post 14 & 15**
100% vs. REF	0.91 (0.43, 1.94)	0.69 (0.33, 1.42)	0.79 (0.33, 1.87)
FP vs. REF	**0.35 (0.17, 0.72)**	**0.47 (0.23, 0.93)**	**0.19 (0.06, 0.57)**
0% vs. REF	1.27 (0.60, 2.68)	0.70 (0.35, 1.42)	0.44 (0.17, 1.19)
0% vs. FP	**3.66 (1.78, 7.49)**	1.50 (0.73, 3.12)	2.34 (0.68, 7.98)

0% vs. 100%	1.39 (0.67, 2.90)	1.02 (0.46, 2.25)	0.56 (0.20, 1.57)
FP vs. 100%	**0.38 (0.18, 0.80)**	0.68 (0.37, 1.25)	**0.24 (0.08, 0.74)**

~~Water~~ Stream Temperature

Maximum 7-day average daily maximum (7-DADMax) stream temperature during the summer of Post 15 (2023) ranged from 9.8 to 16.3 ºC (**Table 16**). In 2023, 7-DADMax ranged from 9.8 to 14.3 ºC in the reference, 11.6 to 16.3 ºC in the 100% treatment, 11.6 to 14.0 ºC in the FP treatment, and 10.2 to 15.6 ºC in the 0% treatment.

Table 16. Maximum 7-day average daily maximum (7-DADMax) stream temperature (ºC) for Post 15 recorded near the F/N break. ~~* asynchronous harvest year (see **Table 3**).~~ An asterisk (*) indicates sites not included in Post 14 & 15 treatment response. A caret (^) indicates WIL-FP-2 was harvested in 2016 and was included as an FP treatment in the Phase III analysis. Data for 2006-2016 reflect values presented in McIntyre et al. (2021).

Site Code	2006 Pre 3	2007 Pre 2	2008 Pre 1	2009 Post 1	2010 Post 2	2015 Post 7	2016 Post 8	2023 Post 15
OLYM-REF	-	11.7	11.8	12.8	11.5	12.4	12.3	14.3
WIL-REF-1	13.3	12.4	12.5	13.4	12.3	13.2	13.6	*
WIL-REF-2	13.2	12.4	13.2	14.6	13.4	13.8	13.6	*
WIL-REF-3	9.2	9.5	9.2	8.9	9.5	10.0	10.5	9.8
CASC-REF	13.9	13.5	13.0	15.3	12.4	14.4	14.3	14.0
OLYM-100%	14.9	13.4	13.4	15.0	13.7	14.5	14.3	14.9
WIL-100%-1	13.0	12.1	12.3	14.3	13.3	13.0	13.0	12.9
WIL-100%-2	12.7	12.0	12.4	14.3	13.2	12.6	12.4	11.6
WIL-100%-3	-	14.6	15.5	19.6	16.0	16.1	15.3	16.3
OLYM-FP	11.1	10.5	10.9	12.4	11.2	12.3	12.0	11.6
WIL-FP-1	11.2	10.3	11.2	14.1	12.7	13.7	13.6	12.1
WIL-FP-2^	13.0	12.2	12.0	13.1	12	13.4	-	14.0 (Post 8)
CASC-FP	12.2	11.7	12.1	12.7	12.1	12.5	12.9	13.9
OLYM-0%	10.4	9.9	9.8	-	11.6	10.6	10.5	10.2
WIL-0%-1	12.0	11.5	11.7	17.5	15.8	12.9	12.8	14.2
WIL-0%-2	14.1	13.3	-	18.6	15.2	14.7	14.8	15.6
CASC-0%	15.1	15.0	16.1	-	19.5	18.4	17.4	13.2

Discussion/Conclusions

Initially, in Post 1 & 2, we observed evidence of increased Coastal Tailed Frog larval densities in the 100% and FP treatments ~~and increased post-metamorph density in the 0% treatment~~ compared to pre-harvest period after controlling for temporal changes in the reference. However, by Post 7 & 8, we estimated declines in all buffer treatments. ~~There was no~~We did not find any evidence of recovery for the species by Post 14 & 15~~, when we estimated a continued decline in Coastal Tailed Frog densities in all buffer treatments.~~. Rather, we ~~Specifically, we~~ estimated ~~a~~ -71%, -95% and -70% declines relative to the reference in stream network-wide larval density in the 100%, FP and 0% treatments, respectively. ~~Note that we had~~We note that we found evidence of a decline in density within the reference between the pre-harvest and Post 14 & 15 periods, but that the within-treatment change in the buffer treatments was greater than that in the references over this same period.

For post-metamorphic Coastal Tailed Frog, we estimated a decline in density for the 100% treatment in Post 1 & 2 compared to pre-harvest period after controlling for temporal changes in the reference, but large increases in density in the 0% treatment. However, similar to our results for larvae, by Post 7 & 8, no evidence existed for an increase in density for any treatment, but we found evidence of a decline in both the 100% and FP treatments. By Post 14 & 15, we had evidence of declines across all buffer treatments, with estimated declines of -98%, -97% and -85% in the 100%, FP and 0% treatments, respectively. We note that ~~these~~ estimated declines in the buffer treatments relative to the reference were driven by an increase in the reference in Post 14 & 15 over pre-harvest densities. Importantly, unlike larvae, post-metamorphic tailed frogs are not restricted to the stream channel, and ~~the declines we~~our ~~estimated~~ density estimates do not account for terrestrial individuals ~~or their movements~~. Changes in riparian conditions may have influenced the proportion of terrestrial individuals versus those that stayed in- or near-stream. ~~Matsuda and Richardson (2005) suggested the possibility of higher post-metamorphic mortality or increased movements and dispersal in clearcut sites.~~

The results from our pre-harvest genetic evaluation revealed high ~~that~~ levels of genetic diversity ~~were high~~ in Coastal Tailed Frog, with little evidence of genetic clustering beyond region. These results suggested ~~, and that~~ large effective population sizes ~~were large~~ (Spear et al., 2011)~~,~~ ~~implying~~ and high levels of connectivity and movement of Coastal Tailed Frogs between drainages. ~~It is possible~~We acknowledge that following upland harvest, tailed frog post-metamorphs may have moved overland into adjacent basins, and/or downstream into an unimpacted reach. The decline we observed in Coastal Tailed Frog at the basin level may be temporary~~, e.g.,~~; that is, ~~if~~ animals ~~successfully~~ may immigrate ~~back~~ into study streams to breed when conditions become more favorable. ~~However, t~~The evaluation of post-harvest effects through Post 14 & 15 is representative of the likely full life span for the species, which is estimated to be as much as 15 to 20 years for the closely-related Rocky Mountain tailed frog, *A. montanus* (Daugherty & Sheldon, 1982).

Similar to our results for the response of Coastal Tailed Frogs to buffer treatments, we found evidence of increased torrent salamander densities only in Post 1 & 2, in this case for all three buffer treatments compared to pre-harvest period after controlling for temporal changes in the reference. However, in Post 7 & 8, we no longer found evidence for increased densities in any

Commented [HB194]: Per Figure 6: The increases are not statistically different from the REF for any of the treatments as indicated by overlapping CI's. This should be said.

Commented [RO195R194]: The pairwise contrasts of change in the treatment versus change in the reference are the basis for strong evidence of an effect. In this cas...

Commented [HB196]: Looking at Tal...

Commented [AM197R196]: For the ...

Commented [HB198]: Per Figure 6, ...

Commented [AK199R198]: Figure 6...

Commented [DM200]: Yellow, ...

Commented [AM201R200]: It was n...

Commented [WB202]: Are these ...

Commented [RO203R202]: Good ...

Commented [HB204]: This is ...

Commented [AM205R204]: We add...

Commented [HB206]: Looking at the...

Commented [AM207R206]: We add...

Commented [HB208]: Per Table 7, th...

Commented [AM209R208]: The onl...

Commented [HB210]: Per Figure 6, th...

Commented [AM211R210]: The onl...

Commented [DM212]: Yellow, ...

Commented [AM213R212]: We are ...

Commented [AJK214]: Chelgren, N.I...

Commented [RO215R214]: AJ, I ...

Commented [HB216]: Please explain...

Commented [AM217R216]: Deleted...

Commented [aa218]: The Daughtery...

Commented [RO219R218]: Good ...

Commented [HB220]: Is this ...

Commented [AM221R220]: The ...

buffer treatment, and instead we had evidence of an estimated 58% decline in the FP treatment. In Post 14 & 15, we estimated an 88% and 80% decline in density for the FP and 0% treatments, respectively.

We suspect that the increase in torrent salamander densities ~~we estimated~~ in Post 1 & 2 may have been at least partially attributable to the presence of stream reaches ~~covered~~ sheltered by dense accumulations of in-channel slash and windthrow, or wood-obstructed reaches, and the way that we accounted for animal densities in these reaches for our estimates of stream network-wide abundance (McIntyre et al., 2018). In Post 1 & 2, we found high densities of torrent salamanders in wood-obstructed reaches. However, the elevated density we observed for torrent salamanders in these reaches did not persist in Post 7 & 8. In fact, we had evidence of a 34% decline in torrent salamander density in wood-obstructed reaches between Post 1 & 2, and Post 7 & 8 (McIntyre et al., 2021). In Post 14 & 15, wood obstructed reaches were so uncommon across all sites that we did not adjust our basin-wide counts by densities in these reach types (see Methods).

Contrary to findings for both Coastal Tailed Frog and torrent salamanders, we lacked evidence of an increase in ~~stream network-wide~~ giant salamander density for any treatment or in any period compared to pre-harvest period after controlling for temporal changes in the reference. In Post 1 & 2, we found evidence of a 65% decline in giant salamander density in the FP treatment. We estimated a similar 53% decline in the FP treatment in Post 7 & 8. In Post 14 & 15 giant salamander density was estimated to decline by 81% in the FP treatment.

~~We are aware of~~A limited number of experimental timber management effectiveness studies ~~that~~ have evaluated ~~the response of~~ stream-associated amphibian responses to ~~upland~~ timber harvest (reviewed in Martin et al., 2021). In a similar experimental study, Jackson et al. (2007) concluded that clearcut timber harvest without riparian buffers had an immediate negative effect on Coastal Tailed Frog populations, that giant salamanders were sensitive to the immediate impacts of upland harvest but that the negative impacts were short-lived (e.g., three years or less), and that torrent salamanders were not greatly affected by timber harvest. However, that study evaluated only the three years following harvest and study findings for Coastal Tailed Frog were based on limited observations.

In another BACI-designed study in western Washington, O'Connell et al. (2000) observed no difference in larval tailed frog densities among variable width buffers. However, this study only monitored amphibian densities for two years post-harvest and had limited statical power. The short-term efforts of many experimental timber harvest studies seem to be~~may be~~ limited in their ability to detect a treatment response for stream-associated amphibians. In fact, had we relied on the results from the first two years post-treatment, we may have erroneously concluded a positive effect of timber harvest for some taxa and buffer treatments. Effects of silvicultural treatments on amphibians, particularly those with relatively long lifespans such as the species included in this study, may not be realized until many years after treatment (Hawkes & Gregory, 2012). ~~Here~~The Trask River Watershed Experiment in the Coast Range of Oregon found some evidence for a negative effect for occupancy probability of giant salamander and Coastal Tailed Frog in streams adjacent to clearcuts during the three years after harvest ~~for occupancy probability of giant salamander and Coastal Tailed Frog in streams adjacent to clearcuts~~, but no or weaker effects on plots downstream from harvest (Duarte et al., 2023).

Commented [aa222]: I would use the verb sheltered to imply the potential mechanism here even though we don't know it.

Commented [aa223]: Must we repeat this phrase every time. Can we not have a statement early on that says that values in x category that are described should be assumed to have been controlled for temporal change in the reference. It would save a ...

Commented [AM224R223]: This writing is consistent with previous reports ...

Commented [HB225]: What about the other treatments? Also, per Figure 12 there ...

Commented [AM226R225]: The only place to discern significance is in the tables ...

Commented [Q(227]: is upland use as opposed to riparian here?

Commented [aa228R227]: Maybe say "adjacent upland timber harvest"

Commented [AM229R227]: Edited.

Commented [HB230]: Per Figure 8, the 0% (clearcut) treatment post-meta densities ...

Commented [AM231R230]: The only place to discern significance is in the tables ...

Commented [aa232]: A power analysis of O'Connell et al. (2000) was done, which ...

Commented [RO233R232]: Added statistical power limitation.

Commented [AJK234]: Duarte et al. 2023 is worth discussing here, although I ...

Commented [aa235R234]: Agreed, you have to walk the discussion of Duarte ...

Commented [OBRA(236R234]: I took a shot at navigating this. Please review.

Commented [HB237]: This is currently an important issue for many of our studies. ...

Commented [AM238R237]: We expand on this in the next paragraph (Haw ...

Our research findings are consistent with an increasing body of evidence concluding the negative effects of timber harvest on stream-associated amphibians. We are aware of two experimental studies that monitored stream-associated amphibian response ~~to timber management~~ over a longer period following timber harvest and that had sufficient data from which to draw conclusions. The longest ongoing effort we are aware of is a long-term research effort by Olson and Ares (2022) to evaluate the response of multiple aquatic species to upland timber thinning with variable width no-entry riparian buffers (~ 70 m, 6 m, and a variable-width buffer with a 15-m minimum width) and a wider thin-through managed buffer in eight study sites in western Oregon. Olson and Ares (2022) reported a delayed negative response developing 10 years after upland thinning of second-growth forest, and additional effects five years after a second upland-forest thinning. Five years after the second thinning, higher densities of Coastal Giant Salamander and torrent salamanders (including Cascade and Southern Torrent Salamanders *R. variegatus*) were detected in no-entry ~70 m wide riparian buffers, compared with lower densities for these species in the other buffers (narrower, and thinning versus clearcut~~-through~~). Unfortunately, a species-specific statistical analysis was not possible for Coastal Tailed Frog as a part of this effort due to low and variable samples sizes (Olson et al., 2014). In another study, Hawkes and Gregory (2012) evaluated tailed frog post-metamorphs ~~and~~ in riparian (5 meters from stream) and upland areas (100 meters from stream), finding that relative abundance declined in clearcut upland habitats 2- and 10-years following timber harvest but not in~~t~~ riparian areas~~?~~.

Our findings are also consistent with several retrospective observational studies that have concluded that tailed frog is less abundant in stands with a history of timber harvest (Ashton et al., 2006; Hawkes & Gregory, 2012; Stoddard & Hayes, 2005; Welsh & Lind, 2002) and another that found that tailed frog occupancy was positively associated with stand age (Kroll et al., 2008). However, other retrospective studies ~~have concluded~~observed a lack of effect of clearcut harvest or stand age on Coastal Tailed Frogs (Matsuda & Richardson, 2005; Richardson & Neill, 1998). We cannot say with certainty why the findings from these latter studies differ from our own. However, Richardson and Neill (1998) evaluated occupancy rather than density, so declines in density would not have been noted. Another possibility is that both these studies were conducted in sites located farther north than our study area, in British Columbia, Canada. It is possible that the response of these species to timber harvest varies with latitude, i.e., the species may respond differently depending on the location within its geographic range (Hayes & Quinn, 2015). Associations with old-growth or late-seral stands may be strongest in the southern range of the distribution (Gilbert & Allwine, 1991), a correlation that is likely to be further intensified by climate change.

Not all evaluations have concluded a negative response of stream-associated amphibians to timber harvest, including ~~evaulations~~evaluation of buffer effectiveness specifically (Martin et al., 2021). Conclusions from retrospective studies evaluating the impacts of forest management on torrent and giant salamanders have been inconsistent (Kroll, 2009). ~~-~~Several studies concluded that torrent salamanders occur in lower abundances in managed stands compared with forest ~~old-growth~~ stands that have not previously been harvested (Bury et al., 1991; Corn & Bury, 1989; Russell et al., 2005). However, some researchers detected no relationship between torrent salamander occupancy or relative abundance and stand age (Jackson et al., 2007). Still others have found that torrent salamander numbers and occupancy were greatest in mid-rotation stands (Russell et al., 2004). In retrospective efforts that studied ~~included~~ the relationship between giant

Commented [JM239]: What kind of timber harvest?

Commented [AM240R239]: This is just a general statement about timber harvest rit large.

Commented [JM241]: Is timber management the same as timber harvest? Does timber management include harvest other than complete basin clear cuts?

Commented [AM242R241]: Deleted, and timber management considerations are outlined in the discussions of the two studies below.

Commented [Q(243]: amphibian?

Commented [AM244R243]: Yes, see results presented, but the study included more than just amphibs.

Commented [Q(245]: not sure what this means?

Commented [AM246R245]: Edited.

Commented [aa247]: We need to clarify that the nature of the upland areas in the Hawkes and Gregory (2012) study. I think this is Tim's point in a separate earlier comment about the same. My recollection of Hawkes and Gregory is that they had too few post-metamorphic tailed frogs to say anyth ...

Commented [OBRA(248R247]: I ...

Commented [HB249]: Maybe discuss ...

Commented [AM250R249]: The ...

Commented [HB251]: Table 6 presen ...

Commented [AM252R251]: Table 6 ...

Commented [HB253]: Another ...

Commented [RO254R253]: Indeed, ...

Commented [WB255]: What about ...

Commented [RO256R255]: I did a ...

Commented [JM257]: How old is old ...

Commented [AM258R257]: The ...

salamander populations ~~relationship to related to~~and stand age, Ashton et al. (2006) observed an increased relative abundance in streams in late-seral forests, and Kroll et al. (2008) found a positive association between giant salamander occupancy and stand age. Conversely, other evaluations have failed to find a relationship between giant salamander abundance (not adjusted for detection) and stand age (Bury et al., 1991; Leuthold et al., 2012). Finally, others concluded that the response of giant salamanders to timber harvest was site dependent, e.g., populations in low gradient channels being more likely to respond negatively to timber management (Corn & Bury, 1989; Murphy & Hall, 1981). However, unlike experimental BACI studies, retrospective efforts cannot account for historic patterns of occupancy or abundance at study sites, and most retrospective studies have not attempted to account for detection probability in their statistical comparisons. Both considerations should be taken into account when interpreting the findings from retrospective efforts.

To maximize our ability to detect changes in abundance and increase the certainty of our conclusions, we adjusted our counts from light-touch sampling for the probability of detection. This allowed us to control for the possibility that treatment may confound our ability to detect amphibians. Occupancy, density and abundance estimates adjusted for detection can be used to confidently compare populations through time and space (Ficetola et al., 2018; Guillera-Arroita et al., 2014; MacKenzie & Kendall, 2002; Mazerolle et al., 2007; McIntyre et al., 2012), and the statistical methods we used to adjust amphibian density have been validated in other amphibians studies (Chelgren et al., 2011; McKenny et al., 2006; Price et al., 2011). We surveyed study sites with an ~~intensity~~ effort that surpasses ~~the intensity~~that of sampling in many other similar studies, with a minimum of 50% of the stream channel network sampled~~. Smaller sites were proportionally sampled with greater intensity~~The stream length sampled was proportionally greater in smaller sites than larger sites. However, ~~L~~light-touch sampling was chosen as a well-established method that ~~to reduce the~~ has less impact ~~of sampling~~on habitat (Quinn et al., 2007). Furthermore, sampling was restricted to a single effort by site and year.

Nevertheless, low counts for Coastal Tailed Frogs, especially in the 0% treatments, led to wide credible intervals and numerically unstable model fits. As such, we were unable to account for detection probabilities in our analysis for Coastal Tailed Frog larvae and post-metamorphs. Despite that issue, the consistency in our study findings across Phase II and Phase III and across larval and post-metamorphic life stages for Coastal Tailed Frog bolsters confidence in our result of a lagged decline in abundance. Low counts in later post-harvest years were almost certainly related to decreased densities at these sites. This conclusion was supported by the fact that additional intensive sampling efforts in Post 7 & 8 (i.e., kick-net and nocturnal surveys) designed to increase tailed frog tissue samples for use in genetic and stable isotopes analyses failed to find numbers of frogs that would suggest our systematic sampling was somehow less effective in this later sample period.

Implications of Forest Management Activities

Although many research efforts have revealed a positive relationship between stream-associated amphibian populations and stand age (Ashton et al., 2006; Pollett et al., 2010; Stoddard & Hayes, 2005; Welsh et al., 2005; Welsh & Lind, 2002), forest age alone likely does not determine amphibian species' occupancy and abundance per se. Rather, occupancy and abundance is likely intrinsically linked to microclimate and microhabitat conditions that tend to vary in relation to

Commented [JM259]: How do you adjust for detection?

Commented [AM260R259]: How we adjusted for detection are described in our methods but there was not attempt to adjust for detection in these studies.

Commented [DM261]: Yellow, Suggest you discuss how sample intensity may influence habitat and population. E.G. At WIL-FP-1 the reach is 325 m long and sample intensity is 100% of the available habitat? Also consider the repeated disruption of habitat may have a cumulative impact over time on both habitat and population recovery

Commented [RO262R261]: Added statement about how sampling effort was proportionally greater at smaller sites.

Commented [HB263]: Credible intervals?

Commented [RO264R263]: Correct! Thanks.

Commented [DM265]: Red Suggest clarifying that your confidence is in measured trend or change. Confidence in causal factors of change are uncertain given there are multiple factors in addition to harvest categories. What harvest factors actually may have caused change? E.g. Temperature along reach, length of stream subject to slash, reduced canopy, and other factors. Also portion reach or actual length disturbed by sampling which is highly variable among sites.

Commented [RO266R265]: Highlighted that the confidence is in the trend, not the secondary causes. I would argue that given the BACI design, we can see evidence of harvest as the cause. It is the secondary changes in habitat conditions that we can't disentangle with current study design.

forest age (Diller & Wallace, 1994; Welsh, 1990). Amphibians have been associated with stream and riparian conditions including stream temperature, overstory canopy, primary productivity, wood loading, sediment retention, flow dynamics, stream and bank morphology, and nutrients, all metrics that likely impact occupancy and abundance at the microhabitat level.

The mechanistic links between timber harvest and riparian stands, wood loading, channel characteristics, stream temperature and cover, discharge, sediment and nutrients have been well documented in the literature (e.g., Moore et al., 2005; Richardson & Béraud, 2014; Yeung et al., 2017). Results for stream-associated amphibians, however, appear somewhat more complex. This is due in part to the fact that these species are long-lived. As such, response of these species in the short-term would largely reflect movement in or out of study sites. Longer-term impacts reflect the additional influence of timber harvest on reproduction and onsite survival. Our study was designed to evaluate treatment effects, not the mechanisms behind potential changes in amphibian ~~abundance~~densities. However, because Phases I and II (McIntyre et al. 2018; 2021) also evaluated changes in stream temperature, overstory canopy, primary productivity, wood loading, sediment retention, flow dynamics, stream and bank morphology, and nutrients, we can suggest potential mechanisms behind the changes we observed in amphibian densities. For a thorough evaluation of potential relationships between changes in microclimate and microhabitat conditions relative to amphibian response, see McIntyre et al., 2021, Chapter 9 – *Stream-associated Amphibians*.

The relationship between reductions in overstory canopy and stream-associated amphibians is complex. Increased light and stream temperatures have been associated with increased instream primary productivity (Kiffney et al., 2003), which may have beneficial consequences for stream-associated amphibians either directly (for grazing Coastal Tailed Frogs; Kiffney & Richardson, 2001) or indirectly, through increased macroinvertebrate prey availability (Hawkins et al., 1983). Conversely, increased sunlight and/or stream temperature can cause a shift in the species composition of periphyton away from diatoms (Beschta et al., 1987), the primary food source for larval tailed frogs (Altig & Brodie, 1972; Nussbaum et al., 1983), which could have negative consequences if food availability is limited. As a part of Phase I, we detected no changes in biofilm or periphyton in harvested sites in the post-harvest period (McIntyre et al., 2018, Chapter 13 – *Biofilm and Periphyton*). Consistent with these findings, our analysis of stable isotopes (McIntyre et al., 2021, Chapter 8 – *Stable Isotopes* in this report) failed to find evidence that harvest in the RMZ resulted in a change in the primary energy source supporting food webs in our small streams. Overall, our results are not consistent with findings for larger and wider stream channels where canopy modification increases trophic support from autotrophic sources (Kaylor & Warren, 2017). Based on our lack of evidence for a change in instream primary ~~production~~ producer biomass in the post-harvest period we do not believe that the stream-associated amphibian response we observed was related to change in periphyton production. However, we did not evaluate periphyton species composition and do not know if the proportion of nutritious diatoms in the periphyton matrix changed as a function of treatment.

All focal amphibians have been found to utilize cool waters or avoid areas with higher stream temperatures (Bury, 2008; de Vlaming & Bury, 1970; Karraker et al., 2006; Pollett et al., 2010). The critical aspect of stream temperature is whether the degree of temperature increase over pre-harvest conditions translates to a biologically risky condition. Currently, very limited critical thermal maximum or stress temperature information exists for stream-associated amphibians. Of

Commented [WB267]: You could also point to the canopy cover measurements and stream level shade to talk more about the limited ability for light to reach the stream in these headwater systems.

Commented [AM268R267]: Given that this is not focus of this current phase, while we considered adding this, I would encourage readers to refer to Phase I and II reports for this level of detail.

Commented [DM269]: Yellow,
You did not estimate "production"; rather you measured biomass or chlorophyl; not the same. Literature shows you can have same biomass, but high turnover resulting in increased production.

Commented [RO270R269]: Clarified "primary producer biomass" not primary production.

Commented [JM271]: How cool is cool? What are the higher stream temperatures?

the taxa included in our study, we do have some information for tailed frog. Coastal Tailed Frog tadpoles had a mean critical thermal maximum (CTmax) of 29.5 °C (Cicchino et al., 2023). In a summary of known oviposition sites, Karraker and colleagues (2006) found that the stream temperature rarely exceeded 14 °C. In a laboratory trial of behavioral responses in thermal gradient chambers, de Vlaming and Bury (1970) found that first year Coastal Tailed Frog larvae congregated in water with temperatures below 10 °C. In a limited field observational study conducted at a single study stream, de Vlaming and Bury (1970) noted that larvae avoided areas of the stream exposed to direct sunlight where temperatures varied between 15 and 20 °C on a clear and sunny summer day, but were found in nearby shaded areas that varied between 13 and 16 °C. Thermal tolerances for torrent salamanders are among the lowest for amphibians (Bury 2008). In laboratory experiments, Olympic Torrent Salamander selected water between 12 and 14 °C (Jones et al. 2005). Likewise, Pollett et al. (2010) found that Cascade Torrent Salamander was nearly absent from streams where water temperatures were ≥14 °C for ≥35 consecutive hours. CTmax have not been estimated for the torrent salamander species included in this study. However, Bury (2008) reported CTmax for Southern Torrent Salamander (*R. variegatus*) as 26.7 °C for larvae and 27.9 °C for adults. However, while CTmax is a valuable metric for understanding lethal temperatures (Hutchison & Dupré, 1992) ~~(see Hutchinson and Dupré, 1992)~~ it does not reflect the potential sublethal effects of thermal stress on these species (Bury 2008).

In Phase II, ~~W~~we observed an increase in July–August daily maximum stream temperatures in all buffer treatments relative to the reference (mean increase of as much as 1.1, 1.1 and 3.8°C in the seven-day average daily maximum temperature response for the 100%, FP, and 0% treatments, respectively, across all post-harvest years), and only the 100% treatment did not differ statistically from the reference nine years post-harvest (McIntyre et al., 2021, Chapter 4 – *Stream Temperature and Cover*). ~~The~~ This previously reported ~~increased~~ increase in stream temperatures ~~we observed in all buffer~~in treatment streams may have ~~affected movement or reproductive success over time~~contributed to the observed declines in amphibian density, especially for Coastal Tailed Frogs and torrent salamanders. Note, however, that post-treatment temperatures did not exceed the CTmax estimates for Coastal Tailed Frog or Southern Torrent Salamander (CTmax has not been evaluated for the torrent salamander species including in this study).

Treatment-related inputs of wood may have impacted habitat quality by increasing the retention of fine sediments, which can negatively affect amphibian occurrence and density (Diller & Wallace, 1996, 1999; Dupuis & Steventon, 1999; Hawkins et al., 1983; Stoddard & Hayes, 2005; Welsh & Lind, 1996; Welsh & Ollivier, 1998). We observed an increase in fine and sand substrates in all buffer treatments in the Post 7 & 8, though the increase was not statistically significant in the 100% treatment (McIntyre et al., 2021, Chapter 7 – *Stream Channel Characteristics*). Fine sediment can modify grazing surfaces and availability of retreats for Coastal Tailed Frog larvae (Gomi et al., 2001; Hassan et al., 2005; Jackson & Sturm, 2002; Maxa, 2009), which are specialized periphyton grazers that preferentially select smooth, exposed rocks for grazing and daytime retreats (Altig & Brodie, 1972).

Timber harvest may impact stream-associated amphibian movement, stream-network wide or between drainages, altering emigration or immigration (Dupuis & Steventon, 1999; Pollett et al., 2010; Stoddard & Hayes, 2005; Vesely & McComb, 2002). Chelgren et al. (2017) observed a downstream biased movement for Coastal Tailed Frog larvae and aquatic Coastal Giant

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Commented [DM272]: Yellow, Ok, but can these changes be linked to amphibians? Simple changes are meaningless. Lethal and sublethal temperature effects on poikilotherms are functionally related to the magnitude and duration of exposure. Changes in the mean temperature for a treatment group (i.e., site differences masked) is unlikely to be causally related to response. Hence saying "increased stream temperatures we observed in all buffer treatment streams may have affected movement or reproductive success over time" is speculation.

Commented [MAP(273R272]: We more clearly articulate that we are comparing observations of treatment response to our amphibian density response.

Commented [HB274]: For what time period? If we have temps for each time per ...

Commented [AM275R274]: The study objective as written and approved was to ...

Commented [HB276]: Yet the Poat 7 & 8 Frog larvae and Post meta density chang ...

Commented [RO277R276]: For post-metamorphs, the FP and the 100% were ...

Commented [JM278]: Was this measures? How much was the increase?

Commented [RO279R278]: It was measured in Phase II (as cited). The ...

Commented [DM280]: Yellow, You did not detect sig. change, yet you ...

Commented [RO281R280]: We are making a connection to a parameter that w ...

Salamanders in a before-after timber harvest experiment in the Oregon Coast Range using marked individuals. However, movement may decline with an increasing density of log jams (Wahbe & Bunnell, 2001). Stream-associated amphibians have been found to resist movement across even relatively small (i.e., 13-m) gaps in stream channel riparian canopy (Cecala et al., 2014)~~, and researcher has shown that post-metamorphic amphibians travel farther away from streams in old-growth forests than in recent clearcuts (Fagan, 2002; Grant et al., 2007).~~. If instream and/or terrestrial environments are unfavorable for movement, isolating amphibian populations or limiting opportunities for immigration by individuals from outside the area, then the population may decline through time.

Notably, however, we had evidence of high levels of gene flow among sites for Coastal Tailed Frogs and Coastal Giant Salamanders in both the pre- and post-harvest periods (Spear et al., 2019). Genetic structure is likely influenced by surrounding basins in addition to site-level treatment effects, providing some support for the hypothesis that site-level declines in densities for these species may be mediated by immigration back into the impacted area over time. However, changes in genetic diversity in response to a disturbance are often not detected until several generations post-impact (Hoban et al., 2013). Furthermore, Cope's Giant Salamander had much more restricted levels of gene flow overall, although there was genetic connectivity among nearby sites. Finally, we did not include the three species of torrent salamanders in our genetic investigation of treatment impacts. However, Emel et al. (2019)~~, one genetic study~~ found that the Columbia Torrent Salamander had a more restricted geographic range and significantly lower average within-population genetic diversity than another closely related torrent salamander species and that reduced gene flow reflected habitat fragmentation and inbreeding (Emel et al., 2019).

~~Pre-treatment occupancy of stream-associated and under less protective regulations.~~ Stream-associated amphibians have ~~C~~continued to ~~occupancy~~ occupy ~~of amphibian populations in our study sites, located within~~ forested stands with a history of ~~prior~~ timber management activities, as evidenced by amphibian presence across our study sites in the pre-treatment period~~, does provide evidence of continued occupancy of previously harvested stands throughout our study area to date~~. ~~Occupancy has continued under historic timber harvest practices and continues now, which may cause some readers to speculate that their continued persistence in watershed is guaranteed, since current forest practices are more protective than historical practices.~~ However, we have ~~have~~ strong evidence of a post-treatment decline in amphibian ~~abundance~~ density for some species and treatments, which we first noted in Post 7 & 8 and that continued in Post 14 & 15, with ~~, with~~ no evidence of recovery for any species in any treatment between those ~~post-harvest~~ periods. ~~Further, we know from our extensive work in managed forests over the last 20 years, that some streams that appear otherwise suitable, do not support particular species~~~~stream-associated amphibians.~~

~~Research supports the conclusion that riparian buffers can ameliorate the impacts of timber harvest on stream-associated amphibians (Jackson et al., 2007; Olson et al., 2014; Russell et al., 2004). However, at least for stream-associated amphibians, the ameliorating effects of riparian buffers depend on the size and extent of the riparian buffers (Olson & Ares, 2022).~~ Our study results showed a ~~We detected~~ substantial decline~~s~~ in density for: Coastal Tailed Frog larvae and post-metamorphs across all buffer configurations evaluated; ~~, for~~ torrent salamanders in the FP and 0% treatments~~;~~, and ~~for~~ giant salamanders in the FP treatment. Considering these results in

Commented [JM282]: How old is old growth? Is a 100 year old alder or is a 1000 year old cedar old growth? Is an 85 year old spruce that is five feet in diameter and 150 feet tall old growth?
Commented [WB283R282]: Is mature forest better here?
Commented [MAP(284R282]: deleted
Commented [JM285]: How recent?
Commented [MAP(286R285]: deleted
Commented [DM287]: Yellow
The gene flow shows connectivity to population (i.e., large-scale than study basin). So movement in highly likely and why they move cannot be assumed due timber harvest given the multiple factors operating at different scales within the population boundary.
Commented [AM288R287]: We agree. See first sentence. We are not assuming ...
Commented [aa289]: I think the ...
Commented [AM290R289]: It is not ...
Commented [aa291]: I really have iss ...
Commented [RO292R291]: Thank y ...
Commented [DM293]: Yellow, ...
Commented [AJK294R293]: The ...
Commented [WB295]: There is a lot ...
Commented [RO296R295]: Substan ...
Commented [AJK297]: This statemen ...
Commented [RO298R297]: Clarifie ...
Commented [aa299]: Unclear to me ...
Commented [AM300R299]: deleted
Commented [AJK301]: The same is t ...
Commented [AM302R301]: Deleted.
Commented [DM303]: Red ...
Commented [AM304R303]: The thr ...

combination leads us to conclude that even the most protective riparian buffer evaluated in this study (i.e., the 100% buffer) was inadequate to meet the Overall Performance Goals to *not significantly impair the capacity of aquatic habitat to support the long-term viability of other covered species* (i.e., the FP-designated amphibians; FP HCP, Schedule L-1, Appendix N), at least at this spatial scale (Type Np stream basin) and this timeline (15 years post-harvest), ~~.~~ where amphibian density was used as a surrogate for "viability". ~~In their efforts to evaluate riparian buffer effects on stream-associated amphibians, Olson and Ares (2022) found evidence of long-term negative effect with upland forest thinning and variable-width riparian buffers with a minimum 15-m width. Similar to our study, the mechanism behind the change was unclear, however, the authors conclude that either lag-time or cumulative effects of factors associated with treatments were developing many years after harvest (Olson & Ares, 2022).~~

Recommendations

The broad distribution of our study sites gave us a unique and important opportunity to better understand the impacts of forest management actions on stream-associated amphibians in occupied basins across western Washington. Coupling our amphibian demographic study with an evaluation of genetic structure (Spear et al., 2011; 2019) allowed us to interpret our basin-scale amphibian responses in context of the larger landscape-scale at which these species appear to operate. Nonetheless, we observed a substantial negative response, especially for Coastal Tailed Frog, to timber harvest in Post 7 & 8 that continued through Post 14 & 15. Considering the result of our demographic evaluation in combination with our previous genetic efforts, we believe an effort to evaluate the status of FP-designated amphibians at broader scales throughout western Washington as a part of a future Forest Practices Adaptive Management Program investigation is warranted. An effort could be added to Extensive Monitoring, a Program that is currently under development. Alternatively, based on the results from the Phase II effort, the Landscape and Wildlife Advisory Group (LWAG) proposed a *Coastal Tailed Frog Extensive Status Project* that could be done independently if desired (CMER Work Plan 2024). The study design for the *Water Temperature and Amphibian Use in Type Np Waters with Discontinuous Surface Flow in Western Washington Project* is currently being developed and is another opportunity to inform how these species are associated with discontinuous flow and temperature in Type Np streams. The results to date provide evidence of a negative and sustained effect of upland timber harvest on stream-associated amphibians in hard rock lithologies. However, without a landscape effort to evaluate occupancy throughout western Washington we are unable to evaluate the long-term consequences at broader spatial scales. Understanding landscape trends will complement our understanding of FP-designated amphibians at the scale of harvest unit.

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Commented [DM305]: Red,
As noted at beginning of this report, you have not defined Viability, nor have you identified criteria for assessing viability. You have not shown how any response metric is related to population viability. E.G>, viability commonly relates to the risk for population ...
Commented [AM306R305]: Long-te ...
Commented [Q(307]: i have not read ...
Commented [AM308R307]: Long-te ...
Commented [JM309]: How long term ...
Commented [AM310R309]: We ...
Commented [aa311]: My recollection ...
Commented [AM312R311]: Deleted ...
Commented [aa313]: I say this is a b ...
Commented [RO314R313]: Because ...
Commented [DM315]: Yellow, ...
Commented [AM316R315]: We ...
Commented [HB317]: This seems lik ...
Commented [RO318R317]: Clarifie ...
Commented [AM319R317]: There ...
Commented [DM320]: Agree ...
Commented [RO321R320]: Thanks.
Commented [HB322]: Perhaps re ...
Commented [RO323R322]: This is ...
Commented [JM324]: Good idea.
Commented [O(325R324]: Thanks
Commented [WB326]: Not sure why ...
Commented [O(327R326]: I added i ...
Commented [WB328]: How does ...
Commented [RO329R328]: Added ...
Formatted: Font: Italic
Commented [DM330]: Red, ...
Commented [AM331R330]: We are ...

[Article]. *Global Ecology and Biogeography*, *11*(2), 169-178. <Go to ISI>://BIOSIS:PREV200200258811

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Appendix

Appendix Table 1. Site codes to reference between current report (Phase III) and previous report phases (Phase I, McIntyre et al., 2018 and Phase II, McIntyre et al., 2021).

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Block	**Treatment**	**Phase I & II Site Code**	**Phase III Site Code**
Olympic	Reference	OLYM-REF	OLYM-REF
	100%	OLYM-100%	OLYM-100%
	Forest Practices	OLYM-FP	OLYM-FP
	0%	OLYM-0%	OLYM-0%
Willapa	Reference	WIL2-REF2	WIL-REF-1*
	Reference	WIL2-REF2	WIL-REF-2*
	Reference	WIL3-REF	WIL-REF-3
	100%	WIL2-100%	WIL-100%-1
	100%	WIL1-100%	WIL-100%-2
	100%	WIL3-100%	WIL-100%-3
	Forest Practices	WIL1-FP	WIL-FP-1
	Forest Practices	WIL2-REF1	WIL-FP-2^
	0%	WIL1-0%	WIL-0%-1
	0%	WIL2-0%	WIL-0%-2
South Cascade	Reference	CASC-REF	CASC-REF
	Forest Practices	CASC-FP	CASC-FP
	0%	CASC-0%	CASC-0%