STATE OF WASHINGTON
FOREST PRACTICES BOARD

PO Box 47012
Olympia, WA 98504-7012

Regular Board Meeting – February 12, 2020

Natural Resources Building, Room 172, Olympia

Please note: All times are estimates to assist in scheduling and may be changed subject to the business of the day and at the Chair's discretion. The meeting will be recorded.

DRAFT AGENDA

9:00 a.m.	**Welcome and Introductions** Safety Briefing – Patricia Anderson, Department of Natural Resources (DNR)
9:05 a.m.	**Approval of Minutes** *Action: Consider approval of November 13, 2019 meeting minutes.*
9:10 a.m.	**Report from Chair**
9:25 a.m.	**Public Comment** – This time is for public comment on general Board topics.
9:45 a.m.	**State Auditor Office Adaptive Management Program Performance Audit -** Bill Wright and TBD, State Auditor's Office
10:05 a.m.	**Introduction of Center for Conservation Peacebuilding** – Francine Madden
10:25 a.m.	**Federal Services –** Brad Thompson & Jennifer Quan
10:45 a.m.	**Break**
11:00 a.m.	**Water Typing Rule Committee Update –** Bob Guenther, Committee Chair
11:15 a.m.	**Public Comment on Committee's Recommendations**
11:25 a.m.	**Water Typing Rule Committee Update –** Bob Guenther, Committee Chair *Action: Consider recommendations.*
11:40 a.m.	**Water Typing Rule Staff Update** – Marc Engel, DNR
12:00 p.m.	**Lunch**
1:00 p.m.	**Public Comment** – This time is for public comment on general Board topics for those that were not able to attend the morning session.
1:15 p.m.	**Current Status of Lidar Acquisition for Forest Lands** – Abigail Gleason, DNR, Washington Geological Survey
1:35 p.m.	**WFPA Presentation on Proposed Type N Buffer Study –** Darin Cramer, Washington Forest Protection Association
2:10 p.m.	**Adaptive Management Program Type N Experimental Buffer Treatment – Genetics Study** – Aime McIntyre, Department of Fish and Wildlife
2:30 p.m.	**Public Comment on Type N Experimental Buffer Treatment – Genetics Study**
2:40 p.m.	**Adaptive Management Program Type N Experimental Buffer Treatment – Genetics Study** – Mark Hicks, AMPA *Action: Consider recommendations.*
2:55 p.m.	**Adaptive Management Program Extensive Riparian Status and Trends Monitoring – Temperature Study** – Bill Ehinger, Department of Ecology
3:05 p.m.	**Public Comment on Extensive Riparian Status and Trends Monitoring – Temperature Study**

3:15 p.m.	**Adaptive Management Program Extensive Riparian Status and Trends Monitoring – Temperature Study** – Mark Hicks, AMPA *Action: Consider recommendations.*
3:30 p.m.	**Break**
3:45 p.m.	**Adaptive Management Program Hardwood Conversion Study** – Mark Hicks, AMPA
4:05 p.m.	**Public Comment on Hardwood Conversion Study**
4:15 p.m.	**Adaptive Management Program Hardwood Conversion Study** – Mark Hicks, AMPA *Action: Consider recommendations.*
4:30 p.m.	**Aerial Herbicides in Forestlands legislative report –** DNR & Department of Agriculture
4:50 p.m.	**Staff Reports** A. **Adaptive Management** – Mark Hicks, AMPA B. **Compliance Monitoring –** Garren Andrews, DNR C. **Small Forest Landowner Office Update -**Tami Miketa, DNR D. **TFW Policy Committee Update** – Terra Rentz and Curt Veldhuisen, Co-chairs E. **Upland Wildlife Update –** Gary Bell, Washington Department of Fish and Wildlife
5:05 p.m.	**2020 Work Planning** – Marc Engel, DNR *Action: Consider any changes as a result of the days meeting.*
	Executive Session To discuss anticipated litigation, pending litigation, or any other matter suitable for Executive Session under RCW 42.30.11.

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Meeting materials and subject presentations are available on Forest Practices Board's website.
https://www.dnr.wa.gov/about/boards-and-councils/forest-practices-board

Members Present
Stephen Bernath, Chair, Department of Natural Resources
Ben Serr, Designee for Director, Department of Commerce
Bob Guenther, General Public Member/Small Forest Landowner
Brent Davies, General Public Member
Carmen Smith, General Public Member/Independent Logging Contractor
Dave Herrera, General Public Member
Jeff Davis, Designee for Director, Department of Fish and Wildlife
Maia Bellon, Department of Ecology
Noel Willet, Timber Products Union Representative
Kelly McLain, Designee for Director, Department of Agriculture
Paula Swedeen, General Public Member
Tom Nelson, General Public Member

Staff
Joe Shramek, Forest Practices Division Manager
Marc Engel, Forest Practices Assistant Division Manager
Patricia Anderson, Rules Coordinator
Phil Ferester, Senior Counsel

WELCOME AND INTRODUCTIONS
Chair Bernath called the Forest Practices Board (Board) meeting to order at 9 a.m. Introductions of Board members and staff were made.

APPROVAL OF MINUTES
MOTION: Bob Guenther moved the Forest Practices Board approve the August 14, 2019 meeting minutes.

SECONDED: Maia Bellon

Board Discussion:
None.

ACTION: Motion passed unanimously.

REPORT FROM CHAIR
The report from the Board Chair included:
- The State Auditor's Office is currently scoping the Adaptive Management Program's (AMP) performance audit project.
- Forest Practice Program's budget proposals for the 2020 legislative session include a correction of a fund source shift that created a budget shortfall; facilitation work by the Center for

Conservation Peacebuilding; additional staff in the Small Forest Landowner Office; and the development of a voluntary programmatic northern spotted owl safe harbor agreement.

- The SSB 5597 workgroup addressing the aerial application of pesticides on forestlands has met several times in locations around the state. A report will be provided to the legislature by the end of 2019.
- An Environmental Protection Agency Exchange Network grant was awarded to DNR last April for $200,000. This will fund a pilot project to assess efforts to convert DNR's hydrography layer into the National Hydrography Dataset.

PUBLIC COMMENT

Ken Miller, Washington Farm Forestry Association (WFFA), recapped the efforts put into WFFA's western Washington small forest landowner riparian alternate plan template proposal. He said TFW Policy Committee (Policy) took four and a half years to determine that the proposal isn't eligible for an alternate plan template in whole, or in part. He said many folks in Policy are not comfortable accepting WFFA's science review, which they believe is a process foul over the approach to evaluate their science. He said the odds are 50/50 on whether the Board will receive recommendations by the August 2020 Board meeting. He ended by saying they were not giving up and will continue no matter how long it takes.

Elaine Oneil, WFFA, said it was a shock to hear that Policy would not be evaluating any of the science included in their proposal initiation since the science track did not include a review by the Cooperative Monitoring, Evaluation, and Research Committee (CMER). She said by not evaluating the science utilized in their proposal makes the whole effort a complete waste of time. It took WFFA a year to develop and an investment of a lot of money – both WFFA funds for the supporting science and AMP funds which paid for an external science review. She said they believe a fix may be forthcoming in Policy but if not, the Board could expect a petition for Board intervention at the February 2020 Board meeting.

WATER TYPING SYSTEM BOARD COMMITTEE RECOMMENDATIONS

Committee Chair Guenther thanked the Water Typing Rule Committee (committee) members and those attending the meetings for their hard work to develop recommendations. The recommendations are outlined in the committee's memo dated November 5, 2019.

Recommendation #1 – Clarify the goals and targets for the water typing system rule. Board member Swedeen said because of the complexity of the issues, stakeholders agreed that defining the goals of the rule and the intent of the Forest Practices Habitat Conservation Plan (FPHCP) as it relates to fish habitat is needed. She also suggested that third-party facilitation will help define the goals and help get folks on the same page.

Recommendations #2/3 – Request DNR to re-do the potential habitat break (PHB) spatial analysis and engage with Policy leads during the PHB and the anadromous fish floor (AFF) spatial analyses. Board member Nelson said these two recommendations show support for effective collaboration during the analyses and to ensure the communication lines remain open for feedback.

Recommendation #4 – Delay the adoption of the rule for eastern Washington and consider phasing the PHB validation study to start in eastern Washington. Board member Herrera said a workgroup will be formed to assess the feasibility of using additional eastern Washington data to supplement the current PHB data set. Acknowledging that this task may take some time, the eastern Washington tribes recommended considering administrative steps to protect fish habitat in eastern Washington in the interim. Committee consensus occurred on the first part of the recommendation (obtaining additional data), but not for implementing the proposed administrative steps.

Recommendation #5 – Request CMER develop revised study designs for the PHB validation, physical characteristics and lidar-based model studies. Board member Davis said this recommendation acknowledges that as the Board moves forward, the AMP can advise and help refine the process. This recommendation tasks CMER to consider revising the study designs, but not necessarily start from scratch.

Recommendation #6 – Acknowledge that a lidar-based model is one of the goals of a permanent water typing system. Board member Guenther said best available science can help inform a new lidar-based model. He also said this aligns with the small forest landowner caucus' request for continued support for a lidar-based model.

Recommendation #7 – Continued support for AFF workgroup and their charter. Board member Guenther said this recommendation grew out of the western Washington tribal initiative to develop a methodology and coordinate a plan to collect data and analyze options for an AFF. He said other caucuses have agreed to work together to help develop the AFF criteria. He acknowledged that funding may be needed for expanding the GIS related work.

Recommendation #8 – Retain the committee to continue working on water typing issues. Board member Guenther said this recommendation is to retain the committee's involvement for oversight to the AFF workgroup and to help work through additional water typing concepts.

Recommendation #9 – Support the effort of the Center for Conservation Peacebuilding to help improve relationships throughout the AMP. Board member Guenther said the committee anticipates that the contract for facilitation may be used to work through one or more of the unresolved issues in the rule making effort.

Marc Engel, DNR, said that not every recommendation requires action by the Board. The following are tasks DNR staff will implement:

- Re-do the PHB spatial analysis including the AFF alternatives. DNR's methodology will be revised given the clarification gained through the committee's work for applying the width-based stream concept. DNR will coordinate with each caucus during the spatial analysis and make information available to stakeholders during the process.
- Request the Washington State Geologic Survey provide a presentation at the February 2020 Board meeting on the current availability of high quality lidar on forested lands, the projected schedule for acquiring additional lidar not currently available and potential funding options to acquire the remaining data.

Chair Bernath clarified that DNR has committed to re-doing the PHB spatial analysis because they have found a way to conduct the analysis in a manner that was not known to DNR during the initial analysis needed for the draft cost-benefit analysis.

Engel presented the necessary Board actions based on the committee's recommendations.

<u>Action #1</u> – Request CMER develop study designs for the PHB validation, physical characteristics, and lidar-based model studies. It is intended that the studies will be designed for cost savings, including the phasing of the studies with eastern Washington to be initiated first and the advisability of combining the three studies with a report on the study designs at the May 2020 Board meeting.

Board member Herrera said he believes this recommendation was to have CMER determine *if* the PHB and stream physical criteria studies should be combined, not necessarily automatically assume the studies will be combined.

<u>Action #2</u> – Have the committee explore whether there is other data available to inform rule criteria in eastern Washington, ensure collaboration is maintained during this effort and have the committee provide recommendations to the Board by the May 2020 meeting. The first step is to evaluate if additional data in eastern Washington can be collected to augment the 18 points used in the initial analysis. He added that if a delay for a rule is inevitable, the committee may evaluate other actions to protect fish habitat in eastern Washington until a rule is effective.

Chair Bernath clarified that if the workgroup is successful in determining possible criteria for an eastern Washington rule, then the Board may not have to implement interim guidance while a rule is being developed.

Board member Davies said that if the Board is being asked to decide on these recommendations, she asked that adequate timelines be provided.

Board member Nelson said he would like the committee to discuss DNR's recommended actions before the Board decides on them today. He suggested the workgroup provide the adequate timeline to complete these actions rather than have the Board determine an arbitrary date such as May 2020.

Board member Bellon recommended DNR staff engage with the committee to determine logical timelines to complete the recommended tasks and report at the February 2020 Board meeting the status of their findings.

<u>Action #3</u> – Approve the AFF workgroup charter, assign the committee to oversee the AFF workgroup and direct the committee to bring recommendations to the Board by the May 2020 meeting. He said the AFF charter specifies that the workgroup will provide recommendations to the committee and the committee will provide recommendations to the full Board.

<u>Action #4</u> – Extend the committee's involvement to May 2020 to oversee the AFF workgroup, evaluate options for an eastern Washington water tying rule and to address additional rule elements.

PUBLIC COMMENT ON WATER TYPING SYSTEM RULE RECOMMENDATIONS

Darin Cramer, Washington Forest Protection Association (WFPA), said confusion and uncertainty exists because discussions have been focused on the timeline rather than resolving the items of substance. He said WFPA is generally supportive of the committee's recommendations, but the priority for rule development should be defining the performance targets since the work hinges on the overall objectives. He said he hopes DNR analyzes the WFPA, WFFA and county caucus PHB option as intended and to work with all PHB proponents during the analysis. He said there is abundant data in eastern Washington to help determine the eastside criteria. WFPA supports maintaining a lidar-based model option and believes it can be developed sooner than some seem to think.

Steve Barnowe-Meyer, WFFA said his caucus supports clarifying the performance goals and targets for the rule. They support DNR working with WFPA, WFFA and counties caucuses to properly complete the PHB spatial analysis. He said collaboration with the various experts may help this effort. He said the validation studies must include the three components – physical stream criteria, PHBs and the lidar-based model. They recommended the Board retain a lidar-based model rule component. He said they support the recommendations in the WFPA letter dated November 10, 2019.

Alec Brown, Washington Environmental Council, said their caucus is concerned that the effort to complete the water typing rule has taken so long, especially since it was estimated to be completed two years ago. They believe the initial system adopted was based on fish habitat, not fish presence. He questioned whether DNR should do a second PHB spatial analysis given that it had already been done. He questioned how DNR could perform a spatial analysis before the AFF workgroup has provided the necessary criteria. He said their caucus is concerned that determining the goals will take time, especially since they believe the goals were conceptualized 20 years ago.

Scott Swanson, Washington State Association of Counties, said they support defining the rule targets, having DNR perform a re-analysis of the PHBs and the commitment for collaboration when working with stakeholders and the AFF workgroup. He said they believe a lidar-based model is still one of the goals of the permanent rule and asked the Board to retain the development of a model. He requested the Board consider all the committee recommendations.

Chris Mendoza, Conservation Caucus, quoted RCW 77.85.180 relating to the use of best available science and RCW 76.09.370 relating to the use of a peer review process. He reminded the Board that the peer review element is a standard practice of CMER. Conducting a peer review retains the integrity for those wanting to refute study results. Addressing the three studies being considered (physical stream criteria, PHBs and lidar-based model) for CMER development, he cautioned that the path forward may unwind the peer review already completed. He asked the Board to clarify what CMER is to do and asked the Board to not undo study development that CMER has already peer reviewed.

Ash Roorbach, Northwest Indian Fisheries Commission, said the AFF workgroup is finalizing their work plan and will work to finalize their timelines needed to complete the AFF analysis. He said they are working with different experts that have performed analyses to compare methodologies. He said a meeting of technical experts is planned for December – after that meeting, the workgroup will provide more accurate timelines for completion of work. The goal is for the technical group to provide the data and information for the committee to make a recommendation to the Board.

Jaime Glasgow, Conservation Caucus, said their caucus wants to get the water typing system right, but not take longer than necessary. He suggested one interim step is to revise Board Manual Section 13 to include guidance for identifying habitat above the last detected fish. To provide context for how the current water type maps are inaccurate, he said Wild Fish Conservancy conducted two surveys and found 5.5 miles of unmapped fish habitat in one system and 24.6 miles of unmapped habitat in another system. Additionally, he said an eDNA research project found evidence of fish presence in 9 out of 29 stream segments upstream from where an electrofishing survey had previously established the Type F and N water break.

WATER TYPING SYSTEM RULE RECOMMENDATIONS

Board members discussed various options for acting on the committee's recommendations, discussed adding potential dates pertinent to the steps included within the recommendations and discussed their interpretation of the recommendations. They also discussed options for drafting motions the Board could vote on.

Board member Davies suggested the Board implement the current physical stream criteria in rule as the determination for fish habitat while considerations for an eastern Washington rule are being evaluated.

Chair Bernath said using the physical stream criteria as proposed by Board member Davies would require a rule change. He added that DNR staff could provide estimated timelines for completion of the rulemaking at the February 2020 Board meeting.

Board member Davis asked if the Board could request the federal services to provide their interpretation of the intent of the FPHCP as it relates to the definition and protection of fish habitat.

Board member Herrera agreed and suggested the federal services provide their understanding at the February 2020 Board meeting.

Board member Swedeen suggested the federal services provide a factual understanding, not policy statements regarding the agreement in place between the federal services and the state.

Phil Ferester, Board counsel, reminded the Board that the FPHCP is composed of the Board's rules and clarifying uncertainty in what the rules say is a matter of state interpretation, not federal interpretation.

Chair Bernath said he will commit to making a request to the federal services.

MOTION: Tom Nelson moved the Forest Practices Board take the following action:

<u>Action 1:</u> Accept the Board's Water Typing Rule Committee recommendations as presented in the memo dated November 5, 2019.

<u>Action 2:</u> (addressing committee recommendation #5)
Recommend the Cooperative Monitoring, Evaluation and Research Committee (CMER) to develop study designs for the PHB validation, physical characteristics, and map based Lidar model studies. Design the studies for cost savings, including the phasing of the studies with eastern Washington to be initiated first, and the possibility and advisability of combining the PHB validation, physical characteristics and map based Lidar model studies, and then to report on the study designs to the Board by their May, 2020 meeting.

<u>Action 3:</u> (addressing committee recommendation #4)
Recommend the Board direct the Board Committee on water typing to explore whether there is other data available to inform the water typing system rule in eastern

Washington, that the work be performed by a collaborative workgroup formed by the Committee, and that the committee bring recommendations to the Board by their May, 2020 meeting.

Action 4: (addressing committee recommendation #7)
Recommend the Board approve the anadromous fish floor workgroup charter, assign the Board Committee on water typing to oversee the anadromous fish floor workgroup, and direct the Board Committee to bring recommendations to the Board by their May 2020 meeting.

Action 5: (addressing committee recommendation #8)
Recommend the Board extend the Board Committee on water typing to the May 2020 Forest Practices Board meeting to provide oversight to the anadromous floor and eastern Washington data workgroups, and to address other outstanding water typing rule issues as assigned by the Board.

SECONDED: Carmen Smith

Board Discussion:
None

ACTION: Motion passed unanimously.

WATER TYPING SYSTEM RULE MAKING UPDATE
Marc Engel, DNR, said staff is continuing to work on other water typing system elements outside the work being considered by the committee – Board Manual Section 23 and the economic analysis. The Board Manual workgroup is focused on guidance for conducting electrofishing surveys upstream from man-made barriers and refining the flow chart for the fish habitat assessment method.

He said the cost-benefit analysis advisory group still needs to determine the process for the qualitative analysis component. The group is preparing to have a biological discussion to address and determine the methodology for the fish population analysis in upstream reaches. DNR has asked stakeholders to bring forward comments for the contractor to address and to evaluate a change in fish populations from the current rule.

He said DNR is preparing to procure services of a contractor to assist in applying the revised width-based PHB methodology for the PHB spatial reanalysis. He said the anticipated time to finalize the contract is most likely late February or early March 2020.

PUBLIC COMMENT (PM)
Alec Brown, Conservation Caucus, thanked DNR staff for their hard work on the water typing rule. He also thanked Director Bellon for her consideration to extend the Clean Water Act (CWA) assurances.

CLEAN WATER ACT ASSURANCES
Maia Bellon, Ecology Director/Board member, acknowledged the historic interface between forest practices regulations and implementing provisions for clean water in the forested environment. She

said Ecology, with the support of the federal Environmental Protection Agency, has maintained the commitment to provide CWA assurances for forest practices in Washington. The assurances provided a predictable and a consistent regulatory framework for the forestry industry.

She said Ecology's original assurances were issued pursuant to Schedule M-2 of the 1999 Forests and Fish Report. Those assurances established a conditional ten-year agreement to treat the development of our traditional clean water program. She said the assurances were implemented as a commitment to work with forest practices program mainly because of the concept of adaptive management. Ecology extended the ten-year extension in 2009 with a deadline of December 2019.

The decision for determining if an extension is warranted beyond 2019 acknowledged the progress the AMP has made to complete milestones including the completion of the Type F Buffer Effectiveness Monitoring Study in eastern Washington as well as the west side Type N Hard Rock Study. She also recognized the importance of the commitments in the Forests and Fish agreement.

As a result of the on-going work, she said she has decided to extend the CWA assurances for an additional two years, to December 31, 2021. She stated that it is her understanding that Policy will have recommendations for a Type Np rule by the summer of 2021 with the expectation that the rule is implemented by the end of 2021. If the Type Np rules are effectively improved at the end of that timeframe, Ecology will consider another extension. She added that the Board will receive a formal letter that will address her comments provided today.

ADAPTIVE MANAGEMENT PROGRAM BUFFER/SHADE EFFECTIVENESS STUDY (AMPHIBIAN RESPONSE)

Mark Hicks, Adaptive Management Program Administrator, provided a summary of the results of the *Stream Associated Amphibian Response to Manipulation of Forest Canopy Shading* study. The three part purpose of the study was to:

- Assess the effects of shade reduction on stream breeding amphibians,
- Determine if there is an optimum level of shade retention, and
- If possible, identify potential causal mechanisms for any changes observed.

Hicks clarified that this is not a study on the effectiveness of Type Np rules. The study did not test the Type Np prescriptions and it did not apply treatments at a spatial scale that is common for commercial harvests. Therefore, the study results can only indirectly inform with regard to the effectiveness of the rule. He said six species of amphibians were tested for three different biological responses; abundance, growth, and body condition and four functional feeding groups of the macroinvertebrates were also tested.

Hicks summarized the study and its key findings as follows: The study examined 25, 50-meter (164-feet) stream reaches across western Washington where overhead stream cover was removed in three different treatment levels (from ≤97% pretreatment cover to 77%, 61%, and 40% post treatment). The step-wise reductions in shade increased photosynthetically active radiation and stream temperatures. Stream temperature increased on average 0.5°C, 2.2°C, and 2.5°C for the three treatments, being statistically significant only in the two most intensive treatments.

He said the changes in macroinvertebrate production seemed to track shade reduction gradient induced changes. Similarly, some of the stream associated amphibian responses are consistent with expectations linked to the shade reduction gradient. Some of the changes or lack of changes in both the macroinvertebrate and stream associated amphibians lacked a clear explanation. He said taken together considering the macroinvertebrates and amphibians collectively, the study found more positive and fewer negative responses in the intermediate than either the no- or the low-shade treatments. This means that a little bit of increased light can have a benefit to stream productivity, and the benefit declines as the amount of light increases.

Hicks concluded by stating that Policy determined that they would not recommend the Board take action in response to this study.

PUBLIC COMMENT ON BUFFER/SHADE STUDY

Darin Cramer, WFPA, said the study is an example of good work by the AMP. He recommended Board members read the full report, and while the study did not test the rule, it provided information that should be considered. He suggested that a continuous riparian buffer containing high density and high shade levels is not what folks typically want and the program should be conducting additional studies that inform learning opportunities.

Ken Miller, WFFA, addressing his earlier testimony, clarified that portions of the small forest landowner alternate plan template includes an alternative prescription applied in 150 foot increments for intermediate size streams.

ADAPTIVE MANAGEMENT PROGRAM BUFFER/SHADE EFFECTIVENESS STUDY (AMPHIBIAN RESPONSE)

MOTION: Carmen Smith moved the Forest Practices Board accept TFW Policy Committee's recommendation to take no action on the Buffer/Shade Effectiveness Study.

SECONDED: Bob Guenther

Board Discussion:
None.

ACTION: Motion passed unanimously.

GUIDELINES FOR EXTENDED MONITORING

Terra Rentz, Policy co-chair, conveyed that in August 2018 the Board asked Policy to develop and present to the Board a process to help decide how to evaluate and prioritize requests for extended monitoring associated with CMER research projects. She said a joint workgroup was created comprised of representatives from both Policy and CMER. The workgroup identified that there are three occasions when the considerations for extended monitoring could arise:

- During project initiation;
- During the mid-point of study projects; and
- Near the end of the field component of a study project.

Rentz said the workgroup developed a decision-making framework to be used if extended monitoring is being considered near the end of a study. The framework includes four main components and considerations:

- If extended monitoring is needed, the associated scientific advisory group will develop a brief extended monitoring proposal by updating the prospective findings report; and
- provide the proposal to CMER for formal review and approval; and

- If approved, CMER will forward the proposal to Policy; and
- If Policy approves, then CMER will work with the appropriate scientific advisory group to implement.

Rentz said it will be important to apply the new framework by December of each year to ensure that Policy includes the extended monitoring proposals within the context of its consideration of CMER recommendations for the biennial master project schedule.

PETITION FOR RULE MAKING RELATING TO THE NORTHERN SPOTTED OWL
Todd Thorne, member of the North Central Washington Audubon Society, addressed the Board regarding the Audubon's northern spotted owl (NSO) rule petition. He said their petition requested a moratorium on timber harvests within eastern Washington spotted owl special emphasis areas (SOSEA) while the NSO protection measures are re-evaluated.

Marc Engel, DNR, provided an overview of the petition and how Forest Practices Applications (FPA) are classified when a proposed forest practices activity falls within suitable owl habitat within an owl circle in a SOSEA. He said SOSEAs are established in rule to provide demographic and dispersal support as necessary to complement the habitat recovery strategies on federal lands. He also shared the State Environmental Policy Act (SEPA) review process for NSO in WAC 222-10-041 as it relates to the FPA classification procedure.

Gary Bell, Washington Department of Wildlife (WDFW), shared the process DNR and WDFW uses to evaluate proposed FPAs within suitable habitat. Each FPA is screened and checked against agency habitat data. In some cases, in order for DNR and WDFW to make the most accurate determination, they ask the applicant to provide current stand data or additional information to help verify correct habitat typing and whether or not the proposed FPA is within suitable habitat.

Engel described DNR's decision process that resulted in approval of the FPAs specific to Audubon's concern. During the period between August 2016 and September 2019, ten FPAs were submitted that contained proposed harvest activities in suitable NSO habitat. The areas were screened and evaluated by WDFW and Yakima Nation biologists prior to FPA submittal or site visits were conducted by interdisciplinary teams to evaluate on-ground habitat conditions. None of the forest stands met the rule definition of suitable habitat and for that reason, the FPAs were categorically exempt from SEPA analysis.

Engel said Audubon's rule petition is focused on how DNR is implementing the SEPA policies in WAC 222-10-041. He recommended the Board deny the petitioner's moratorium request for harvesting in eastern Washington SOSEA circles based on two reasons: (1) the Board does not have the authority to enact a moratorium (as determined by AGO Opinion in 2015) and (2) the SEPA policies do not establish substantive standards for types of timber harvests or a locations of harvest if a proposal does not include harvest in NSO habitat.

Board member Swedeen acknowledged that the petition focuses on SEPA policies, but said the petition raises a concern that the owl is using forests that does not meet the current rule definition of NSO habitat and that the forest being used by this particular owl pair is being harvested. She questioned if the habitat rules are actually protecting these owls and, if not, she questioned what the Board should do to re-evaluate the habitat rule definition.

Board member Davis thanked the Audubon Society for having “eyes on the ground”. He said WDFW is likewise concerned because the NSO is on the brink of being extirpated in Washington. He said one major factor is the presence of the barred owl and suggested an interim strategy may be needed for this particular situation. He also suggested WDFW provide the Board with a presentation at the February 2020 Board meeting on the current status of the NSO or form a workgroup to discuss potential solutions.

Bell said that evaluation of habitat typing continues to occur within NSO circles. He said past habitat typing through photo interpretation alone was not always accurate. He added that the US Fish and Wildlife Service has not been engaged in the habitat typing along with DNR and WDFW, although they are welcomed to do so as participants on interdisciplinary teams.

Chair Bernath summarized the discussion to include a WDFW NSO update at the February 2020 Board meeting, the formation a workgroup to evaluate habitat criteria and the continuation of the development of a safe harbor agreement.

PUBLIC COMMENT ON PETITION FOR RULE MAKING

Todd Thorne, North Central Washington Audubon Society, said they believe this owl pair was the only documented successful breeding pair in eastern Washington in 2018. He said they are concerned that continued harvests in non-habitat will contribute to a downward population trend and increase the challenges for maintaining adequate habitat. He said while he understands the Board lacks the authority to place a moratorium on harvesting, rule amendments are needed for the overall protection of the NSO.

Martha Wehling, WFPA, said the reproduction trend of these owl shows that the pair are fine and that this particular area of the state has successfully had breeding pairs for many years. She said the current regulatory systems allows for the protection of the NSO through the ability to appeal a FPA to the Pollution Control Hearing Board, the on-going work from the NSO advisory group and DNR’s conditioning authority. She said WFPA supports the staff recommendation and supports the development of additional voluntary protection approaches.

PETITION FOR RULE MAKING RELATING TO THE NORTHERN SPOTTED OWL

MOTION: Paula Swedeen moved the Forest Practices Board deny the petition for rule making related to the Northern Spotted Owl due to lack of authority for a moratorium to harvest. She further requested WDFW work with U.S. Forest Service, DNR and the associated forest landowners to provide additional information and recommendations on alternative solutions at the February 2020 meeting.

SECONDED: Tom Nelson

Board Discussion:

Board member Willet said he believes this petition is based on an assumption as to why the owl pair moved. He agreed with the path outlined today, but is uncomfortable with the concept of assuming the owl pair’s movement was because of timber harvest.

Board member Davis said the goal of WDFW is to protect the northern spotted owl in the interim while the long-term conservation strategy for the NSO is being developed.

ACTION: Motion passed (11 Support / 1 Abstention (Bellon)).

NORTHERN SPOTTED OWL CONSERVATION ADVISORY GROUP

Marc Engel, DNR, provided background that resulted in the development of the Northern Spotted Owl Conservation Advisory Group. He said the rule forming the group was adopted in 2010 to allow time to develop a long-term conservation strategy. The rule established a three-member group designated by the Board with members having a working knowledge of NSO habitat relationships and factors affecting owl conservation. Current members are: Marty Vaughn, forest product industry; Kara Whitaker, conservation organization; and Stephen Bernath, DNR Forest Practices Program. The group's process is to evaluate WDFW-approved NSO surveys showing the absence of an owl. The group determines if the habitat in the circle needs to be maintained to contribute to the recovery of the owl on federal lands.

He said the rule is open-ended with an annual review to ensure that potential habitat is maintained while the Board develops a long-term NSO conservation strategy. He recommended the Board retain the group while the Board pursues voluntary spotted owl recovery measures.

Board member Davis suggested that WDFW, although not a member of the group, may recommend that the Board not de-certify a NSO site center simply because a survey found no owls during a particular year.

Engel felt that the group would consider the biological expertise of WDFW during their evaluation should a survey occur showing no owls.

PUBLIC COMMENT ON NSO CONSERVATION ADVISORY GROUP

None

NORTHERN SPOTTED OWL CONSERVATION ADVISORY GROUP

MOTION: Maia Bellon moved the Forest Practices Board maintain the Northern Spotted Owl Conservation Advisory Group for another year.

SECONDED: Ben Serr

Board Discussion:
None.

ACTION: Motion passed unanimously. (Brent Davies not available for vote.)

ADAPTIVE MANAGEMENT PROGRAM FISCAL AUDIT REPORT

Joe Shramek, DNR, summarized the October 30, 2019 memo included in the meeting information packet (beginning on page 209) regarding the outcome from the AMP fiscal audit performed under contract with Jennifer Woods, CPA, CIA, CFE, CRMA from the Department of Retirement Services in partial fulfillment of requirements of WAC 222-12-045(2)(e). The audit covered the 2017-2019 biennium and approximately $14.5 million dollars in contracts. The audit focused in three areas:

- Assurances that the processes used for AMP science contracts followed applicable state rules and regulations;
- That only allowable costs where paid under non-governmental participation grants; and

- That only allowable costs where paid for the one time travel participation grants for cultural resources projects.

The fiscal audit found the program implemented a process that protects state funds and is compliant with state laws and regulations. He said fiscal audits don't generally address performance actions, but one example where a performance improvement is needed was related to verbal agreements that were given for minor contract changes. He said such changes require a written authorization and that DNR has taken steps to make this adjustment.

RECOMMENDATION ON CRITICAL HABITAT (STATE) FOR THE CARIBOU
Marc Engel, DNR, reported that US Fish & Wildlife Service has amended their Endangered Species Act listing for woodland caribou which reconfirmed previously designated critical habitat for 17-subpopulations. The Board's critical habitats rule (WAC 222-16-080 (1)(c)) includes the mountain woodland caribou. The Board's rules require DNR to consult with WDFW and then provide a recommendation to the Board.

He said WDFW considers the remaining Washington caribou as extirpated from the state and that WDFW has concluded that forest practices are not having any negative affect on caribou habitat. WDFW endorses the action to retain habitat in the state for the species. He recommended the Board make no change at this time to the Board's critical habitat rule for the caribou.

Board members Davis noted the species is currently no longer in the state and is declining in British Columbia and Alberta.

PUBLIC COMMENT ON CRITICAL HABITAT FOR THE CARIBOU
None.

RECOMMENDATION ON CRITICAL HABITAT (STATE) FOR THE CARIBOU
MOTION: Carmen Smith moved the Forest Practices Board not amend the current protection measures in WAC 222-16-080 for the mountain (woodland) caribou at this time.

SECONDED: Noel Willet

Board Discussion:
None.

ACTION: Motion passed unanimously. (Brent Davies not available for vote.)

STAFF REPORTS
There were no questions on the following reports:
- Adaptive Management
- Compliance Monitoring
- Small Forest Landowner Office
- TFW Policy Committee Work Plan
- Upland Wildlife

2020 WORK PLANNING

Marc Engel, DNR, presented a draft Board Work Plan for calendar year 2020. The 2020 Board meeting dates will be February 12, May 13, August 12 and November 12.

MOTION: Carmen Smith moved the Forest Practices Board approve the 2020 work plan as amended.

SECONDED: Ben Serr

Board Discussion:

None.

ACTION: Motion passed unanimously. (Brent Davies not available for vote.)

EXECUTIVE SESSION

None.

Meeting adjourned at 4:25 p.m.

STATE OF WASHINGTON **PO Box 47012**
FOREST PRACTICES BOARD
Olympia, WA 98504-7012

January 10, 2020

To: Forest Practices Board

From: Water Typing System Rule Committee
Bob Guenther, Paula Swedeen, Tom Nelson, Dave Herrera and Jeff Davis

RE: Recommendations on Outstanding Water Typing System Rule Issues

The Forest Practices Board (Board), at their November 13, 2019 meeting, accepted the Water Typing System Rule Committee's (Committee) recommendations to assist the Board in resolving outstanding issues in the development of a permanent water typing system rule. These recommendations retained Committee oversight of the Anadromous Fish Floor Workgroup and an Eastern Washington Fish Habitat Data Workgroup. Specific to the tasks for these workgroups, the Committee recommends the following:

- Anadromous Fish Floor – The Committee recommends the Board approve funding of up to $75,000 to contract GIS expertise to perform an analysis in support of the product being developed by the Anadromous Fish Floor Workgroup. The Committee has asked the workgroup to provide an update to the Committee to present to the Board on the scope of work and refinements to the budget needed for the contracted analysis by the February 12 Board meeting.

- Eastern Washington Fish Habitat Data – The Committee recommends the Board acknowledge the establishment of a small technical group to share available fish habitat data and assess the applicability of the data for inclusion in the PHB spatial analysis to inform a rule criteria for eastern Washington. It is anticipated one or two meetings are necessary for this group to determine potential options and inform the Committee if data gaps exist requiring additional fish data to be collected. The Committee will ask the technical group to provide the potential options to the Committee by early April.

DEPARTMENT OF
NATURAL RESOURCES

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MEMORANDUM

January 16, 2020

To: Forest Practices Board

Form: Mark Hicks, Adaptive Management Program Administrator

Subject: Type N Experimental Hardrock Genetics Study

At their September 5, 2019 meeting, TFW Policy (Policy) formally accepted the Findings Report and associated materials for the study entitled ***Type N Experimental Buffer Treatment Study: Post-harvest comparison of genetic diversity and demographic findings for three stream-associated amphibians***. The purpose of this memo is to transmit the final study report to the Board along with a summary of the report's findings and Policy's recommendations.

The genetics report is part of the overall Type N Experimental Buffer Treatment study. The genetics study component was developed to supplement the amphibian demographics data that has also been collected. Using a Before-After Control-Impact (BACI) study design, this study examines the genetic response of three stream-associated amphibian species (Coastal Tailed Frog, Cope's Giant Salamander, and Coastal Giant Salamander) before and after clearcut timber harvest of small headwater basins in response to four experimental treatments, including an unharvested reference and three riparian buffer treatments.

Riparian buffer treatments included a two-sided 50-ft (15.2-m) riparian leave-tree buffer along the entire riparian management zone (RMZ) (100% treatment), a two-sided 50-ft (15.2-m) riparian buffer along at least 50% of the RMZ, consistent with the Washington State forest practices buffer prescription for non-fish-bearing streams (FP treatment), and a clearcut harvest throughout the entire RMZ (0% treatment). This report compares changes in genetic diversity 7-8 years post-harvest to results from the analysis of demographic data collected at the same study sites in the initial two year period post-harvest. Demographic data for the period 7-8 years post-harvest will be presented separately as part of the overall phase II Type N Experimental Buffer Treatment report that is currently in ISPR.

The current study did not detect a strong shift in genetic diversity metrics due to treatment, suggesting the treatments did not cause severe declines in the three species tested in the initial 2-years post-harvest. Overall, the authors are confident a severe (> 95%) immediate decline in genetic diversity did not occur at the treatment sites. The authors do caution, however, that increased sample size and additional sampling across future generations may be necessary to detect a trend, given simulations suggest steady declines are often not detected until several generations.

After considering the findings, TFW Policy agreed by consensus not to recommend the Board take specific action in response to this study.

However, a decision on the need for action may need to be revisited when the demographic results from the 8-year Phase II Type N Experimental Buffer Treatment extended monitoring study (in review) is complete and the question of whether abundance has significantly declined can be answered.

Type N Experimental Buffer Treatment Study: Post-harvest comparison of genetic diversity and demographic findings for three stream-associated amphibians

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1-1. ABSTRACT

Genetic monitoring provides a complementary approach to demographic monitoring, and can provide additional information on a population's response to disturbance. For instance, genetic monitoring can identify rapid declines in population size and non-random mating that may lead to future inbreeding depression. As part of the Type N Experimental Buffer Treatment Study, we assessed the genetic response of three stream-associated amphibian species (Coastal Tailed Frog, Cope's Giant Salamander, and Coastal Giant Salamander) before and after clearcut timber harvest of small headwater basins. We used a Before-After Control-Impact (BACI) study design to evaluate amphibian genetic response to four experimental treatments, including an unharvested reference (i.e., in the harvest rotation but withheld from harvest) and three riparian buffer treatments involving clearcut harvest of the entire basin. Riparian buffer treatments included a two-sided 50-ft (15.2-m) riparian leave-tree buffer along the entire riparian management zone (RMZ; 100% treatment), a two-sided 50-ft (15.2-m) riparian buffer along at least 50% of the RMZ, consistent with the Washington State Forest Practices buffer prescription for non-fish-bearing streams (FP treatment), and clearcut harvest throughout the entire RMZ (0% treatment). We used several metrics to characterize levels of genetic diversity before and after harvest. These included number of full siblings, allelic diversity, heterozygosity, inbreeding coefficient, and heterozygosity excess. We compared changes in genetic diversity 7-8 years post-harvest to results from the analysis of demographic data collected at the same study sites in the two years post-harvest. We also identified genetic clusters across study sites to determine the role of gene flow in the observed genetic response. Overall, we found little evidence for a change in genetic diversity as a result of riparian buffer treatments. No significant treatment effects were observed between the pre- and post-harvest periods for Coastal Tailed Frogs. Cope's Giant Salamander generally lacked evidence of significant treatment effects for most metrics, although we saw a significant pairwise decrease in F_{IS} for the 100% treatment relative to the FP treatment (-0.10, p = 0.02). We observed a significant (p = 0.03) treatment effect for the change in number of unique full sibling families of Coastal Giant Salamanders, which was driven by the observed decrease (-24.0) in unique full sibling families within the 100% treatment. There were no treatment effects on the change in proportion of full sibling families, and therefore the significance of the decline is due to a decrease in sampling numbers. We observed a significant change in F_{IS} for Coastal Giant Salamanders (p = 0.05) that resulted from a decrease in both the 100% treatment (-0.17; p = 0.02) and the 0% (-0.16; p = 0.03) relative to the reference. Decreases in F_{IS} typically indicate mating between more distantly related individuals and is consistent with a shift in immigration/emigration dynamics. Several sites showed a signature of recent genetic bottlenecks based on an increase in heterozygosity excess for both the Coastal Tailed Frog and the Cope's Giant Salamander. However, we detected significant heterozygosity excess in both the reference and treatment sites, suggesting no clear pattern due to treatment. We detected no evidence of heterozygosity excess for Coastal Giant Salamanders. We did not see clear associations of genetic patterns with the demographic analyses conducted on data collected immediately post-harvest. We note that the demographic and genetic analyses do not represent concurrent sampling. Both Coastal Tailed Frogs and Coastal Giant Salamanders had high levels of gene flow among sites in both pre- and post-harvest periods. Cope's Giant Salamander has much more restricted levels of gene flow overall, although there was genetic connectivity among nearby sites. There was a slight decrease in genetic differentiation post-harvest in Cope's Giant Salamander, which could be consistent with the decrease in F_{IS}. However, for all three species,

genetic structure is likely influenced by surrounding basins in addition to site-level treatment effects. Although we do not see evidence of a change in genetic diversity due to clearcut timber harvest and alternative riparian buffer treatments, we caution that increased sample size and additional sampling across future generations may be necessary to detect a trend, as simulations have demonstrated that steady declines are often not detected until several generations post-decline.

1-2. INTRODUCTION

Genetic monitoring (Schwartz *et al.* 2007) has emerged as a complementary approach to typical demographic monitoring approaches due to the development of genetic markers that respond at a relatively fine temporal and spatial scale. At a broad scale, genetic diversity is required to provide the raw material for populations to evolve in response to environmental changes and therefore persist over the long term. Techniques to estimate demographic trends in population size (e.g., mark-recapture or detection probability) require multiple sampling occasions and intense sampling effort. In contrast, accurately characterizing genetic structure generally requires sampling a smaller proportion of the population and as few as one site visit within a period of interest (Pierson *et al.* 2015). It can become difficult to determine decreases in reproductive success in long-lived species over short periods. In cases in which larval or juvenile stages are sampled, the young individuals may only be offspring of a small number of parents from the previous generation. Genetic markers can help estimate the number of unrelated individuals at a site, infer the predominant mating system, and provide opportunities for mark-recapture through genetic identification of the same individual.

The simplest indicator of genetic diversity is the number of alleles present in a population. When strong population declines occur, alleles are typically lost from the population (Luikart *et al.* 1998; Allendorf and Luikart 2007) suggesting allelic diversity may be one of the better measures for genetic monitoring. In fact, Hoban *et al.* (2014) demonstrated through simulations that a change in the average number of alleles per locus had the highest power to detect evidence of a population decline. Additional common measures of genetic diversity include heterozygosity and Wright's inbreeding coefficient (F_{IS}). Although heterozygosity and F_{IS} had lower power in the simulations conducted by Hoban *et al.* (2014), the authors assumed random mating. Non-random mating has a strong effect on both observed heterozygosity and F_{IS}, and both metrics are often used as an assessment of whether mating is random (Allendorf and Luikart 2007). Relatively low heterozygosity and increased F_{IS} are signs of mating among close relatives, whereas the opposite patterns are often indicative of increased immigration into the focal site.

Genetic data can provide information on individual family relationships (parentage, siblings) and estimate effective population size (N_e), both of which complement demographic estimates such as census population size of adults and larvae. While genetics have long been used to describe pedigrees in well-sampled systems, only recently have researchers had the statistical tools to estimate family relationships for populations in which pedigree information is lacking (Wang 2004). With relatively few genetic loci, we can now estimate full siblings and putative parents with confidence given sufficient sampling effort. While estimating family groups is a useful rationale for genetic monitoring, estimating effective population size is often the focus of genetic studies (Waples 2005; Luikart *et al.* 2010). The reason for this emphasis is that effective population size provides the best indication of the evolutionary potential of the population (Waples 2005). There are several estimators for effective population size; however, high variability frequently exists among estimators and the best estimator is often situation-specific (Gilbert and Whitlock 2015). Therefore, effective population size may not be a consistent metric to include in genetic monitoring studies.

Most genetic monitoring (herein defined as the use of genetic markers to estimate genetic diversity and connectivity) has focused on single samples to assess the current genetic diversity of populations, or has used genetic information to detect individuals or populations of secretive taxa (i.e., non-invasive environmental sampling). Evaluations of temporal data have typically used historical samples to compare with recent samples, and often span many generations (Kekkonen *et al.* 2011). Examples of genetic monitoring that follow or even resemble a Before-After Control-Impact (BACI) design (Eberhardt 1976; Green 1979), such as the one we report on here, are rare. Relevant examples include experimental removal of bush rats to assess changes in genetic structure (Peakall and Lindenmayer 2006), change in lizard genetic structure before and after a major drought (Vandergast *et al.* 2016), and the genetic response of sailfin mollies to a major hurricane in Florida (Apodaca *et al.* 2013). These studies all detected differences in genetic differentiation among populations but relatively little change in genetic diversity. Furthermore, none of these studies examined changes in parameters such as increased presence of full siblings or higher relatedness.

Amphibians are sensitive to changes in environmental conditions (Stuart *et al.* 2004) and thus are used as an indicator to monitor changes in forested environments due to natural and anthropogenic disturbance (e.g., Welsh and Ollivier 1998; Lawler *et al.* 2010). Management practices that reduce structural complexity of aquatic and terrestrial habitats can negatively impact stream-associated amphibian species in forested environments (Corn and Bury 1989; Kroll 2009). While some have concluded that some stream-associated amphibians are sensitive to forest management (Bury and Corn 1988; Welsh *et al.* 2005; Hawkes and Gregory 2012; Maigret *et al.* 2014), many researchers have documented stream-associated amphibians in abundance in streams located in forest stands with a history of timber harvest (Russell *et al.* 2004; Hayes *et al.* 2006; Olson *et al.* 2014).

During the Forests & Fish (USFWS 1999) negotiations leading to the development of Washington State's current Forest Practices rules, several stream-associated amphibians were selected for protection in perennial non-fish-bearing streams (Type N Waters) including: Coastal Tailed Frog (*Ascaphus truei*); and Olympic, Columbia and Cascade Torrent Salamanders (*Rhyacotriton olympicus*, *R. kezeri*, and *R. cascadae*). At the time of negotiations almost no published studies addressed the efficacy of riparian buffers for maintaining these amphibian species in Type N Waters or provided clear or compelling guidance addressing conservation needs of stream-associated amphibians.

Most studies of amphibian response to timber management in headwater basins have been based on monitoring changes in occupancy or abundance (e.g., Diller and Wallace 1999; Wilkins and Peterson 2000; Jackson *et al.* 2007; Kroll *et al.* 2010; Pollett *et al.* 2010; Olson *et al.* 2014). Over short periods, amphibian demography can be highly variable (Pechmann *et al.* 1991). Genetic structure would not be expected to change as rapidly and can give a better indication of long-term response to disturbance. In this study, we compare amphibian genetic structure before and eight years after timber harvest with variable retention riparian buffer treatments. Although we likely do not have power to detect smaller genetic changes eight years since disturbance (i.e., timber harvest; Hoban *et al.* 2014), genetic monitoring may be more sensitive to severe bottlenecks or an increase in inbreeding than demographic measures alone.

1-3. BACKGROUND AND STUDY DESIGN

In the Type N Experimental Buffer Treatment Study (hereafter, Type N Study) we evaluated the effectiveness of current riparian management prescriptions for non-fish-bearing streams (Type N waters) for western Washington. We compared the effectiveness of the current riparian buffer prescription in maintaining riparian structures, functions and processes important to the riparian forest and associated aquatic system to buffer alternatives. A primary focus was stream-associated amphibians (specifically Coastal Tailed Frog [*A. truei*], and torrent [*Rhyacotriton*] and giant [*Dicamptodon*] salamanders). We also evaluated the response of riparian tree mortality and tree fall, in-channel wood recruitment and loading, stream temperature and shade, discharge, nutrient export, suspended sediment export, channel characteristics, litterfall input and detritus export, biofilm and periphyton, and macroinvertebrate export.

An important component of our study was the characterization of genetic diversity for stream-associated amphibians to refine information for making predictions about both short- and long-term responses of amphibians to timber management. An evaluation of amphibian populations at multiple levels of biological organization (e.g., demographic and genetic) and in conjunction with measures of ecosystem conditions (e.g., stream temperature, stream channel characteristics) is imperative for understanding the potential consequences of human-induced disturbances (Surasinghe 2013; Clipp and Anderson 2014). Baseline, pre-harvest measures of genetic structure were reported for Coastal Tailed Frog, Coastal Giant Salamanders (*D. tenebrosus*) and Cope's Giant Salamanders (*D. copei*) in The Type N Experimental Buffer Treatment Study: Baseline Measures of Genetic Diversity and Gene Flow of Three Stream-associated Amphibians (Spear *et al.* 2011), hereafter Baseline Genetic Report. Simulation data based on the baseline genetic measures indicated that we would have power to detect severe reductions in population size (i.e. effective population sizes reduced to 6-34 individuals). Torrent salamanders were not included in the genetic analysis since three species of the genus (*R. cascadae*, *R. kezeri* and *R. olympicus*) occur throughout the study area, but are distributed geographically in a non-overlapping manner that would confound treatment comparisons.

The pre-harvest genetic sampling for Coastal Tailed Frogs, Cope's Giant Salamander, and Coastal Giant Salamander not only provided the baseline and comparison for the present study, but data were combined with additional sampling to evaluate genetic connectivity across the forest landscapes of western Washington. Coastal Tailed Frogs exhibited extensive genetic connectivity across both the Olympic Peninsula and the South Cascades, including a rapid genetic recovery of the Mt. St. Helens blast zone (Spear and Storfer 2008; Spear *et al.* 2012). While overall gene flow was high in all landscapes, there was some evidence of a negative effect of timber harvest on genetic connectivity in Olympic National Forest (Spear and Storfer 2008) and a greater negative impact of climatic variables in the salvage logged areas surrounding Mt. St. Helens (Spear *et al.* 2012). Furthermore, there were evidence of population bottlenecks in the harvested forest in the Olympics (Spear and Storfer 2008). That study was unable to identify the exact mechanism leading to the observed genetic effects, which the present study could help address. A landscape genetic study with Cope's Giant Salamander did not directly address forest management practices, but did examine genetic connectivity within each of the three main regions sampled in this study (Trumbo *et al.* 2013).The study found different landscape factors that were significant by region, with stream connectivity being most important in the Olympics and Willapa Hills, whereas heat load index had the greatest effect on connectivity in the South Cascades. Finally, Dudianec *et al.* (2012) examined Coastal Giant Salamander genetic structure in response to several environmental variables, finding a strong response of genetic connectivity to frost-free period in the South Cascades, but no significant effects on connectivity in the Willapa Hills. As with the Cope's Giant Salamander, this study was not specifically designed to evaluate the impact of forest management.

1-3.1. STUDY SITES AND TREATMENTS

Study sites included 17 Type N basins of second-growth forested stands located on hard rock (i.e., competent) lithologies. Each watershed was a perennially flowing, non-fish-bearing, first-, second- or third-order stream basin (*sensu*, Strahler 1952) located along the Clearwater, Humptulips and Wishkah rivers in the Olympic Mountains; the North, Willapa, Nemah, Grays and Skamokawa rivers and Smith Creek in the Willapa Hills; and the Washougal River and Hamilton and Trout creeks in the southern Cascades (N45°48.42' – N47°38.87', W122°15.88' – W124°12.07', elevation 22 – 730 m; **Figure 1**). Watersheds occurred in managed Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) dominated second-growth forests on private, state and federal timberlands. Watersheds ranged from 12.5 to 76.1 ha (measured utilizing a Geographic Information System (GIS), specifically ArcMap (ESRI 2004) and were dominated (≥84% of total watershed area) by forest stands with ages ranging from 32 to 80 years.

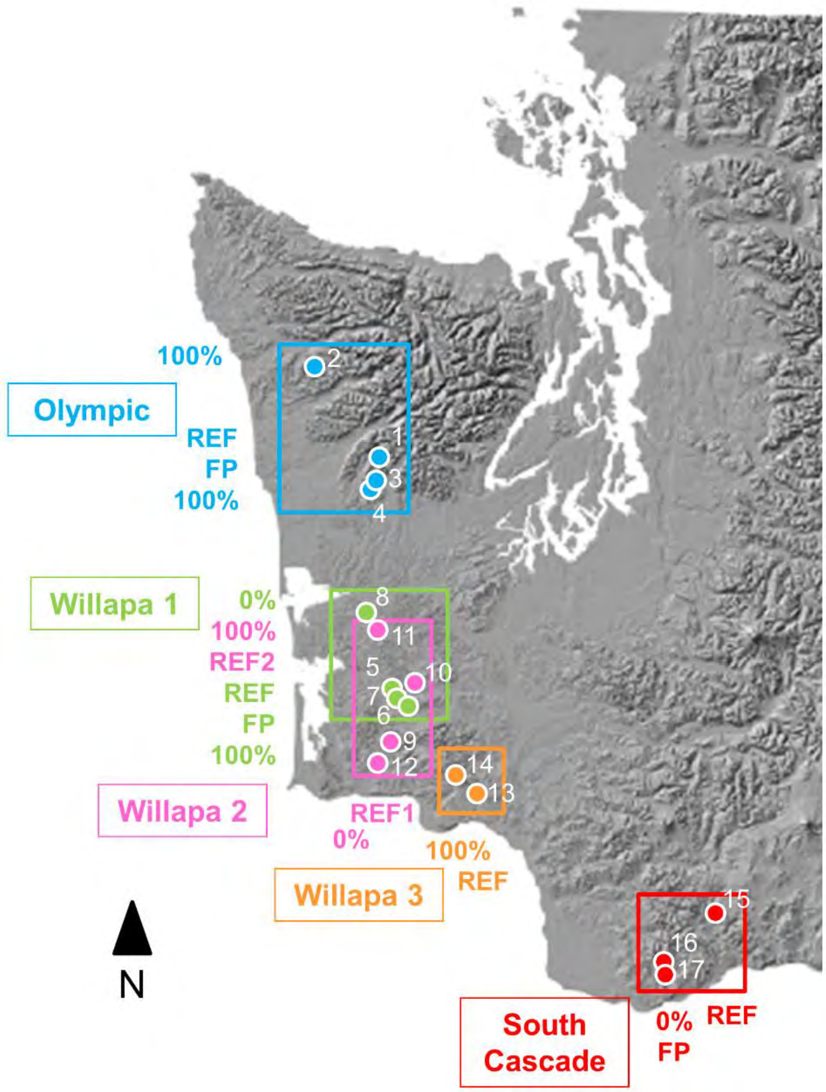

Figure 1. Distribution of study sites and treatment allocation for the Type N Study, 2006 – 2010. Study sites are blocked (grouped) based on geography. The five blocks are color-coded such that sites in a block are the same color. Treatments include REF (reference), and 100%, FP (Forest Practices) and 0% buffer treatments. Site IDs used for genetic clustering figures are shown in white.

We established four treatments: three different riparian buffer configurations in basins that were otherwise fully clearcut to maximize the potential impact of treatments, and a reference (i.e., control) with no timber removal (see McIntyre *et al.* 2018c, Chapter 3 - Management Prescriptions). The intent of this design was to harvest riparian management zones (RMZs) at intensities both greater and less than current Forest practice rules such that we could evaluate the relative effectiveness of alternative treatments in meeting the four key goals established by the Washington Forest Practices Board (WFPB; see McIntyre *et al.* 2018a, Chapter 1 - Introduction and Background). The four experimental treatments included (**Figure 2**):

1) **Reference (REF):** unharvested reference with no timber harvest activities within the study site during the study period;

2) **100% treatment (100%):** clearcut harvest with a riparian leave-tree buffer (i.e., two-sided 50-ft [15-m]) throughout the RMZ;

3) **Forest Practices treatment (FP):** clearcut harvest with current Forest Practices riparian leave-tree buffer (i.e., clearcut harvest with a two-sided 50-ft [15-m] riparian buffer along ≥ 50% of the RMZ, including buffers prescribed for sensitive sites [side-slope and headwall seeps, headwater springs, Type Np intersections and alluvial fans]). In practice, the stream length buffered ranged from 55% to 73% of the Type N stream length.; and

4) **0% treatment (0%):** clearcut harvest with no riparian buffer retained within the RMZ.

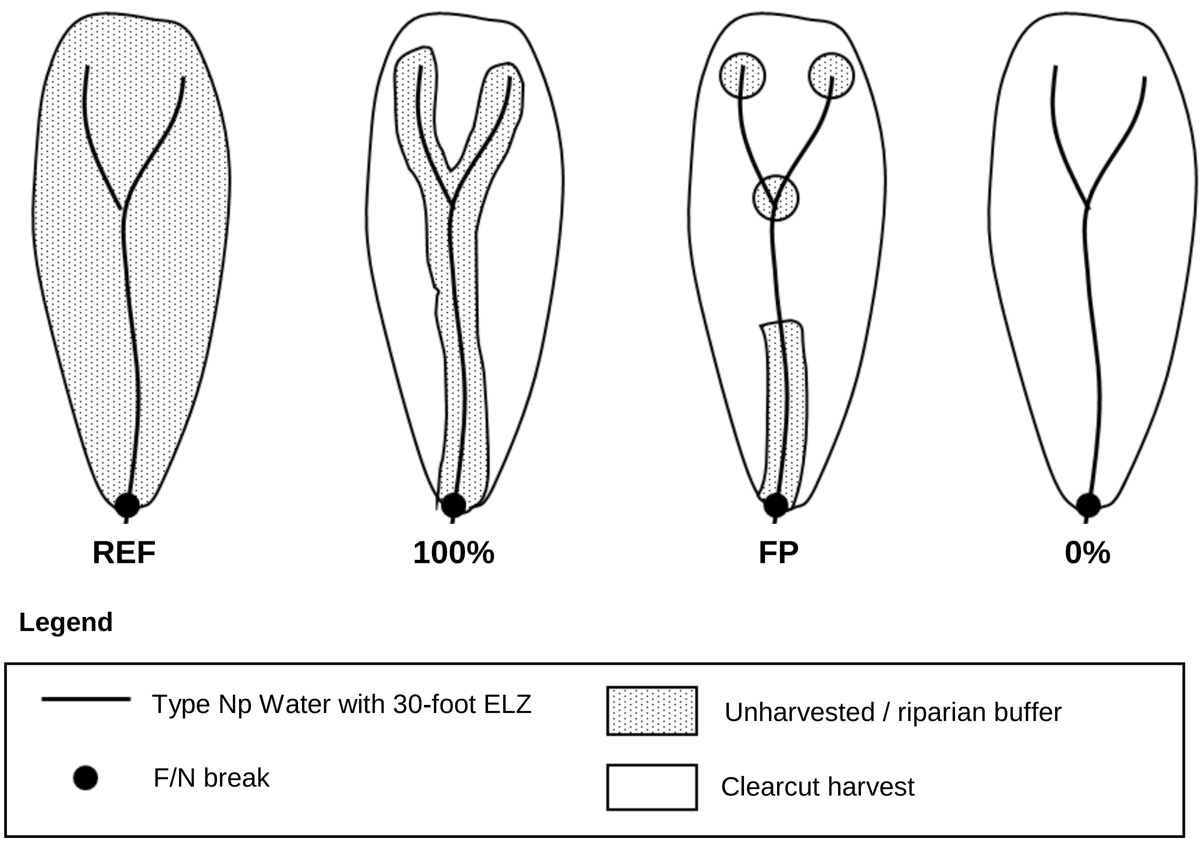

Figure 2. Schematic of the four experimental treatments included in the Type N Study. Treatments include unharvested reference sites (REF) and sites receiving a clearcut harvest with one of three riparian buffer treatments along the Type Np Water RMZ: two-sided 50-ft (15-m) riparian buffers of 100%, Forest Practice (FP), and 0%. FP and 100% treatments include 56-ft (17-m) radius buffers around Type Np intersections and headwater springs. All streams are protected by a two-sided 30-ft (9-m) equipment limitation zone (ELZ).

To maximize the influence of the riparian buffer treatments and reduce confounding effects, harvest units were applied to the entire Type N basin, where possible. In five study sites <1% – 15% of a basin could not be harvested due to regulatory or logistic constraints (see McIntyre *et al.* 2018c, Chapter 3 - Management Prescriptions). Harvest unit size was operationally meaningful, ranging from 12 ha (30 ac), the unit size identified by landowners as the minimum typically harvested, to 54 ha (133 ac). The maximum harvest unit size allowable under Forest Practices is 49 ha (120 ac) without an exception based on review by an interdisciplinary science team (WFPB 2001).

Besides application of the treatment, harvest practices followed Forest Practices rules (e.g., a 30-ft [9-m] equipment limitation zone (ELZ) was maintained along all Type Np and Ns[1] Waters, regardless of treatment). We blocked (grouped) study sites based on geography to minimize variability and randomly assigned sites within each block to one of the four treatments, when possible (see McIntyre *et al.* 2009). Sites within a block were located within the same physiographic region (Olympic, Willapa Hills, and South Cascade). We had one block of four sites in the Olympic region, two blocks of four sites each and one block of two sites in the Willapa Hills region, and one block of three sites in the South Cascade region (

Table 1; **Figure 1**). We established an acronym for each study site, based on the combination of the block to which it was assigned and the treatment applied. We use these acronyms in tables and figures throughout this report (**Table 2**). Identification numbers, referenced in **Table 2**, were used in the Baseline Genetic Report.

Table 1. Distribution and numbers of sites among geographic blocks and treatments for the Type N Study.

Block	Number of Sites	Treatment			
		REF	100%	FP	0%
Olympic (OLYM)	4	1	1	1	1
Willapa 1 (WIL1)	4	1	1	1	1
Willapa 2 (WIL2)	4	2	1	0	1
Willapa 3 (WIL3)	2	1	1	0	0
South Cascade (CASC)	3	1	0	1	1
Total	17	6	4	3	4

[1] A Type Ns Water, or non-perennial, seasonally intermittent stream includes all segments of natural waters within the bankfull width of the defined channels that are not Type S, F, or Np Waters. These are seasonal, non-fish habitat streams in which surface flow is not present for at least some portion of a year of normal rainfall and are not located downstream from any stream reach that is a Type Np Water. Ns Waters must be physically connected by an above-ground channel system to Type S, F, or Np Waters (WAC 222-16-030).

Table 2. Study site acronyms for each block and treatment combination. For cross reference purposes, the identification number used in the Baseline Genetic Report (Report ID) is included. Site ID is the identification number used in all genetic clustering figures.

Block	Treatment	Site Acronym	Report ID	Site ID
Olympic	Reference	OLYM-REF	1099	1
	100% treatment	OLYM-100%	363	2
	FP treatment	OLYM-FP	1197	3
	0% treatment	OLYM-0%	1236	4
Willapa 1	Reference	WIL1-REF	3098	5
	100% treatment	WIL1-100%	3111	6
	FP treatment	WIL1-FP	3110	7
	0% treatment	WIL1-0%	2260	8
Willapa 2	Reference 1	WIL2-REF1	3437	9
	Reference 2	WIL2-REF2	3074	10
	100% treatment	WIL2-100%	2468	11
	0% treatment	WIL2-0%	3576	12
Willapa 3	Reference	WIL3-REF	5785	13
	100% treatment	WIL3-100%	3914	14
South Cascade	Reference	CASC-REF	5378	15
	FP treatment	CASC-FP	5595S	16
	0% treatment	CASC-0%	5595N	17

1-3.2. STUDY TIMELINE

We collected the baseline data for all response metrics presented in the Baseline Genetic Report during the pre-harvest period (2006 – 2008). Harvest occurred in buffer treatment from July 2008 through August 2009. We collected two years of post-harvest data in the extended study period, seven and eight years after harvest (2015 and 2016). Few studies have provided size and age information for tailed frogs and giant salamanders. The best data available for tailed frogs are for the Rocky Mountain Tailed Frog (*A. montanus*), a species that is closely related to the Coastal Tailed Frog and was considered the same species until recently (Neilson *et al.* 2001). Daugherty and Sheldon (1982) estimated the size of 8+ year old Rocky Mountain Tailed Frogs in Montana to be ≥44 mm snout-vent length (SVL) for females and ≥40 mm SVL for males. Sagar *et al.* (2007) found that second- and third-year Coastal Giant Salamanders in coastal Oregon ranged from 54 to 99 mm SVL and that aquatic adults four years of age and older had SVLs ≥100 m. Similar size and age information for Cope's giant salamander were not available, so we will assume that the same size and age classes apply to both giant salamander species. All larval individuals of all taxa encountered during our post-harvest sampling would have been born after treatment implementation. We estimate that all post-metamorphic tailed frogs less than 42 mm SVL and giant salamanders less than 100 mm SVL would be younger than eight years, and thus also born after treatment implementation.

1-3.3. BASELINE AMPHIBIAN GENETICS

As part of the Baseline Genetic Report, we measured stream-associated amphibian genetic diversity and genetic differentiation within and among populations to provide insight into trends in population size and to identify the level of migration among sites. We also used genetic identification to differentiate between larval giant salamanders. The added benefits of including amphibian genetics, in addition to demographic information, included (see Spear *et al.* 2011):

1) Genetic markers are the best means of ensuring unambiguous identifications for the two giant salamander species.

2) Stream-associated amphibian population estimates are usually larval-biased. Multiple amphibian larvae can be the offspring of one parent, and larvae typically suffer high mortality rates prior to metamorphosis. Therefore, larval abundance estimates are unlikely to fairly represent adult population size. Genetic markers can estimate the number of unique families that are represented and identify sibling groups.

3) Genetic diversity statistics can be used to infer changes in population size, and populations with decreased genetic diversity and increased levels of inbreeding may not be sustainable at the scale of tens to hundreds of generations.

4) Genetic data can be used to estimate the degree of gene flow across a study area.

1-4. **OBJECTIVES**

The population genetics portion of the Type N Study had five main objectives:

1) Correctly identify giant salamander individuals to species level (Cope’s or Coastal) and identify hybrids in sites where the two species co-occur. Evaluate changes in the proportion of each species and the extent of hybridization post-harvest.

2) Generate post-harvest measures of genetic diversity (i.e., allelic richness, heterozygosity and inbreeding coefficient) for each species and study site and test whether these measures differ from those obtained during the pre-harvest period.

3) Test for evidence of recent population bottlenecks.

4) Estimate spatial extent of gene flow (through genetic clustering) for both the pre-harvest and post-harvest periods. Results will indicate the potential effect of gene flow on metrics of within-basin genetic diversity, as well as identify any changes in number of genetic clusters between periods.

5) Provide a framework for future genetic monitoring of amphibian populations, both in our study sites and in Type N basins across the landscape.

1-5. MATERIALS AND METHODS

1-5.1. AMPHIBIAN SAMPLING AND GENETIC TISSUE COLLECTION

We collected tissue samples for genetic analysis from 23 June through 2 November in 2006 – 2008 (pre-harvest period), and 2015 and 2016 (post-harvest period). We used two amphibian sampling methodologies, each designed to detect and capture both tailed frogs and giant salamanders: light-touch (Lowe and Bolger 2002) and rubble-rouse sampling (Bury and Corn 1991). Both are commonly used for surveys of headwater amphibians in the Pacific Northwest (e.g., Welsh and Lind 1996; Wilkins and Peterson 2000; Steele *et al.* 2003; Russell *et al.* 2004; Quinn *et al.* 2007). Sampling efforts were intensive, covering much of the stream length in every study site. Study stream length ranged from 325 m (1,066 ft) to 2,737 m (8,980 ft). We conducted light-touch sampling along every tributary, in 10-m sample reaches systematically distributed between a point located up to 100 m below the fish-end-point and upstream to each tributary headwall, with a minimum of 25% of the total stream length in each site sampled each year. In addition to this site-wide sampling, we divided the 200 meters above the fish-end-point into 10 meter segments and sampled 1-m rubble-rouse plots randomly located within each of these 20 intervals. Additional rubble-rouse sampling was conducted in post-harvest years in study sites where wood obstructions prevented light-touch sampling. In this instance, plots were 3-m long and the number of plots per site depended on the proportion of the stream length in which light-touch sampling could not be effectively implemented (seeMcIntyre *et al.* 2018b, Chapter 15 - Stream-associated Amphibians for details on the distribution and number of plots per site). We made an effort to collect tissue from individuals distributed throughout the entire stream network to better characterize the genetic population structure.

We used sterilized dissecting scissors to obtain tissue samples. We collected tail tissue from larval tailed frogs and larval and post-metamorphic giant salamanders. The target tissue size was 0.5 cm^2 collected with a single snip to the tip of the tail. We collected a single toe from metamorphosed tailed frogs. Tissue samples were stored in 96% ethanol. We had a minimum goal of sampling 30 individuals per taxa and study site. Individuals with evidence of previous tissue removal were not sampled. For sites where the minimum of 30 samples per taxa were not obtained with standard light-touch and rubble-rouse sampling, we conducted additional nocturnal light-touch surveys, and diurnal light-touch, rubble-rouse and kick sampling (e.g., Arkle and Pilliod 2010) to increase sample sizes.

1-5.2. LABORATORY METHODS

We extracted Coastal Tailed Frog (N = 360) and giant salamander (N = 1,106) tissues collected in the post-harvest period with the Qiagen DNeasy Tissue kit, as per manufacturer's protocol (Qiagen Inc., Germantown, MD). Tailed frog and giant salamander samples were amplified at 13 (Spear *et al.* 2008) and 11 microsatellite loci (Steele *et al.* 2008) respectively. PCR amplifications were carried out with Qiagen Master Mix (Qiagen Inc., Germantown, MD). Samples that did not amplify at >70% of the loci or had identical genotypes were not included in the analyses. Full descriptions of the PCR conditions and thermal profiles for each species multiplex reaction can be found in **Appendix A** and **Appendix B**. Primer sequences are listed in Spear *et al.* (2008) and Steele *et al.* (2008). PCR products were visualized on an ABI 3730 sequencer (Applied Biosystems, Foster City, CA) concurrent with LIZ500 size standard. Alleles were scored using the GENEMAPPER 5 software (Applied Biosystems, Foster City, CA).

1-5.3. SALAMANDER SPECIES IDENTIFICATION

We used the program NewHybrids (Anderson and Thompson 2002) to identify pure or hybrid individuals of Coastal or Cope's Giant Salamander. NewHybrids uses a Bayesian framework to calculate posterior probabilities of sampled individuals belonging to six categories of hybrid status: pure Coastal, pure Cope's, F1 hybrid, F2 hybrid, backcross on Coastal, and backcross on Cope's. We selected Jeffrey's prior (a non-informative objective prior) for θ and π. NewHybrids was run with a burn-in of 10,000 followed by 100,000 iterations. We classified individuals into three categories based on the posterior probabilities: 1) Pure Coastal or Cope's, 2) Hybrid, and 3) No call (data were insufficient or ambiguous). A posterior probability of 0.90 or greater determined the classification of an individual to either a Coastal or Cope's Giant Salamander. An individual was classified as a hybrid if the sum of all hybrid classes was 0.90 or higher. Individuals that had insufficient or ambiguous data (posterior probability for pure or hybrid class ranging between 0.48 – 0.75) were classified as no call. However, we recorded the category with the highest posterior probability in the final table.

1-5.4. GENETIC ANALYSES

We first prepared genotypes in the software CONVERT (Glaubitz 2004) for further downstream conversion of genetic data files for the various population genetic analysis software packages we used. We tested each locus and site for violations of Hardy-Weinberg equilibrium and presence of linkage disequilibrium using Genepop on the web (Raymond and Rousset 1995; Rousset 2008). We also tested for proportion of null alleles (a common cause of Hardy-Weinberg violations) using the software FreeNA (Chapuis and Estoup 2007).

We tested for the presence of full siblings using Colony v2 0.6.3 (Wang 2004). This is especially important because a high proportion of our samples were larval individuals that may have a high representation of family groups. In the Baseline Genetic Report (Spear *et al.* 2011) we removed siblings from the dataset for genetic analyses because of concerns that the presence of full siblings can bias results (Goldberg and Waits 2010). However, recent research has indicated that automatically removing siblings may not give a better representation of actual population genetic structure, especially for estimates of genetic diversity (Waples and Anderson 2017). Therefore, we elected to retain all unique individuals while using the proportion and number of full siblings as a potential indicator of treatment effects. We note that this means that some of the pre-harvest measures presented herein may not exactly match tables from the Baseline Genetic Report (Spear *et al.* 2011). For the Colony analyses we assumed polygamy for both sexes, did not include a Bayesian prior (i.e. did not assume a particular distribution in advance), and included the null allele rates for each locus as potential error affecting estimation. We used Cervus v3.0.7 (Kalinowski *et al.* 2007) to estimate the probability that two individuals would have the same genotype by chance (P_{ID}). We estimated P_{ID} for both unrelated individuals and for full siblings.

We estimated several measures of genetic diversity using the software GDA 1.1 (Lewis and Zaykin 2002). Variables included average number of alleles per locus, observed heterozygosity, and Wright's inbreeding coefficient (F_{IS}). Number of alleles per locus is the clearest measure of genetic diversity at the site level as it simply records the number of alleles present. The average number of alleles can be misleading if variation in sample size exists; more individuals sampled increases the chance for additional alleles. Therefore, we also calculated allelic richness. Allelic richness estimates the number of alleles that would be present if sample sizes were equal across all sites and is based on the lowest sample size available. As our comparison of interest was pre- versus post-harvest, we calculated allelic richness separately for each site incorporating sample size of both periods. Allelic richness was calculated using Fstat (Goudet 2001). Observed heterozygosity is the measure of the proportion of individuals that have two different alleles at a locus. It can be seen as a measure of genetic diversity within individuals at a site. F_{IS} is typically estimated by comparing the difference between the observed heterozygosity and the theoretical levels of heterozygosity expected based on the number of alleles. If mating is random, then we would expect observed heterozygosity to match expected heterozygosity and F_{IS} would be zero. If mating occurs between individuals that are more genetically similar than random, the F_{IS} increases (hence the name of the metric). F_{IS} can also be negative if mating occurs among individuals that are more distantly related than random. F_{IS} ranges from -1 to 1, but values are typically much lower than one. For instance, a F_{IS} of 0.05 can represent the equivalence of mating between first cousins. We also attempted to include effective population size as a metric of genetic diversity. However, the method used to estimate effective population size (Onesamp; Tallmon *et al.* 2008) in the Baseline Genetic Report (Spear *et al.* 2011) is only available as a web interface and was no longer available for the post-harvest analysis. We used another common estimator based on linkage disequilibrium (LDNe; Do *et al.* 2014) and noted both large confidence intervals and little consistency with the pre-harvest Onesamp estimates for the same individuals. Based on this we did not include effective population size in our current analysis.

We tested for significant reductions in effective population size (bottlenecks) using two methods: the heterozygosity excess test (Cornuet and Luikart 1996) and shifted allele distributions (Luikart *et al.* 1998). Spear *et al.* (2011) included a third test in the Baseline Genetic Report based on a metric known as M-ratio (Garza and Williamson 2001). We did not retain the M-ratio for this analysis as Peery *et al.* (2012) demonstrated through simulations that the M-ratio test was susceptible to a high Type I error rate. The first method, heterozygosity excess test, detects bottlenecks through an increase in expected heterozygosity relative to theoretical expectations. This increase in expected heterozygosity is an ephemeral signature after a bottleneck because allelic diversity is lost before heterozygosity begins to decrease. We tested for heterozygosity excess in the software Bottleneck (Piry *et al.* 1999). We assumed a two-phase mutation model with 10% multistep mutations and 12% variance in size of multi-step mutations. This was the recommended value by Piry *et al.* (1999). Peery *et al.* (2012) note that though the exact justification for these values is not clear, heterozygosity excess is relatively robust to the exact parameter values. We assessed significance using a Wilcoxon sign-rank test. The second test, a shifted allele distribution, measures the loss of rare alleles. Microsatellites are typically characterized by a high proportion of rare alleles. Rare alleles are lost first in a bottleneck and therefore we expect that the distribution of allele frequencies should shift toward a greater frequency of more common alleles. The test for shifted allele distribution was also implemented in the Bottleneck software.

Finally, we estimated the amount of genetic connectivity and scale of genetic neighborhoods using the Bayesian population clustering algorithm STRUCTURE (Pritchard *et al.* 2000). While population clustering is determined by factors at a much broader scale than our treatment sites, understanding the scale of genetic connectivity is useful to understand the degree to which migration might influence site-level genetic results. One of the difficulties of using STRUCTURE and other clustering algorithms is determining the best supported number of clusters (*K*). In the Baseline Genetic Report (Spear *et al.* 2011) we used a hierarchical partitioning of sites using the second order rate of change in model likelihood, a statistic known as ΔK (Evanno *et al.* 2005). However, recent research has highlighted problems with the ΔK metric, specifically that it tends to select a *K* of 2 and underestimates substructure (Puechmaille 2016; Janes *et al.* 2017). The hierarchical approach of running STRUCTURE at multiple levels helps to address the weakness in the ΔK approach, but can complicate interpretation of clustering plots. Puechmaille *et al.* (2016) developed four related metrics that they found to be more informative across a wider range of population scenarios. These metrics calculate the proportion membership of each individual to each of the *K* clusters. The mean or median (depending on exact metric) of cluster membership is calculated across each sampling site, and the number of clusters that have a mean/median membership of a threshold (0.5 or greater) in at least one population is recorded. Therefore, the method only considers clusters that can be assigned to at least one sampling site. For each method (the mean or median), the metric identifies two values of *K*: one that is the median value among all replicates, and one that is the maximum value among all replicates. The four metrics are abbreviated MedMedK (median value of *K* from the median membership), MaxMedK (maximum value of *K* from the median membership), MedMeanK (median value of *K* from the mean membership), and MaxMeanK (maximum value of *K* from the mean membership). Puechmaille *et al.* (2016) recommends calculating each of the four metrics at thresholds ranging from 0.5-0.8 to evaluate the most consistent number of clusters. We used the median value of *K* from the 16 different possibilities (four types of metrics multiplied by four different thresholds). We also ran STRUCTURE for the pre-treatment genetic data using the same metrics and method for choosing *K*. This allowed us to identify any change in genetic admixture within a site that may have become more or less differentiated post-harvest. For each of the replicate STRUCTURE runs, we used the admixture model with a burn-in of 100,000 iterations and 100,000 iterations after burn-in. We ran 20 replicates for each value of number of clusters and we considered *K* and up to be the total number of sites for which sampling occurred for each species. We did not include a location prior and we assumed correlated allele frequencies. We averaged runs and calculated metrics using StructureSelector (Li and Liu 2018).

1-5.5. STATISTICAL ANALYSES

We used a linear mixed effects model to assess the effect of treatment on change in measures of genetic diversity. Our fixed effects were time (pre- or post-harvest), treatment, and the treatment × time interaction. Our random effects were block and site. We evaluated whether there was a significant treatment × time effect using a Wald-type test on linear contrasts of fixed effects. Consistent with McIntyre *et al.* (2018b, Chapter 15 - Stream-associated Amphibians), we used an alpha of 0.10. We believe this approach is appropriate for applying a reasonable level of confidence to significant results, in light of the lower number of replicates due to the constraints of the field BACI design and time separating sampling periods. If a treatment × time effect less than 0.1 existed, we examined pairwise contrasts among each treatment combination. We used the nlme package (Pinheiro *et al.* 2015) in R v.3.2.3 (R Core Team 2015). We assessed models for lack-of-fit using residual diagnostic plots. In sum, we performed 18 significance tests for mixed effect models across all species and genetic diversity metrics, 18 significance tests for pairwise contrasts, and 37 significance tests for the post-harvest heterozygosity excess tests.

1-6. RESULTS

Of the Coastal Tailed Frogs included in the analysis for the post-harvest period (N = 354), 31% were larvae, 21% were in the process of metamorphosing, and 48% were post-metamorphic. Of the post-metamorphic individuals, less than 1% were greater than 42 mm SVL (**Figure 3**). Of the giant salamanders included in the analysis for the post-harvest period (N =1,073), greater than 99% were ≤100 mm SVL, less than 1% were >100 mm SVL, and less than 1% were post-metamorphs (**Figure 4**).We detected greater numbers of both taxa in the pre-harvest period: Coastal Tailed Frog N = 573, giant salamanders N = 1,504 (Spear *et al.* 2011).

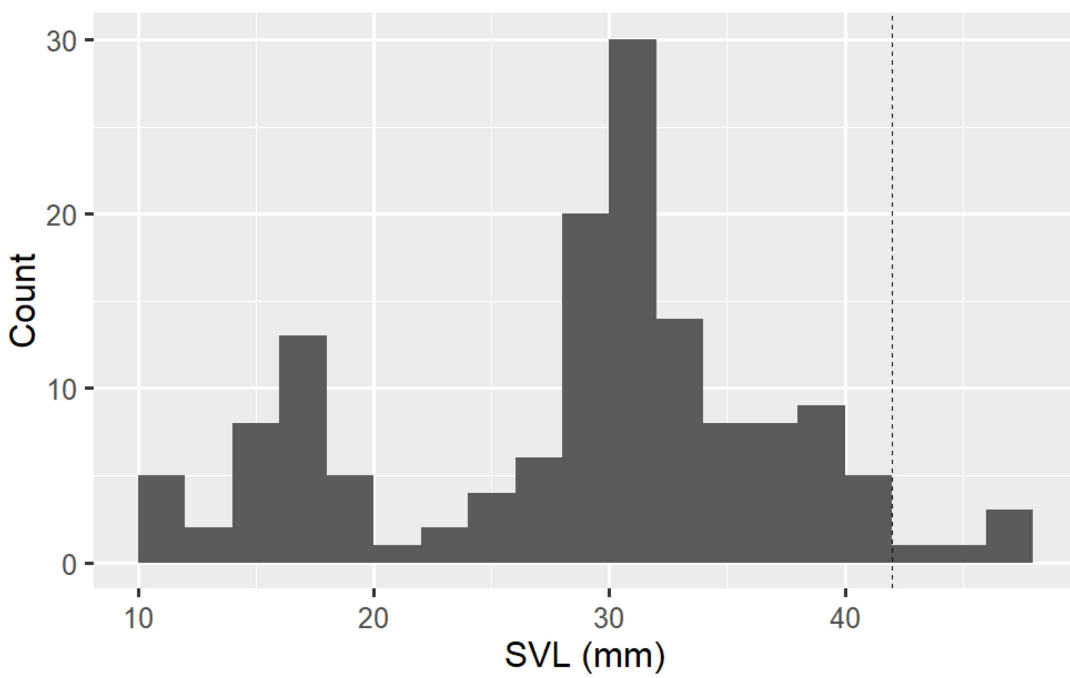

Figure 3. Size distribution of post-metamorphic Coastal Tailed Frog snout-vent lengths (SVL) for animals sampled in the post-harvest period. The dotted line at 42 mm SVL is the minimum size for which we estimated post-metamorphic tailed frogs to be younger than eight years, and thus also born after treatment implementation

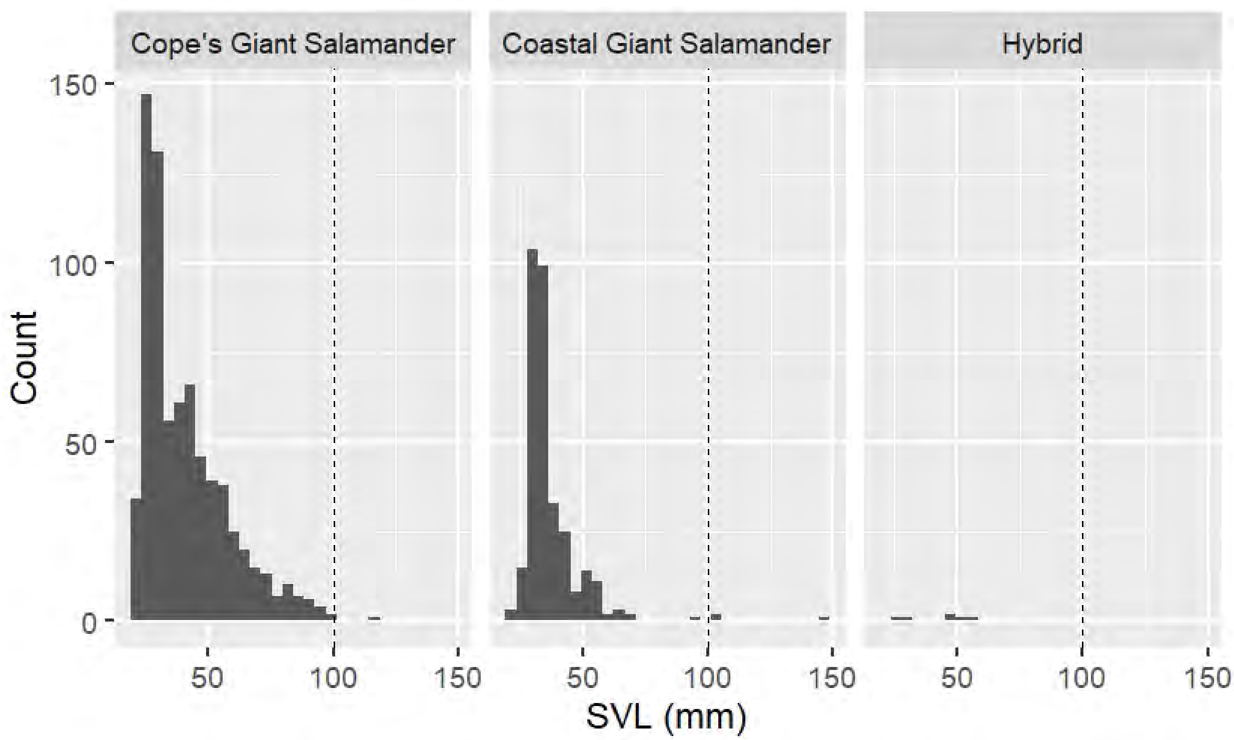

Figure 4. Size distributions of larval, neotenic and post-metamorphic giant salamander snout-vent lengths (SVL) for Cope's (N = 737), Coastal (N = 329) and hybrid (N = 7) giant salamanders sampled in the post-harvest period. The dotted line at 100 mm SVL is the minimum size for which we estimated giant salamanders to be younger than eight years, and thus also born after treatment implementation.

1-6.1. GENETIC DIVERSITY

1-6.1.1. Sample size and full sibling groups

1-6.1.1.a. Coastal Tailed Frog

A total of 353 unique tailed frog individuals successfully amplified at >70% of the loci (**Table 3**). Consistent with the Baseline Genetic Report (Spear *et al.* 2011), four loci (A14, A2, A29, A3) had evidence of null alleles and violations of Hardy-Weinberg equilibrium at multiple sites. Therefore, as with the Baseline Genetic Report (Spear *et al.* 2011), we eliminated these loci from further analysis. None of the nine remaining loci had evidence of null alleles or consistent Hardy-Weinberg violations. Sample number ranged from 3-56 individuals (mean = 24.86, SE = 4.22; **Appendix C**). Even though fewer individuals were sampled post-harvest across treatments (**Table 3**; **Figure 5**), there was no difference in the magnitude of change between treatments (F = 1.47; P = 0.28; **Table 4** and **Table 5**). The P_{ID} for unrelated tailed frog individuals was 5 x 10^{-19} and the full sibling P_{ID} was 2 x 10^{-5}. Therefore, it is highly unlikely we would infer unrelated individuals as within a family group due to chance. The average number of unrelated individuals (i.e. unique family groups) was 22.64 (SE = 4.08) in the post-harvest period (**Appendix C**). This average is lower than that seen in the pre-harvest period (33.5), but the difference can be entirely explained by a change in sample size (**Figure 5** and **Figure 6**). We detected no significant treatment effect on the change in number of unique full-sibling family groups ($F = 1.40$, $P = 0.30$; **Table 6**; **Figure 6**). The pattern of between-treatment change in family number was also very similar to overall sample size (**Table 7**).

Table 3. Sample size for each species from post-harvest genetic sampling. Samples that did not amplify at >70% of the loci or had identical genotypes were not included in the total. Hybrid represents crosses between the two giant salamander species. Site ID is the identification number referred to throughout the genetic clustering figures.

Block	**Site**	**Site ID**	**Coastal Tailed Frog**	**Giant Salamanders**		
				Cope's	**Coastal**	**Hybrid**
OLYM	REF	1	56	90	0	0
	100%	2	5	52	0	0
	FP	3	7	26	0	0
	0%	4	33	41	0	0
Subtotal			**101**	**209**	**0**	**0**
WIL1	REF	5	27	14	30	1
	100%	6	3	15	23	0
	FP	7	13	26	37	1
	0%	8	26	58	0	0
Subtotal			**69**	**113**	**90**	**2**
WIL2	REF1	9	49	92	30	1
	REF2	10	18	39	2	1
	100%	11	28	55	0	0
	0%	12	13	74	23	0
Subtotal			**108**	**260**	**55**	**2**
WIL3	REF	13	33	28	22	1
	100%	14	7	6	34	1
Subtotal			**40**	**34**	**56**	**2**
CASC	REF	15	35	48	30	1
	FP	16	0	59	65	0
	0%	17	0	14	33	0
Subtotal			**35**	**121**	**128**	**1**
Grand total			**353**	**737**	**329**	**7**

Table 4. Within-treatment change (Estimate) and 95% CI in number of individuals sampled between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error. The p-value for this model was 0.28, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	-0.67	6.30	-16.87	15.53
100%	-24.67	13.69	-83.58	34.25
FP	-29.00	12.00	-181.52	123.52
0%	-13.67	16.15	-83.15	55.82

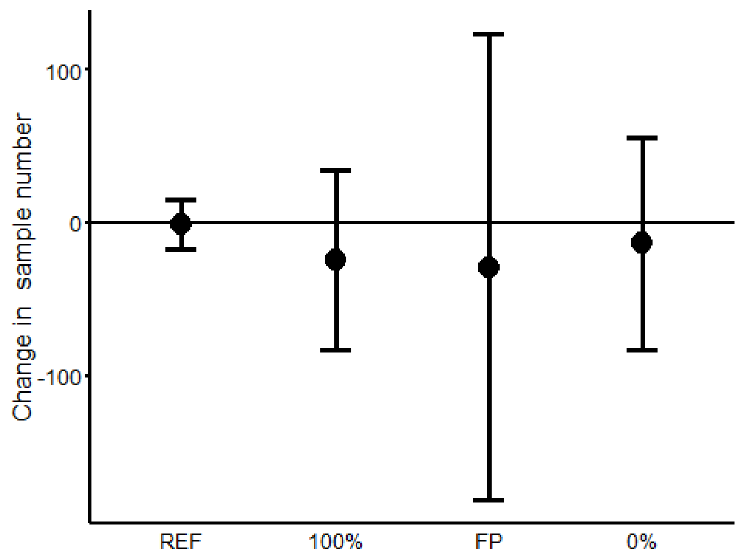

Figure 5. Within-treatment change and 95% CI in number of individuals sampled between pre- and post-harvest sampling for Coastal Tailed Frogs.

Table 5. Pairwise contrasts of the between-treatment change (Estimate) in the number of individuals sampled between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-24.00	14.43	-52.28	4.28
FP vs. REF	-28.30	16.67	-60.97	4.37
0% vs. REF	-13.00	14.43	-41.28	15.28
100% vs FP	4.33	18.64	-32.20	40.86
100% vs. 0%	-11.00	16.67	-43.67	21.67
FP vs. 0%	-15.00	18.64	-51.53	21.53

Table 6. Within-treatment change (Estimate) and 95% CI in number of unique full-sibling families sampled between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error. The p-value for this model was 0.30, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.33	5.57	-13.99	14.66
100%	-22.33	14.31	-83.91	39.24
FP	-25.00	13.00	-190.23	140.23
0%	-12.33	14.10	-73.00	48.33

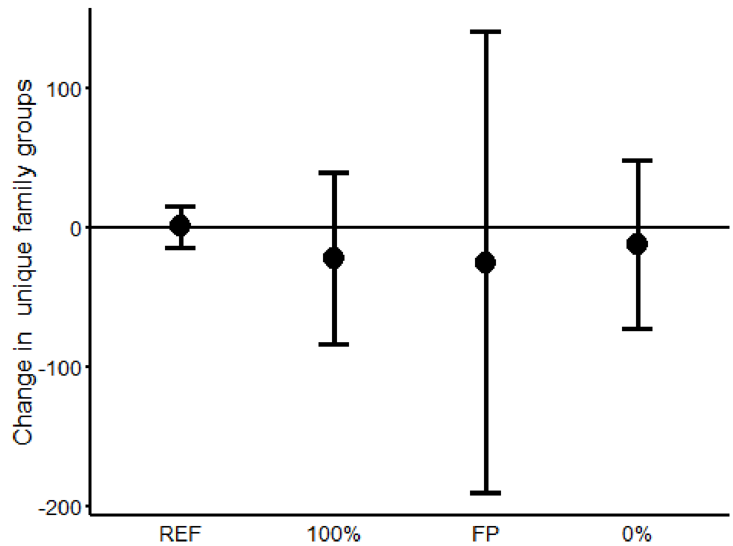

Figure 6. Within-treatment change and 95% CI in number of unique full-sibling families sampled between pre- and post-harvest sampling for Coastal Tailed Frogs.

Table 7. Pairwise contrasts of the between-treatment change (Estimate) in the number of unique full-sibling families sampled between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-22.67	13.58	-49.29	3.95
FP vs. REF	-25.33	15.69	-56.08	5.42
0% vs. REF	-12.67	13.58	-39.29	13.95
100% vs FP	2.67	17.54	-31.71	37.05
100% vs. 0%	-10.00	15.69	-40.75	20.75
FP vs. 0%	-12.67	17.54	-47.05	21.71

1-6.1.1.b. Giant salamander species identification

We were able to obtain unique genotypes from a total of 1,073 giant salamander individuals. We removed two of the eleven markers (D05 and D24) for the purposes of species identification because they were not reliably scored. The presence/absence marker (D15) was also removed since it does not amplify in Coastal Giant Salamander. We therefore used a total of eight loci for species identification. We identified a total of 737 Cope’s Giant Salamanders, 329 Coastal Giant Salamanders, and 7 hybrids (**Table 3**). Hybrids made up less than 1% of all samples. There was no significant difference (F = 0.78; P = 0.54) in the proportion of Cope's giant salamanders per site between the pre-harvest and post-harvest period (

Table 8 and **Table 9**; **Figure 7** and **Figure 8**).

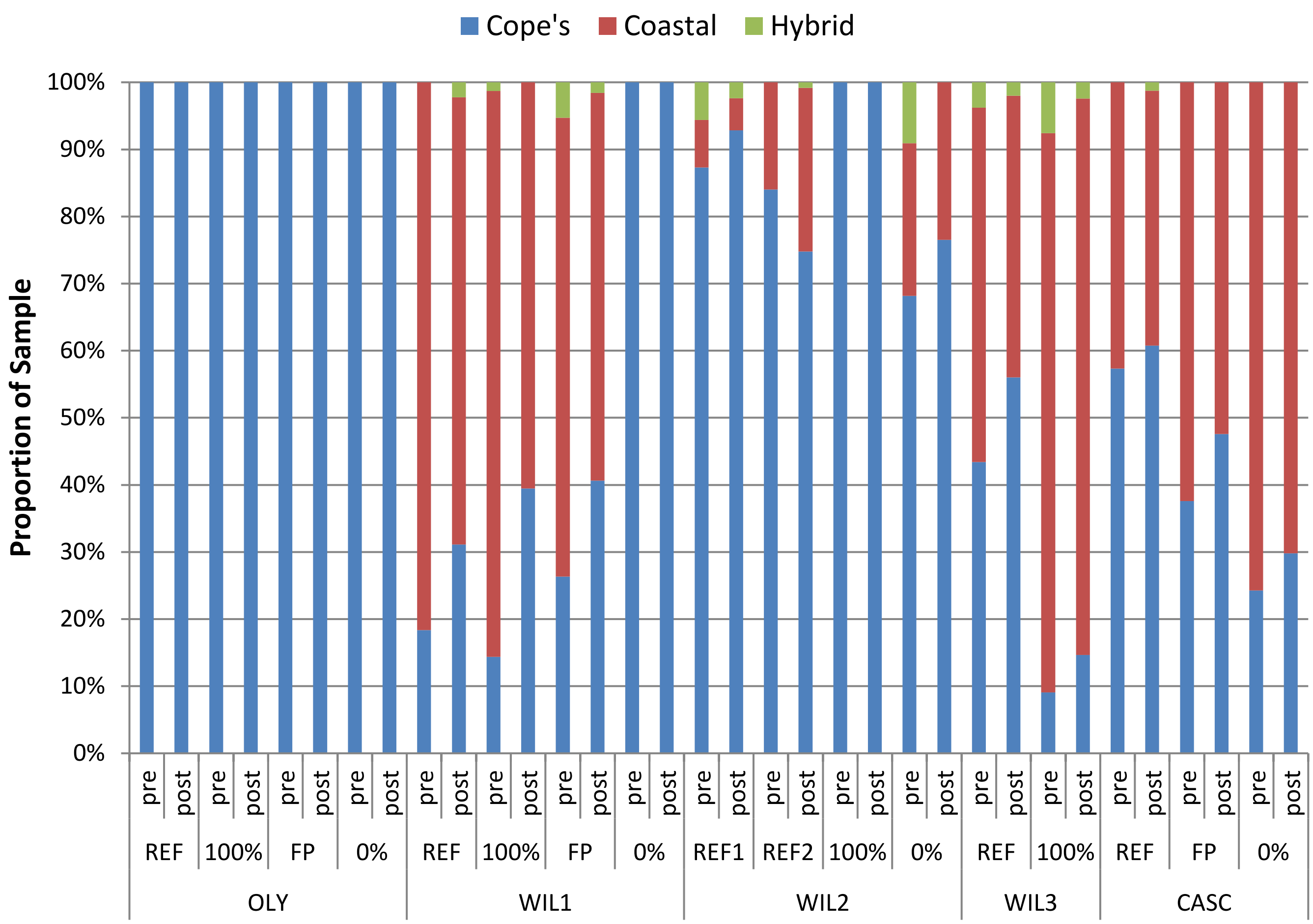

Figure 7. Proportion of Cope's, Coastal, and hybrid Giant Salamanders individuals sampled in the pre-harvest (pre) and post-harvest (post) periods. Each column represents the total sample collected in a site within each period.

Table 8. Within-treatment change (Estimate) and 95% CI in proportion of Cope's Giant Salamander sampled between pre- and post-harvest sampling for all giant salamanders. SE represents standard error. The p-value for this model was 0.54, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.03	0.06	-0.13	0.20
100%	0.16	0.09	-1.01	1.34
FP	0.13	0.06	-0.63	0.90
0%	0.07	0.00	0.01	0.13

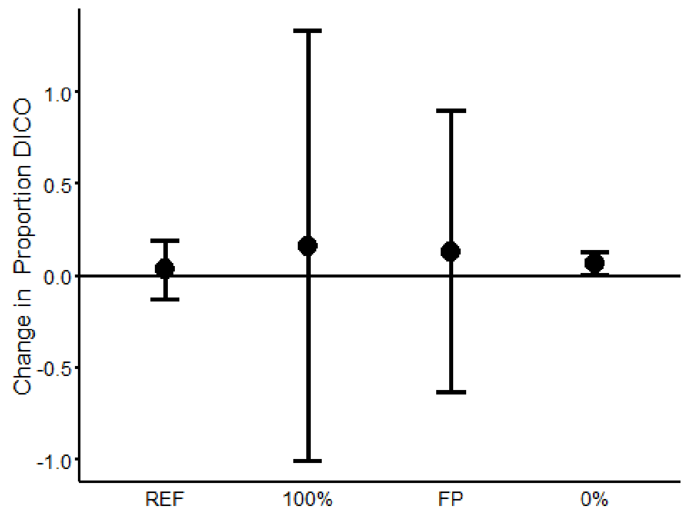

Figure 8. Within-treatment change and 95% CI in proportion of Cope's Giant Salamander (DICO) sampled between pre- and post-harvest sampling relative to total giant salamanders (sum of Cope's, Coastal, and hybrid).

Table 9. Pairwise contrasts of the between-treatment change (Estimate) in the proportion of overall giant salamanders that were Cope's Giant Salamanders between pre- and post-harvest sampling. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.13	0.1	-0.07	0.33
FP vs. REF	0.10	0.1	-0.10	0.30
0% vs. REF	0.04	0.1	-0.16	0.24
0% vs. FP	0.03	0.12	-0.21	0.27
0% vs. 100%	0.09	0.12	-0.15	0.33
FP vs. 100%	0.06	0.12	-0.18	0.30

1-6.1.1.b.(i). **Cope's Giant Salamander**

We did not see any consistent evidence of Hardy-Weinberg violations by loci or of null alleles, thus, all eleven loci were retained for Cope's Giant Salamander. Sample size per site ranged from 6-92 (mean=43.35, SE = 6.35; **Appendix D**). There was no treatment effect on change in overall sample size (F = 0.63; P = 0.61) and little change in sample size from the baseline genetic survey. Only the reference sites had a confidence interval that did not overlap zero (**Table 10** and **Table 11**; **Figure 9**). The P_{ID} for unrelated Cope's Giant Salamander individuals was 4 x 10^{-19} and the full sibling P_{ID} was 4 x 10^{-6}. The proportion of unique family groups was high with an average of 85% (**Appendix D**) While there was no difference in change in proportion by treatment (F = 0.66; P = 0.59), all treatments had an increased proportion of unique families relative to the baseline surveys (**Table 12** and **Table 13**; **Figure 10**).

Table 10. Within-treatment change (Estimate) and 95% CI in number of individuals sampled between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error. The p-value for this model was 0.61, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	11.50	5.66	-3.04	26.04
100%	2.50	6.33	-17.65	22.65
FP	-2.67	4.06	-20.12	14.78
0%	-2.25	15.35	-51.09	46.59

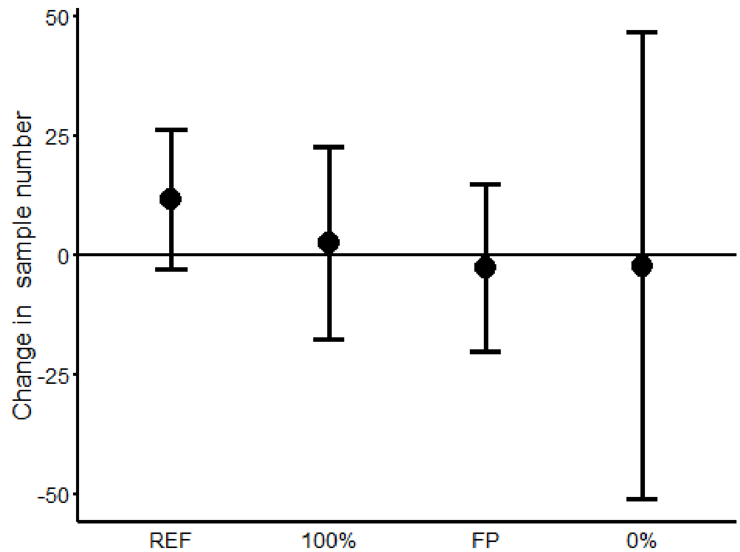

Figure 9. Within-treatment change and 95% CI in number of individuals sampled between pre- and post-harvest sampling for Cope's Giant Salamander.

Table 11. Pairwise contrasts of the between-treatment change (Estimate) in the number of individuals sampled between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-9.00	11.83	-32.19	14.19
FP vs. REF	-14.17	12.96	-39.57	11.23
0% vs. REF	-13.75	11.83	-36.94	9.44
100% vs FP	5.17	14.00	-22.27	32.61
100% vs. 0%	4.75	12.96	-20.65	30.15
FP vs. 0%	-0.42	14.00	-27.86	27.02

Table 12. Within-treatment change (Estimate) and 95% CI for the proportion of unique full-sibling families relative to total sample size between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error. The p-value for this model was 0.59, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.02	0.06	-0.13	0.29
100%	0.11	0.05	-0.06	0.47
FP	0.11	0.08	-0.25	0.44
0%	0.14	0.10	-0.16	0.52

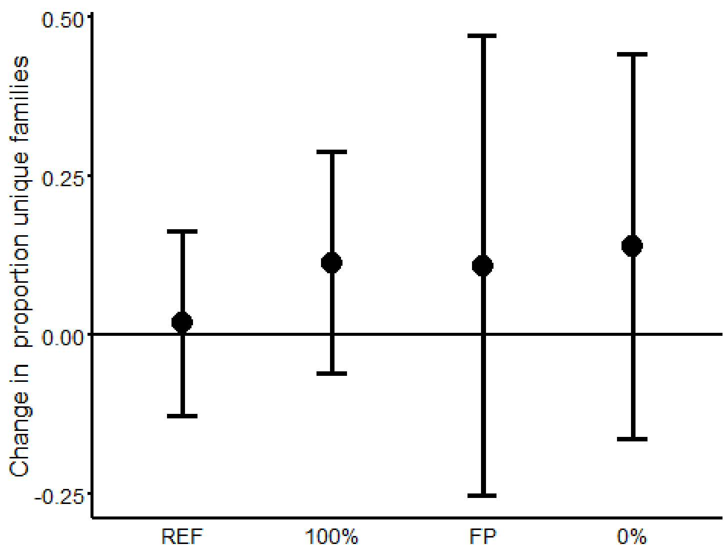

Figure 10. Within-treatment change and 95% CI in proportion of unique full-sibling families relative to total sample size between pre- and post-harvest sampling for Cope's Giant Salamander.

Table 13. Pairwise contrasts of the between-treatment change (Estimate) in proportion of unique full-sibling families relative to total sample size between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.09	0.10	-0.11	0.29
FP vs. REF	0.09	0.10	-0.11	0.29
0% vs. REF	0.12	0.10	-0.08	0.32
100% vs FP	0.00	0.11	-0.22	0.22
100% vs. 0%	-0.03	0.10	-0.23	0.17
FP vs. 0%	-0.03	0.11	-0.25	0.19

1-6.1.1.b.(ii). **Coastal Giant Salamander**

Of the 11 total giant salamander loci only five loci (D04, D13, D18, D23, D24) did not have high instances of missing data or evidence of null alleles in Coastal Giant Salamander samples. Therefore, we only retained these five loci for further analysis. Sample size ranged from 2-65 (mean of 29.91, SE = 4.52; **Appendix E**). We did not test for differences by treatment in sample number due to violations of normality (and inability of transformations to correct this) but we did model the difference in both number of unique families and proportion of unique families to gain insight into whether there were differences in overall sample size. The P_{ID} for unrelated Coastal Giant Salamander individuals was 6×10^{-5} and the full sibling P_{ID} was 0.03. Due to the fewer number of loci, there is a greater chance of identical genotypes by chance in this species compared to Coastal Tailed Frog or Cope's Giant Salamander. However, there is still only a 6 in 100,000 chance that unrelated individuals would have the same genotype, and therefore we are confident our estimated family groups are not likely to consist of unrelated individuals. The number of unique families per site averaged 23.55 (SE = 3.83; **Appendix E**). There was a significant treatment effect in the change in number of unique full sibling family groups (F = 5.15; P = 0.03). This effect was driven by a decrease in the number of unique family groups in the 100% treatment (**Table 14**; **Figure 11**) and all pairwise comparisons with the 100% treatment were significantly different (**Table 15**). There were no treatment effects with respect to change in proportion of full sibling family groups relative to total sample size (F = 1.14; P = 0.40; **Table 16** and **Table 17**; **Figure 12**). Therefore, the significant decline in full-sibling family groups in the 100% treatment is due to a decrease in overall number of individuals.

Table 14. Within-treatment change (Estimate) and 95% CI in number of unique full-sibling families sampled between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error. The p-value for this model was 0.03, which indicated a significant difference based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	5.40	3.80	-5.16	15.96
100%	-24.00	10.00	-151.10	103.10
FP	4.50	2.50	-27.28	36.28
0%	-1.00	7.00	-89.97	87.97

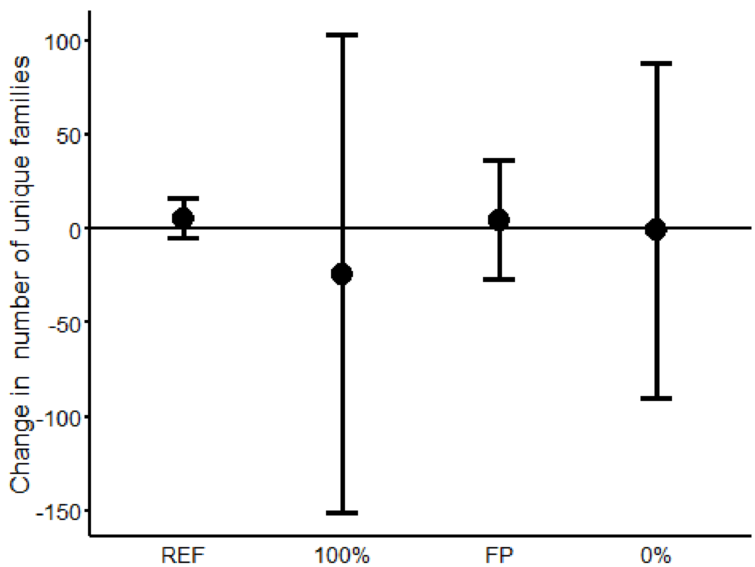

Figure 11. Within-treatment change and 95% CI in number of unique full-sibling families sampled between pre- and post-harvest sampling for Coastal Giant Salamander.

Table 15. Pairwise contrasts of the between-treatment change (Estimate) in the number of unique full-sibling families sampled between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first. We used an alpha of 0.10 to assess significance based on the p-value.

Contrast	Estimate	SE	P-value	95% CI	
				Lower	Upper
100% vs. REF	-29.4	7.74	0.01	-44.57	-14.23
FP vs. REF	-0.90	7.74	0.91	-16.07	14.27
0% vs. REF	-6.40	7.74	0.44	-21.57	8.77
100% vs FP	-28.50	9.26	0.02	-46.65	-10.35
100% vs. 0%	-23.00	9.26	0.04	-41.15	-4.85
FP vs. 0%	5.50	9.26	0.57	-12.65	23.65

Table 16. Within-treatment change (Estimate) and 95% CI for the proportion of unique full-sibling families relative to total sample size between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error. The p-value for this model was 0.40, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.17	0.09	-0.07	0.42
100%	0.34	0.10	-0.88	1.56
FP	0.40	0.07	-0.53	1.33
0%	0.18	0.11	-1.20	1.56

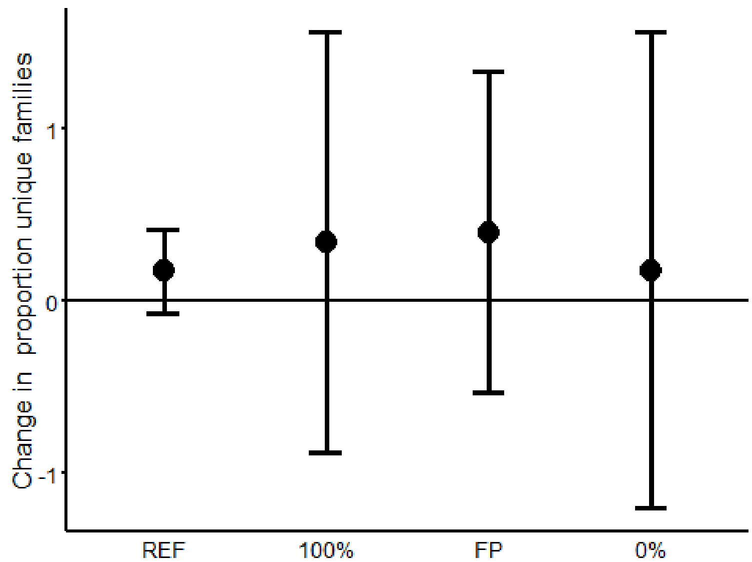

Figure 12. Within-treatment change and 95% CI in proportion of unique full-sibling families relative to total sample size between pre- and post-harvest sampling for Coastal Giant Salamander.

Table 17. Pairwise contrasts of the between-treatment change (Estimate) in proportion of unique full-sibling families relative to total sample size between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.17	0.14	-0.10	0.44
FP vs. REF	0.23	0.14	-0.04	0.50
0% vs. REF	0.00	0.14	-0.27	0.27
100% vs FP	-0.06	0.17	-0.39	0.27
100% vs. 0%	0.16	0.17	-0.17	0.49
FP vs. 0%	0.22	0.17	-0.11	0.55

1-6.1.2. Allelic Diversity

1-6.1.2.a. Coastal Tailed Frog

The average number of alleles per locus ranged from 4.7 to 19.0 with an average of 13.6 (SE = 1.12; **Appendix C**). We detected no treatment effect on differences in average number of alleles per locus for Coastal Tailed Frogs (F = 1.65; P = 0.24; **Table 18** and **Table 19**; **Figure 13**). The pattern in allele number was very similar to the pattern observed for sample size demonstrating that total allelic diversity largely followed sample size in this system. We did not find a significant treatment effect on change in allelic richness (F = 1.27; P = 0.34). However, there was a consistent trend among buffer treatments with respect to mean change in allelic richness (**Table 20** and **Table 21**; **Figure 14**). There was a mean increase in richness from the reference in the 100% treatment, with corresponding lower means as the forested buffer decreased, and very little mean difference between the reference and 0% treatment.

Table 18. Within-treatment change (Estimate) and 95% CI in average number of alleles per locus between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error. The p-value for this model was 0.24, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	-0.35	0.76	-2.30	1.59
100%	-6.74	4.73	-27.09	13.60
FP	-5.83	2.39	-36.20	24.53
0%	-2.30	3.34	-16.66	12.07

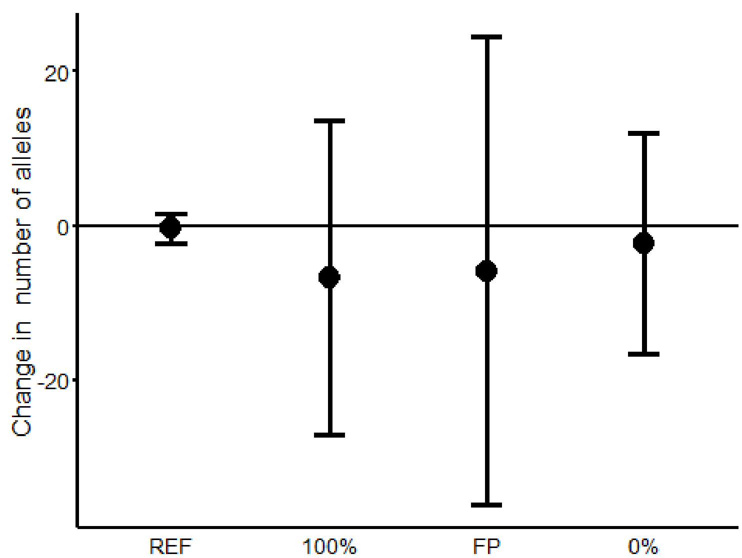

Figure 13. Within-treatment change and 95% CI in average number of alleles per locus between pre- and post-harvest sampling for Coastal Tailed Frogs.

Table 19. Pairwise contrasts of the between-treatment change (Estimate) in the average number of alleles per locus between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-6.39	3.20	-12.66	-0.12
FP vs. REF	-5.48	3.70	-12.73	1.77
0% vs. REF	-1.94	3.20	-8.21	4.33
100% vs FP	-0.91	4.13	-9.00	7.18
100% vs. 0%	-4.44	3.70	-11.69	2.81
FP vs. 0%	-3.54	4.13	-11.63	4.55

Table 20. Within-treatment change (Estimate) and 95% CI in allelic richness between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error. The p-value for this model was 0.34, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	-0.14	0.18	-0.60	0.31
100%	0.89	0.72	-2.22	4.01
FP	0.25	0.64	-7.92	8.41
0%	-0.33	0.66	-3.15	2.49

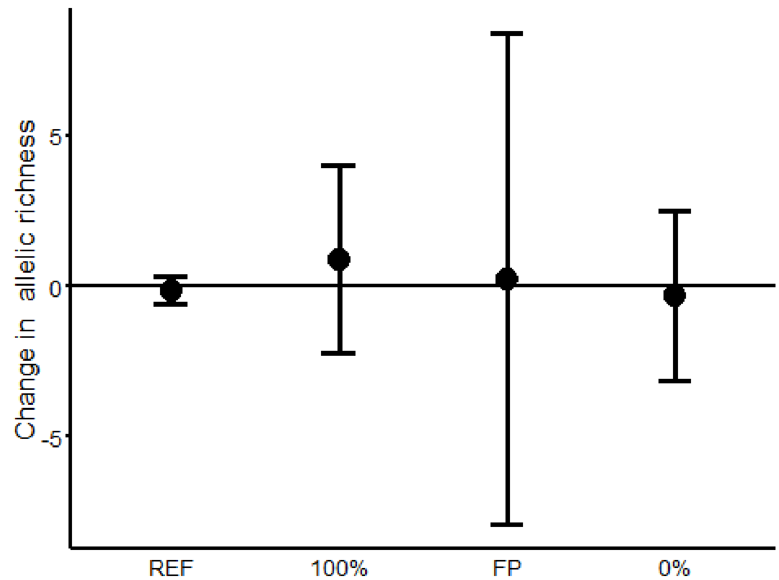

Figure 14. Within-treatment change and 95% CI in allelic richness between pre- and post-harvest sampling for Coastal Tailed Frogs.

Table 21. Pairwise contrasts of the between-treatment change (Estimate) in allelic richness between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	1.04	0.61	-0.16	2.24
FP vs. REF	0.39	0.71	-1.00	1.78
0% vs. REF	-0.19	0.61	-1.39	1.01
100% vs FP	0.65	0.79	-0.99	2.20
100% vs. 0%	1.23	0.71	-0.16	2.62
FP vs. 0%	0.58	0.79	-0.97	2.13

1-6.1.2.b. Cope's Giant Salamander

Average allelic number per loci ranged from 4.0 to 15.0 with a mean of 9.4 alleles (SE = 0.72; **Appendix D**). There was no evidence of a treatment effect on the change of either average number of alleles per locus or allelic richness for Cope's Giant Salamander (allele number: F = 0.22; P = 0.88, allelic richness: F = 0.30; P = 0.82). The allelic diversity was very stable across all treatments compared to the baseline condition with the average change being less than one (**Tables 22-25**; **Figure 15** and **Figure 16**).

Table 22. Within-treatment change (Estimate) and 95% CI in average number of alleles per locus between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error. The p-value for this model was 0.88, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.20	0.13	-0.12	0.52
100%	-0.18	0.54	-1.89	1.53
FP	-0.03	0.51	-2.22	2.16
0%	-0.07	0.44	-1.46	1.32

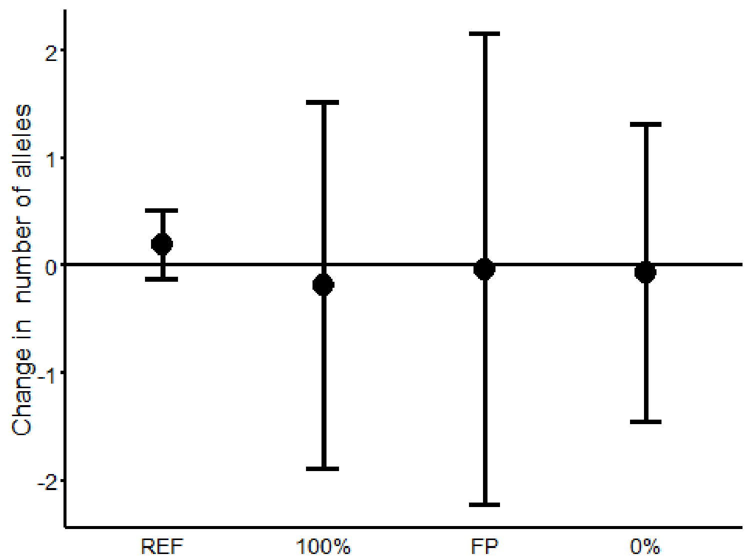

Figure 15. Within-treatment change and 95% CI in average number of alleles per locus between pre- and post-harvest sampling for Cope's Giant Salamander.

Table 23. Pairwise contrasts of the between-treatment change (Estimate) in the average number of alleles per locus between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-0.38	0.50	-1.36	0.60
FP vs. REF	-0.23	0.55	-1.31	0.85
0% vs. REF	-0.27	0.50	-1.25	0.71
0% vs. FP	-0.15	0.59	-1.31	1.01
0% vs. 100%	-0.11	0.55	-1.19	0.97
FP vs. 100%	0.04	0.59	-1.12	1.20

Table 24. Within-treatment change (Estimate) and 95% CI in allelic richness between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error. The p-value for this model was 0.82, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	-0.18	0.15	-0.57	0.21
100%	0.06	0.23	-0.68	0.81
FP	-0.07	0.34	-1.53	1.39
0%	-0.06	0.08	-0.31	0.18

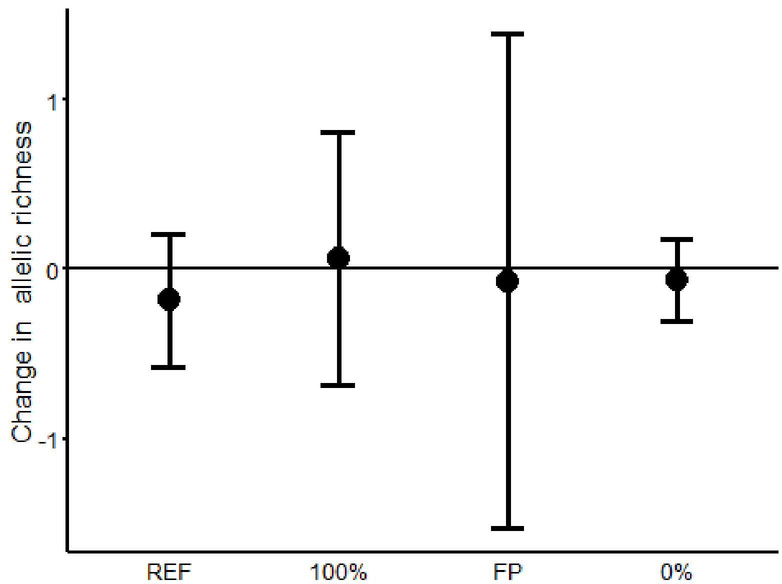

Figure 16. Within-treatment change and 95% CI in allelic richness between pre- and post-harvest sampling for Cope's Giant Salamander.

Table 25. Pairwise contrasts of the between-treatment change (Estimate) in allelic richness between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.25	0.26	-0.26	0.76
FP vs. REF	0.11	0.28	-0.44	0.66
0% vs. REF	0.12	0.26	-0.39	0.63
100% vs FP	0.13	0.31	-0.48	0.74
100% vs. 0%	0.13	0.28	-0.42	0.68
FP vs. 0%	-0.01	0.31	-0.62	0.60

1-6.1.2.c. Coastal Giant Salamander

Average alleles per locus in Coastal Giant Salamander sites ranged from 2.2 to 7.8 with an average of 5.6 (SE = 0.46; **Appendix E**). We did not detect any treatment effect on the number of alleles per locus (F = 2.29; P = 0.17) and differences among periods were generally small with only the 100% treatment having a mean change greater than one (**Table 26** and **Table 27**; **Figure 17**). We did not test for differences in allelic richness due to violations of normality assumptions.

Table 26. Within-treatment change (Estimate) and 95% CI in average number of alleles per locus between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error. The p-value for this model was 0.17, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.72	0.79	-1.48	2.92
100%	-3.20	1.20	-18.45	12.05
FP	-0.90	0.30	-4.71	2.91
0%	-0.70	1.90	-24.85	23.45

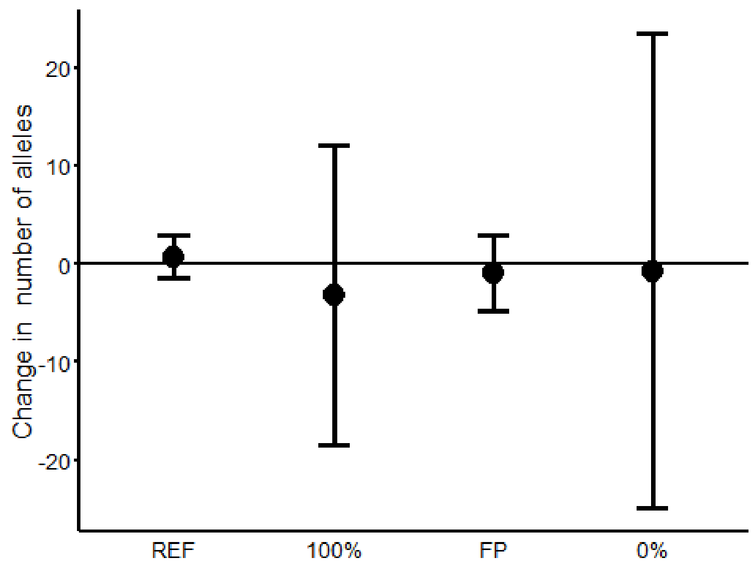

Figure 17. Within-treatment change and 95% CI in average number of alleles per locus between pre- and post-harvest sampling for Coastal Giant Salamander.

Table 27. Pairwise contrasts of the between-treatment change (Estimate) in the average number of alleles per locus between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-3.92	1.51	-6.88	-0.96
FP vs. REF	-1.62	1.51	-4.58	1.34
0% vs. REF	-1.42	1.51	-4.38	1.54
100% vs FP	-2.30	1.81	-5.85	1.25
100% vs. 0%	-2.50	1.81	-6.05	1.05
FP vs. 0%	-0.20	1.81	-3.75	3.35

1-6.1.3. Observed Heterozygosity

1-6.1.3.a. Coastal Tailed Frog

Observed heterozygosity was high, ranging from 0.83 to 0.94 within sites with an overall average of 0.88 (SE = 0.01; **Appendix C**). There was no treatment effect on heterozygosity (F = 2.12; P = 0.16), and the overall magnitude of change was small relative to overall heterozygosity (**Table 28** and **Table 29**; **Figure 18**).

Table 28. Within-treatment change (Estimate) and 95% CI in observed heterozygosity between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error. The p-value for this model was 0.16, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.02	0.01	-0.01	0.06
100%	-0.03	0.02	-0.10	0.04
FP	-0.01	0.04	-0.50	0.48
0%	0.02	0.01	-0.04	0.08

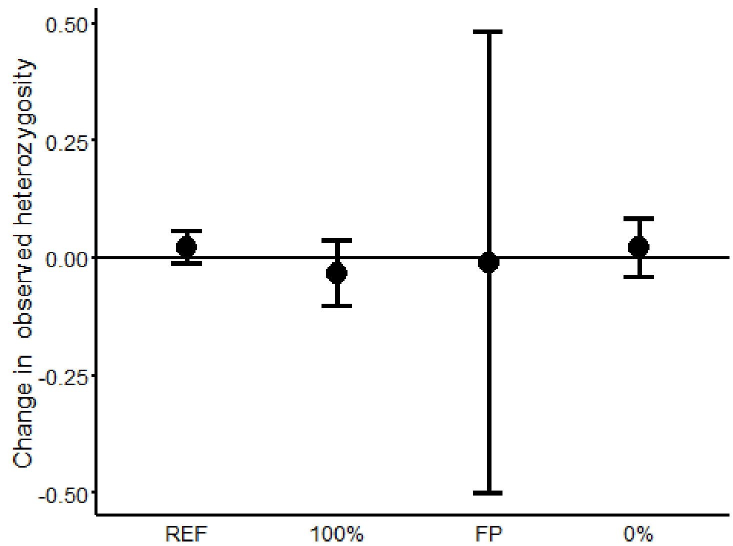

Figure 18. Within-treatment change and 95% CI in observed heterozygosity between pre- and post-harvest sampling for Coastal Tailed Frogs.

Table 29. Pairwise contrasts of the between-treatment change (Estimate) in observed heterozygosity between pre- and post-harvest sampling for Coastal Tailed Frogs. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	-0.05	0.02	-0.09	-0.01
FP vs. REF	-0.03	0.03	-0.09	0.03
0% vs. REF	0.00	0.02	-0.04	0.04
100% vs FP	-0.02	0.03	-0.08	0.04
100% vs. 0%	-0.05	0.03	-0.11	0.01
FP vs. 0%	-0.03	0.03	-0.09	0.03

1-6.1.3.b. Cope's Giant Salamander

Observed heterozygosity in Cope's Giant Salamander sites ranged from 0.45 to 0.84 with an average of 0.72 (SE = 0.03; **Appendix D**). We logit-transformed observed heterozygosity values for analysis due to violations of normality assumptions. There was no treatment effect on the change in heterozygosity (F = 1.31; P = 0.31). The mean observed heterozygosity in all treatments was higher than baseline averages (**Table 30** and **Table 31**; **Figure 19**).

Table 30. Within-treatment change (Estimate) and 95% CI in logit-transformed observed heterozygosity between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error. The p-value for this model was 0.31, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.12	0.05	-0.02	0.25
100%	0.16	0.04	0.04	0.27
FP	0.02	0.04	-0.16	0.20
0%	0.06	0.05	-0.09	0.21

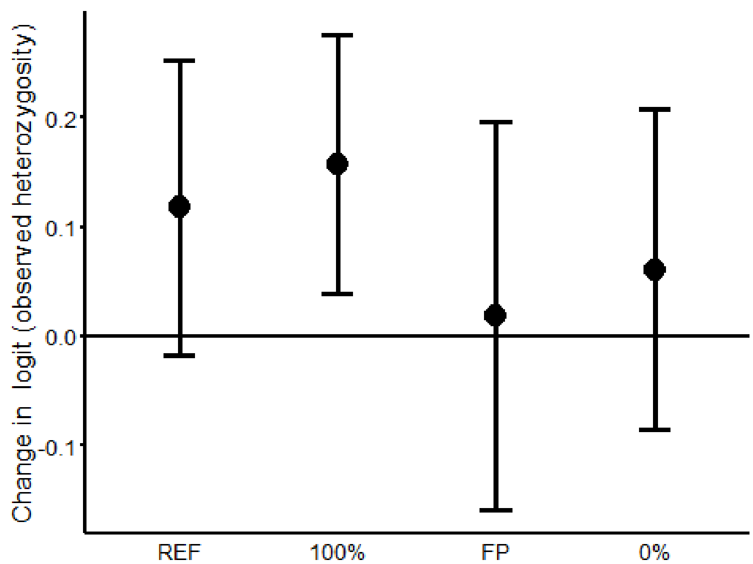

Figure 19. Within-treatment change and 95% CI in logit-transformed observed heterozygosity between pre- and post-harvest sampling for Cope's Giant Salamander.

Table 31. Pairwise contrasts of the between-treatment change (Estimate) in logit-transformed observed heterozygosity between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.09	0.15	-0.20	0.38
FP vs. REF	-0.23	0.17	-0.56	0.10
0% vs. REF	-0.13	0.10	-0.33	0.07
100% vs FP	0.32	0.18	-0.03	0.67
100% vs. 0%	0.22	0.17	-0.11	0.55
FP vs. 0%	-0.10	0.18	-0.45	0.25

1-6.1.3.c. Coastal Giant Salamander

Observed heterozygosity ranged from 0.44 to 0.67, with an average of 0.53 (SE = 0.02; **Appendix E**). There was no effect of treatment on change in heterozygosity (F = 0.17; P = 0.92). Overall, there was a small increase in heterozygosity across all treatments relative to the baseline surveys and (**Table 32** and **Table 33**; **Figure 20**).

Table 32. Within-treatment change (Estimate) and 95% CI in observed heterozygosity between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error. The p-value for this model was 0.92, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.05	0.05	-0.10	0.20
100%	0.08	0.02	-0.22	0.37
FP	0.02	0.04	-0.52	0.55
0%	0.02	0.01	-0.05	0.09

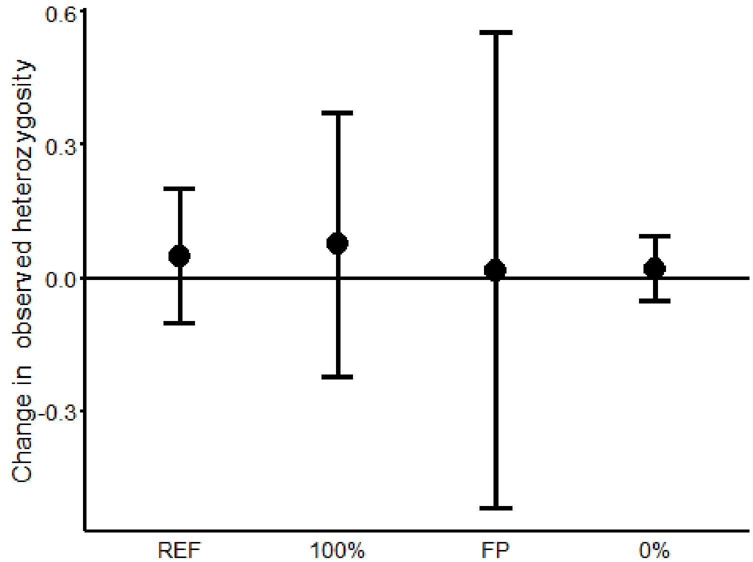

Figure 20. Within-treatment change and 95% CI in observed heterozygosity between pre- and post-harvest sampling for Coastal Giant Salamander.

Table 33. Pairwise contrasts of the between-treatment change (Estimate) in observed heterozygosity between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.03	0.08	-0.13	0.19
FP vs. REF	-0.03	0.08	-0.19	0.13
0% vs. REF	-0.03	0.08	-0.19	0.13
100% vs FP	0.06	0.10	-0.14	0.26
100% vs. 0%	0.05	0.10	-0.15	0.25
FP vs. 0%	0.00	0.10	-0.20	0.20

1-6.1.4. Wright's Inbreeding Coefficient

1-6.1.4.a. Coastal Tailed Frog

Average Wright's inbreeding coefficient (F_{IS}) for Coastal Tailed Frog across all sites was 0.02 (SE = 0.01; **Appendix C**) There was no significant treatment effect on the change in F_{IS} (F = 1.61; P = 0.25) and no consistent pattern in the direction of the change in F_{IS} (**Table 34** and **Table 35**; **Figure 21**).

Table 34. Within-treatment change (Estimate) and 95% CI in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Coastal Tailed Frog. SE represents standard error. The p-value for this model was 0.25, which indicated no significant differences based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	-0.03	0.02	-0.07	-0.01
100%	0.03	0.03	-0.11	-0.17
FP	0.00	0.05	-0.59	-0.59
0%	-0.03	0.03	-0.14	-0.09

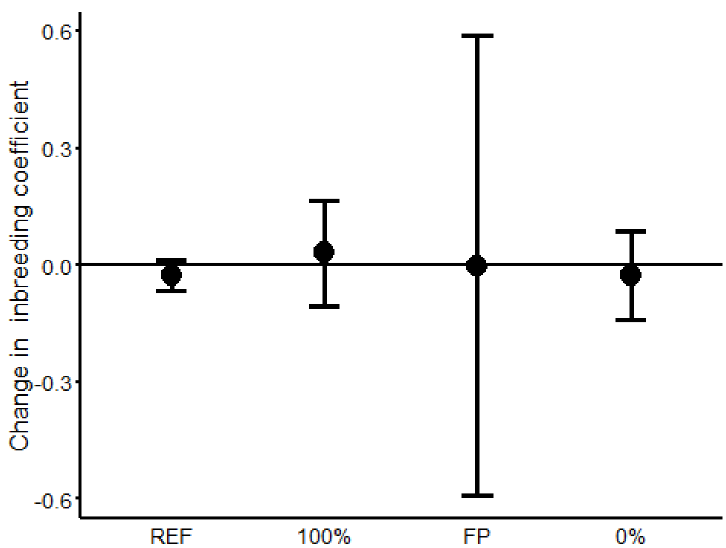

Figure 21. Within-treatment change and 95% CI in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Coastal Tailed Frog.

Table 35. Pairwise contrasts of the between-treatment change (Estimate) in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Coastal Tailed Frog. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first.

Contrast	Estimate	SE	95% CI	
			Lower	Upper
100% vs. REF	0.06	0.03	0.00	0.12
FP vs. REF	0.03	0.03	-0.03	0.09
0% vs. REF	0.00	0.03	-0.06	0.06
100% vs FP	0.03	0.04	-0.05	0.11
100% vs. 0%	0.06	0.03	0.00	0.12
FP vs. 0%	0.03	0.04	-0.05	0.11

1-6.1.4.b. Cope's Giant Salamander

The average F_{IS} for Cope's Giant Salamander across sites was 0.01 (SE = 0.01; **Appendix D**). While we did not observe an overall significant treatment effect on F_{IS} (F = 2.49, P = 0.105; **Table 36**; **Figure 22**), we did observe a pairwise significant difference (p = 0.02) between the FP and 100% treatments (**Table 37**). The F_{IS} for the FP treatment was exactly the same as in the baseline conditions, with all other treatments decreasing in F_{IS}.

Table 36. Within-treatment change (Estimate) and 95% CI in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error. The p-value for this model was 0.105, which approached our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	-0.04	0.02	-0.09	0.01
100%	-0.10	0.02	-0.18	-0.02
FP	0.00	0.03	-0.14	0.15
0%	-0.04	0.02	-0.11	0.03

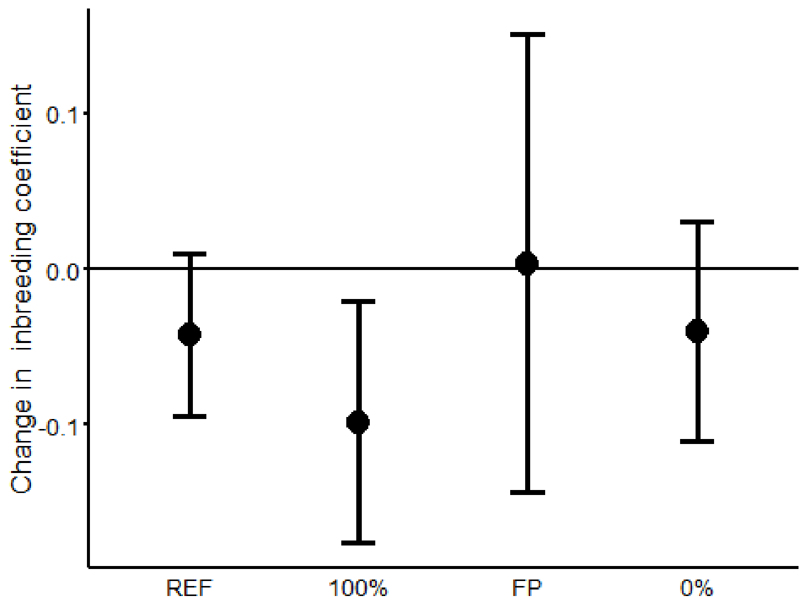

Figure 22. Within-treatment change and 95% CI in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Cope's Giant Salamander.

Table 37. Pairwise contrasts of the between-treatment change (Estimate) in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Cope's Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first. We used an alpha of 0.10 to assess significance based on the p-values.

Contrast	Estimate	SE	P-value	95% CI	
				Lower	Upper
100% vs. REF	-0.06	0.03	0.11	-0.12	0.00
FP vs. REF	-0.05	0.04	0.21	-0.12	0.02
0% vs. REF	0.00	0.03	0.95	-0.06	0.06
100% vs. FP	-0.10	0.04	0.02	-0.18	-0.02
0% vs. 100%	-0.06	0.04	0.12	-0.14	0.02
FP vs. 0%	0.04	0.04	0.27	-0.04	0.12

1-6.1.4.c. Coastal Giant Salamander

The average F_{IS} for Coastal Giant Salamander was 0.01 (SE = 0.02; **Appendix E**). We detected a significant treatment effect on change in F_{IS} (F = 4.23; P = 0.05; **Table 38**; **Figure 23**). The treatment effect was due to significant pairwise contrasts of reference versus both the 100% and

0% treatments (p = 0.02 and p = 0.03; **Table 39**). The average F_{IS} in the 100% and 0% treatments were lower than reference with the FP treatment mean as intermediate.

Table 38. Within-treatment change (Estimate) and 95% CI in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error. The p-value for this model was 0.05, which indicated a significant difference based on our alpha of 0.10.

Treatment	Estimate	SE	95% CI	
			Lower	Upper
REF	0.06	0.03	-0.04	0.15
100%	-0.11	0.01	-0.22	0.00
FP	0.01	0.06	-0.78	0.79
0%	-0.10	0.03	-0.52	0.32

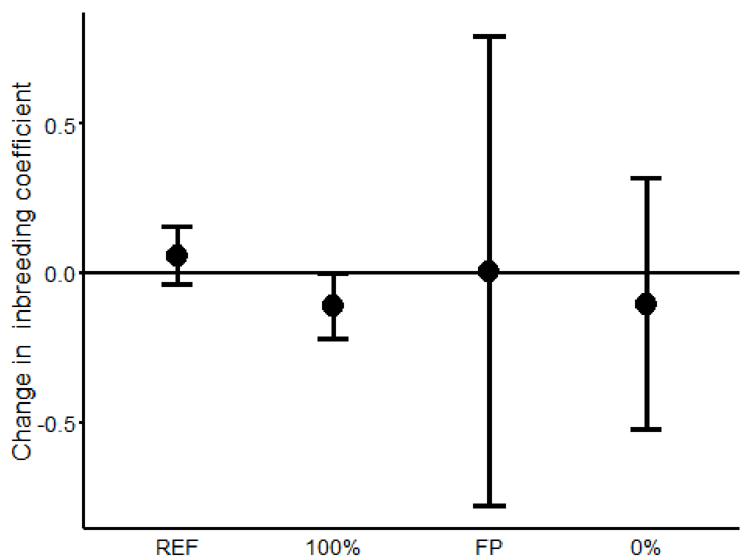

Figure 23. Within-treatment change and 95% CI in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Coastal Giant Salamander.

Table 39. Pairwise contrasts of the between-treatment change (Estimate) in Wright's inbreeding coefficient (F_{IS}) between pre- and post-harvest sampling for Coastal Giant Salamander. SE represents standard error and 95% CI is the 95% confidence interval. For the estimate, the second treatment listed in the contrast is subtracted from the first. We used an alpha of 0.10 to assess significance using the p-values.

Contrast	Estimate	SE	P-value	95% CI	
				Lower	Upper
100% vs. REF	-0.17	0.06	0.02	-0.29	-0.05
FP vs. REF	-0.05	0.06	0.40	-0.17	0.07
0% vs. REF	-0.16	0.06	0.03	-0.28	-0.04
100% vs FP	-0.12	0.07	0.14	-0.26	0.02
100% vs. 0%	-0.01	0.07	0.94	-0.15	0.13
FP vs. 0%	0.11	0.07	0.16	-0.03	0.25

1-6.1.5. Test for Recent Population Size declines

1-6.1.5.a. Coastal Tailed Frog

The heterozygosity excess test provided evidence for recent population size declines for Coastal Tailed Frogs at six sites in the post-harvest period (**Table 40**). Three of these sites (OLYM-REF, WIL1-REF, and OLYM-0%) also had heterozygosity excess in the pre-harvest period, but there were no shifted allelic distributions at any sites. The other three sites only showed heterozygosity excess in the post-harvest period; two of these sites were references (WIL2-REF1 and WIL2-REF2). The only site with a significant (p = 0.02 heterozygosity excess after a treatment was the WIL1-0%. Two sites with significant heterozygosity excess in the pre-harvest period (WIL1-100% and OLYM-FP) had insufficient sample size in the post-harvest period to conduct the tests. Two sites (WIL3-REF and WIL1-FP) had heterozygosity excess before the treatment period but no evidence of heterozygosity excess afterwards.

Table 40. Results of tests for recent population size declines in Coastal Tailed Frogs for both pre- and post-harvest periods. The tests included were the heterozygosity excess tests and shifted allele distributions. H_e represents actual expected heterozygosity and H_{eq} represents heterozygosity expected under equilibrium conditions. A significant p-value (bolded and underlined) indicates a significant heterozygosity excess relative to equilibrium expectations. The Shifted? column indicates whether allelic distributions were normal or skewed. Grayed out cells indicate that sample size was not sufficient to conduct these tests.

	Pre-harvest				Post-harvest			
Site	H_e	H_{eq}	**p-value**	**Shifted?**	H_e	H_{eq}	**p-value**	**Shifted?**
OLYM-REF	0.91	0.88	**0.00**	normal	0.90	0.89	**0.00**	normal
WIL1-REF	0.91	0.89	**0.02**	normal	0.90	0.89	**0.02**	normal
WIL2-REF1	0.90	0.90	0.29	normal	0.90	0.89	**0.00**	normal
WIL2-REF2	0.90	0.89	0.18	normal	0.90	0.88	**0.01**	normal
WIL3-REF	0.92	0.91	**0.02**	normal	0.90	0.90	0.33	normal
CASC-REF	0.85	0.89	0.25	normal	0.87	0.88	0.12	normal
WIL1-100%	0.91	0.90	**0.02**	normal				
WIL2-100%	0.87	0.88	0.75	normal	0.90	0.90	0.37	normal
WIL3-100%	0.90	0.89	0.25	normal				
OLYM-FP	0.88	0.86	**0.02**	normal				
WIL1-FP	0.91	0.90	**0.10**	normal	0.90	0.89	0.82	normal
OLYM-0%	0.90	0.87	**0.00**	normal	0.89	0.87	**0.01**	normal
WIL1-0%	0.87	0.88	0.37	normal	0.88	0.86	**0.02**	normal
WIL2-0%	0.90	0.90	0.18	normal	0.88	0.88	0.46	normal

1-6.1.5.b. Cope's Giant Salamander

Four sites had evidence of population size reductions based on heterozygosity excess for Cope's Giant Salamander (**Table 41**). Two of these sites (WIL2-REF1 and WIL2-0%) had heterozygosity excess in both pre- and post-harvest periods. Of the two sites that had evidence of declines post-harvest, one was a reference (WIL2-REF2) and the other was a FP treatment (WIL1-FP). No sites had shifted allele distributions.

Table 41. Results of tests for recent population size declines in Cope's Giant Salamanders for both pre- and post-harvest periods. The tests included were the heterozygosity excess tests and shifted allele distributions. H_e represents actual expected heterozygosity and H_{eq} represents heterozygosity expected under equilibrium conditions. A significant p-value (bolded and underlined) indicates a significant heterozygosity excess relative to equilibrium expectations. The Shifted? Column indicates whether allelic distributions were normal or skewed. Grayed out cells indicate that sample size was not sufficient to conduct these tests.

	Pre-harvest				Post-harvest			
Site	H_e	H_{eq}	**p-value**	**Shifted?**	H_e	H_{eq}	**p-value**	**Shifted?**
OLYM-REF	0.66	0.72	0.97	normal	0.65	0.73	0.97	normal
WIL1-REF	0.83	0.83	0.38	normal	0.81	0.84	0.14	normal
WIL2-REF1	0.87	0.86	**<u>0.03</u>**	normal	0.86	0.85	**<u>0.07</u>**	normal
WIL2-REF2	0.85	0.84	0.21	normal	0.85	0.83	**<u>0.00</u>**	normal
WIL3-REF	0.85	0.87	0.55	normal	0.88	0.88	0.38	normal
CASC-REF	0.69	0.77	0.99	normal	0.72	0.77	0.97	normal
OLYM-100%	0.58	0.61	0.55	normal	0.51	0.59	0.82	normal
WIL1-100%	0.86	0.88	0.58	normal	0.84	0.85	0.74	normal
WIL2-100%	0.76	0.76	0.42	normal	0.77	0.79	0.21	normal
WIL3-100%								
OLYM-FP	0.67	0.67	0.42	normal	0.65	0.69	0.82	normal
WIL1-FP	0.81	0.81	0.48	normal	0.85	0.84	**<u>0.05</u>**	normal
CASC-FP	0.84	0.85	0.84	normal	0.84	0.83	0.12	normal
OLYM-0%	0.65	0.68	0.45	normal	0.63	0.72	0.75	normal
WIL1-0%	0.74	0.77	0.55	normal	0.73	0.79	0.28	normal
WIL2-0%	0.86	0.83	**<u>0.01</u>**	normal	0.85	0.84	**<u>0.09</u>**	normal
CASC-0%	0.84	0.83	0.16	normal	0.83	0.84	0.71	normal

1-6.1.5.c. Coastal Giant Salamander

There was no evidence for recent reductions in population size for Coastal Giant Salamanders based on either heterozygosity excess or shifted allele distributions (**Table 42**).

Table 42. Results of tests for recent population size declines in Coastal Giant Salamanders for both pre- and post-harvest periods. The tests included were the heterozygosity excess tests and shifted allele distributions. H_e represents actual expected heterozygosity and H_{eq} represents heterozygosity expected under equilibrium conditions. A significant p-value (bolded and underlined) indicates a significant heterozygosity excess relative to equilibrium expectations. The Shifted? Column indicates whether allelic distributions were normal or skewed. Grayed out cells indicate that sample size was not sufficient to conduct these tests.

	Pre-harvest				Post-harvest			
Site	H_e	H_{eq}	**p-value**	**Shifted?**	He	H_{eq}	**p-value**	**Shifted?**
WIL1-REF	0.59	0.59	0.41	normal	0.58	0.60	0.41	normal
WIL2-REF1					0.60	0.63	0.89	normal
WIL2-REF2								
WIL3-REF	0.66	0.73	0.95	normal	0.69	0.78	0.89	normal
CASC-REF	0.37	0.64	0.91	normal	0.44	0.65	0.94	normal
WIL1-100%	0.66	0.80	0.98	normal	0.71	0.74	0.69	normal
WIL3-100%	0.61	0.78	0.95	normal	0.62	0.70	0.95	normal
WIL1-FP	0.58	0.71	0.92	normal	0.65	0.65	0.31	normal
CASC-FP	0.53	0.60	0.92	normal	0.48	0.56	0.92	normal
WIL2-0%	0.65	0.67	0.69	normal	0.68	0.72	1.00	normal
CASC-0%	0.47	0.70	0.97	normal	0.42	0.56	0.84	normal

1-6.2. GENETIC CLUSTERING

1-6.2.1. Coastal Tailed Frog

The median value of *K* for Coastal Tailed Frog in both pre- and post-harvest was 3 (**Figure 24**and **Figure 25**), although *K* = 2 and *K* = 4 were selected by some of the individual metrics (**Appendix F**). The arrangement of clusters was also similar between the two periods, with sites showing evidence of clustering by region but little evidence of significant genetic structure within each of the three regions. The Olympic region is most clearly differentiated, with a higher degree of admixture between the Willapa Hills and South Cascades.

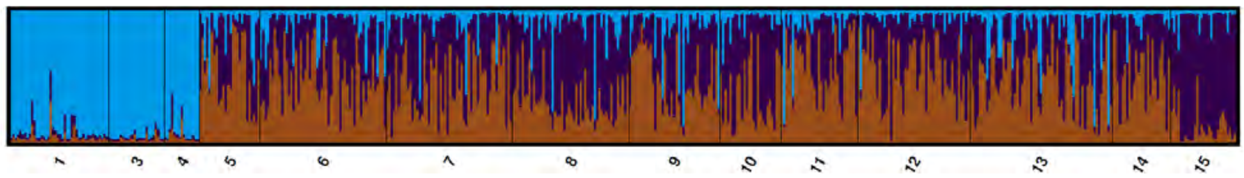

Figure 24. Bayesian genetic clustering results for all samples of Coastal Tailed Frogs pre-harvest assuming *K*=3. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and site 15 in the South Cascades.

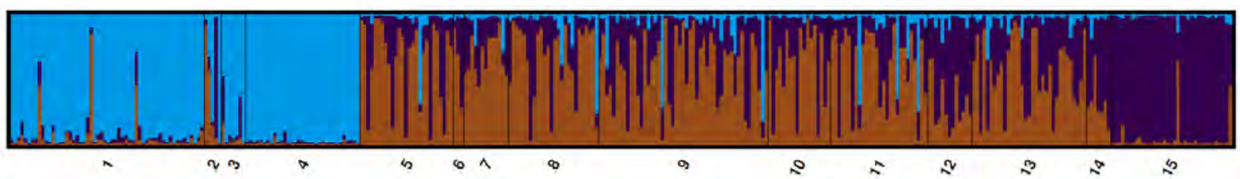

Figure 25. Bayesian genetic clustering results for all samples of Coastal Tailed Frogs post-harvest assuming *K*=3. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

1-6.2.2. Cope's Giant Salamander

There was a difference between estimated values of *K* between periods for Cope's Giant Salamander. The median value of *K* pre-harvest was nine and the median value of *K* post-harvest was between seven and eight (**Figure 26 -28)**. Other values of *K* receiving some support for the pre-harvest period include 7, 8, 10, 11, and 12 (**Appendix G**). In the post-harvest period, *K* = 6, 9, and 10 were selected with some of the individual metrics (**Appendix G**). Despite the different median values of *K*, the pattern of clustering between the periods was very similar. The Olympic and South Cascades regions represented clear clusters and had little substructure within each region. The Willapa Hills region had the greatest subdivision, although the region still had a pattern of high admixture among sites. The major differences were that sites 7 (WIL1-FP) and 11 (WIL2-100%) are differentiated in the pre-harvest period but admixed with other sites post-harvest. Site 2 (OLYM-100%) is completely within the Olympic cluster post-harvest, whereas it is admixed with a separate cluster pre-harvest.

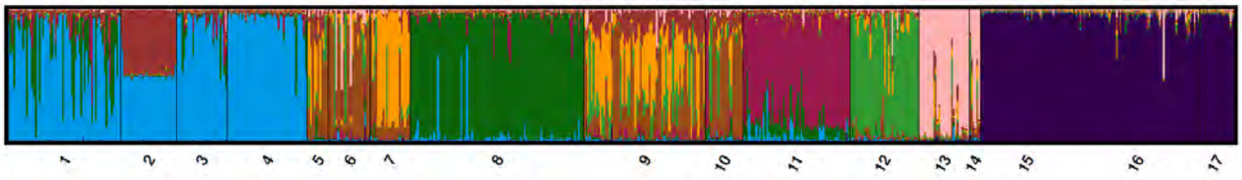

Figure 26. Bayesian genetic clustering results for all samples of Cope's Giant Salamanders pre-harvest assuming K = 9. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

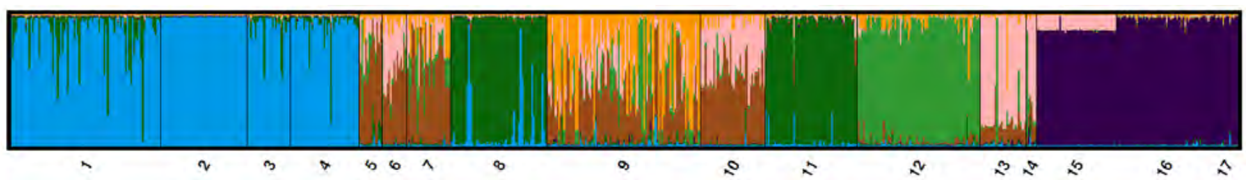

Figure 27. Bayesian genetic clustering results for all samples of Cope's Giant Salamanders post-harvest assuming K = 7. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

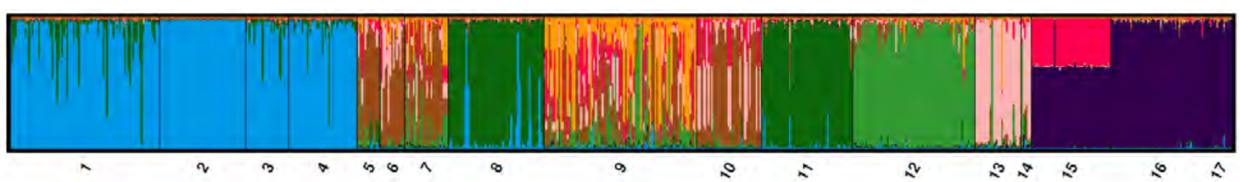

Figure 28. Bayesian genetic clustering results for all samples of Cope's Giant Salamanders post-harvest assuming K = 8. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

1-6.2.3. Coastal Giant Salamander

Coastal Giant Salamanders (which are absent from the Olympics and not sampled north of the Willapa River) separate into three clusters across the Willapa Hills and South Cascades in both pre- and post-harvest periods (**Figure 29** and **Figure 30**), although values of K = 2, 4, and 5 also received some support (**Appendix H**). The South Cascades form their own cluster with some limited connectivity to the Willapa sites. The Willapa Hills sites form two clusters, but the composition of the clusters varies between periods. In the pre-harvest period, site 6 (WIL1-100%) represents one cluster (albeit with admixture with other Willapa Hills sites), whereas in the post-harvest period, site 6 clusters more strongly with other members of the Willapa 1 block (sites 5 and 7). Sites 5-7 are in relative close geographic proximity, so genetic connectivity among them is not unexpected, but like the Cope's Giant Salamander, is consistent with increased migration post-harvest.

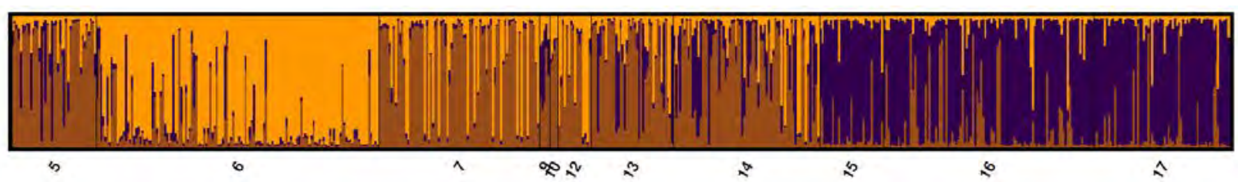

Figure 29. Bayesian genetic clustering results for all samples of Coastal Giant Salamanders pre-harvest assuming K = 3. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent site in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

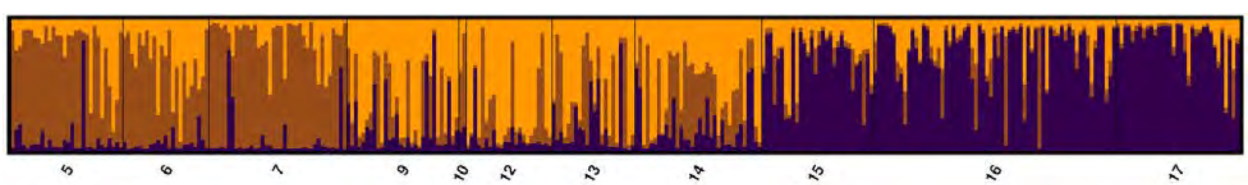

Figure 30. Bayesian genetic clustering results for all samples of Coastal Giant Salamanders post-harvest assuming K = 3. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent site in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

1-7. DISCUSSION

We assumed our samples were representative of individuals born after the study treatments were implemented because less than 1% of post-metamorphic tailed frogs sampled had an SVL ≥ 42 mm, and only <1% of giant salamanders sampled had an SVL ≥ 100 mm.

1-7.1. GIANT SALAMANDER SPECIES IDENTIFICATION AND HYBRIDS

As expected, we identified both species of giant salamanders in sites located in the Willapa Hills and South Cascades. We did not detect Coastal Giant Salamanders in sites located in the Olympics, a finding consistent with previous observations and the documented range limit for the species (Welsh 2005). We also observed only Cope's Giant Salamanders in the two study sites located in the northernmost extent of the Willapa Hills (WIL1-0% and WIL2-100%). Interestingly, we did detect a single Coastal Giant Salamander in WIL2-100% during post-harvest amphibian demographic sampling in 2009 and 2010, which we verified with genetic analysis. We detected only seven hybrid giant salamanders in the post-harvest sampling. While numerically this is fewer than the 33 detected in the pre-harvest period by Spear *et al.* (2011), the sample sizes were too low to statistically compare change between the two periods. However, it certainly does not support the hypothesis of increased opportunities for hybridization due to habitat disturbance (see Mallet 2005 for an in-depth exploration of this issue).

1-7.2. COMPARISON OF GENETIC DIVERSITY MEASURES AMONG TREATMENTS WITHIN SPECIES

Disturbance is considered one of the major impacts on a species' genetic diversity and thus its ability to respond and adapt to future perturbations (Banks *et al.* 2013). There are a number of potential effects of disturbance on genetic diversity and genetic structure. These include direct loss of genetic diversity through population reductions and alteration of genetic connectivity by either facilitating or reducing dispersal. These impacts can interact with each other to further exacerbate disturbance impacts. For instance, the loss of genetic diversity due to population bottlenecks increases the strength of genetic drift, which itself leads to loss of diversity. Loss of genetic connectivity also increases the rate of genetic diversity loss. Conversely, if a disturbances increases migration or dispersal, gene flow could increase maladaptive genotypes if the populations were formerly local adapted. Yet, there are only a handful of studies that have sampled populations both before and after a disturbance (Keyghobadi *et al.* 2005; Peakall and Lindenmayer 2006; Apodaca *et al.* 2013; Vandergast *et al.* 2016). In general, these studies have found a shift in genetic structure with relatively little change in diversity metrics such as allelic diversity and heterozygosity. This is because allele frequency changes (the basis for metrics such as the F-statistics) are more likely to occur than the outright loss of alleles in the absence of strong bottlenecks. In fact, the Baseline Genetic Report (Spear *et al.* 2011) estimated through simulations that effective population size would need to be reduced to as low as 6 to 34 individuals (depending on species) to detect a pattern. We did not detect a strong shift in genetic diversity metrics due to treatment, suggesting that treatments did not cause severe declines for the three species tested in this study.

1-7.2.1. Coastal Tailed Frogs

None of our comparisons were significant at $\alpha = 0.10$ for Coastal Tailed Frogs. Part of this is likely due to broad confidence intervals across the treatment categories compared to the reference condition due to the uneven number of replicates per treatment. We also had relatively small samples sizes for tailed frogs in some sites and years, including some zeros. This was the case even with a substantial sampling effort that was relatively similar across sites and years. For instance, the only site with tailed frogs in the Cascades block for either period was the reference site, and no tailed frogs were detected in the 100% treatment in the Olympic block in the pre-treatment period. Standard errors for the reference sites were always smaller than any of the other treatments.

There are a number of potential impacts that harvest treatments could have on stream amphibian populations. These include increased sedimentation in streams (reducing larval habitat), increased stream temperatures, and loss of forest cover constraining terrestrial dispersal by metamorphs and adults (Chelgren and Adams 2017). One of the most immediate effects we thought we might observe if there was a treatment effect was an increase in the number of full siblings relative to total sample size. We hypothesized such an effect because a reduction in population size should lead to fewer breeding individuals and thus fewer family groups represented. The number of unique family groups did numerically decline in the buffer treatments however, this decline mirrored almost exactly a decline in sample number. Therefore, we see no evidence that number of unique family groups had a response to treatment.

While there was an average loss of several alleles for each of the buffer treatment categories, with no change in the reference sites, this finding was not significant and clearly reflected the reduced sample number. Allelic richness, which is independent of sample size, had at most an average change of one allele, and that was an increase in the 100% treatment. Observed heterozygosity was high in tailed frogs (mean = 0.88) and the average change in heterozygosity was small (3%). A high level of heterozygosity is characteristic of tailed frog populations across several watersheds and in both species (Spear and Storfer 2008; Spear and Storfer 2010; Spear *et al.* 2012; Aguilar *et al.* 2013), so high heterozygosity is not surprising. As a result, allelic diversity and heterozygosity are unlikely to be highly sensitive to disturbance in tailed frogs.

F_{IS} can be seen as an evaluation of the extent of random mating given the available genetic diversity. It is easy to see why this might be expected to change quicker than other genetic measures as mating patterns could shift in a single generation. For instance, there is evidence that Coastal Tailed Frog adults move seasonally (Hayes *et al.* 2006), and loss of riparian cover has the potential to inhibit breeding movements and therefore prevent random mating within a population. For the tailed frogs analyzed in this study the mean F_{IS} was close to zero and the confidence intervals for the change in treatments also overlapped zero. Therefore, it appears that tailed frogs did not deviate from random mating regardless of treatment during the period of study. However, the period of study represents a relatively short time for this species, i.e., life span for this species is estimated to be 15 to 20 years (Daugherty and Sheldon 1982). It is entirely possible that the result may differ if populations in our study sites were sampled after a longer time has passed.

The only genetic diversity tests where we did see evidence of a pre- to post-harvest difference in tailed frogs were for the tests for recent reductions in population size, also known as bottleneck tests. In the Baseline Genetic Report (Spear *et al.* 2011) apparent population reductions were detected based on heterozygosity excess tests in multiple sites in the pre-harvest period, especially in the Olympic region. Several of these sites still have the bottleneck signature. Treatment had no consistent effect on bottleneck status, and based on the geographic clustering of several of these sites it is likely a landscape-level effect. Importantly, the ability to detect population declines genetically through these tests is still somewhat uncertain. Peery *et al.*

(2012) and Hoban *et al.* (2013) used simulations to extensively examine the performance of the heterozygosity excess and M-ratio test. Both concluded that heterozygosity excess is characterized by low power and that power is increased with larger bottlenecks, more loci, and more individuals. In our study the number of loci and sample size fall into the low power categories. Therefore, declines may have existed that we did not detect. Peery *et al.* (2012) did demonstrate a low Type I error rate for the heterozygosity excess which increases our confidence in the sites that did have a signature of heterozygosity excess. This is in contrast to the M-ratio which has high Type I error rates and was therefore omitted from post-harvest analysis. The other bottleneck test we used, shifted allele distributions, did not have any deviations from an expected pattern. The research on power of the shifted allele distribution test is lacking, but given that it relies on the loss of rare alleles, it is probably less suitable for detecting bottlenecks within a shorter time representing less than one or even a few generations.

1-7.2.2. Cope's Giant Salamander

The only potential treatment effect we detected in Cope's Giant Salamander was on F_{IS}. The p-value for this variable (0.105) was slightly above our alpha of 0.10, but was close enough that we felt it was worthy of consideration especially since non-random mating is a potential result of population disturbance. The big decrease in the 100% treatment suggests that individuals were more likely to be mating with less related individuals. A F_{IS} decrease of 0.10 represents a large change from non-random mating and is most consistent with migration of individuals from outside genetic populations into the site. Alternatively, it could be due to more dispersal out of the site by related individuals reducing the relatedness of sampled individuals within the site. We do not currently have data to distinguish between these two hypotheses. Regardless of movement direction, the outbreeding seen in the 100% buffer could be due to a combination of harvest disturbance increasing the probability of movement by individuals, with the riparian buffer facilitation such movements. Further research is needed to determine if this hypothesis is likely.

While there was almost no change in allelic diversity across years for Cope's Giant Salamander, we did see an interesting, albeit non-significant, trend in observed heterozygosity. Both the reference and 100% treatment had higher mean heterozygosity than either the FP or 0% treatment. However, heterozygosity did not decrease in any treatment. Finally, there was some limited evidence for significant bottlenecks, although as with tailed frogs, there was no clear pattern by treatment. Two sites had evidence of heterozygosity excess, one reference and one FP. The same caveats as presented for tailed frogs apply for the heterozygosity excess test, although we may have had slightly more power due to more loci and greater sample size.

1-7.2.3. Coastal Giant Salamander

Coastal Giant Salamanders had the fewest number of loci and number of sites and therefore had the lowest power to detect differences. Surprisingly, this was the species with the most effects by treatment; however, some of these differences can be attributed to sample size. For example, Coastal Giant Salamander had a large decrease in the number of unique full-sibling families which, combined with no effect by treatment for the proportion of full siblings, indicates the significant result is due to reduced sample size. Of more immediate relevance to this study was the significant difference by treatment in F_{IS}. Specifically, the 100% and 0% treatments had a decrease in F_{IS} relative to the reference. This was similar to the pattern seen with Cope's Giant

Salamander and likely represents migration in or out of the site. Given the decreased sampling number for the 100% treatment it most likely represents movement out of the site. The hypothesis we proposed for why immigration might increase in a 100% buffer for Cope's Giant Salamander might also apply to Coastal Giant Salamander. However, we hesitate to infer too much from our Coastal Giant Salamander results, as the Type N study was not designed for this species and the species was detected in only 11 of 17 study sites. An increase in sampling intensity and increased number of loci would be warranted in future studies.

The other genetic diversity metrics (allelic number, observed heterozygosity, bottleneck tests) did not show any indication of effect by treatment. The only thing resembling a trend among these three variables was a decrease in allelic number for the 100% treatment which is certainly due to the decrease in sampled individuals. Unlike the other two species there was no evidence for population bottlenecks, although we had poor power to detect any differences if they existed.

1-7.3. INFLUENCE OF THE SPATIAL EXTENT OF GENE FLOW ON POST-HARVEST RESULTS

The Type N Experimental Buffer Treatment study was designed to focus on the individual basin as the experimental unit and does not incorporate landscape level variation. Therefore, a genetic assessment of experimental buffer effects must focus on at-site genetic variables, largely the metrics of genetic diversity, as we discuss in the previous section. Yet genetic diversity is influenced strongly by aspects of genetic connectivity, which requires examining the spatial extent of gene flow across the landscape. Our use of Bayesian clustering analyses is meant to provide context for how we might interpret at-site genetic diversity results. The higher the levels of genetic connectivity among study basins, the greater the magnitude that a treatment effect would need to be to show any changes in genetic diversity within the study period. We can also infer the potential change in genetic diversity by examining genetic clustering patterns between periods; similar clustering patterns means that genetic connectivity is not likely to change rapidly.

Our clustering results across both periods clearly demonstrate a consistent pattern of relative genetic connectivity among the three species, with Coastal Tailed Frogs having the highest genetic connectivity, Coastal Giant Salamanders intermediate, and Cope's Giant Salamander the lowest. This ordering is consistent with previous genetic studies that have been done with the three species (Spear and Storfer 2008; Steele *et al.* 2009; Dudaniec *et al.* 2012; Spear *et al.* 2012; Trumbo *et al.* 2013), although it is important to note that most of these studies included samples from the pre-harvest period and are not completely independent studies. Still, our post-harvest genetic clustering was largely concordant with pre-harvest clustering results, so gene flow patterns are likely stable over short periods to time. With respect to tailed frogs, landscape genetic studies suggests extensive overland gene flow (Spear and Storfer 2008; Spear *et al.* 2012). The gene flow pattern can shift to individuals following stream corridors on managed timberlands (Spear and Storfer 2010). Such versatility in gene flow likely allows tailed frogs to persist under a variety of disturbance regimes as long as the instream environment is suitable for occupancy (e.g., Matsuda and Richardson 2005) and lessens the chance that fine-scale landscape effects (such as the timber harvest treatments included in the Type N study) will significantly impact genetic diversity over short time scales. On the other hand, Cope's Giant Salamander does show significant substructure within regions, and indeed was the only species to show a difference in the estimated value of *K* between periods.

All of the effects that were significant for giant salamanders are suggestive of movement in and out of study sites; changes in number of individuals sampled without concurrent changes in allelic diversity or heterozygosity and a decrease in F_{IS}. The post-harvest reduction in the estimate of *K* for Cope's Giant Salamander is consistent with this effect, and the most obvious change in clustering was for a site with a 100% harvest treatment, the treatment which had the greatest change in F_{IS}. While the estimate of *K* for Coastal Giant Salamander did not change between periods, the pattern of site clustering also showed increased admixture post-harvest. It is difficult to infer what proportion of these changes were due to within-basin changes relative to the broader landscape, but we can conclude that it is possible to detect some change in genetic structure in giant salamander over a relatively short period, whereas we cannot make that assumption for Coastal Tailed Frogs.

1-8. CONCLUSIONS

Based on our genetic analyses, we did not see any significant evidence that the FP treatment will have a negative effect on future persistence of Coastal Tailed Frogs or giant salamanders at study sites. However, one disadvantage of using genetic metrics to evaluate treatment effects is that a temporal lag frequently exists, unless the effects are extreme (Hoban *et al.* 2014). Despite the possibility of a temporal lag in response, we argue that the genetic portion of this study is critical to fully evaluate the treatments. Larval individuals tend to make up the majority of samples for all three of the species included in these analyses, and relying on demographic estimates of larval density alone is problematic. If a treatment affected factors such as survival through metamorphosis, larval individuals may not represent the total population. One possible outcome of genetically evaluating the larval portion of a population is the possibility of finding that larvae were the offspring of only one or a few adults, which would be an indication of a declining population, a signature that may be missed with a demographic-focused study. We did not see anything resembling this pattern in our genetic results.

There are a number of caveats that should be considered before concluding no genetic impact as a result of harvest treatments. Based on simulation results presented in the Baseline Genetic Report (Spear *et al.* 2011), as well as the more general study of Hoban *et al.* (2014), a severe immediate population decline would be necessary to detect reductions in genetic diversity over the study period, which represented a timeframe of less than one generational turnover. Furthermore, sample sizes of 50 or greater are recommended (Hoban *et al.* 2014). If the harvest treatments did not result in an immediate decline in abundance, but rather resulted in a small but continuous decline over time, several generations would be needed to detect a difference. Overall, we are confident that a severe (> 95%) immediate decline did not occur in our treatment sites. We strongly recommend follow-up genetic investigations in future generations to evaluate the possibility of future declines.

This study represented a rare opportunity to investigate change in genetic diversity and structure immediately after a disturbance. Despite the obvious implications for genetic diversity as a response variable to disturbance (Banks *et al.* 2013), very few empirical examples of how genetic diversity may respond to altered landscapes exist. This study provides one example of the genetic change we might expect to see in stream-associated amphibian diversity over an eight-year period and contributes further to the understanding of the amphibian population dynamics in Pacific Northwest forests. The dataset also provides an excellent starting point to assess evolutionary dynamics in these three species in the future. We strongly recommend that genetic monitoring be continued at these sites at regular intervals (every 15-20 years) into the future, at least for Cope's Giant Salamander. Sampling each generation would help us understand the population dynamics of stream amphibians following fine-scale disturbance and would likely address some of the uncertainty in previous demographic studies (Kroll 2009). Finally, our study indicates that F_{IS} may be more sensitive than other genetic diversity metrics to short-term changes, a finding that is valuable for future studies.

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Appendix A. Multiplex PCR conditions for Coastal Tailed Frog (locus names per Spear *et al.* 2008)

Multiplexes consist of:

	Per Sample
Qiagen Master Mix	5µl
Q solution	0.5 µl
Primer Mix (5µM stock)	See Below
Water	See Below
Template DNA	1 µl
Total	10 µl

Multiplex TF-A: [96ºC for 10 min, (94ºC for 30 s, 55ºC for 90 s, 72ºC for 1 min) X28, 60ºC for 30 min]

A4-NED- 0.90 µl
A12-6FAM- 0.10 µl
A31-VIC- 0.10 µl
Water- 2.4 µl

Multiplex TF-B: [96ºC for 10 min, (94ºC for 30 s, 55ºC for 90 s, 72ºC for 1 min) X28, 60ºC for 30 min]

A15-6FAM- 0.60 µl
A26-NED- 0.50 µl
A29-PET- 0.20 µl
Water -2.0 µl

Multiplex TF-C: [96ºC for 10 min, (94ºC for 30 s, 60ºC for 90 s, 72ºC for 1 min) X28, 60ºC for 30 min]

A3-PET- 0.90 µl
A13-NED- 0.20 µl
A14-VIC- 0.30 µl
A17-6FAM- 0.30 µl
Water- 1.8 µl

Multiplex TF-D: [96ºC for 10 min, (94ºC for 30 s, 55ºC for 90 s, 72ºC for 1 min) X28, 60ºC for 30 min]

A24-6FAM- 0.26 µl
A1-VIC- 0.14 µl
A2-PET- 0.60 µl
Water- 2.5 µl

Appendix B. Multiplex PCR conditions for giant salamanders (locus names per Steele *et al.* 2009)

Multiplexes consist of:

	Per Sample
Qiagen Master Mix	5µl
Q solution	0.5 µl
Primer Mix (2µM stock; Forward and Reverse, mixed)	1 µl
Water	2.5 µl
Template DNA	1 µl
Total	10 µl

Multiplex DICAMP1: [95ºC for 15 min, (94ºC for 30 s, 53ºC for 90 s, 72ºC for 1 min) X30, 60ºC for 30 min]

D18-6FAM
D13-VIC
D04-PET

Multiplex DICAMP2.1: [95ºC for 15 min, (94ºC for 30 s, 60ºC for 90 s, 72ºC for 1 min) X30, 60ºC for 30 min]

D24-6FAM
D07-NED

Multiplex DICAMP2.2: [95ºC for 15 min, (94ºC for 30 s, 60ºC for 90 s, 72ºC for 1 min) X30, 60ºC for 30 min]

D17-PET

Multiplex DICAMP4: [95ºC for 15 min, (94ºC for 30 s, 60ºC for 90 s, 72ºC for 1 min) X30, 60ºC for 30 min]

D14-6FAM
D05-NED
D06-PET

Multiplex DICAMP5: [95ºC for 15 min, (94ºC for 30 s, 60ºC for 90 s, 72ºC for 1 min) X30, 60ºC for 30 min]

D15-6FAM
D23-VIC

Appendix C. Genetic Diversity Measures of Coastal Tailed Frogs

Pre- and post-harvest estimates for genetic diversity measures of Coastal Tailed Frogs. *N* represents number of unique individuals sampled, Fam represents number of unique family groups, Prop is the proportion of unique family groups relative to total samples, A is total number of alleles, A_r is allelic richness, H_o is observed heterozygosity, and F_{IS} is Wright's inbreeding coefficient.

Period	Site	*N*	Fam	Prop	A	A_r	H_o	F_{IS}
Pre-harvest	OLYM-REF	42.00	41.00	0.98	16.11	16.02	0.86	0.05
	OLYM-FP	24.00	19.00	0.79	12.00	7.67	0.92	0.00
	OLYM-0%	15.00	12.00	0.80	10.22	9.88	0.91	-0.01
	WIL1-REF	26.00	22.00	0.85	15.33	15.22	0.86	0.06
	WIL1-100%	54.00	52.00	0.96	19.22	4.83	0.86	0.06
	WIL1-FP	54.00	51.00	0.94	20.67	12.45	0.84	0.08
	WIL1-0%	50.00	46.00	0.92	15.78	13.79	0.84	0.02
	WIL2-REF1	39.00	34.00	0.87	18.56	18.07	0.88	0.03
	WIL2-REF2	26.00	23.00	0.88	16.67	14.49	0.86	0.04
	WIL2-100%	33.00	27.00	0.82	14.56	13.58	0.85	0.03
	WIL2-0%	48.00	42.00	0.88	18.89	12.26	0.89	0.01
	WIL3-REF	61.00	52.00	0.85	20.89	18.29	0.89	0.03
	WIL3-100%	25.00	24.00	0.96	16.11	7.86	0.90	0.01
	CASC-REF	28.00	24.00	0.86	16.56	16.56	0.82	0.02
	Average	**37.50**	**33.50**	**0.88**	**16.54**	**12.92**	**0.87**	**0.03**
Post-harvest	OLYM-REF	56.00	55.00	0.98	17.89	16.54	0.92	-0.02
	OLYM-FP	7.00	7.00	1.00	8.56	8.56	0.87	0.04
	OLYM-0%	33.00	27.00	0.82	13.56	10.48	0.91	-0.02
	WIL1-REF	27.00	21.00	0.78	15.67	15.28	0.92	-0.02
	WIL1-100%	3.00	3.00	1.00	4.67	4.67	0.85	0.03
	WIL1-FP	13.00	13.00	1.00	12.44	12.05	0.87	0.03
	WIL1-0%	26.00	26.00	1.00	13.78	13.78	0.85	0.03
	WIL2-REF1	49.00	49.00	1.00	19.00	17.47	0.87	0.04
	WIL2-REF2	18.00	18.00	1.00	14.56	14.56	0.87	0.03
	WIL2-100%	28.00	27.00	0.96	16.33	15.86	0.83	0.07
	WIL2-0%	13.00	10.00	0.77	10.67	10.67	0.94	-0.07
	WIL3-REF	33.00	30.00	0.91	17.78	17.78	0.88	0.02
	WIL3-100%	7.00	6.00	0.86	8.67	8.42	0.84	0.09
	CASC-REF	35.00	25.00	0.71	17.11	16.17	0.86	0.01
	Average	**24.86**	**22.64**	**0.91**	**13.62**	**13.02**	**0.88**	**0.02**

Appendix D. Genetic Diversity Measures of Cope's Giant Salamander

Pre- and post-harvest estimates for genetic diversity measures of Cope's Giant Salamander. Column abbreviations are as in **Appendix C**.

Period	Site	*N*	Fam	Prop	A	*A*r	*H*e	*H*o	F_{IS}
Pre-harvest	OLYM-REF	62.00	46.00	0.74	7.64	7.63	0.66	0.66	-0.01
	OLYM-100%	31.00	17.00	0.55	4.00	3.75	0.52	0.45	0.15
	OLYM-FP	28.00	17.00	0.61	5.82	5.59	0.65	0.65	0.01
	OLYM-0%	44.00	29.00	0.66	6.09	6.02	0.64	0.65	-0.02
	WIL1-REF	12.00	11.00	0.92	9.18	8.95	0.83	0.77	0.08
	WIL1-100%	22.00	18.00	0.82	12.00	10.77	0.85	0.78	0.08
	WIL1-FP	22.00	14.00	0.64	10.00	9.92	0.81	0.82	-0.02
	WIL1-0%	96.00	62.00	0.65	9.27	8.58	0.74	0.68	0.07
	WIL2-REF1	67.00	41.00	0.61	15.00	14.93	0.86	0.84	0.03
	WIL2-REF2	21.00	17.00	0.81	11.09	10.98	0.84	0.79	0.07
	WIL2-100%	59.00	47.00	0.80	9.36	9.21	0.75	0.66	0.12
	WIL2-0%	37.00	33.00	0.89	13.00	12.83	0.85	0.75	0.12
	WIL3-REF	28.00	23.00	0.82	12.18	11.91	0.84	0.76	0.10
	WIL3-100%	6.00	6.00	1.00	6.36	5.84	0.80	0.74	0.09
	CASC-REF	52.00	37.00	0.71	8.18	7.96	0.68	0.67	0.02
	CASC-FP	69.00	62.00	0.90	11.91	11.56	0.83	0.77	0.08
	CASC-0%	19.00	16.00	0.84	8.82	8.04	0.83	0.77	0.08
	Average	**39.71**	**29.18**	**0.76**	**9.41**	**9.09**	**0.76**	**0.72**	**0.06**
Post-harvest	OLYM-REF	90.00	86.00	0.96	7.55	7.20	0.64	0.63	0.01
	OLYM-100%	52.00	41.00	0.79	4.00	3.61	0.48	0.49	-0.02
	OLYM-FP	26.00	23.00	0.88	6.00	5.85	0.65	0.66	-0.01
	OLYM-0%	41.00	38.00	0.93	5.91	5.88	0.63	0.63	-0.01
	WIL1-REF	14.00	12.00	0.86	9.18	8.48	0.81	0.83	-0.02
	WIL1-100%	15.00	13.00	0.87	10.27	10.27	0.84	0.84	0.00
	WIL1-FP	26.00	17.00	0.65	10.73	10.20	0.85	0.80	0.05
	WIL1-0%	58.00	53.00	0.91	8.45	8.43	0.73	0.70	0.03
	WIL2-REF1	92.00	55.00	0.60	15.18	14.50	0.86	0.85	0.01
	WIL2-REF2	39.00	25.00	0.64	11.82	10.63	0.85	0.86	-0.01
	WIL2-100%	55.00	53.00	0.96	9.64	9.59	0.76	0.72	0.05
	WIL2-0%	74.00	56.00	0.76	14.18	12.71	0.84	0.78	0.08
	WIL3-REF	28.00	23.00	0.82	12.55	12.28	0.87	0.86	0.01
	WIL3-100%	6.00	6.00	1.00	7.09	6.35	0.85	0.83	0.02
	CASC-REF	48.00	41.00	0.85	8.18	8.16	0.72	0.70	0.03
	CASC-FP	59.00	55.00	0.93	10.91	10.81	0.83	0.80	0.04
	CASC-0%	14.00	14.00	1.00	8.36	8.20	0.82	0.84	-0.02
	Average	**43.35**	**35.94**	**0.85**	**9.41**	**9.01**	**0.77**	**0.75**	**0.01**

Appendix E. Genetic Diversity Measures of Coastal Giant Salamander

Pre- and post-harvest estimates for genetic diversity measures of Coastal Giant Salamander. Column abbreviations are as in **Appendix C**.

Period	Site	*N*	Fam	Prop	A	*A*r	*H*o	F_{IS}
Pre-harvest	WIL1-REF	41.00	14.00	0.34	5.60	5.14	0.57	-0.11
	WIL1-100%	137.00	53.00	0.39	10.80	6.84	0.57	0.09
	WIL1-FP	78.00	20.00	0.26	6.80	5.17	0.53	-0.04
	WIL2-REF1	5.00	4.00	0.80	2.00	1.53	0.28	-0.22
	WIL2-REF2	4.00	4.00	1.00	3.20	2.27	0.55	-0.12
	WIL2-0%	16.00	10.00	0.63	5.40	4.75	0.55	0.14
	WIL3-REF	40.00	23.00	0.58	7.20	5.82	0.53	0.17
	WIL3-100%	71.00	43.00	0.61	9.20	6.94	0.45	0.17
	CASC-REF	31.00	14.00	0.45	4.40	4.38	0.40	-0.09
	CASC-FP	102.00	53.00	0.52	6.60	6.34	0.49	0.07
	CASC-0%	66.00	35.00	0.53	6.80	5.64	0.41	0.11
	Average	**53.73**	**24.82**	**0.55**	**6.18**	**4.98**	**0.48**	**0.02**
Post-harvest	WIL1-REF	30.00	21.00	0.70	5.20	4.91	0.53	-0.08
	WIL1-100%	23.00	19.00	0.83	6.40	6.19	0.67	-0.01
	WIL1-FP	37.00	27.00	0.73	5.60	5.16	0.59	0.03
	WIL2-REF1	30.00	22.00	0.73	5.60	2.16	0.53	-0.06
	WIL2-REF2	2.00	2.00	1.00	2.20	2.20	0.50	0.00
	WIL2-0%	23.00	16.00	0.70	6.60	5.27	0.56	0.07
	WIL3-REF	22.00	20.00	0.91	7.80	7.22	0.53	0.16
	WIL3-100%	34.00	29.00	0.85	7.20	6.63	0.50	0.05
	CASC-REF	30.00	21.00	0.70	5.20	5.20	0.48	-0.09
	CASC-FP	65.00	55.00	0.85	6.00	5.99	0.46	0.02
	CASC-0%	33.00	27.00	0.82	4.20	4.20	0.44	-0.03
	Average	**29.60**	**23.20**	**0.80**	**5.78**	**5.09**	**0.54**	**0.01**

Appendix F. Genetic clustering of Coastal Tailed Frogs

STRUCTURE bar plots for *K* = *2* and *K* = 4 for both pre- and post-harvest samples of Coastal Tailed Frogs.

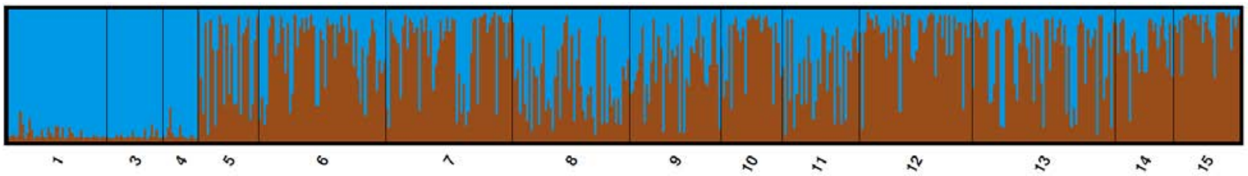

Figure F1. Bayesian genetic clustering results for all samples of Coastal Tailed Frogs pre-harvest assuming *K*=2. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and site 15 in the South Cascades.

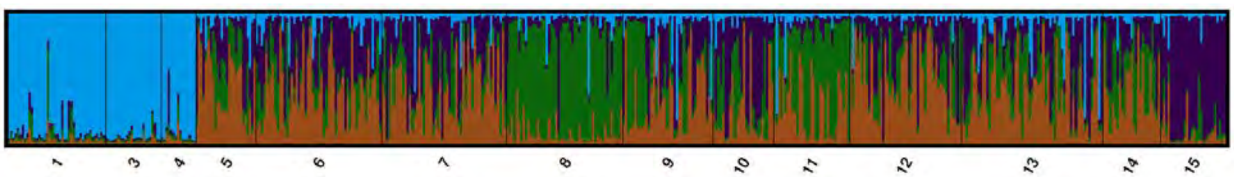

Figure F2. Bayesian genetic clustering results for all samples of Coastal Tailed Frogs pre-harvest assuming *K*=4. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and site 15 in the South Cascades.

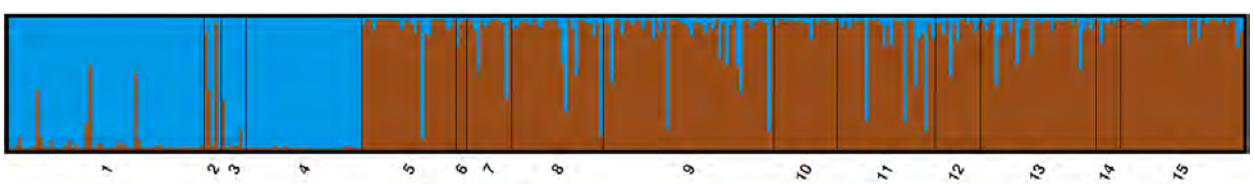

Figure F3. Bayesian genetic clustering results for all samples of Coastal Tailed Frogs post-harvest assuming *K*=2. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and site 15 in the South Cascades.

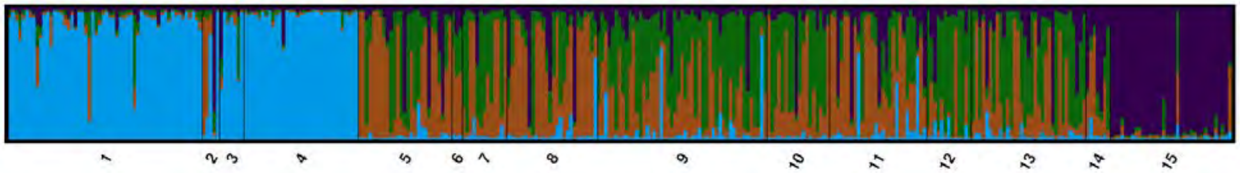

Figure F2. Bayesian genetic clustering results for all samples of Coastal Tailed Frogs post-harvest assuming *K*=4. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**.

Appendix G. Genetic clustering of Cope's Giant Salamander

STRUCTURE bar plots for K = 7, 8, 10, 11, and 12 for pre-treatment period and K = 6, 9, and 10 for the post-harvest period for Cope's Giant Salamander.

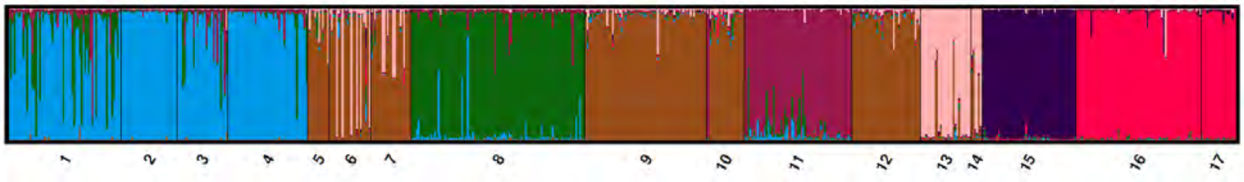

Figure G1. Bayesian genetic clustering results for all samples of Cope's Giant Salamander pre-harvest assuming K=7. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

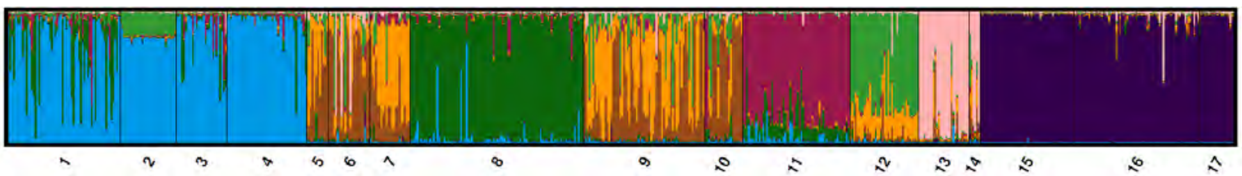

Figure G2. Bayesian genetic clustering results for all samples of Cope's Giant Salamander pre-harvest assuming K=8. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

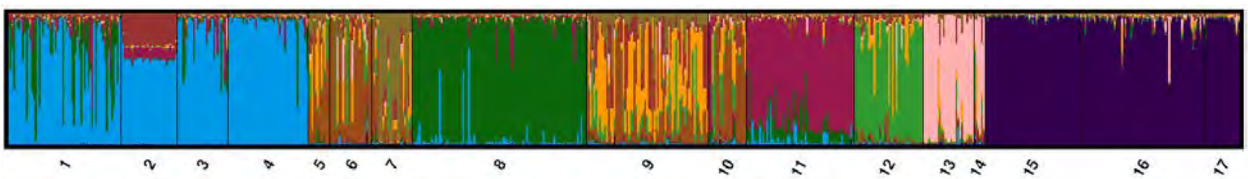

Figure G3. Bayesian genetic clustering results for all samples of Cope's Giant Salamander pre-harvest assuming K=10. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

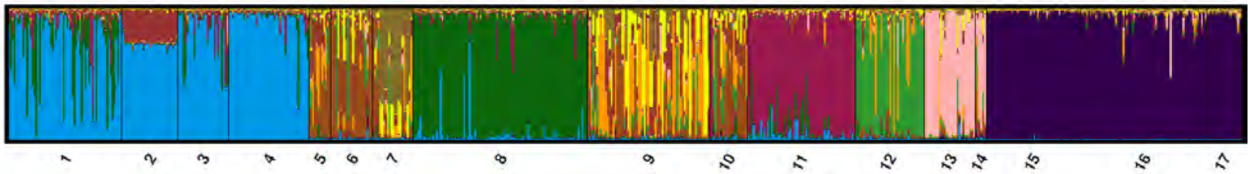

Figure G4. Bayesian genetic clustering results for all samples of Cope's Giant Salamander pre-harvest assuming *K*=11. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

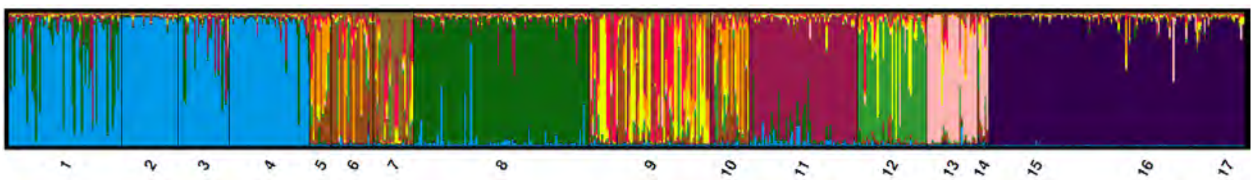

Figure G5. Bayesian genetic clustering results for all samples of Cope's Giant Salamander pre-harvest assuming *K*=12. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

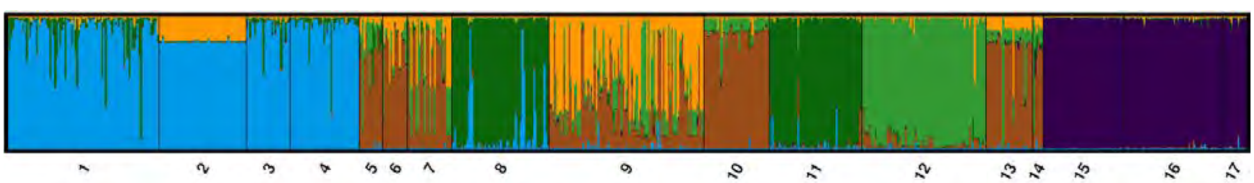

Figure G6. Bayesian genetic clustering results for all samples of Cope's Giant Salamander post-harvest assuming *K*=6. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

Figure G7. Bayesian genetic clustering results for all samples of Cope's Giant Salamander post-harvest assuming *K*=9. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

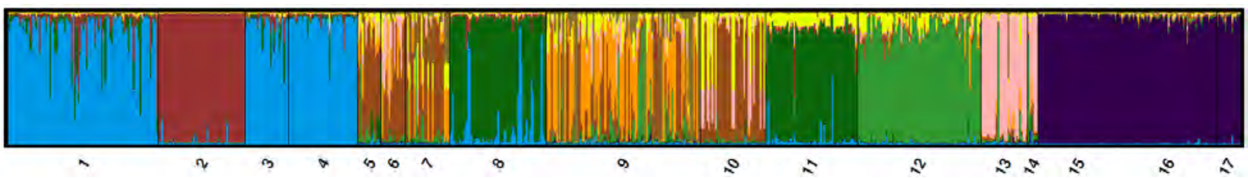

Figure G8. Bayesian genetic clustering results for all samples of Cope's Giant Salamander post-harvest assuming *K*=10. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 1-4 located in the Olympics, sites 5-14 in the Willapa Hills and sites 15-17 in the South Cascades.

Appendix H. Genetic clustering of Coastal Giant Salamander

STRUCTURE bar plots for K = 2, 4, and 5 for pre-treatment period and K = 2 and 5 for the post-harvest period for Coastal Giant Salamander.

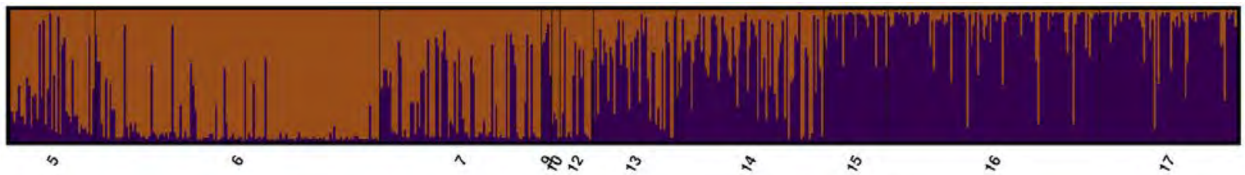

Figure H1. Bayesian genetic clustering results for all samples of Coastal Giant Salamander pre-harvest assuming K=2. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

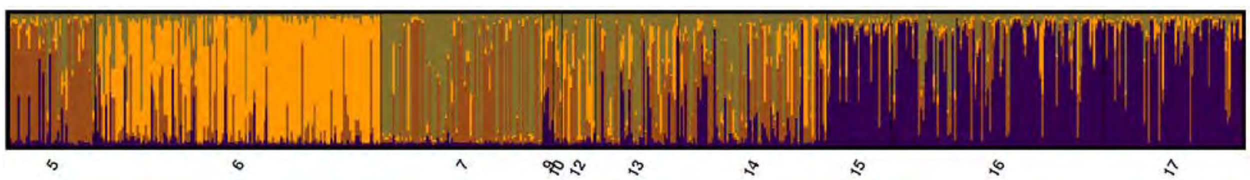

Figure H2. Bayesian genetic clustering results for all samples of Coastal Giant Salamander pre-harvest assuming K=4. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

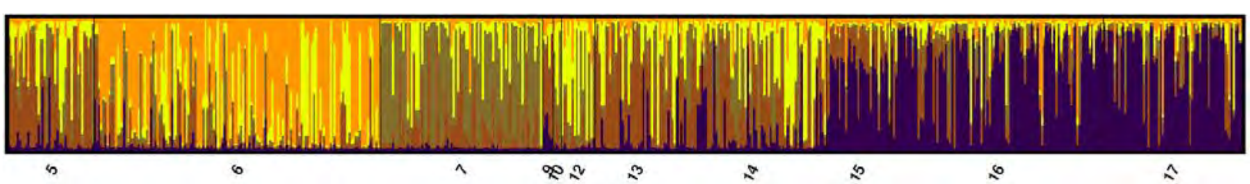

Figure H3. Bayesian genetic clustering results for all samples of Coastal Giant Salamander pre-harvest assuming K=5. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

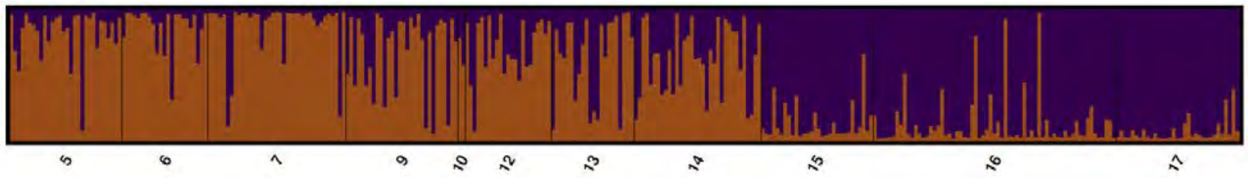

Figure H4. Bayesian genetic clustering results for all samples of Coastal Giant Salamander post-harvest assuming *K*=2. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

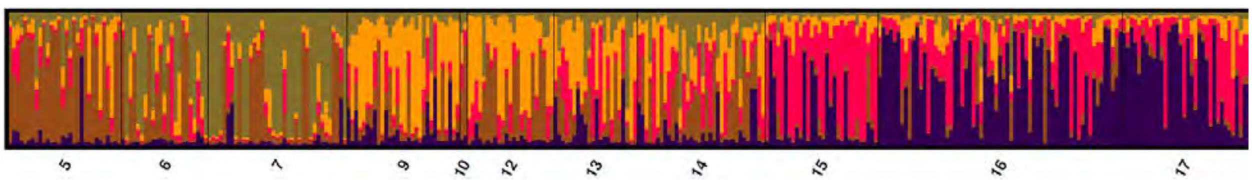

Figure H5. Bayesian genetic clustering results for all samples of Coastal Giant Salamander post-harvest assuming *K*=5. The y-axis represents proportion of individual membership to each cluster. Colors indicate different clusters. Numbers on the x-axis represent sites in the order presented in **Table 2**, with sites 5-7, 9, 10 and 12-14 in the Willapa Hills and sites 15-17 in the South Cascades.

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MEMORANDUM

January 16, 2020

To: Forest Practices Board

Form: Mark Hicks, Adaptive Management Program Administrator

Subject: Extensive Riparian Status and Trends -Temperature Study

At their October 31, 2019 meeting, TFW Policy (Policy) formally accepted the findings and associated materials for the study entitled ***Extensive Riparian Status and Trends Monitoring Project - Stream Temperature Westside Type F/S and Type Np***. The purpose of this memo is to transmit the final study report to the Board along with a summary of the report's findings and Policy's recommendations.

This study was initiated to provide data needed to evaluate landscape-scale effects of implementing forest practices riparian prescriptions, and to evaluate progress toward meeting Clean Water Act (1977) requirements and riparian resource objectives.

A probability-based (random) sampling design was used to sample stream temperature and canopy closure on Type F/S (fish-bearing) and Type Np (non-fish-bearing perennial) streams on land regulated under the forest practices rules in western Washington over a two year period (2008 and 2009). Because only about half of the sites were monitored in 2008 due to delays in acquiring permission to access the sites, the statistics presented were based only on the 2009 sample year (July-August). Monitoring included 61 Type F/S stream sites and 54 sites on Type Np streams.

For each stream type, cumulative distribution function (CDF) plots were presented to illustrate the distribution of water temperature and canopy closure across each stream type, along with the estimated 25%-tile, median, and 75%-tile values (see below), for maximum summer stream temperature, the seven-day average maximum stream temperature (7DADM), canopy closure, and change in the 7DADM (ΔDADM) between the top and bottom of the sample site (see table below).

Since the study represents a single status measurement in 2008, it cannot be used determine if temperatures have been cooling since the Forests-and-Fish-based rules were put into to place. It additionally does not provide a basis to determine how well the forest practices rules influenced the temperatures observed at the sample sites. Thus it is not possible to make an assessment of the effectiveness of the regulations using this study.

Stream Type	Metric	25%-tile	Median	75%-tile
F/S	Canopy closure	39%	78%	96%
	Maximum temperature	16.0 °C	18.7 °C	20.4 °C
	7DADM	15.4 °C	18.1 °C	19.5 °C
	ΔDADM	-0.2 °C	0.1 °C	0.4 °C
Np	Canopy closure	73%	93%	98%
	Maximum temperature	14.0 °C	16.2 °C	17.3 °C
	7DADM	13.2 °C	15.2 °C	16.5 °C
	ΔDADM	-0.2 °C	0.8 °C	2.3 °C

Even with the challenges of encountering mistyped streams and the difficulty of accessing sample sites on small forest landowner properties, the study retained 70% and 68% of the original sample frame for Type F/S and Type Np streams, respectively.

After reviewing the study findings, Policy agreed by consensus not to recommend the Board take any formal action in response to this study.

Though no action is recommended by the Board, TFW Policy directed the study be provided as supporting technical information to the Type Np Prescription Workgroup.

Future and continued data collection (resampling) is possible if interest exists at Policy and the Board. However, the long-term trend monitoring component of this study was removed from the MPS because: i) small forest landowners are generally unwilling to allow access to their lands and this results in a study that only examines a portion of the managed landscape, and ii) landscape-level status and trends monitoring cannot be used effectively to assess prescription effectiveness.

Although funding was removed to directly assess temperature trends, CMER studies are ongoing that explore the extent remote sensing can be used to fulfill some of the original goals of the status and trends monitoring program (see Extensive Vegetation Monitoring Project). This is in part because the use of remote sensing is a way to reduce the problem of landowners not allowing access for sampling.

EXTENSIVE RIPARIAN STATUS AND TRENDS MONITORING PROGRAM - STREAM TEMPERATURE

Phase I:

Westside Type F/S and Type Np Monitoring Project

March 2019

Prepared for:

The Riparian Science Advisory Group of the

Cooperative Monitoring, Evaluation, and Research (CMER) Committee

Adaptive Management Program

Washington Department of Natural Resources

Olympia, WA

Washington State Department of Ecology

Forest Practices Adaptive Management Program

The Washington Forest Practices Board (FPB) adopted an adaptive management program in concurrence with the Forests & Fish Report (USFWS 1999) and subsequent legislation. The purpose of this program is to:

> Provide science-based recommendations and technical information to assist the board in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives (Forest Practices Rules, WAC 222-12-045).

To provide the science needed to support adaptive management, the FPB made the Cooperative Monitoring, Evaluation and Research Committee (CMER) a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with guidelines recommended in the FFR.

Disclaimer

The opinions, findings, conclusions, or recommendations expressed in this report are those of the authors. They do not necessarily reflect the views of any participant in, or committee of, the Timber/Fish/Wildlife Agreement, the Forests and Fish Agreement, the Washington Forest Practices Board, or the Washington Department of Natural Resources; nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Full Citation

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Acknowledgements

Thanks to the members and co-chairs of the Riparian Science Advisory Group and all others who helped scope, design, and review this project. Your comments and thoughts are appreciated. Reviewers included Lyle Almond, Mark Hicks, Doug Martin, Dick Miller, Teresa Miskovic, and Terry Jackson. Jenelle Black performed the site selection process. Jack Janisch analyzed the temperature and descriptive data using R, developed the associated tables and figures, and contributed text to the final. Thanks also to Matt Peter and the field crews for their dedication.

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Executive Summary

This study was initiated to provide data needed to evaluate landscape-scale effects of implementing the forest practices riparian prescriptions and to evaluate progress toward meeting Clean Water Act (1977) requirements and riparian resource objectives.

We used a probability-based sampling design to sample stream temperature and canopy closure on Type F/S (fish-bearing) and Type Np (non-fish-bearing perennial) streams on land regulated under the Forest Practices Rules in western Washington. We monitored stream temperature and canopy closure over the summer of 2008 and 2009. Because only about half of the sites were monitored in 2008 due to delays in acquiring permission to access the sites, the statistics presented below are based on the 2009 sample year (July-August).

A Generalized Random Tessellation Stratified survey design for a linear resource was used to establish a statewide probability master sample of Type F/S streams and Type Np streams. A total of 61 sites on Type F/S streams were sampled of the 120 sites that were evaluated. Fifty-four sites on Type Np streams were sampled of the 228 sites evaluated.

For each stream type, cumulative distribution function (CDF) plots are presented, along with the estimated 25%-tile, median, and 75%-tile CDF values, for maximum summer stream temperature, the seven-day average maximum stream temperature (7DADM), and canopy closure (shown in the table below).

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

Three difficulties were encountered during implementation:

1. For both Type F/S and Type Np waters, small forest landowners were less likely to participate than industrial forest land owners. As a result, a substantial proportion of the land base was not sampled. However, it is unclear whether this introduced substantive bias into the study.

2. There were errors in the sampling frame that resulted in misclassification of some sampling sites (i.e., wrong water type or incorrect land use). These errors were relatively minor and expected when applying a regulatory definition to GIS-derived stream layers.

3. Some Type Np streams had too little water in the summer to submerge data loggers.

In spite of these difficulties, the estimated scope of inference was 70% and 68% of the original sample frame for Type F/S and Type Np streams, respectively.

Introduction

Washington State regulates forest management activities within riparian buffers to limit the loss of riparian shade and mitigate the effects of forest harvest on stream temperature. The rules differ for fish-bearing streams (Type F/S) and non-fish-bearing perennial streams (Type Np). On westside Type Np streams, 50-foot width buffers must be left along at least 50% of the perennial stream length, including buffers at tributary junctions, the upper most point of perennial flow, and several types of sensitive sites. The riparian management zone for westside Type F/S streams varies in width based upon soil site class and stream width, but all streams include a core zone comprised of a minimum 50-foot width no-cut buffer adjacent to each side of the stream. Outside the core zone are the inner zone and outer zone where some harvest is permitted. Several studies are currently underway to evaluate the effectiveness of riparian buffer requirements in maintaining adequate shade and preventing increased stream temperature in western Washington, non-fish-bearing streams (Hayes *et al.* 2005; Ehinger *et al.* 2011; McCracken *et al.*, in prep) and in eastern Washington fish-bearing streams (Light *et al*. 2003; Ehinger 2013; Cupp and Lofgren 2014).

The goals of this study are to collect an unbiased dataset (for later comparison against applicable water quality standards) and provide unbiased status estimates of two key riparian indicators at the landscape level—summer stream temperature and riparian canopy closure—for Type F/S and Type Np streams on forest lands in western Washington regulated under the Forest Practices Rules (FPR). These data will complement other effectiveness monitoring projects by allowing the estimation of the proportion of streams within specific water quality thresholds on a random sample of streams and providing context for other study results. We use a probability sampling design to provide robust statistical inference at the landscape scale. Probability sampling also offers a consistent approach to sampling statewide resources (e.g., Overton *et al.* 1990; Diaz-Ramos *et al.* 1996). To date, sampling of stream temperature and canopy cover condition in Washington state has been insufficient to characterize streams on the millions of acres of private and public forest lands because most data come from sites selected using criteria specific to that study (e.g., Hayes *et al.* 2005; Ehinger *et al.* 2011).

Context for Extensive Monitoring

The Extensive Riparian Status and Trends (ERST) monitoring program is organized into four separate projects (**Appendix A**) and two phases. The projects stratify Washington state by geographic region (eastside/westside) and by stream type (Type F/S—fish-bearing, Type Np—non-fish-bearing perennial). The phases refer to the status (Phase I) and trends (Phase II) components of the monitoring design.

The Phase I report for the Eastside Type F/S streams was completed in 2013 (Ehinger 2013).

This report summarizes results of Phase I for both Westside Type F/S and Type Np streams. The objectives include:

- Describe the frequency distribution of stream temperature (maximum summer stream temperature and seven-day average maximum stream temperature) and canopy closure in

Type F/S and Type Np streams on forest lands managed under the FPR in western Washington.

- Estimate frequency distributions of several descriptive non-temperature variables.

Methods

Study Design

In 2006, a Generalized Random Tessellation Stratified (GRTS) survey design for a linear resource was used to establish a statewide probability master sample[1] (**Table 1**; **Appendix B**)[2]. To optimize flexibility, no multi-density categories, oversample, panels, or stratifications were imposed. Only reverse hierarchical ordering was retained, applied simultaneously statewide so that any consecutive subset of sites is spatially balanced[3]. For the master sample, both inclusion probability and survey design weight were approximately equal to 1.0 (i.e., expected sample size = one site per km of stream length in the sample frame[4]). Each sample site consists of a latitude-longitude coordinate pair along a Type F/S or Type Np stream.

In 2007, the master sample was partitioned to meet the selection criteria for an FPR lands domain[5] in western Washington, hereafter referred to as the target lands domain. This target lands domain was defined by four criteria:

- Forested land cover, from USGS Landsat-based 'Forest Land' classification.
- Not federal ownership.
- Not part of a separate Habitat Conservation Plan.
- Not included in an Urban Growth Area.

Forested land not explicitly excluded by one of the last three criteria was considered part of the target lands domain and all Type F/S or Type Np streams within the target lands domain were candidates to be sampled[6].

---

[1] The master sample consists of approximately 380,000 points, drawn by EPA from compiled coverages at the WRIA scale. For a summary of probability sample features, see **Appendix B**.

[2] See **Appendix C** for archived data types and locations.

[3] Provided any differential sampling is accounted for.

[4] A sample frame consists of a list, map, or other description of the units of the population to be sampled. (http://stats.oecd.org/glossary/about.asp).

[5]The target domain is used to describe the spatial extent of the target population, or 'the set of elements about which information is wanted and estimates are required' (http://stats.oecd.org/glossary/about.asp).

[6] Imperfections in stream classification in the hydrologic GIS layers resulted in a list of candidate sites consisting of a mixture of both target and non-target sites.

Hydrographic length was then calculated, taking into account partitioning to the target lands domain. For Type F/S surface waters, the result was 25,669 potential sampling sites (i.e., a sample frame length of 25,669 km and actual hydrographic segment length, as calculated by ArcMap, = 25,714 km) (**Table 1**). For Type Np surface waters, the result was 49,317 potential sampling sites (i.e., a sample frame length of 49,317 km and actual hydrographic segment length, as calculated by ArcMap, = 49,089 km). Greater than 80% of Type F/S hydrographic length and associated sampling sites corresponded to modeled water sub-type F1 (**Table 2**). Approximately 54% of Type Np hydrographic length corresponded to modeled water sub-type N1 (**Table 3**).

Because stream temperature is an issue in all streams, regardless of size, no stratification by stream size or Strahler order (Horton 1945; Strahler 1957) was imposed. Probability of a stream reach of any specific order being selected was thus in proportion to the stream order proportions of the hydrographic layer.

For each water type, the goal was a base sample of 50[7] sites. To achieve this, 120 Type F/S sites and 228 Type Np sites were evaluated (**Figure 1**) for use in the study. Sites were drawn sequentially to maintain spatial balance, and screened with high-resolution orthophotos to establish candidate sites. Parcel ownership was determined from county tax records. Landowner contact (i.e., permission to visit candidate sites) was made in person, where feasible, or by phone or letter. Where public access was available, some sites were first inspected to determine if the stream met the land use and stream type criteria prior to contacting the landowner. Sites determined to be non-target (e.g., not the appropriate water type, not forestry land use, not regulated under the FPR) were replaced by adhering to the GRTS sequence order and site-replacement process.

For Type F/S streams, the three main reasons for rejecting sites were: 1) no response from the landowner, 2) land was not used for forestry, and 3) incorrect water type (**Table 4**). We categorized each site into landowner categories (public lands—PUB, industrial landowners—IND, and small forest landowners—SFLO) to show rejection rates (**Table 5**). Of the 42 sites rejected for the reasons above, 36 were located on small forest landowner properties. Overall, the rejection rate on SFLO properties was 80%, compared to a 25% rejection rate on IND properties. Although SFLO sites comprised 42% of the sites evaluated, they comprised only 16% of the sites sampled.

For Type Np streams, the three main reasons for rejecting a site were: 1) incorrect water type, 2) land was not used for forestry, and 3) landowner declined to participate (**Table 6**). Of the 69 sites rejected for the reasons above, only 20 were on SFLO properties (**Table 7**). The rejection rate for both SFLO and IND properties was higher than for Type F/S streams, mainly due to the large number of incorrect water type designations on the hydrolayer.

All evaluated sites were plotted to show location and landowner category in **Figure 2**. If permission to access was granted, a hand-held GPS device was used to navigate to the site

[7] To balance level of precision and sampling effort, GRTS designs often are variations on sampling 50 sites. This equates to +/- 10% precision and 90% confidence. Sample size is to some degree design dependent and can either be established prior to the sample draw and is used to fix design factors, or open-ended and determined by adequate representation of sub-populations or strata (see http://www.epa.gov/nheerl/arm/surdesignfaqs.htm#manysamples).

coordinates, the location monumented with a semi-permanent marker driven into the soil near the stream, the marker flagged, and relationship of the marker to the stream sample point described. Later, a second crew installed temperature data loggers and recorded non-temperature variables (see below).

Assumptions and Constraints

A number of assumptions were made regarding the target population, how it was identified, and the indicators measured. Some apply to GRTS, in general, and others, specifically to this study.

Assumptions

GRTS

- Landowner class does not influence response.
- Spatial balancing variable (hydrography) is correlated with response.
- Excluded sites have the same statistical properties as monitored sites (i.e., missing completely at random).
- Indicators integrate the processes being assessed.

ERST

- Errors in hydrography and water typing are recognized and corrected to the extent possible.
- Sample describes landscape-scale variability.
- Variability can be adequately quantified by GRTS probability approach.

Known Constraints

- Hydrography layer varies in stream density. National Map Accuracy Standard is ± 12.19 m (40 ft). Source scale is 1:24,000.
- The sample frame changes over time. Hydrography is continuously updated thru the Timber, Fish, and Wildlife Agreement water type modification process. In any given year, the modifications represent a very small proportion of the entire stream network, but over several decades, the change could be substantial.
- The fish-bearing/non-fish-bearing junctions were derived from a mix of model predictions, fish presence/absence surveys, and previous water type classification.

Variables Measured

This study measured a subset of stressor variables with special emphasis on stream temperature and riparian canopy closure. Water temperature is one of the most commonly violated water quality standards in Washington State and riparian shade, via riparian buffer requirements, is the regulatory means of meeting targets for stream temperature. Other non-temperature variables were also measured or derived to provide context for the stream temperature results and are described below.

Non-Temperature Variables

GIS-derived variables

Four study variables—elevation, catchment area, distance-to-divide, and catchment slope—were GIS-derived from readily available statewide public data. These provide a description of the sites included for temperature monitoring. Definitions for these variables and their source GIS layers are listed in **Table 8**.

Measured variables

A limited survey was undertaken to quantify several easily measured descriptors of study reaches (**Table 8**). Reach length was 30 times the average bankfull width (BFW), based on five BFW measurements. We set a minimum reach length of 150 m and maximum of 500 m. At one Type Np site, reach length was only 130 m because that was the length of the entire upstream perennial stream channel. Study reaches were evaluated by establishing six equally spaced transects perpendicular to stream flow running upstream from the sample point. Methods were adapted from Peck and colleagues (2006) and Schuett-Hames and colleagues (1999a, 1999b).

Thirteen site-level variables were quantified. Nine were quantified at the transects: 1) bankfull width, 2) wetted width, 3) mean depth, 4) channel gradient, 5) riparian canopy closure, 6) thalweg depth, 7) embeddedness, 8) bed particle size, and 9) channel aspect; and four were quantified over the intervals between transects: 10) LWD_{downed}, 11) $LWD_{suspended}$, 12) LWD_{jam}, and 13) riparian overstory type. Variables one through nine were included to assess reach-scale correlation with temperature. Variables ten through twelve were measured because LWD recruitment is a resource objective. Overstory type provides context for other results. These variables are referred to hereafter as habitat variables. Site-level and catchment-level characteristics are summarized in **Appendix D**. The measurement methods were chosen to conform to those identified in the FPR (e.g., canopy closure) or established Timber, Fish, Wildlife protocols (Schuett-Hames *et al.* 1999a, 1999b).

Temperature Variables

Stream temperature monitoring began in 2008. The intent was to monitor at least 50 sites in each stream type and to install all temperature loggers by 30 June 2008 to record each stream's annual thermal peak. However, by mid-July 2008 only one half that number of sites were installed due to delays in locating and obtaining permission to access private property. We continued in spring 2009 and by 1 July 2009 had installed loggers at 53 of 61 Type F/S sites and at 53 of 54 Type Np sites. The remaining sites were installed by 9 July 2009.

Temperature was recorded at 30-minute intervals at the upper and lower end of each study reach with *in situ* TidbiT data loggers (Onset Computer Corporation 2004) using the methods described in Schuett-Hames and colleagues (1999a). Data loggers were attached using zip ties to iron rebar driven into the stream bed. The Tidbits were suspended in the water column, and shielded from direct sun using perforated white PVC tubing. An air temperature data logger was deployed adjacent to the lower monitoring station approximately 30 cm above the water surface and shielded from direct sun (Schuett-Hames *et al.* 1999a). Height and distance from the stream varied where necessary to protect the data logger from direct sun.

Data loggers remained in place at least through August in each year. Peak summer maximum temperatures occurred over a one-week period at nearly all sites in each year, centered on 17 August in 2008 and 30 July in 2009, so it is unlikely that we missed the thermal peak. Temperature metrics were calculated for those sample sites with at least 30 days of data over the period 1 July through 31 August 2009 (**Appendix E**). Metrics for water temperature were:

- Maximum summer stream temperature (Tmax, upstream and downstream).
- Seven-day average of daily maximum summer stream temperature (7Tmax, upstream and downstream).
- Change in maximum summer stream temperature along reach (downstream minus upstream) for Tmax (D_Tmax).
- Change in seven-day average of daily maximum summer stream temperature along reach (downstream minus upstream) for 7Tmax (D_7Tmax).

Metrics for air were:

- Maximum summer air temperature (air_Tmax).
- Seven-day average of daily maximum summer air temperature (air_7Tmax).

We show the cumulative distribution plots only for Tmax, D_Tmax, and air_Tmax because they are very similar to those for seven-day averages. However, **Table 9** and **Table 10** include both maximum temperature and seven-day average maximum temperature.

Quality Assurance

Prior to deployment, temperature data loggers were compared to a National Institute of Science and Technology (NIST) thermometer by submerging them in an ambient room temperature (~20°C) water bath and in an ice-water bath at 0°C. Data loggers outside the manufacturer's stated accuracy (0.2°C for water temperature range data loggers, 0.4°C for air temperature range data loggers) in either water bath temperature were not deployed.

During the study, data loggers at several monitoring stations were exposed to air as stream water levels dropped. These data were identified and excluded from analysis. First, field notes were used to flag sites and general time periods when data loggers may have been exposed. Second, both stream and air temperature data for each site were examined to determine the date and time when a data logger may have been exposed. As a data logger becomes exposed to the air, the stream temperature record, especially daytime temperatures, more closely track air temperature. Because of the typically large difference between afternoon air and water temperature, it was usually apparent when a data logger became exposed. Full data filtering procedures are documented in the quality assurance plan (Ehinger *et al.* 2010).

In addition, as specified in the study plan for the ERST program (Ehinger *et al*. 2007), repeatability of data collection methods for non-temperature variables was evaluated at approximately 10% of the study sites. This subset of sites was randomly selected and methods were performed by different field crews during the repeat visit. In general, the mean coefficient of variation was less than 10% for wetted width and depth, bankfull width, gradient, and canopy closure; less than 20% for bankfull height and embeddedness; but sometimes exceeded 20% for particle size. Results are summarized in **Appendix F**.

Analysis

Effects of Site Rejection

Three observed categories of site rejection occurred frequently enough to affect the sampling:

1. No response from landowner (NR). This occurred more frequently with small forest landowners than the industrial landowners for both Type F/S (34% of SLFO sites attempted) (**Table 5**) and Type Np (9% of SFLO sites attempted) (**Table 7**). This unintended stratification changed the study design from equi-probability to variable-probability (see below). As this was not determined until after sampling, an alternative form of the Horvitz-Thompson π-weighted estimator (Horvitz and Thompson 1952; Thompson 2002) was incorporated during analysis to adjust initial weight for stratification by ownership. The rationale to account for potential biases introduced by differential loss of sites during evaluation, that is, loss other than completely at random, is described by Stevens and Jensen (2007).

2. Non-target (other) waters (OW). Approximately 8% of Type F/S sites evaluated (**Table 4**) and 22% of Type Np sites evaluated (**Table 6**) were misclassified (i.e., not the expected water type). This was seen across both main ownership classes but was higher for SFLO, affecting 14% of Type F/S sites in this ownership (**Table 5**) and 41% of Type Np sites (**Table 7**).

3. Target not sampled (TN). These sites were excluded typically due to insufficient water in the channel to submerge dataloggers, permission to access the site was obtained too late to be included, or additional sites were not needed. These exclusions comprise 8% of Type F/S sites evaluated (**Table 4**) and 40% of Type Np sites evaluated (**Table 6**).

Cumulative Distribution Functions

Data for the analysis were summarized for the period from 1 July through 31 August 2009. Results were calculated using the GRTS spatial survey design and analysis package (*spsurvey* v. 2.2; Kincaid and Olson 2011) and the accessory package *sp* (Pebesma and Bivand 2011). These packages provide overview, survey design, and data analysis for areal, finite, and linear resources, and automate plotting and confidence band estimation using cumulative distribution functions (CDF). Currently, these flexible, non-standard functions only exist for R, an open-source implementation of the S statistical language developed at Bell Laboratories. See Ihaka and Gentleman (1996) for the original published description of the R Project, and Becker and colleagues (1988) for development of S. The R code is included in **Appendix G**.

Initial per site weights for the sample domain and target population were 213.908 for Type F/S and 216.303 for Type Np. The site weight represents the hydrologic length in kilometers that each site represents. Final weights per site, adjusted using the *adjwgt* function to take into account post-sampling stratification by ownership and the number of sites of indeterminate status as target or non-target, were:

- Industrial landowners (IND) = 266.810 (Type F/S), 587.410 (Type Np).
- Municipal landowners (MUN) = 648.908 (Type Np only).
- Small forest landowners (SFLO) = 434.501 (Type F/S), 1378.929 (Type Np) (personal communication (J.E.J.), D.P. Larson and T. Olson, E.P.A.).

Latitude and longitude were transformed to Albers projection, spheroid Clarke 1866 (Snyder 1987), using the *albersgeod* function, consistent with the original sample draw.

Results are reported as:

- CDFs and mean catchment-scale characteristics of base sample.
- CDFs and mean reach-scale characteristics of base sample.
- CDFs of canopy closure and maximum temperature.

The analysis pathway defines vectors for sites, sub-populations, design, and variables of interest, and then calls functions to write results as percentiles and overall means and plots CDFs. Confidence bands are shown in figures at the 95% level. Although mean values are more intuitive to resource managers, they may be biased. The percentile estimates are not biased. Both are reported for the reader.

The R package *spsurvey* contains a function to examine year-to-year cumulative distribution function inference for probability survey data. However, installation of data loggers, which began in 2008, tended to follow site availability rather than GRTS order, which disturbed the study's spatial balance for the year of initial installation. This was resolved in 2009. Only the 2009 data were analyzed.

To evaluate the relationship of temperature results to regional climatic influences, the historical mean of daily maximum air temperature for July was calculated for seven sites in western Washington: Buckley (Pierce County), Centralia (Lewis County), Elma (Grays Harbor County), Forks (Clallam County), Longview (Cowlitz County), Peterson's Ranch (Skamania County), and Sedro-Woolley (Skagit County). These sites were selected because of proximity to forest lands distributed throughout western Washington, and because of their long data record. The time period of these data was 1958-2008.

Correlation analyses

We used a Spearman rank correlation to assess the strength of the relationship between downstream water temperature and upstream water temperature, air temperature, canopy closure, and eleven of the GIS-derived and habitat variables, including: mean depth, thalweg depth, wetted and bankfull width, width:depth ration stream gradient, total LWD, elevation, catchment area, distance to divide, and catchment slope.

We ran the analysis using all Type F/S and Np sites together and for each stream type alone to distinguish between relationships that actually differ between stream types or only because the streams represent opposite extremes of the distribution. Only sites for which both downstream water temperature and air temperature data were available were used for the correlations.

Results

Type F/S streams

Stream aspect was relatively uniformly distributed except that very few sites with a northeast aspect were sampled (**Figure 3**). Median canopy closure was similar for coniferous and mixed riparian vegetation types, 87% and 88%, respectively (**Figure 4**). Median canopy closure for the deciduous vegetation type was lower, 67%, and more variable with minimum and maximum values near 0% and 100%. Overall median canopy closure was 78% (mean 68%) and the 25th percentile of the estimated canopy closure distribution was 39% (i.e., 75% of the population is estimated to exceed 39% canopy closure) (**Figure 5**).

The GIS-derived catchment variables and several habitat variables varied widely across sites with a few very high values skewing the distribution (**Appendix D**; **Table D-1)**. For example, median catchment area was 193 ha and the mean was 5970 ha. Median distance to divide was 2622 m and mean was 11,493 m. Median station elevation was 94 m and the mean was 150 m. Median and mean catchment slope were 6.9% and 9.3%, respectively. Likewise bankfull width and wetted width were skewed with median values of 4.9 m and 3.0 m, respectively and mean values of 10.5 m and 7.5 m, respectively; median particle size was 6.4 mm and mean was 22.3 mm. Median thalweg depth and mean depth were 0.3 m and 0.1 m, respectively and mean values were 0.4 m and 0.2 m, respectively. Median total LWD pieces was 21.6 pieces per 100 m and mean was 27.4. CDFs and summary statistics are compiled in **Appendix D**.

The median Tmax and 7Tmax at the downstream locations were 18.7°C and 18.1°C, respectively (**Table 9**; **Figure 6**). The median D_Tmax and D_7Tmax (i.e., upstream-downstream differences in Tmax) was 0.1°C for both metrics, indicating little temperature change across the sampling reach. Median air TMax was 28.3°C (**Table 9**; **Figure 7**).

The 2009 season was much warmer than 2008. Maximum daily air temperature in July, during the period of maximum stream temperature, exceeded the 75th percentile of the historical record (1958-2008) at several locations around the study area (Buckley, Centralia, Elma, Longview, Peterson’s Ranch, and Sedro) (**Figure 8**). As a result, stream temperatures in 2009 were warmer than in 2008. The mean Tmax and 7Tmax were 2.6°C and 2.7°C higher, respectively, and the mean air Tmax and 7Tmax were 3.3°C and 2.9°C higher, respectively, in 2009 than in 2008 at sites monitored in both years (**Figure 9**). In addition, maximum stream temperatures occurred three weeks earlier in 2009 than in 2008 (**Figure 10**).

Type Np streams

Stream aspect was patchily distributed with few sites having northeast or east aspects (**Figure 11**). Greater median canopy closure (median 95%) was observed at sites with mixed riparian canopy vegetation than at sites characterized as either coniferous (median 74%) or deciduous (median 70%) (**Figure 12**). Overall median percent canopy closure was 93% (mean 82%) and the 25th percentile was 73% (**Figure 13**).

Type Np catchment area ranged from 1.3 to 83.1 ha with a median and mean of 10.9 and 20.0 ha, respectively (**Appendix D**; **Table D-2**). Catchment slope was much steeper than the Type F/S streams, with a median and mean catchment slope of 22.4% and 21.9%, respectively, and at nearly twice the elevation, with a median and mean elevation of 258 m and 335 m, respectively. Distance to divide ranged from 156 m to 1976 m with a median value of 614 m.

Median and mean bankfull widths were 1.6 m and 1.9 m, respectively, and median and mean wetted widths were 0.9 m and 1.1 m, respectively. Thalweg depth and mean depth never exceeded 0.25 m and 0.19 m, respectively, with median values of 0.07 m and 0.03 m, respectively. Median and mean total LWD pieces were 32.7 and 38.6 pieces per 100 m. CDFs and summary statistics are compiled in **Appendix D**.

The median Tmax and 7Tmax at the downstream locations was 16.2°C and 15.2°C, respectively (**Table 10**; **Figure 14**). The median D_Tmax and D_7Tmax was 0.8°C for both metrics, a greater temperature change across the sampled reach than in the Type F/S sites. Median air 7Tmax was 23.9°C, compared to 25.1°C at the Type F/S sites (**Figure 15**).

The mean Tmax and 7Tmax were 1.1°C and 1.2°C higher, respectively, and mean air Tmax and 7Tmax were both 3.5°C higher, respectively, in 2009 than in 2008 at sites monitored in both years. Similar to the Type F/S sites, peak stream temperatures occurred three weeks earlier in 2009 than in 2008 (**Figure 10**).

Correlation analyses

For Type F/S, Type Np, and all sites combined, the strongest correlations were with upstream water temperature and air temperature (**Table 11**; **Figure 16**). For the habitat variables, there were significant positive correlations with width (wetted and bankfull), thalweg depth, catchment area, and distance to divide in the Type F/S and pooled sites, but no correlation in the Type Np sites. Similarly, there were significant negative correlations with canopy closure, stream gradient, total LWD, and catchment slope in Type F/S and pooled sites, but no correlation in the Type Np sites. For mean depth, there was a significant positive correlation in the Type F/S and pooled sites, but a significant negative correlation in the Type Np sites. There was a positive correlation in the ratio of width to depth in the Type Np sites, but no correlation in the Type F/S or pooled sites. Elevation was not correlated with stream temperature.

Discussion

Stream temperature and canopy closure

Canopy closure on Type F/S streams averaged 68% but was heavily impacted by eight locations with less than 20% canopy closure and bankfull widths ranging from 22 to 61 m, suggesting that the low shading was due to the width of the stream rather than the lack of riparian vegetation. Mean canopy closure on Type Np streams was influenced by six sites with some portion of the sampled reach unbuffered. Current forest practices rules require a buffer along at least 50% of Type Np streams, so this was not unexpected. Canopy closure ranged from 1% to 35% at these sites. However, overall Type Np sites averaged 82%, only slightly less than that observed by Schuett-Hames and colleagues (2011), Janisch and colleagues (2012), and McIntyre and colleagues (2018) in unharvested Type Np streams in western Washington. Other factors likely influencing canopy closure are stand type (**Figure 4** and **Figure 12**) and forest management history (which was not recorded).

In this study, maximum summer water temperatures in the Type Np streams were warmer, on average, and more variable among sites (spanned a wider range) than similar-sized streams in other recent studies from western Washington and Oregon (Dent *et al*. 2008; Groom *et al*. 2011; Kibler *et al*. 2013; Bladon *et al*. 2018; McIntyre *et al.* 2018). This is likely a sampling artifact of comparing this random sample with streams chosen because of specific physical (e.g., unharvested mature forest) or biotic (e.g., presence of cool water species) characteristics. The situation is similar when comparing our Type F/S sites with other studies because the range in size of Type F/S streams is even greater than in Type Np.

Air temperature in 2009 was much warmer than 2008 and this is reflected in the stream temperatures. The 1.2°C difference in mean 7Tmax between years observed here is similar to the 1.3°C difference observed by McIntyre and colleagues (2018) in unharvested western Washington Type Np streams between the same years. The between-year difference in 7Tmax in the Type F/S streams was even greater at 2.7°C. Between-year (2007 vs. 2008) differences in maximum stream temperature of 1.0°C were seen in eastern Washington Type F/S streams (Ehinger 2013), and were associated with air temperatures that were, on average, 1.7°C higher in 2007 than 2008. Between-year differences of this magnitude in the absence of forest management activities will make long-term effects of forest harvest on stream temperature difficult to distinguish from natural variability or climate change.

Correlation of water temperature with other variables

The significant correlations between stream temperature and the habitat variables seen in the Type F/S streams alone and in the pooled data set were predictable. The strong correlation with upstream water temperature was noted by Groom and colleagues (2011) and is likely even stronger in our streams because of the shorter reach lengths. Similarly, the correlation with air temperature and some habitat variables has been observed in western Washington Type Np streams (Ecology, unpublished data). A negative correlation of stream temperature with canopy closure has been observed elsewhere and is likely related to increased solar insolation due to less riparian shade, which may partially be a function of wider bankfull widths in larger catchments.

Many of the habitat variables are themselves correlated. For example, catchment area and distance to divide are measures of area above the sampling site, larger catchments tend to have wider streams, and wider forested streams tend to be less shaded. Nearly all of the correlations with stream temperature followed expected patterns of higher stream temperature in less-shaded streams, which tended to be wider and have larger catchments. One exception was mean water depth, which was positively correlated with stream temperature for the Type F/S and pooled data, but negatively correlated for the Type Np sites. This suggests that the positive correlation is an effect of catchment size, while the negative correlation for Type Np streams may reflect water volume.

Stream temperature was not correlated with most habitat variables for the Type Np sites. This is likely because the Type Np sites spanned a very narrow range of habitat values (e.g., wetted width, bankfull width, catchment area, distance to divide) (**Figure 16**) or in some cases did not include the very low values where the change in temperature was greatest (e.g., stream gradient or catchment slope). This is well illustrated in **Figure 17**, where Type F/S shade values are relatively uniformly distributed across the entire graph while Type Np shade values are bunched at 80%.

Comparison of Type F/S with Type Np streams

Three observations were made comparing Type F/S and Type Np streams.

1. Tmax was, on average, 3.0°C warmer in Type F/S streams than in Type Np streams. Mean Tmax at the downstream stations was 19.0°C (95% CI: 18.2-19.8°C) in Type F/S streams (**Table 9**) compared to 16.0°C (95% CI: 15.3-16.7°C) for Type Np streams (**Table 10**).

2. Mean D_Tmax at Type Np sites (1.2°C) was nearly four times that observed at Type F/S sites (0.3°C).

3. Stream temperature was correlated with many of the site level habitat variables in Type F/S streams, but not in the Type Np streams (**Table 11**).

These differences were not surprising. Type Np streams were, in general, located at higher elevations and were narrower than the Type F/S streams. As such, they experienced cooler air temperatures and were more shaded than the wider Type F/S streams, resulting in cooler stream temperatures. The greater temperature change from upstream to downstream in the Type Np streams is likely the result of lower water volumes (i.e., less thermal inertia) in the Type Np than in the Type F/S streams.

Implementation

The rate of site rejection was higher for Type Np sites than for Type F/S sites, but not atypical compared to other studies (Merritt *et al.* 1999; Herger and Hayslip 2000; Hayslip *et al.* 2004). GRTS designs allow site rejection rates to vary and, when this occurs prior to sampling, this may simply amount to refining the sampling frame. High rates of rejection not due to lack of access are a sign that a sampling frame was poorly defined. It is critical, however, that randomization and the matching between spatial balance of the target population and the sample is maintained.

As our results show, GRTS offers robust methods permitting inference in the presence of errors to the sampling frame (**Table 12** and **Table 13**). However, both study design and the scope of inference were weakened by unintended errors in implementation, the former by disturbance of the design-based spatial balance of the target population and the latter from bias introduced against sampling SFLO lands (**Figure 2**). Much of the inferential power to the western flank of the Cascades and Puget Sound regions was lost because few sites were sampled there (**Figure 1** and **Figure 2**). In this particular application of GRTS, some SFLO declined to participate (**Table 4** through **Table 7**; **Figure 2**), but other reasons for loss of sites were more significant, most notably:

- No response from the landowner.
- Lands converted to other purposes.
- Insufficient water in the stream.

Without re-sampling, complete correction is not possible. The remedy for future efforts is to replace excluded sites on an ownership-by-ownership basis until the target sample size is reached. Sufficient over-sample exists to accomplish this. It is also necessary to consider whether SFLO lands within the FPR lands domain meet the FPR land definition because many parcels are of mixed land use. However, this was beyond the scope of this project to evaluate.

Several other sources of uncertainty affect inference to the target population, but differ in their impact (**Table 12** and **Table 13**). Misclassification of ownership, for example, can occur if parcels mix land uses (e.g., agricultural and forest lands), if parcels are undergoing transfer of ownership, or if gaps exist in the ownership data derived from tax records. With careful review, this error can be minimized. The impact on inference to a non-stratified target population would be slight. Misclassification of Type F/S waters as Type Np or Type Np waters as Type F/S also occurred. This error, which can be introduced both before and during sampling, can alter the scope of inference. However, its impact is also expected to be slight given on-site stream type evaluations. Potentially of greatest significance to the scope of inference is inclusion of non-target waters and non-target lands in the sample frame (**Table 4** and **Table 6**). This is likely to affect the length of stream within the sample frame rather than the areal extent of the sample frame. Conversely, it is unknown how many waters were excluded by the target population definition. No design can evaluate resource fractions excluded from sample frames.

Several analysis options for this study were possible, depending on the underlying assumptions. For example, is the SFLO class sufficiently different in its management to affect the range of conditions of the stream and channel variables studied? If not, then the differential loss of sites related to ownership, rather than missing completely at random, can be overcome. In effect, ownership would be an irrelevant stratification imposed on an underlying uniform resource. Of significance to this study, however, was that the differential loss of sites disturbed the underlying design-based spatial dispersion of the sample relative to the target population. Taken together, all ownerships combined (**Figure 2**) seem to approximate the distribution of the target population.

Also of significance is how to account for sites of indeterminate target status because they could not be visited. Without further assumptions, loss of these sites reduces the inference domain from 25669 km to 20535 km of Type F/S stream and from 49317 km to 45207 km of Type Np stream.

We calculated the scope of inference using four different sets of assumptions (**Table 12** and **Table 13**) for both stream types. Ratios derived from the sites that were visited were used to approximate the proportion of indeterminate sites that were actually part of the target population. Using the hydrologic definition developed from available linework for a sampling frame consisting of Type F/S streams on western Washington FPR lands (**Table 1**), the sample frame length was 25669 km (**Table 12**: Case 1). This assumed that all sites were target. Accounting for misclassified sites (which were actually non-target) reduced the scope of inference to 23530 km (Case 2). This holds only if no other cases of non-target sites existed in the sample. However, there were 24 indeterminate (with respect to target vs. non-target) sites in the Type F/S sampling and 19 indeterminate sites in the Type Np sampling. Case 3 factors in the indeterminate sites by using the ratio of target to non-target sites, derived from the known sample sites, to estimate the proportion of the full sample which is actually in the target population. This reduced the scope of inference for Case 3 to 18984 km. Case 4 uses analogous calculations but goes one step further by estimating the proportion of non-target sites by ownership stratum. The scope of inference for Case 4 is reduced to 17952 km, or approximately 70% of the original sample frame. The percent of the estimated target population on which the inference is based is approximately 86%. The final scope of inference for Type Np sites was 33581 km, or 68% of the original sample frame of 49317 km (**Table 13**). The percent of the estimated target population on which the inference is based is approximately 37%. For both Type F/S and Type Np analyses, Case 4 can be viewed as a conservative estimate.

Although misclassification of stream reaches and the lack of access to some properties affected the study, even the most conservative estimates of the scope of inference (Case 4) are near 70%. More importantly, this is the only available unbiased estimate of current status of stream temperature and canopy cover in western Washington and so will prove valuable both in assessing compliance with the threshold (i.e., not to exceed) water temperature standards and in providing context for the experimental studies underway in western Washington (Hayes *et al.* 2005; Ehinger *et al.* 2011). The question as to whether there will be further work to assess trends over time is largely a policy issue that must include the cost of this study and other competing research needs.

Conclusions

In spite of the difficulties with landowner access, this study met its Phase I goal of providing a status estimate of stream temperature and canopy cover.

1. Mean canopy closure in the Type Np sites was 82%, very similar to unharvested Type Np sites in several western Washington Type Np studies. Likewise, mean canopy cover in the Type F/S streams was 68%, in spite of eight sites with bankfull widths exceeding 20 m and canopy closure less than 20%.

2. Median Tmax and 7Tmax was 18.7°C and 18.1°C, respectively, in the Type F/S streams, and 16.2°C and 15.2°C, respectively, in the Type Np streams in 2009.

3. Average change in stream temperature across the sample site was 1.2°C in the Type Np streams compared to 0.3°C in the Type F/S, in spite of the much shorter reach lengths in the Type Np (150 m) than the Type F/S (272 m) sites.

4. The strong correlation between stream and air temperature along with the differences between 2008 and 2009 stream and air temperatures suggest that it will be difficult to differentiate long-term changes in stream temperature due to forest harvest from natural variability and climate change.

The scope of inference for westside applications of ERST was reduced by the lack of access to small forest landowner sites and misclassifications of streams on the hydrolayer. For Type F/S waters, the target population inference was reduced to 70% of the original sample frame (from 25669 km to 17952 km) (**Table 12**). Likewise, for Type Np waters the scope of inference was 68% of the original sampling frame (from 49317 km to 33581 km) (**Table 13**). Though the distinction between areal extent of the target population (westside FPR lands) vs. length of target population (km of stream by water type) should be noted, the scope of inference is a function of the underlying assumptions.

If the Phase II of this study is implemented, we recommend:

1. Sites should be plotted during site selection to evaluate whether the underlying spatial balance of the sample is being maintained.

2. Land ownership should be evaluated during implementation to determine if unintended differential sampling is occurring.

3. Ongoing consultations with an expert knowledgeable in GRTS surveys during planning, implementation, and analysis of any future implementation of probability sampling to fully realize the potential of GRTS designs.

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Table 1. Hydrographic length and number of sites in the initial sample are shown below. Of these, 120 Type F/S sites were evaluated and 61 were sampled. Two hundred twenty-eight Type Np sites were evaluated and 55 were sampled.

	Type F/S	Type Np
Hydrographic length (km)	25,714	49,089
Number of initial sites	25,669	49,317
Number of sites evaluated	120	228
Initial weighting	213.908	216.303
Number of sites sampled	61	55

Table 2. Percent of total Type F/S stream length within the target domain vs. percent of initial sample points, by waters' sub-type. This shows that, after sampling, proportions of the Type F sub-types were largely preserved.

Sub-type	Definition	% of target domain	% of sample
F1	fish habitat	85.3	81.3
F2	unmodeled; no DEM-to-stream match; field survey/former water type indicates fish use/habitat	4.3	7.7
F3	interior arc of Type F impoundment	1.7	2.2
F4	mapping anomaly such as irrigation canal; former water type indicated fish use/habitat	0.2	1.1
F5	diversion waters or former Type 2 waters	5.6	3.3
F7	model override; data indicate fish use/habitat upstream of modeled end-of-fish habitat	2.7	4.4

Source: Metadata, Washington State Water Course Hydrography and FPARS Water Type Data Dictionary

Table 3. Percent of total Type Np stream length within the target domain vs. percent of initial sample points, by waters' sub-type. This shows that, after sampling, proportions of the Type Np sub-types were largely preserved.

Sub-type	Definition	% of target domain	% of sample
N1	non-fish habitat; upstream of modeled fish habitat	54.4	53.9
N2	unmodeled; no DEM-to-stream match; field survey/former water type indicates non-fish use/habitat	18.2	19.3
N4	mapping anomaly such as irrigation canal; former water type indicated no fish use/habitat	0.1	0.4
N6	previously untyped water upstream of a modeled end point	26.4	25.4
N7	model override; data indicate end of fish use/habitat downstream of modeled end-of-fish habitat	0.8	0.9

Source: Metadata, Washington State Water Course Hydrography, and FPARS Water Type data Dictionary

Table 4. Counts and percentages of the evaluated Type F/S sites (*n* = 120) and the reasons for rejection or inclusion as GRTS-derived, randomly-selected temperature monitoring stations.

Reason code	No. of sites	% evaluated sample	Definition
NR	17	14.2	no response from landowner
OL	15	12.5	other lands (non-FPR, non-forest)
OW	10	8.3	other waters (non-Type F)
TN	10	8.3	target not sampled
TS	61	50.8	target sampled
UK	7	5.8	reason for rejection unknown
Total	120		

Table 5. Summary of reasons for rejection or inclusion of Type F/S sites (*n* = 120) by land ownership class. PUB = public lands; IND = industrial landowners; SFLO = small forest landowners. See **Table 4** for definition of reason codes.

Reason code	PUB	IND	SFLO
NR	0	0	17
OL	2	1	12
OW	0	3	7
TN	0	7	3
TS	0	51	10
UK	0	6	1
Sum	2	68	50
% of total sample	1.7	56.7	41.7
Success rate	0%	75%	20%

Table 6. Counts and percentages of the evaluated Type Np sites (*n* = 228) and the reasons for rejection or inclusion as GRTS-derived, randomly-selected temperature monitoring stations.

Reason code	No. of sites	% evaluated sample	Definition
LD	5	2.2	landowner declined
NR	3	1.3	no response from landowner
OL	13	5.7	other lands (non-FPR, non-forest)
OW	51	22.4	other waters (non-Type Np or no channel)
TN	91	39.9	target not sampled
TS	54	23.7	target sampled
UK	11	4.8	reason for rejection unknown
Total	228		

Table 7. Summary of reasons for rejection or inclusion of Type Np sites (*n* = 228) by land ownership class. PUB = public lands; IND = industrial landowners; SFLO = small forest landowners; MUN = municipal landowners. See **Table 6** for definition of reason codes.

Reason code	PUB	IND	SFLO	MUN	Note
LD	0	0	5	0	
NR	0	0	3	0	affects SFLO class
OL	8	4	1	0	
OW	4	31	14	2	affects all ownership classes
TN	1	82	7	1	
TS	0	51	2	1	
UK	0	7	2	2	
Sum	13	175	34	6	
% of total sample	5.7	76.8	14.9	2.6	
Success rate	0%	29%	6%	17%	

Table 8. Definitions of catchment-scale and reach-scale non-temperature variables used by the Extensive Riparian Status and Trends study.

Variable	Definition	Source	Metric
Catchment area	Modeled runoff area (ha) above downstream sampling point; Model: Hydrologic Modeling Extension, Spatial Analyst, ArcView 3.2	30 m DEM hydrography	as defined
Catchment slope	Modeled cell slope (%) of catchment surface above downstream sampling point; Model: Surface tool, Spatial Analyst, ArcView 3.2; extent is catchment area	30 m DEM hydrography	average
Elevation	Value of grid cell (m) at downstream sample point	30 m DEM	as defined
Distance to divide	Estimated horizontal distance (m) between sampled reach and drainage divide associated with the main channel head	30 m DEM	as defined
Bankfull width[5]	Horizontal distance (m) either between upper scour lines on opposite banks or tops of banks, perpendicular to flow	on site	mean[1]
Wetted width[5]	Horizontal distance (m) between points on opposite banks, perpendicular to flow, at which substrate particles are no longer surrounded by free water	on site	mean[1]
Mean depth[5]	Vertical distance (m) between substrate and stream surface, perpendicular to substrate	on site	mean[2]
Thalweg depth	Maximum wetted depth (m)	on site	mean[1]
Gradient	Gradient (%) measured between successive transects using a clinometer and flagged height pole	on site	mean[3]
Aspect	Direction (degrees) perpendicular to valley floor slope as determined by compass at downstream sample point	on site	as defined
Embeddedness, mid-channel	Degree of fine sediments (%) surrounding coarse sediments at the surface of a streambed	on site	mean[6]
Particle size	Quantification of the distribution of particle size (geometric mean (mm)) at the surface of a streambed	on site	mean[6]
Canopy closure	Number of quarter concave densiometer cells >50% center-shaded, as read at center of bankfull channel	on site	mean[4]
Riparian vegetation	Category of dominant riparian vegetation: CONIF= coniferous; DECID=deciduous; SHRUB=shrub; GRASS=grass; BURNED=recent fire	on site	category
Large woody debris[5]	Number of dead, non-self-supporting pieces of wood >10 cm diameter and >2 m length, intersecting the bankfull zone; DOWN=modifying flow at bankfull; SUSPENDED=above flow at bankfull; JAM=10+ grouped, touching, pieces of qualifying wood	on site	count/100 m

[1] 6 transects, 1 measurement each
[2] 6 transects, 5 equally spaced measurements per transect: left bank, left center, center, right center, right bank
[3] 5 sub-reaches, 1 measurement each
[4] 6 transects, 4 readings per transect: left bank, right bank, upstream, downstream; corrected to percent
[5] adapted from Schuett-Hames *et al.* 1999a, 1999b
[6] 6 transects, 11 equally spaced estimates per transect, left bank to right bank

Table 9. Estimated mean, 25%-tile, median, and 75%-tile cumulative distribution function (CDF) values for Type F/S temperature metrics as calculated using the R package *spsurvey*.

Year	Matrix	Metric	n	Mean	Minimum	25%-tile (CDF)	Median (CDF)	75%-tile (CDF)	Maximum
2009	Air	Air Tmax	60	28.4	18.5	23.7	28.3	32.5	40.8
		Air 7Tmax	60	25.3	16.6	21.1	25.1	29.0	35.1
	Water	Upstream Tmax	60	18.6	12.4	15.7	18.5	20.0	28.1
		Upstream 7Tmax	60	17.7	11.8	15.0	17.7	19.1	26.9
		Downstream Tmax	55	19.0	12.6	16.0	18.7	20.4	27.6
		Downtream 7Tmax	55	18.0	12.1	15.4	18.1	19.5	26.4
		D_Tmax	54	0.3	-4.6	-0.2	0.1	0.5	7.4
		D_7Tmax	54	0.2	-4.3	-0.2	0.1	0.4	6.6

Table 10. Estimated mean, 25%-tile, median, and 75%-tile cumulative distribution function (CDF) values for Type Np temperature metrics as calculated using the R package *spsurvey*.

Year	Matrix	Metric	n	Mean	Minimum	25%-tile (CDF)	Median (CDF)	75%-tile (CDF)	Maximum
2009	Air	Air Tmax	51	26.5	15.2	22.8	26.2	28.6	41.2
		Air 7Tmax	51	24.2	14.8	20.3	23.9	27.0	35.3
	Water	Upstream Tmax	49	14.9	7.8	12.6	14.8	16.4	24.4
		Upstream 7Tmax	49	14.1	7.2	12.1	14.1	15.6	23.4
		Downstream Tmax	50	16.0	9.7	14.0	16.2	17.3	25.0
		Downstream 7Tmax	50	15.2	8.6	13.2	15.2	16.5	23.7
		D_Tmax	47	1.2	-4.3	-0.6	0.8	2.5	7.0
		D_7Tmax	47	1.1	-4.9	-0.2	0.8	2.3	5.8

Table 11. Summary of Pearson correlations (r), uncorrected p-values, and number of observations (n) between temperature metrics and habitat variables in Type F/S and Type Np streams. Correlations in **bold** print indicate P ≤0.05.

		All sites		Type F/S		Type Np	
		Tmax	7Tmax	Tmax	7Tmax	Tmax	7Tmax
	r	**0.889**	**0.884**	**0.949**	**0.934**	**0.757**	**0.728**
Upstream Tmax	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	n	**109**	**109**	**60**	**60**	**49**	**49**
	r	**0.572**	**0.598**	**0.704**	**0.739**	**0.359**	**0.394**
Air Tmax 2009	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.010**	**0.004**
	n	**111**	**111**	**60**	**60**	**51**	**51**
	r	**-0.418**	**-0.433**	**-0.522**	**-0.545**	-0.194	-0.210
Canopy closure	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.168	0.135
	n	**113**	**113**	**61**	**61**	52	52
	r	**0.404**	**0.425**	**0.645**	**0.649**	**-0.320**	**-0.293**
Mean depth	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.021**	**0.035**
	n	**112**	**112**	**60**	**60**	**52**	**52**
	r	**0.420**	**0.442**	**0.649**	**0.657**	-0.249	-0.218
Thalweg depth	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.075	0.121
	n	**112**	**112**	**60**	**60**	52	52
	r	**0.510**	**0.534**	**0.672**	**0.686**	0.047	0.089
Wetted width	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.739	0.532
	n	**112**	**112**	**60**	**60**	52	52
	r	**0.535**	**0.552**	**0.667**	**0.685**	0.132	0.156
Bankfull width	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.352	0.270
	n	**112**	**112**	**60**	**60**	52	52
	r	0.172	0.169	0.147	0.169	**0.323**	**0.319**
Width:depth	p-value	0.070	0.075	0.261	0.198	**0.020**	**0.021**
	n	112	112	60	60	**52**	**52**
	r	**-0.371**	**-0.372**	**-0.432**	**-0.418**	0.200	0.190
Gradient	p-value	**<0.0001**	**<0.0001**	**0.001**	**0.001**	0.154	0.178
	n	**113**	**113**	**61**	**61**	52	52
	r	**-0.440**	**-0.454**	**-0.471**	**-0.497**	-0.218	-0.248
Total LWD	p-value	**<0.0001**	**<0.0001**	**0.000**	**<0.0001**	0.120	0.076
	n	**113**	**113**	**61**	**61**	52	52
	r	-0.083	-0.037	-0.061	0.003	0.090	0.149
Elevation	p-value	0.385	0.698	0.638	0.982	0.527	0.293
	n	113	113	61	61	52	52
	r	**0.541**	**0.570**	**0.668**	**0.690**	0.088	0.158
Catchment area	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.535	0.262
	n	**113**	**113**	**61**	**61**	52	52
	r	**0.579**	**0.603**	**0.713**	**0.726**	0.162	0.216
Distance to divide	p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.250	0.124
	n	**113**	**113**	**61**	**61**	52	52
	r	**-0.339**	**-0.329**	**-0.431**	**-0.398**	0.054	0.081
Catchment slope	p-value	**0.000**	**0.000**	**0.001**	**0.002**	0.702	0.568
	n	**113**	**113**	**61**	**61**	52	52

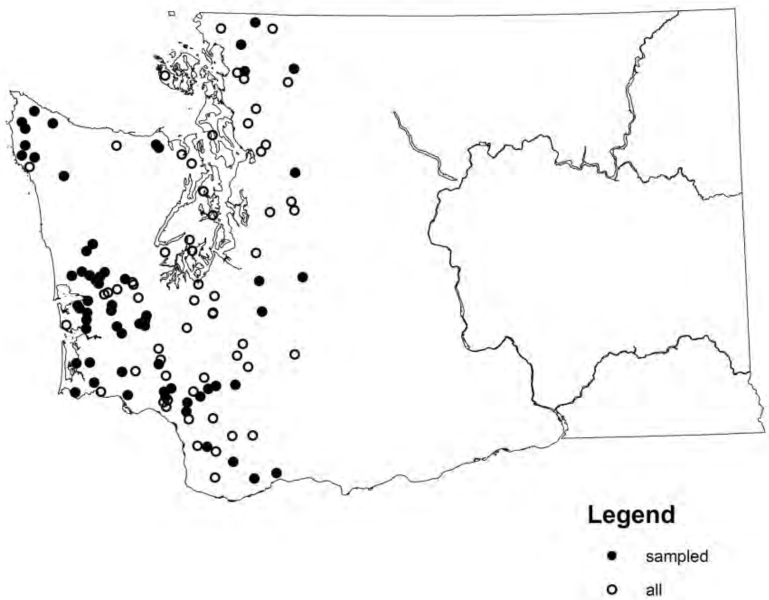
Table 12. Case-wise consideration of how assumptions can influence scope of inference (km of stream) using data from Type F/S streams. IND = industrial landowners; SFLO = small forest landowners.

Properties	Case 1	Case 2	Case 3	Case 4
Sample frame	25669 km	25669 km	25669 km	25669 km
Conditions	all sites are target	mix of target and non-target	mix of target and non-target	mix of target and non-target
	no loss of sites	loss of sites completely at random	loss of sites completely at random	differential loss of sites
	no ownership strata	no ownership strata	no ownership strata	strata by ownership
		if non-target = 10 sites in sample, then reduction in sample frame:	if target = 71 sites in sample, then estimated target of indeterminate sites: 71/96*24 = 17.8 estimated target: 71 + 17.8 = 88.8	estimated target using similar calculation IND + SFLO: 83.9
Inference scope		10/120 * 25669	88.75/120 * 25669	83.9/120 * 25669
	25669 km	23529.9 km	18984.4 km	17952.3 km
	100% of original sample frame	91.7% of original sample frame	73% of original sample frame	69.9% of original sample frame
Percent of estimated target population on which inference is based, if sample = 61 sites:			61/71*18984.4 = 16310.5 km, or ~86%	

Table 13. Case-wise consideration of how assumptions can influence scope of inference (km of stream) using data from Type Np streams. IND = industrial landowners; SFLO = small forest landowners.

Properties	Case 1	Case 2	Case 3	Case 4
Sample frame	49317 km	49317 km	49317 km	49317 km
Conditions	all sites are target	mix of target and non-target	mix of target and non-target	mix of target and non-target
	no loss of sites	loss of sites completely at random	loss of sites completely at random	differential loss of sites
	no ownership strata	no ownership strata	no ownership strata	strata by ownership
		if non-target = 51 sites in sample, then reduction in sample frame:	if target = 145 sites in sample, then estimated target of indeterminate sites: 145/209*19 = 13.1 estimated target: 145 + 13.1 = 158.2	estimated target using similar calculation for IND + SFLO: 155.3
Inference scope		51/228 * 49317	158.2/228 * 49317	155.3/228 * 49317
	49317 km	38285.6 km	34215.1 km	33581 km
	100% of original sample frame	77.6% of original sample frame	69.4% of original sample frame	68.1% of original sample frame
Percent of estimated target population on which inference is based, if sample = 54 sites:			54/145*34215.1 = 12742.2 km, or ~37%	

a) Type F/S



b) Type Np

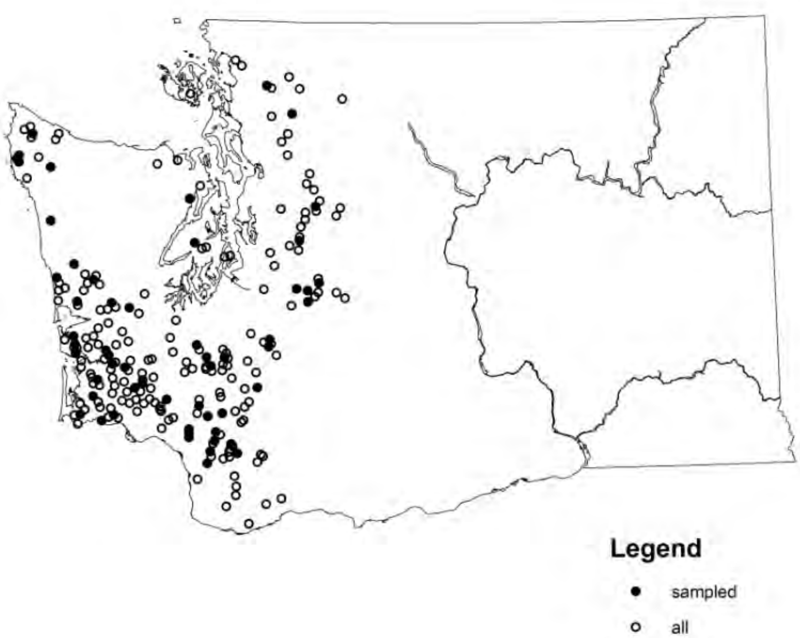


Figure 1. Map of a) Type F/S sites and b) Type Np sites that were sampled (shaded) or rejected (unshaded). Of the Type F/S sites, 61 sites were sampled and 59 rejected. Of the Type Np sites, 54 sites were sampled and 174 rejected.

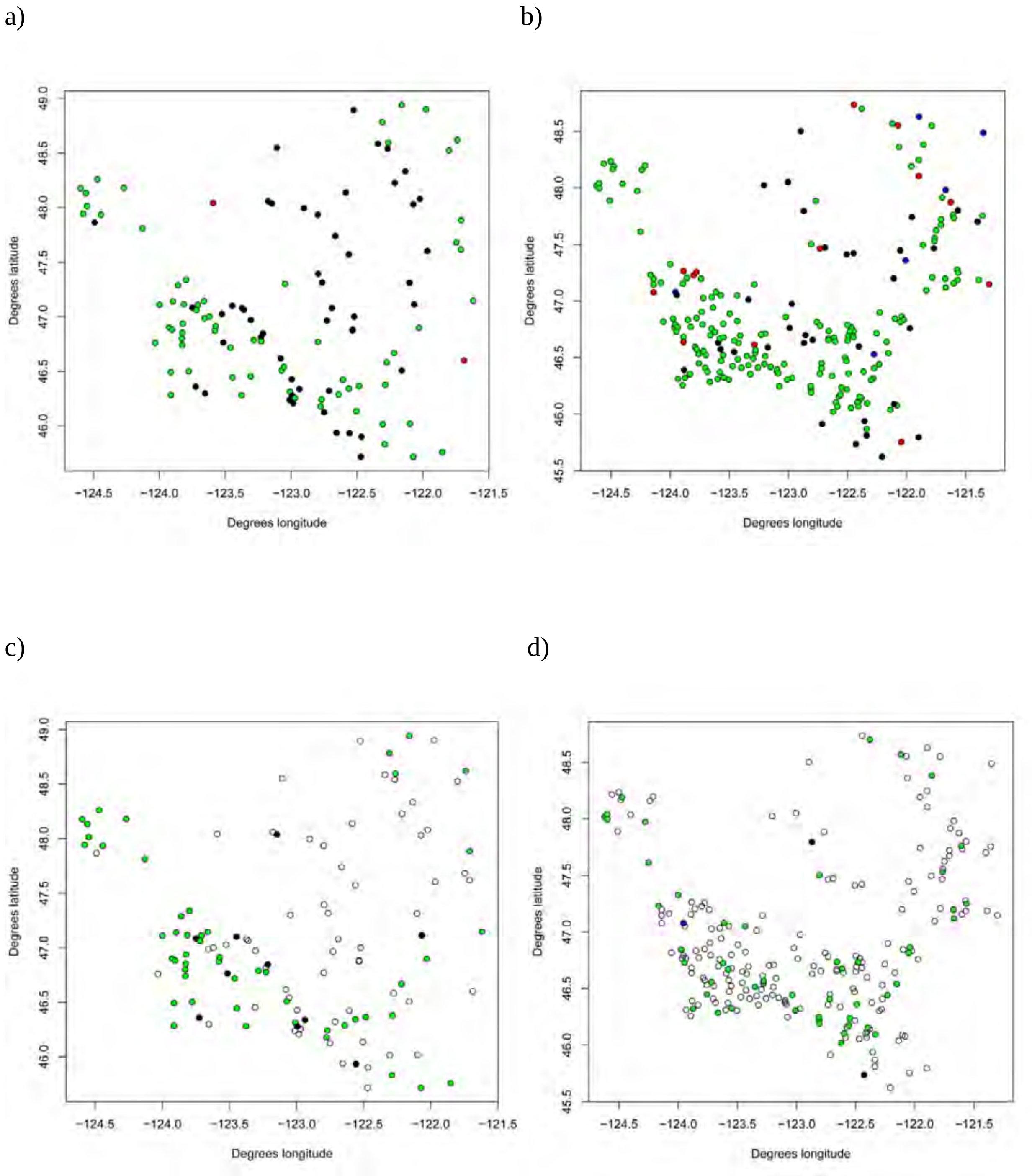


Figure 2. The upper two plots show the sites evaluated for a) Type F/S and b) Type Np by landowner class (green = industrial landowners, black = small forest landowners, red = public lands, and blue = municipal landowners). Plots c) and d) mirror plots a) and b), except that shaded circles are sites that were sampled and unshaded circles are sites that were not sampled.

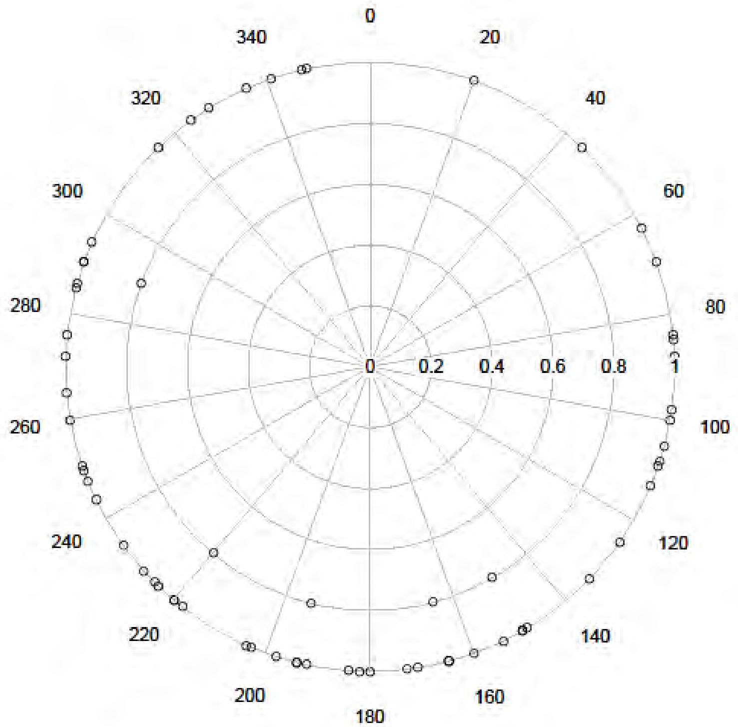


Figure 3. Reach aspect (in degrees) at Type F/S temperature monitoring stations. Each unique aspect value is represented by a point plotted at radial distance = 1. Cases in which a given aspect was common to more than one study reach are represented by points plotted at radial distance = 0.8.

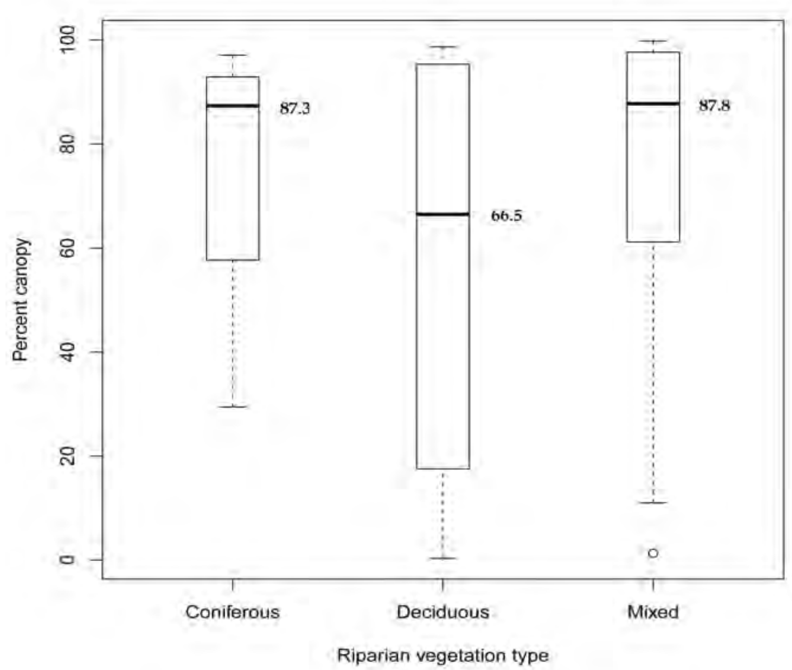


Figure 4. Percent riparian canopy closure by category of riparian vegetation encountered along Type F/S study reaches at temperature monitoring stations. Box plots show medians, quartiles, extremes, and outliers. Samples sizes were 4, 22, and 35 for coniferous, deciduous, and mixed vegetation types, respectively.

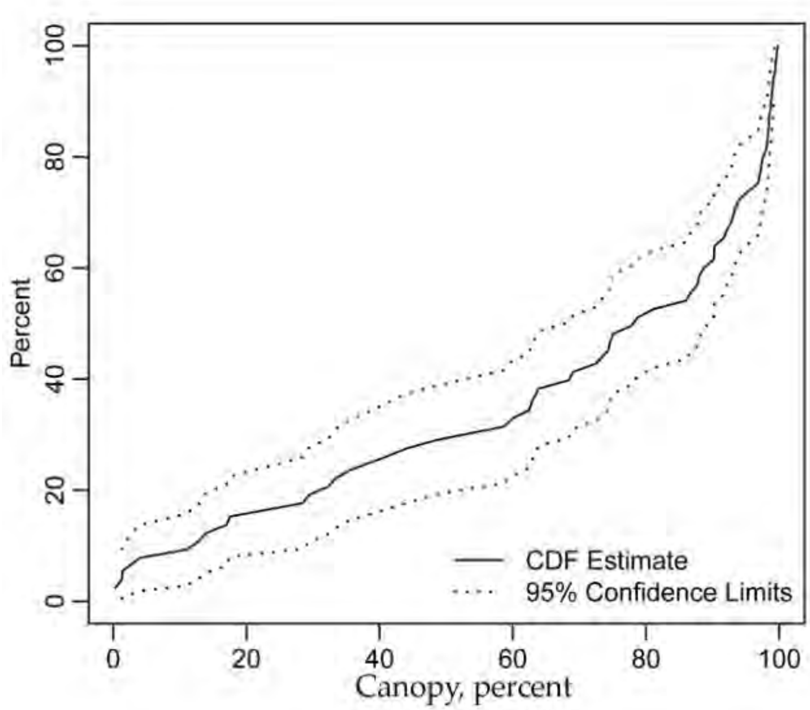
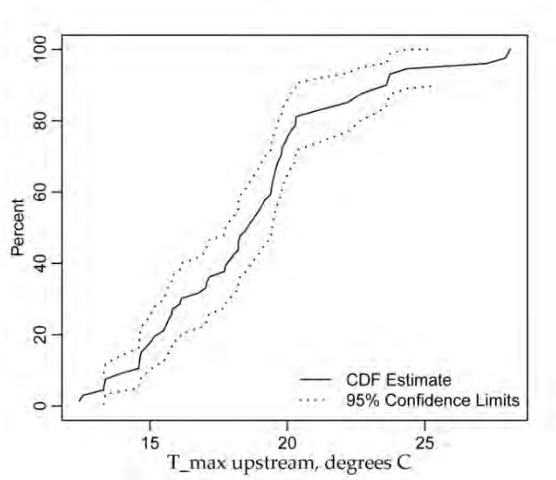
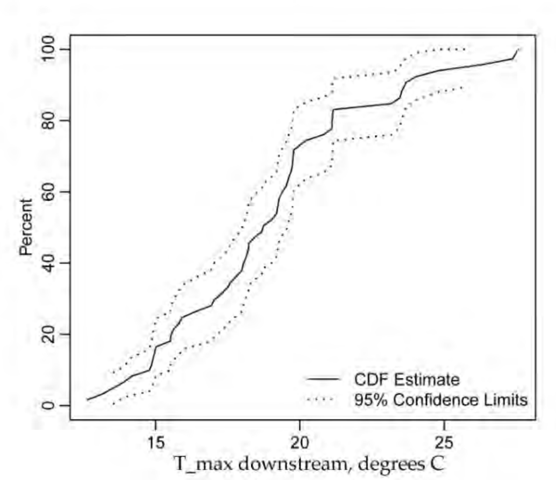


Figure 5. Cumulative distribution function (CDF) and 95% confidence limits for riparian canopy closure measured along Type F/S study reaches at temperature monitoring stations.

a)



b)



c)

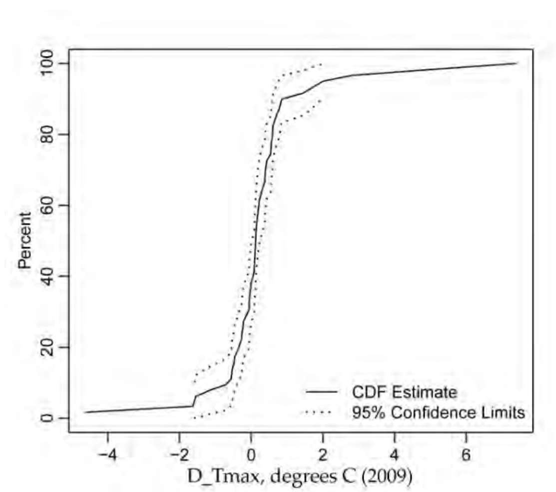


Figure 6. Cumulative distribution function (CDF) and 95% confidence limits for stream temperature metrics from the Type F/S temperature monitoring stations. Panel a) shows maximum summer temperature at the upstream end of the study reaches, panel b) shows maximum summer temperature at the downstream end of the study reaches, and panel c) shows differences (by site) between upstream and downstream maximum summer temperatures.

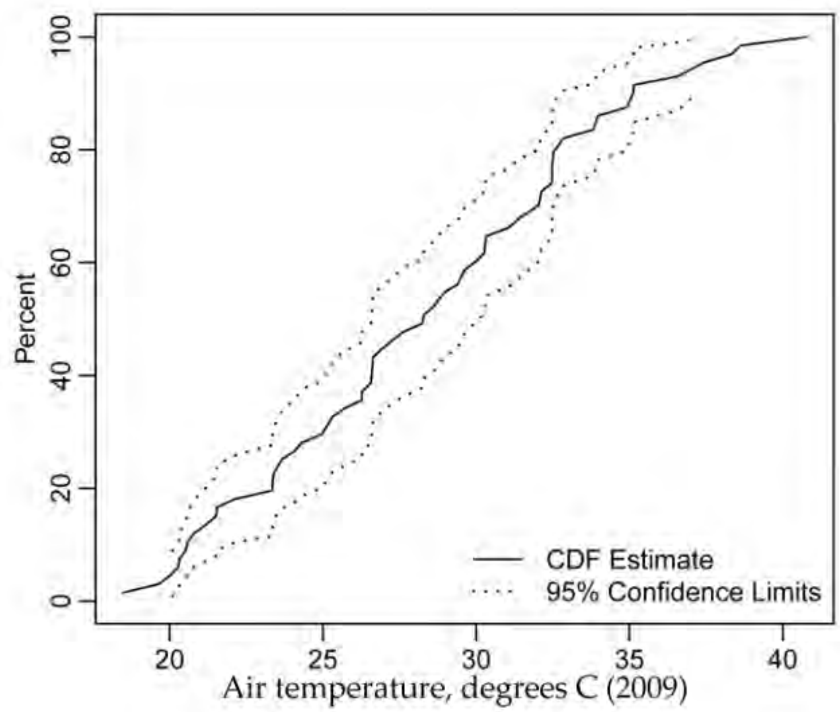


Figure 7. Cumulative distribution function (CDF) and 95% confidence limits for 2009 maximum summer air temperatures from the Type F/S sites (n = 60).

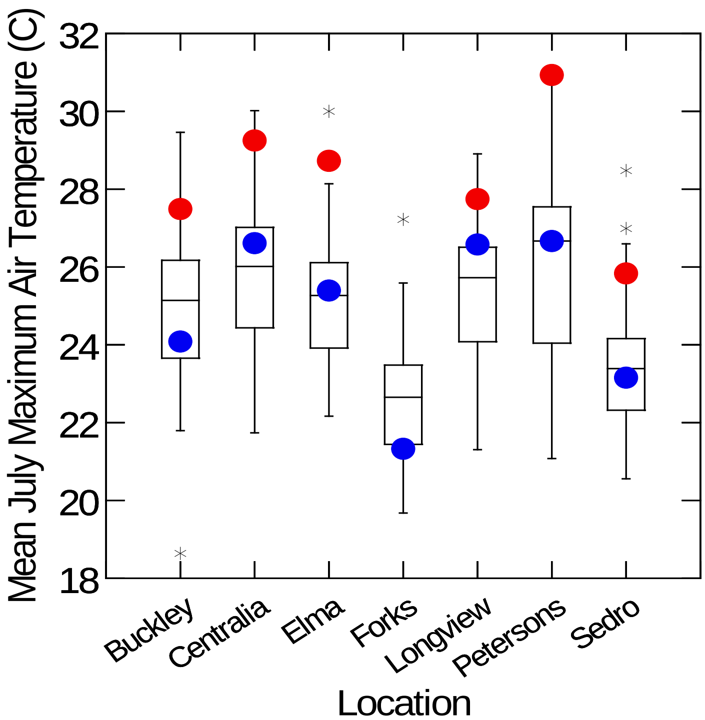


Figure 8. Distribution of mean daily maximum July air temperature values from 1958-2009 for seven locations in western Washington. Dots indicate mean daily maximum air temperatures for July 2008 (blue) and July 2009 (red) for these locations. July 2009 was warmer than July 2008, exceeding the seventy-fifth percentile of the historic record for the six stations with available 2009 data.

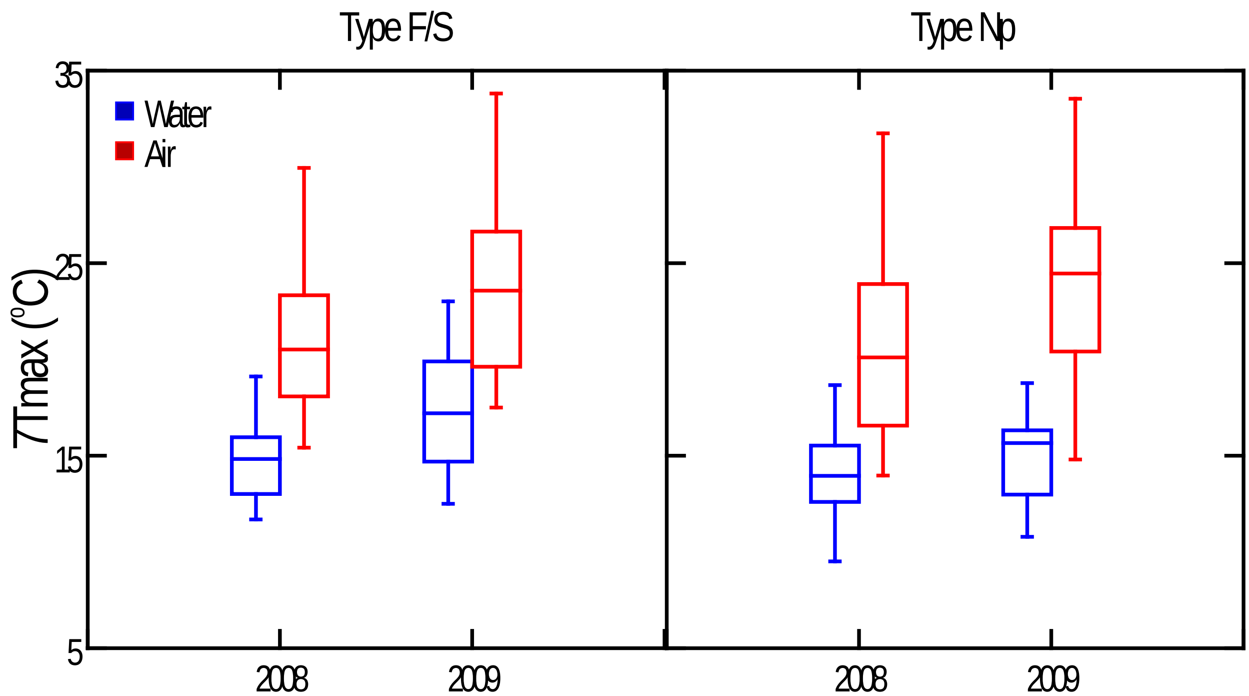


Figure 9. Seven-day average of daily maximum summer stream and air temperatures in Type F/S and Type Np streams sampled in both 2008 and 2009.

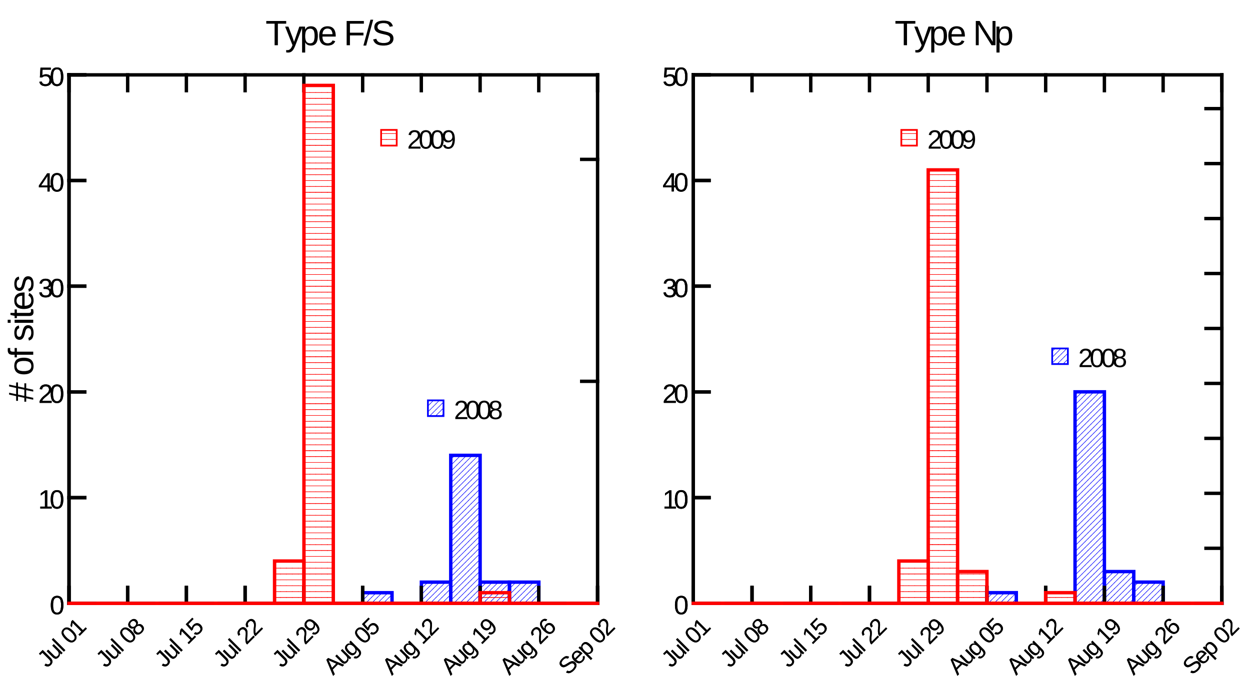


Figure 10. Date of maximum summer stream temperatures in 2008 (blue) and 2009 (red).

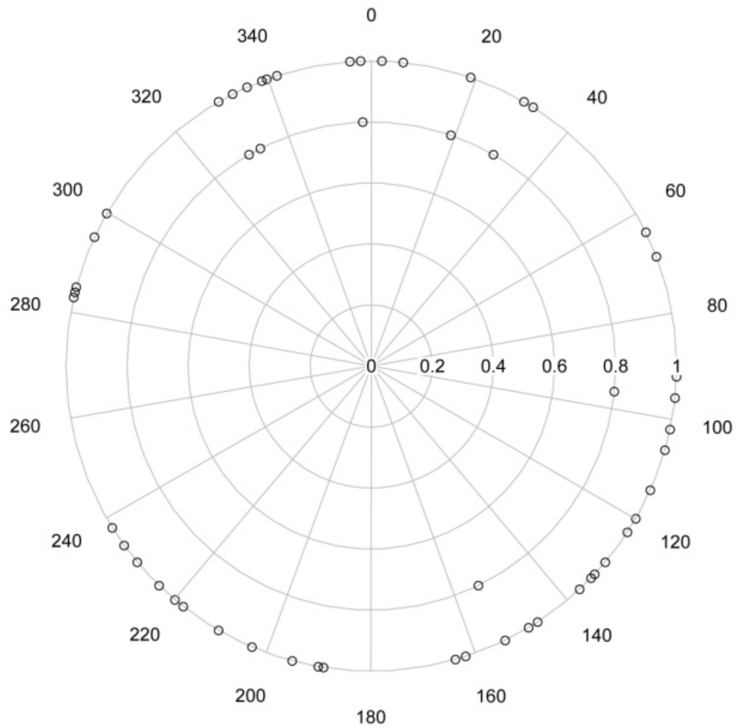


Figure 11. Reach aspect (in degrees) at Type Np temperature monitoring stations. Each unique aspect value is represented by a point plotted at radial distance = 1. Cases in which a given aspect was common to more than one study reach are represented by points plotted at radial distance = 0.8.

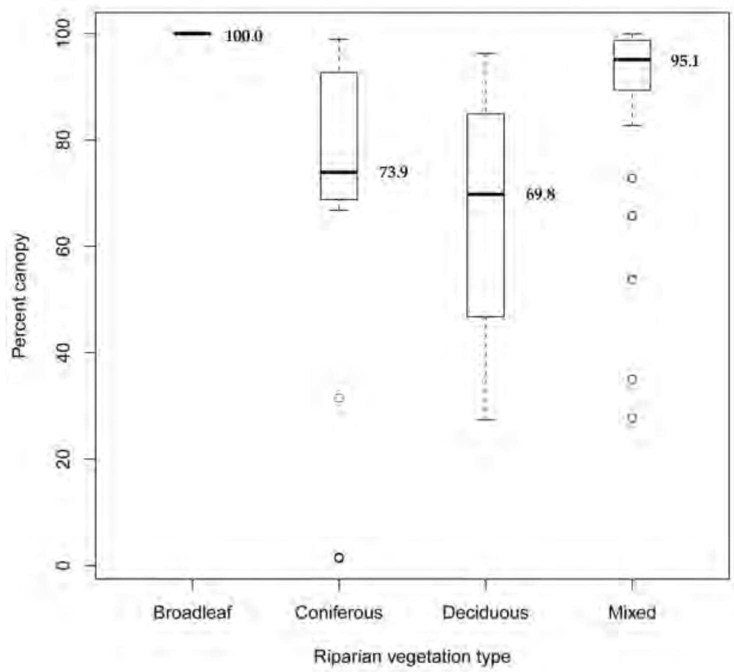


Figure 12. Percent riparian canopy closure by category of riparian vegetation encountered along Type Np study reaches at temperature monitoring stations. Box plots show medians, quartiles, extremes, and outliers. Samples sizes were 1, 15, 4, and 35 for broadleaf, coniferous, deciduous, and mixed vegetation types, respectively.

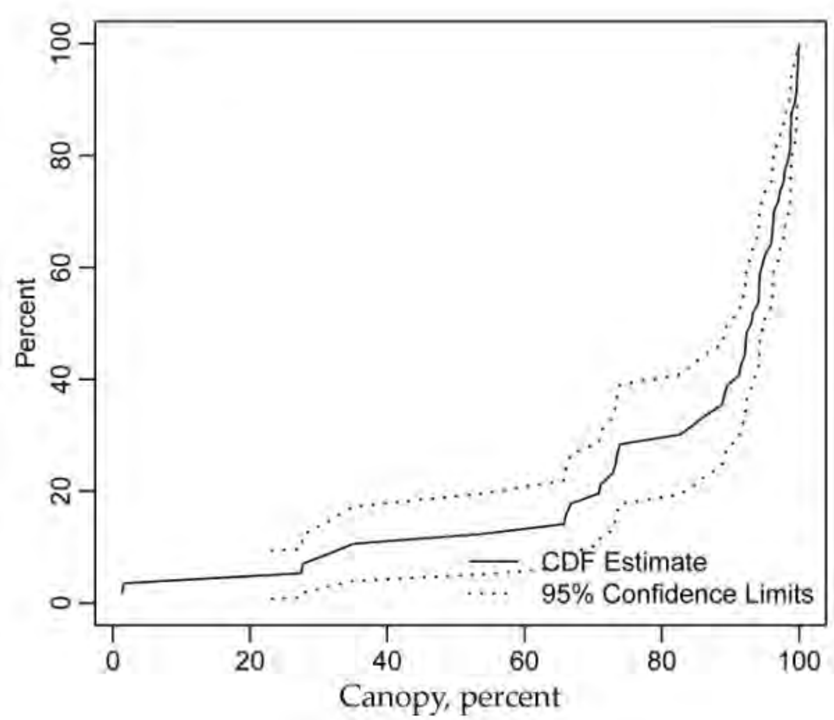
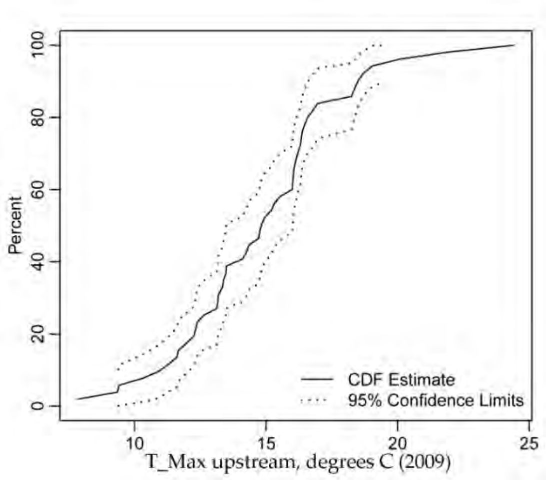
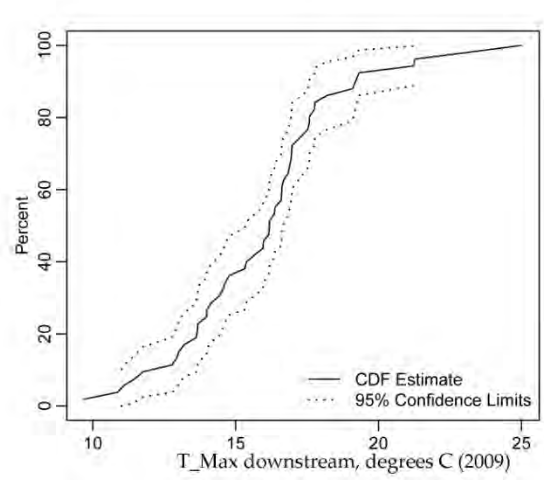


Figure 13. Cumulative distribution function (CDF) and 95% confidence limits for riparian canopy closure measured along Type Np study reaches at temperature monitoring stations.

a)



b)



c)

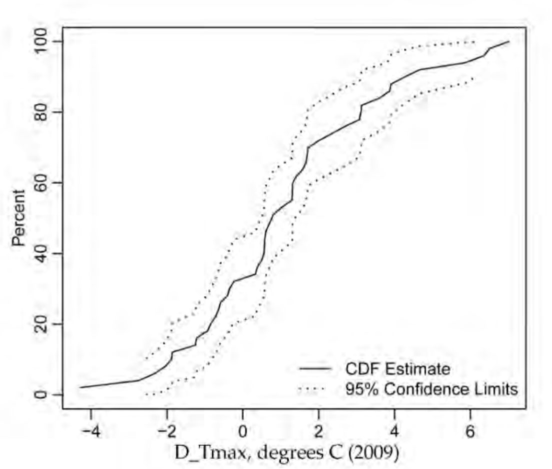


Figure 14. Cumulative distribution function (CDF) and 95% confidence limits for stream temperature metrics from the Type Np temperature monitoring stations. Panel a) shows maximum summer temperature at the upstream end of the study reaches, panel b) shows maximum summer temperature at the downstream end of the study reaches, and panel c) shows differences (by site) between upstream and downstream maximum summer temperatures.

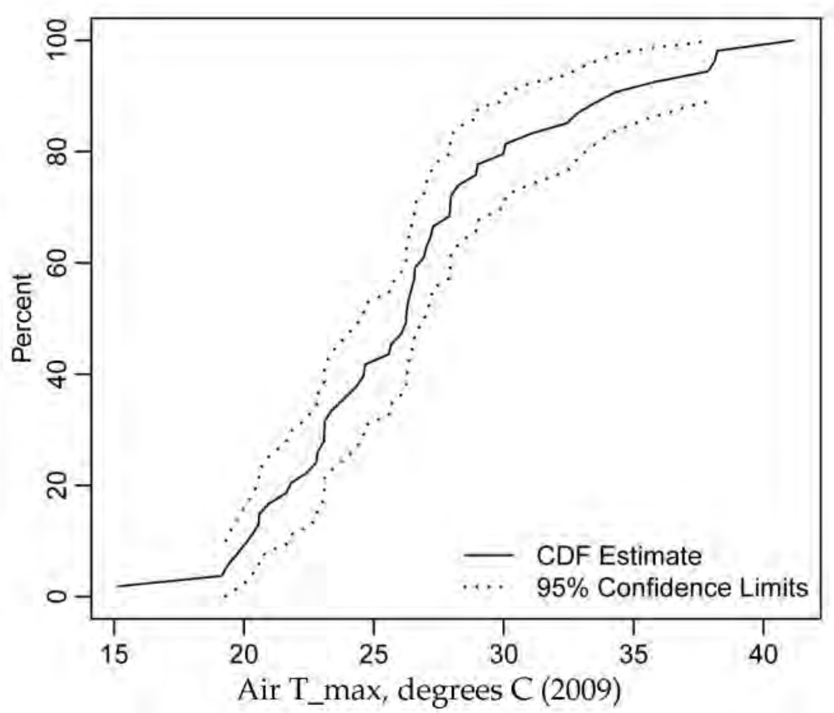


Figure 15. Cumulative distribution function (CDF) and 95% confidence limits for 2009 maximum summer air temperatures from the Type Np sites (n = 51).

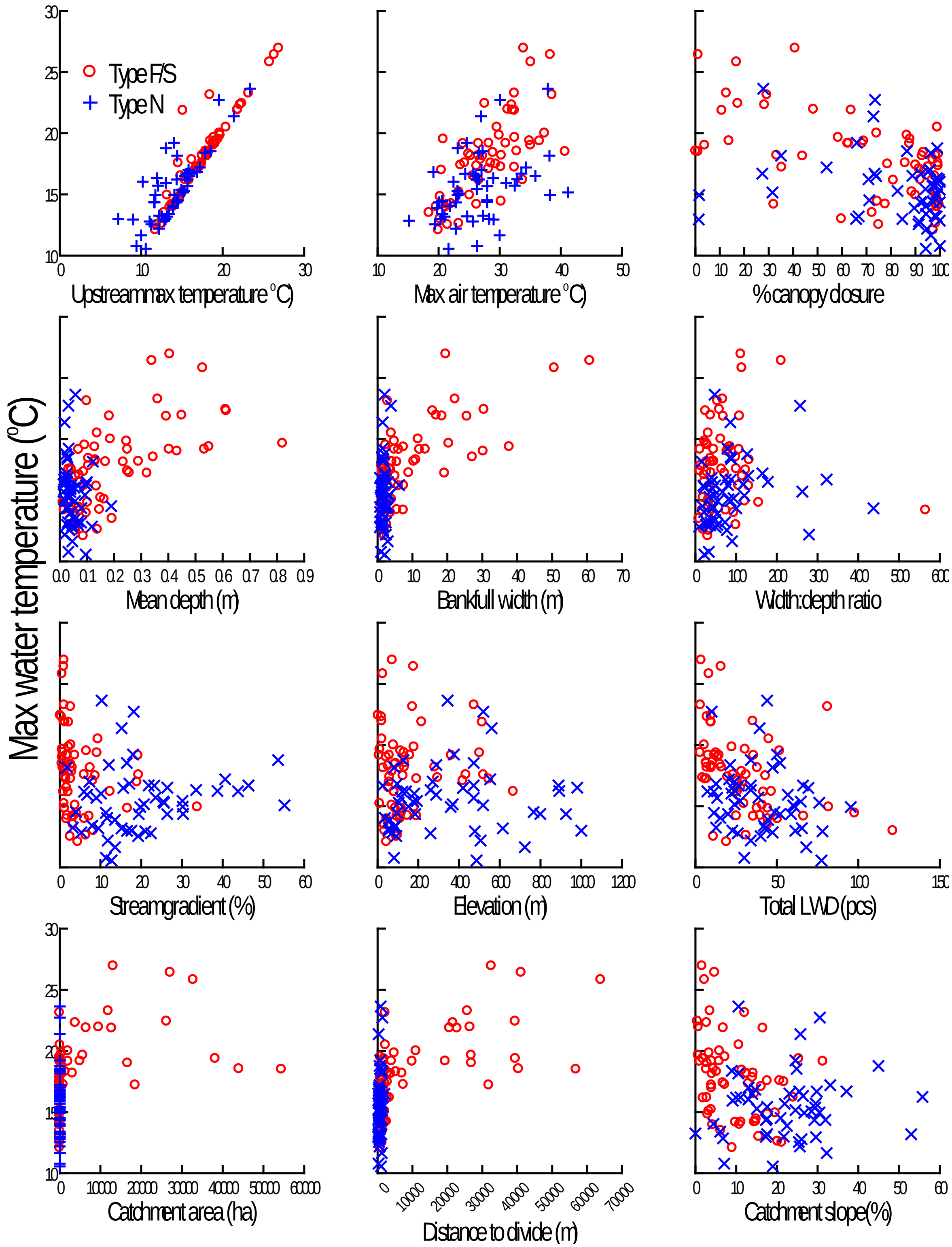


Figure 16. Scatterplots of maximum downstream water temperature versus upstream water temperature, air temperature, and habitat variables for Type F/S and Type Np streams.

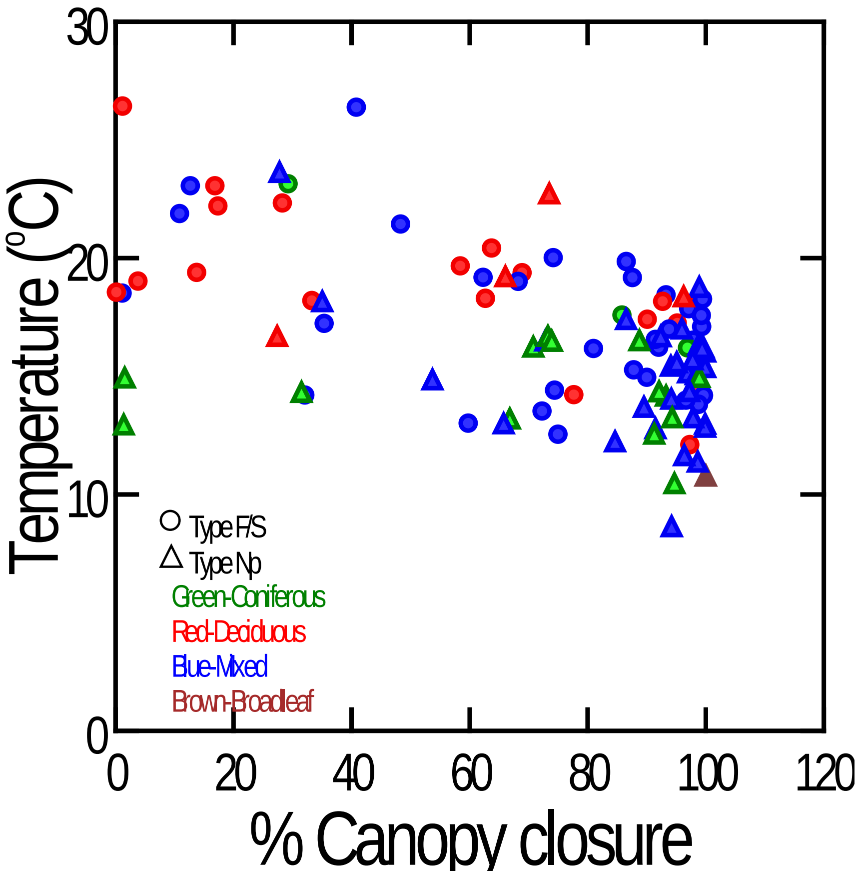


Figure 17. Seven-day average maximum stream temperature versus canopy closure for the 2009 sampling year.

Appendix A. ERST timeline and modules.

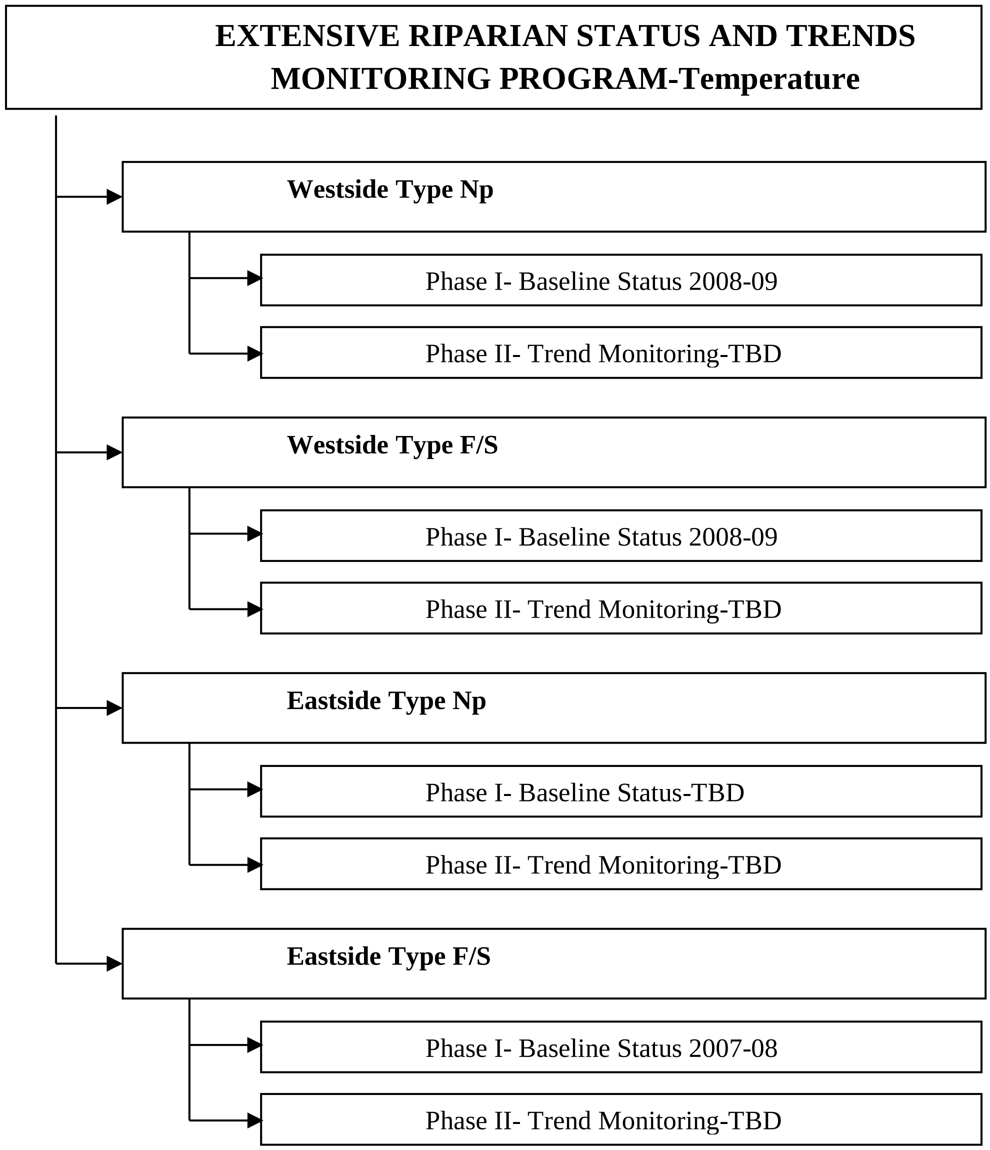


Figure A-1. Project implementation schedule. Data collection for the Westside Type F/S and Type Np Extensive Riparian Status and Trends monitoring program began in spring 2008 and was completed in spring 2010. The Eastside Type Np project is not scheduled at this time. Phase II monitoring implementation has not yet begun. Water types: F = fish-bearing, S = shorelines, Np = non-fish-bearing perennial (from Ehinger *et al.* 2007).

Appendix B. Survey design and sampling frame construction.

The Generalized Random Tessellation Stratified (GRTS) probability sampling design developed by the U.S. Environmental Protection Agency for the Environmental Mapping and Assessment Program (EMAP; see https://archive.epa.gov/emap/archive-emap/web/html/index.html) treats variability as intrinsic to natural resource indicators. Rather than attempt to remove or control for this variability, GRTS reports proportions of the resource, relative to the range of variability observed, as cumulative distribution function (CDFs). This means GRTS is not constrained by a need for experimental controls. Instead, a single application of GRTS describes the resource, as currently known, with associated confidence bands. Trends in resource condition follow from subsequent implementations of GRTS, as change between successive CDFs. As would be anticipated, GRTS easily adjusts to evaluating inter-annual variation through repeated monitoring at fixed sub-sets of sites.

Probability samples have the following distinct features:

- Each member of a target population has an inclusion probability > 0 (Stevens and Jensen 2007).
- Randomization allows statistically valid inferences from samples to populations (Overton *et al.* 1990; Diaz-Ramos *et al.* 1996).
- Inference to population results from design rather than statistical model (e.g., Smith 1976; Hansen *et al.* 1983).
- Apply to any point (i.e., discreet), linear, or areal (i.e., extensive) natural resource at a range of spatial scales (Diaz-Ramos *et al.* 1996).
- Translate population definition into a population frame.
- Estimate status, trend, or change in selected indicator with known confidence (Overton *et al.* 1990; Stevens 1994).
- Estimates are free from selection bias, if implemented as designed (e.g., Stevens and Jensen 2007).
- Theoretical justification for estimates is well-established by the Horvitz-Thompson Theorem (Horvitz and Thompson 1952).
- Very specific regarding what and where to sample and how to analyze the data (i.e., probability structures of sampling and analysis must match (Diaz-Ramos *et al* 1996).

Probability samples, implemented as designed, are representative of target populations, free of sampling bias, and useful for describing status and trends of resources at various spatial scales. These strengths are realized with sequential implementations of GRTS, which, if successful, offers additional advantages:

- Effectively increase sample size and trend detection power.
- More precise estimates than equally-sized simple random sample—i.e., incorporates target population spatial structure (i.e., spatial balancing; Stevens and Jensen 2007).

- Alternative to modeling for scaling stream temperature to landscapes.
- Inform need of states to periodically report status of impaired surface waters (EPA 2010).
- Analyses adaptable from equi-probability to variable probability after sampling is complete. Loss of a sampling site, common to natural resource studies, may thus be overcome[8].
- Spatial density pattern of sample matched to that of the resource (i.e., reverse hierarchical ordering; Stevens and Olsen 2001).

Conversely, there are tradeoffs. Population frame and sampling frame (**Figure B-1**) definitions must be sufficiently rigorous to minimize bias or contamination of estimates. That is, inclusion probabilities for undetected elements of a target population are zero. Also, sampling effort rises geometrically with increasing study complexity—a consideration even without stratification as random selection from the target population does not guarantee normal distributions of other associated variables. And, notably, what resulting data such as stream temperature represent must be considered, as do sample size and evaluation methods for sufficient precision and confidence in the resource estimate to match study objectives. Lastly, data must be analyzed with R[9].

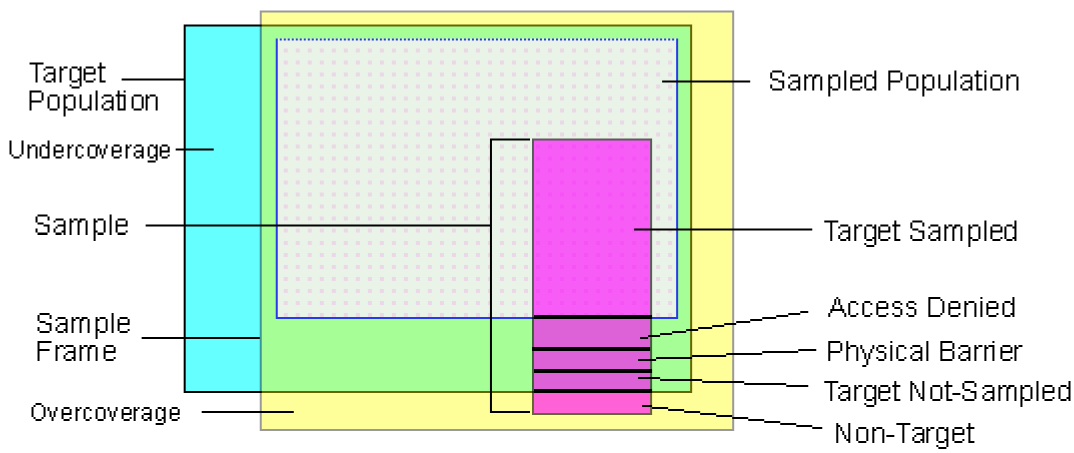


Figure B-1. Generalized GRTS sampling frame construction showing relationship of the target population to frame and sampling imperfections[10].

[8]Non-target sites in a GRTS sample can be replaced by evaluating the next site in the sequence (assuming a sufficient oversample) until base sample size is achieved. Random spatial dispersion is thus maintained. However site replacement must be sufficiently described to a) correctly adjust survey design weights, b) account for any resulting selection stratification, and c) account for any resulting unequal probability of selection. Inaccuracies will affect computation of estimates of characteristics for target populations.

[9] www.r-project.org

[10] http://www.epa.gov/nheerl/arm/designpages/monitdesign/targetpopframe.htm

GRTS assumptions[11] include:

- Estimates from sampled sites apply to sampled population with no additional assumptions.
- Estimates from sampled population apply to remainder of target population within sample frame only if candidate sites are skipped independent of site characteristics (missing completely at random).
- Remainder of target population outside sample frame of same characteristics as sampled population.

Under these conditions, initial design weights need no adjustment unless base sample size and design sample size differ.

References

Diaz-Ramos, S., D.L. Stevens, Jr., and A.R. Olsen. 1996. *EMAP Statistical Methods Manual*. EPA/620/R-96/002. US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Corvallis, OR.

Hansen, M.H., W.G. Madow, and B.J. Tepping. 1983. An evaluation of model-dependent and probability sampling inferences in sample surveys. *Journal of the American Statistical Association* 78:776-760.

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Stevens, D.L., Jr. and A.R. Olsen. 2001. Spatially-balanced sampling of natural resources in the presence of frame imperfections. Joint Statistical Meetings, Atlanta, GA, USA.

[11] Aquatic Resources Monitoring, U.S. EPA, accessed 09 August 2011 http://www.epa.gov/nheerl/arm/analysispages/analysisadjwts.htm

Stevens, D.L., Jr. and S.F. Jensen. 2007. Sample design, execution, and analysis for wetland assessment. *Wetlands* 27:515-523.

Appendix C. ERST archive content.

Location: Washington Dept. of Ecology, Olympia, WA

Recipient: Environmental Assessment Program

Retention: compliance with agency policies

Archive content. =Includes available meta-data.

Category	Description	Format	Author
GRTS sample draw			
	design	.pdf	EPA
	WA hydrography, 24k	.shp	DNR
	statewide master sample	.shp	EPA
Evaluated sample			
	CMER/ FFR lands, West	.shp	mixed
	WA east-west divide	.shp	DNR
	Site list	spreadsheet	mixed
	Site evaluation orthos	.pdf	mixed
	Site validation forms	spreadsheet	mixed
	Type F/S (n = 120) and Type Np (n =228)	.shp	ECY
	Scanned data sheets, per site	.pdf	ECY
Analysis and Results			
	all raw data, temperature, 2008-2009	.mdb	ECY
	all raw data, other variables, 2008-2009	.mdb	ECY
	metric calculations	spreadsheet	ECY
	results summary	.csv, .pdf	ECY
Misc			
	method development	varies	mixed

Appendix D. Catchment characteristics and habitat variables.

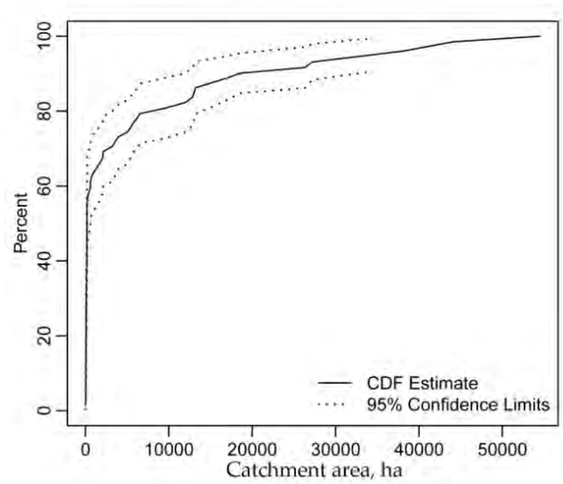
Table D-1. Estimated 25%, 50%, 75%, and 95% cumulative distribution function (CDF) values for Type F/S catchment-scale characteristics and habitat variables as calculated using the R package *spsurvey*, where *n* = number of cases associated with a given percentile of the CDF. Means (se) are also reported.

Variable	n	Mean (se)	Minimum	25%-tile	Median	75%-tile	95%-tile	Maximum
Catchment area, ha	61	5970	9.5	67	193	5212	34279	54491
Elevation, m	61	149.5	5	49	94	178	511	668
Catchment slope, %	61	9.3	0.6	3.4	6.9	14.3	21.6	31.4
Canopy closure, %	61	68	1.3	39	78	97	99	99.1
Bankfull width, m	60	10.5	1.2	2.4	4.9	15.4	30.5	60.9
Gradient, %	61	4.6	0.2	1.2	2.3	5.8	18.2	33.9
Thalweg depth, m	60	0.4	0.0	0.2	0.3	0.6	1.0	1.5
Wetted width, m	60	7.5	0.2	1.6	3.0	9.1	25.6	44.4
Mean depth, m	60	0.2	0.0	0.1	0.1	0.3	0.6	0.8
Embeddedness, %	60	45.5	2.2	32.6	40.2	57.5	83.5	96.9
Particle size, mm, geometric mean	60	22.3	0.2	1.7	6.4	30.9	83.7	100.3
Distance to divide, m	61	11493	513	1458	2622	20910	40266	63975
LWD, down	61	20.3	1.6	7.3	15.4	29.4	46.6	76.7
LWD, suspended	61	7.0	0.0	0.8	2.5	8.0	18.4	75.3
LWD, jam	61	0.5	0.0	0	0	0.5	2.4	4.7
LWD, total	61	27.4	3.2	9.5	21.6	38.2	76.0	121.3

Table D-2. Estimated mean, 25%, 50%, 75%, and 95% cumulative distribution function (CDF) values for Type Np catchment-scale characteristics and habitat variables as calculated using the R package *spsurvey*.

Variable	n	Mean	Minimum	25%-tile	Median	75%-tile	95%-tile	Maximum
Catchment area, ha	54	20.0	1.3	4.5	10.9	26.3	60.4	83.1
Elevation, m	54	335	26.0	95.7	258.4	484.4	897.3	1000
Catchment slope, %	54	21.9	0.0	13.1	22.4	22.9	38.3	55.7
Canopy closure, %	54	82	1.4	73	93	98	99.8	99.9
Bankfull width, m	54	1.9	0.7	1.2	1.6	2.2	3.5	6.2
Gradient, %	54	19.6	1.8	11.3	17.1	25.1	44.2	55.2
Thalweg depth, m	54	0.1	0.03	0.04	0.07	0.10	0.18	0.25
Wetted width, m	54	1.1	0.4	0.7	0.9	1.3	2.7	2.9
Mean depth, m	54	0.05	0.00	0.02	0.03	0.05	0.10	0.19
Embeddedness, %	54	48.3	6.0	32.8	46.5	62.5	88.8	98.9
Particle size, mm, geometric mean	54	30.3	0.2	1.0	5.7	12.4	83.9	656.7
Distance to divide, m	54	719	156.2	384.2	614.2	936.6	1477.1	1976.1
LWD, down	54	25.5	4.0	14.7	20.4	32.5	58.4	68.0
LWD, suspended	54	13.1	0.0	3.7	7.0	19.4	37.4	67.3
LWD, jam	54	0.4	0.0	0	0	0.2	1.4	6.7
LWD, total	54	38.6	7.3	21.9	32.7	51.9	76.2	95.3

a)



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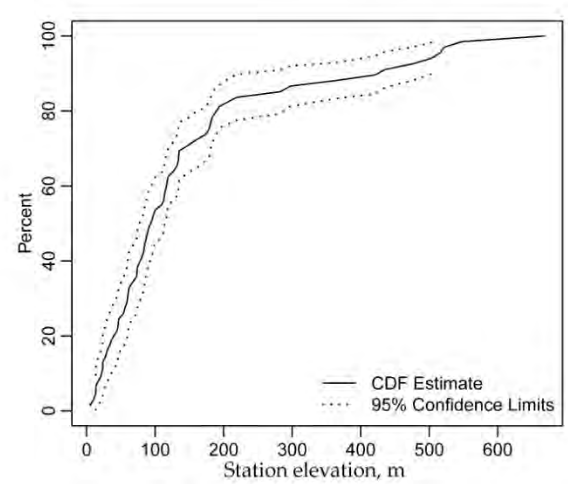


c)

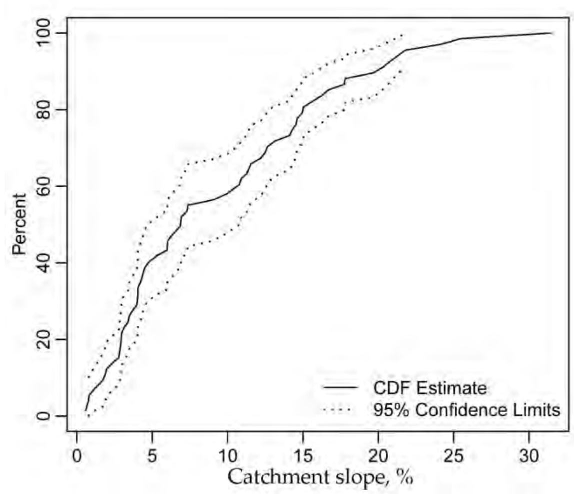
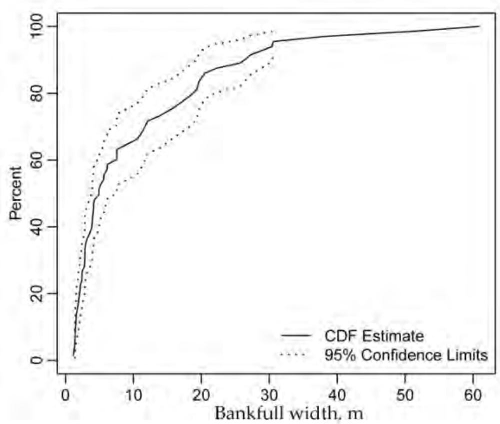


Figure D-1. Cumulative distribution function (CDF) and 95% confidence limits for Type F/S GIS-derived variables. Data are: a) planographic catchment area above monitoring station locations, b) elevation estimated from coordinates of the monitoring station using a 30 m DEM, and c) mean slope of catchment area upstream of monitoring station locations.

a)



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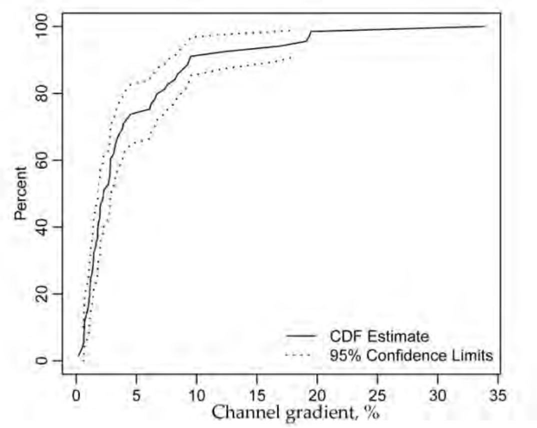

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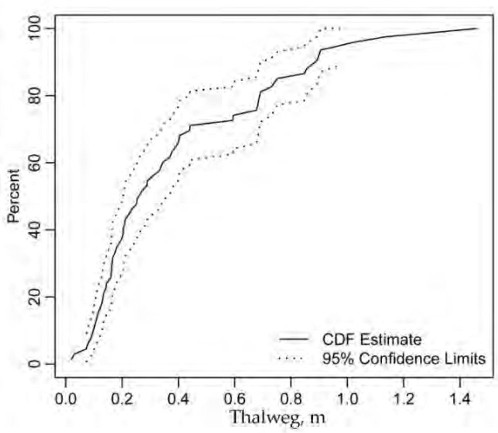


d)

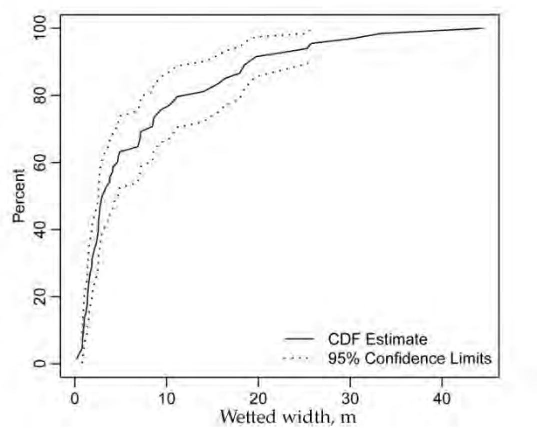
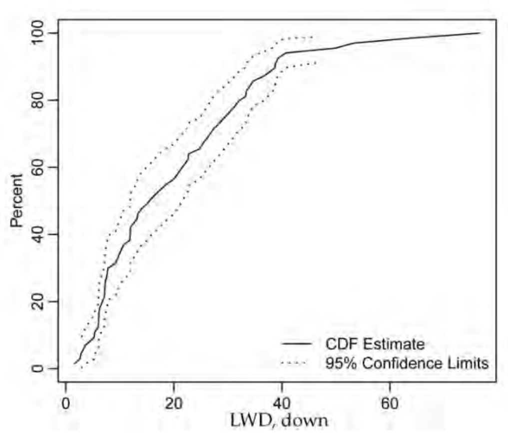
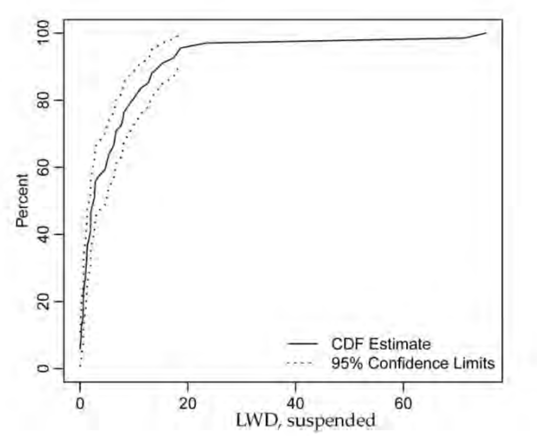


Figure D-2. Cumulative distribution function (CDF) and 95% confidence limits for Type F/S habitat variables. Data are: a) mean bankfull width, b) mean channel gradient, c) mean thalweg depth, and d) wetted width.

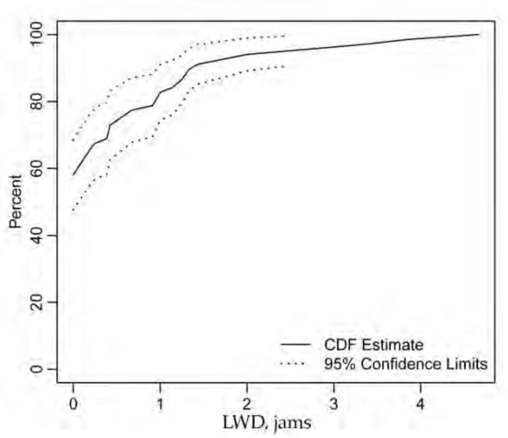
e)



f)



g)



h)

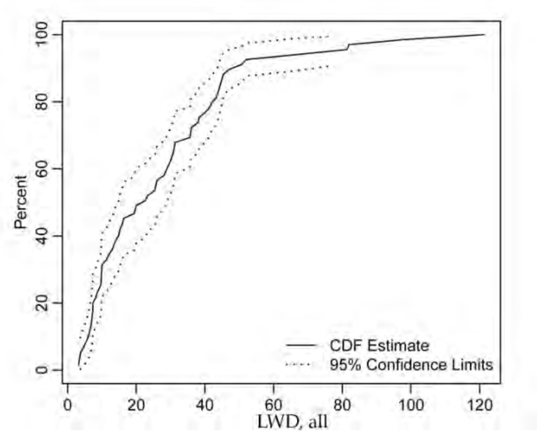
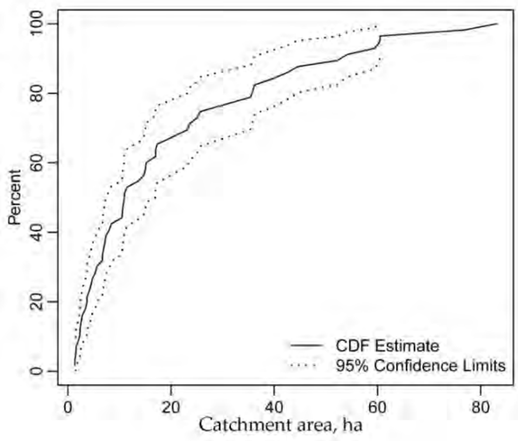


Figure D-2 (continued). Cumulative distribution function (CDF) and 95% confidence limits for Type F/S habitat variables. Data are: e) mean count of down, in-channel large woody debris (LWD), f) mean count of LWD suspended over the channel, g) mean count of LWD jams, and h) mean count of all categories of in-channel LWD inventoried.

a)



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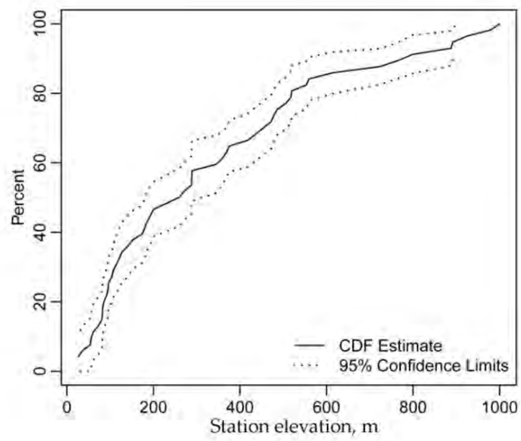


c)

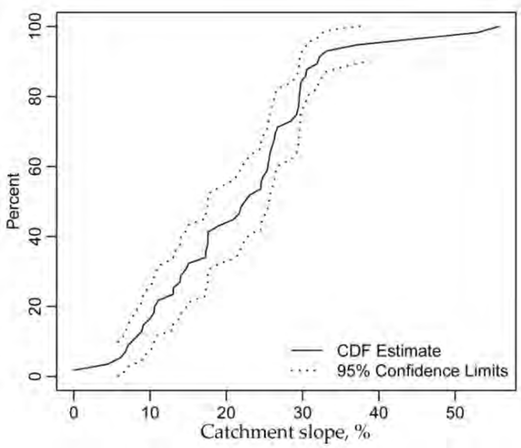
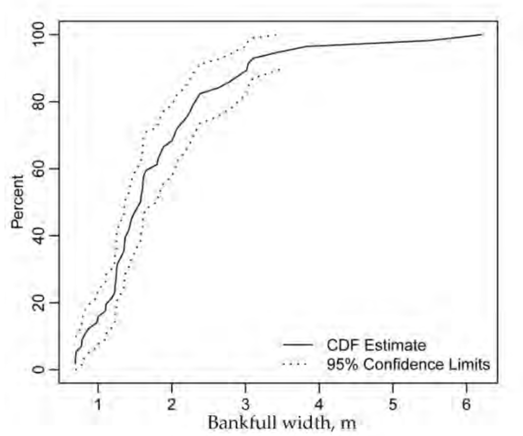


Figure D-3. Cumulative distribution function (CDF) and 95% confidence limits for Type Np GIS-derived variables. Data are: a) planographic catchment area above monitoring station locations, b) elevation estimated from coordinates of the monitoring station using a 30 m DEM, and c) mean slope of catchment area upstream of monitoring station locations.

a)



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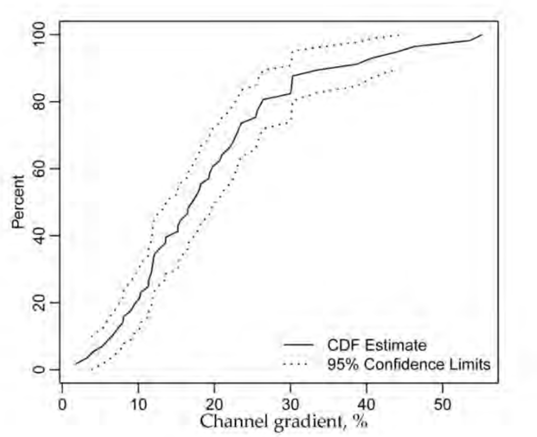

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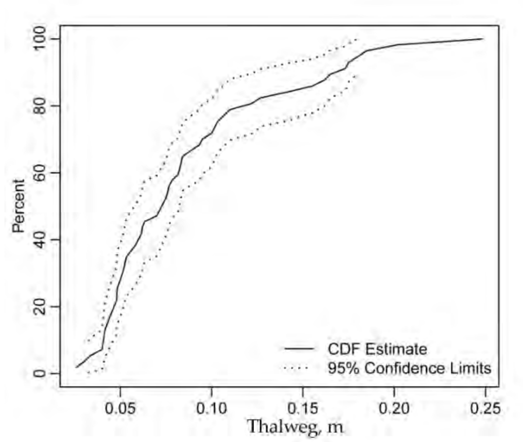


d)

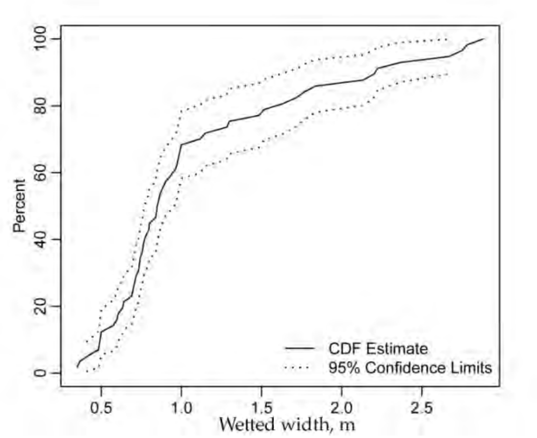
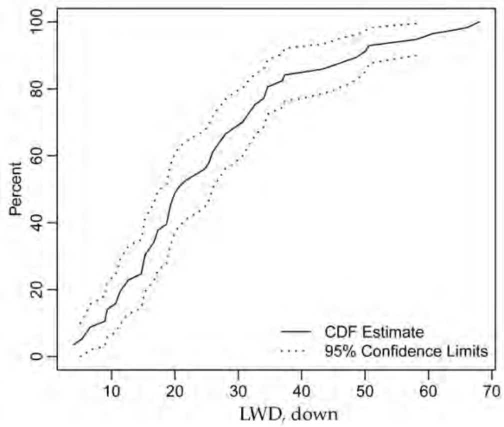
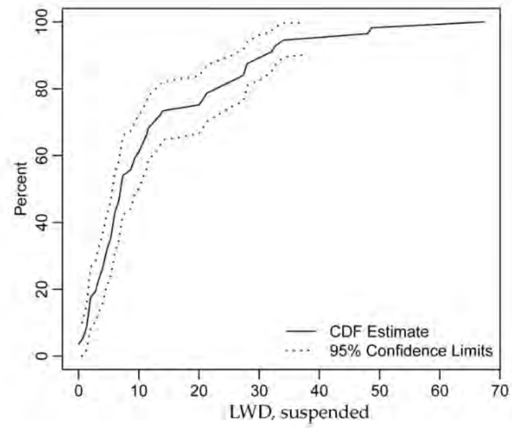


Figure D-4. Cumulative distribution function (CDF) and 95% confidence limits for Type Np habitat variables. Data are: a) mean bankfull width, b) mean channel gradient, c) mean thalweg depth, and d) wetted width.

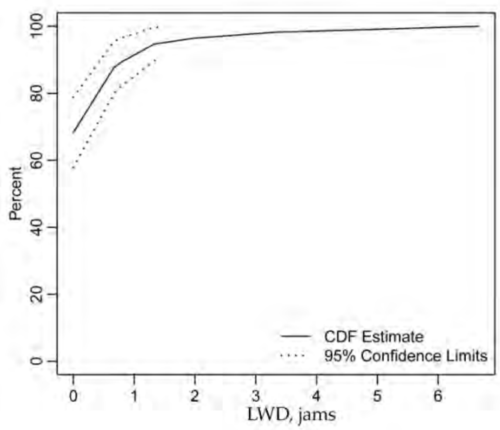
e)



f)



g)



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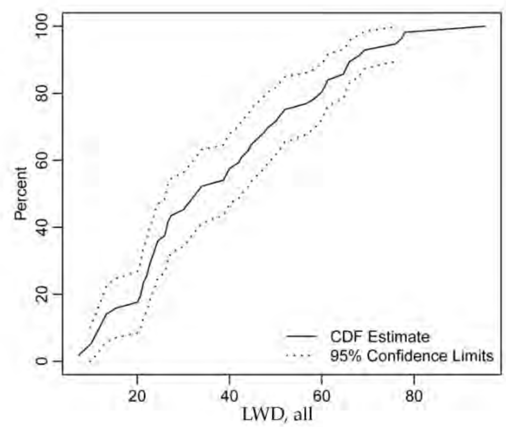

Figure D-4 (continued). Cumulative distribution function (CDF) and 95% confidence limits for Type Np habitat variables. Data are: e) mean count of down, in-channel large woody debris (LWD), f) mean count of LWD suspended over the channel, g) mean count of LWD jams, and h) mean count of all categories of in-channel LWD inventoried.

Appendix E. Inventory of temperature data gaps and data summaries.

Table E-1. Site-level catchment, canopy, and channel descriptions, collected 2008 and 2009, for Type F/S sites.

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
22	98.2	1590.0	15.0	150	4.2	119	182	74.6	Mixed
78	171.3	2844.0	2.0	150	2.2	83	203	81.2	Mixed
98	205.3	2098.4	24.1	260	12.5	668	88	92.2	Mixed
101	122.5	2902.6	12.6	150	3.2	134	198	98.5	Deciduous
111	32844.6	63975.0	2.3	500	0.7	28	260	17.0	Deciduous
118	197.3	2435.5	11.5	150	2.8	87	204	93.4	Mixed
172	3220.0	7106.3	14.3	400	1.5	283	105	33.4	Deciduous
237	63.6	1279.7	4.0	150	1.2	13	341	88.7	Coniferous
270	16764.7	27012.2	3.0	500	0.7	45	228	4.0	Deciduous
286	30.4	1119.9	3.1	150	1.3	89	70	98.8	Mixed
315	54491.7	56932.5	2.8	768	0.6	91	290	1.3	Mixed
334	18620.7	31987.9	4.0	500	1.7	548	272	35.5	Mixed
346	29.0	659.1	15.6	150	8.4	37	44	59.9	Mixed
377	3912.0	21694.4	2.9	475	0.5	21	220	28.4	Deciduous
409	319.2	3738.1	12.5	175	7.6	110	84	92.9	Deciduous
429	22.0	601.2	17.8	150	16.8	119	100	98.7	Deciduous
489	52.5	1299.1	16.2	150	8.2	421	328	91.7	Mixed
577	226.1	1972.7	25.4	270	9.3	503	294	69.1	Deciduous
605	992.7	7493.6	7.3	350	2.8	194	149	95.4	Deciduous
650	63.2	1583.6	6.3	150	3.4	34	324	72.4	Mixed
699	5075.1	19495.0	6.0	500	3.8	160	154	62.5	Mixed
718	9.5	513.3	9.9	145	3.3	97	194	99.8	Mixed

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
762	6576.4	20717.5	6.9	475	1.4	219	336	63.9	Deciduous
774	589.3	4899.2	3.5	150	2.3	181	194	86.7	Mixed
793	90.8	1437.7	21.3	150	2.7	95	251	75.1	Mixed
809	158.3	2374.0	10.8	150	9.5	24	134	99.1	Mixed
846	2108.4	10031.4	1.1	400	1.8	10	290	87.8	Mixed
884	209.0	2219.7	14.6	260	3.6	194	316	77.8	Deciduous
905	2092.1	11119.3	6.0	400	2.9	80	160	74.4	Mixed
950	670.8	3936.4	4.2	150	0.9	30	192	44.1	Mixed
969	49.5	911.0	7.4	150	6.7	116	184	88.0	Mixed
976	108.9	1770.4	31.4	150	19.3	364	265	68.4	Mixed
982	44.5	814.4	14.6	150	1.8	56	220	98.0	Mixed
1014	550.3	4097.6	4.1	150	2.0	60	248	62.8	Deciduous
1034	12855.0	22889.4	16.7	500	2.3	516	286	11.0	Mixed
1199	26315.6	39517.2	0.6	500	0.2	5	180	17.5	Deciduous
1217	38272.5	39579.1	1.9	500	0.9	132	150	13.9	Deciduous
1252	75.2	1037.3	10.9	150	6.2	113	225	99.0	Mixed
1261	202.8	2681.5	15.0	220	2.0	148	276	98.3	Mixed
1278	32.5	1461.1	11.3	150	7.3	114	109	32.2	Mixed
1284	9663.5	26567.7	0.8	500	1.1	23	234	48.5	Mixed
1324	123.6	2940.4	21.8	150	8.8	127	165	78.8	Deciduous
1366	145.8	2156.3	6.9	150	1.4	62	90	90.3	Deciduous
1513	12020.7	25841.2	3.7	500	1.2	476	224	12.8	Mixed
1530	5770.6	26945.1	0.8	500	0.7	14	218	58.6	Deciduous
1610	35.9	867.2	9.1	150	4.5	46	108	97.5	Deciduous
1633	13206.2	32679.5	1.7	500	1.2	74	150	41.0	Mixed
1658	159.1	2177.5	3.4	150	3.9	73	113	98.2	Deciduous

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
1686	58.0	850.3	14.1	150	3.1	73	85	97.3	Mixed
1716	136.9	3528.4	2.9	150	1.0	84	171	97.1	Coniferous
1717	66.4	1495.9	13.1	150	1.6	297	285	99.5	Mixed
1738	27.3	541.8	20.3	150	6.5	100	244	98.5	Deciduous
1791	44077.5	40463.4	4.5	500	2.0	135	20	0.3	Deciduous
1816	1468.5	5389.2	5.3	400	1.9	54	347	99.7	Mixed
1833	169.0	1429.1	20.8	150	6.1	436	98	86.0	Coniferous
1856	67.4	1153.3	19.7	150	33.9	183	63	90.2	Mixed
1870	140.7	1753.9	4.3	150	1.8	47	125	96.8	Mixed
1873	38.1	1442.9	17.7	150	19.5	522	165	99.4	Mixed
1894	113.4	1876.0	4.1	150	19.1	59	250	94.0	Mixed
1923	63.4	2297.6	12.2	150	2.8	174	173	29.4	Coniferous
1929	27205.6	41236.4	4.8	500	1.1	179	348	1.3	Deciduous

Table E-2. Site-level catchment, canopy, and channel descriptions, collected 2008 and 2009, for Type Np sites.

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
70	11.0	647.3	25.5	150	21.8	472	295	27.4	Deciduous
197	3.7	435.3	26.4	150	33.5	260	92	98.8	Mixed
263	39.6	1507.9	11.1	150	43.8	140	147	99.6	Mixed
310	10.9	889.8	20.9	130	4.0	766	283	71.1	Coniferous
319	10.5	583.3	44.9	150	53.6	127	284	98.9	Mixed
324	2.4	300.3	26.3	150	30.0	200	123	89.1	Mixed
389	17.0	994.9	19.0	150	12.7	486	358	94.2	Mixed
452	17.0	891.7	14.0	150	8.1	107	154	93.1	Mixed
482	7.0	514.1	29.6	150	21.0	478	96	1.4	Coniferous
506	2.8	250.0	17.6	150	9.5	56	114	66.8	Coniferous
553	1.6	224.0	24.6	150	20.7	369	120	31.5	Coniferous
625	36.2	1209.9	21.9	150	9.0	472	134	97.0	Mixed
629	7.3	361.8	9.1	150	6.7	288	130	98.8	Mixed
641	35.4	1219.9	8.9	150	12.1	289	342	96.3	Deciduous
653	15.1	817.7	28.5	150	55.2	518	336	98.3	Mixed
669	17.3	670.0	29.4	150	25.4	174	32	99.9	Mixed
697	5.0	228.8	30.2	150	20.7	56	69	92.2	Mixed
698	35.8	1207.4	10.5	150	1.8	82	220	35.0	Mixed
701	6.7	522.4	26.0	150	22.4	260	356	91.5	Mixed
715	59.5	1471.2	55.7	250	38.7	892	189	70.8	Coniferous
756	4.7	231.0	17.3	150	19.4	185	218	99.9	Mixed
770	8.4	521.1	13.0	150	10.1	180	300	99.9	Mixed
886	2.1	156.2	17.3	150	16.5	54	340	84.6	Mixed
933	25.7	906.7	10.6	150	10.3	344	154	27.8	Mixed

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
942	8.0	605.0	6.8	150	5.3	73	234	99.9	Mixed
956	25.1	737.7	24.5	150	18.0	375	210	66.1	Deciduous
1037	15.2	701.9	10.0	150	6.0	121	133	99.4	Mixed
1062	1.4	216.7	23.1	150	26.4	980	2	88.8	Coniferous
1074	1.3	530.2	15.1	150	25.6	104	6	82.7	Mixed
1082	4.1	296.8	7.1	150	11.3	81	106	100.0	Broadleaf
1094	76.9	1074.9	52.9	150	15.2	615	230	98.7	Mixed
1113	42.4	1515.9	17.6	150	30.1	193	19	94.1	Mixed
1125	4.5	302.7	25.8	150	15.2	560	203	72.8	Mixed
1180	11.5	636.2	37.1	150	46.3	888	164	73.3	Coniferous
1192	10.6	596.8	25.6	150	11.8	506	333	94.7	Coniferous
1193	44.5	724.9	24.8	150	16.5	472	30	86.5	Mixed
1255	6.7	341.8	30.4	150	30.2	152	30	98.9	Coniferous
1323	23.1	953.6	29.8	150	23.2	26	96	92.4	Mixed
1341	7.2	540.7	33.1	150	40.6	553	339	53.7	Mixed
1374	23.6	700.2	21.7	150	17.6	1000	102	65.8	Mixed
1459	2.3	395.0	14.7	150	17.1	96	224	95.1	Mixed
1493	60.4	1217.1	32.2	150	13.6	723	162	96.4	Mixed
1535	2.6	296.2	17.6	150	11.3	95	285	93.3	Coniferous
1538	13.7	527.5	26.7	150	19.8	359	330	1.6	Coniferous
1565	3.7	396.0	29.5	150	23.6	114	238	97.8	Mixed
1582	83.1	1268.7	31.9	150	30.3	799	333	97.2	Mixed
1597	60.5	1369.0	30.5	150	18.2	519	149	73.5	Deciduous
1641	5.3	413.9	25.4	150	19.3	92	195	91.3	Coniferous
1653	54.2	1976.1	14.0	150	15.6	419	19	73.9	Coniferous
1781	3.4	383.0	13.1	150	7.3	271	330	96.0	Mixed

Site ID Number	Catchment Area (ha)	Catchment DTD (m)	Average Catchment Slope (%)	Reach Length (m)	Reach Gradient (%)	Site Elevation (m)	Site Aspect (degrees)	Canopy Cover (%)	Dominant Vegetation Type
1786	14.8	838.8	29.2	150	26.4	925	330	92.1	Coniferous
1817	10.7	360.6	4.4	150	11.6	36	190	94.2	Mixed
1859	52.2	677.1	0.0	150	3.2	83	358	97.9	Mixed
1862	5.6	329.0	6.1	150	8.0	86	64	94.3	Coniferous
1926	1.6	400.6	22.5	150	13.6	61	137	89.5	Mixed

Table E-3. Site-level temperature metrics for data collected July and August 2009, for Type F/S sites.

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
22	2009	30.3	23.0	15.6	14.4	15.5	14.4	-0.1	0.0
78	2009	26.6	23.8	17.1	15.9	17.3	16.1	0.2	0.2
98	2009	26.6	25.8	15.7	15.4	16.4	16.2	0.7	0.8
101	2009	26.6	24.8	19.1	18.1	18.7	18.0	-0.4	-0.2
111	2009	35.2	29.9	27.9	25.8	26.3	23.0	-1.6	-2.8
118	2009	29.0	25.6	19.5	18.3	19.6	18.4	0.1	0.1
172	2009	30.3	28.6	17.9	17.5	18.4	18.2	0.6	0.6
237	2009	23.4	19.6	15.8	15.2	*	*	*	*
270	2009	35.1	30.4	19.7	18.9	19.8	19.0	0.1	0.1
286	2009	*	*	15.8	14.8	15.9	14.5	0.1	-0.3
315	2009	40.8	31.5	19.0	18.2	19.3	18.5	0.3	0.3
334	2009	32.5	30.3	17.2	16.8	17.6	17.2	0.4	0.4
346	2009	20.3	17.5	13.4	12.7	13.5	13.0	0.1	0.3
377	2009	32.0	26.3	23.6	22.2	23.7	22.3	0.1	0.1
409	2009	25.3	23.1	19.2	18.1	19.4	18.1	0.2	0.1
429	2009	20.3	19.0	15.0	14.8	14.8	14.4	-0.3	-0.4
489	2009	28.2	26.2	17.7	17.1	17.0	16.5	-0.7	-0.5
577	2009	36.6	34.5	19.6	19.1	19.5	19.3	-0.1	0.2
605	2009	30.3	26.9	18.0	17.2	18.0	17.2	0.0	0.0
650	2009	18.5	16.6	13.3	12.9	13.9	13.5	0.6	0.6
699	2009	31.1	28.7	19.4	18.8	19.7	19.1	0.3	0.3
718	2009	21.5	19.1	14.6	13.8	15.0	14.1	0.4	0.3
762	2009	32.1	29.0	22.7	21.9	21.1	20.4	-1.6	-1.5
774	2009	30.0	26.6	21.0	19.8	21.1	19.8	0.1	0.1

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
793	2009	21.5	17.9	12.6	11.9	13.2	12.5	0.6	0.6
809	2009	29.6	27.2	22.2	20.5	*	*	*	*
846	2009	26.6	22.3	20.3	19.0	20.8	19.1	0.5	0.2
884	2009	20.6	18.5	*	*	14.9	14.2	*	*
905	2009	37.4	33.8	19.8	19.7	20.2	20.0	0.4	0.3
950	2009	27.3	22.8	19.4	18.1	*	*	*	*
969	2009	20.8	19.9	20.1	19.5	15.5	15.2	-4.6	-4.3
976	2009	24.1	22.5	20.0	19.1	19.8	19.0	-0.2	-0.2
982	2009	25.7	24.1	15.5	14.9	16.9	16.5	1.4	1.6
1014	2009	28.3	24.9	19.9	19.1	18.7	18.3	-1.2	-0.9
1034	2009	32.5	30.9	16.1	15.2	23.5	21.8	7.4	6.7
1199	2009	27.6	22.9	24.3	22.4	24.0	22.2	-0.3	-0.2
1217	2009	34.9	33.7	19.0	18.6	19.7	19.4	0.8	0.8
1252	2009	19.7	17.8	14.6	14.0	14.2	13.8	-0.5	-0.2
1261	2009	22.1	18.7	14.7	14.2	*	*	*	*
1278	2009	26.3	23.4	14.9	14.0	15.0	14.2	0.1	0.2
1284	2009	31.4	26.1	23.7	21.9	23.2	21.4	-0.6	-0.5
1324	2009	29.4	27.2	18.2	17.5	*	*	*	*
1366	2009	23.7	21.2	18.2	17.4	18.2	17.4	0.0	0.0
1513	2009	32.5	30.5	23.7	23.2	23.5	23.0	-0.1	-0.2
1530	2009	32.5	26.8	20.3	19.0	21.2	19.6	0.9	0.7
1610	2009	20.0	17.8	12.4	11.8	12.6	12.1	0.2	0.3
1633	2009	34.0	31.3	28.1	26.9	27.6	26.3	-0.5	-0.6
1658	2009	23.4	20.1	16.1	15.1	15.8	14.9	-0.3	-0.2
1686	2009	26.9	24.8	17.0	16.3	19.0	17.8	2.0	1.6
1716	2009	33.8	29.2	16.8	15.9	17.5	16.2	0.7	0.2

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
1717	2009	26.3	23.8	18.5	17.3	18.0	17.1	-0.5	-0.2
1738	2009	23.4	20.3	13.3	12.6	*	*	*	*
1791	2009	32.9	29.0	18.7	18.0	19.3	18.5	0.6	0.5
1816	2009	25.0	23.1	19.4	18.3	19.2	18.2	-0.2	-0.1
1833	2009	24.3	22.6	18.3	17.5	18.2	17.5	-0.1	0.0
1856	2009	25.1	24.5	13.9	13.2	15.6	14.9	1.7	1.7
1870	2009	21.2	18.7	14.6	13.6	14.9	13.9	0.2	0.4
1873	2009	28.6	25.6	15.2	14.6	18.0	17.5	2.8	2.9
1894	2009	20.5	18.6	17.7	16.7	18.1	17.0	0.4	0.3
1923	2009	38.6	35.1	19.8	18.5	24.8	23.1	5.0	4.6
1929	2009	38.4	33.3	27.2	26.4	27.4	26.4	0.1	0.0
n	61	60	60	60	60	55	55	54	54

* Indicates datasets with less than 30 days of data from July through August 2009.

Table E-4. Site-level temperature metrics for data collected July and August 2009, for Type Np sites.

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
70	2009	33.5	32.3	16.0	15.6	17.8	16.7	1.7	1.1
197	2009	28.9	25.6	12.3	11.9	17.0	16.3	4.6	4.4
263	2009	26.6	24.4	15.0	14.3	16.9	16.2	2.0	1.9
310	2009	27.9	26.8	14.8	14.5	*	*	*	*
319	2009	23.1	20.7	14.3	13.0	21.3	18.8	7.0	5.7
324	2009	*	*	*	*	*	*	*	*
389	2009	21.6	20.2	10.9	10.6	9.7	8.6	-1.2	-1.9
452	2009	*	*	*	*	*	*	*	*
482	2009	29.0	27.2	9.3	9.0	13.2	12.9	3.9	3.9
506	2009	24.7	22.5	13.4	12.5	14.0	13.2	0.6	0.7
553	2009	41.2	35.3	16.3	15.2	15.4	14.3	-0.9	-0.8
625	2009	28.0	24.7	16.8	15.7	16.2	15.2	-0.6	-0.5
629	2009	31.1	28.4	13.5	13.0	16.6	15.9	3.1	2.9
641	2009	26.6	24.6	18.5	17.9	19.3	18.4	0.8	0.5
653	2009	23.4	22.4	*	*	15.3	15.1		
669	2009	*	*	16.3	14.9	16.8	15.4	0.5	0.4
697	2009	*	*	*	*	*	*	*	*
698	2009	38.1	33.5	14.8	14.4	19.1	18.2	4.3	3.7
701	2009	25.6	22.0	11.3	11.0	13.6	12.8	2.3	1.7
715	2009	32.9	31.2	*	*	16.4	16.2	*	*
756	2009	22.8	19.4	15.5	14.3	13.7	13.0	-1.9	-1.4
770	2009	22.4	20.9	10.3	10.2	16.7	16.0	6.4	5.8
886	2009	20.3	17.5	13.5	13.0	12.8	12.2	-0.7	-0.7
933	2009	37.9	34.1	24.4	23.4	25.0	23.6	0.6	0.3
942	2009	15.2	14.8	13.2	12.8	12.9	12.8	-0.2	0.0

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
956	2009	24.6	23.5	14.7	14.0	21.2	19.2	6.5	5.2
1037	2009	26.3	24.5	16.0	15.7	16.6	16.2	0.6	0.5
1062	2009	35.8	34.5	16.0	15.4	17.6	16.5	1.6	1.1
1074	2009	23.1	20.0	17.0	15.3	*	*	*	*
1082	2009	26.3	24.0	9.4	9.4	11.1	10.8	1.7	1.4
1094	2009	21.0	20.4	13.3	13.2	11.5	11.4	-1.9	-1.8
1113	2009	26.2	23.5	*	*	16.4	15.4	*	*
1125	2009	26.9	24.6	21.9	21.4	17.6	16.5	-4.3	-4.9
1180	2009	25.7	25.0	16.4	16.0	16.9	16.7	0.6	0.7
1192	2009	22.8	21.4	13.2	12.2	10.9	10.5	-2.3	-1.7
1193	2009	27.2	25.2	19.0	18.5	17.8	17.4	-1.3	-1.1
1255	2009	23.1	19.1	15.3	14.1	16.6	15.0	1.3	0.9
1323	2009	24.3	21.9	16.2	15.5	17.5	16.7	1.3	1.1
1341	2009	34.3	30.1	18.7	17.2	16.0	14.9	-2.8	-2.3
1374	2009	28.3	27.3	7.8	7.2	13.7	13.0	5.9	5.8
1459	2009	19.1	18.0	18.2	16.8	16.2	15.6	-2.0	-1.3
1493	2009	30.0	29.5	12.6	10.0	11.8	11.6	-0.8	1.7
1535	2009	20.6	17.9	16.1	14.5	15.7	14.2	-0.4	-0.3
1538	2009	38.2	33.4	12.4	11.7	16.0	14.9	3.6	3.2
1565	2009	32.4	30.1	12.3	12.1	16.2	15.7	3.9	3.6
1582	2009	27.9	25.7	11.7	11.6	14.8	14.4	3.1	2.8
1597	2009	30.1	27.9	20.1	19.5	23.2	22.7	3.1	3.2
1641	2009	19.4	16.8	11.6	11.3	13.0	12.6	1.4	1.3
1653	2009	26.1	23.5	16.6	15.9	17.0	16.5	0.4	0.6
1781	2009	27.0	23.9	16.5	15.8	18.2	17.0	1.7	1.2
1786	2009	20.0	19.4	12.0	11.6	14.6	14.3	2.7	2.7

Site Number	Year	Air Tmax (°C)	Air 7Tmax (°C)	Upstream Tmax (°C)	Upstream 7Tmax (°C)	Downstream Tmax (°C)	Downstream 7Tmax (°C)	D_Tmax (°C)	D_7Tmax (°C)
1817	2009	21.8	19.6	14.1	13.9	14.4	14.0	0.3	0.1
1859	2009	27.3	24.0	13.1	12.2	14.2	13.2	1.0	1.0
1862	2009	20.6	18.4	14.4	13.4	14.0	13.2	-0.3	-0.2
1926	2009	19.7	17.0	15.2	13.9	14.6	13.7	-0.6	-0.2
n	55	51	51	49	49	50	50	47	47

* Indicates datasets with less than 30 days of data from July through August 2009.

Appendix F. Quality assurance results.

In accordance with the study plan for the Extensive Riparian Status and Trends monitoring program, approximately 10% of the study sites underwent repeated measurements for quality assurance purposes. Riparian shade and in channel measurements across the reach length of each site were performed by different crew members at five randomly selected sites for each waters type.

Table F-1. Results of repeated sampling events at five Type F/S sites. Numbers are mean site values per visit. An 'R' following the site number indicates the second sampling event.

Site Number	22	22R	98	98R	270	270R	969	969R	1278	1278R	1873	1873R
Wetted width (m)	1.8	1.6	4.7	4.6	25.3	25.9	1.6	1.6	2.1	1.8	1.0	1.1
Bankfull width(m)	2.2	2.5	7.6	7.4	30.4	30.5	2.4	2.6	2.9	2.8	1.5	1.5
Thalweg depth (cm)	11.4	12.0	17.5	20.3	89.3	91.3	16.2	14.3	14.5	13.3	7.8	8.7
Particle size (mm)	2.6	2.6	79.4	79.7	14.4	8.5	8.2	4.4	1.8	4.7	34.2	33.4
Gradient (%)	4.2	4.6	12.5	14.8	0.7	0.8	6.7	5.6	7.3	7.0	19.5	20.5
Embeddedness (%)	47.8	69.5	38.7	36.0	31.1	45.8	42.1	47.4	68.6	62.4	34.8	44.7
Canopy closure (%)	74.6	70.3	92.2	76.8	4.0	19.3	88.0	88.4	32.3	34.3	99.4	99.7
Total LWD (pieces per 100 m)	98.0	89.3	47.3	57.3	14.0	9.2	52.0	36.0	66.7	75.3	23.3	22.0
Dominant vegetation class	Mixed	Mixed	Mixed	Mixed	Deciduous	Deciduous	Mixed	Mixed	Mixed	Deciduous	Mixed	Mixed

Table F-2. Standard deviation (SD), coefficient of variation (CV), and root mean square (RMS) for the five Type F/S sites that underwent quality assurance procedures.

Site Number	22			98			270			969			1278			1873		
	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS
Wetted width (m)	0.2	9.0	1.7	0.1	1.8	4.7	0.4	1.5	25.6	0.0	0.4	1.6	0.2	11.1	2.0	0.1	8.9	1.1
Bankfull width(m)	0.2	10.1	2.4	0.1	1.9	7.5	0.1	0.3	30.5	0.1	3.4	2.5	0.1	2.8	2.9	0.0	0.0	1.5
Thalweg depth (cm)	0.4	3.6	11.7	2.0	10.5	19.0	1.4	1.6	90.3	1.3	8.8	15.3	0.8	6.1	13.9	0.6	7.7	8.3
Particle size (mm)	0.0	0.0	2.6	0.2	0.2	79.6	4.2	36.8	11.8	2.7	42.8	6.6	2.1	64.0	3.6	0.6	1.7	33.8
Gradient (%)	0.3	6.4	4.4	1.6	12.0	13.7	0.1	9.4	0.8	0.8	12.7	6.2	0.2	3.4	7.2	0.7	3.5	20.0
Embeddedness (%)	15.3	26.1	59.6	1.9	5.1	37.4	10.4	27.1	39.1	3.7	8.3	44.8	4.4	6.7	65.6	7.0	17.6	40.1
Canopy closure (%)	3.0	4.2	72.5	10.9	12.9	84.9	10.8	93.0	13.9	0.3	0.3	88.2	1.4	4.3	33.3	0.1	0.1	99.6
Total LWD (pieces per 100 m)	6.1	6.5	93.8	7.1	13.5	52.5	3.4	29.3	11.8	11.3	25.7	44.7	6.1	8.6	71.1	0.9	4.1	22.7

Table F-3. Results of repeated sampling events at five Type Np sites. Numbers are mean site values per visit. An 'R' following the site number indicates the second sampling event.

Site Number	698	698R	933	933R	1323	1323R	1597	1597R	1926	1926R
Wetted width (m)	1.5	1.8	1.8	1.8	0.7	0.7	1.3	1.2	0.8	0.7
Bankfull width (m)	1.6	1.8	2.0	2.1	1.4	1.4	3.8	3.2	1.5	1.6
Thalweg depth (cm)	18.5	19.7	12.7	15.0	4.2	5.0	7.3	7.3	5.8	5.0
Particle size (mm)	0.2	0.2	0.7	0.9	8.8	7.8	5.7	9.0	0.3	0.4
Gradient (%)	1.8	1.5	10.3	9.9	23.2	23.6	18.2	16.4	13.6	12.4
Embeddedness (%)	96.1	93.3	64.7	66.1	58.9	59.9	63.2	53.0	92.1	84.2
Canopy closure (%)	35.0	34.0	27.8	30.0	92.4	82.9	73.5	61.2	89.5	94.9
Total LWD (pieces per 100 m)	54.7	50.0	44.0	42.0	26.7	25.3	10.0	8.4	52.0	60.0
Dominant vegetation class	Mixed	Mixed	Mixed	Mixed	Deciduous	Deciduous	Mixed	Mixed	Mixed	Deciduous

Table F-4. Standard deviation (SD), coefficient of variation (CV), and root mean square (RMS) for the five Type Np sites that underwent quality assurance procedures.

Site Number	698			933			1323			1597			1926		
	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS	SD	CV (%)	RMS
Wetted width (m)	0.2	9.9	1.7	0.0	2.7	1.8	0.0	2.0	0.7	0.1	5.2	1.3	0.0	4.8	0.8
Bankfull width(m)	0.2	9.2	1.7	0.1	3.4	2.1	0.0	1.5	1.4	0.5	13.3	3.5	0.0	3.2	1.6
Thalweg depth (cm)	0.8	4.4	19.1	1.6	11.7	13.9	0.6	12.3	4.6	0.0	0.0	7.3	0.6	10.5	5.4
Particle size (mm)	0.0	20.2	0.2	0.1	17.3	0.8	0.7	8.8	8.3	2.3	32.1	7.5	0.0	11.8	0.4
Gradient (%)	0.2	12.9	1.7	0.3	2.9	10.1	0.3	1.2	23.4	1.3	7.5	17.3	0.9	6.7	13.0
Embeddedness (%)	2.0	2.1	94.7	1.0	1.5	65.4	0.6	1.1	59.4	7.2	12.4	58.3	5.6	6.3	88.2
Canopy closure (%)	0.7	2.0	34.5	1.6	5.4	28.9	6.7	7.7	87.8	8.7	12.9	67.6	3.8	4.1	92.2
Total LWD (pieces per 100 m)	3.3	6.3	52.4	1.4	3.3	43.0	1.0	3.8	26.0	1.1	12.3	9.2	5.7	10.1	56.1

Appendix G. Sample R code used for Cumulative Distribution Functions.

```
#Explore Jack J. files for determining site weights for target population.

setwd("C:/Program Files/R/R-2.12.2/erst_n_09")

sfr.7.15 <- read.csv('ERST_W_N_rev2_parcelout_modi.csv', header=TRUE)
dim(sfr.7.15)
names(sfr.7.15) <- tolower(names(sfr.7.15))
names(sfr.7.15)

addmargins(table(sfr.7.15$strat_a))
addmargins(table(sfr.7.15$strat_b))
addmargins(table(sfr.7.15$status))
addmargins(table(sfr.7.15$t_nt))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$strat_b))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$status))
addmargins(table(sfr.7.15$strat_b,sfr.7.15$status))
addmargins(table(sfr.7.15$reason,sfr.7.15$strat_b))

plot(sfr.7.15$ww,sfr.7.15$bfw)

############################################
#explore cont.analysis using Tom's TinnR template:
# File: CDF_Estimates.R
# Purpose: Calculate CDF and percentile estimates and test for differences among
#         CDFs for the zzz survey
# Programmer: Tom Kincaid
# Date: May 17, 2011

# Create a text file for output
sink("Janish_CDF_Estimates.txt")
cat("CDF Estimation for the ECY temperature Survey\1.1")

# Read the file containing data for CDF estimates
cdf <- sfr.7.15 <- read.csv('ERST_W_N_rev2_parcelout_modi.csv', header=TRUE)
names(cdf) <- tolower(names(cdf))
dim(cdf)
names(cdf)
nr <- nrow(cdf)

temp <- geodalbers(cdf$longnad83h,cdf$latnad83h, sph="Clarke1866", clon=-96, clat=23,
sp1=29.5, sp2=45.5)
```

```
  dim(temp)
  head(temp)
cdf$xalbers <- temp$xcoord
cdf$yalbers <- temp$ycoord

 head(cdf$xalbers)
 head(cdf$yalbers)

#This sets up the adjusted weights we calculated separately;
cdf$final.wgt <- 0
cdf$final.wgt[cdf$strat_b=='IND' & cdf$status=='TS'] <- 587.4101
cdf$final.wgt[cdf$strat_b=='PUB' & cdf$status=='TS'] <- 216.3026
cdf$final.wgt[cdf$strat_b=='SFL' & cdf$status=='TS'] <- 1378.9293
cdf$final.wgt[cdf$strat_b=='MUN' & cdf$status=='TS'] <- 648.9079

#check weight assignments to cdf$final.wgt
addmargins(table(cdf$final.wgt))


sites.CDF <- data.frame(siteID=cdf$site_id,
                        #Use=cdf$t_nt[cdf$t_nt=='T'])
                        Use=cdf$status=='TS')

# Create the subpop data frame, which defines populations and subpopulations for
# which estimates are desired
subpop.CDF <- data.frame(siteID=cdf$site_id,
                         All_Sites=rep("All_Sites", nr),
                         pop1=cdf$strat_b)

# Create the design data frame, which identifies the stratum code, weight,
# x-coordinate, and y-coordinate for each site ID
design.CDF <- data.frame(siteID=cdf$site_id,
                         wgt=cdf$final.wgt,
                         #stratum=cdf$stratum,    above defined the subpopulations; no stratification in
the design
                         #xcoord=cdf$x,
                                      #ycoord=cdf$y,
                                              xcoord=cdf$xalbers,
                         ycoord=cdf$yalbers)

# Create the data.cont data frame, which specifies the variables to use in the
# analysis
data.cont.CDF <- data.frame(siteID=cdf$site_id,
                            thalweg=cdf$thlwg,        #you could just replace "var1" with thalweg and
"var2" with wetted width
                            wettedwidth=cdf$ww,
```

```
                                             bankfullwidth=cdf$bfw,
                                             gradient=cdf$grad,
                                             area_ha=cdf$area_ha,
                                             elevation=cdf$wa30,
                                             slope=cdf$slope_avg,
                                             aspect=cdf$aspect,
                                             lwd_d=cdf$lwd_down,
                                             lwd_s=cdf$lwd_sus,
                                             lwd_j=cdf$lwd_jams,
                                             total_lwd=cdf$t_lwd,
                                             canopy=cdf$pcan,
                              distance_divide=cdf$dtd_m,
                                             geo_mn=cdf$geo_mean,
                              embededness_mid=cdf$mid_emb)
                        # depth=cdf$depth_mn,
                        # distance_between=cdf$distance,
                        # bankfull_r=cdf$bf_rat,
                        # width_r=cdf$w_rat,
                        # embededness=cdf$emb,
                                   # air_tmx_09=cdf$airtmx09,
                # dtempmx09=cdf$dtempmx09,
                                   # air_7d_09=cdf$airt7d09,
                                   # ustmx09=cdf$ustmx09,
                                   # ust7d09=cdf$ust7d09,
                                   # dstmx09=cdf$dstmx09,
                                   # dst7d09=cdf$dst7d09,
                                   # dtemp7d09=cdf$dtemp7d09)
                                   # airtmx08=cdf$airtmx08,
                                   # airt7d08=cdf$airt7d08,
                                   # ustmx08=cdf$ustmx08
                                   # ust7d08=cdf$ust7d08,
                                   # dstmx08=cdf$dstmx08,
                                   # dst7d08=cdf$dst7d08,
                                   # dtempmx08=cdf$dtempmx08,
                                   # dtemp7d08=cdf$dtemp7d08)

# Calculate the estimates
cat("\nCalculate Janish_CDF_estimates\n")  # the \n are carriage returns
#needed unless you want one long line.  \n\n creates two carriage returns.
sink()     #closes the diversion to the file; output again appears in the R window
if(exists("warn.df")) rm("warn.df")
Janish_CDF_Estimates <- cont.analysis(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF,
   popsize=list("All_Sites"=49317,
         pop1=list(IND=37852.9605,
              PUB=2811.9342,
              SFL=7354.2895,
```

```
                    MUN=1297.8158)))
            # pop2=list("subpop1"=,
             #        "subpop2"=,
              #       "subpop3"=))

# Check for warning messages and print them if any exist
sink("Janish_CDF_Estimates.txt", append=TRUE)  #opens the file again; the append
#adds the new output to the original output; without the append, the original would
#disappear.
if(exists("warn.df")) {
  cat("\nWarning messages generated during the call to cont.analysis:\n\n")
  warnprnt()
} else {
  cat("\nNo warning messages were generated during the call to cont.analysis.\n")
}

# Write CDF estimates as a comma-separated value (csv) file
write.table(Janish_CDF_Estimates$CDF, file="Janish_CDF_Estimates.csv", sep=",",
        row.names=FALSE)

# Create a PDF file containing plots of the CDF estimates
cont.cdfplot("Janish_CDF_Estimates.pdf", Janish_CDF_Estimates$CDF)

# Write percentile estimates as a csv file
write.table(Janish_CDF_Estimates$Pct, file="Janish_Percentile_Estimates.csv", sep=",",
        row.names=FALSE)

## Close the output text file
sink()
# Test for differences among CDFs   which I didn't do in the example
#

CDF_Tests <- cont.cdftest(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF,
   popsize=list("All_Sites"=49317,
             pop1=list(IND=37852.9605,
                   PUB=2811.9342,
                   SFL=7354.2895,
                   MUN=1297.8158)))
               #      "subpop4"=),
            # pop2=list("subpop1"=,
             #        "subpop2"=,
              #       "subpop3"=)))

# Write CDF test results as a csv file
write.table(CDF_Tests, file="CDF_Tests.csv", sep=",", row.names=FALSE)
```

```
# Close the output text file
sink()
#  cont.analysis(sites=mysites, subpop=mysubpop, design=mydesign,
#   data.cont=mydata.cont, popsize=mypopsize)

//////////////////////////////////////////////////////////////////////
#temp comparisons

setwd("C:/Program Files/R/R-2.12.2/erst_07")

sfr.7.15 <- read.csv('between_yrs.csv', header=TRUE)
dim(sfr.7.15)
names(sfr.7.15) <- tolower(names(sfr.7.15))
names(sfr.7.15)

addmargins(table(sfr.7.15$strat_a))
addmargins(table(sfr.7.15$strat_b))
addmargins(table(sfr.7.15$status))
addmargins(table(sfr.7.15$t_nt))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$strat_b))
addmargins(table(sfr.7.15$t_nt,sfr.7.15$status))
addmargins(table(sfr.7.15$strat_b,sfr.7.15$status))
addmargins(table(sfr.7.15$reason,sfr.7.15$strat_b))
plot(sfr.7.15$ustmx07,sfr.7.15$dstmx07)

 ##########################################
#explore cont.analysis using Tom's TinnR template:

# File: CDF_Estimates.R
# Purpose: Calculate CDF and percentile estimates and test for differences among
#          CDFs for the zzz survey
# Programmer: Tom Kincaid
# Date: May 17, 2011


# Create a text file for output
sink("between_yrs.txt")
cat("CDF Estimation for the ECY temperature Survey\1.1")


# Read the file containing data for CDF estimates
cdf <- sfr.7.15 <- read.csv('between_yrs.csv', header=TRUE)
names(cdf) <- tolower(names(cdf))
dim(cdf)
names(cdf)
nr <- nrow(cdf)
```

```
temp <- geodalbers(cdf$longnad83h,cdf$latnad83h, sph="Clarke1866", clon=-96, clat=23,
sp1=29.5, sp2=45.5)
  dim(temp)
  head(temp)
cdf$xalbers <- temp$xcoord
cdf$yalbers <- temp$ycoord

 head(cdf$xalbers)
 head(cdf$yalbers)

#This sets up the adjusted weights we calculated separately;
cdf$final.wgt <- 0
cdf$final.wgt[cdf$strat_b=='IND' & cdf$status=='TS'] <- 33.78102
cdf$final.wgt[cdf$strat_b=='PUB' & cdf$status=='TS'] <- 34.9441
cdf$final.wgt[cdf$strat_b=='SFL' & cdf$status=='TS'] <- 58.0077

#check weight assignments to cdf$final.wgt
addmargins(table(cdf$final.wgt))


sites.CDF <- data.frame(siteID=cdf$site_id,
                    #Use=cdf$t_nt[cdf$t_nt=='T'])
                    Use=cdf$status=='TS')


# Create the subpop data frame, which defines populations and subpopulations for
# which estimates are desired
subpop.CDF <- data.frame(siteID=cdf$site_id,
                    All_Sites=rep("All_Sites", nr),
                    pop1=cdf$year)

# Create the design data frame, which identifies the stratum code, weight,
# x-coordinate, and y-coordinate for each site ID
design.CDF <- data.frame(siteID=cdf$site_id,
                    wgt=cdf$final.wgt,
                    #stratum=cdf$stratum,    above defined the subpopulations; no stratification in
the design
                    #xcoord=cdf$x,
                    #ycoord=cdf$y,
                    xcoord=cdf$xalbers,
                    ycoord=cdf$yalbers)

# Create the data.cont data frame, which specifies the variables to use in the
# analysis
data.cont.CDF <- data.frame(siteID=cdf$site_id,
```

```
                    #  thalweg=cdf$thlwg,         #you could just replace "var1" with thalweg and
"var2" with wetted width
                    #  wettedwidth=cdf$ww,
                                   # bankfullwidth=cdf$bfw,
                                   #  gradient=cdf$grad,
                                   #  elevation=cdf$wa30,
                                   #  slope=cdf$slope_avg,
                                   #  area=cdf$area_ha,
                                   #  aspect=cdf$aspect,
                                   #  lwd_d=cdf$lwd_down,
                                   #  lwd_s=cdf$lwd_sus,
                                   #  lwd_j=cdf$lwd_jams,
                                   #  lwd_t=cdf$t_lwd,
                                   #  canopy=cdf$pcan)
                                   #  air_m_07=cdf$airtmx07,
                                     air_7d_07=cdf$airt7d07)
                                    # ustmx07=cdf$ustmx07,
                                   #  ust7d07=cdf$ust7d07,
                                   #   dstmx07=cdf$dstmx07,
                                   #   dst7d07=cdf$dst7d07
                                   #   dtempmx07=cdf$dtempmx07,
                                   #    dtemp7d07=cdf$dtemp7d07,
                                   #   airtmx08=cdf$airtmx08,
                                   #   airt7d08=cdf$airt7d08,
                                   #  ustmx08=cdf$ustmx08)
                                   #  ust7d08=cdf$ust7d08,
                                   #  dstmx08=cdf$dstmx08,
                                   #  dst7d08=cdf$dst7d08,
                                   #  dtempmx08=cdf$dtempmx08,
                                   #  dtemp7d08=cdf$dtemp7d08)

# Calculate the estimates
cat("\nCalculate Janish_CDF_estimates\n")  # another section of the output file; the \n are
carriage returns
#needed unless you want one long line.  \n\n creates two carriage returns.
sink()        #closes the diversion to the file; output again appears in the R window
if(exists("warn.df")) rm("warn.df")
between_yrs_results <- cont.analysis(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF)
    #popsize=list("All_Sites"=7224,
              #pop1=list(IND=1487.745,
               #        PUB=1211.669,
               #       SFL=4524.586))
              #         "subpop4"=),
             # pop2=list("subpop1"=,
              #         "subpop2"=,
               #        "subpop3"=))
```

```
# Check for warning messages and print them if any exist
sink("between_yrs.txt", append=TRUE)  #opens the file again; the append
#adds the new output to the original output; without the append, the original would
#disappear.
if(exists("warn.df")) {
  cat("\nWarning messages generated during the call to cont.analysis:\n\n")
  warnprnt()
} else {
  cat("\nNo warning messages were generated during the call to cont.analysis.\n")
}

# Write CDF estimates as a comma-separated value (csv) file
write.table(between_yrs_results$CDF, file="between_yrs_results.csv", sep=",",
        row.names=FALSE)

# Create a PDF file containing plots of the CDF estimates
cont.cdfplot("between_yrs_results.pdf", between_yrs_results$CDF)

# Write percentile estimates as a csv file
write.table(between_yrs_results$Pct, file="between_yrs_percentiles.csv", sep=",",
        row.names=FALSE)

## Close the output text file
sink()
# Test for differences among CDFs   which I didn't do in the example
#

CDF_Tests <- cont.cdftest(sites.CDF, subpop.CDF, design.CDF, data.cont.CDF,
   popsize=list("All_Sites"=7224,
           pop1=list(T07=7224,
                 T08=7224)))
               #    SFL=4524.586)))
              #      "subpop4"=),
           # pop2=list("subpop1"=,
            #         "subpop2"=,
             #        "subpop3"=)))

# Write CDF test results as a csv file
write.table(CDF_Tests, file="CDF_Tests.csv", sep=",", row.names=FALSE)

# Close the output text file
sink()
```

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MEMORANDUM

January 16, 2020

To: Forest Practices Board

Form: Mark Hicks, Adaptive Management Program Administrator

Subject: Hardwood Conversion Report

At their October 31, 2019 meeting, TFW Policy (Policy) formally accepted the findings report and associated materials for the study entitled ***Hardwood Conversion Study (HCS) Summary Report***. The purpose of this memo is to transmit the final study report to the Board along with a summary of the report's findings and Policy's recommendations.

The Cooperative Monitoring, Evaluation, and Research Committee (CMER) conducted the Hardwood Conversion Study to evaluate the effectiveness of hardwood conversions conducted in riparian areas of western Washington. Monitoring took place at eight study sites to evaluate the effectiveness and operational and economic feasibility of hardwood conversion treatments in reestablishing conifers in hardwood-dominated riparian stands.

Harvest and regeneration prescriptions were left to the discretion of landowners within the following constraints: no harvest within 25' feet of the edge of stream at bank-full or the CMZ; retain residual conifers in the core and inner zones and, where reforestation was required, after harvesting, the goal was to successfully re-establish conifer, and that conifer be on track to dominate the converted Riparian Management Zone. As a result, landowners employed many different strategies of buffer retention, vegetation and predator control, and seedling selection.

Silvicultural results from the study suggest:

- The highest survival 10 years after planting was associated with planting shade- and moisture-tolerant species, planting seedlings at high densities, and controlling competing vegetation.
- Competing vegetation, which increased in height and cover after harvest, appears to be the biggest challenge to successful regeneration of planted conifer seedlings.
- Height growth rates are greater once the leaders of conifer are above competing vegetation.

Economic Results from the study suggest:

- Hardwood conversions are economically feasible when there is sufficient harvest volume to make conversion profitable.
- Per-acre harvest volumes tended to be lower in the conversion area, resulting in lower per-acre harvest revenue relative to upland areas.
- Harvest and regeneration costs were generally similar between conversion and upland areas.

The Hardwood Conversion Study does not tell us several important things:

- The effects hardwood conversion treatments in riparian stands have on shade, stream temperature, and LWD recruitment; as well as what the effect of hardwood conversion practices are as a function of buffer width and length of stream treated.
- When or if conversions will be successful relative to the criteria set out in WAC 222-30-021(1)(b)(i)(D). As of the 10-year measurements, trees have not yet attained the 8-inch diameter at breast height (dbh) target.
- If the findings from the case study results are representative other potential hardwood conversion sites across western Washington. With the spatial clustering of the case study sites, this study does not cover the extent of the forest area where conversion could happen.
- As Alternate Plan case studies, the study did not assess the effectiveness of the standard forest practices rule for hardwood conversion, Washington Administrative Code (WAC) 222-30-021(1)(b)(i).

This study provided valuable insights into the economic feasibility of hardwood conversion activities, and it could serve as a pilot study for helping to design a more rigorous hardwood conversion study. The study did not test the hardwood conversion rules directly, and as implemented as a series of case studies, it also does not provide a basis to assert what effect riparian harvest of hardwood stands have on many key riparian functions, such as stream temperature and large woody debris.

After reviewing the study findings, Policy agreed by consensus not to recommend the Board take any formal action in response to this study.

However, Policy will be considering at a later time if they want to re-measure conditions at these sites over time to identify when they finally meet restoration target criteria required by rule. Policy will also be considering whether to recommend CMER initiate a more rigorous study to examine the effects of the hardwood conversion rules on stream protection, and to better identify the best management practices associated with successful conifer restoration.

HARDWOOD CONVERSION STUDY (HCS)
SUMMARY REPORT

Prepared by:

CRAMER
FISH SCIENCES

Kevin Ceder, Mark Teply,
Kai Ross

June 28, 2019

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EXECUTIVE SUMMARY

Since 2003, the Cooperative Monitoring, Evaluation, and Research Committee (CMER) has conducted the Hardwood Conversion Study to evaluate the effectiveness of hardwood conversions conducted in riparian areas of western Washington under the Washington Administrative Code (WAC) 222-30-021(1)(b)(i). Monitoring was conducted at eight study sites to evaluate the effectiveness and the operational and economic feasibility of hardwood conversion treatments in reestablishing conifers in hardwood-dominated riparian stands. This report summarizes the conditions and trends of regeneration response that has occurred, summarizes revenues and costs associated with hardwood conversion treatments, and summarizes factors strongly related to meeting stocking standards and the feasibility of doing so.

Hardwood conversion treatments were implemented on a total of 20.5 acres across eight study sites located in lowland forests of western Washington. Treatments are generally described, as follows, in the Case Study Report (Brown 2106):

> "Harvest and regeneration prescriptions were left to the discretion of landowners with the following requirements: no harvest within 25' feet of the edge of bank-full or CMZ [channel migration zone]; retain residual conifers in the core and inner zones; and, where reforestation was required, after harvesting, the goal was to successfully re-establish conifer, and that conifer be on track to dominate the converted [Riparian Management Zone]."

Treatments are recorded in the Case Study Report for each site and a summary is provided in the Harvest Practices and Regeneration Practices sections of this summary report. Overall there is no experimental design across the case studies with each landowner using treatments that fit the conditions of the case study site.

Generally, harvest values and harvest costs in hardwood conversion areas compared favorably to upland areas—average per-MBF stumpage values were higher in hardwood conversion areas ($333, SD = $49) than in adjacent uplands ($277, SD = $63) and average per-acre conversion costs were lower in hardwood conversion areas ($528, SD = $369) than in adjacent uplands ($575, SD = $625). But, because more volume could be harvested from upland areas (about 26 MBF per acre, on average, SD = 10 MBF) compared to that from the hardwood conversion areas (about 14 MBF per acre, on average, SD = 5 MBF/ac), the overall profitability of operations in the adjacent upland areas ($6,257 per acre, on average, SD = $1,448/ac) was greater than in hardwood conversion areas ($4,148 per acre, on average, SD = $1,627/ac).

As of the latest monitoring—10 years after planting—hardwood conversion areas have not yet met stocking standards prescribed under WAC 222-30-021(1)(b)(i)(D)—that is, 150 trees per acre greater than 8 inches dbh. Though all eight sites had more than 150 conifer trees per acre, no tree had yet reached 8 inches dbh. Three sites appear to be on track (sites 8, 11, and 12). These three sites were planted heavily with Sitka spruce, which has persisted at higher rates than any other species planted over a range of site conditions. The robust performance of Sitka spruce and the high numbers of this species planted at these three sites increase the likelihood of meeting the stocking standard. Where other sites were planted with Douglas-fir, which is less shade-tolerant and less persistent under shade than other species, the likelihood of meeting the stocking standard appears lower.

There is some evidence supporting a positive relationship between brush control and regeneration performance. However, because sites with the greatest brush control also had the highest levels of Sitka spruce, this relationship is masked by the persistence of Sitka spruce, which was observed across a range of brush competition. Yet, it *is* clear that seedlings with leaders above the brush were more likely to grow faster and survive. Therefore, the absence of competing vegetation or the act of reducing competing vegetation, where needed, has apparent value. But, because brush control was not performed at those sites that are also depauperate of Sitka spruce, some of which had inherently low brush levels, it is unclear whether a greater investment in brush control would have improved the growth and survival of the other species planted at those sites.

Finally, we were unable to discern the relationship between animal control or animal damage and regeneration performance. Though sites with the greatest animal control also had the highest populations of animals to control, these sites also have the highest levels of Sitka spruce, which are not preferred by browsers. This masked the relationship between animal control and conifer survival. Compounding matters, field crews were unable to reliably discern the cause of mortality during monitoring. All that is known is that a seedling died—the cause is unknown—further complicating our ability to interpret the relationship between animal damage and conifer survival.

Overall, the authors stress that the results summarized in this report are from case studies that, though they were established professionally and monitored rigorously, were not designed experimentally. This limits the inferences that can be drawn from them and the application of any findings beyond these sites. Therefore, the findings summarized herein are relationships observed in the monitoring data that serve as indicators of "success," and "failure," and should only be considered as such in rule deliberations.

INTRODUCTION

Background

The Washington Administrative Code (WAC) contains several rules governing a landowner's decision to convert hardwood-dominated stands in the inner zone[1] of the riparian management zone (RMZ)[2] to conifer-dominated stands:

- When projected stand development of the existing stands in the combined core and inner zone falls short of attaining the desired future condition of 325 square feet per acre basal area conifers by 140 years, WAC 222-30-021(1)(b)(i) stipulates that no harvest is permitted in the inner zone, except in connection with hardwood conversion[3].

- The landowner may elect conversion of hardwood-dominated stands in the inner zone if the core and inner zone meets specified conditions outlined in WAC 222-30-021(1)(b)(i)(A) for contiguous ownership, pre-conversion stocking, pre-harvest stream shade, likelihood of conversion success, and prior conversion success.

- When hardwood conversion occurs in the inner zone, it must be implemented under WAC 222-30-021(1)(b)(i)(B) through (D) which prescribes: limitations due to land ownership, retention of conifers during harvesting, requirements for conifer reforestation, and requirements for post-conversion monitoring.

These WACs were adopted in in 2001, and it was recognized that they would need to be validated using an adaptive management framework which involves monitoring to evaluate: a) the effectiveness of hardwood conversion treatments in reestablishing conifers; b) the economic and operational feasibility of hardwood conversion; and, c) the effects of the hardwood conversion on shade, stream temperature, and instream large wood.

In December 2003, the Forest Practices Board authorized the "Riparian Research Pilot Study" to achieve these adaptive management monitoring objectives. Now known as the Hardwood

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[1] The "inner zone" of the RMZ is immediately upslope of a 50-foot stream-adjacent "core zone." The width of the inner zone varies under the WACs according to the site class in and stream width along the RMZ.
[2] The "riparian management zone" is the combined core, inner, and outer zones within an RMZ. The width of the riparian management zone varies under the WACs according to the site class in and stream width along the RMZ.
[3] When the case study sites were harvested in 2006, the DFC target adopted in 2001 ranged from 190 - 285 square feet per acre basal area conifers by 140 years depending on site class (Fairweather 2001).

Conversion Study, this study was designed to evaluate the effectiveness of hardwood conversions under the WACs, specifically to describe and quantify costs and benefits of implementing hardwood conversions in riparian areas of western Washington.

Shortly afterward, eight study sites were selected for monitoring. In 2006, hardwood conversion practices were implemented through alternative plans developed under the WACs. Monitoring has occurred on three occasions since: during planting, four years post-harvest, and ten years post-harvest[4]. A Case Study Report (Brown 2016) was published describing hardwood conversion treatments, silvicultural performance, and economic performance.

This report presents a summary of the findings of the hardwood conversion study to date—synthesizing information presented in the Case Study report—and provides further understanding of the silvicultural and economic performance of the hardwood conversions.

Purpose

The purpose of this report is to summarize conditions and trends from post-harvest monitoring, four and ten years since harvesting. Specifically, it addresses the following Rule Group Critical Questions outlined in Table 19 of the 2014 CMER workplan:

- How effective are different hardwood conversion treatments in reestablishing conifers in hardwood-dominated riparian stands?
- Is hardwood conversion in riparian stands operationally feasible, and what are the economic costs and benefits of the hardwood conversion treatments?

Though partially addressed by the Hardwood Conversion Study Plan, the following Rule Group Critical Questions are not addressed in this report:

- What effects do hardwood conversion treatments in riparian stands have on shade, stream temperature, and large woody debris (LWD) recruitment?
- What is the effect of hardwood conversion practices on stream temperature as a function of buffer width and length of stream treated?

A summary report of the shade and temperature study was prepared by Hunter (2010).

Study Objectives

This report addresses the following Questions of Interest posed in the Hardwood Conversion Study Plan, answering the two Rule Group Critical Questions carried forward in this report:

---

[4] There is some variance among sites in the length of time between harvesting and planting. In some cases, planting occurred in the same year as harvest. In others, planting occurred year(s) after harvest. Therefore, for consistency, we refer to "post-harvest" measurements for consistency in this report and with other reports.

Silvicultural Performance:

- What were the survival rates of planted seedlings in the RMZ?
- What were the growth rates of planted seedlings in the RMZ?
- What regeneration strategies did landowners use to ensure successful conifer regeneration in the RMZs?
- What were the primary problems that landowners faced regenerating the RMZs with conifers?

Economic Performance:

- What additional harvest costs resulted from adding hardwood conversion treatments to the harvest prescription?
- How much wood (volume, board feet) was harvested from the riparian management zones [the converted area including the inner zone and portions of the core zone of the RMZ]?
- How much wood (volume, board feet) was harvested from the upslope portions of the units [the outer zone of the RMZ and the remainder of the harvest unit]?
- What were the cost differences between successfully regenerating conifers in the riparian area [the converted area including the inner zone and portions of the core zone of the RMZ] versus successfully regenerating conifers in the adjacent, upslope areas [the outer zone of the RMZ and the remainder of the harvest unit]?
- What were the net financial gains (or losses) that resulted from adding riparian hardwood conversion treatments to the harvest prescriptions?
- What were the primary reasons for different costs (if any) between regenerating conifers in riparian areas versus regenerating conifers in adjacent, upslope areas?

Though the 2016 Hardwood Conversion Case Study Report addresses these questions on a site-by-site basis, this report addresses these Questions of Interest on a summary basis.

Additionally, this report addresses one Question of Interest posed by the CMER Policy Committee which provided the impetus for the latest round of monitoring:

- How many conifers are free-to-grow in the [converted core and inner zone portions of the] RMZ?

This report also addresses this Question of Interest on a summary basis.

METHODS

Study Sites

Site Selection

Eight riparian study sites were selected from a pool of twenty sites volunteered by participating landowners (see **Error! Reference source not found.**) that met the following selection criteria:

- Hardwoods must dominate over conifers (WAC 222-30-023(1)(i)),
- There is evidence (such as conifer stumps, historical photos, or a conifer understory) that the conversion area can be successfully reforested with conifers and support the development of conifer stands (WAC 222-30-023(1)(i)(A)), and
- Landowners must be willing to participate in the study and share information about their sites and silvicultural practices to meet overall project objectives.

Harvest and regeneration prescriptions were left to the discretion of landowners. However, they were given the following guidelines to regulate their treatment activities: no harvest could occur within 25' feet of the edge of bank-full or channel migration zone; conifers must be retained in the core and inner zones; and, conifers must be adequately stocked and free-to-grow and be on track to dominate the converted RMZ, regardless of cost.

The site selection criteria did not require any physical characteristics. Therefore, stream and buffer widths varied among sites with 6 of 8 sites along large streams (bankfull width over 10 feet) and 7 of 8 sites along low gradient streams (Table 2). Sites are primarily high productivity with 4 sites being DNR Site Class II, 2 sites being DNR Site Class III, and 2 sites being DNR Site Class V resulting in most sites having wider overall buffers. Sites also tend to be near the coast with 3 sites located on the northwest part of the Olympic Peninsula, 3 sites in southwest Washington in the Willapa Hills, 1 site on the northeast Olympic Peninsula, and 1 site in the southwest Washington Cascade foothills (Figure 1).

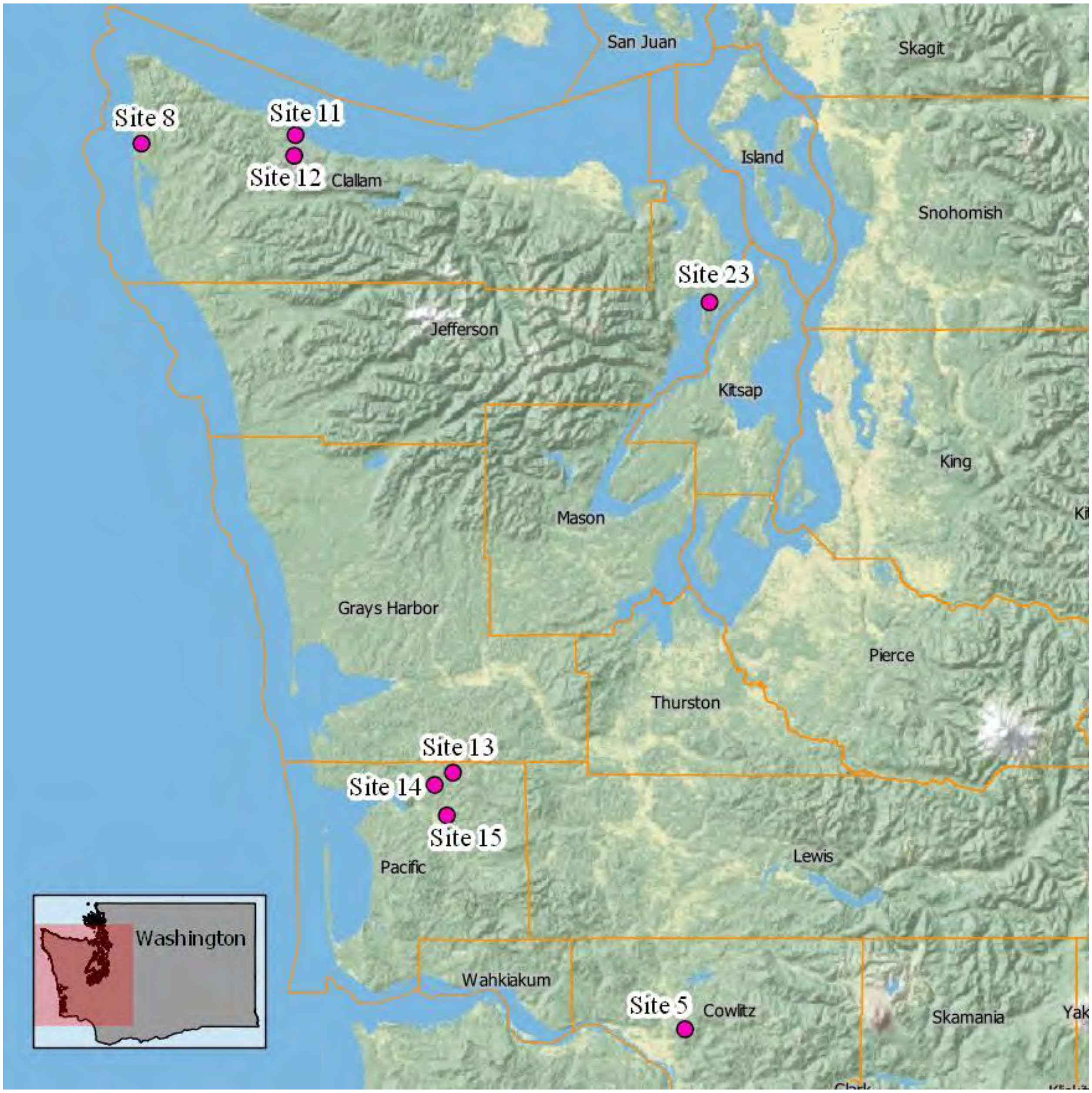

Figure 1: Location of Hardwood Conversion Study sites.

Monitoring

Monitoring hardwood conversion case study sites was performed with a combination of information provided by landowners through written surveys along with pre- and post-harvest vegetation surveys. Briefly, Landowners provided information about these sites—landowner objectives, harvest practices, and regeneration practices—in answers to a series of questionnaires. Pre-harvest vegetation surveys used a transect plot design while post-harvest surveys used a combination of a 100% survey of standing trees, snag, and stumps within the riparian zone and a grid of monumented 1/50th acre circular plots at 60-by-60-foot spacing to sample planted trees, volunteer hardwoods, and competing vegetation. Post-harvest monitoring occurred the year of planting followed by approximately 4 and 10 years after harvest. Complete information about survey methods can found in the WDNR Hardwood Conversion Procedures Manual[5] for pre-harvest surveys, the Post-Harvest 100% and Stump Procedures Manual (Versions 1.1 – 2.0, Duck Creek Associates 2007a, 2007b, 2015a) for overstory trees, and the Post-Harvest Regeneration Survey Procedures Manual (Versions 1.3 – 2.1, Duck Creek Associates 2006, 2007c, 2009, 2015b) for regeneration and vegetation surveys.

The following sections summarize the findings of these landowner questionnaires and field surveys, characterizing pre- and post-harvest conditions at the eight riparian study sites. The Case Study Report provides detailed assessments on a site-by-site basis.

Landowner Objectives

At the beginning of the study, management of the eight study sites was distributed amongst five landowners. Since then, Weyerhaeuser acquired lands owned by Longview Fibre (see Table 1) and now manages half (4) of the study sites. All landowners were motivated by financial objectives to consider hardwood conversion practices. Environmental stewardship objectives guided only two landowners—Green Crow (site 8) and Merrill and Ring (sites 11 and 12).

Table 1. Landowner management objectives for the Hardwood Conversion Study sites.

Landowner	Site Number	Immediate Financial Gain	Increase Conifer Acreage (Future Gain)	Ecological Stewardship
Weyerhaeuser/ Longview Fiber	5, 13, 14, 15	X	--	--
Green Crow	8	X	--	X
Merrill and Ring	11, 12	X	X	X
Pope Resources	23	X	--	--

Site Characteristics

Various site attributes, derived from GIS data layers, were downloaded from WDNR and USDA spatial data clearinghouses. Climate data were obtained from National Weather Service and NOAA National Climate Data Center climate stations (Western Regional Climate Center 1971 - 2000). Soils information was compiled from digital soils data obtained from the Natural Resources Conservation Service Web Soil Survey website (Soil Survey Staff).

[5] From Brown 2016: "Pre-harvest vegetation surveys, and initial post-harvest surveys, done at 4 sites, were conducted using a transect plot design. After review of the variability in the initial post-harvest transect data, the Riparian Scientific Advisory Group (RSAG) decided to discontinue its use for collecting post-harvest vegetation data. In place of the transect survey post-harvest, a 100-percent RMZ survey was used to collect large tree data (≥ 5.5" DBH), including stumps, snags, and fallen/windthrown trees, and a 1/50th acre circular plot design to collect regeneration and lesser vegetation data in the planted RMZ. Although the two methods are not directly comparable, the pre-harvest survey data offers insights into the small tree and lesser vegetative composition and percent cover. Furthermore, the 100-percent data is used to reconstruct both pre and post-harvest condition for large trees, while circular plot data can be compared to assess changes in lesser vegetation composition and percent cover, and seedling growth and survival post- harvest."

Landscape characteristics reflect lowland forest conditions on the Olympic Peninsula and along the Washington coast (see Table 2). All sites are rain-dominated, below 650 feet elevation. Average precipitation ranges from 48 to 103 inches per year. Generally, the highest precipitation levels occur at the coastal sites, the lone exception being coastal site 13 where the climate more closely resembles that of the two leeward sites (5 and 23).

Six of the eight sites (8, 11, 12, 14, 15, and 23) occur along low gradient streams and are wider than 10 feet; four of these six sites are along relatively unconfined, softrock channels. The other two sites (5, 13) occur along streams narrower than 10 feet. Site 5 is along a high gradient, confined hardrock stream. Site (13) is along a low gradient, confined, colluvial stream.

Table 2. Landscape and stream characteristics at the Hardwood Conversion Study sites.

Site	Landscape Characteristics			Riparian Management Zone Characteristics		
	Mean elevation (ft)	Parent material	Mean annual precipitation (in)	Slope (mean %, % range)	Mean bankfull width (ft)	Mean stream gradient (%)
5	643	Basalt	48	39 (20–80)	7.6	17
8	185	alluvium	103	4 (0– 35)	23.9	2
11	340	basalt	95	<2 (0–10)	13.9	1
12	270	colluvium	95	30 (20-40)[1]	34.5	1
13	460	colluvium	53	51 (10–110)	5.9	3
14	383	colluvium	83	23 (5–85)	10.9	1
15	219	colluvium	83	22 (2–50)	18.0	1
23	249	alluvium & basalt	55	8 (0–45)	21.4	2

[1]Estimate provided by the landowner.

Pre-harvest Stocking

A 100-percent survey was conducted within the combined core and inner zones to collect large tree data (> 5.5 inches dbh) including stumps, snags, and fallen trees. The 100-percent surveys were used to characterize both pre- and post-harvest stocking for large trees; however, stocking specific to the conversion areas, which includes the inner zone and the outer portion of core zone up to 25 feet of the stream, areas cannot be extracted from the 100-percent surveys.

Based on the landowner's professional judgement, it was determined that all eight study sites lacked sufficient stocking in the combined core and inner zones to be on track to meet the desired future condition of 190 - 285 square feet per acre of conifer basal area by 140 years depending on site class (

Table 3). Hardwoods, mostly red alder, dominated on all sites on both basal area and trees-per-acre bases.

Though conifer stocking was limited, average conifer diameters were the same or larger than the dominant hardwoods. Nearly all sites had one or more of the following conifer species: Douglas-fir, western hemlock, and western redcedar. Sitka spruce occurred on half of the coastal sites (sites 8, 11, and 14) and was the only conifer species observed on site 14.

Table 3. Pre-harvest riparian stand characteristics within the combined core and inner zone. Values in parenthesis are percent.

Site	Total	Hardwood			Conifer		
	BA (sq ft/ac)	BA (sq ft/ac)	TPA	Mean dbh	BA (sq ft/ac)	TPA	Mean dbh
5	109	90 (83)	93 (83)	12.9	19 (17)	19 (17)	12.3
8	239	177 (74)	175 (78)	13.1	62 (26)	48 (22)	13.2
11	236	174 (74)	122 (72)	15.6	62 (26)	48 (28)	13.7
12	229	148 (65)	133 (76)	13.7	81 (35)	43 (24)	16.7
13	150	82 (55)	88 (70)	12.4	68 (45)	38 (30)	15.7
14	162	128 (79)	111 (94)	13.7	34 (21)	7 (6)	27.0
15	152	135 (89)	123 (96)	13.4	16 (11)	5 (4)	22.2
23	200	177 (89)	133 (92)	14.9	23 (11)	11 (8)	16.4

Harvest Practices

Figure 2 through Figure 9 depict the spatial extents of the harvest units, hardwood conversion areas, and no-cut harvest riparian buffers. Hardwood conversion areas are located within the area of the core zone and the inner zone not included in the no-cut harvest buffers. Several trends in harvest layout and practice are notable among the study sites.

Generally, harvest units on lands managed by larger industrial landowners (Weyerhaeuser, Longview Fibre, and Pope Resources) are larger than those on lands managed by smaller industrial landowners (Merrill and Ring and Green Crow). For example, sites 5, 13, 14, 15, and 23 include relatively larger proportion of the harvest units in upland[6] areas while sites 8, 11, and 12 have a higher proportion of their harvest unit in the RMZ.

Hardwood conversion prescriptions were approved under a “Feasibility/Pilot Study” alternate plan. Relative to standard rules, these prescriptions more than doubled the harvestable areas in the core and inner zones. The alternate plan used in the study allowed landowners to harvest up to 25 feet from the stream bank—half of the width of the core zone. Rules protecting “sensitive sites” still applied and landowners were expected to leave all conifers.

Hardwood conversion areas tend to be variable in width depending on many factors, including: the location of accessible and commercially valuable hardwoods; presence of sensitive sites, typically seeps; un-harvestable pockets of dense vine maple or other shrubs; areas with low

[6] Upland refers to the harvested area encompassed by the outer zone of the RMZ plus all harvested areas outside the RMZ. These are areas that would be harvested without hardwood conversion.

probability of successful conifer regeneration; patches of conifers which did not represent an obstruction or hazard; and, other inaccessible areas of the core/inner zone.

Despite these differences in unit layouts, all sites had relatively small (that is, less than 5 acres) hardwood conversion areas (Table 4). In total, only 20.5 acres were converted during this pilot study. Hardwood conversion areas were largest, both in total extent and relative extent, at sites managed by Green Crow and Merrill and Ring. In comparison, hardwood conversion areas were smaller where the overall unit size was greater.

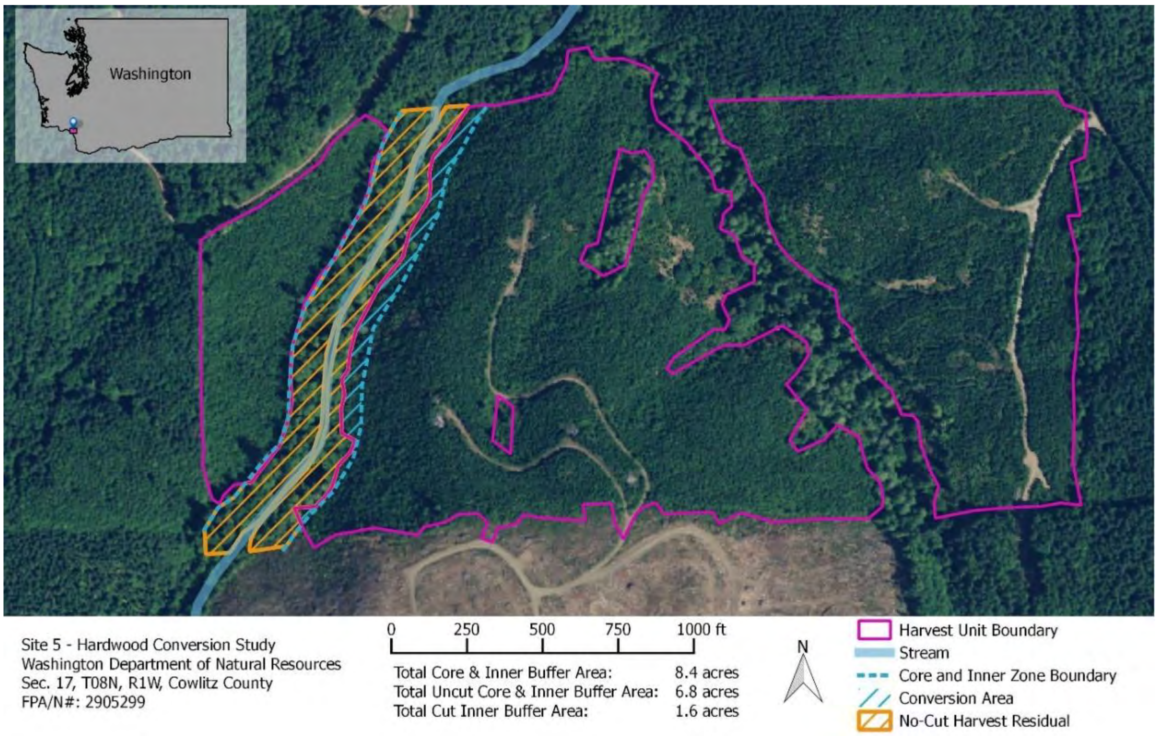

Figure 2. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 5. Aerial imagery collected in 2016.

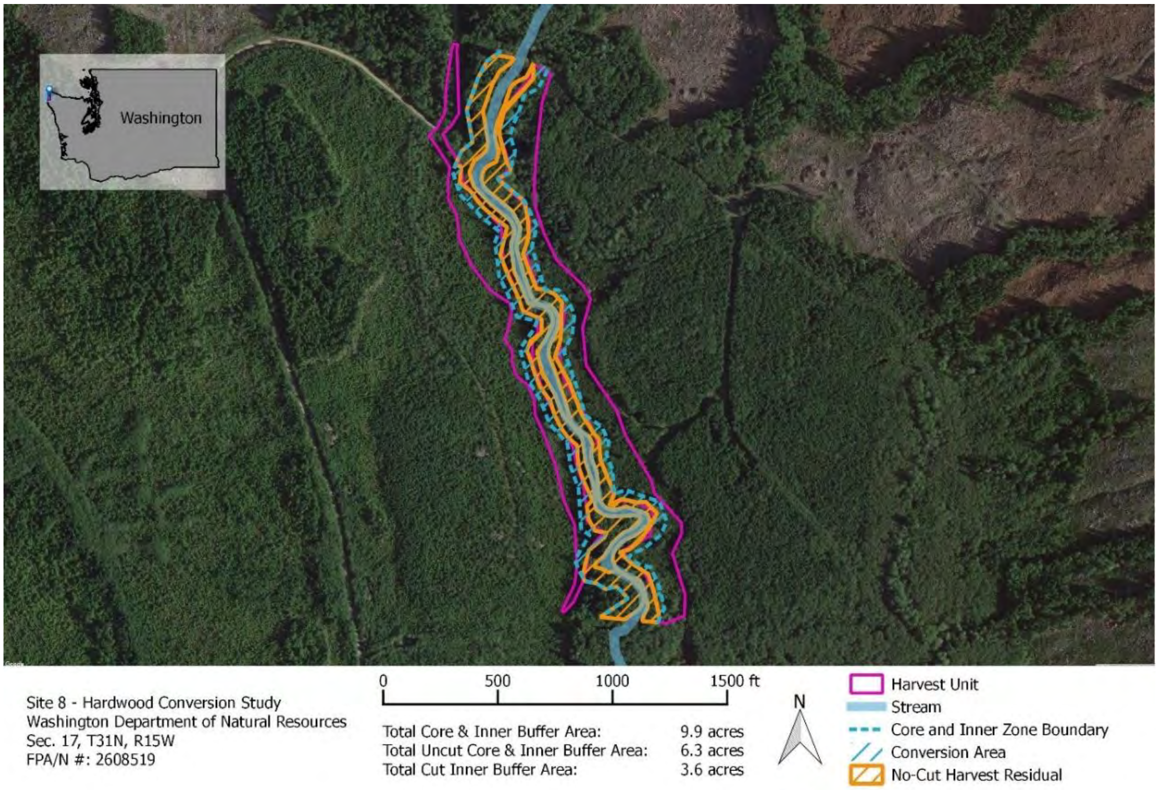

Figure 3. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 8. Aerial imagery collected in 2016.

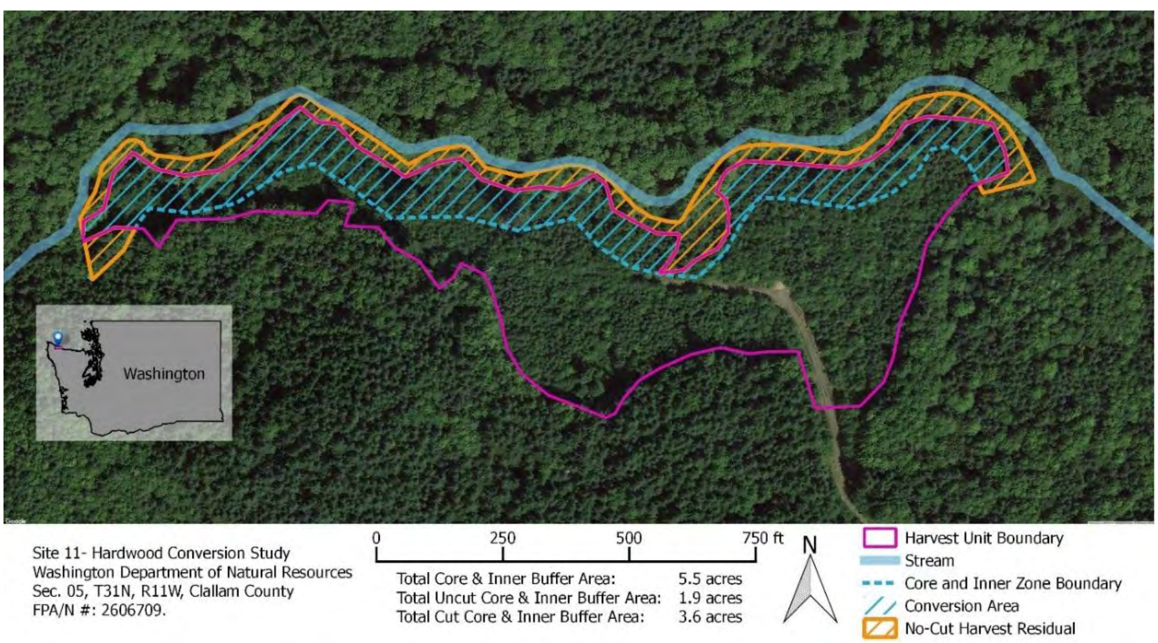

Figure 4. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 11. Aerial imagery collected in 2016.

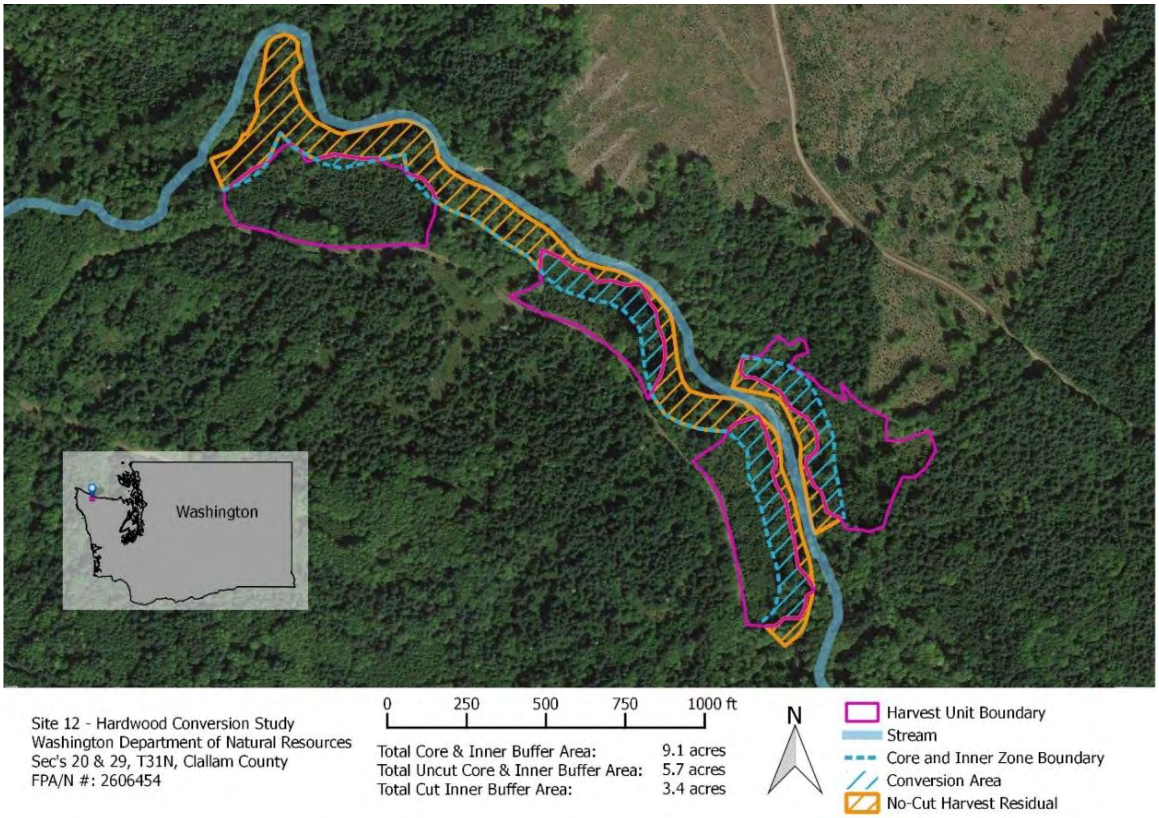

Figure 5. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 12. Aerial imagery collected in 2016.

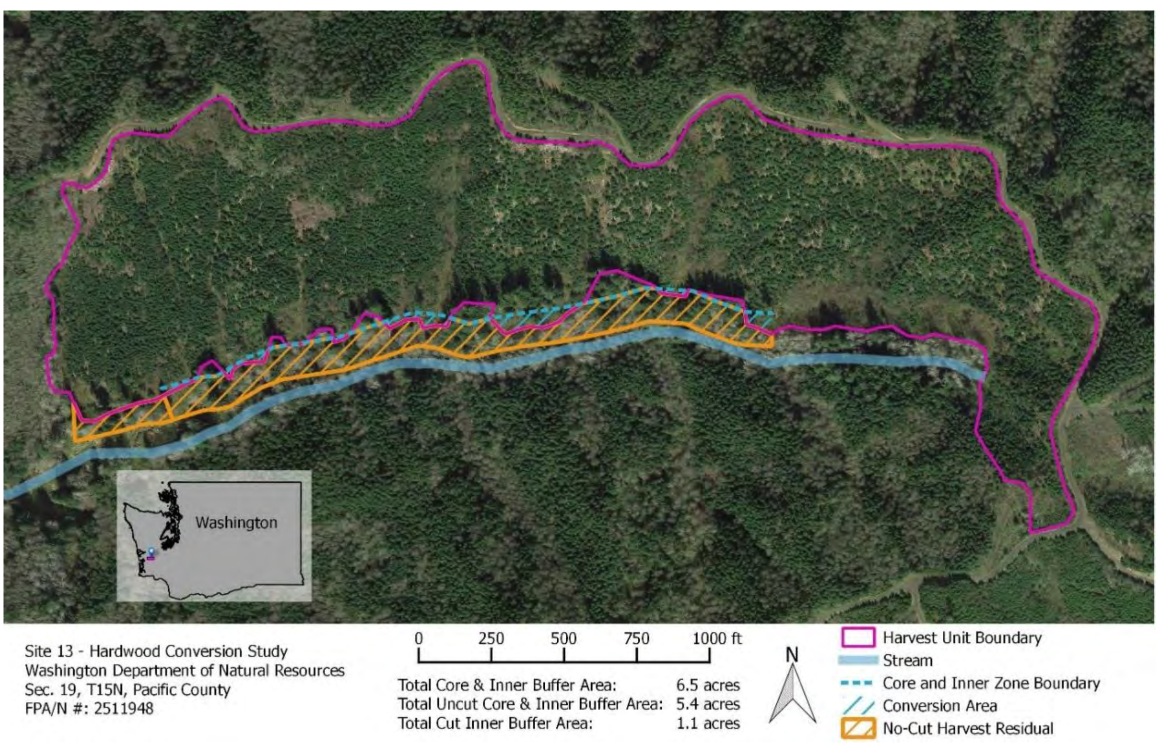

Figure 6. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 13. Aerial imagery collected in 2016.

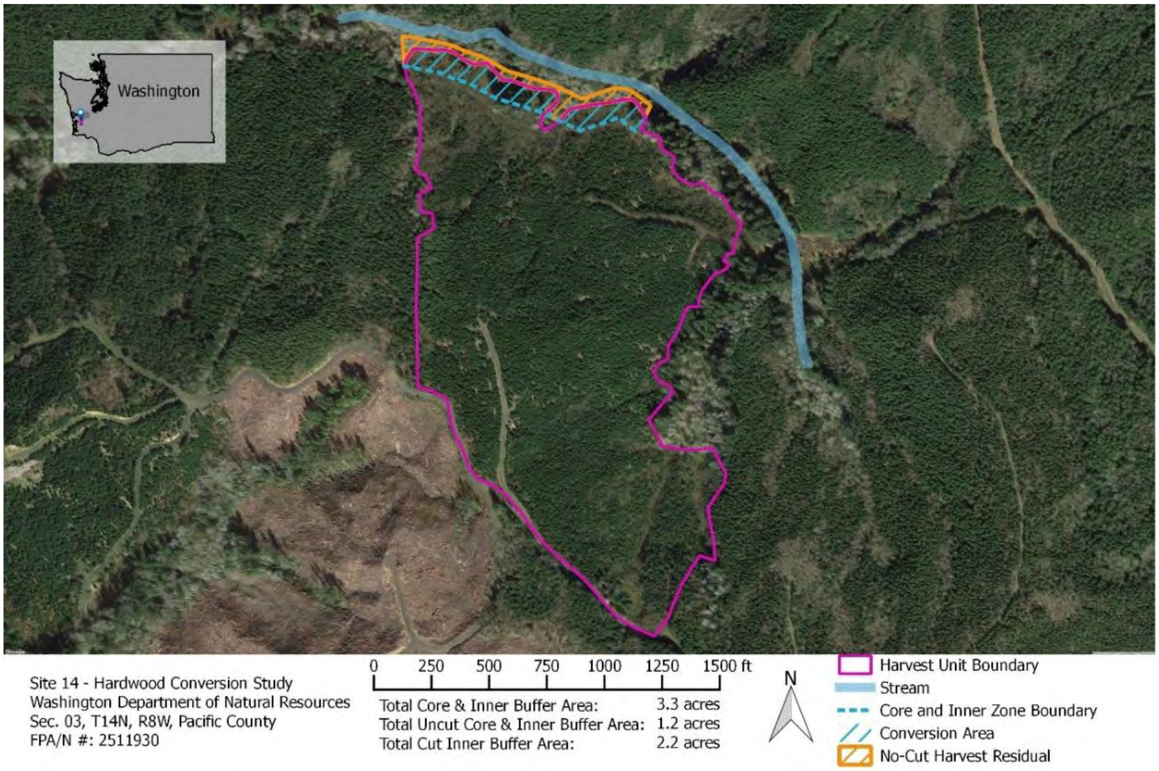

Figure 7. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 14. Aerial imagery collected in 2016.

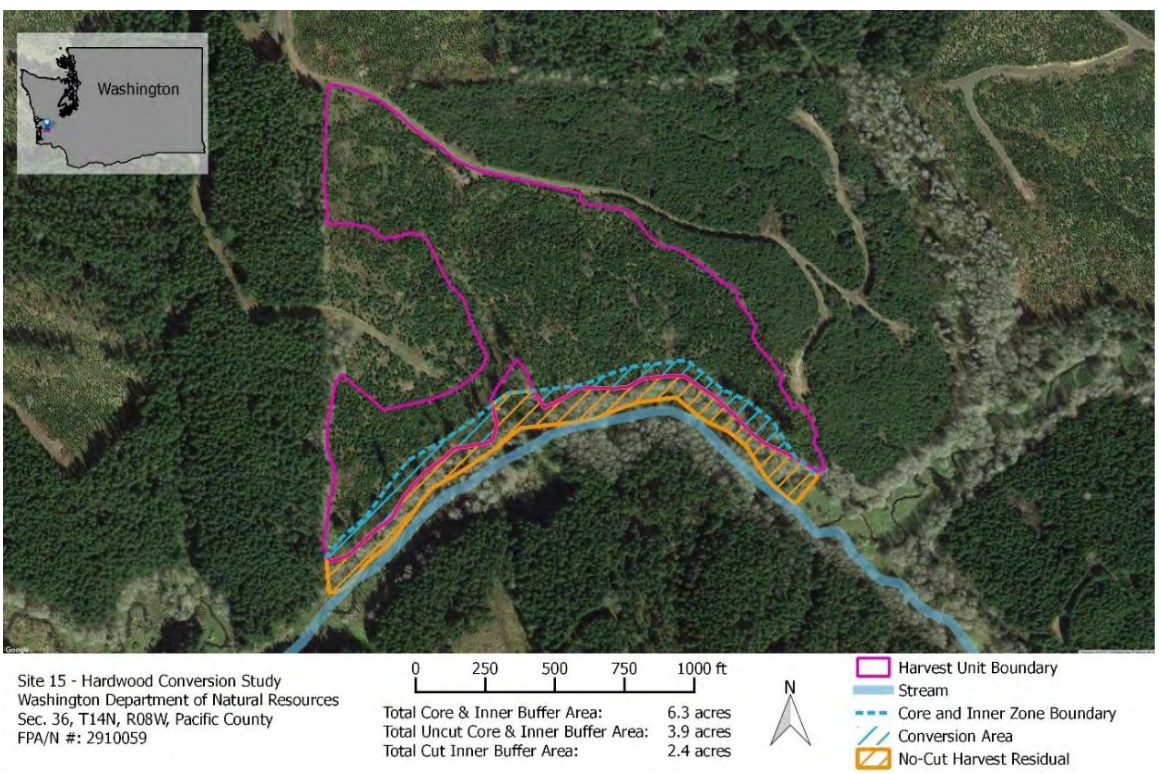

Figure 8. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 15. Aerial imagery collected in 2016.

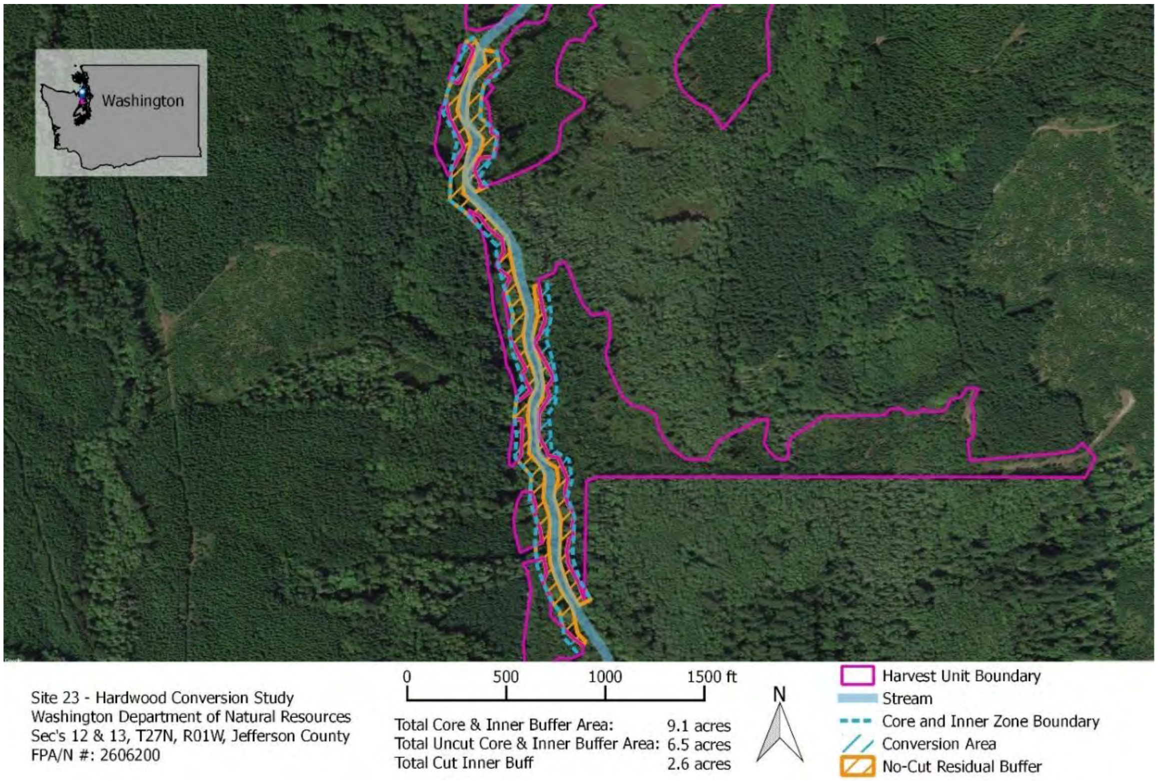

Figure 9. Harvest unit boundary, combined core and inner zone boundary, conversion area, and no-cut buffer, Site 23. Aerial imagery collected in 2016.

Table 4. Extent of harvest unit, upland, combined core and inner zones, and hardwood conversion areas.

Site	Harvest Unit Area (ac)	RMZ Width (ft)	Stream Segment Length (ft)	Upland Area (ac)	Combined Core and Inner Zone Area (acre)	Hardwood Conversion Area (ac)
5	68.0	113	1,800	66.4	8.4	1.6
8	14.0	68	2,970	10.4	9.9	3.6
11	8.5	105	2,200	4.9	5.5	3.6
12	15.0	105	3,500	11.6	9.1	3.4
13	62.0	128 -- 113	2,600	60.9	6.5	1.1
14	51.0	128	1,150	48.8	3.3	2.2
15	33.0	128	2,100	30.6	6.3	2.4
23	62.7	68	3,100	60.1	9.1	2.6

Post-harvest Stocking

Post-harvest stocking (nominally, Year 0) was determined for both the combined core zone and inner zone as well as for the hardwood conversion areas within the combined core zone and inner zone. Post-harvest stocking in the combined core zone and inner zones could be summarized directly from post-harvest plot measurements (Table 5). Compared to pre-harvest levels in the combined core zone and inner zone (

Table 3), post-harvest stocking was between about 50 and 80 percent of pre-harvest stocking levels.

Post-harvest stocking in the hardwood conversion areas (Table 6) was estimated by applying ratios calculated at year 10 (stocking in hardwood conversion area to stocking in the combined core zone and inner zone) to the Year 0 values reported in the combined core zone and inner zone (Table 5). Compared to pre-harvest levels in the combined core zone and inner zone (

Table 3), post-harvest stocking in the hardwood conversion areas is substantially lower. Little to no hardwood stocking remains and very little conifer was removed.

Table 5. Post-harvest riparian stand characteristics within the combined core and inner zone. Values in parenthesis are the percent of basal area remaining after harvest.

Site	Total	Hardwood			Conifer		
	BA (sq ft/ac)	BA (sq ft/ac)	TPA	Mean dbh	BA (sq ft/ac)	TPA	Mean dbh
5	84 (77)	72 (80)	72	13.2	12 (63)	8	14.4
8	182 (76)	125 (71)	118	13.4	57 (92)	41	13.7
11	118 (50)	87 (50)	48	17.8	31 (50)	24	13.7
12	154 (67)	77 (52)	66	14.1	77 (95)	39	17.0
13	124 (83)	58 (71)	61	12.5	67 (99)	36	15.9
14	85 (52)	62 (48)	52	13.9	23 (68)	4	30.8
15	107 (70)	91 (67)	70	14.6	16 (100)	5	22.7
23	129 (65)	109 (62)	82	15.0	20 (87)	9	16.9

Table 6. Post-harvest riparian stand characteristics within the hardwood conversion areas. Values in parentheses are percentages remaining after harvest.

Site	Total	Hardwood			Conifer		
	BA (sq ft/ac)	BA (sq ft/ac)	TPA	Mean dbh	BA (sq ft/ac)	TPA	Mean dbh
5	6	6 (100)	80 (94)	0.9	0 (0)	5 (6)	1.9
8	64	15 (23)	110 (72)	1.7	41 (77)	43 (18)	9.8
11	27	1 (4)	57 (71)	0.1	23 (96)	23 (29)	11.1
12	65	7 (11)	57 (58)	1.7	55 (89)	41 (42)	10.8
13	41	0 (0)	-- (0)	0.0	37 (100)	47 (100)	5.3
14	36	0 (0)	-- (0)	0.0	28 (100)	4 (100)	35.5
15	28	1 (4)	67 (93)	0.2	22 (96)	5 (7)	26.8
23	5	0 (0)	-- (0)	0.0	4 (100)	7 (100)	5.5

Post-harvest Overstory Cover

Post-harvest overstory cover[7] in the hardwood conversion areas is calculated two ways in Table 7—the percent of all regeneration plots where overstory cover existed and the average percent overstory cover over all plots. Overstory cover could occur from residual conifers and hardwoods as well as from adjacent, overhanging hardwood or conifer trees. Though the percent of regeneration plots with some overstory cover could be relatively high—most sites had nearly 50 percent or more plots with some cover—the overall average percent overstory cover at these sites was relatively low—most sites had less than 15 percent cover.

Table 7. Post-harvest overstory tree cover within the hardwood conversion areas. Values in parentheses are standard deviation.

	Overstory Above Sample Plots	
Site	**Percent of regeneration plots with overstory cover (%)**	**Average percent overstory cover (%)**
5	7	1 (2.7)
8	32	4 (5.9)
11	47	8 (13.1)
12	50	10 (15.7)
13	46	5 (6.3)
14	45	13 (22.0)
15	84	22 (23.5)
23	83	11 (10.9)

[7] Overstory cover sampling methodologies were not specified in field protocols provided for this summary report, which introduces an unknowable level of uncertainty in these values. Values reported in this section come from Brown (2016).

Regeneration Practices

Regeneration practices employed at the eight study sites are summarized in

Table 8. Key practices included site preparation, animal control, planting, and vegetation control that occurred after planting. Additional information about planting histories and the planted tree heights are summarized in

Table 9 and Table 10. Detailed accounts of the regeneration practices employed are provided in the Case Study Report. A brief synthesis is provided here.

Though all sites were treated with what most foresters would consider standard regeneration practices for the region, hardwood conversion areas managed by Merrill and Ring (sites 11 and 12) received the most intensive regeneration management:

- Only the sites managed by Merrill and Ring (11 and 12) received site preparation. This consisted of shovel-piling slash and shrubs—notably including large vine maple plants—in the conversion areas outside the equipment exclusion zone prior to planting, and then burning the debris before or during the planting period.
- Mountain beavers were trapped three times at these two sites, each trapping associated with each of the three different plantings that occurred—one initial planting with two follow-up interplantings to “fill” stocking. The six other study sites received one trapping, at most, after the initial planting.
- Western redcedar planting densities were higher at these two sites than at other sites. To minimize browse damage, Sitka spruce was planted in the same planting hole as western redcedar so that the prickly needles of the spruce would deter deer- and elk-browse. (The landowner plans to remove the Sitka spruce when western redcedar seedlings exceed browsing height.)
- When the double planting is accounted for, actual planting densities are about one-third lower than shown in

- Table 8. Even with an adjustment, planting densities are higher than at the other sites. Merrill and Ring interplanted their two sites twice.
- Less emphasis was placed on Douglas-fir planting at these two sites compared to that at all but one (site 8) of the six other study sites.
- Sites 11 and 12 were the only study sites to receive post-planting brush control. Brush was cut with a chainsaw 1 year after the initial planting at site 12 and cut with a chainsaw 2 years after the initial planting at site 11.
- Alder slashing was conducted at sites 11 and 12 to control volunteer hardwood stocking.

In comparison, the six other study sites—managed by Green Crown, Pope Resources, and Weyerhaeuser/Longview Fibre—received no site preparation prior to planting, and two sites (5 and 8) received brush control after planting. Other key differences at these other study sites include:

- Weyerhaeuser (sites 13, 14 and 15) trapped mountain beavers once: in January, after their three sites were initially planted with western hemlock. Sites 5, 8 and 23 had little if any evidence of mountain beaver, thus no mountain beaver trapping was done.
- Longview Fibre (site 5), installed paper bud caps on the planted Douglas-fir and mesh tubing on the planted western redcedar seedlings. Pope Resources (site 23) installed mesh tubing on about one quarter of the western redcedar seedlings that were interplanted 3 years after the initial planting event.
- With the exception of the site managed by Green Crow (site 8), Douglas-fir was the species of emphasis on the six other study sites. It was planted in association with, or after planting, one or more of the following species: western hemlock, Sitka spruce, western redcedar, and grand fir. In most instances, Douglas-fir was planted the year following harvest.
- Sitka spruce was the only species planted at the Green Crow site (site 8). Harry Bell, chief forester at Green Crow explained that his preference is to plant Sitka spruce in areas not susceptible to tip weevil damage when there is no expectation of future harvest (RSAG, personal communication).
- Precommercial thinning and hardwood slashing was conducted at sites 5 and 8.

Table 8. Summary of regeneration practices employed within hardwood conversion areas.

	Site							
	5	8	11	12	13	14	15	23
Site preparation:								
Mechanical slash pile & burn	--	--	Yes	Yes	--	--	--	--
Animal control:								
Mtn. beaver trappings (no.)	--	--	3	3	1	1	1	-
Seedling Protection	Y[1]	--	Y[2]	Y[2]	--	--	-	Y[3]
Planting:								
Growing seasons before planted	1	0	0	0	0	0	0	0
Initial planting (TPA)[4]	554	451	752	740	212	80	145	248
Inter-plant (TPA)	0	0	275	450	215	245	158	15
Douglas-fir (%)	86	0	4	4	50	75	52	36
Major stock type	FP+1[5]	P+1[6]	P+1	P+1	1+1[7]	1+1[7]	1+1[7]	P+1
After planting brush control:								
Hand Brushing (w/ chainsaw)	--	--	Y	Y	--	--	--	--
PCT/Slashing	Y	Y	Y	Y	--	--	--	--

[1]Paper bud caps and mesh tubing; [2]Sitka spruce planted with redcedar; [3]Mesh tubing on western redcedar at time of planting, nets with stakes on 150 of the 600 interplanted redcedar; [4] density estimates based on field data; [5]FP+1 = plug+1 seedlings transplanted early ('F' signifies fall transplanting) to increase time in nursery bed prior to outplanting at site; [6]P+1 = seedlings grown in a container (plug) for 1 year, then grown in nursery bed for 1 year; [7]1+1 = seedlings grown in nursery bed at high density for 1 year, then transplanted to a lower density and grown for 1 year.

Table 9. Summary of trees per acre (TPA) planting density in hardwood conversion areas.

Site	Planting Date	TPA Planted					Total
		DF	WH	RC	SS	GF	
5	Feb. '07	479	--	75	--	--	554
8	March '08	--	--	--	451	--	451
11	Feb. '06	31	161	288	295	--	775
	Feb. '07	2	48	92	88	--	230
	Feb. '10	--		34	30	--	64
12	Feb. '06	15	140	290	295	--	740
	Feb. '07	40	48	148	138	--	373
	Feb. '10	--		63	63	--	126
13	Spring '05	--	219	--	--	--	219
	March '06	215		--	--	--	215
14	Spring '05	--	83	--	--	--	83
	March '06	243		--	--	--	243
15	Spring '05	--	147	--	--	--	147
	Feb. '06	158	--	--	--	--	158
23	Jan. '05	94	--	38	102	15	249
	Jan. '09	--	--	15	--	--	15

Table 10. Summary of planted tree heights, in inches, in hardwood conversion areas.

Species	Site							
	5	8	11	12	13	14	15	23
Douglas-fir	20.4	--	14.4	13.2	13.2	14.4	13.2	19.2 [2]
Western hemlock	--	--	22.8	24.0	28.8 [1]	30.0 [1]	26.4 [1]	--
Sitka spruce	--	15.6	16.8	16.8	--	--	--	18.0 [2]
Western redcedar	12.0	--	16.8	16.8	--	--	--	21.6 [2]
Grand fir	--	--	--	--	--	--	--	16.8 [2]
Mean	19.3	15.6	17.9	18.1	13.2	14.4	13.2	18.9

[1]Seedling height at the time of planting was likely shorter because heights were first measured approximately 12 months after planting.

[2]Seedling height at the time of planting was likely shorter because heights were measured approximately 16 months after planting.

Evaluation

Table 11 summarizes metrics used to answer Questions of Interest posed in the Hardwood Conversion Study Plan that are being addressed in this report. Generally, silvicultural performance is evaluated by survival, height growth, and free-to-grow status. Economic performance is evaluated by harvest and regeneration costs. Factors related to silvicultural and economic performance are evaluated using modeling described in the Discussion section.

Table 11. Analytical metrics used to address selected Questions of Interest in the Hardwood Conversion Study Plan.

Question of Interest	Analytical Metrics
Silvicultural Performance	
What were the survival rates of planted seedlings in the RMZ?	Survival at year 4 and year 10.
What were the growth rates of planted seedlings in the RMZ?	Height growth at year 4 and year 10.
How many conifers are free-to-grow in the RMZ?	Number of conifers greater than 8 inches dbh, number of seedlings and saplings above brush, number of seedlings and saplings above natural hardwood regeneration, and percent stocking of conifers seedlings and saplings at year 4 and year 10.
What regeneration strategies did landowners use to ensure successful conifer regeneration in the RMZs?	Correlation of stocking, survival, growth rate, free-to-grow, at year 4 and year 10, to selected landowner cultural practices (such as animal control, brush control, and alder control).
What were the primary problems that landowners faced regenerating the RMZs with conifers?	Correlation of stocking, survival, growth rate, free-to-grow, at year 4 and year 10 to selected site factors (such as habitat type group, overstory cover, understory cover, landform, distance to stream, need for animal control).
Economic Performance	
What additional harvest costs resulted from adding hardwood conversion treatments to the harvest prescription?	Harvest costs.
How much wood (volume, board feet) was harvested from the riparian management zones?	Harvest volumes.
How much wood (volume, board feet) was harvested from the upslope portions of the units?	Harvest volumes.
What were the cost differences between successfully regenerating conifers in the riparian area versus successfully regenerating conifers in the adjacent, upslope areas?	Regeneration costs.
What were the net financial gains (or losses) that resulted from adding riparian hardwood conversion treatments to the harvest prescriptions?	Residual value.
What were the primary reasons for different costs (if any) between regenerating conifers in riparian areas versus regenerating conifers in adjacent, upslope areas?	Correlation of regeneration costs to cultural factors and site factors listed above.

Silvicultural Performance

Metrics used to answer questions regarding silvicultural performance are based on regeneration surveys that have been conducted following the procedures outlined in a series of Post-Harvest Regeneration Survey Procedures Manuals (Versions 1.3 thru 2.1). These procedures include plot layout, data collection, and data reduction protocols:

- Regeneration plot layout – Planted tree and competing vegetation data have been collected on monumented, 1/50–acre circular plots (33.3 feet in diameter) installed on a grid pattern within the hardwood conversion areas. Plot-center spacing is approximately 60 by 60 feet. The number of plots and realized sampling intensity varied by site (Table 12) with an average of approximately 22 plots used covering approximately 18% of the hardwood conversion areas.

- Tree data collection – During each sampling event, the number of live and dead planted and natural seedlings are recorded by species, along with tree attributes including height, diameter at breast height, and live-crown ratio. Tree surveys are conducted either in the spring, prior to conifer "budbreak" and seasonal height growth, or in late fall after most seasonal conifer height growth had occurred.

  The concept of a "Growth Year" was used to establish the period that the data represent. We define growth year as a one-year period starting July 1, and use the year associated with the July 1 start date to designate the growth year (e.g., a survey conducted on April 15, 2006 would be in the 2005 Growth Year).

  Though field crews could reliably observe conifer mortality—including missing trees presumed dead, as well as extant dead trees—field crews were not able to reliably assign specific causes of mortality. This confounds data interpretation, particularly the interpretation of the relationships with animal-browse and of the relationships with animal control.

  Likewise, crews were not able to readily identify damage or causes of damage to seedlings resulting in some trees losing height between measurements, which would not occur without damage to the tree. These "shrinking" trees were not used in height growth calculations because these trees would introduce bias to the analysis. However, these trees were used in other analyses.

- Competing vegetation data collection – During each sampling event, the mean percent cover of residual trees, shrubs, ferns, grasses, and herbs are visually estimated within each plot. These surveys are conducted at the same time as the planted tree surveys. Though these shoulder seasons increased the visibility of conifer while brush was not leafed-out, they are not the ideal time to observe some vegetation species because many have not emerged, have not leafed out, or have already receded since their peak.

- Data reduction – Field data are recorded in a Microsoft Access database and reduced following standard forest biometrics practices. Database schemas are documented via Post-Harvest Regeneration Survey Procedures Manuals (Versions 1.3 thru 2.1). Data reduction routines were implemented using R software (R Core Team 2017). R code for this report is documented in the R project distributed with this report.

- Statistical modeling – To identify factors statistically explaining free-to-grow status of planted trees in the hardwood conversion areas, we created a generalized linear model using logistic regression in the R statistical software (R Core Team 2017). Free-to-grow status is dichotomous variable specifying whether tree was alive and did, or did not, have its leader above the brush at 10 years after planting. Stepwise regression was used to sequentially select the most influential factors explaining the likelihood of a tree surviving and having its leader above the brush 10 years after planting. Factors considered in the stepwise regression included:
  - Site-level (N = 8):
    - Site number as a surrogate for all unmeasured site variables
    - Site preparation occurrence
    - Brush control occurrence
    - Planted trees per acre for each species
  - Plot-level (N = 94):
    - Year 0 post-harvest cover and mean height of shrubs, ferns, herbs, and grasses
    - Year 4 post-harvest cover and mean height of shrubs, ferns, herbs, and grasses
    - Year 0 post-harvest volunteer hardwood basal area and trees per acre
    - Year 4 post-harvest volunteer hardwood basal area and trees per acre
    - Year 0 post-harvest retained overstory cover
    - Landform - hill slope or grouped fluvial terrace/floodplain
    - Slope
    - Aspect
    - Plot center distance from the stream
  - Tree-level (N = 2,122 unique trees):
    - Tree species
    - Interplanting status – whether the tree was planted initially or in one of the interplantings.

Parameters were selected in stepwise regression using the stepAIC function starting with a null model with only an intercept parameter and then sequentially adding parameters keeping only those that reduce the resulting model's AIC score. Significance of terms in the final model were evaluated relative to an *a priori* five percent level of significance (i.e., P-value <= 0.05).

In this report, metrics are calculated for nominal time periods "Year 0" (post-harvest), "Year 4" (four years since timber harvest), and "Year 10" (ten years since timber harvest). However, because timber harvest and planting occurred on different schedules, the actual time periods vary site-to-site as reported within tables and figures.

Table 12: Sampling plot summary including the number of plots, sampling intensity, and percent area sampled at each site.

Site	Hardwood Conversion Area (ac)	Plots	Sampling Intensity (plots/ac)	Percent Area Sampled
5	1.6	14	8.8	17.5
8	3.6	38	10.6	21.1
11	3.6	32	8.9	17.8
12	3.4	20	5.9	11.8
13	1.1	13	11.8	23.6
14	2.2	20	9.1	18.2
15	2.4	19	7.9	15.8
23	2.6	23	8.8	17.7

Economic Performance

To assess the cost/benefit of adding hardwood conversion to the harvest unit prescription, the following study-specific definitions are used in evaluating economic performance:

- Upland refers to the harvested area encompassed by the outer zone of the RMZ plus all harvested areas outside the RMZ. These are areas that would be harvested without hardwood conversion.

- Conversion area refers to the area within the core and inner zones of the RMZ that is being converted to conifer-dominated stands under WAC 222-30-021(1)(b)(i).

This area distinction permits comparison of the economic performance of site operations with hardwood conversion areas to economic performance without hardwood conversion. Without hardwood conversion, it is assumed that riparian harvest would only have occurred in the outer zone. Thus, the designation of the outer zone as “upland” is made solely to support the economic analysis—this designation does not presume any ecological meaning.

This report summarizes, at a unit level, the detailed economics analyses presented in the Case Study Report. Briefly, economic analyses use stumpage values published by the Washington Department of Revenue for the period when harvesting occurred (2005 – 2007 when red alder log prices were relatively consistent), which includes mill-gate log prices, harvest system-based stump-to-truck costs, and location-based haul costs. Additional costs, including site preparation and planting, unit layout, and administrative costs provided by landowner are deducted from the overall stumpage to arrive at a net residual value. For details of the economic analysis see the Case Study Report for economic data sources, methods, assumptions, and limitations underlying its evaluation of economic performance.

Study Limitations

Because this study was a collection of case studies there is no overarching experimental design. Conditions on the site do not span the range of conditions that may be encountered across the population of sites that may be encountered in areas that may be candidates for hardwood conversions. Further, site-specific prescriptions were developed by landowner to fit site conditions and operability within the limitations of the general prescription guidelines resulting in unique site-specific prescriptions. While the lack of experimental design can preclude inference about the larger population of potential hardwood conversion sites, the data can be qualitatively evaluated to elucidate overarching patterns across the sites.

RESULTS

Silvicultural Performance

Shrubs, Forbs, and Grass

Appendix A, Figure 10, and

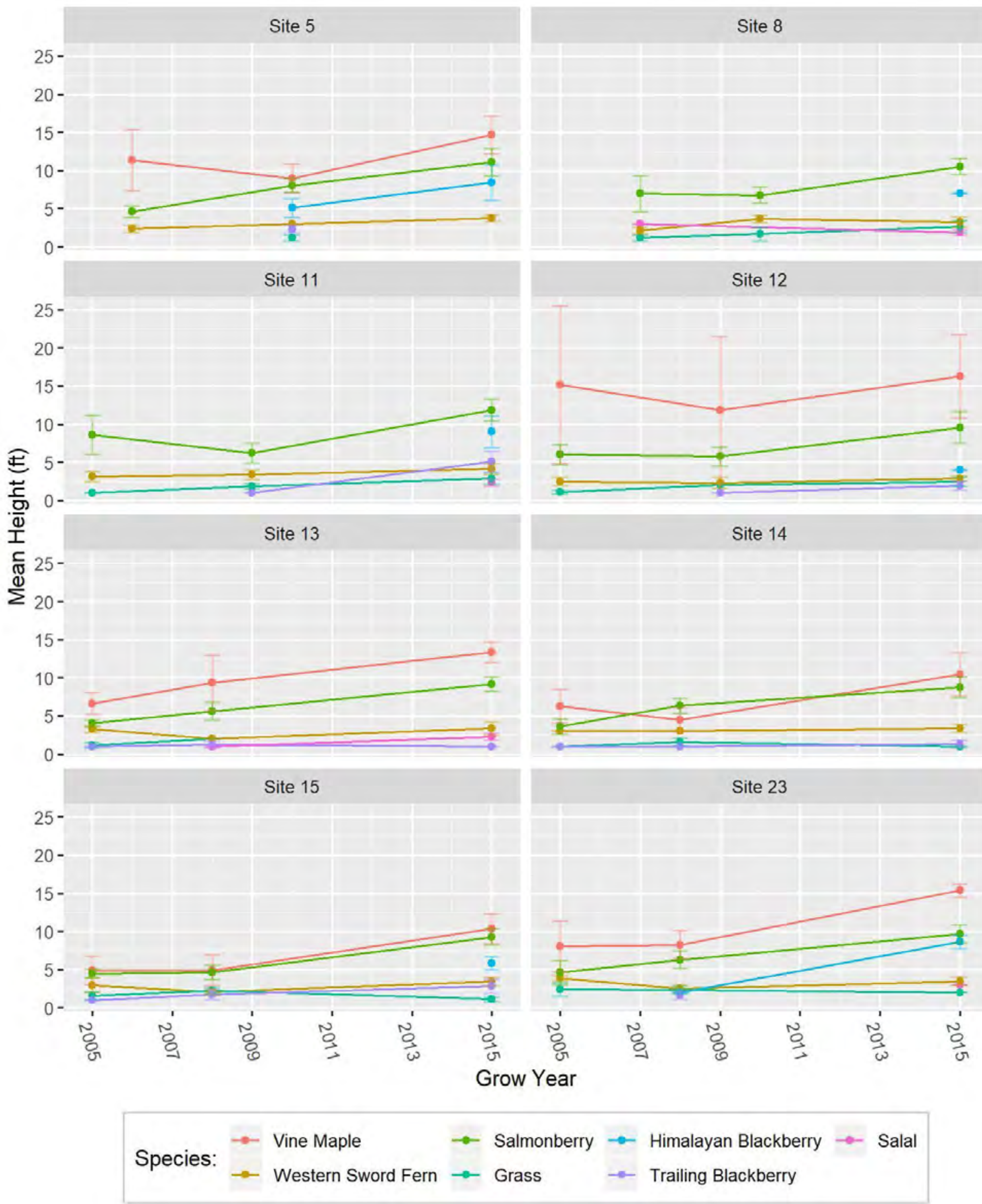

Figure 11 summarize the average shrub (including vine maple (*Acer circinatum*), salmonberry (*Rubus spectabilis*), salal (*Galtheria shallon*), trailing blackberry (*Rubus ursinus*), and Himalayan blackberry (*Rubus armeniacus*)), forb (primarily western sword fern (*Polystichum munitum*)), and grass cover and height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Where mechanical site preparation within the hardwood conversion areas was conducted to reduce shrub cover prior to planting (sites 11 and 12), year 0 shrub cover was less than 20 percent and remained below 20 percent four years post-harvest, presumably because of hand-brushing that occurred after the initial planting. Elsewhere, shrub cover exceeded 20 percent, often by a large amount, at year zero- and four-years post-harvest. By year 10 shrub cover exceeded 20 percent within regeneration plots on all eight study sites.

Salmonberry was the most common shrub at all but one site (site 15) by year 4 and remained the most common shrub at most sites 10 years post-harvest. By year 4, mean heights of salmonberry ranged between about 5 to 8 feet. By year 10, mean heights of salmonberry ranged between about 9 and 16 feet—near its maximum height potential of about 13 feet (Barber 1976). Other notable shrubs observed at the study sites included vine maple (3 sites), trailing blackberry (3), Himalayan blackberry (1), and salal (1). Vine maple and Himalayan blackberry tended to be as tall as salmonberry where they co-occurred; trailing blackberry and salal were significantly shorter, with average heights of less than 3 feet.

Grass and forbs (predominantly western sword fern) also occurred in various combinations at all study sites, but they occurred at relatively lower average percent covers compared to the predominant shrub cover (average combined cover at most sites was less than 30 percent) and at relatively lower average heights compared to the predominant shrub cover (average height was less than 4 feet). Percent cover of grass and forbs has decreased over time, presumably as shade from shrub cover has increased.

Volunteer Hardwoods

Appendix B, Figure 12, and Figure 13 summarize the average trees per acre stocking and the average height of volunteer hardwoods on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Though absent from most sites immediately post-harvest, red alder has been recorded at all sites since then. Though trends in red alder stocking over time are mixed—stocking is decreasing at some sites, while stocking is increasing at others—by year 10, red alder stocking was low to moderate—ranging between about 20 trees per acre and 200 trees per acre—at all but site 11 (about 500 trees per acre).

At year 0, the average height of red alder was less than 3 feet when it was found. By year 4, the average height of red alder ranged between about 3 and 7 feet. After year 4, height growth ranged between 2 and 3 feet per year at most sites. By year 10, the average heights of red alder were about 20 feet at most sites. Red alder height growth was very high at site 23 (about 4 feet per year) yielding an average height of nearly 40 feet—about twice the average height of red alder at all other sites.

Other volunteer hardwood species recorded at these sites were present at lower stocking levels and/or lower canopy positions compared to those of red alder. Cascara has been recorded at six of the eight study sites and has predominated on the three study sites converted by Weyerhaeuser (sites 13, 14, and 15). Where cascara occurred, average heights were always lower than those of red alder. Big leaf maple and bitter cherry have occurred on some sites, but at relatively low stocking levels and, in the case of bitter cherry, at relatively low heights.

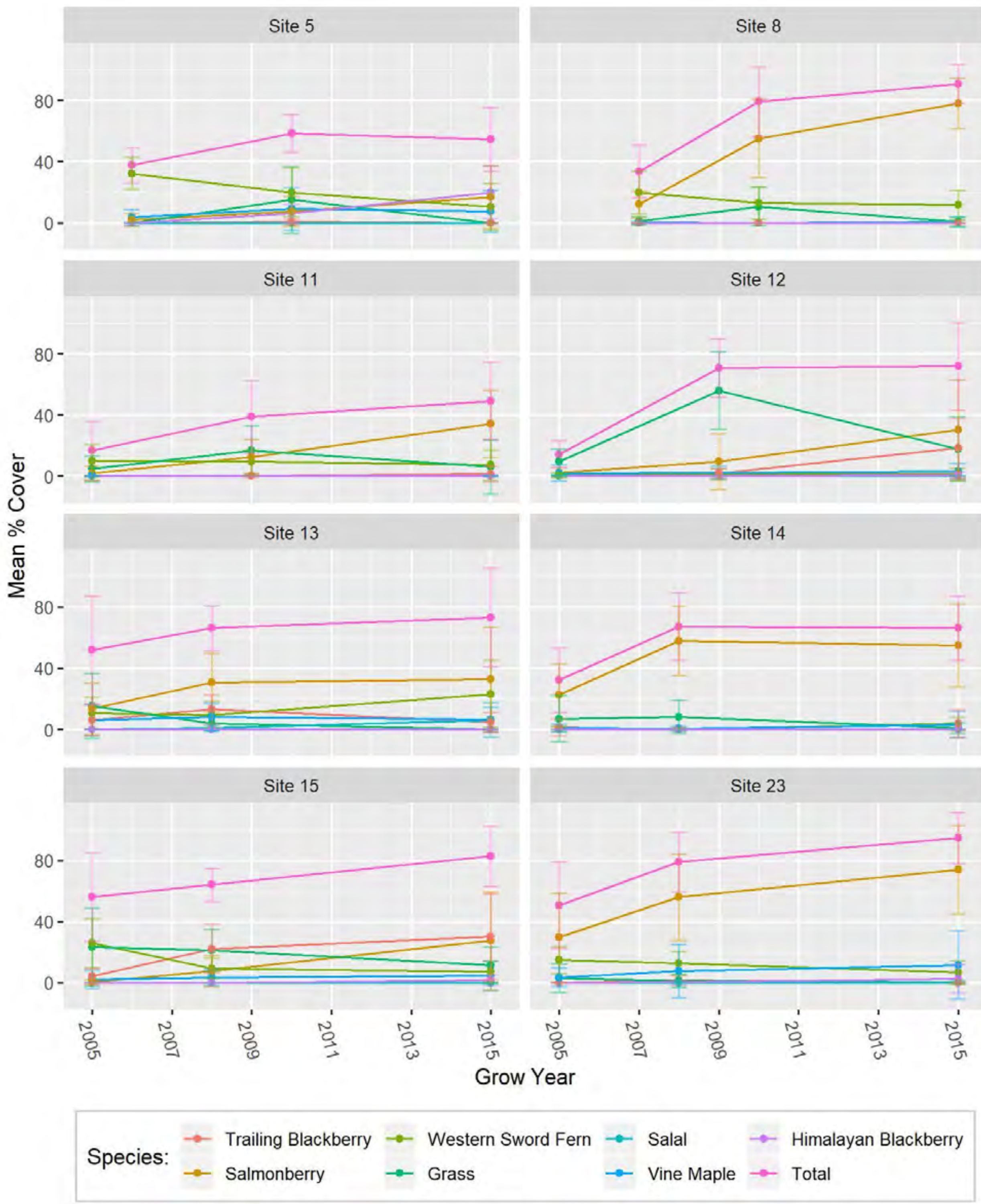

Figure 10. Average shrub, forb, and grass cover on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are one standard deviation.

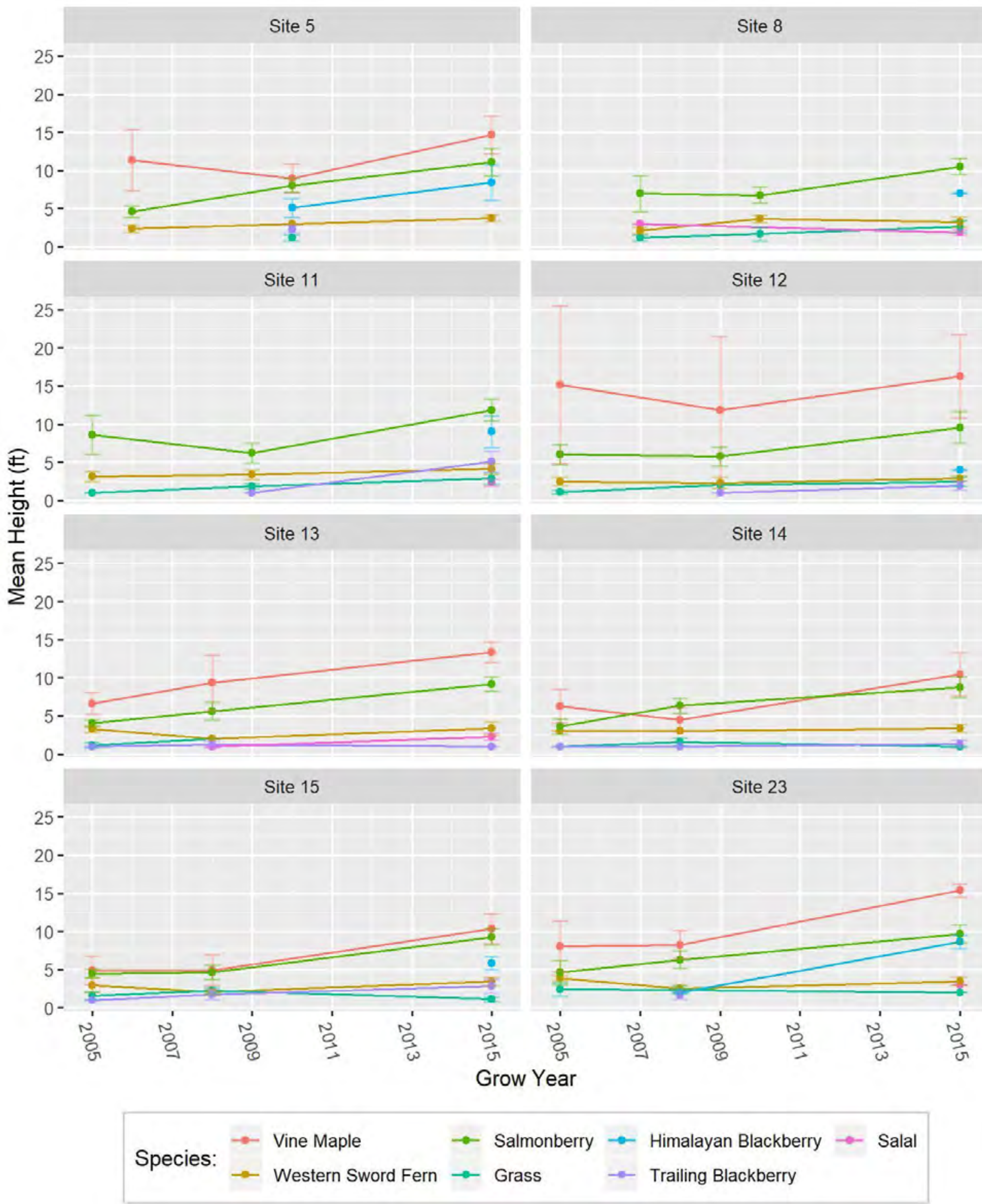

Figure 11. Average shrub, forb, and grass height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are one standard deviation.

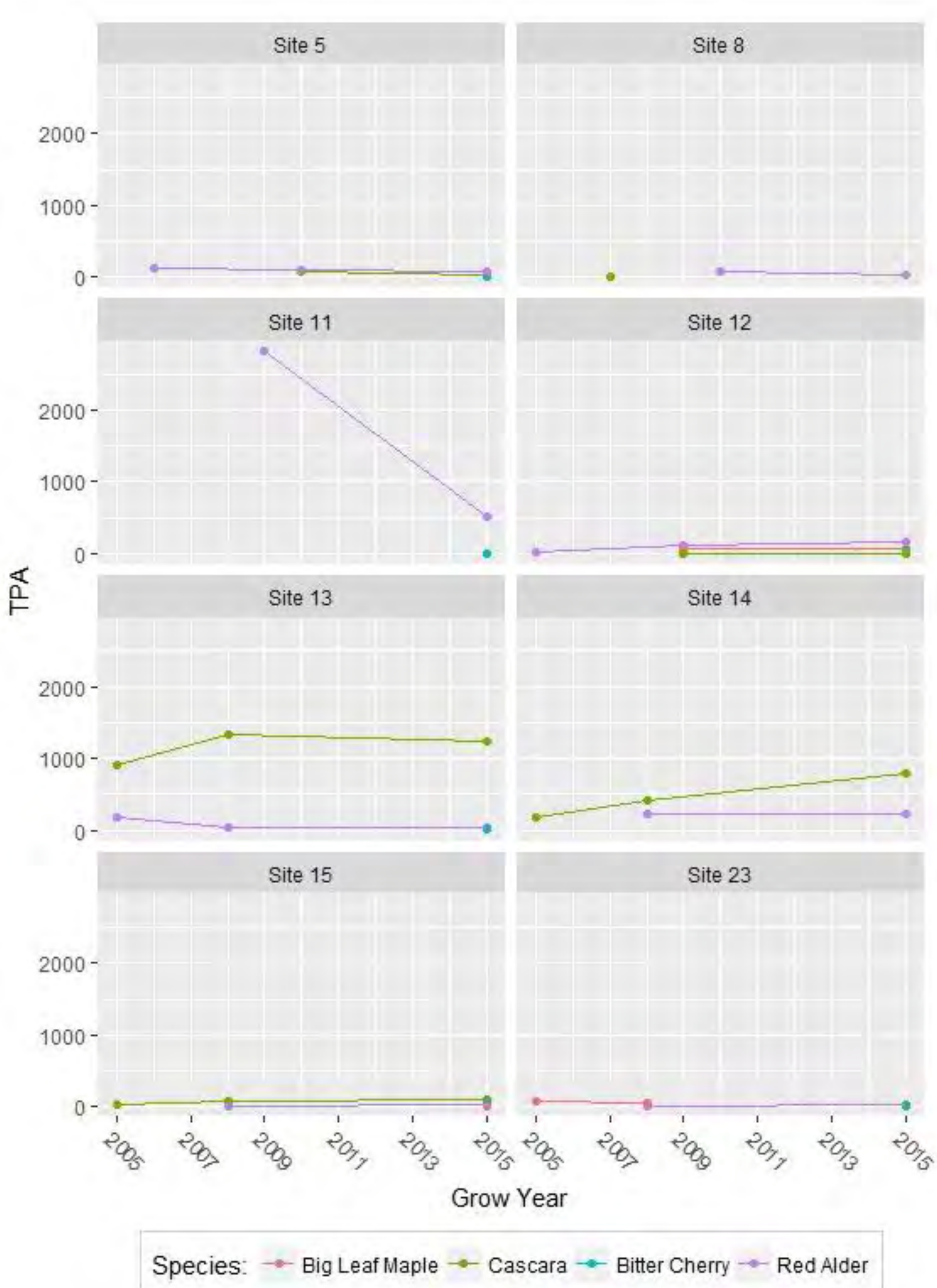

Figure 12. Average volunteer hardwood stocking on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are omitted for clarity of trends due to extremely high Coefficients of Variation.

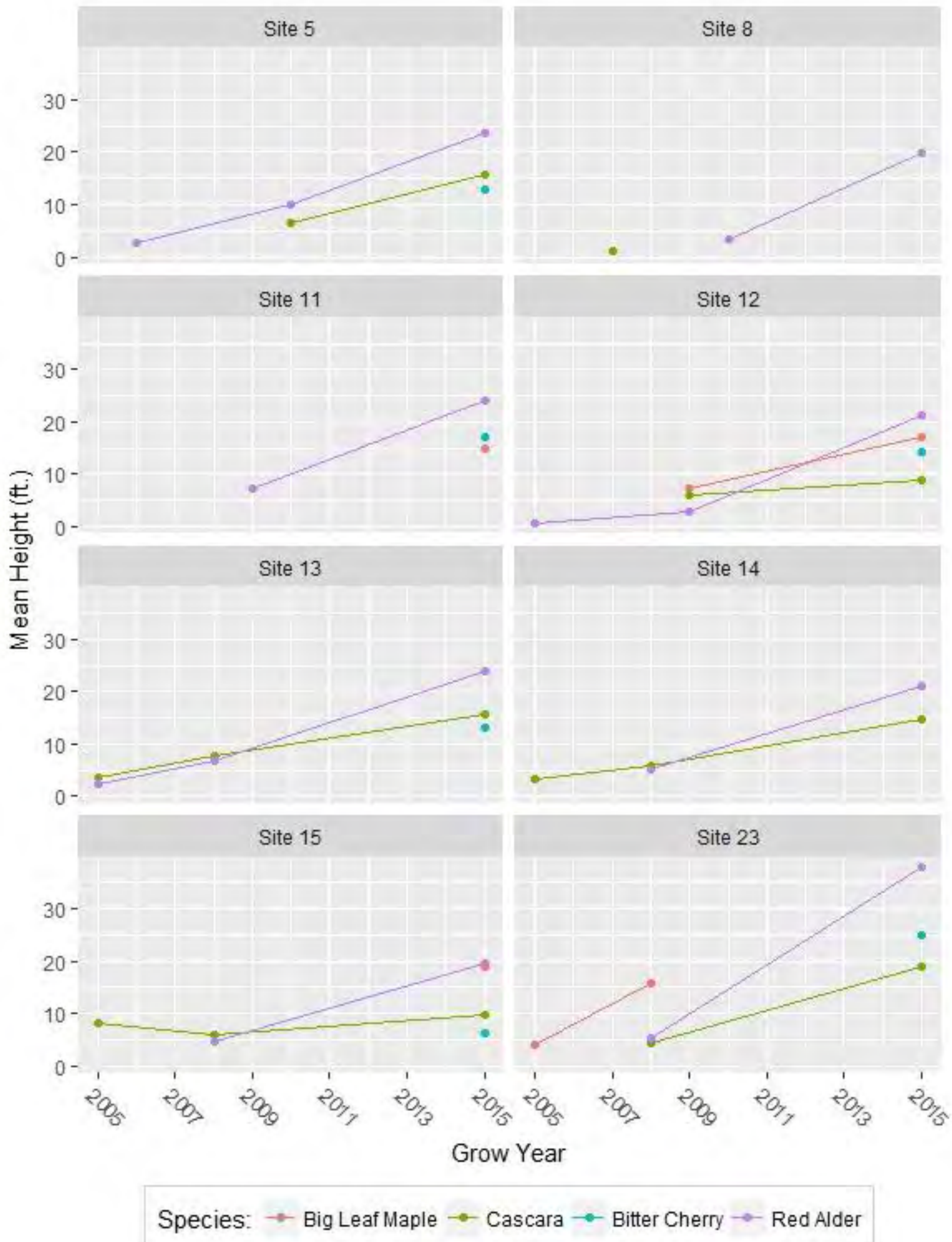

Figure 13. Average volunteer hardwood height on regeneration plots within hardwood conversion areas measured zero, four, and ten years post-harvest. Error bars are omitted for clarity of trends due to extremely high Coefficients of Variation.

Conifer Height Growth

Appendix C, Figure 14, and Figure 15 summarize the average height growth of conifers, by species and by leader position, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest. Height growth of all species accelerated over time. Where western hemlock was planted—sites planted by Merrill and Ring (sites 11 and 12) and Weyerhaeuser (sites 13, 14, and 15)—the species usually exhibited the greatest height growth—1.9 feet per year (site14, SD = 0.27) to 2.6 feet per year (site 11, SD = 0.59) by year 10 in trees from the initial plantings. At sites were Douglas-fir was planted in the initial planting the species exhibited the height growth comparable to western hemlock—1.7 feet per year (site 11, SD = 1.15) to 2.4 feet per year (site 15, SD = 0.51) by year 10. At sites 8, 11, 12, and 23, where Sitka spruce was planted in the initial planting growth ranged from 0.6 feet per year (site 23, SD = .038) to 2.2 feet per year (site 11, SD = 0.84) by year 10. Western redcedar, which was planted in the initial planting on sites 5, 11, 12, and 23, showed the lowest growth rates—0.8 feet per year (site 23, SD = 0.42) to 1.0 foot per year (site 5, SD = 0.41) by year 10. Where trees were interplanted after the initial planting—sites 12 and 13—average height growth was lower than the trees that were planted during the initial planting.

Average height growth of trees that had their leader above the brush at year 4 consistently exceeded height growth of trees that had their leaders within the brush or overtopped by the brush. The greatest difference was realized by western hemlock at site 11—growth of trees with leaders above the brush at this site by year 4 exceeded the growth of western hemlock with leaders within or below the brush by over 2 feet per year. The difference was slightly less among Douglas-fir—the growth of trees with leaders above the brush was about 1 to 2 feet per year higher than trees with leaders within or overtopped by the brush. The difference was least among other species—western redcedar and Sitka spruce—and among western hemlock planted at sites 13, 14, and 15; the growth differential was less than 1 foot per year. On sites 11 and 12 the growth of interplanted trees was generally comparable to trees planted in the initial planting when they have comparable leader positions.

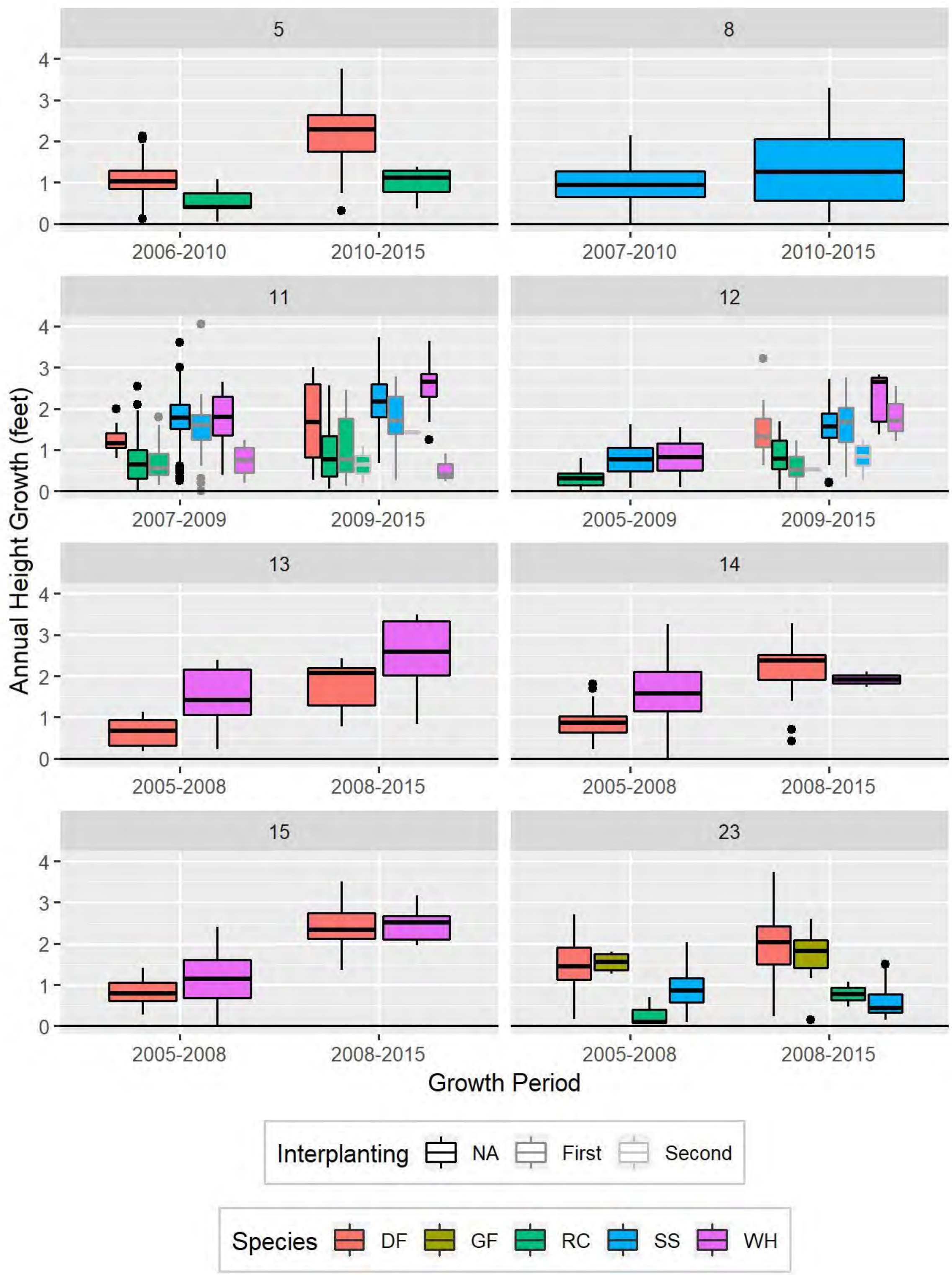

Figure 14. Average height growth of conifers, by species and interplanting, on regeneration plots within hardwood conversion areas measured four- and ten-years post-harvest. Black dots represent trees that had unusually high or low height growth (potential outliers). Gray bar outlines signify interplanted trees.

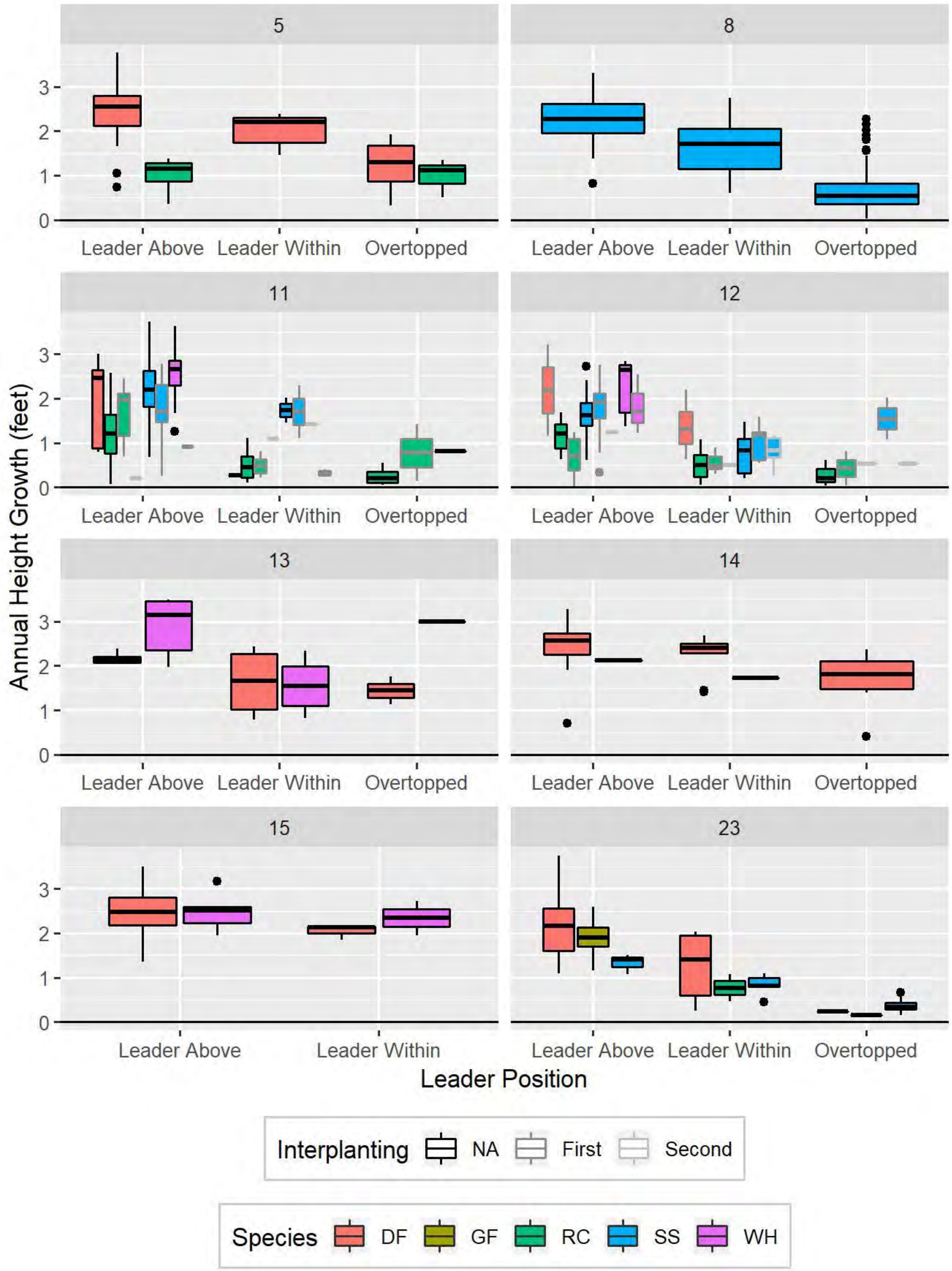

Figure 15. Average height growth of conifers, by species and interplanting, from year 4 to year 10, by leader position at year 4, on regeneration plots within hardwood conversion areas measured four- and ten-years post-harvest. Black dots represent trees that had unusually high or low height growth (potential outliers). Gray bar outlines signify interplanted trees.

Conifer Survival

Appendix D, Figure 16, and Figure 17 summarize the survival of planted conifers, by species and leader position, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest. Overall survival of all species declined over time, irrespective of leader position (i.e., above, within, or below the brush). Where Sitka spruce was planted—sites planted by Green Crow (site 8), Merrill and Ring (sites 11 and 12), and Pope Resources (site 23)—the species usually exhibited the highest survival rates by year 10 (61 – 87 percent, median 74 percent). Survival rates were markedly lower (less than 50 percent) for the other planted species: western redcedar (21 - 62 percent, median 47 percent), Douglas-fir (21 - 77 percent, median 38 percent), and western hemlock (10 – 64 percent, median 36 percent). Survival of trees that had their leader above the brush at year 4 consistently exceeded the survival of trees that had their leaders within the brush or leaders overtopped by the brush. Sitka spruce had the highest survival rates regardless of leader position. Otherwise, the strongest relationship with leader position was seen in Douglas-fir—survival rate of trees with their leader above the brush was more than double the rate of trees that had their leaders within or overtopped by the brush. The difference in survival among leader positions was less for western redcedar—survival rates of trees with leaders above the brush was 74 percent higher than trees with lesser leader positions. Apart from Sitka spruce, the difference in survival among leader positions was least for western hemlock—survival rates of trees with their leader above the brush were 44 percent higher. On sites 11 and 12 interplanted trees generally had lower survivorship than trees planted in the initial planting at both 4 and 10 years after planting and regardless of leader position at year 4.

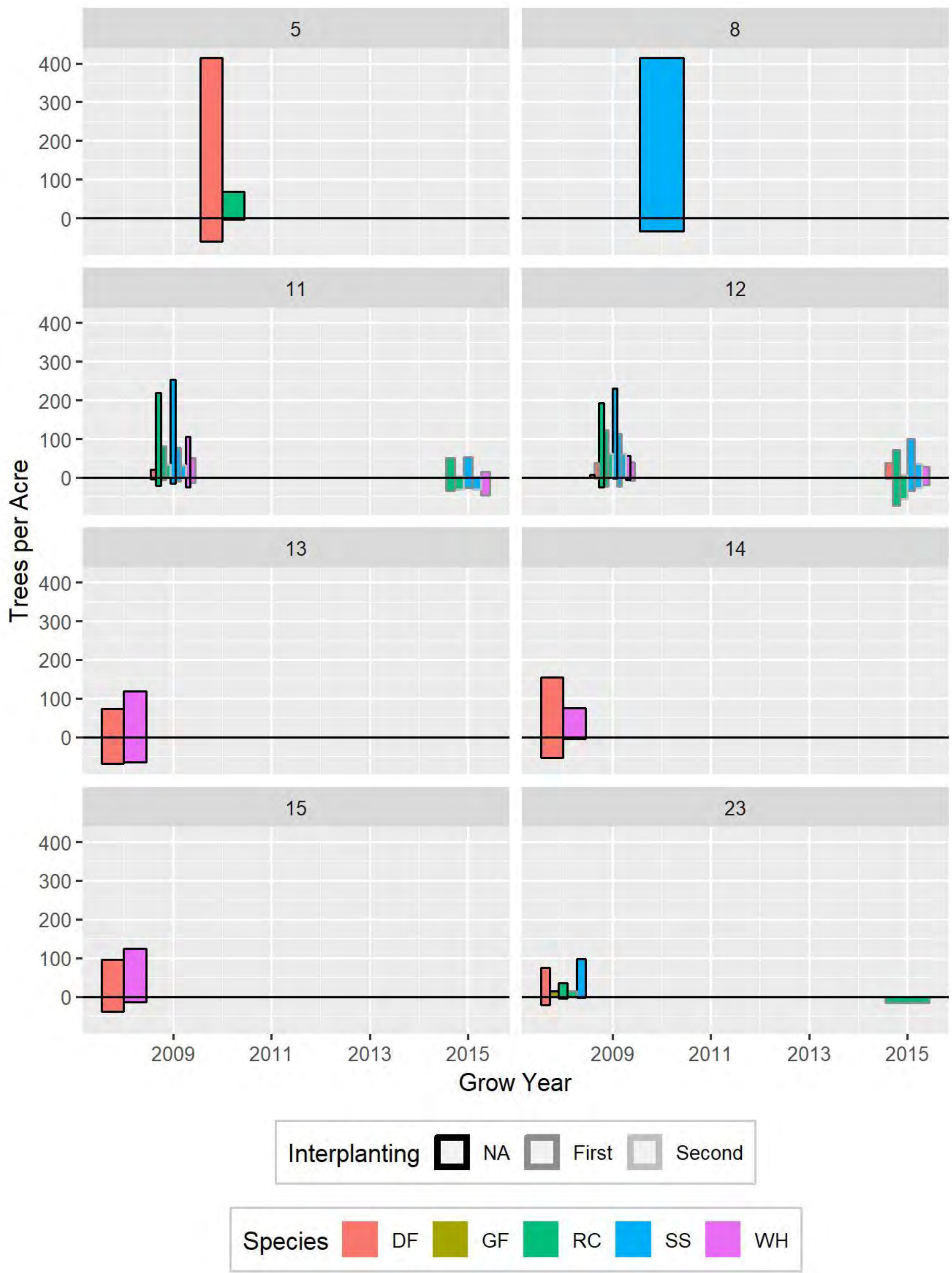

Figure 16. Tree status (live, dead) of planted conifers, by species and interplanting, on regeneration plots within hardwood conversion areas measured four- and ten-years post-harvest. Gray bar outline signifies interplanted trees.

Figure 17. Tree status (live, dead) of planted conifers, by species, interplanting, and leader status at year 4, on regeneration plots within hardwood conversion areas measured ten years post-harvest. Gray bar outline signifies interplanted trees.

Free-to-Grow

Conifer stocking at year 4 and year 10 were compared to requirements for hardwood conversion areas in WAC 222-30-021(1)(b)(i)(D) which stipulates that:

> Following harvest in conversion areas, the landowner must: … Conduct postharvest treatment … until the conifer trees necessary to meet acceptable stocking levels in WAC 222-34-010(2) have crowns above the brush or until the conversion area contains a minimum of one hundred fifty conifer trees greater than eight inches dbh per acre.

The referenced rule, WAC 222-34-010(2), stipulates that:

> A harvested area is reforested when that area contains an average of 190 or more vigorous, undamaged commercial species seedlings per acre that have survived on the site for at least 1 growing season. Up to 20 percent of the harvested area may contain fewer than 190 seedlings per acre, but no portion of the harvested area with timber growing capacity may contain less than 150 seedlings per acre. The department may determine that less than an average of 190 seedlings per acre is acceptable if fewer seedlings will reasonably utilize the timber growing capacity of the site.

Because WAC 222-30-021(1)(b)(i)(D) stipulates conifer tree stocking, "commercial species" in WAC 222-34-010(2) was interpreted to be "conifer species," consistent with the study's intent. Though alder has become designated as a commercial species since these rules were written, it does not change the logical interpretation relying on WAC 222-30-021(1)(b)(i)(D). That is, from an enforcement standpoint, though a site may meet stocking requirements under WAC 222-34-010(2) by virtue of its hardwood stocking, it may not necessarily meet WAC 222-30-021(1)(b)(i)(D) because of lack of conifers. Further, because this is a hardwood conversion study, inclusion of hardwoods in a free-to-grow evaluation would be counterintuitive.

Assessment of stocking one year after planting is complicated by the multiple plantings that occurred at most sites. Therefore, our assessment of stocking relative to the rules begins at year 4, acknowledging that it represents stocking more than 1 year after most trees were planted. We evaluated year 4 stocking relative to the portion of WAC 222-30-021(1)(b)(i)(D) that, when combined with WAC 222-34-010(2), stipulates that there be 190 conifer trees with their crowns above the brush. As shown by the stocking summaries in Table 13

Factors selected as important in explaining regeneration performance in the stepwise model include species, whether a tree was interplanted, competition with volunteer hardwoods and understory vegetation, and landform (Table 15). Tree species was the first parameter selected in the stepwise regression with Sitka spruce having greater odds of having a leader above the brush at year 10 than Douglas-fir ($p < 0.001$) while the odds of western redcedar having a leader above the brush at year 10 are lower than Douglas-fir ($p < 0.001$). The odds of western hemlock having a leader above the brush at year 10 are lower than Douglas-fir but not statistically different. When trees are interplanted trees have lower odds of having a leader above the brush at year 10, especially for the second interplanting ($p < 0.001$). The influence of volunteer hardwoods and understory vegetation is mixed. Taller shrubs and grass at year 0 along with more hardwood basal area, higher shrub and herb cover all reduce the odds of trees having their leader above the brush at age 10. However, higher shrub cover and taller ferns at year 0 along with more hardwood trees per acre and taller herbs and grasses increase the odds. Landform may have a significant influence as well with trees on hillslope landforms having increased odds of having a leader above the brush than on floodplain terrace landforms. The surrogate variable for site conditions that were not measured, which may have had in influence beyond what was measured, was not selected by the stepwise regression.

Table 13, only three sites (sites 5, 11, and 12) met this standard at year 4. Of those three sites, only one (site 11) had a small portion (3 percent) of the hardwood conversion area with less than 150 trees per acre.

By year 10, all sites have passed the point in time when the seedling-oriented requirements of WAC 222-34-010(2) were relevant. Therefore, we turned our attention to evaluating conifer stocking relative to the portion of WAC 222-30-021(1)(b)(i)(D) which stipulates that the conversion area contains a minimum of 150 conifer trees greater than eight inches dbh per acre. By year 10, no conifers had attained a diameter exceeding 8 inches dbh (Figure 18). Therefore, the comparison of year 10 results serves only as an indicator of the attainability of this standard. As shown in Table 14, all sites had conifer stocking exceeding 150 trees per acre by year 10. Though we could extrapolate past performance to project future stocking levels (e.g., based on species composition and leader position), the issue of meeting regulatory regeneration standards truly remains inconclusive until conifers attain 8 inches dbh at a future monitoring event.

Factors selected as important in explaining regeneration performance in the stepwise model include species, whether a tree was interplanted, competition with volunteer hardwoods and understory vegetation, and landform (Table 15). Tree species was the first parameter selected in the stepwise regression with Sitka spruce having greater odds of having a leader above the brush at year 10 than Douglas-fir ($p < 0.001$) while the odds of western redcedar having a leader above the brush at year 10 are lower than Douglas-fir ($p < 0.001$). The odds of western hemlock having a leader above the brush at year 10 are lower than Douglas-fir but not statistically different. When trees are interplanted trees have lower odds of having a leader above the brush at year 10, especially for the second interplanting ($p < 0.001$). The influence of volunteer hardwoods and understory vegetation is mixed. Taller shrubs and grass at year 0 along with more hardwood basal area, higher shrub and herb cover all reduce the odds of trees having their leader above the brush at age 10. However, higher shrub cover and taller ferns at year 0 along with more hardwood trees per acre and taller herbs and grasses increase the odds. Landform may have a significant influence as well with trees on hillslope landforms having increased odds of having a leader above the brush than on floodplain terrace landforms. The surrogate variable for site conditions that were not measured, which may have had in influence beyond what was measured, was not selected by the stepwise regression.

Table 13. Conifer stocking (trees per acre, TPA) at year 4 by leader position, species, and site[1].

Site	Year	Species	TPA Above	TPA Within	TPA Overtopped	Total TPA
5	2010	Douglas-fir	196.43	100.00	121.43	417.86
		Western redcedar	25.00	14.29	28.57	67.86
		Total	**221.43**	**114.29**	**150.00**	**485.72**
8	2010	Sitka spruce	103.95	96.05	228.95	428.95
		Western hemlock	11.84	10.53	22.37	44.74
		Total	**115.79**	**106.58**	**251.32**	**473.69**
11	2009	Douglas-fir	15.63	4.69	1.56	21.88
		Western redcedar	131.25	92.19	110.94	334.38
		Sitka spruce	298.44	35.94	46.88	381.26
		Western hemlock	120.31	18.75	32.81	171.87
		Total	**565.63**	**151.56**	**192.19**	**909.38**
12	2009	Douglas-fir	12.50	30.00	7.50	50.00
		Western redcedar	100.00	125.00	152.50	377.50
		Sitka spruce	255.00	105.00	50.00	410.00
		Western hemlock	55.00	32.50	15.00	102.50
		Total	**422.50**	**292.50**	**225.00**	**940.00**
13	2008	Douglas-fir	15.38	30.77	26.92	73.07
		Western redcedar	NA	3.85	3.85	7.70
		Sitka spruce	NA	3.85	NA	3.85
		Western hemlock	65.38	30.77	23.08	119.23
		Total	**80.77**	**69.23**	**53.85**	**203.85**
14	2008	Douglas-fir	40.00	65.00	52.50	157.50
		Sitka spruce	2.50	15.00	2.50	20.00
		Western hemlock	55.00	27.50	15.00	97.50
		Total	**97.50**	**107.50**	**70.00**	**875.00**
15	2008	Douglas-fir	63.16	23.68	7.89	94.73
		Western hemlock	86.84	28.95	15.79	131.58
		Total	**150.00**	**52.63**	**23.68**	**226.31**
23	2008	Douglas-fir	45.65	15.22	13.04	73.91
		Grand Fir	13.04	NA	2.17	15.21

Site	Year	Species	TPA Above	TPA Within	TPA Overtopped	Total TPA
		Western redcedar	NA	10.87	39.13	50.00
		Sitka Spruce	21.74	23.91	52.17	97.82
		Western Hemlock	4.35	NA	NA	4.35
		Total	**84.78**	**50.00**	**106.52**	**241.29**

[1]At sites 11 and 12, western redcedar and Sitka spruce were co-planted.

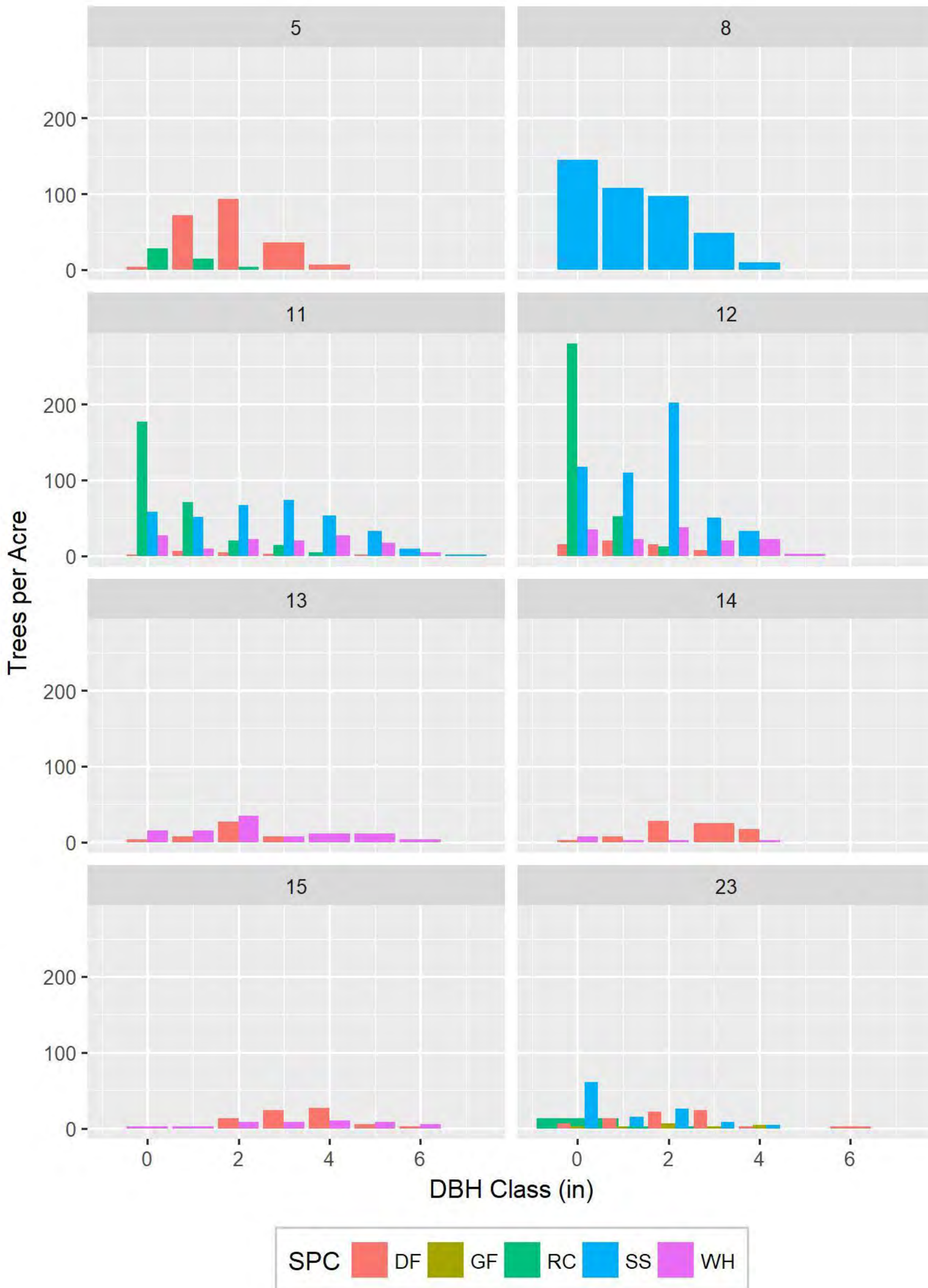

Figure 18. Diameter distributions of planted conifers by dbh class and site on regeneration plots within hardwood conversion areas measured ten years post-harvest.

Table 14. Conifer stocking by trees per acre (TPA) and leader position relative to competing brush (above, within, or overtopped) at year 10 by leader position, species, and site[1].

Site	Year	Species	TPA Above	TPA Within	TPA Overtopped	Total TPA
5	2015	Douglas-fir	132.14	21.43	21.43	175.00
		Western redcedar	25.00	7.14	14.29	46.43
		Total	**157.14**	**28.57**	**35.71**	**221.42**
8	2015	Sitka spruce	184.21	26.32	172.37	382.90
		Western hemlock	40.79	7.89	6.58	55.26
		Total	**225.00**	**34.21**	**178.95**	**438.16**
11	2015	Douglas-fir	6.25	NA	6.25	12.50
		Western redcedar	35.94	20.31	151.56	207.81
		Sitka spruce	153.13	31.25	78.13	262.51
		Western Hemlock	60.94	3.13	29.69	93.76
		Total	**256.25**	**54.69**	**265.63**	**576.57**
12	2015	Douglas-fir	32.50	7.50	35.00	75.00
		Western redcedar	67.50	27.50	127.50	222.50
		Sitka spruce	265.00	27.50	57.50	350.00
		Western hemlock	55.00	NA	20.00	75.00
		Total	**420.00**	**62.50**	**240.00**	**722.50**
13	2015	Douglas-fir	42.31	NA	11.54	53.85
		Western redcedar	3.85	NA	NA	3.85
		Western hemlock	69.23	23.08	34.62	126.93
		Total	**115.38**	**23.08**	**46.15**	**184.63**
14	2015	Douglas-fir	47.50	10.00	30.00	87.50
		Sitka spruce	20.00	5.00	12.50	37.50
		Western hemlock	15.00	2.50	17.50	35.00
		Total	**82.50**	**17.50**	**60.00**	**160.00**
15	2015	Douglas-fir	89.47	NA	5.26	49.73
		Sitka spruce	2.63	NA	NA	2.63
		Western hemlock	50.00	2.63	5.26	57.89
		Total	**142.11**	**2.63**	**10.53**	**110.25**
23	2015	Douglas-fir	47.83	2.17	10.87	60.87
		Grand fir	6.52	2.17	6.52	15.21
		Western redcedar	NA	2.17	8.70	10.87
		Sitka spruce	26.09	13.04	50.00	89.13
		Western hemlock	4.35	NA	NA	4.35
		Total	**84.78**	**19.57**	**76.09**	**180.43**

[1]At sites 11 and 12, western redcedar and Sitka spruce were co-planted.

Table 15. Factors influencing tree growth and survival to free-to-grow status (leader above the brush) at year 10 selected by stepwise logistic regression. Positive parameter values indicate factors that increase the odds of surviving and having a leader above the brush at year 10. Negative parameter values indicate factors that decrease the odds of surviving and having a leader above the brush at year 10. Statistically significant parameters are in bold text. *Note that Douglas-fir and fluvial terrace/floodplain are not included in the table and are the basis for species and landform comparisons*.

	Estimate	Std. Error	z value	p-value
(Intercept)	**-1.1445**	**0.2822**	**-4.0555**	**0.0001**
Western redcedar	**-1.0138**	**0.2035**	**-4.9809**	**<0.0001**
Sitka spruce	**0.9374**	**0.1677**	**5.5909**	**<0.0001**
Western hemlock	-0.3161	0.1845	-1.7130	0.0867
First interplanting	-0.2892	0.1691	-1.7103	0.0872
Second interplanting	**-1.6403**	**0.3878**	**-4.2297**	**<0.0001**
Retained overstory cover	**0.0142**	**0.0047**	**3.0333**	**0.0024**
Year 0 hardwood basal area	-0.1646	0.1138	-1.4465	0.1480
Year 0 shrub cover	**1.0453**	**0.4616**	**2.2645**	**0.0235**
Year 0 shrub height	**-0.0592**	**0.0218**	**-2.7195**	**0.0065**
Year 0 fern height	**0.2146**	**0.0458**	**4.6829**	**<0.0001**
Year 0 grass height	**-0.2585**	**0.1088**	**-2.3754**	**0.0175**
Year 4 hardwood basal area	**-0.1152**	**0.0230**	**-5.0100**	**<0.0001**
Year 4 hardwood trees per acre	**0.0011**	**0.0005**	**2.1585**	**0.0309**
Year 4 shrub cover	**-1.3012**	**0.3054**	**-4.2605**	**<0.0001**
Year 4 shrub height	-0.0402	0.0276	-1.4597	0.1444
Year 4 herb cover	**-1.9299**	**0.5583**	**-3.4566**	**0.0005**
Year 4 herb height	**0.3582**	**0.1359**	**2.6353**	**0.0084**
Year 4 grass height	**0.1860**	**0.0691**	**2.6917**	**0.0071**
Hillslope landform	**0.3468**	**0.1406**	**2.4676**	**0.0136**

Economic Performance

The summary of economic performance reported in this section is compiled from detailed site-by-site analysis reported in the Case Study Report. Note that in compiling this summary we observed that upland acres derived from GIS boundaries do not precisely match those reported in the Case Study Report. While these differences may affect per-acre economics in the upland area, the total upland area economics would not be affected. Furthermore, because the issue is isolated to the uplands, economics within the hardwood conversion areas would not be affected. Therefore, the decision was made to use values detailed in the Case Study Report.

Harvest Economics

Table 16 summarizes the harvest area, harvest volume, and adjusted stumpage value for the upland area and the hardwood conversion area at each study site. Adjusted stumpage includes traditional elements of stumpage (log pond values minus logging and hauling cost) plus adjustments for excise tax, per-acre road costs, and per-acre administrative costs. Regeneration costs are *not* included in this stumpage adjustment. Average per-MBF stumpage value was greater in hardwood conversion areas ($333, SD = $49) than in adjacent uplands ($277, SD = $63) because the conversion areas generally had greater volumes of high-value red alder than uplands. However, because more volume could be harvested from each upland acre (about 26 MBF per acre, on average, SD = 10 MBF/ac) compared to that from the hardwood conversion areas (about 14 MBF per acre, on average, SE = 5 MBF/ac) the per-acre stumpage value was greater in upland operations ($6,257 per acre, on average, SE = $1,448/ac) than in hardwood conversion areas ($4,148 per acre, on average, SE = $1,627/ac).

Table 16. Area, harvest volume, and adjusted stumpage values of timber harvest in upland areas and hardwood conversion areas, by site. Adjusted stumpage includes stumpage value minus excise tax, per-acre road costs, and per-acre administration costs.

Site	Acres			Harvest Volume (MBF)			Adjusted Stumpage ($)		
	Upland	Conversion area	Total	Upland	Conversion area	Total	Upland	Conversion area	Total
5	66.4	1.6	68.0	1,008.5	17.3	1,025.8	301,826	6,343	308,169
8	10.4	3.6	14.0	445.3	40.3	405.0	92,039	17,801	109,840
11	4.9	3.6	8.5	182.6	60.4	243.0	33,836	19,116	52,952
12	11.6	3.4	15.0	253.6	50.4	304.0	89,176	16,247	105,423
13	60.9	1.1	62.0	1,404.9	11.4	1,416.3	410,791	3,299	414,090
14	48.8	2.2	51.0	1,686.3	29.9	1,716.2	383,787	9,086	392,873
15	30.6	2.4	33.0	515.2	24.7	539.9	158,336	7,783	166,119
23	60.1	2.6	62.7	1,192.7	66.9	1,259.6	414,250	20,901	435,151

Regeneration Economics

Table 17 and Table 18 summarize regeneration costs in the upland area and the hardwood conversion area, respectively, at each study site. On a per-acre basis, total regeneration costs were greater in upland areas than they were in hardwood conversion areas. And, because both the area treated and the per-acre regeneration costs were greater in upland areas, total regeneration costs were greater in the upland areas than they were in hardwood conversion areas. The difference was mostly due to relatively higher investments in site prep, brush control, precommercial thinning, and slashing in upland areas. Otherwise, costs for animal control and planting were consistent between upland areas and hardwood conversion areas.

Among the hardwood conversion areas, the investment in regeneration varied from less than $200 per acre to over $1,000 per acre.

Table 8 in the Site Selection section summarizes the regeneration practices that accounted for the difference in costs across sites. As was reported in that section, site 11 and site 12 had greater control of competing vegetation, more intensive animal control measures, and higher planting densities. As a result, these sites had an order-of-magnitude greater investment in site prep, animal control, planting, and brush control. Among the remaining sites (sites 5, 8, 13, 14, 15, and 23), there were minor differences in per acre-costs related to minor differences in animal control costs and planting costs.

Table 17. Total and per-acre regeneration costs in upland areas, by site.

Site	Upland Acres	Per Acre Costs						Total Regen Costs
		Site prep	Animal control	Planting	Brush control	PCT/ Slashing	Total	
5	66.4	58.88	57.53	327.94	--	110.00	554.35	36,809
8	10.4	--	--	228.29	--	73.00	301.29	3,133
11	4.9	230.81	176.97	559.58	240.89	--	1,208.25	5,920
12	11.6	228.82	219.47	557.48	118.80	--	1,124.57	13,045
13	60.9	69.00	31.00	209.00	32.00	--	341.00	20,767
14	48.8	61.00	31.00	209.00	33.00	6.15	340.15	16,599
15	30.6	104.00	27.00	209.00	48.00	4.60	392.50	12,010
23	60.1	--	10.55	268.09	6.41	59.63	344.68	20,715

Table 18. Total and per-acre regeneration costs in hardwood conversion areas, by site.

Site	Conversion Area Acres	Per Acre Costs						Total Regen Costs
		Site prep	Animal control	Planting	Brush control	PCT/ Slashing	Total	
5	1.6	--	57.53	327.94	--	110.00	495.47	793
8	3.6	--	--	228.29	--	73.00	301.29	1,085
11	3.6	230.81	176.97	559.58		191.89	1,159.25	4,173
12	3.4	228.82	219.47	557.48		49.83	1,055.60	3,589
13	1.1	--	31.00	313.50	--	--	344.50	379
14	2.2	--	31.00	313.50	--	--	344.50	758
15	2.4	--	27.00	313.50	--	--	340.50	817
23	2.6	--	9.75	166.26	--	--	183.21	476

Residual Value

Table 19 and Figure 19 calculate the total and per acre residual values, respectively, of operations at each site—in upland areas and in hardwood conversion areas—calculated as the total adjusted stumpage (from Table 16) value minus regeneration costs (from Table 17 and Table 18). On a per acre basis, residual value of upland harvests was greater than hardwood conversion areas at all sites, except site 23. Per acre residual values in upland harvest areas usually exceeded those in hardwood conversion areas because of the greater volume that could be harvested from them—upland harvests permit greater harvest of conifers than hardwood conversions—resulting in higher per-acre stumpage in upland versus conversion areas. A combination of factors account for the aberration observed at site 23, including relatively higher hardwood harvest levels and stumpage values and slightly lower conifer harvest levels and stumpage values—regeneration costs were a relatively small factor.

Table 19. Summary of total residual values in uplands and hardwood conversion areas, and in total, by site.

Site	Upland			Conversion Area			Total		
	Stumpage	Regen	Residual	Stumpage	Regen	Residual	Stumpage	Regen	Residual
5	301,826	36,809	265,017	6,343	793	5,550	308,169	37,602	270,567
8	92,039	3,133	88,906	17,801	1,085	16,716	109,840	4,218	105,622
11	33,836	5,920	27,916	19,116	4,173	14,943	52,952	10,094	42,858
12	89,176	13,045	76,131	16,247	3,589	12,658	105,423	16,634	88,789
13	410,791	20,767	390,024	3,299	379	2,920	414,090	21,146	392,944
14	383,787	16,599	367,188	9,086	758	8,328	392,873	17,357	375,516
15	158,336	12,010	146,326	7,783	817	6,966	166,119	12,828	153,291
23	414,250	20,715	393,535	20,901	476	20,425	435,151	21,192	413,959

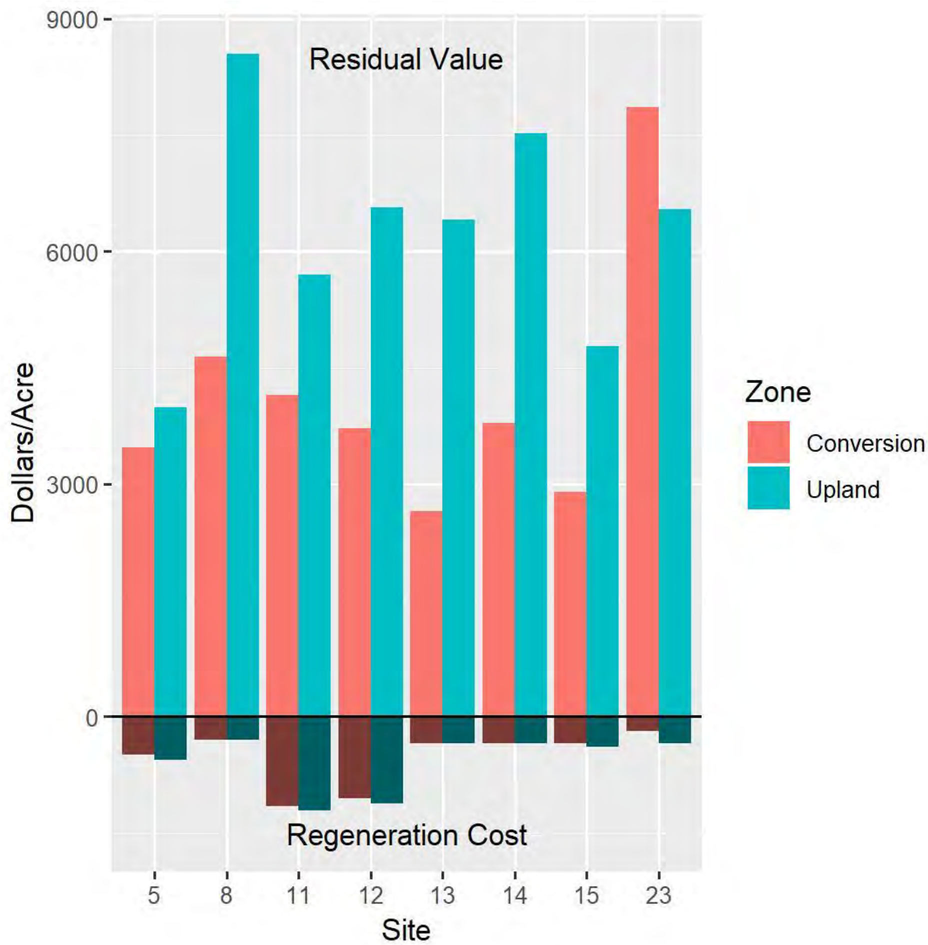

Figure 19: Comparison of residual value and regeneration costs for the conversion and upland areas in each study site.

DISCUSSION

Qualitative Interpretation of Stocking Trends

Figure 20 and Figure 21 compare the distribution of conifers and hardwoods, relative to the average competing brush height, on regeneration plots within hardwood conversion areas measured four and ten years post-harvest, respectively. The general trends, year 4 to year 10, are for the distributions of conifers to move to the right, keeping pace with, "catching up" with, or sometimes surpassing the distribution of hardwoods and average height of brush. This trend highlights "the race" that silviculturists "run" to improve the chances that planted conifers rise above the competing vegetation. Results thus far in the Hardwood Conversion Study provide some insight into management alternatives that can help with meeting the regulatory stocking standard.

Among the sites most on track to achieve the WAC stocking standard for hardwood conversion areas (sites 8, 11, and 12), the factors accounting for their trajectory towards this standard appear to be low levels of competing brush at year 4, relatively high overall planting densities, high planting densities of Sitka spruce, and use of P+1 nursery stock. Not explicitly evaluated, but likely a factor in the overall trajectory of these sites, is the relatively high resistance of Sitka spruce to animal predation and the resistance of Sitka spruce to spruce tip weevil when the species co-occurs with red alder (Almond 2006). Looking forward, these sites likely face challenges in the form of excessive hardwood competition and, in the case of sites 11 and 12, removal of Sitka spruce where it was planted along with western redcedar in the same hole.

Among those sites that are least on track to achieve the WAC stocking standard (sites 5, 13, 14, 15, and 23), the chances of meeting the standard rely on survival of the remaining conifers which, in the case of these sites, appears limited by the relatively high levels of Douglas-fir and the hopes that would have to be put in the survival and growth of trees within or overtopped by brush. Based on past performance, the chances of adequate growth and survival do not appear great. Yet, as argued above, though we could extrapolate past performance to project future stocking levels (e.g., based on species composition and leader position), these sites have not achieved of the stocking standard yet and it truly remains unknown if the sites will until conifers attain 8 inches dbh at some future date.

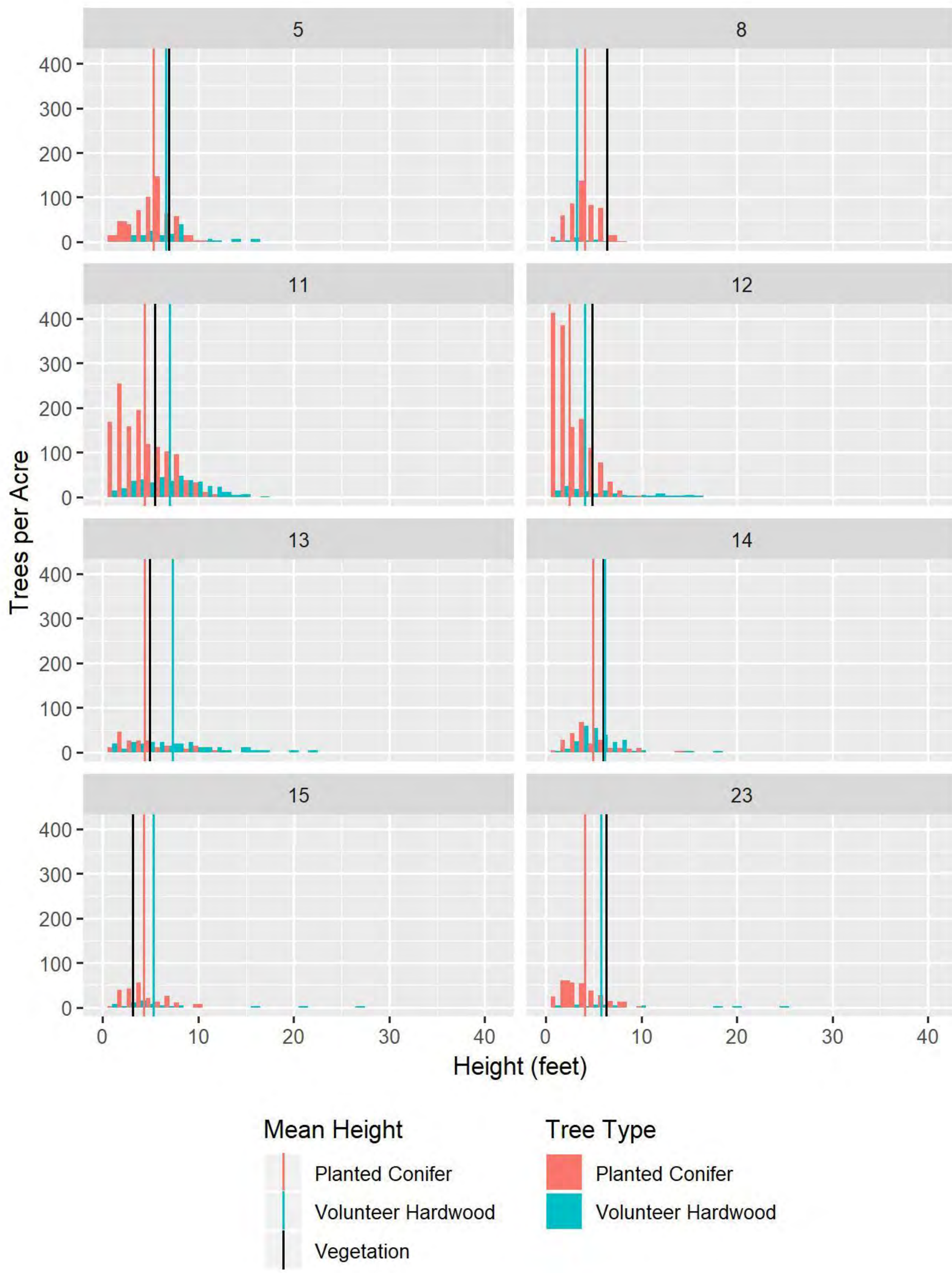

Figure 20. Frequency distribution of conifers and hardwoods by one-foot height class, relative to the average planted confer (vertical red line), volunteer hardwood (vertical blue line) and competing brush (vertical black line) heights, on regeneration plots within hardwood conversion areas measured four years post-harvest.

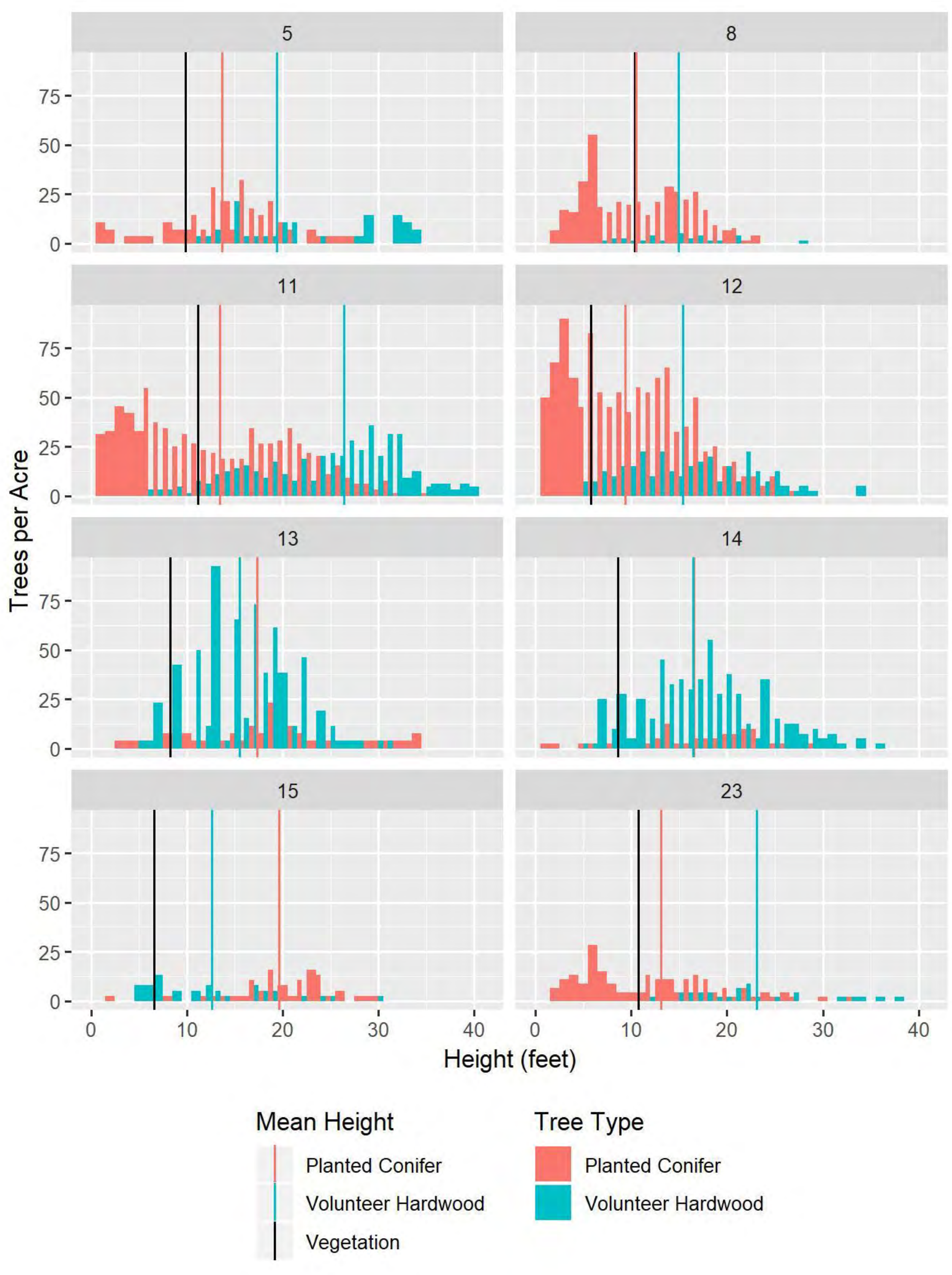

Figure 21. Frequency distribution of conifers and hardwoods by one-foot height class, relative to the average planted confer (vertical red line), volunteer hardwood (vertical blue line) and competing brush (vertical black line) heights, on regeneration plots within hardwood conversion areas measured ten years post-harvest.

Site-level Effects of Investment on Stocking

Site-to-site differences in silvicultural performance are positively related to landowner investment in regeneration activities (Figure 22). Though a small sample size, the range of investment is broad. Both total conifers and conifers above the brush are strongly correlated with regeneration costs. This correlation is largely driven by investments made at sites 11 and 12 in cultural treatments that did not occur elsewhere—site prep and brush control—or in cultural practices that occurred with greater intensity than elsewhere—animal control and planting density. The only outlier in this relationship is the other site most on track to achieve the WAC standard (site 8). The high stocking level achieved at year 10 at site 8 (greater than 400 trees per acre total, greater than 200 trees per acre with leaders above the brush) appears to have been achieved with relatively low investment, planting only Sitka spruce. Because of the small sample size and lack of an experimental design, this relationship may be coincidental.

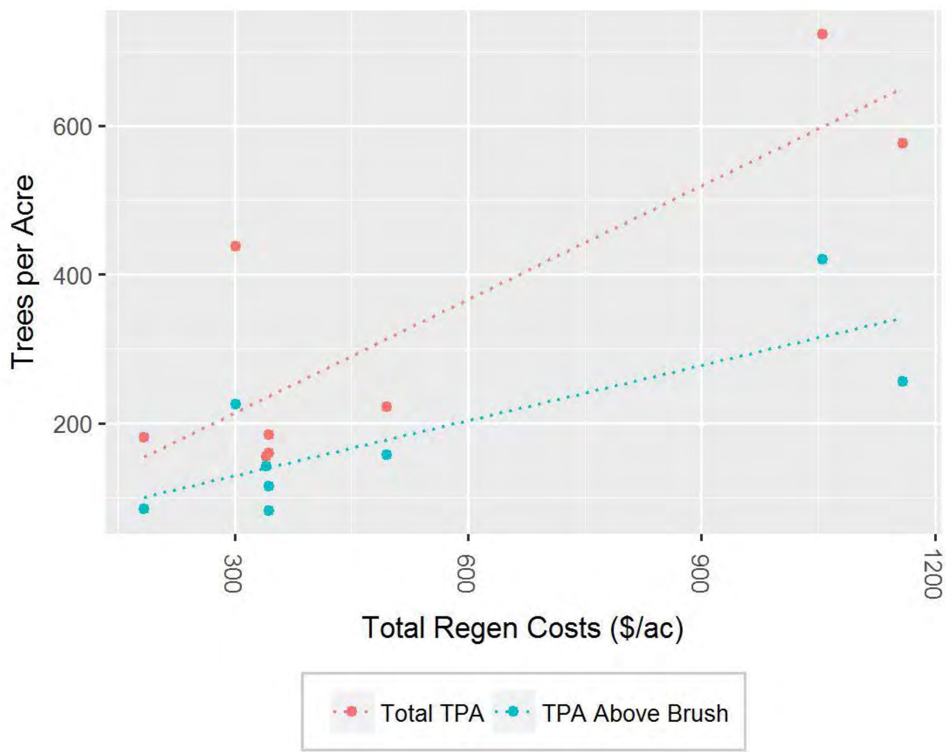

Figure 22. Relationship between total regeneration costs and conifer stocking at year 10, for all conifers and for conifers with their leaders above the brush (free-to-grow).

Factors Explaining Free-to-Grow Status

Though well-intentioned, we found that statistically significant factors in the final stepwise model (Table 15) reflect differences in hardwood conversion areas managed by Weyerhaeuser (sites 5, 13, 14, and 15) and Pope Resources (23)—where regeneration performance has *generally* been poorer—and those managed by Green Crow (8) and Merrill and Ring (11 and 12)—where regeneration performance has *generally* been better. Discernment of potentially influential factors (from a standpoint of cause-effect) required qualitative, rather than quantative, interpretation of the results.

Statistically significant factors explaining regeneration performance in the step wise model include topographic position, species selection, and competing vegetation. Weyerhaeuser plots occur predominantly on hillslopes, were planted predominantly with Douglas-fir, and generally have had lower competing vegetation. Most other landowners' plots occur predominantly on fluvial terraces and floodplains, were planted with more diverse species mixes, and generally have had greater competing vegetation. But, which of these factors are, in fact, meaningful?

Of these three factors, the effect of topographic position and competing vegetation may simply be coincidental. The lack of balance within each site (and landowner) limits the ability to discern the ecological influence of floodplain and fluvial terrace sites versus hillslope sites from the coincidental trajectory towards stocking standards on Green Crow and Merrill and Ring. Further, the better regeneration performance on these sites, despite having higher levels of competing vegetation, seems counterintuitive. Though significant, it's difficult to find meaning in these terms. Species selection, however, has both significance and meaning. Sitka spruce is statistically more likely to become free-to-grow at year 10. Likely because of Sitka spruce's shade tolerance, moisture tolerance, and resistance to animal predation, this species has had higher survival. The resistance of Sitka spruce to spruce tip weevil when the species co-occurs with red alder (Almond 2006) likely contributes to its success, however, comparative information on weevil damage was not recorded.

Though these are general trends, two sites push against this interpretation, underscoring the limitations of the data set. Site 5—a Weyerhaeuser site—has slightly better survival than the other Weyerhaeuser sites despite the predominance of Douglas-fir planting. This perhaps reflects a better matching of species to site—where site 5 occurs within a Douglas-fir zone—compared to the other Weyerhaeuser sites—which occur within a western hemlock zone.

Site 23—the Pope Resources site—has slightly poorer performance than Green Crow and Merrill and Ring sites, despite the high levels of Sitka spruce planted at the site. This perhaps reflects a poor matching of species to site—where site 23 occurs within a drier precipitation zone—compared to the Green Crow and Merrill and Ring sites—which occur in higher precipitation zones. The exceptions at sites 5 and 23 underscore the limitations of the data.

Technical Recommendations

Though some sites appear more likely than others to achieve stocking standards for hardwood conversion areas under WAC 222-30-021(1)(b)(i)(D), planted conifers have not yet achieved the 8 inches dbh size limit required to make this determination. One could extrapolate past survival and growth to project future stocking levels, or one could apply models to project stand development, but this would be fraught with uncertainty. Additional monitoring of tree growth and actual observation would provide a more definitive determination of whether this part of WAC 222-30-021(1)(b)(i)(D) is being met. CMER Policy will need to determine if such additional monitoring is a priority for the adaptive management program. If so, this could be achieved through remeasurement of vegetation monitoring plots, or by simpler stand inventory techniques focused solely on tree stocking. In either case, stocking evaluations will require waiting for enough conifer trees to reach 8 inches dbh. Based on professional judgement, this would occur at least 10 years after the year 10 remeasurement (i.e., at 20 years post-harvest).

Potential Management Implications

Though it is too soon to certify successful hardwood conversions, several factors appear to be important to putting stands on a trajectory towards the stocking standard. Most influential to growth and survival appear to be common-sense planting strategies: matching the species to the site, planting P+1 nursery stock, and planting at high densities. This trifecta is achieved at those sites most likely to succeed (Sites 8, 11, and 12), and one or more of these factors is achieved at those sites that may be marginally successful (Sites 5 and 23). None of these strategies was employed at the three Weyerhaeuser sites (13, 14, and 15) which are most likely to fall short of the stocking standard. Though these strategies comport with basic ecological and silvicultural principles, detailed recommendations beyond these general strategies remain elusive.

Because the number of monitoring sites is limited, it is more difficult to extract common-sense vegetation control strategies from the data. Though it appears important that conifers have their leaders above competing brush, it is not clear how and where or when this must be achieved. The planting strategies outlined in the previous paragraph are likely important contributors because they not only improve height growth, but they also improve the numerical odds. But, in comparison, the value of actively controlling competing vegetation appears mixed. The data suggest that it may be dependent on the site—that is, where Douglas-fir is best matched to the site, maintaining low levels of competing vegetation may be more important than where Sitka spruce is best matched. Again, this comports with basic ecological and silvicultural principles, but detailed recommendations beyond this general strategy remain elusive.

Finally, though intuition suggests that there is value in animal control, it is difficult to interpret its potential value from the data. Enough anecdotal evidence is provided in the Case Study Report to suggest that, where the potential for animal predation was observed (e.g., beaver presence, animal-browse), animal control measures were employed (e.g., trapping, barriers, deception). However, observations on animal damage are limited, making it difficult to quantify effectiveness. There are instances where animal control appears consequential (e.g., Sites 11 and 12), there are those where animal control appears inconsequential (e.g., Sites 13, 14, and 15), and there are those where it's simply too difficult to discern (e.g., Sites 5 and 23). Therefore, we can only make the conservative recommendation—that is, that animal control measures should be employed where there is a risk for animal predation.

SUMMARY

The Hardwood Conversion Study evaluated the economic and silvicultural feasibility of converting hardwood-dominated riparian areas, which had evidence of past conifer presence, back to being conifer dominated. Eight sites were volunteered by landowners for the study that are located across western Washington but primarily near the coast in southwest Washington or on the northwest Olympic Peninsula. Across these sites there was no overarching experimental design, which limits the inference that can be made about hardwood conversions in general. However, some general patterns across these eight sites are apparent. All conversion areas were economically feasible with net-positive residual values after deducting regeneration and administration costs from the stumpage value. Success in regenerating sites varied but was facilitated when landowners invested in site preparation and competing vegetation control or planted shade- and moisture-tolerant species such as western hemlock and Sitka spruce. Growth of these species planted in riparian zones was generally better than Douglas-fir, which is less shade- and moisture-tolerant. Co-planting western redcedar with Sitka spruce to minimize browse damage appears to be successful in sustaining some of these trees where this method was used. When Sitka spruce is planted it is more likely to be free-to-grow at 10 years after planting, which may be related to its shade- and moisture-tolerance as well as very stiff leaders and shoots and sharp needles. However, after 10 years of monitoring, none of the sites have met the regulatory success criterion: 150 trees per acre with d.b.h of at least 8 inches. Additional monitoring would be needed to determine when this success criterion is met.

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APPENDIX A: COMPETING VEGETATION RESPONSE

Mean height and cover of shrubs, forbs, and grasses by site and by species zero, four, and ten years post-harvest. Only species with mean cover greater than 5 percent are reported. Values in parentheses are standard deviations.

Site	Species	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover
5	Grass	2006	0.00 (0)	0.00% (0)	2010	1.21 (0.41)	15% (22.01%)	2015	0.00 (0)	0.00% (0)
	Himalayan blackberry	2006	0.00 (0)	0.00% (0)	2010	4.94 (1.31)	6.07% (6.26%)	2015	8.14 (2.58)	20% (17.1%)
	Salmonberry	2006	4.2 (1)	1.79% (4.21%)	2010	8.1 (1.16)	7.5% (9.95%)	2015	10.98 (1.85)	16.79% (20.53%)
	Vine Maple	2006	8.11 (3.45)	3.21% (5.04%)	2010	9.35 (2.14)	9.29% (13.99%)	2015	14.76 (2.68)	7.5% (13.41%)
	Western Sword Fern	2006	2.38 (0.49)	30% (13.16%)	2010	3 (0)	20% (16.05%)	2015	3.83 (0.38)	10.36% (15.25%)
8	Grass	2007	1.2 (0.4)	1.32% (2.77%)	2010	1.68 (0.87)	10.66% (12.64%)	2015	0.00 (0)	0.00% (0)
	Salmonberry	2007	6.95 (2.25)	12.11% (8.75%)	2010	6.7 (1.03)	55.26% (25.57%)	2015	10.47 (1.08)	77.87% (16.63%)
	Western Sword Fern	2007	2.2 (0.45)	19.87% (14.07%)	2010	3.68 (0.49)	13.16% (10.68%)	2015	3.13 (0.7)	11.58% (9.59%)
11	Grass	2005	1 (0)	2.97% (7.06%)	2009	1.97 (0.17)	15.63% (16.05%)	2015	2.97 (0.7)	6.09% (17.63%)
	Salmonberry	2005	6.25 (2.25)	1.25% (3.81%)	2009	6.08 (1.18)	11.56% (11.67%)	2015	12.15 (1.48)	34.22% (22.04%)
	Western Sword Fern	2005	3.04 (0.88)	6.19% (9.6%)	2009	2.91 (0.51)	8.91% (7.7%)	2015	3.85 (0.89)	7.19% (10.08%)
12	Grass	2005	1.07 (0.26)	7% (8.18%)	2009	2 (0)	56% (25.37%)	2015	2.56 (0.58)	17.75% (20.93%)
	Salmonberry	2005	4.57 (2.02)	1.75% (2.94%)	2009	5.32 (1.22)	9.5% (18.42%)	2015	9.4 (2.28)	30.25% (32.95%)
	Trailing blackberry	2005	0.00 (0)	0.00% (0)	2009	0.00 (0)	0.00% (0)	2015	2.11 (0.63)	18.5% (18.99%)
13	Salal	2005	0.00 (0)	0.00% (0)	2008	0.00 (0)	0.00% (0)	2015	2.25 (0.44)	6.15% (11.21%)
	Salmonberry	2005	4.03 (0.45)	13.46% (16.76%)	2008	5.63 (1.15)	30.77% (19.02%)	2015	9.18 (0.95)	32.69% (33.89%)
	Trailing blackberry	2005	1 (0)	6.15% (10.24%)	2008	1.24 (0.43)	13.08% (9.69%)	2015	0.00 (0)	0.00% (0)
	Vine Maple	2005	6.63 (1.46)	6.15% (10.24%)	2008	9.33 (3.62)	8.08% (8.79%)	2015	13.35 (1.33)	6.54% (8.01%)
	Western Sword Fern	2005	3.29 (0.45)	10.77% (10.17%)	2008	2 (0)	9.62% (8.77%)	2015	3.35 (0.87)	23.08% (21.94%)

Site	Species	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover	Year	Mean Height	Mean Cover
14	Grass	2005	1 (0)	7% (14.99%)	2008	1.58 (0.5)	8.25% (10.79%)	2015	0.00 (0)	0.00% (0)
	Salmonberry	2005	3.62 (0.99)	22.5% (20.55%)	2008	6.32 (0.99)	58% (22.5%)	2015	8.77 (1.36)	54.75% (27.22%)
15	Grass	2005	1.57 (0.5)	23.42% (25.61%)	2008	2.25 (0.43)	21.32% (13.63%)	2015	1.12 (0.32)	11.32% (11.88%)
	Salmonberry	2005	4.5 (0.53)	0.53% (1.58%)	2008	4.62 (0.93)	7.63% (10.05%)	2015	9.25 (1.06)	27.37% (32.03%)
	Trailing blackberry	2005	1 (0)	4.21% (5.07%)	2008	1.71 (0.68)	22.11% (15.93%)	2015	2.82 (0.89)	30.26% (28.11%)
	Western Sword Fern	2005	2.9 (0.93)	25.79% (16.01%)	2008	2.06 (0.41)	9.47% (6.64%)	2015	3.43 (0.56)	7.37% (7.14%)
23	Salmonberry	2005	4.25 (1.07)	29.57% (29.23%)	2008	6.16 (1.06)	55.87% (28.15%)	2015	15.28 (0.88)	11.52% (22.23%)
	Vine Maple	2005	7.63 (3.64)	3.48% (6.11%)	2008	8.29 (1.93)	7.61% (17.38%)	2015	9.77 (1.26)	73.7% (28.87%)
	Western Sword Fern	2005	3.84 (0.37)	14.78% (8.98%)	2008	2.48 (0.5)	12.61% (7.67%)	2015	3.39 (0.61)	6.74% (7.48%)

APPENDIX B: VOLUNTEER HARDWOOD RESPONSE

Mean height and stocking of volunteer hardwoods by site and by species zero, four, and ten years post-harvest. Values in parentheses are standard deviations.

Site	Species	Year	Mean Ht.	TPA	Year	Mean Ht.	TPA	Year	Mean HT.	TPA
5	Cascara	2006	0.00 (0)	0.00	2010	6.55 (1.5)	78.57	2015	15.8 (2.59)	17.86
	Bitter Cherry	2006	0.00(0)	0.00	2010	0.00(0)	0.00	2015	13.00 (0)	3.57
	Red Alder	2006	2.67 (0.48)	117.86	2010	10 (2.61)	107.14	2015	23.48 (8.98)	82.14
8	Cascara	2007	1.00 (0)	1.32	2010	0.00(0)	0.00	2015	0.00(0)	0.00
	Red Alder	2007	0.00(0)	0.00	2010	3.32 (1.22)	65.79	2015	19.89 (20.1)	35.53
11	Big Leaf Maple	2005	0.00(0)	0.00	2009	0.00(0)	0.00	2015	15 (1.73)	4.69
	Bitter Cherry	2005	0.00(0)	0.00	2009	0.00(0)	0.00	2015	17 (3.61)	4.69
	Red Alder	2005	0.00(0)	0.00	2009	7.3 (2.61)	2821.88	2015	24.1 (9.58)	523.44
12	Big Leaf Maple	2005	0.00(0)	0.00	2009	7.35 (2.5)	77.50	2015	17.11 (2.69)	70.00
	Cascara	2005	0.00(0)	0.00	2009	6.00 (0)	2.50	2015	9 (5.66)	5.00
	Bitter Cherry	2005	0.00(0)	0.00	2009	0.00(0)	0.00	2015	14.11 (5.1)	47.50
	Red Alder	2005	0.50 (0)	10.00	2009	2.86 (1.98)	122.50	2015	21.27 (17.99)	157.50
13	Cascara	2005	3.67 (2.31)	915.38	2008	7.74 (3.2)	1338.46	2015	15.66 (4.32)	1234.62
	Bitter Cherry	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	13.00 (0)	3.85
	Red Alder	2005	2.49 (0.38)	173.08	2008	6.94 (3.69)	42.31	2015	23.9 (5.93)	38.46
14	Cascara	2005	3.29 (1.12)	170.00	2008	5.87 (2.51)	420.00	2015	14.72 (5.33)	785.00
	Red Alder	2005	0.00 (0)	0.00	2008	5.31 (1.63)	222.50	2015	21.15 (8.95)	215.00
15	Big Leaf Maple	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	19.0 (0)	2.63
	Cascara	2005	8.17 (8.09)	23.68	2008	6.03 (5.97)	73.68	2015	9.89 (5.8)	94.74
	Bitter Cherry	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	6.28 (3.52)	42.11
	Red Alder	2005	0.00(0)	0.00	2008	4.85 (0.64)	5.26	2015	19.44 (14.47)	23.68
23	Big Leaf Maple	2005	4.0 (0)	65.22	2008	15.86 (5.35)	60.87	2015	0.0 (0)	0.00
	Cascara	2005	0.00(0)	0.00	2008	4.25 (1.83)	17.39	2015	19.08 (2.87)	26.09
	Bitter Cherry	2005	0.00(0)	0.00	2008	0.00(0)	0.00	2015	25.0 (0)	2.17
	Red Alder	2005	0.00(0)	0.00	2008	5.4 (1.52)	10.87	2015	38.09 (28.8)	23.91

APPENDIX C: CONIFER HEIGHT GROWTH RESPONSE

Mean annual height growth by species for all trees (Overall) and by leader position at the beginning of the growth period.

Site	Species	Growth Period	Overall	Growth Period	Overall	Leader Above	Leader Within	Overtopped
5	DF	2006-2010	1.1	2010-2015	2.2	2.4	2	1.2
	RC	2006-2010	0.5	2010-2015	0.9	1	-	0.7
8	SS	2007-2010	0.9	2010-2015	1.3	2.3	1.6	0.7
11	DF	2007-2009	1	2009-2015	1.7	2	0.3	-
	RC	2007-2009	0.6	2009-2015	0.9	1.3	0.5	0.3
	SS	2007-2009	1.7	2009-2015	2.1	2.1	1.4	0.8
	WH	2007-2009	1.3	2009-2015	2.4	2.6	0.3	
12	DF	2005-2009	0	2009-2015	1.6	2.2	1.3	-
	RC	2005-2009	0.3	2009-2015	0.7	1	0.5	0.4
	SS	2005-2009	0.7	2009-2015	1.5	1.7	0.9	1.2
	WH	2005-2009	0.7	2009-2015	2.2	2.2	-	-
13	DF	2005-2008	0.6	2008-2015	1.8	2.2	1.6	1.4
	WH	2005-2008	1.2	2008-2015	2.5	2.9	1.6	3
14	DF	2005-2008	0.9	2008-2015	2.2	2.4	2.2	1.7
	WH	2005-2008	1.5	2008-2015	1.9	2.1	1.7	-
15	DF	2005-2008	0.8	2008-2015	2.4	2.5	2.1	-
	WH	2005-2008	1.1	2008-2015	2.5	2.5	2.3	-
23	DF	2005-2008	1.4	2008-2015	1.9	2.2	1.3	0.2
	GF	2005-2008	1.5	2008-2015	1.6	1.9	-	0.2
	RC	2005-2008	0.2	2008-2015	0.3	-	0.5	0
	SS	2005-2008	0.9	2008-2015	0.6	1.3	0.8	0.4

APPENDIX D: CONIFER SURVIVAL RESPONSE

Trees per acre and percent of planted trees (in parentheses) surviving at the 4-year and 10-year measurements, by species, for all trees and by leader position at the previous measurement.

Site	Species	Grow Year	All	Leader Above	Leader Within	Overtopped	Grow Year	All	Leader Above	Leader Within	Overtopped
5	DF	2010	414.29 (86.49)	196.43 (41.01)	96.43 (20.13)	121.43 (25.35)	2015	175.00 (36.53)	132.14 (27.59)	21.43 (4.47)	21.43 (4.47)
	RC	2010	67.86 (90.48)	25.00 (33.33)	14.29 (19.05)	28.57 (38.09)	2015	46.43 (61.91)	25.00 (33.33)	7.14 (9.52)	14.29 (19.05)
8	SS	2010	414.47 (91.90)	97.37 (21.59)	94.74 (21.01)	222.37 (49.31)	2015	356.58 (79.06)	161.84 (35.88)	23.68 (5.25)	171.05 (37.93)
11	DF	2009	20.31 (61.55)	15.62 (47.33)	3.12 (9.45)	1.56 (4.73)	2015	12.50 (37.88)	6.25 (18.94)	-	6.25 (18.94)
	RC	2009	334.38 (80.77)	131.25 (31.70)	92.19 (22.27)	110.94 (26.80)	2015	207.81 (50.20)	35.94 (8.68)	20.31 (4.91)	151.56 (36.61)
	SS	2009	362.50 (87.77)	296.88 (71.88)	31.25 (7.57)	34.38 (8.32)	2015	251.56 (60.91)	145.31 (35.18)	29.69 (7.19)	76.56 (18.54)
	WH	2009	157.81 (75.51)	118.75 (56.82)	15.62 (7.47)	23.44 (11.22)	2015	84.38 (40.37)	53.12 (25.42)	3.12 (1.49)	28.12 (13.45)
12	DF	2009	45.00 (81.82)	12.50 (22.73)	27.50 (50.00)	5.00 (9.09)	2015	42.50 (77.27)	12.50 (22.73)	5.00 (9.09)	25.00 (45.45)
	RC	2009	377.50 (75.35)	100.00 (19.96)	125.00 (24.95)	152.50 (30.44)	2015	217.50 (43.41)	65.00 (12.97)	27.50 (5.49)	125.00 (24.95)
	SS	2009	405.00 (81.65)	252.50 (50.91)	102.50 (20.67)	50.00 (10.08)	2015	342.50 (69.05)	260.00 (52.42)	27.50 (5.54)	55.00 (11.09)
	WH	2009	97.50 (51.86)	55.00 (29.26)	27.50 (14.63)	15.00 (7.98)	2015	67.50 (35.90)	47.50 (25.27)	-	20.00 (10.64)
13	DF	2008	73.08 (33.99)	15.38 (7.15)	30.77 (14.31)	26.92 (12.52)	2015	46.15 (21.47)	34.62 (16.10)	-	11.54 (5.37)
	WH	2008	119.23 (54.44)	65.38 (29.85)	30.77 (14.05)	23.08 (10.54)	2015	100.00 (45.66)	61.54 (28.10)	11.54 (5.27)	26.92 (12.29)

Site	Species	Grow Year	All	Leader Above	Leader Within	Overtopped	Grow Year	All	Leader Above	Leader Within	Overtopped
14	DF	2008	155.00 (63.79)	40.00 (16.46)	62.50 (25.72)	52.50 (21.60)	2015	80.00 (32.92)	45.00 (18.52)	10.00 (4.12)	25.00 (10.29)
	WH	2008	75.00 (90.36)	52.50 (63.25)	15.00 (18.07)	7.50 (9.04)	2015	15.00 (18.07)	5.00 (6.02)	2.50 (3.01)	7.50 (9.04)
15	DF	2008	94.74 (59.96)	63.16 (39.97)	23.68 (14.99)	7.89 (4.99)	2015	71.05 (44.97)	68.42 (43.30)	-	2.63 (1.66)
	WH	2008	123.68 (84.14)	86.84 (59.07)	23.68 (16.11)	13.16 (8.95)	2015	28.95 (19.69)	23.68 (16.11)	-	5.26 (3.58)
23	DF	2008	73.91 (78.63)	45.65 (48.56)	15.22 (16.19)	13.04 (13.87)	2015	60.87 (64.76)	47.83 (50.88)	2.17 (2.31)	10.87 (11.56)
	GF	2008	15.22 (101.47)	13.04 (86.93)	-	2.17 (14.47)	2015	15.22 (101.47)	6.52 (43.47)	2.17 (14.47)	6.52 (43.47)
	RC	2008	50.00 (94.34)	-	10.87 (20.51)	39.13 (73.83)	2015	10.87 (20.51)	-	2.17 (4.09)	8.70 (16.42)
	SS	2008	97.83 (95.91)	21.74 (21.31)	23.91 (23.44)	52.17 (51.15)	2015	89.13 (87.38)	26.09 (25.58)	13.04 (12.78)	50.00 (49.02)

Aerial Herbicides in Forestlands

December 2019

Report to the Legislature per SSB 5597, passed by the 2019 Legislature

Prepared by:

Aerial Application of Herbicides on Forestlands Workgroup

Report Authors

The members of the Aerial Application of Herbicides on Forestlands Workgroup

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Executive Summary

During the 2019 Session, the Washington State Legislature passed Substitute Senate Bill 5597, creating the Aerial Application of Herbicides in Forestlands workgroup and directing a report back to the Legisalture.

The bill recognized that forest managers, state agencies, and the broader community share an interest in minimizing human and environmental exposure to herbicides. Forest landowners have made significant gains in the protection of riparian and wetland areas along the state's waterways, as well as protecting the health and safety of the public and forest workers, through a combination of scientific advancements, ongoing education and training, improved technologies, and proper monitoring and regulation under the Forests Practices statute (Chapter 76.09 RCW) and the associated Forest Practices Rules (Chapter 222-16 WAC).

The legislation established a workgroup on aerial application of herbicides on private and state-owned forestlands. This group was tasked with reviewing and evaluating existing best management practices and, if necessary, recommending improvements to those practices. Workgroup members included legislators from both chambers and caucuses, as well as representation from state and local government, private timber management, pesticide applicators, tribes, and environmental organizations.

The workgroup sought public participation to learn more about currently implemented best management practices and discuss specific topics:

- Review the roles and regulatory requirements of management and regulatory agencies relating to the approval and use of herbicides in aerial applications on forestlands. This includes review of state and federal regulatory authorities concerning aerial herbicide applications.
- Review current herbicide application technology in the state and throughout the nation to increase application accuracy and other best management practices focused on reducing drift and exposure to humans, fish, and wildlife, as well as impacts on surface water, drinking water, and wetlands.
- Review research, reports, and data from all sources on the herbicides most commonly used in aerial application on forestlands.
- Develop recommendations, if appropriate, for managing working forestlands through an integrated pest management approach. Any recommended alternatives must consider the toxicity, mobility, and bioaccumulation of those alternatives as compared to traditional operations.

Many stakeholders, including but not limited to local timber landowner hosts, neighboring non-timber property owners, aerial applicators and concerned members of the public, contributed valuable assistance and input. To meet the timeline established by the legislation, the workgroup met seven times in five months at various locations throughout the state. The

workgroup enjoyed substantial public participation and received in-person comments as well as written comments relevant to the work group's tasks.

The workgroup reached nine noteworthy recommendations regarding considerations that may improve best management practices:

Recommendations for Best Management Practices (BMPs):

- The workgroup recommends that non-chemical vegetation management strategies should continue to be evaluated and small trials should be conducted in consultation with the Washington State Department of Natural Resources, the U.S. Forest Service, the University of Washington, and Washington State University. When possible, this should be completed using existing research cooperatives.
- The workgroup recommends that the Forest Practices Board clarify adjacent property buffer rules, particularly concerning buffers around residences and agricultural land.

Recommendations for Communication:

- The workgroup recommends that DNR's Forest Practices Application Review System replacement or upgrade include an improved user interface for chemical application review.
- The workgroup recommends that DNR evaluate placement of the FPARS link on the DNR website homepage to make it more accessible (user-friendly) to the general public.
- The workgroup recommends that the signage in the Forest Practices Illustrated (FPI) and Forest Practices Board Manual section 12 be updated to reflect improvements to the legally required posting.

Recommendations for Administrative and Regulatory Issues:

- The workgroup recommends that the Washington State Department of Agriculture contract a literature review to identify possible data gaps as it relates to forestry herbicides in seasonal streams (first flush of rainwater after the dry season), buffer effectiveness, fish, and soil health. If gaps are identified, WSDA will work to obtain funding and address potential next steps.
- The workgroup recommends that the following agencies convene an external stakeholder workgroup to evaluate pesticide investigation rules and processes and report back to the Legislature any recommended changes, including how complaints should be reported and making sure the complaint is properly referred: Department of Natural Resources (DNR), Department of Agriculture (WSDA), Labor & Industries (L&I), Washington State Patrol (WSP), Department of Health (DOH), Department of Ecology

(ECY), the Poison Center, and local health jurisdictions/county health departments (LHJs).

- The workgroup recommends that DNR include herbicide applications into its larger biennial forest practices rules compliance monitoring sampling.
- The workgroup recommends the Forest Practices Board, using a stakeholder process, update the board manual section 12 for the Board's consideration and approval. The update should include best management practices and technical guidance consistent with the current forest practices rules, including but not limited to, equipment, weather conditions, neighbor communication BMPs, information about alternatives to herbicides, and signage.

These recommendations represent what could be agreed to by a majority of workgroup members within the time limits of meetings. The workgroup ran out of time to thoroughly discuss several topics and would have required additional meetings, which were not possible within the deadlines outlined in the legislation. Topics that were identified, but not fully addressed, included the evaluation of current State Environmental Policy Act (SEPA) thresholds, pesticide sensitivity registry, aerial application certification, and WSDA separating of reporting of forestry and agriculture.

This report was drafted by staff at the Washington State Departments of Agriculture and Natural Resources and reviewed by members of the Aerial Application of Herbicides on Forestlands Workgroup.

Introduction

During the 2019 legislative session, the Washingtion State Legislature passed Substitute Senate Bill (SSB) 5597, creating the Aerial Application of Herbicides on Forestlands Workgroup. The bill established that forest managers, state agencies, and the broader community share an interest in minimizing human and environmental exposure to herbicides. In addition, the Legislature found that forest landowners have made significant gains in the protection of riparian and wetland areas along the state's waterways, as well as protecting the health and safety of the public and forest workers, through a combination of scientific advancements, ongoing education and training, improved technologies, and proper monitoring and regulation under the Forests and Fish Law and the associated Forest Practices Rules.

SSB 5597 created the workgroup to develop recommendations for improving the best management practices used in aerial applications of herbicides on forestlands in Washington. The workgroup was co-chaired by Stephen Bernath of the Washington State Department of Natural Resources and Kelly McLain of the Washington State Department of Agriculture. Legislators appointed to the work group included Sen. Christine Rolfes, Sen. Keith Wagoner, Rep. Tom Dent, and Rep. Beth Doglio. The full workgroup membership is listed in Appendix A.

The workgroup was directed to:

- Review the roles and regulatory requirements of management and regulatory agencies relating to the approval and use of herbicides in aerial applications on forestlands. This includes review of state and federal regulatory authorities concerning aerial herbicide applications.
- Review current herbicide application technology in the state and throughout the nation to increase application accuracy and other best management practices focused on reducing drift and exposure to humans, fish, and wildlife, as well as impacts on surface water, drinking water, and wetlands.
- Review research, reports, and data from all sources on the herbicides most commonly used in aerial application on forestlands.
- Develop recommendations, if appropriate, for managing working forestlands through an integrated pest management approach. Any recommended alternatives must consider the toxicity, mobility, and bioaccumulation of those alternatives as compared to traditional operations.

<u>Workgroup Meetings</u>

As part of their review, the workgroup held four, all-day meetings beginning in August 2019 to hear from state agencies, organizations, and individuals involved in or living near public and private forestlands. Here are summaries of each meeting:

<u>August 2, 2019, Jane Russell Commons, University of Washington Tacoma – Tacoma, WA</u>

This was the first convened meeting of the workgroup. After introductions, the group received presentations from the Department of Agriculture, Department of Natural Resources, Department of Ecology, and the Department of Health regarding regulatory roles around pesticides. Additionally, Edward Kasner with the University of Washington's Pacific Northwest Agricultural Safety and Health Center (PNASH) presented about prior research that illustrated methods of measuring human exposure and the roles of application technology and applicator precision in minimizing human exposure near a treatment site. Washington State University weed scientist Steven Seefeldt gave an overview of herbicides, their modes of action, and how they affect plants differently than animals or mammals. Each member of the workgroup discussed the things they hoped would be accomplished between August and December 2019.

<u>September 6, 2019, Field tour on private forestland in and around Deer Park, WA and open public meeting</u>

This meeting day began with a field trip to private lands owned by Hancock Forest Products in Northeast Washington. This included comparisons between sites managed through clearcut-type harvest and selective harvest, as well as sites managed for weeds before and after a major forest fire. Representatives from the Confederated Tribes of the Colville Reservation also spoke on the tour about the tribal forest management perspective, including how they combat weeds without herbicides through heavy tree planting rates. The afternoon meeting included a recap of the tour and conversations about notification, site posting, and general neighbor relations. Spokane Tribe of Indians representatives were also in attendance and provided comments to the workgroup.

<u>October 9, 2019, Field tour and meeting, neighboring property and private forestland, Kitsap County, WA</u>

The tour portion of the day began at a privately owned farm (Rainbowzen Farm) that sits adjacent to lands managed and previously clear-cut by Pope Resources. Pope Resources also allowed the workgroup to tour the site they intended to manage with aerial application in late summer 2018 but suspended treatment plans after public outcry. Topics presented in the field included weed and tree competition issues, neighbor notification and posting of properties, and tree stocking rates. The afternoon public meeting included a presentation on glyphosate and risk communication by Dan Wixted from Cornell University, and a presentation on pesticides and water resources from Jeffrey Jenkins from the National Pesticide Information Center at Oregon State University. An additional session at this afternoon meeting covered the local community perspective, including Tom DeBor from Kitsap Environmental Coalition, Kitsap Public Utility District Commissioner Debra Lester, Port Gamble S'Klallam Tribe Chairman Jeromy Sullivan, Jefferson County Commissioner Kate Dean, and Kitsap County Noxious Weed Board director Dana Coggon.

<u>November 1, 2019, DNR-managed forestland and Great Wolf Lodge, Grand Mound, WA</u>

The tour was hosted on DNR trust lands and included an overview of application technology, state lands process for posting and state lands neighbor notification. The afternoon meeting included DNR staff Taylor Mizar and Jack Shambo providing an in-depth review of the Forest Practices Application review process, including when SEPA is triggered; a discussion and sharing of studies on glyphosate impacts on organisms from Dr. Stephen Whitesides; a presentation on elk hoof rot disease by Kyle Garrison of the Washington Department of Fish and Wildlife and Dr. Margaret Wild of Washington State University; and coverage of notification, the Sustainable Forestry Initiative certification program, and the small forest landowner perspective by Meghan Tuttle of Weyerhaeuser and small forest landowner Steve Barnowe-Meyer. The Swinomish Indian Tribal Community also provided comments during this meeting.

November 19, 2019, Olympia, WA

The workgroup met at the Olympia Center to begin working through what information was still needed to start developing recommendations. It was determined there was still information needed, which led to developing an agenda for a meeting on December 5, 2019. In addition, a report was given in summary terms of the results of the investigation of the Pope Resources spray application in Jefferson County, and initial themes for the legislative report were identified.

December 5, 2019, Olympia, WA

The workgroup met at the Natural Resources Building in Olympia, with some members participating remotely, and evaluated information provided as a result of the “what’s missing?” exercise at the November 19 meeting. This included information provided by WSDA about investigation protocols, the pesticide sensitivity registry, EPA registration review analysis, and toxicity information for current use herbicides and possible organically registered alternatives. DNR also provided data available for Forest Practices compliance inspections since 2016. In addition, Dr. Tim Harrington, senior researcher with the U.S. Forest Service, gave a presentation on a recently completed study on the use of slash materials (tree debris on site during harvest) along with herbicides as a form of weed suppression.

December 19, 2019, Olympia, WA

The workgroup met to propose and agree on recommendations to be included in this legislative report. The agreed-upon findings and recommendations are included in a later section of this report.

Stakeholder Communication and Participation

The Washington State Department of Natural Resources (DNR) frequently used email to notify stakeholders about upcoming meetings and opportunities to provide comments or testimony to the workgroup. Written public comments were also accepted. Stakeholders participating and attending the meetings included, but were not limited to, concerned property owners living in the vicinity of managed timber, aerial applicators, farmers, local government representatives, tribal representatives, and large and small forest landowners. Written comments have also been received from members of the Kitsap Environmental Coalition, the Jefferson Environmental Coalition, cities within Kitsap County, Kitsap and Jefferson County government, and other interested parties. DNR created a website for this workgroup, and all meeting information and presentations can be found at dnr.wa.gov/aerial-herbicide-application-working-group.

Report Content

The legislation tasked the workgroup with developing recommendations, if appropriate, for managing working forestlands through an integrated pest management approach and improving exisitng best management practices. As a result, report content focuses on “any findings, recommendations, and draft legislation” reflecting this legislative intent. This report was drafted by staff at WSDA and DNR and reviewed and evaluated by members of the workgroup.

Workgroup Findings and Recommendations

The workgroup identified a number of similar themes from the presentations, background materials, and public comments. These themes include overall transparency with a focus on Best Management Practices, Communications, Regulatory and Administrative Processes, and Science.

Findings related to Best Management Practices

- The workgroup recommends that non-chemical vegetation management strategies should continue to be evaluated and small trials should be conducted in consultation with the Washington State Department of Natural Resources, the U.S. Forest Service, the University of Washington, and Washington State University. When possible, this should be completed using existing research cooperatives.

Yes: 19
No: 0

Abstain: 1

- The workgroup recommends that the Forest Practices Board clarify adjacent property buffer rules, particularly in regards to residences and agricultural lands.

Yes: 15
No: 4
Abstain: 1

Findings related to Communications

- The workgroup recommends that DNR's Forest Practices Application Review System replacement or upgrade include an improved user interface for chemical application review.

Yes: 20
No: 0
Abstain: 0

- The workgroup recommends that DNR evaluate placement of the FPARS link on the DNR website homepage to make it more accessible (user-friendly) to the general public.

Yes: 20
No: 0
Abstain: 0

- The workgroup recommends that the signage description in the Forest Practices Illustrated (FPI) and Forest Practices Board Manual section 12 be updated to reflect improvements to the legally required posting.

Yes: 20
No: 0
Abstain: 0

Findings related to Administrative and Regulatory Processes

- The workgroup recommends that the Washington State Department of Agriculture contract the completion of a literature review to identify possible data gaps as it relates to forestry herbicides in seasonal streams (first flush of rainwater after the dry season), buffer effectiveness, fish, and soil health. If gaps are identified, WSDA will work to obtain funding and address potential next steps.

Yes: 18
No: 0
Abstain: 0
Absent: 2

- The workgroup recommends that the following agencies convene an external stakeholder workgroup to evaluate pesticide investigations rules and processes and report back to the Legislature any recommended changes, including how to report complaints and making sure complaints are properly referred: Department of Natural Resources (DNR), Department of Agriculture (WSDA), Labor & Industries (L&I), Washington State Patrol (WSP), Department of Health (DOH), Department of Ecology (ECY), the Poison Center, and local health jurisdictions/county health departments (LHJs).

Yes: 17
No: 1
Abstain: 1
Absent: 1

- The workgroup recommends that DNR should formally include herbicide applications into its larger biennial forest practices rules compliance monitoring sampling.

Yes: 20
No: 0
Abstain: 0

- The workgroup recommends the Forest Practices Board, using a stakeholder process, update the board manual section 12 for the Board's consideration and approval. The update should include best management practices and technical guidance consistent with the current forest practice rules, including, but not limited to, equipment, weather conditions, neighbor communication BMPs, information about alternatives to herbicides, and signage.

Yes: 20
No: 0
Abstain: 0

Two recommendations were discussed and voted on but did not receive a majority support vote to move forward. Those recommendations and the vote record are listed below.

Findings related to Administrative and Regulatory Processes

- The workgroup recommends seeking statutory and/or rule changes, as needed, to require that proponents provide to DNR, following completion of an aerial herbicide application, information that can be used to better understand and communicate such as: location, number of acres, date of application, type of and amount of herbicide applied, and Forest Practices Application number.

Yes: 8
No: 9
Abstain: 3

Findings regarding Science

- The workgroup recommends that after approximately five years of EPA pesticide registration review that the state contract a literature review of newly available science associated with forestry herbicides.

Yes: 9
No: 9
Abstain: 1
Absent: 1

There were also additional suggested recommendations within these topical areas; however, due to time constraints, for some of these areas we were not able to complete discussions within the deadlines outlined with the legislation. Some topics tabled by the workgroup would have required additional meetings, which was not possible. Topics that were identified, but not fully addressed, included use of SEPA, pesticide sensitivity registry, aerial application certification, and WSDA separation of reporting by forestry and agriculture.

Conclusion

Although the practices implemented in Washington around aerial application of herbicides in forestlands have reduced human and environmental exposure, the consensus of the workgroup is that this program could continue to benefit from improved distribution of information to interested parties and the public. Support was expressed for: improving signage, accessibility to FPARS for the public and an improved interface for all users of the FPARS system, additional scientific research associated with aerial herbicide applications, updates to the Forest Practices Board manual section that covers herbicide use, continued improvement of pesticide investigations, and, finally, formalizing herbicide application compliance monitoring conducted by DNR. Although some topics covered by this workgroup did not result in formal recommendations, the workgroup completed extensive work on the aerial application of herbicides on forestlands and identified improvements that will help all parties going forward, including relying on some of these topics to be addressed by the newly formed Pesticide Application Safety Committee.

Appendices

Appendix A: Aerial Application of Herbicides in Forestlands Workgroup Members

	Name	Association
Legislative Member	Senator Christine Rolfes	Senate Democratic Caucus
Legislative Member	Representative Tom Dent	House Republican Caucus
Legislative Member	Senator Keith Wagoner	Senate Republican Caucus
Legislative Member	Representative Beth Doglio	House Democratic Caucus
Legislative Member	Representative Mary Dye	House Republican Caucus (Alternate)
Tribal Representative	Valentino Villaluz	Swinomish Indian Tribal Community
Tribal Representative	Paul McCollum	Port Gamble S'Klallam Tribe
Tribal Representative	Cody Desautel	Confederated Tribes of the Colville Reservation
Co-Chair	Stephen Bernath	Department of Natural Resources
Co-Chair	Kelly McLain	Department of Agriculture
State Agency Member	Glenn Patrick	Department of Health
State Agency Member	Robin Schoen-Nessa	Department of Agriculture

State Agency Member	Joseph Shramek	Department of Natural Resources
State Agency Member	Rich Doenges	Department of Ecology
State Agency Member	Jeff Davis	Department of Fish and Wildlife
Noxious Weed Representative	Dana Coggon	Kitsap County Noxious Weed Control Board
Small Forest Landowner	Steve Barnowe-Meyer	Washington Farm Forestry Association
Industrial Timber – West	Meghan Tuttle	Weyerhaeuser
Industrial Timber – East	Scott Ketchum	Hancock Forest Products
Environmental Representative No. 1	Megan Dunn	Northwest Center for Alternatives to Pesticides
Environmental Representative No. 2	Tom DeBor	Kitsap Environmental Coalition
Environmental Representative No. 3	Alec Brown	Washington Environmental Council
Aerial Applicator	Corey Fransen	Wilbur-Ellis
Pesticide Representative	Wes Wasson	Helena Agri-Chemicals
University of Washington	Edward Kasner	Pacific Northwest Agricultural Safety and Health Center
Washington State University	Carol Black	Pesticide Safety Education Program

Appendix B: Acknowledgements

The Aerial Application of Herbicides on Forestlands Workgroup would like to thank all of the many people and organizations that helped contribute to the meetings, offered public comments, and hosted field site visits or facilities. This includes but is not limited to:

Joanne	Prado	Washington State Department of Health
Robin	Schoen-Nessa	Washington State Department of Agriculture
Rich	Doenges	Washington State Department of Ecology
Kelly	McLain	Washington State Department of Agriculture
Joseph	Shramek	Washington State Department of Natural Resources
Edward	Kasner	University of Washington Pacific Northwest Agricultural Safety and Health Center
Dr. Steven	Seefeldt	Washington State University
Scott	Ketchum	Hancock Forest Products
Cody	Desautel	Confederated Tribes of the Colville Reservation
Lisa	Hurt	Rainbowzen Farms
Adrian	Miller	Pope Resources
Dan	Wixted	Cornell University
Dr. Jeffrey	Jenkins	Oregon State University
Tom	DeBor	Kitsap Environmental Coalition
Debbie	Lester	Kitsap County Public Utility District commissioner
Kate	Dean	Jefferson County Board of Commissioners
Jeromy	Sullivan	Port Gamble S'Klallam Tribe
Taylor	Mizar	Washington State Department of Natural Resources
Jack	Shambo	Washington State Department of Natural Resources
Dr. Stephen	Whitesides	
Meghan	Tuttle	Weyerhaeuser
Steven	Barnowe-Meyer	Small forest landowner
Kyle	Garrison	Washington Department of Fish and Wildlife
Dr. Margaret	Wild	Washington State University
Dr. Tim	Harrington	U.S. Forest Service

Washington Forest Protection Association
Members of Kitsap Environmental Coalition
Jefferson County citizens
Members of the Spokane Tribe of Indians

White Horse Golf Club
University of Washington Tacoma
Spokane County Fire District 4
Washington Friends of Farms and Forests
Weyerhaeuser Co.
Wilbur-Ellis Co.

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MEMORANDUM

January 16, 2020

TO: Forest Practices Board

FROM: Mark Hicks, Adaptive Management Program Administrator

SUBJECT: Adaptive Management Program Quarterly Report

This memo highlights work completed and progress made in the Adaptive Management Program (AMP) since your November 2019 meeting.

AMP Staffing Update

Jacob Hibbeln was hired as Senior Secretary tasked with coordinating the logistics of the Cooperative Monitoring, Evaluation, and Research Committee (CMER) and TFW Policy Committee (Policy) meetings; including working with co-chairs to set up agendas, and taking minutes. This will free up the time of our Contract Manager who was doing this work for CMER and replaces Triangle and Associates staff who were assisting TFW Policy.

We have filled our two vacant Project Manager positions. Ben Flint is now serving as our supervisory project manager and Eszter Munes has filled our vacant Environmental Planner position. Ben will manage a portfolio of projects and additionally oversee the day to day work of the other 3 project managers.

The Eastern Washington CMER staff scientist position has just been filled with Malia Volke, our top candidate. She will be located at leased space in Ecology's Regional Office in Spokane and report directly to the Adaptive Management Program Administrator (AMPA). Malia will be part of the overall state-wide science team supporting CMER research.

The Northwest Indian Fisheries Commission oversees the remaining CMER staff scientists (four positions). The commission is actively moving to fill their two vacancies before the end of this fiscal year. They are planning to replace the vacant Wetland and Riparian Scientist positions.

<u>Cooperative Monitoring, Evaluation and Research Committee (CMER) Update</u>

Projects with Key Stages Completed:

The Extensive Monitoring Status and Trends – Temperature Report characterizing the summer temperatures of western Washington streams has been approved by CMER, Independent Scientific Peer Review (ISPR), and Policy. TFW Policy's recommendations will be presented at the Board's February 2020 meeting.

The Hardwood Conversion Case Studies Report examining the operational and financial feasibility of reestablishing conifer in western Washington riparian areas has been approved by CMER, ISPR and TFW Policy. TFW Policy's recommendations will be presented at the Board's February 2020 meeting.

The Type N Hard Rock Amphibian Genetics Study examining genetic changes in amphibian populations 7-8 years post-harvest has been approved by CMER, ISPR, and Policy. TFW Policy's recommendations will be presented at the Board's February 2020 meeting.

The Westside Type N Buffer Characteristics Integrity and Function Report, examining changes in forest stands in western Washington after harvest has been approved by CMER, ISPR, and transmitted to Policy. TFW Policy's recommendations are expected to be ready for the Board in May 2020.

The Eastside Type F Riparian Effectiveness Bull Trout Add-On Study, examining changes to riparian stands in eastern Washington after harvest, has been approved by CMER and ISPR, and transmitted to Policy. TFW Policy's recommendations are expected to be ready for the Board in May 2020.

The Unstable Slopes Criteria Project study design for Project 2 of this 5-part study has been approved by CMER and ISPR. The study design is expected to be delivered to TFW Policy in April 2020 for approval to begin implementation.

The Forested Wetlands Effectiveness Monitoring Project study design for a phase I pilot study has been approved by CMER and ISPR. The study design is expected to be delivered to TFW Policy in May 2020 for approval to begin implementation.

The Type N Hard Rock Phase II Extended Monitoring Report, has been sent to ISPR who is currently working to find reviewers. This is expected to take 4-6 months to move through the ISPR process before it can return to CMER for final approval.

The Eastside Modeling Effectiveness Project applying forest health and fire risk models to eastside riparian areas has a draft report approved by CMER and now in ISPR review.

Projects in Active Development:

The Road Prescription Scale Effectiveness Monitoring Project is now in full implementation. Project costs have gone up to fully cover site maintenance and monitoring.

The Eastside Type N Riparian Effectiveness Project (ENREP) project team has completed the first year of pre-harvest monitoring on 3 pairs of study sites in Northeast Washington, and has confirmed applicability and availability of 1 more pair of study sites along the east slope of the Cascades. Two pairs of monitoring sites along the east slopes have been lost due to conflict with potential Spotted Owl habitat. The project team is looking for two replacement sites pairs, ideally in the East Cascades region but the NE is also acceptable if that is where the only viable sites are.

The Type N Soft Rock Study Report is in its second round of CMER reviews. If successful in accommodating CMER comments, the report should be ready to send to ISPR in January or February 2020.

Projects under the Deep-Seated Landslide Research Strategy are still in scoping within the Upland Processes Science Advisory Group (UPSAG). The first scoping document will be for the Landslide Mapping and Classification Phase and should be ready for CMER review by June 2020.

The Eastside Timber Habitat Evaluation Project is still in scoping within the Science Advisory Group for the Eastside (SAGE).

The draft Extensive Monitoring Status and Trends - Vegetation Pilot Study (transferability) report is in CMER review. This pilot study is part of a series of study components examining the use of Light Detection and Ranging (LiDAR) remote sensing-based modeling to inventory riparian stands. It is anticipated to be approved by CMER in January or February 2020.

Type F Effectiveness Monitoring Project Phase I Pilot Study is in report preparation and is intended to be used to develop a study design for a more rigorous test of the effectiveness of the Type F rule buffers.

The LiDAR-based wetlands identification Tool project is nearing completion. It is expected this tool will be used to produce maps to assist with site selection for the Forested Wetlands Effectiveness Monitoring study.

The Riparian Characteristics and Shade Project will examine the effects of various buffer widths and intensities of riparian management on shade across the state. Policy had asked that study designs be developed for their two top alternatives. These study designs are in CMER review with issues of concern being addressed by the Riparian Science Advisory Group (RSAG) and

CMER reviewers. Once resolved the draft study designs will go to Policy who will select a preferred option to go through ISPR and be implemented.

A Charter for the Amphibians in Intermittent Streams Study is in CMER review with expectations it will be approved at the January 2020 CMER meeting; allowing project scoping to commence.

The Wetland Management Zone Effectiveness Monitoring Study which will examine rule effectiveness on non-forested wetlands is in the early stages of scoping.

A new Large Woody Debris Recruitment Study is being scoped within the RSAG.

TFW Policy Committee Update

TFW Policy responded to the recommendations of the Small Forest Landowner template workgroup tasked with reviewing the Washington Farm Forestry Association Alternative Plan Template Proposal. By consensus, TFW Policy agreed: 1) the SFL template as submitted does not meet the criteria of a template, 2) to fund a riparian literature synthesis for CMER to complete, and 3) to develop charters and provide staffing for two technical workgroups who would: (a) complete the two draft Experimental Harvest Prescriptions for Small Forest Landowners, and (b) advise policy makers on where and under what conditions it would be appropriate to apply 25 foot buffers to Type Np waters, and 50 foot and 75 foot buffers to Type F waters. The workgroups are to provide recommendations to the TFW Policy Committee by May 2020.

The Type Np Prescriptions Workgroup met three times since October 2019, with monthly meetings scheduled through June 2020. The Type N Workgroup has been reviewing CMER approved Type N project reports and meeting with Principal Investigators from those projects to clarify any remaining questions regarding the reports. The Workgroup also visited a field site from one of the studies to see how the prescription was applied on the landscape.

Policy accepted the findings for the Hardwood Conversion Study and agreed by consensus the study results do not warrant action by the Forest Practices Board. TFW Policy's recommendations will be presented at the Board's February 2020 meeting.

If you have any questions, please feel free to contact me (mark.hicks@dnr.wa.gov, 360-902-1909).

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January 6, 2020

TO: Forest Practices Board

FROM: Tami Miketa, Manager, Small Forest Landowner Office – Forest Practices

SUBJECT: Small Forest Landowner Office and Advisory Committee

Small Forest Landowner Office Advisory Committee
Since my last report, the Small Forest Landowner Office Advisory Committee held one meeting on November 19, 2019. Discussions focused on the following topics:

- SFLO Program Updates
- Potential Low Impact Harvest Prescriptions
- FPA Forms and Updates
- Update of Small Forest Landowner Office Advisory Committee Action Plan.

SFLO Program Updates
The Forest Practices Division is excited to announce that Mary McDonald has agreed to join the Forest Practices Division leadership team as Assistant Division Manager for Policy and Services. Mary is a long-term DNR employee with experience in forest practices, state lands trust management and wildfire response. For the last eight years, she has been a Pacific Cascade Region Assistant Manager, with responsibility for managing the state uplands transaction, recreation and natural areas programs. Prior to that, she worked in the Forest Practices Division.

Mary has extensive and varied experience in the Forest Practices Program, in both Region and Division positions. She worked for three years as a Forest Practices Forester, for four years as a Small Forest Landowner Specialist, and for seven years as the Manager of the Small Forest Landowner Office. She also served the program as acting Assistant Division Manager for operations for seven months in 2009, and as acting Division Manager for six months in 2013. Mary has extensive experience and a passion for supporting her staff and a track record of building and maintaining strong working relationships with diverse types of external stakeholders.

Mary is a forester by training, with a B.S. in Forest Resource Management from the University of Montana. She is a graduate of the Washington Agforestry Leadership Program, and is a small forest landowner herself. Mary officially began in this position in on December 9, 2019, in which she now oversees the Small Forest Landowner Office, the Policy staff that supports the Forest Practices Board, and the Forest Practices Habitat Conservation Program reporting.

Brandon Austin, who was the SFLO cruise contract specialist for the Forestry Riparian Easement Program and the Rivers and Habitat Open Space Program, has accepted a promotion with Dept. of Ecology. We are currently recruiting for a replacement for this position.

Recently, the Governor released his FY20 Supplemental Operating and Capital Budgets. As part of DNR's supplemental budget request, the Small Forest Landowner Office requested an additional 4 FTE's for Small Forest Landowner Regulation Assistance support. The Governor's budget recommended allotment of 0.5 FTE for this technical support which would fund one staff person for FY21. Additionally, the Governor's budget reallocated $520,000 to the FREP budget with an additional $1 million reallocated to FREP from another program. . In total, if approved the Governor's budget would increase the FREP Program funding to a total of $4.02 million for the FY20-21biennium.

Long Term Applications (LTA)
There are a total of 283 approved long term applications, which is an increase of 6 approved applications since the end of the last reporting period (10/03/2019).

LTA Applications	LTA Phase 1	LTA Phase 2	TOTAL
Under Review	6	1	**7**
Approved	5	283	**288**
TOTAL	**11**	**284**	**295**

Upcoming Landowner Events
Forest Stewardship Coached Planning Short Courses
WSU Extension's flagship course will teach landowners how to assess their trees, avoid insect and disease problems, attract wildlife, and take practical steps to keep their forest on track to provide enjoyment and even income for years to come. In this course landowners will develop their own Forest Stewardship Plan, which brings state recognition as a Stewardship Forest and eligibility for cost-share assistance, and may also qualify them for significant property tax reductions.

Online Forest Stewardship Coached Planning Short course
Tuesdays, Starting January 28, 2020

Foresters Roundtable
Spokane, WA
Thursday January 23, 2020

28th Family Foresters Workshop
Coeur d'Alene, ID
Friday January 24, 2020

Forest Owners Winter School

- Colville, WA, Saturday February 1, 2020
- Vancouver, WA, Saturday February 8, 2020
- Auburn, WA, Saturday February 29, 2020

For more information regarding these events go to http://forestry.wsu.edu/

Please contact me at (360) 902-1415 or tami.miketa@dnr.wa.gov if you have questions.
TM/

TIMBER FISH
& WILDLIFE

Timber, Fish and Wildlife Policy Committee
Forest Practices Board

PO BOX 47012, Olympia, WA 98504-4712

Policy Co-Chairs:
Terra Rentz, WA Department of Fish & Wildlife
Curt Veldhuisen, Skagit River System Cooperative

January 27, 2020

TO: Washington Forest Practices Board

FROM: Terra Rentz and Curt Veldhuisen

SUBJECT: TFW Policy Committee Report (October, November, & December 2019; January 2020)

SUMMARY OF POLICY RECOMMENDATIONS TO THE BOARD

Action Items

Recommend to the Forest Practices Board that the Small Forest Landowner (SFL) Alternate Prescription (AP) Template proposal does not meet the criteria of a template per the rule standards in WAC 222-12-0403(3) in whole, but may in part be a template or other form of prescription with more site specific criteria.

(Request for inclusion on the May 2020 agenda)

Recommended Actions to be Presented by the AMPA

1. Accept Policy's October 3, 2019 recommendation that the Amphibian Genetic findings do not warrant action by the Forest Practices Board.
2. Accept Policy's October 31, 2019 recommendation that the ERSTM Temperature Study findings do not warrant action by the Forest Practices Board.
3. Accept Policy's December 5, 2019 recommendation that the Hardwood Conversion Study findings do not warrant action by the Forest Practices Board.

BUSINESS UPDATE

Small Forest Landowner Alternate Plan (SFL AP) Template Proposal

At the October 31, 2019 TFW meeting the SFL AP Template Workgroup submitted a report and recommendations to Policy for consideration and decision at the December 2019 meeting. Specifically, the workgroup determined, through a no consensus majority (SFL caucus as decent), the following findings:

1. As a whole, the proposed template does not meet the criteria of an alternate plan template; and
2. In part, the proposed template does not meet the criteria of an alternate plan template.

That recommendation was accompanied by two additional consensus decisions:

1. The experimental conifer restoration and conifer thinning alternate harvest prescriptions should continue to be developed; and
2. There are proposed prescriptions within the SFL AP template proposal which could be changed to become qualified as an alternate plan template or a set of prescriptions.

Substantial discussion occurred around the report and scientific justification submitted by the SFL caucus and the subsequent review conducted by Teply. It was found that, although a science product, this review *did not* go through the CMER process and did not receive the necessary consensus stages that allow Policy to make strong, justifiable, and informed decisions from scientific evidence. Although an important element of the SFL proposal, Policy struggled with how to adequately take into account this report as it was the source of much concern by multiple caucuses.

At the December 5, 2019 Policy meeting, policy deliberated on the recommendations from the workgroup. Substantial discussion occurred and a concerted effort was made by all parties to find areas of consensus. Specifically, co-chairs asked Policy to review, accept, reject or modify each of the recommendations from the workgroup. It was found, first, that two additional areas of work are present: (1) continued work on the conifer restoration and thinning alternate prescriptions, and (2) more specific and situational considerations of the applicability of 75-, 50- and 25-foot buffers. Policy continued to clarify these topics, and a consensus decision was made to form two new technical workgroups:

> **Decision**: Form a technical workgroup including the State caucuses and other interested parties to continue work on the experimental conifer restoration and conifer thinning alternate harvest prescriptions, including consideration of a monitoring and evaluation component that would later be developed by CMER. The workgroup shall provide a recommendation to Policy by May 2020. (Conservation and Industry caucuses sideways; Eastside tribal and Federal caucuses absent; all other caucuses thumbs up)

> **Decision**: Form a small technical workgroup to evaluate under what, if any, site-specific conditions a 75-foot and 50-foot buffer, respectively, would be acceptable as a prescription for Type F streams; and under what, if any, site-specific conditions a 25-foot buffer would be acceptable as a prescription for Type Np streams. The workgroup shall provide a recommendation to Policy by May 2020. (Westside tribes, WDFW/Ecology, and DNR caucuses voted sideways; Counties, Conservation, SFL, and Industry caucuses voted thumbs up; Eastside Tribes and Federal caucuses absent)

Policy had a goal of reviewing draft charters for each workgroup in January, but due to scheduling that did not occur. Co-chairs and AMP staff are presently struggling with the specific outcome and deliverable of each workgroup as each has a science component and likely needs engagement by CMER.

In addition to these two workgroups, the following overarching consensus recommendation was made to the board:

> **Recommendation:** Recommend to the Forest Practices Board that the SFL AP Template proposal does not meet the criteria of a template per the rule standards in WAC 222-12-0403(3) in whole, but may in part be a template or other form of prescription with more site specific criteria. (All caucuses thumbs up; Eastside tribes and Federal caucus absent).

Finally, Policy spent a substantial amount of time reviewing the record of actions associated with the SFL Template to identify where and when the process took an alternative pathway that did not follow the standard Adaptive Management Program process. In that assessment it became apparently clear that both the Board and Policy directed the AMPA on multiple occasions to facilitate, through CMER, the completion of a Riparian Literature Synthesis. That synthesis was purported, through multiple updates, to be the focus of the Teply review when, in fact, a different review was occurring that simply focused on an assessment of the report provided by the SFL caucus and, per the direction of the then-AMPA, did not provide the normal practices of consensus endorsement and review by caucuses. Further, it was identified that although a funded line item in previous Master Project Schedules, the Riparian Literature Synthesis was dropped, without direction from Policy or CMER, and replaced with funding for the Teply review. Policy noted that integrating a riparian literature synthesis is necessary to adequately evaluate proposed changes put forth by the SFL caucus and felt it important to clearly readdress the need with the following motion:

> **Decision:** Fund a specific line item for the Riparian Literature Synthesis (RLS), move it to the implementation phase in the MPS, and request CMER complete the RLS. Recommend that CMER work with the AMPA to complete any necessary contracting for the completion of the RLS as soon as possible. (Industry caucus sideways thumb; All other caucuses voted thumbs up; Eastside tribal and Federal caucuses absent).

As of the authoring of this report, Charters for both workgroups are being drafted, clarity is being sought as to the specific desired outcomes and deliverables from the new workgroups so as not to commit the same science process-related error as previously done, and the AMPA is assessing the viability and timeliness of integrating the RLS into the current MPS.

Policy members acknowledged the desire by the SFL caucus for an expediated completion and are moving as quickly as staff availability from each caucus allows. Per the request of the board, we are happy to provide another update at the May 202 Board meeting.

Amphibian Genetic Findings Report for Type N

In September 2019, policy was provided with a presentation and findings report for the amphibian genetics study associated with the Type N Hardrock study. Per our Board Manual, policy had approximately 1 month to consider those findings to make a determination for the Board. A robust discussion occurred at the October 3rd meeting that identified both this study and previous studies have identified ancillary findings for how to improve the AMP process that may require additional attention by Policy. Further, Policy deliberated the specific findings associated with this study and determined that the genetic findings did not demonstrate a substantial effect from the Type N treatment prescriptions and that no action was warranted by the Boards.

> **Recommendation:** Policy recommends that the Amphibian Genetics findings report does not warrant action by the Forest Practices Board. (All caucuses thumbs up; Eastside tribal and Federal caucuses absent)

Extensive Riparian Status and Trends (ERST) – Temperature Monitoring

Findings and a presentation were received at the October 3, 2019 TFW Meeting. Per Board manual, Policy deliberated on October 31, 2019 to determine if the findings of this study warranted action by the board. Although it was noted that this study should be directed to the Type N Workgroup for inclusion in their decision-making process, Policy determined that the findings warranted no action; a recommendation that has been forwarded to the Board for acceptance.

> **Recommendation**: Policy recommends no action by the Forest Practices Board is warranted on the ERSTM Temperature Study (All caucuses thumbs up; Eastside Tribal and Federal caucuses absent)

Hardwood Conversion Study Findings

At the December 5, 2019 meeting Policy was reminded that the Hardwood Conversion Study was designed a few years ago and had some limitations in informing the adaptive management process as it did not evaluate any specific treatment. Policy received a presentation from Cramer Fish Sciences on this study at the October 31st meeting and, per Board Manual deliberated on the findings at the December 5 policy meeting. It was noted that a more rigorous hardwood study may be warranted and should be discussed in greater detail at a later date. Specifically, policy made the following consensus decision to the Board:

> **Recommendation**: Policy recommend that the findings in the Hardwood Conversion Study do not warrant action by the Forest Practices Board (All caucuses thumbs up; Eastside Tribal and Federal caucuses absent)

ENREP – Eastside Type N Riparian Effectiveness Project

At the October 31, 2019 TFW meeting, policy concluded a multi-month investigation into cost saving feasibility of the ENREP study. Through that process, greater awareness of the study factor elements was gained, in addition to new information regarding site availability.

Site availability: DNR State Lands cannot allow the Study to use the Rattlesnake Basin site pair because of the presence of the Northern Spotted Owl (NSO) dispersal habitat. The loss od the study site diminished the ability of the study to infer responses of streams located in wetter/colder regions. Communication was also received by the AMPA regarding concern about NSO dispersal habitat at the Sedge site pair – prior to the new AMPA, a commitment was made to work with USFWS to get approval to reduce the amount of dispersal habitat under the HCP – then AMPA Berge never followed up with FWS, which may reduce the availability of this site.

> **Decision:** Recommend replacing the Rattlesnake site pair, and if needed the Sedge pair, and look for two additional site pairs (All caucuses thumbs up; Eastside Tribal and Federal caucuses absent)

Study Factors: At the ENREP workshop hosted by TFW in summer 2019, multiple factors were identified in which CMER's expert opinion was sought to determine the effects to future decision making at the conclusion of ENREP if specific study factors were eliminated to achieve cost saving objectives. A report was provided by CMER to Policy at the October 31, 2020 meeting which provided enough information to inform Policy's decision space. At the conclusion of this discussion, no formal motion was made to reduce study factors.

Riparian Characteristics and Shade Study

At the October 3,2019 meeting, AMP project manager, Teresa Miskovic, presented the RCS Study Charter for Policy approval. Per the AMP process, this CMER approved document required Policy discussion and final approval to move forward. The purpose of this study is to quantify how stream shade responds to different buffer widths and thinning treatments and is presently in the study design phase (which was intended to be completed by July 2019 but has been delayed).

> **Decision:** Policy accept the Riparian Characteristics and Shade Charter (All caucuses thumbs up; Eastside Tribal and Federal caucuses absent)

At the January 6, 2020 Policy meeting, CMER asked Policy for direction and clarity. Previously, Policy asked CMER to scope two variations of the study design to assess costs and future decision-making potential. That lack of clarity created conflicts at the SAG and PI level regarding what specifically Policy wanted the study to accomplish. Per Policy's request, two study designs were developed however it is unclear if, at this stage, both needed to go through the ISPR process or if Policy could support CMER's evaluation and recommendation on a single study to move forward. Policy requested to see both study designs prior to going to ISPR so that a single study design could be selected to move forward.

> **Decision:** Direct CMER to send Policy alternate study designs prior to them being sent to ISPR. (All caucuses thumbs up; Eastside Tribal and Federal caucuses absent)

Budget and Finance

The new AMPA has been undergoing herculean task at retrofitting the project budget and accounting process to ensure more accurate, transparent, and timely financial updates are available for CMER and Policy. At the February TFW meeting, Policy will be hosting our annual budget workshop to understand changes to existing projects and to identify unspent (or overspent) funds. Modifications will be made, as needed, to the MPS and an updated budget will be presented to the Board at the May 2020 meeting for approval.

Technical Type Np Workgroup Status

The Technical Type Np Workgroup, which was formed as an outcome of the Type N Hardrock study, has convened and met multiple times since October. The Workgroup members had heard from principle investigators associated with the Type N study, are assessing related CMER products, and are functioning effectively. Policy will be receiving quarterly updates to provide adequate briefings to the Board.

Upcoming Decisions

CMER is continuing to move projects through the chain towards completion. The following projects (or project phases) are awaiting decision by policy or are nearing completion:

- Buffer Characteristics and shade study (BCIF) findings – action warranted determination 2/7/2020
- Bull Trout Overlay Add-on Project findings – action wettened determination 2/7/2020
- Extensive LiDAR Pilot – presentation likely March 2020
- Scoping and study alternative for the Unstable Slopes Criteria project – March 2020
- Extensive Riparian Status and Trends Vegetation study – presentation and findings report March 2020
- Type N Soft Rock – presentation likely August 2020
- Hard Rock Phase II Extended – presentation likely November 2020

This list is likely to change but reflects Policies current estimates on projects.

State of Washington
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February 12, 2019

MEMORANDUM

To: **Forest Practices Board**

From: **Gary Bell, Wildlife Biologist, Forest Habitats Section**

Subject: **Upland Wildlife Update**

The following provides a brief status update for ongoing or pending actions pertaining to priority wildlife species in forested habitats:

Marbled Murrelet

1992: Federally listed as Threatened
1993: State listed as Threatened
1996: Federal critical habitat designated by USFWS
1997: FPB enacted State Forest Practices Rules
2017: State up-listed to Endangered

With a continued average population decline of approximately 4.4% since 2001, the status of the Marbled Murrelet in Washington has not improved since state listing in 1993. Given the 2017 uplisting to state endangered, the Washington Department of Natural Resources (WDNR), in consultation with Washington Department of Fish and Wildlife (WDFW), recommended that the Forest Practices Board (Board) support WDFW's initiation of a Marbled Murrelet forest practices rule (FP Rule) assessment involving a diverse group of stakeholders. WDFW established a Wildlife Working Group (WWG) to evaluate rule effectiveness in protecting murrelet habitat, identify weaknesses in rule language and on-the-ground implementation, consider potential habitat conservation incentives, and bring consensus recommendations regarding FP Rule improvements to the Board for their consideration.

The WWG held its most recent meeting December 13, 2019 (a meeting was also held January 22nd, 2020, after submittal of this update), further identifying and evaluating the best available science intended to inform the appropriate definition of Marbled Murrelet habitat based on habitat characteristics and selection by murrelets. Information gathered is meant to provide updated knowledge on murrelet ecology and help the group evaluate if the current habitat definition identifies correct habitat attributes that provide functional murrelet habitat. Once this task is complete, focus will move on to evaluation of the FP Rule processes and implementation aspects that may need changes based on the recommended habitat definition* (**may not change from what is now in FP Rule*).

WDFW continues to monitor marbled murrelet populations at-sea in both Zones 1 (Puget Sound and Strait) and Zone 2 (Washington coast). Each zone is monitored in alternating years. Zone 2 was monitored in 2019. WDFW just started the eighth year of Navy funded non-breeding season surveys in Puget Sound. The 2018/2019 survey report will be available shortly. The NW Forest Plan Effectiveness Monitoring team is currently drafting the 25-year report, which is expected to be released in spring of 2020. And finally, WDFW Research Scientist Scott Pearson is currently drafting a manuscript summarizing the Navy funded survey results.

Canada Lynx
1993: State listed as Threatened
1994: FPB enacted voluntary management approach
2000: Federally listed as Threatened
2017: State up-listed to Endangered

Up-listing of the lynx from state threatened to endangered became effective on February 4, 2017. At that time, WDFW recommended to WDNR (and WDNR in turn to the Board) that no action be taken to add lynx to the forest practices rule designation for critical habitats (state). WDFW also recommended maintaining the voluntary protection approach for lynx while efforts continue to evaluate existing protection mechanisms and identify conservation options in collaboration with landowners, Canadian federal and provincial entities, US Fish & Wildlife Service (USFWS), US Forest Service (USFS), conservation organizations, tribes and academic partners. The goal is to refine recovery actions that can be implemented in the near- and long-term to benefit lynx conservation in Washington.

WDFW continues screening forest practices for potential impacts to lynx and coordinating with conservation partners to maintain awareness about the importance of protecting remaining habitat in the face of wildfires that may affect lynx. WDFW also continues active participation in the *Transboundary Lynx Work Group*, exploring conservation strategies which have included a feasibility assessment for translocating lynx into the Kettle Lynx Management Zone, as well as coordination with southern British Columbia conservation partners concerning demographic support for Washington's transboundary lynx population.

The November 2017 USFWS summary of the lynx 5-year Species Status Assessment determined that regulatory improvements addressed the threat that led to the original listing of the lynx distinct population segment (DPS). However, the proposal to remove lynx from the federal list of threatened and endangered species is still pending at this time.

Northern Spotted Owl
1988: State listed as Endangered
1990: Federally listed as Threatened
1996: FPB enacted State Forest Practices Rules
2012: USFWS designation of revised critical habitat
2016: State retention of Endangered status

Recognized as a state endangered species, the Northern Spotted Owl (NSO) population has continued to decline in recent years primarily due to ongoing competitive interactions with Barred Owls, as well as habitat changes from timber harvests, forest health issues, and wildfires. The Northern Spotted Owl Implementation Team (NSOIT) continues working to develop a programmatic Safe Harbor Agreement (SHA) for forest landowners that will provide federal assurances while protecting existing habitat and recruiting new habitat, although progress remains slow. The group is also exploring other opportunities for landowner incentives.

In October 2019, the North Central Washington Audubon Society submitted a petition to the Board regarding NSO in eastern Washington. The petition called to question the effectiveness of the FP Rules in protecting NSO habitat and ultimately requested that a moratorium be placed on logging anywhere within Spotted Owl Special Emphasis Areas (SOSEAs) in eastern Washington, reconsideration of WAC 222-10-041 which addresses policies for forest practices subject to SEPA, and confirmation that the NSO rules are being implemented appropriately. The Board considered the petition at its November 13, 2019 meeting, ultimately denying the petition for rule making related to the NSO due to lack of authority to place a moratorium on harvest. They further requested WDFW work with U.S. Forest Service, DNR and the associated forest landowners to provide additional information and recommendations on alternative solutions to protect NSO at the February 2020 meeting, and WDFW will present information on progress-to-date at that time.

Fisher

1998: State listed as Endangered
2016: Federal status: Final decision for west coast DPS - not warranted for listing (April 2016)
2018: Northern District Court of California ruling on 2017 USFWS fisher ESA listing withdrawal
2019: Federal publication of Candidate Notice of Review (October), including fisher

Fisher reintroductions into Washington have continued by WDFW and its partners. To date, a total of 255 fishers have been reintroduced, including 90 in Olympic National Park (2008-2010), and 165 in other federal lands within the southern and northern Cascade Mountains. A total of 81 fishers have now been released at Mount Rainier National Park and the Gifford Pinchot National Forest since December 2015. And, since December 2018, 84 fishers have been translocated from the Calgary Zoo and released into the North Cascades Recovery Area. One additional fisher release of up to 8 individuals is still planned for the North Cascades in late January or early February.

Combined with the Candidate Conservation Agreement with Assurances (CCAA) program administered by WDFW, the reintroductions are assisting the species return to the state. Non-federal landowners can continue to enroll in the CCAA and receive federal regulatory assurances in the event that the fisher becomes listed under the ESA in the future. By signing on to the CCAA, landowners agree to follow basic conservation measures that protect fishers that may use private lands. To date, 60 landowners and 3,318,228 acres of non-federal forest lands are enrolled in the CCAA.

In early November 2019, the USFWS published a revised proposed rule for fishers, which replaces the 2014 proposed rule. As stipulated in the September 2018 court decision, USFWS will deliver a final rule to the Federal Register by April 25, 2020. Most notably, the revised rule does not include Washington State in the distinct population segment and proposes to list fishers in southern Oregon, northern California, and the Sierra Nevada as a threatened species under the ESA. This announcement also opened a 30-day comment period on the revised proposed rule, which closed December 9, 2019.

Of note, the revised proposed rule refers to fishers in Washington as "non-native", a term that both USFWS and WDFW have officially commented about several times in the past. Fishers in Washington historically shared a close relationship with fishers in British Columbia and western Alberta, and there is no evidence to suggest that "non-native" is an appropriate descriptor given the historical connectedness of fishers across this area. The Columbia River, on the other hand, was and continues to be a significant barrier between fishers in Washington and Oregon. USFWS will work internally to revise the language (for the final rule) around why a different distinct population segment boundary that excludes Washington fisher was determined to be most appropriate.

Future Updates to the Board

The forest practices rules require that when a species is listed by the Washington Fish and Wildlife Commission and/or the U.S. Secretary of the Interior or Commerce, DNR consults with WDFW and makes a recommendation to the Forest Practices Board as to whether protection is needed under the Critical Habitat (State) rule (WAC 222-16-080). WDFW and DNR continue coordinating to anticipate federal actions and to respond to changes in the status of any given species.

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FOREST PRACTICES BOARD
2020 WORK PLAN

2020 Meeting Dates: February 12 / May 13 / August 12 / November 12

TASK	**COMPLETION DATE/STATUS**
Adaptive Management Program	
• CMER Master Project Schedule Compliance Review*	August
• CMER Master Project Schedule Review*	May
• CWA LWAG Type N Experimental Buffer Treatment – Genetics	February
• CWA Type N Experimental Buffer Treatment in Soft Rock Lithology	November
• Eastside Modeling Evaluation Project	May
• Hardwood Conversion Study	February
• Small Forest Landowner Western Washington Low Impact Template: TFW Policy Recommended Review Process & Timeline*****	August
• State Auditor Performance Audit Report	November
• TFW Policy Committee Progress Report on Unstable Slopes Recommendations from the Board approved Proposal Initiation	November
• Type N Experimental Buffer Treatment in Hard Rock Lithology	November
• Type Np Prescriptions Workgroup*	On-going
• Water Typing Strategy	On-going
• Water Typing Studies	May
Annual Reports	
WAC 222-08-160 Continuing review of FP rules (Annual Evaluations), *by tradition the Board has received an annual evaluation of the implementation of cultural resources protections*	August
• Clean Water Act Assurances	August
• Northern Spotted Owl Conservation Advisory Group	November
• TFW Policy Committee Priorities*	August
• Western Gray Squirrel	August
Board Manual Development	
• Section 23 (Part 1) Field Protocol to Locate Mapped Divisions Between Stream Types*	On-going
• Section 23 (Part 2) Perennial Stream Identification*	On-going
CMER Membership	As needed
Compliance Monitoring 2018-2019 Biennial Report	August
Critical Habitat - State/federal species listings and critical habitat designations	As needed
Field Tour	April
Rule Making	
• Water Typing System	On-going
• Rule Clarifications	May
Committee Recommendations on Water Typing System Rule	On-going
NSO Recommendations	February

Italics = proposed changes
**= TFW Policy Committee*

Approved November 2019

FOREST PRACTICES BOARD
2020 WORK PLAN

Quarterly Reports	
• Adaptive Management Program*	Each regular meeting
• Board Manual Development	Each regular meeting
• Compliance Monitoring	Each regular meeting
• Clean Water Act Assurances	February
• Legislative Activity	February & May
• NSO Implementation Team	Each regular meeting
• Rule Making Activities	Each regular meeting
• Small Forest Landowner Advisory Committee & Office	Each regular meeting
• TFW Cultural Resources Roundtable	*To be determined*
• TFW Policy Committee Work Plan Accomplishments & Priorities*	Each regular meeting
• Upland Wildlife Working Group	Each regular meeting
• **Work Planning for 2021**	November