United States Department of Agriculture Forest Service	United States Department of Commerce National Oceanic and Atmospheric Administration Fisheries	United States Department of the Interior Bureau of Land Management	United States Department of the Interior Fish and Wildlife Service

Reply to: 2670(FS)/6841(BLM) **Date:** June 6, 2013

BLM/FS/FWS/NOAA Fisheries-Memorandum

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Dear Regional Executive Team Members:

In 1995, with revisions in 1999, the U.S. Forest Service (FS), Bureau of Land Management (BLM), National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) signed the Streamlined Consultation Procedures for Section 7 of the Endangered Species Act (ESA) (Streamlining Agreement). The purpose of the Streamlining Agreement is to reduce the likelihood of conflicts between listed species or critical habitat and proposed actions, to improve the efficiency of plan and programmatic section 7 consultations under the ESA, and to enhance the effectiveness of these consultations for the conservation of listed species while delivering appropriate goods and services provided by lands and resources managed by the signatory agencies. This agreement reflects the common goal of the four agencies for an easier and more transparent process for interagency cooperation during ESA consultation, while furthering the conservation of listed and proposed species. As of 2013, the process and guidance provided in the Streamlining Agreement are still being implemented in a manner that has generally met the objectives described above.

Under the Streamlining Agreement, Level 1 and 2 interagency teams were established on a geographic basis. Level 1 teams are comprised of staff resource specialists from each of the agencies; Level 2 teams are comprised of management staff. A Regional Technical Team (RTT), an Interagency Coordinating Subcommittee (ICS), comprised of mid-level managers, and a Regional Executive Team were also established. The Streamlining Agreement also formally established a dispute resolution process. This letter addresses two issues elevated to the Regional Executive Team from the Northwest Oregon Level 2 Team for resolution.

Elevated Issues

In February 2010, the Level 2 Team for Northwest Oregon elevated two issues to the Regional Executive Team for resolution. Issue 1 pertains to disagreements about the identification and the interpretation of the best available scientific information to determine the effects of riparian forest management and restoration on salmonid fishes and their habitats. The disagreements focused on the interpretation of science on the effects of riparian thinning on wood recruitment and stream temperature. Issue 2 pertains to the process and timeframes in the 1999 Streamlining Agreement that are not being met or fully implemented. The Level 2 Team asked the Regional Executives to provide predictable timeframes for completing ESA consultations and to further clarify the Streamlined Consultation Agreement with respect to the roles of the Level 1 and 2 teams and the procedures under which they operate.

The Regional Executive Team referred the two issues to the ICS to develop recommendations for the Regional Executive Team to consider for resolving the above two issues. In Attachment 1, we describe the process used to resolve the elevation and develop recommendations. Attachment 2 includes the streamlining process goals and recommendations developed by the ICS to resolve issues 1 and 2 described above. Attachment 3 includes multiple documents including a description of the process used by agency scientists to discuss and resolve the first issue pertaining to the best available science, and three documents that discuss the state of the science relative to riparian thinning in northwest Oregon and the effects on wood recruitment, stream temperature, northern spotted owl and marbled murrelet. These documents address the first elevated issue, and have been distributed to the Level 1 and Level 2 teams. The ICS recommends concluding this elevation through the implementation of the recommendations in Attachment 2. Further, we recommend a joint rollout of this conclusion that includes Level 1 and 2 teams from both Northwest Oregon and Southwest Oregon, and includes members of the Science Review Team (SRT), if logistically possible.

Your signature on the following page indicates your concurrence with the ICS recommendations and proposed process changes. Please return the signed concurrence page to your appropriate ICS representative; upon receipt of all signed pages the ICS will schedule the meeting with the Level 1 and 2 teams. If you do not concur, please contact your ICS representative immediately so that we may resolve your concerns.

If you have any questions regarding this elevation, please do not hesitate to contact any of the ICS representatives.

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Debbie A. Hollen
USDA Forest Service

Marilet A. Zablan
USDI, Fish & Wildlife Service

Lee Folliard
USDI, Bureau of Land Management

Enclosures:

- Attachment 1: Elevation Process
- Attachment 2: ESA Consultation Process Guidance
- Attachment 3: Science Review Team Process and Reports, including appendices

cc:
Level 2 Team NW Province
Lisa Northrop – Forest Supervisor, MTH
Meg Mitchell – Forest Supervisor, WIL
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Regional Executive Team Members

I concur:

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MAY 3 0 2013 WILL STELLE DATE Regional Administrator USDC, National Marine Fisheries Service Northwest Region	Robyn Thorson ROBYN THORSON DATE 6/18/13 Regional Director USDI, Fish and Wildlife Service Pacific Region

ATTACHMENT 1

Elevation Process

The ICS asked the Level 2 Team and the respective agencies for clarification and more information on the issues elevated. In the summer of 2010, the ICS received 'position papers' from BLM, FS and NMFS. In addition to more detail on the issues, the agencies asked that an interdisciplinary team of scientists be convened to address the elevation issues, and they asked that the team include key scientists in the Northwest who are knowledgeable of local forest conditions and management practices.

The ICS contracted with Oregon Consensus to assist with convening and facilitating the Science Review Team (SRT). The eight-member SRT was composed of scientists representing six Federal agencies (BLM, FS-PNW, FWS, NMFS, EPA, and USGS). Oregon Consensus worked with the ICS to develop a set of questions for the SRT; the questions addressed the three key areas identified in the elevation documents: (1) the effect of riparian thinning on stream temperature; (2) the effect of riparian thinning on wood recruitment in streams; and (3) the effects of thinning on other aspects of ecosystem function. Although the SRT was initially scheduled to meet three times, they had more than ten meetings including a two-day workshop. The number of meetings reflects the substantial technical complexity of the issues with which they were grappling. The ICS attended portions of some of the SRT meetings to provide direction and clarify intent. In winter of 2012, the ICS received drafts of three documents (to address each of the three topic areas above), and these documents were combined and finalized in the fall 2012/winter 2013.

Because of the technical complexity of the issues and the scarcity of empirical science to clearly resolve the science questions, the ICS explored other approaches to supplement the SRT work that would help resolve the policy challenges in completing ESA consultations that included riparian thinning. The ICS and RTT participated in a strategic decision-making process, facilitated by experts from USFWS and USFS that was designed to identify areas of agreement and areas of disagreement using hypothetical project variables. Through this process the ICS articulated differences in a hypothetical project's effect determination related to levels of risk management. Ultimately the ICS decided not to move this work forward because it would not aid the consultation process.

Two work products were developed during this elevation; the first is the technical assessments developed by the SRT, and the second is a set of recommendations developed by the ICS to address future conflicts during the streamlining process.

1. <u>Science Review Team documents</u>. The SRT was asked to synthesize the science pertaining to the effects of riparian thinning on wood recruitment, water temperature, and two ESA-listed

birds, the northern spotted owl and the marbled murrelet. A description of the SRT process and the three documents (plus appendices) developed by the SRT are in attachment 3.

The SRT documents include published information, unpublished data and model results, new interpretation of data, and best professional judgment on the part of the scientists who participated. Each document represents the SRT's understanding of the best available information to guide riparian thinning actions in western Oregon. However, they are not exhaustive literature reviews. Some have had broader scientific review by others outside the SRT (e.g. the stream temperature document) and others include very preliminary ideas for consideration (see authors' notes in the wood recruitment paper—simulation modeling was not comprehensive or rigorous and should be viewed as preliminary). These documents add to our understanding of management effects on riparian systems, but also underscore the paucity of scientific information that addresses this topic directly. The SRT documents can be considered, along with other relevant information (including monitoring data) and best professional judgment. As new scientific information becomes available, it should also be considered in the consultation process.

2. Recommendation: ESA Consultation process guidance. The ICS believes the Streamlined Consultation Agreement is still relevant, and remains an effective tool for completing efficient and collaborative ESA consultations. However, the ICS also believes some additional guidance is warranted to clarify and elaborate on the streamlining consultation process. This guidance, provided in Attachment 2, also includes new measures that discuss how to proceed when the Level 1 and Level 2 teams have different perspectives related to effect determinations and/or reasonable and prudent measures included in an incidental take statement of a draft biological opinion.

ATTACHMENT 2

ICS Recommendation: *ESA Consultation Process Guidance*

The processes, and the roles and responsibilities of the Level 1 and Level 2 teams described in the 1999 Streamlined Consultation Agreement, and supplementary documents and implementation memos provided on the NW Interagency ESA website (http://www.blm.gov/or/esa/procedure.htm) are still valid and should be implemented. However, we are providing additional guidance to the western Oregon teams and other western Oregon units; this guidance is needed because of the paucity of science available to guide program scale assessments of site-specific riparian thinning, and the challenge of making trade-offs between the needs of different listed species and achieving ecosystem goals. The goals of this additional guidance include:

- To support increased transparency and certainty for the consultation process, particularly for actions that have adverse effects on ESA-listed salmonids;
- To acknowledge that timelines for completing formal ESA-consultations have not been met in recent years in Northwest Oregon. The reasons for this are multiple: (1) Few empirical studies exist describing the effects of riparian thinning on ESA-listed species, including salmonids, northern spotted owls and marbled murrelets; (2) an evolving understanding of the effects on listed species as new models are developed by agency scientists; (3) agency differences in interpretation of the data, perception of risk, and willingness to accept risk based on agency culture and, more importantly, agency mission; and (4) an enhanced review process by NMFS in response to maintaining the authority to sign biological opinions within the Northwest Region;
- To shorten existing timelines for ESA consultations, and to move projects through formal consultation more rapidly when there is interagency disagreement about the level of effect to ESA-listed species. Our recommendations are intended to provide more certainty in the consultation process, in the face of uncertainty in the science and in interpretation of the science for the analysis of effects of riparian thinning projects on ESA-listed species;
- To emphasize that the streamlined consultation process, which was developed to efficiently complete ESA consultations while furthering the conservation of listed and proposed species process, uses interagency teams to improve communication early in the consultation process, to review preliminary project design, and to review preliminary determinations of effect to ascertain the likely effects of the proposed action. The

interagency teams may also identify any alternatives to avoid jeopardizing listed species or adversely modifying critical habitat, if warranted;

- To enhance communication during the development and submittal of the biological assessment by the Federal action agency, the development by the FWS and/or NMFS of concurrence letters for actions that are not likely to adversely affect (NLAA) ESA-listed species or critical habitats, and the development of biological opinions for actions that are likely to adversely affect (LAA) listed species or critical habitats;
- To clarify that FS and BLM can develop actions that meet the NEPA standards of an EA/FONSI and an ESA effects determination of LAA, and remain consistent with agency policy. In other words, it is possible to have an EA/FONSI for a project and still require a biological opinion. NMFS and the FWS will consult on actions that include thinning of trees in riparian reserves even when those actions will result in adverse effects on listed species and/or critical habitat;
- To clarify that the purpose of a biological opinion is to determine whether the proposed Federal action is likely to jeopardize the continued existence of a listed species (jeopardy) or destroy or adversely modify critical habitat (adverse modification). A biological opinion also serves several other functions; it (1) determines the amount or extent of anticipated incidental take; (2) identifies the nature and extent of the effects of Federal agency actions on listed species and critical habitat; (3) provides reasonable and prudent measures to minimize incidental take; and (4) identifies reasonable and prudent alternatives, if any, when the action is likely to result in jeopardy or adverse modification, among others. While the analysis conducted during formal consultation is undertaken cooperatively between the agencies, the conclusion of a biological opinion by NMFS or FWS cannot be determined prior to completing an independent analysis of the best available information and is solely within the authority of the regulatory agencies; and
- To clarify that NMFS and FWS will develop reasonable and prudent measures and terms and conditions in incidental take statements to minimize the impacts of incidental take of listed species caused by the proposed Federal action in a manner that respects the minor change rule described in the implementing regulations for ESA section 7 (i.e., that do not alter the basic design, location, scope, duration). Terms and conditions will not result in a change in the effects determination for the proposed action. If issues regarding implementation of the minor change rule arise during individual project consultations the ICS requests to be notified so that additional interagency coordination can occur.

ICS-recommended clarifications and additions to the Streamlined Consultation Process:

1. Level 1 teams should continue to work together to develop information needs for the analysis of the proposed action in a biological assessment, to determine the level of effect

for the proposed action, and identify measures to minimize the impacts of incidental take on the listed species.

2. Level 1 teams should not feel compelled to modify a proposed action in order to reach a NLAA determination. Projects that are LAA listed species or critical habitat requiring formal consultations are a reasonable outcome, not a failure of, the Level 1 process.
3. All Level 1 team members should coordinate internally such that all available and relevant information is provided in the BA in a timely manner. This should minimize any changes to the determination of effect after formal submission of the biological assessment to the regulatory agencies.[1] Level 1 teams are encouraged to document their decisions and the substance of the decisions pertaining to when an adequate biological assessment has been developed and is ready for submittal by the action agencies.
4. As described in the Analytical Process for developing biological assessments for "may affect" timber sales in the Northwest Forest Plan area, the spatial level of analysis should be both the project site and watershed scales.
5. The goal of the Level 1 team process is to produce an adequate biological assessment that will facilitate and expedite issuance of a biological opinion or concurrence letter. The Level 1 team's role is satisfied when the team reaches agreement that a biological assessment is complete. The regulatory agencies will acknowledge receipt of the action agency Level 1 team approved biological assessment, and if necessary, request any additional information needed within 2 weeks (April 7, 2000 memorandum[2]).
6. In response to NMFS's concerns that draft biological assessments and other information is provided too late to be considered adequately during the Level 1 team meeting, FS and BLM commit to providing all relevant and needed information 2 weeks in advance of scheduled meetings.
7. In response to BLM and FS concerns about the internal review process at NMFS and the potential for a change in either the level of effect of the proposed action or the measures required to minimize the impacts of incidental take on the listed species, NMFS commits to:
    a. Increased internal communication during the Level 1 review of actions to minimize the likelihood of later changes.
    b. If there is a change in the determination of effect, NMFS will communicate the reason for the change to the action agency. If the change is from LAA to NLAA, NMFS will proceed and prepare a concurrence letter. If the change is from NLAA to LAA, NMFS will give the action agency an opportunity to provide

[1] The final determination of the effect of a proposed action on listed species and critical habitat and the conclusion of a biological opinion is the responsibility of the regulatory agencies.
[2] http://www.blm.gov/or/esa/procedure.htm

additional information or modifications (e.g., project design changes, change in species or population information, additional physical/hydrological data, etc.). These discussions would include both the Level 1 and Level 2 teams. If the action agency does not wish to provide additional information or modify the action, NMFS will proceed and finalize the biological opinion with time for the action agencies to review the terms and conditions in the draft biological opinion before it is finalized. This may result in consultations that do not meet intended timelines, however, there should not be a need for significant new information or analysis beyond the original biological assessment.

8. The Level 1 and 2 teams for Northwest Oregon have assigned a management liaison to aid in communication between the Level 1 and level 2 teams, and within the teams. The teams anticipate the management liaison will be particularly useful if the effect determination in a biological assessment is questioned during the development of a concurrence letter or a biological opinion. The management liaison will facilitate discussions between the Level 1 and 2 Teams and the line officer concerning potential project modifications, the need for additional information, and decisions about proceeding with development of decision documents by the regulatory agencies.

9. This elevation arose in part due to agency differences in interpretation of science and balancing risk of uncertainty. In order to move beyond these challenges, we need to recognize these differences and develop processes to accommodate them. In an effort to increase consultation efficiency: (1) NMFS will complete more formal consultations on proposed actions that include riparian thinning, when appropriate (i.e., at some point it becomes counterproductive to try and reach interagency agreement on NLAA determinations); and (2) FS and BLM will recognize NMFS's risk tolerance and utilize the formal consultation process to a higher degree, when appropriate.

10. The ICS acknowledges the Level 2 team's request for certainty in the timeline for completing consultations. The steps described above are designed primarily to minimize the time required to complete ESA consultations. NMFS will continue to work to meet statutory deadlines, and acknowledge that timelines provided in the Streamlining Agreement are unrealistic in light of current budgets (e.g., furloughs, hiring freezes), and history of litigation specific to forest management. Programmatic consultations can be considered as a tool that may be useful in expediting consultation timelines for projects.

ATTACHMENT 3

Attachment Science Review Team (SRT) Documents

Background
In February 2010 the Northwest Oregon Level 2 team elevated two issues to the Regional Executives for resolution: (1) disagreements about the identification and interpretation of the best available scientific information to determine effects of riparian forest management and restoration on salmon and their habitat, and (2) concerns that the processes and timeframes in the 1999 streamlining agreement were not being met or fully implemented. The Regional Executives engaged the Interagency Coordinators Subgroup (ICS) and the ICS reviewed the initial elevation materials. In April 2010, the ICS requested additional information from the Northwest Oregon Level 2 team.

In July of 2010, the ICS received issues papers from USFS, BLM and NMFS that provided background information and detailed their concerns relative to the two elevated issues (wood recruitment and temperature effects from riparian thinning)—specific agency issues are summarized at the end of this document. According to streamlining procedures, the ICS typically engages the Regional Technical Team (RTT) to address the scientific questions raised in elevations. The RTT would then prepare a short report for the ICS, and then the ICS would make a recommendation to the Regional Executives on how to resolve the issue.

That procedure was not appropriate for this elevation because: (1) the RTT had already worked with Level 1 and Level 2 teams on the technical issues and not been able to resolve the concerns; and (2) the Level 2 team specifically requested the engagement of scientists from the USFS PNW Research Station, the NMFS Northwest Fisheries Science Center (NWFSC) and USGS to develop a white paper to review, synthesize and interpret the relevant scientific information.

In January of 2011, the Regional Executives approved the establishment of a Science Review Team (SRT) to function as the RTT for this elevation. They also approved the use of a third party facilitator to convene the SRT, and subsequently, the ICS engaged Oregon Consensus (Turner Odell and Peter Harkema) to work with the SRT.

The Science Review Team members were:

- Dr. Michael Pollack, NWFSC
- Dr. Tim Beechie, NWFWC
- Dr. Peter Leinenbach, EPA
- George McFadden, BLM
- Dr. Christian Torgersen, EPA
- Dr. Robert Anthony, under contract to USFWS
- Dr. Thomas Spies, PNW
- Dr. Gordon Reeves, PNW

The SRT first met in April 2011 to address these specific tasks: (1) Establish where there is agreement on the scientific issues; and (2) address how use the best available science to avoid jeopardy and conserve listed salmon. The SRT was asked to:

- Participate in a collaborative process with an interagency group of scientists tasked with integrating and synthesizing the available science pertinent to riparian thinning

in western Oregon and highlighting areas of uncertainty and where additional information or research is needed;
- Participate in a workshop with the ICS to discuss the application of their findings to the ESA consultation; and applying the synthesized science to the consultation questions.
- Participate in a briefing/presentation of proposed solutions to agency Level 2 members and the Regional Executives.

Members of the SRT collaborated for more than a year to integrate and review the science pertinent to riparian thinning in western Oregon, and describe the effects to salmon and steelhead habitat, and habitat for the northern spotted owl and marbled murrelets. The SRT also participated in multiple meetings with the ICS to discuss progress and clarify goals, and a meeting in January 2012 with Level 2 Team members from western Oregon. The SRT finalized their documents in the fall of 2012. The attached documents were produced as part of that collaborative process.

SRT Documents

The SRT worked together as a group during meetings to discuss the relevant science. The scientists then divided themselves into groups to develop the three attached documents; the three groups were delineated based on each scientist's expertise. They produced the following three documents:

I. Effects of Riparian Thinning on Wood Recruitment: A Scientific Synthesis
II. Effects of Riparian Management Strategies on Stream Temperature (with 4 appendices)
III. Effects of Riparian Thinning on Marbled Murrelets and Northern Spotted Owls

Each document represents the SRT's understanding of the best available information to guide riparian thinning actions in western Oregon. They are not exhaustive literature reviews. These documents advance our understanding of the effects of riparian thinning actions in young, even-aged forests of western Oregon. The SRT agrees with the Level 1 and Level 2 teams that the effects are complex, site specific, and highly variable depending on variety of physical and biological factors. Similarly, the answers to the agencies' questions are not simple. Despite this, the ICS considers the SRT work to be a success for a variety of reasons. The SRT members concurred on a number of points, and their understanding and use of models to predict thinning effects to wood recruitment was greatly clarified. As such, these documents were instrumental in the development of management recommendations by the ICS.

Summary of the Specific Technical Questions Raised in Agency Issue Papers

USFS Questions
1. Size of non-treatment buffers needed to avoid temperature increases in streams with listed fish, and the distance above listed fish habitat to which these buffers should apply.
2. Benefits of thinning to increase tree growth for future large wood vs benefits of maintaining dense small trees with slower growth for current shade and structural needs.

3. Contribution of residual stands to stream wood recruitment following thinning treatments. (role, function and management of riparian reserves in supply of instream structure).
4. Buffers needed to prevent sedimentation in fish habitat and the site specific conditions, such as heavy ground vegetation, that should influence the size of those buffers.
5. The application of research based on clear-cut treatments to thinning projects and the overall applicability of local research and site characteristics vs non-local research and models.
6. Recognition of future benefits that will contribute to resiliency of fish habitat and the need to implement actions in anticipation of climate change impacts to fish habitat.
7. How wide an area of riparian edge needs to be retained in an undisturbed state to avoid risk of significant effects to stream shade, bank and channel stability, and nutrients/structural inputs, and how would that width depending upon site specific conditions.

BLM Questions
1. The Districts do not concur with the conclusions NMFS has reached concerning active management of dense riparian conifer stands on salmon and their habitat. The Districts have determined that thinning in Riparian Reserves can be accomplished without have adverse effects (NLAA) to salmon as the effects to stream temperature and wood recruitment will be insignificant.
2. Table of primary shade zone---for trees of different height and on different hill slopes.
3. Recommends an interdisciplinary panel of expert scientists should evaluate the Districts' riparian thinning practices that achieve riparian habitat objectives, and the resulting biological and physical effects of these riparian thinning practices on salmon and habitat.
4. Should clarify ranges in magnitude of effects for important habitat variables (shade, wood recruitment) that would occur with project implementation.

NMFS Questions
1. Effects of silvicultural actions on recruitment of wood to stream channels.
    a. How much instream conifer wood is enough, when will it arrive and what will be its source?
    b. Does heavy thinning of riparian conifer forests lead to more instream wood?
    c. Will riparian thinning along streams prone to debris flows increase the amount of wood (and sediment) in fish-bearing stream?
    d. Are there any kinds of riparian conifer forest where thinning might be beneficial?
    e. Isn't very large wood (e.g. 24" dbh or greater) the only size of wood needed to restore instream habitat?
    f. How important is tree mortality caused by landslides?
    g. Can large wood help to keep streams cool?
    h. What are trigger trees?
    i. Are riparian roads an issue?
    j. Does managing riparian forests for instream wood conflict with other ecological management objectives?
2. Effects of silvicultrual action on stream shade and water temperature.

I. Effects of Riparian Thinning on Wood Recruitment: A Scientific Synthesis

Science Review Team Wood Recruitment Subgroup

Thomas Spies[1], Michael Pollock[2], Gordon Reeves[1] and Tim Beechie[2]

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Executive Summary

For forests in northwest Oregon, we were asked to provide a scientific perspective on "…*the anticipated contributions of large woody debris from young (up to 120 years) unthinned (and generally even-aged) riparian forests, in the short term and long term, and describe how that recruitment changes under various riparian thinning regimes. Describe how the outcomes are affected by the tree species composition. Include information regarding large woody debris for aquatic and terrestrial systems"*

Approach

We used published empirical and theoretical studies, simulation modeling (done especially for this project) and professional opinion to synthesize the science. In general, there is very little published science about the effects of thinning on dead wood recruitment and virtually none on thinning effects on wood recruitment in riparian zones. We conducted some limited simulation modeling to illustrate some of the relationships between thinning and dead wood recruitment. The simulations (and comparison of models) were not comprehensive or a rigorous analysis of thinning effects and should be viewed as preliminary. Below we provide 15 key points from our efforts:

Key Points

1. <u>Thinning is most beneficial in dense young stands</u>. Existing literature and stand development theory suggest that the greatest potential ecological benefits of thinning to accelerate the development of older forest structure (e.g. large trees, large dead trees, spatial structural and compositional heterogeneity, etc.) comes in dense uniform plantations less than 80 years and especially less than 50 years old. The benefits of thinning for older forest ecological objectives are less clear in stands over 80 years of age. Hence, our report focused primarily on plantations less than 50 years of age.

2. <u>Results may not be applicable to all stand conditions</u>. For this synthesis, many of our conclusions were based on modeling the effects of thinning 30 to 40 year old Douglas-fir plantation stands that range

in density from 200 to 270 trees per acre (tpa). We consider such stands moderately dense, as young plantation stand densities range from less than 100 to greater than 450 tpa. In terms of dead wood production, higher density stands are likely to see more benefits from thinning, and lower density stands less benefits.

3. Accurate assessments of thinning effects requires site-specific information. The effects of thinning regimes on dead wood creation and recruitment (relative to no-thinning) will depend on many factors including initial stand conditions, particularly stand density, and thinning prescription—it is difficult to generalize about the effects of thinning on dead wood without specifying the particulars of the management regime and stand conditions.

4. Conventional thinning generally produces fewer large dead trees. Thinning with removal of trees (conventional thinning) will generally produce fewer large dead trees across a range of sizes over the several decades following thinning and the life-time of the stand relative to equivalent stands that are not thinned. Generally, recruitment of dead wood to streams would likewise be reduced in conventionally thinned stands relative to unthinned stands.

5. Conventional thinning can accelerate the development of very large diameter trees. In stands that are conventionally thinned, the appearance of very large diameter dead trees (greater than 40") may be *accelerated* by 1 to 20 years relative to unthinned plantations, depending on thinning intensity and initial stand conditions. Trees of such sizes typically begin to appear 5 to 10 decades after thinning 30 to 40 year old stands.

6. Nonconventional thinning can substantially accelerate dead wood production. Stands thinned with prescriptions that leave some or all of the dead wood may more rapidly produce both large diameter dead trees in the short-term and very large diameter dead trees (especially greater than 40") in the long-term, relative to unthinned stands. Instream wood placement gets wood into streams much sooner than by natural recruitment, and can offset negative effects of thinning on dead wood production.

7. Assessments of thinning effects may vary depending on the forest growth model. The previous statements are supported by three stand simulation models (FVS, ORGANON, and ZELIG). However, the magnitude and timing of effects of thinning on dead wood recruitment and stand growth varied among models.

8. Dead wood in streams comes from multiple sources. Dead wood in streams is primarily recruited through near-stream inputs (e.g. tree mortality and bank erosion) and landslides and debris flows. All types of recruitment are important and the relative importance varies with site and stream characteristics.

9. 95% of near-stream wood inputs come from within 82 to 148 feet of a stream. The distance of near-stream inputs to streams varies with forest conditions and geomorphology. Empirical studies indicate that 95% of total instream wood (from near-stream sources) comes from distances of 82 to 148 feet. Shorter distances occur in young, shorter stands and longer distances occur in older and taller stands.

10. Thinning can increase the amount of pool-forming wood under certain conditions. Thinning can increase the amount of pool-forming wood only when the thinned trees are smaller in diameter than the average diameter of pool-forming wood (which varies with stream size).

11. The function of instream wood varies with size and location. Large instream wood can serve as stable "key" pieces that create instream obstructions and form wood jams by racking up numerous

smaller pieces of wood that are mobile during high flows. Such wood jams typically consist of a wide range of piece sizes and provide multiple ecological functions that vary with stream size and gradient.

12. Effects of thinning on instream wood needs to be placed in a watershed context. Assessing the relative effect of riparian thinning on instream wood loads at a site and over the long term requires an estimation of the likely wood recruitment that will occur from the opposite bank, from upstream transport, and the rate of decay and downstream transport of wood from the site.

13. The ecological effects of thinning needs to be placed in a watershed context. Watershed-scale perspectives are needed to restore streams and riparian vegetation. The ecological effects of thinning on instream habitat will vary depending upon location in the stream network. Riparian management practices can be varied to match the ecological functions of streams.

14. Variation in thinning is essential (i.e. don't do the same thing everywhere). Variation in thinning prescriptions will produce more variable forest and wood recruitment conditions, which may more closely mimic natural forest conditions. Using a variety of treatments is also consistent with the tenets of adaptive management in situations where the outcomes of treatments are uncertain.

15. Healthy, diverse forests contain many dead trees. Numerous terrestrial forest species require large dead or dying trees as essential habitat. Some directly, others indirectly; to support the food web within which they exist. Abundant large snags and large down wood on the forest floor are common features of natural forests and essential for the maintenance of biological diversity.

Contents

Charge To SRT From Interagency Coordinating Subgroup:

Characterize the anticipated contributions of large woody debris from young (up to 120 years) unthinned (and generally even-aged) riparian forests, in the short term and long term, and describe how that recruitment changes under various riparian thinning regimes.

- *Describe how the outcomes are affected by the tree species composition.*
- *Include information regarding large woody debris for aquatic and terrestrial systems.*

Introduction

The future abundance of dead wood in aquatic and terrestrial systems is difficult to accurately predict because the natural processes that produce dead wood in ecosystems are highly variable. In stream networks, dead wood abundance and structure is a function of four major processes: stand mortality, bank erosion that recruits trees from streamside areas, debris flows and landslides that recruit trees and/or redistribute wood across stream networks, and wood depletion (loss) in streams. General predictions about the long-term effect of thinning on dead wood production are also difficult to make because of variation in thinning prescriptions and stand conditions, as well as, the absence of empirical long-term scientific studies and the limited number of modeling studies. Consequently, to answer the charge, we relied on a combination of theory, relevant scientific literature, unpublished simulation models, and professional opinion. We were not asked to develop management guidelines for thinning in riparian areas nor did we comment on the adequacy of current or alternative management practices to meet management goals.

We primarily used English units of measure, because that is what most foresters use, even though scientific journals generally use metric (SI) units. However, we occasionally provide metric conversions in places throughout the document. For those wanting to convert to metric, helpful conversions for this document are: 100 cm = 40”, 50 cm = 20”, 30 cm = 12”, 1 hectare = 2.5 acres.

Stand Age And Thinning Effects

In northwest Oregon (Coast Range and western Cascades), the greatest opportunity to influence old forest tree and stand development through thinning appears to be in young uniform stands (roughly less than 80 years), when stem growth and crown expansion rates are highest (McArdle et al. 1930) and have a strong influence on the diameters of future old trees (100 to 300 years old) (Tappeiner et al. 1997, Poage and Tappeiner 2002). Individual Douglas-fir trees can respond to changes in density (Gray et al. in press) in older stands (greater than 80 years) but by this age, if not sooner, most of these stands will be near the end of self-thinning period, when most density dependent mortality already occurred (Franklin et al. 2002). Consequently, the potential to accelerate the development of late-successional forest structure by silvicultural thinning is limited. For example, in many stands over 80 years on productive sites the majority of the trees will already be relatively large (greater than 20” dbh), so thinning these stands could remove ecologically valuable large diameter trees and growth enhancement from density reduction would be less than in denser, smaller diameter stands. Based on these considerations the largest potential benefits of thinning on ecological structures and functions related to old forests will likely occur in dense young stands that are less than 80 years old, and in many cases less than 50 years old (Poage and Tappeiner 2002). The following discussion of thinning effects focuses on young, moderately dense plantations and naturally regenerated stands about 30 to 50 years of age, and may not necessarily be applicable to older or younger stands, or stands with higher or lower tree densities.

Evaluating Thinning Effects On Dead Wood Production With Stand Development Models

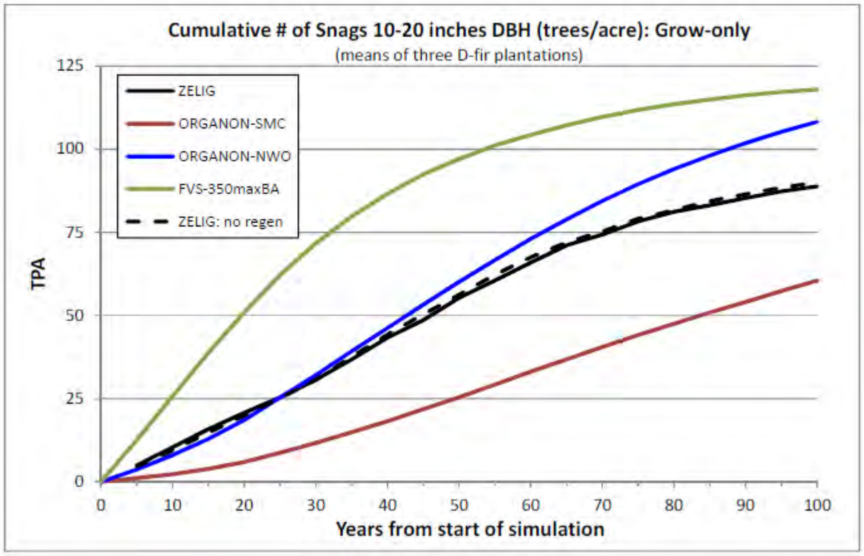
The (Limited) Scientific Literature On Thinning And Dead Wood Production

No empirical studies have documented the effects of thinning on dead wood production in Pacific Northwest forests over the lifetime of a natural or planted stand. However, one experimental study (Dodson et al. 2012) found that 11 years after thinning young conifer stands, the stands produced fewer dead trees than in the unthinned control and most residual live trees grew faster than in the control. We are aware of only one published study that modeled future trajectories of dead wood from thinning over many decades (Garman et al. 2003). That study found that dead wood production in thinned stands was less than in unthinned stands, and that dead trees had to be artificially created to accelerate the development of snags to meet old-growth forest structure objectives.

Given the lack of empirical and modeling studies of the effects of thinning on dead wood recruitment we conducted our own simulation experiments. *These simulations are preliminary and should not be viewed as a robust analysis of the subject*. However, we believe the findings are useful for the purposes of illustrating the general effects of thinning on dead wood production.

Comparison Of 3 Different Forest Growth Models Used To Evaluate Thinning Effects

For one of our analyses we compared the results of three forest growth and/or succession models used to evaluate thinning effects: FVS, ORGANON and ZELIG. Results (see below) of all three models show that conventional thinning (i.e. removal of all or most of the dead wood from the site) can greatly reduce the total number of the future dead trees that would be produced in a young Douglas-fir stand. Some of the simulations also showed that thinning can accelerate the appearance of very large (greater than 40”) dead trees. However, models differ in trajectories of dead wood production and rates at which some size classes of dead trees develop (Figures 1-3). For example, FVS tended to grow big trees faster than the other models and produce larger numbers of large dead trees over most of the simulations we examined. FVS also tended to show a greater difference in dead wood production between unthinned and thinned prescriptions. ORGANON (both variants but especially the SMC variant) on the other hand, appears to have lower growth rates and very low competition mortality rates compared to the other models for the scenarios examined. ZELIG is a gap succession model (Garman et al. 2003) that is fundamentally different from FVS and ORGANON, which are based on statistical relationships for use in growth and yield prediction. ZELIG simulates succession using ecological relationships (processes) related to growth, competition, mortality, light, and belowground resources. It is designed to simulate succession over long time frames and across a range of forests types without the need for empirical data sets on forest growth. For these runs, ZELIG included non-density-dependent mortality (e.g. disease, windthrow) but did not include successional changes from regeneration of shade tolerant trees. Differences between models can be attributed in part to how growth and mortality rates are parameterized. For example, parameters in the FVS model can be adjusted to better match the growth and mortality of a particular set of stands and ZELIG, although is it an ecological process model, can be calibrated against empirical data to improve its predictions power (Pabst et al. 2008). It appears that options for adjusting growth and mortality rates in ORGANON may be more limited.



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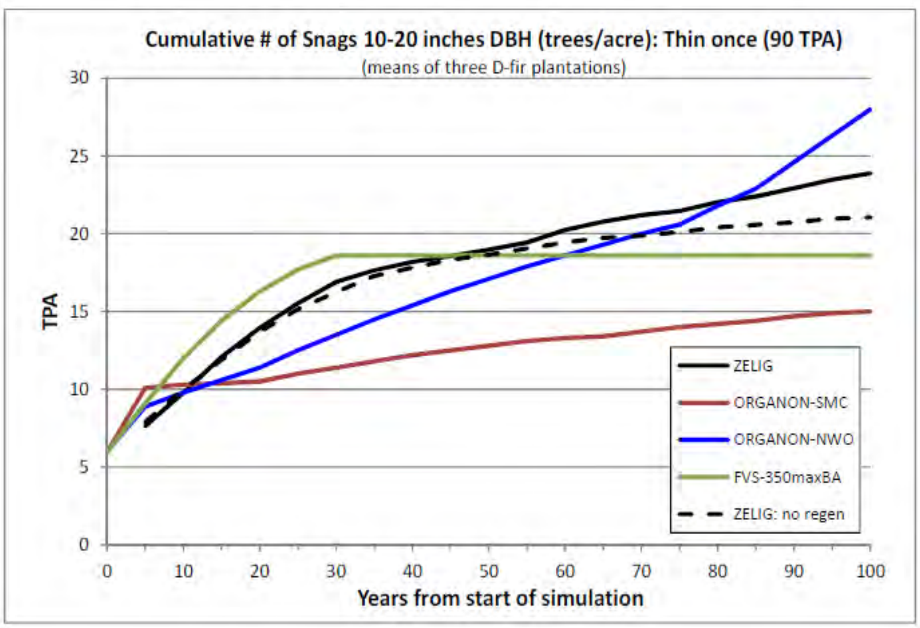


Figure 1. *Comparison of cumulative snag production for 10 to 20" dbh trees under a no-thin and thin once prescription for three different forest growth/succession models and their variants. ZELIG no- regeneration simulations do not include ingrowth but do include mortality from non-density dependent sources. Stands were Douglas-fir dominated and 31 to 35 years old with an average density of 293 trees per acre (range 267 to 308 tpa). The thinning prescription was thin from below to 90 tpa and create 6 snags/ac in year one of the simulation. Simulations courtesy of Stu Johnston, Siuslaw N.F. and Rob Pabst, Oregon State University.*

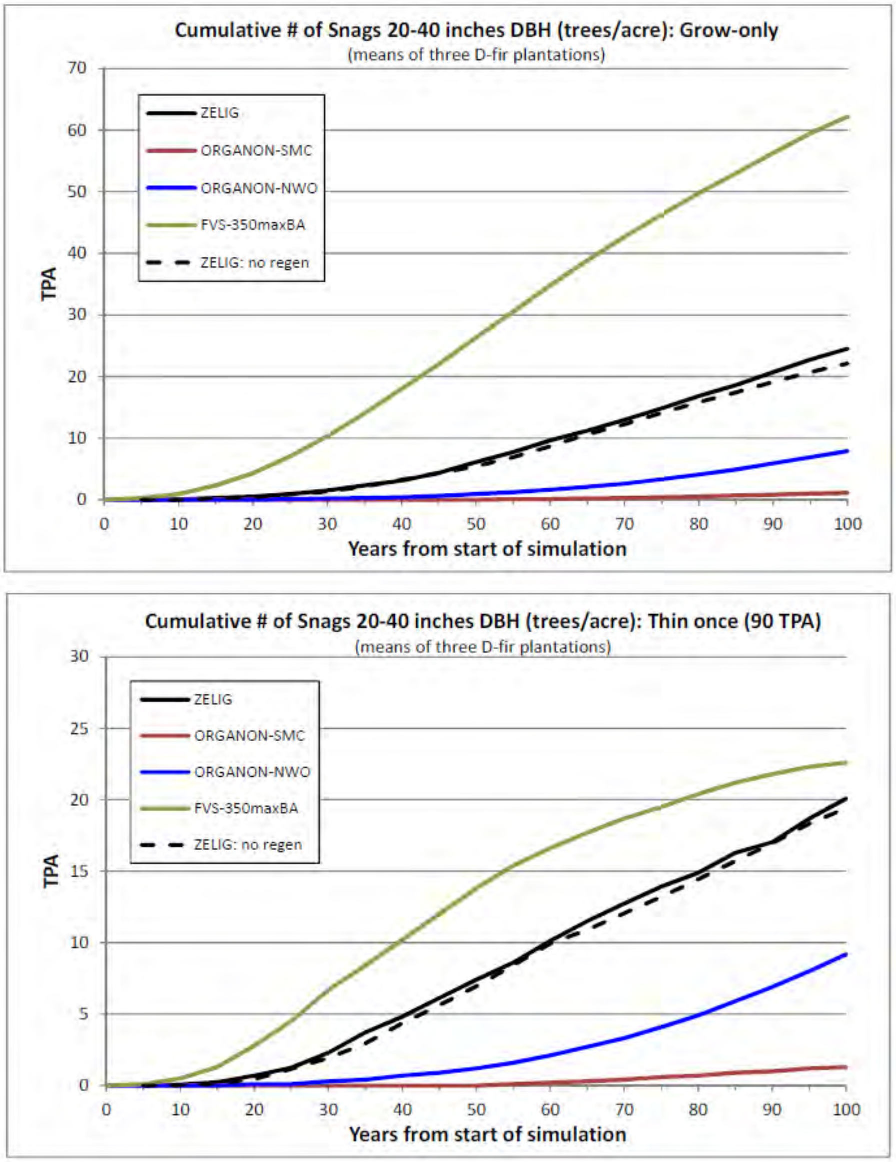
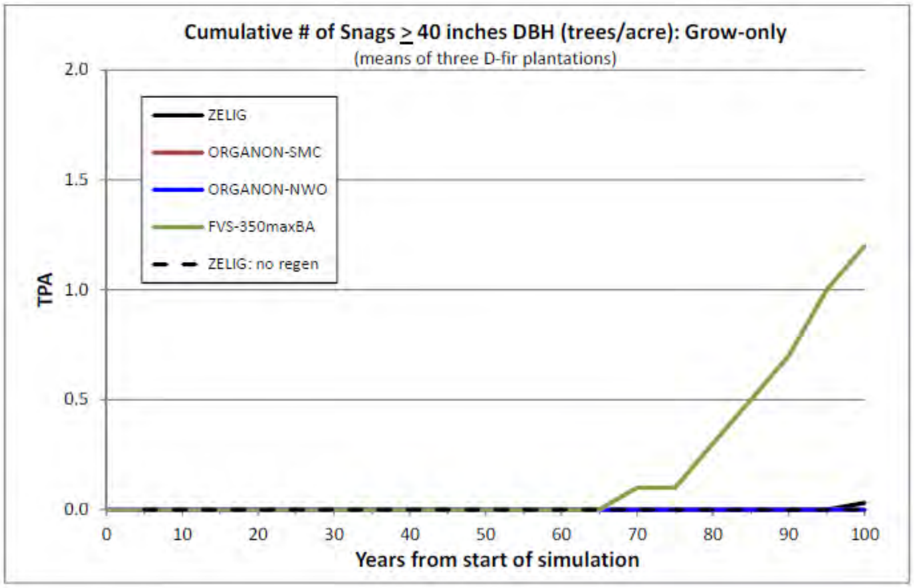


Figure 2. *Comparison of cumulative snag production for 20 to 40" diameter at breast height (dbh) trees under a no-thin and thin once prescription for three different forest growth/succession models and their variants. See Figure 1 caption for details.*



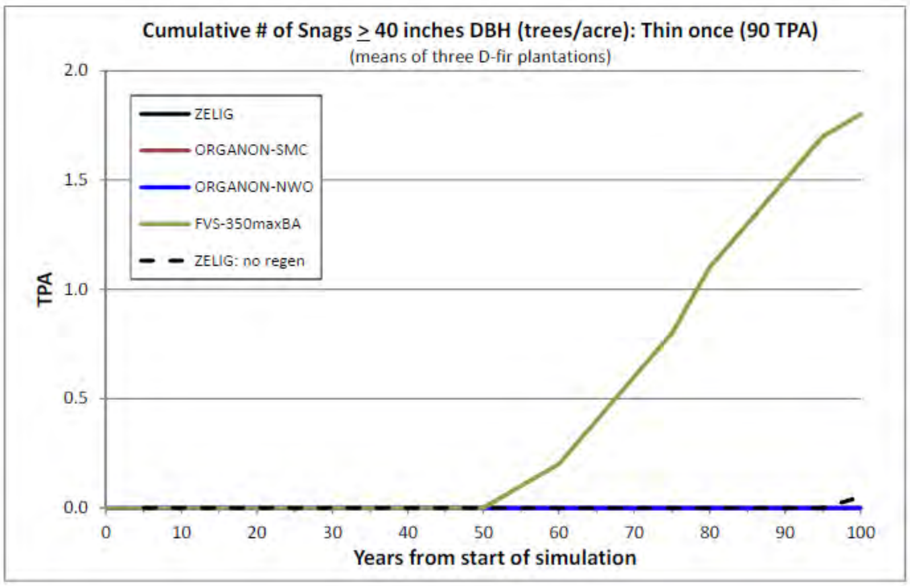


Figure 3. *Comparison of cumulative snag production for trees less than 40" dbh under a no-thin and thin once prescription for three different forest growth/succession models and their variants. See Figure 4 caption for details.*

It is difficult to say which of the models is "best" for assessing the potential effects of thinning without further evaluation of different initial stand conditions, prescriptions, and model parameterization. Based on our *preliminary* analysis, it appears that FVS and ZELIG may be the best of the three models for estimating the effects of thinning on dead wood production relative to not thinning, especially for diameters greater than 20" dbh. Of the three models, ZELIG is the only one that has been evaluated in peer reviewed literature for applications related to restoration thinning to accelerate old-growth forest structure in moist conifer forests of the Pacific Northwest (Garman et al. 2003, Pabst et al. 2008).

Managers may want to examine more than one model, but projections of levels of future dead wood production resulting from different management practices will always be uncertain, especially for the larger diameter classes and longer-time frames for which the models have not been tested. Major sources of uncertainty also include expected mortality from non-density dependent factors (e.g. windthrow, bank erosion) which will become more important over time especially for projections that extend out 50 to 100 years as most of our simulations did.

Dead Wood Production From Young Unthinned Stands

Production of dead wood from typical young, managed Douglas-fir stands in northwest Oregon (e.g. 30 to 40 years old with greater than 300 tpa of conifers) will vary over time and as a function of stand conditions, thinning regime, site productivity, and numerous other biophysical factors. Douglas-fir is a fast growing tree, and intense competition within these forests can result rapid emergence of dominant trees and senescence and death of subordinate trees. On productive sites, this period of intense competition and self thinning begins around 20 to 30 years (Franklin et al. 2002) and continues for several decades. Using our simulation models, we illustrate how dead wood production from young, unthinned Douglas-fir forests could develop over time. Dead wood gradually accumulates and produces relatively high numbers of large dead wood across a wide range of size classes (from 12" to greater than 36") for at least a century (Figure 4). Similar patterns are seen for large wood biomass (Figure 5). Under a grow-only (no-thin) scenario (Figure 1) the cumulative number of boles of dead trees resulting from competition mortality in a young stand would be expected to be low for at least 10 years (i.e. up to age 40 or 50). During the first couple of decades (i.e. when stands are 30 to 60 years of age), all of the stand models we used showed that most dead trees would be less than 10" in diameter and there would be little or no production of dead trees greater than 20" dbh. However, the magnitude of the differences depends on the vegetation simulator used (see above) as well as initial stand conditions and other factors. For example, the cumulative production of dead trees greater than 20" dbh at 20 years (stand age ~52 yrs) ranged from 0 to 5 trees per acre for the three different models (Figure 2). For very large dead trees (greater than 40"), our simulation exercise indicated that few, if any, of these would be produced in the first 65 years (stand age ~95 yrs) (Figure 3). These outcomes for large and very large dead trees would vary by initial stand and site condition and parameter assumptions in the models.

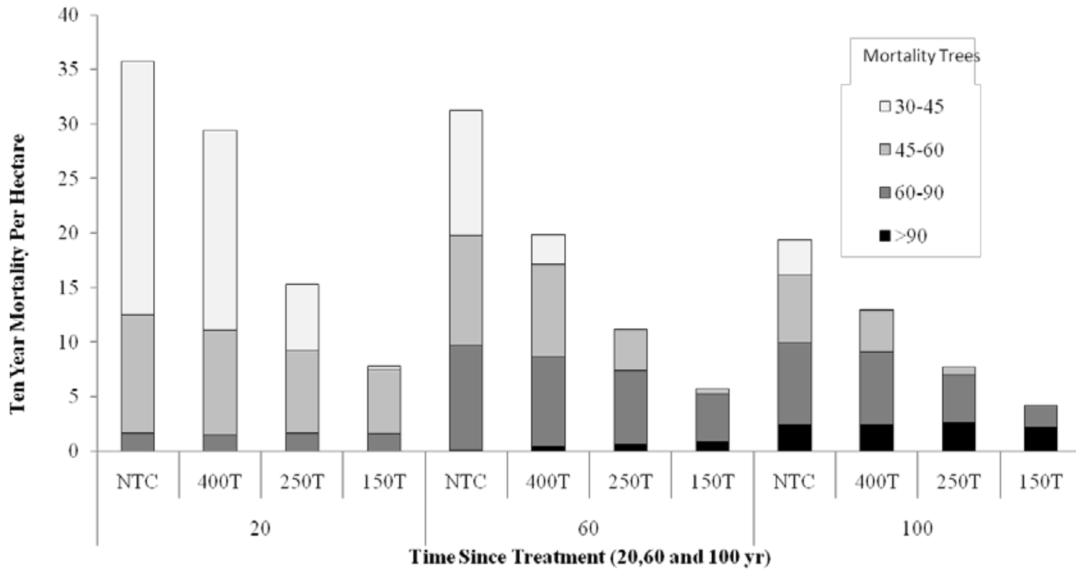


Figure 4. FVS simulation of the effects of different thinning levels on tree mortality rates for the average of seven 30 to 40 year Douglas-fir stands in northwest Oregon, with stand densities averaging about 600 tph. The figure shows the mortality rates at 20 years, 60 years, and 100 years after thinning, for a no-thin scenario (NTC), and thinning to 400 tph (162 tpa), 250 tph (101 tpa), and 150 tph 61 tpa). Four size classes of mortality trees are modeled, 30 to 45 cm (12-18"), 45-60 cm (18-24"), 60-90 cm (24-36") and greater than 90 cm (greater than 36"). Mortality rates are the number of trees dying per decade and represent the combined number of snags and downed wood produced.

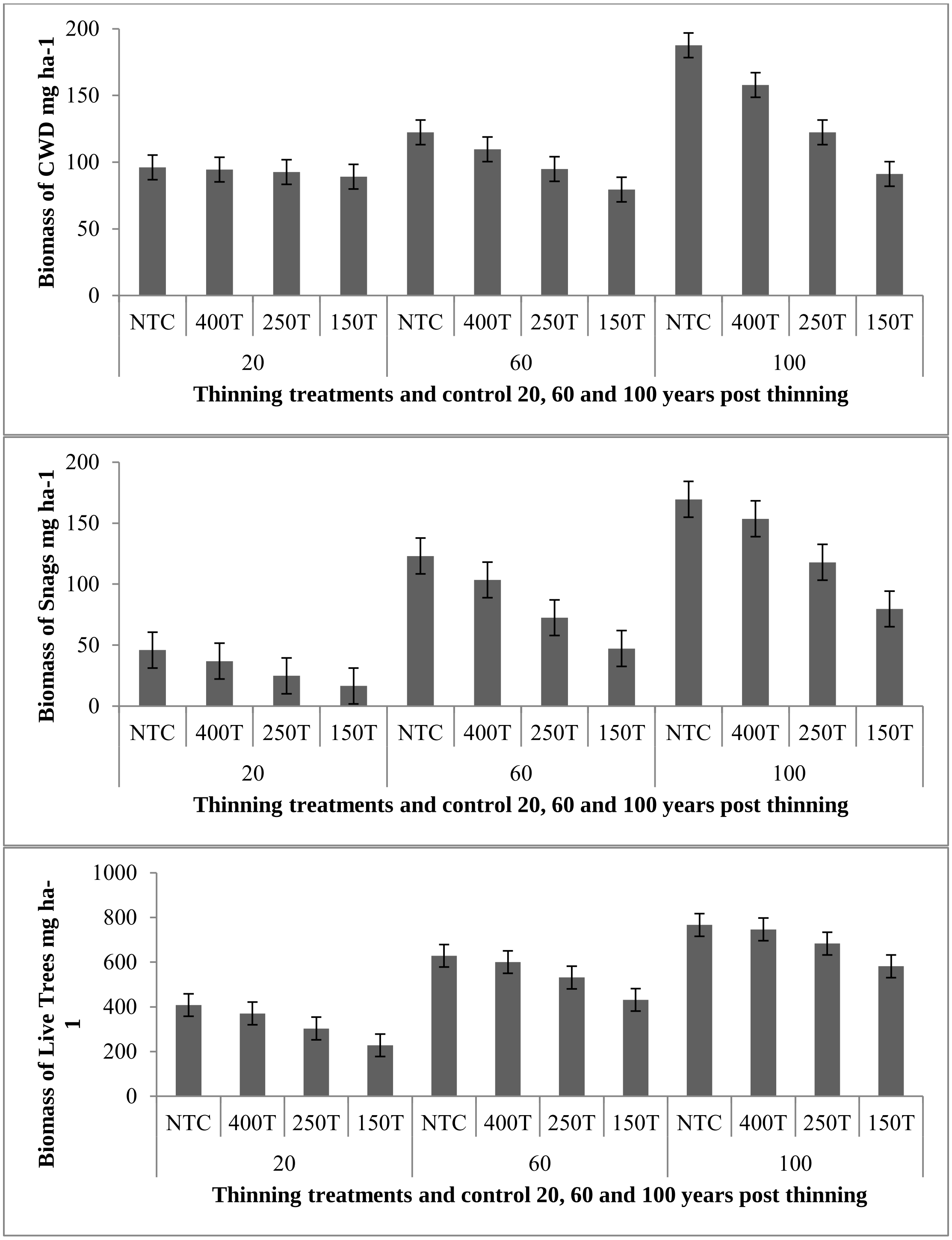


Figure 5. Comparison of average biomass (+ se) of snags, coarse woody debris and live trees, 20, 60 and 100 years post thinning of seven Pseudotsuga menziesii stands for a naturally thinned control, and silvicultural thins of 400 tph (162 tpa), 250 tph (101 tpa) and 150 tph (61 tpa)-(NTC, 400T, 250T, 150T). The FVS growth model was used to simulate tree growth and simulate dead wood biomass production. Additional details on estimating dead wood production can be found at the USFS DecAID web site (http://www.fs.fed.us/r6/nr/wildlife/decaid/).

We used all three simulation models to explore how thinning prescriptions could affect dead wood production in young Douglas-fir stands. In one of our simulations using FVS, high intensity thins (e.g. 60 tpa) substantially reduced the production of dead wood in all size classes between 12” to 36” dbh for a century or more (relative to no-thin or lighter thinning scenarios) but slightly accelerated the production of dead wood greater than 90 cm (36”) dbh (Figure 4). By year 100 the unthinned stand produced 4 times as many 12” snags as the heavy thinned stand and the number of 36” snags was about the same among the treatments. Other metrics, such as biomass of snags, down wood and live trees follow similar trends. One hundred years post-thinning, live tree, snag and down wood biomass were all highest in the unthinned stands and all lowest in the high intensity thins (Figures 5).

Other simulation examples (with FVS, ZELIG and ORGANON) also show that thinning with removal of dead trees will reduce the future number of dead trees in many size classes, however, the magnitude of the differences between thinned and unthinned stands varied among the models (see discussion above). For example, a prescription of thinning young stands to 90 tpa and leaving a few dead trees reduced the cumulative production of dead trees less than 40” dbh relative to an unthinned stand (Figures 1-3). Over a 100 year period, the cumulative production of 10” to 20” dbh dead tree boles were reduced from 60 to 120 tpa down to 15 to 30 tpa, (75-85%) depending on the simulation model used (Figure 1). These prescriptions are also likely to reduce the total production of 20” to 40” dbh dead trees over 100 years but by a lesser amount than dead trees 10” to 20” (Figure 2). All the models except FVS showed little to no effect of thinning (to 90 tpa) on the production of dead trees greater than 40” dbh 100 years post thinning for three particular stands (Figure 3). In this FVS simulation, the occurrence of greater than 40” dbh dead trees (1/acre) appeared more than 15 years earlier in the thinned stand compared to the unthinned stand, but the total number of dead trees by 100 years was only slightly higher in the unthinned stand (1.8 vs. 1.2 tpa). Another FVS simulation also suggested that thinning down to 150 to 400 trees per hectare (TPH) (60 to 162 tpa) accelerates the production of very large diameter trees (greater than 90 cm /36”) from 1 to 9 years, depending on the intensity of the thin (Figure 6). A different simulation with ZELIG of conventional thinning indicated that the diameter distribution of snags produced over a 100 year period is quite different from the unthinned stand and shifted toward the larger size classes (Figure 7).

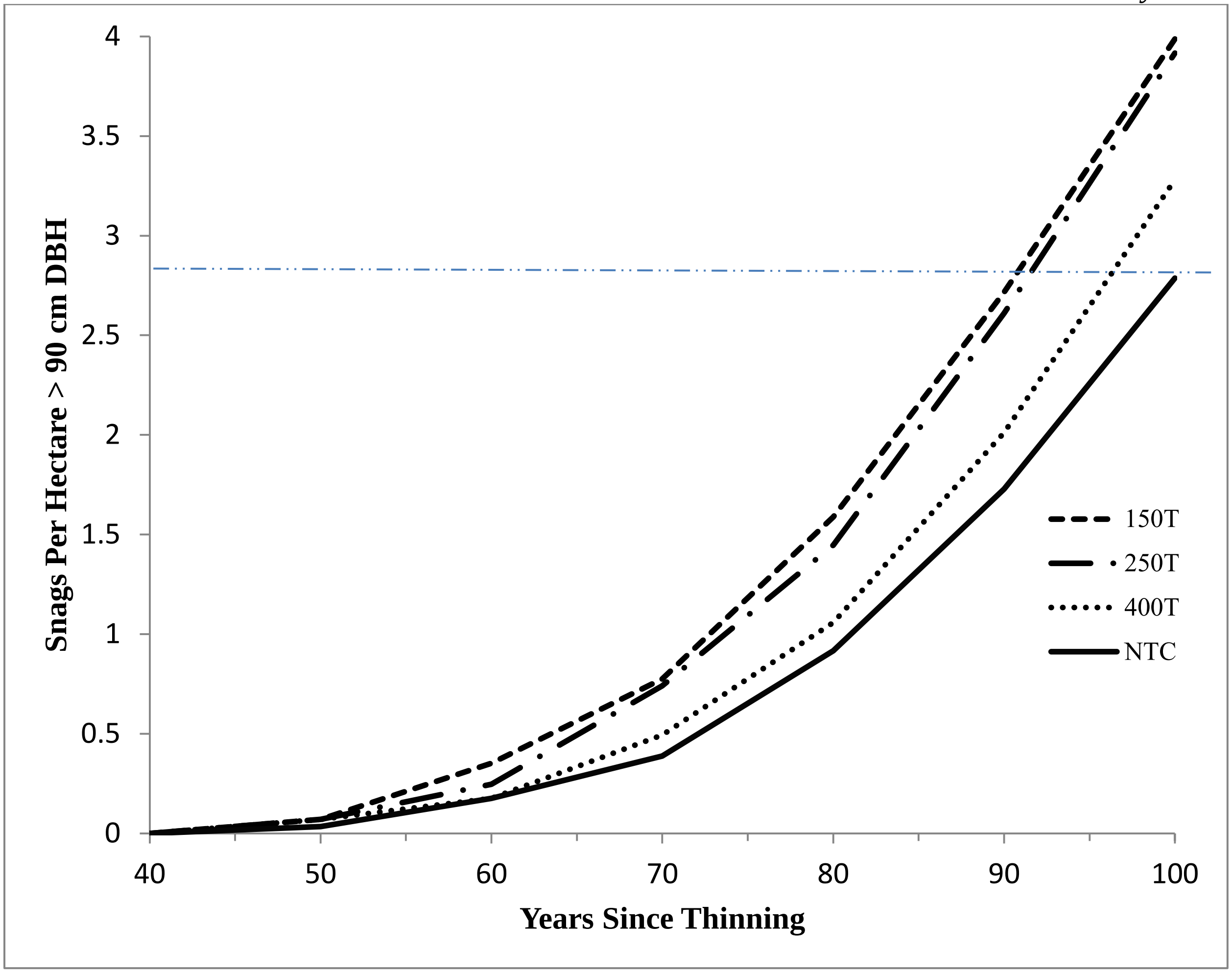


Figure 6. The effect of thinning on the average production rate of very large diameter (greater than 90 cm) snags for seven 30 to 40 year old Pseudotsuga menziesii stands for a naturally thinned control, and silvicultural thins of 400 (161 tpa), 250 (101 tpa) and 150 (60 tpa) trees per hectare (NTC, 400T, 250T, 150T) from initial stand densities averaging about 600 tph, using FVS. The heaviest silvicultural thin produces more very large snags sooner, the 250T, 400T and control lag a few years behind in the production rate of greater than 90 cm dbh snags. For example, it takes the 150T treatment 91 years to produce 2.8 greater than 90 cm dbh snags ha-1, while it takes the 250T, 400T and control, 92, 97 and 100 years to produce the same number of greater than 90 cm dbh snags (dashed horizontal line).

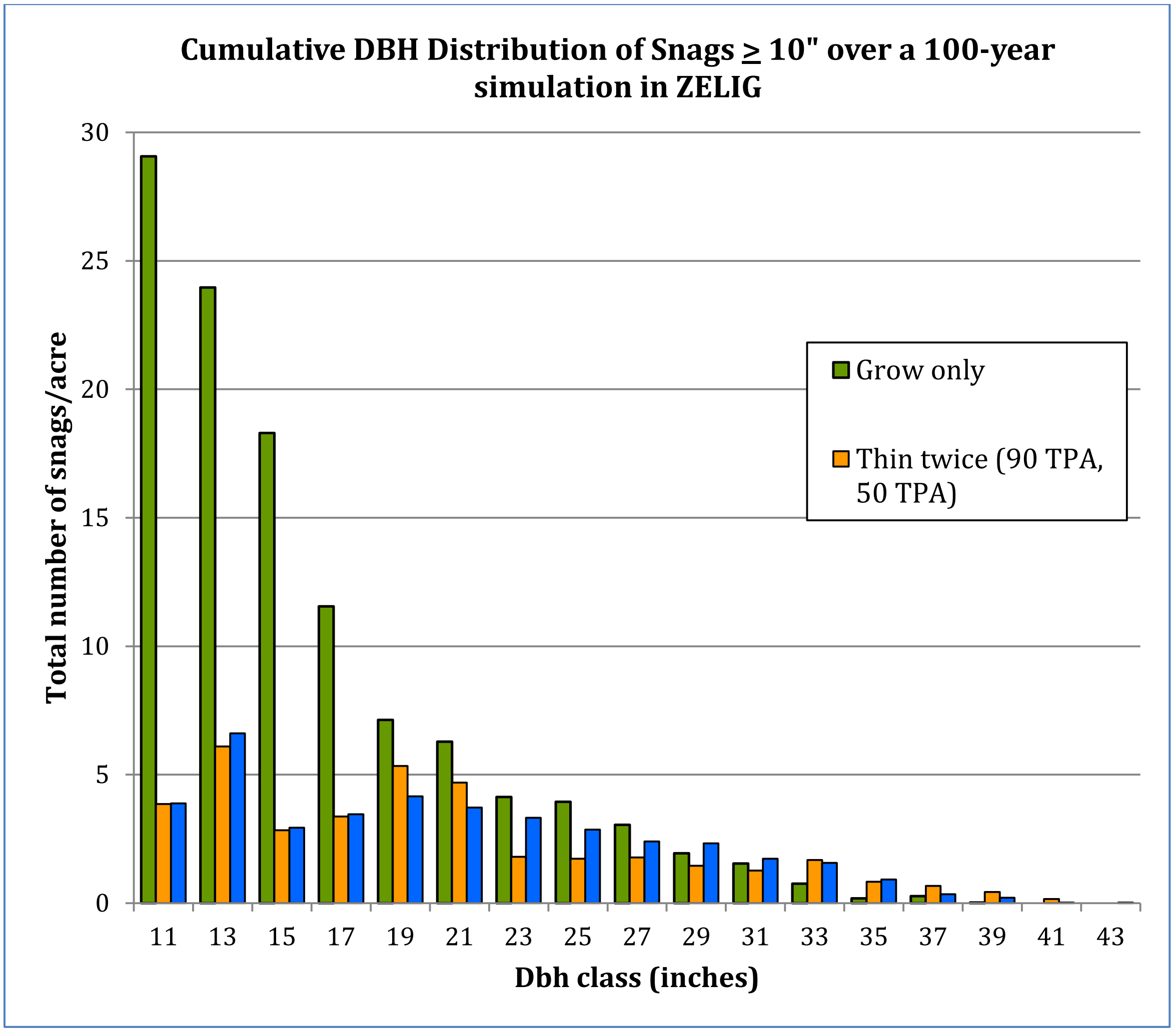


Figure 7. Mean diameter distribution of cumulative snag production over 100 years for no-thin and two thinning prescriptions based on three 31 to 35 year old Douglas-fir stands with an average density of 293 trees per acre (range 267 to 308 tpa). Simulation with ZELIG by Rob Pabst, Oregon State University. Data available upon request.

Thinning Prescriptions That Increase Dead Wood Production.

The loss of dead wood production due to thinning with removal can be offset or even reversed using thinning prescriptions where some or all of the thinned trees are left on the site and some felled into the stream. Intentionally creating many snags or felling trees into streams could strongly accelerate recruitment into streams of 10” to 20” trees during the first 10 to 50 years following treatment (Figure 8). Thinning with dead wood creation (*aka* dead wood restoration thinning) is already practiced by some managers (Stuart Johnston and Paul Anderson personal communication), has been identified as a potential restoration technique in the literature (Garman et al. 2003, Dodson et al. 2012), and could immediately reduce deficiencies in dead wood that exist in many streams and riparian areas. If trees are tipped with rootwads they may become even more stable in the stream. This prescription would produce more dead wood in riparian areas and streams in the short term than a stand that is left unthinned where dead trees slowly accumulate as a result of competition, disease, disturbance and other factors. Given the right stand conditions, such actions could have the added benefit of accelerating the future production of very larger diameter (greater than 40”) trees.

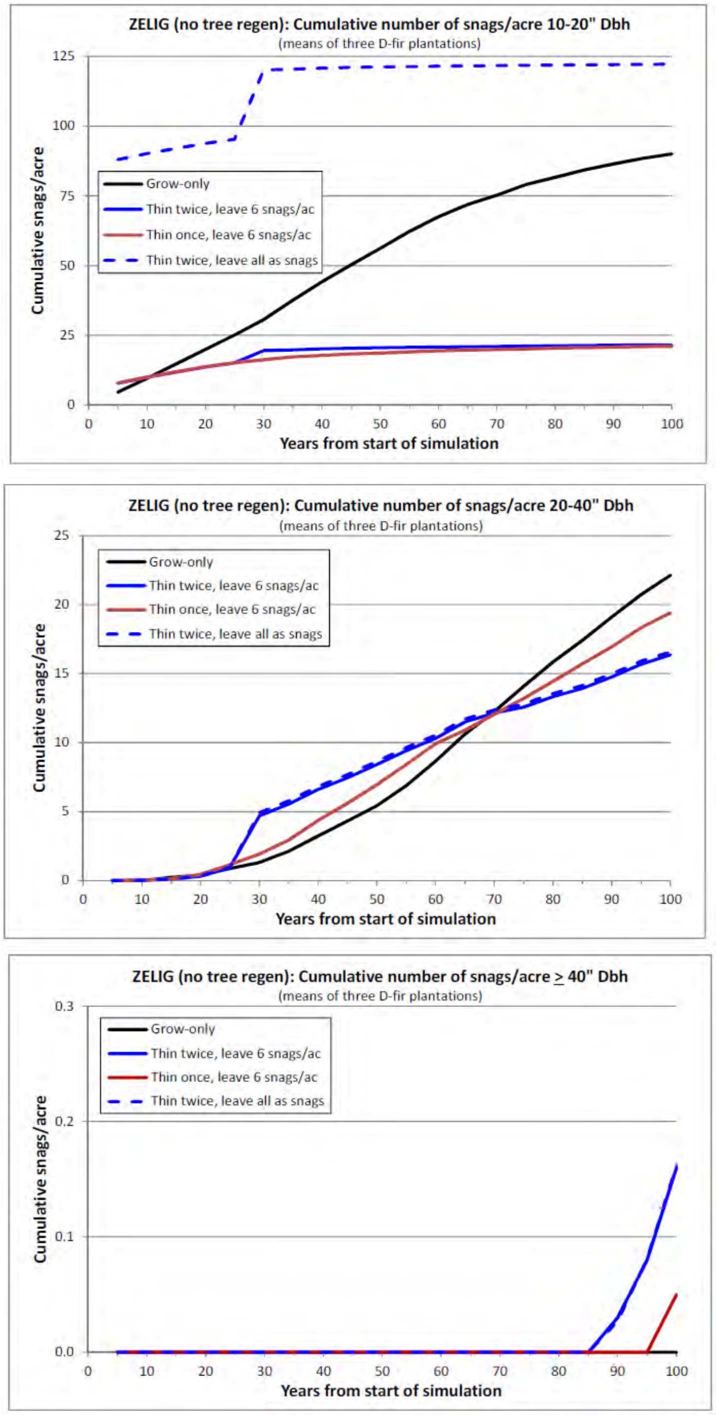


Figure 8. Simulated cumulative snag production for three different diameter classes for four thinning prescriptions including a prescription that leaves all the cut trees on the site. Curves are from an average of three 31 to 35 year old Douglas-fir plantations from the Oregon Coast Range. Simulations from ZELIG model courtesy of Rob Pabst, Oregon State University.

Landscape Scale Considerations

At the landscape level, variation in thinning regimes can create variation in the size and diameter of dead wood and live trees. A single type of thinning treatment could lead to forest structure simplification at the landscape level (Figure 9). By varying thinning prescriptions, a diversity of forest conditions can be produced that may be more reflective of the variability that occurs within unmanaged riparian areas. Using a variety of treatments is also consistent with the tenets of adaptive management in situations where the outcomes of treatments are uncertain.

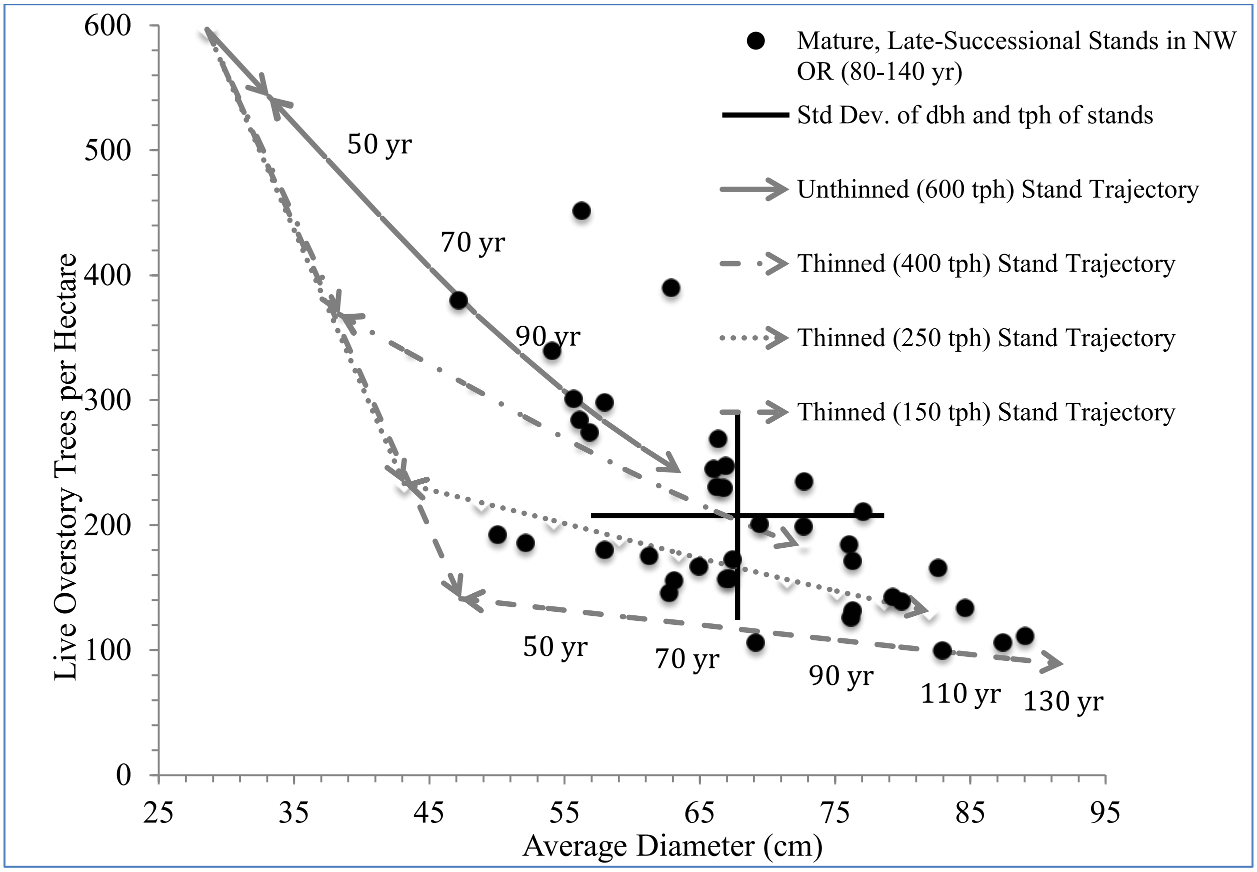


Figure 9. The projected effect of different thinning treatments on future tree density and diameter relative to undisturbed, mature (80 to 140 year old), late-successional Douglas-fir dominated forests in northwest Oregon. Trajectories are the simulated changes (using FVS) 100 years post thinning for each of the four treatments of an average of seven typical 30-40 year old (600 tph average), managed Douglas-fir stand in northwest Oregon. Each arrow head represents a 10 year interval in the simulation, ending at year 130. (a) Light, moderate and no thins options project live overstory tree densities and diameters similar to the late successional stands (i.e. within a standard deviation of the average diameter and density), but the no thin option does so at a much slower rate. Heavy thinning increases the average diameter of live trees, but densities are low relative to the late successional stands (and the light, moderate and no thin options). These data lend support to the hypothesis that young, managed Douglas-fir stands in northwest Oregon are growing at higher densities than is typical of natural stands, and that light to moderate levels of thinning will accelerate the development of live tree densities typical of mature, late-successional forests. The late-successional stands in this example were Douglas fir dominated USFS CVS plots and do not necessarily represent the diversity of stand conditions that would occur across a riparian network or within different regions of the Pacific Northwest.

Thinning And Wood Recruitment To Streams

The (Limited) Scientific Literature On Thinning And Wood Recruitment To Streams

No published empirical studies characterize the effect of thinning in riparian areas on the recruitment of wood to streams. Only one peer reviewed simulation study (Beechie et al. 2000) and two unpublished studies (Pollock et al. and Benda et al.) describe how thinning could affect wood recruitment. These studies indicate that effects of thinning on wood in the stream will be a function of stand conditions (e.g. tree size, species composition and density), thinning prescription, the location of the thinning relative to the stream and physical characteristics of the stream (e.g. size and gradient). There is general agreement on two key aspects of this issue:

- Instream wood recruitment mechanisms vary with location in the channel network
- Instream wood functions vary with the size of wood relative to the size and type of the channel

Effects Of Conventional Thinning On Near-Stream Inputs Of Dead Wood

For near-stream riparian inputs, empirical and modeling studies suggest that stream wood input rates decline exponentially with distance from the stream and varies by stand type and age (McDade et al. 1990, Van Sickle and Gregory 1990, Gregory et al. 2003) (Figure 10). For example, 95% of the total instream wood inputs in these studies came from distances that ranged between about 25 and 45 m (about 82 to 148 feet) depending on the stand conditions. Given these relationships we can assume that (all other factors being equal), increasing distance of thinning from a stream (i.e. increasing the no cut buffer width) will reduce the degree to which thinning affects instream wood recruitment over time. In general, different combinations of no-cut buffer widths and thinning intensities will have different effects relative to the unthinned condition. Figure 11 illustrates how one particular prescription affects instream delivery across a range of no-cut buffer widths—other prescriptions would have different outcomes.

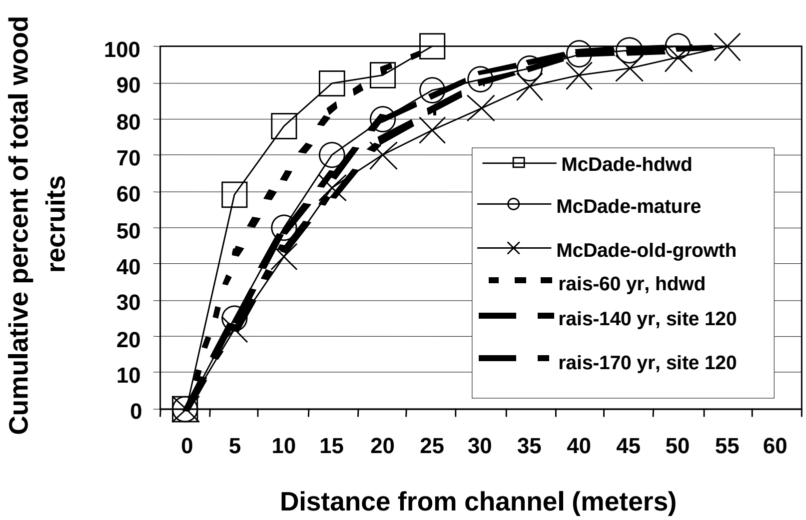


Figure 10. *Comparison of predictions of total wood accumulation with distance from channels using the Organon forest growth model and the RAIS instream wood recruitment model versus the observations of McDade et al. (1990) for streams in the Cascade mountains of Oregon and Washington. The data suggest that for old-growth forests, little*

to no instream wood is recruitment from beyond 55 m (180 ft) from the stream, while for younger (e.g. mature)forests, virtually all wood is recruited from within 40 m (131 ft) of the stream Figure from Welty et al. (2002). Note also that the simulation does not predict the total amount of wood that will be in the stream, because it does not include existing insteam wood loads, wood losses due to downstream transport, and wood delivery from upstream sources and from stands on the opposite bank. It simply predicts the relative effect of different management option on the delivery of instream wood from a stand.

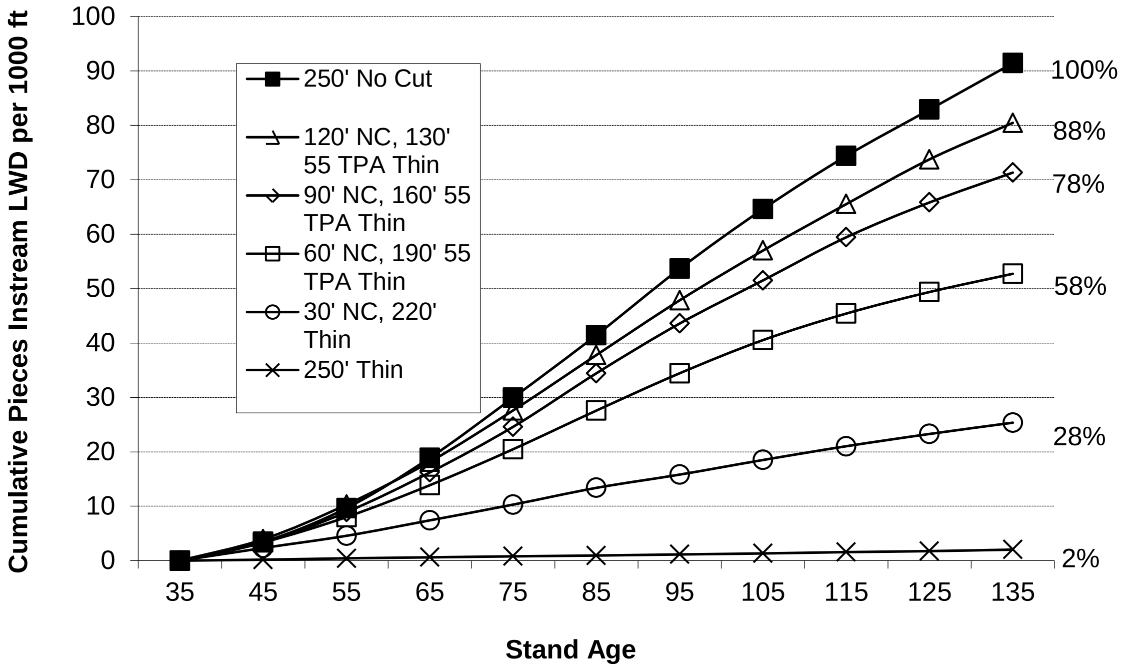


Figure 11. *Comparison of the modeled effect of various no-cut buffer width adjacent to a 55 TPA thin on cumulative large wood inputs from the modeled stand to a stream for 100 years post thinning for a young, managed Douglas-fir stand in northwest Oregon. Percentages on the right of figure are relative to a 250 foot no cut buffer, a width equal to the site potential tree height for the area. Forest growth was simulated using Organon and wood inputs were simulated using Streamwood. Stand data used in the simulation were provided by the Siuslaw National Forest and are included in their East Alsea Landscape Management Plan. The pre- and post-thin tree size and density is typical of the stands in the project where thinning is proposed. (Figure from Pollock et al., in preparation). The range of no-cut buffer widths and thinning regime examined are for comparative purposes only and is not meant to imply that they are all appropriate for meeting ACS objectives. Note also that the simulation does not predict the total amount of wood that will be in the stream, because it does not include existing insteam wood loads, wood losses due to downstream transport, and wood delivery from upstream sources and from stands on the opposite bank, It simply predicts the relative effect of different management options on the delivery of instream wood from a stand.*

Studies also show that the amount of in-stream wood is a function of the input rates and depletion rates, which results from fragmentation and movement; in general, smaller pieces and hardwood pieces have high depletion rates and larger pieces and conifer pieces, especially those with rootwads, are more stable and do not require as high a rate of input to accumulate in the stream (Kennard et al. 1998, Beechie et al. 2000, Meleason 2001, Welty et al. 2002). However, smaller pieces tend to accumulate in wood jams and perform similar functions to or enhance the functionality of larger single pieces (Bilby 1981, Bilby and Ward 1989, Bilby and Ward 1991).

Because most instream wood recruitment models (e.g. Streamwood, RIAB and RAIS) use the mortality outputs from forest growth models, estimates of potential instream wood recruitment are dependent on the forest growth model used. It is essential to assess the effects of thinning on instream wood recruitment on a relative scale (e.g. percentages, as illustrated in Figure 11). Caution should be exercised in comparing absolute outputs between different forest growth or instream wood recruitment models (e.g. see above section on forest growth models).

We used some of our forest growth and mortality simulations (see Figures 1-3) as input to a instream wood recruitment model (Figure 12). The pattern of recruitment of small and medium sized pieces were similar using ORGANON and ZELIG; there were declines in recruitment of smaller pieces as a result of thinning. However, the magnitude of the differences were greater with ORGANON. The pattern differed for the larger size categories. Very few pieces in either category were recruited under ORGANON (see model discussion section). For the large size pieces (24” to 30”), the volume from thinned stands was slightly higher than unthinned from 30 to 80 years but by 100 years there was less recruitment under this thinning prescription. Thinning slightly increased the instream volume of the largest diameter class (greater than 30”) category.

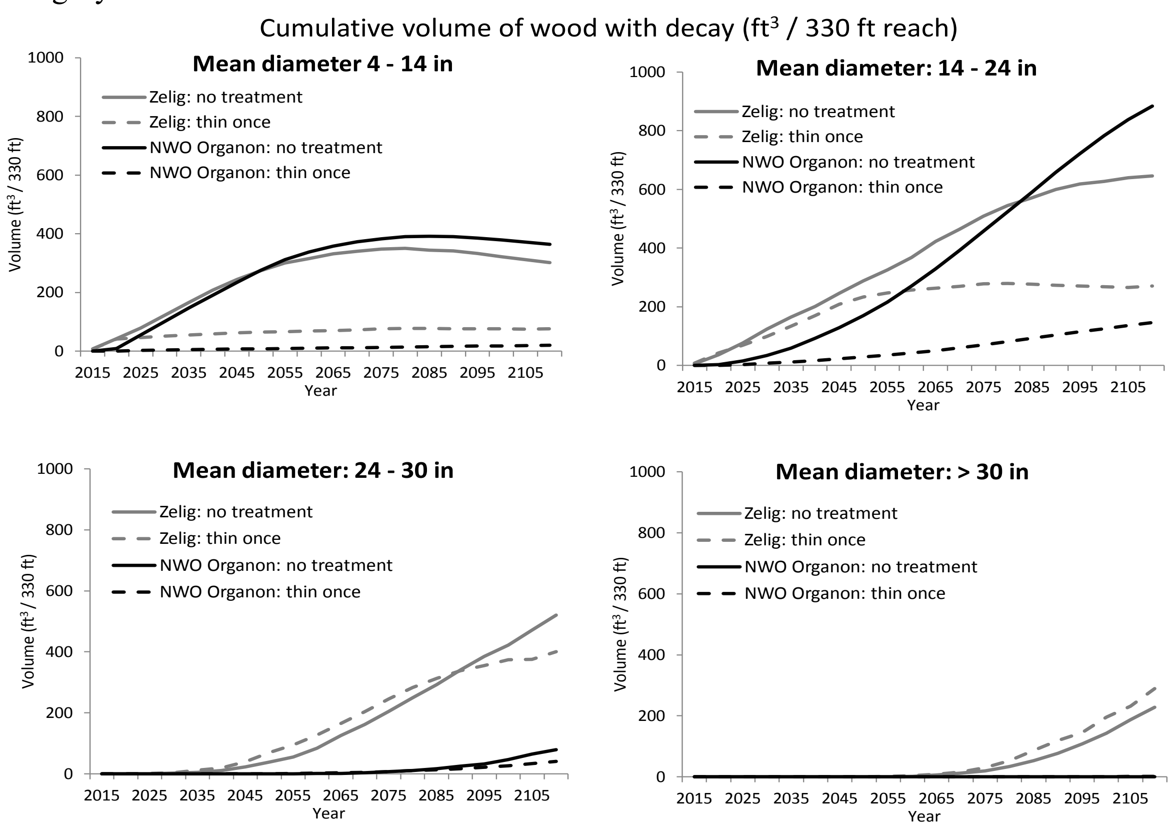


Figure 12. *Comparison of model results of potential wood recruitment to the channels using Zelig and NWO ORGANON. The thinning scenario modeled was thinning 31 to 35 year old Douglas-fir stand from 400 tpa to 90 trees/acre and leaving 6 dead snags per acre. The wood recruitment model was a modified version of Streamwood (Meleason et al. 2003) that is in NetMap. Simulations from S. Leichart and L. Benda, Earth Systems Institute. (see Figure 1 for stand modeling details)*

Using FVS in conjunction with a stream wood recruitment model, Beechie et al. (2000) showed that the effect thinning on wood recruitment and pool formation was a function of the size of trees at the time of thinning relative to the size of wood desired for a specific instream functions (Figure 13). That study focused on floodplains and gently sloping low terraces on relatively productive sites (site II) in Washington. It examined the size of wood that independently (i.e. not in conjunction with other obstructions such as boulders, bedrocks, channel constrictions, other wood, etc.) form pools in a stream of a given width. The general result was that thinning increased the supply of pool-forming wood for those stream conditions (5 to 30 m wide) when the average diameter of trees in the stand was smaller than the average minimum diameter of pool-forming wood, and that when trees were already at the pool-forming size, thinning simply reduced the amount of pool-forming wood recruited to a stream. This study also found that red alder could perform the same function as smaller sized conifers in creating pools, but that alder wood abundance decreased rapidly after 70 years. When production of larger instream wood such as key pieces (Abbe et al. 1996, Montgomery et al. 1996, Fox and Bolton 2007) is targeted, thinning stands with larger trees will be consistent with that goal, provided that the size of the trees in the stand is smaller than the target size of the key pieces. Although Beechie et al. (2000) did not examine scenarios that included no-cut buffers adjacent to the streams, the same principle still applies when no-cut buffers are present: *If the stand to be thinned already has trees that are large enough to have the desired function if they fall into a stream, then thinning is not going to increase the abundance of "functional" trees (unless some of the thinned trees are felled and left onsite, as illustrated in Figure 14).* More generally, as thinning operations move away from the edge of the stream, the opportunities for thinning treatments to increase the amount of pool-forming wood (or any size class of instream wood) diminishes.

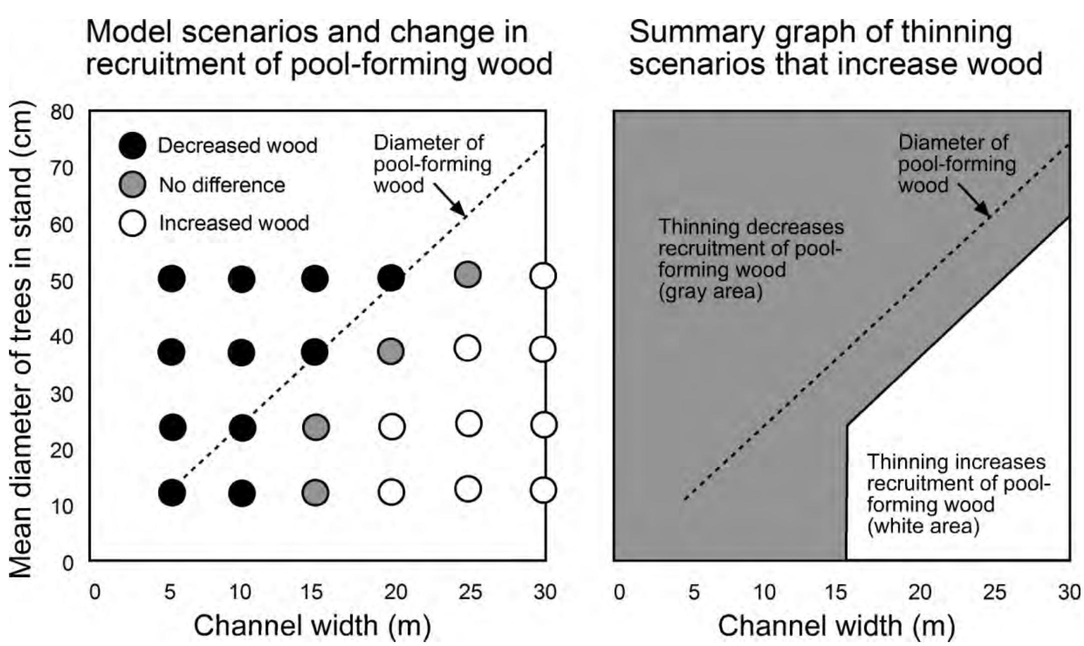


Figure 13. *Example of combinations of size of trees and channel widths where Douglas fir thinning enhances recruitment of pool-forming wood (left panel). Each dot represents a model run for a particular channel width and quadratic mean diameter of trees in the riparian stand at time of thinning, and dot shading represents the change in recruitment of pool-forming wood over a 100 year simulation (adapted from Beechie et al 2000). The dashed line shows the minimum diameter of pool-forming wood by channel width. The right panel is the summary graph illustrating combinations of stand diameter and channel width for which thinning can increase recruitment of pool-*

forming wood over 100 years (Beechie et al. 2000). For the thinning regimes examined, combinations of stand diameter and channel width in the shaded area represent cases where thinning will reduce recruitment of pool-forming wood, and combinations in the unshaded area will increase recruitment of pool-forming wood. In general, when trees in the riparian zone are large enough to form pools thinning simply removes potential pool-forming wood. Where trees are too small to form pools, thinning can increase growth rates and increase recruitment of pool-forming wood. Douglas-fir stands modeled for this figure had a 100 year site index of 52 m (170 ft), pre-thin average diameters of 12-51 cm (5 to 20"), pre-thin stand densities ranging from 420 to 1065 trees/ha (170 to 431 tpa) and post thin densities ranging from 220-370 trees/ha (93 to 150 tpa). Stands were modeled up to 100 years of age using Forest Vegetation Simulator. Additional details can be found in Beechie et al 2000).

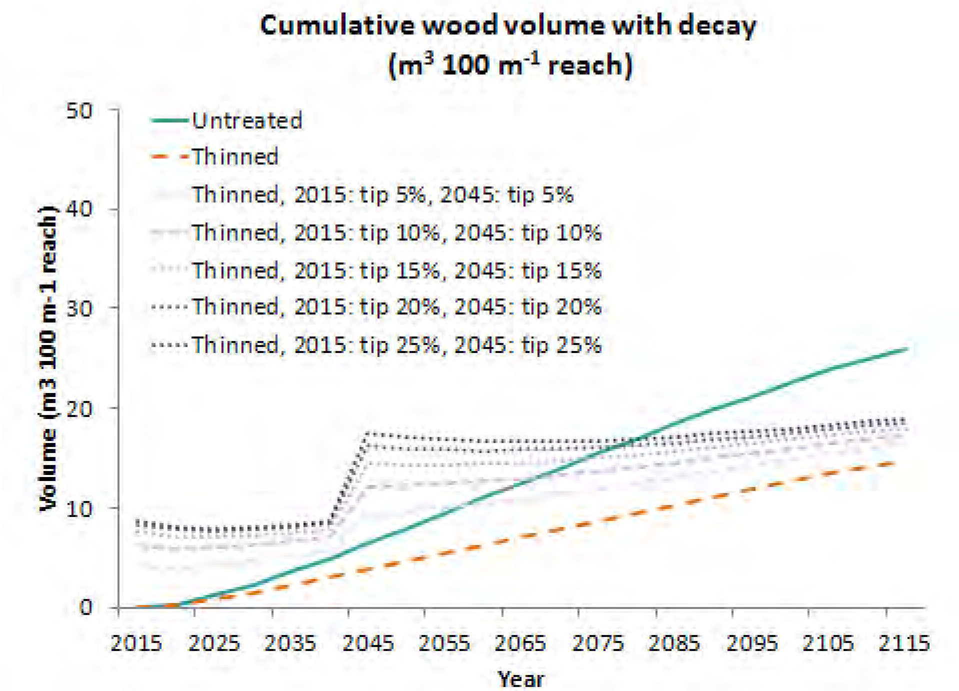


Figure. 14. *Simulation (using the forest growth model, Zelig) of the estimated volume of in-channel wood (m^3/100 m) under different options for directionally falling or tipping of wood during thinning operations. The modeled stand was a xx year old Douglas-fir stand thinned from 400 to 90 trees/acre and there were two entries. Wood input from only one bank was considered.*

If instream wood goals focused on key-sized pieces, the intensity of thinning and range of stand conditions where thinning would be appropriate would likely increase. However, the effects of management on key pieces has not been studied to date, and we are not yet able to quantify the range of potential outcomes on total wood recruitment and function. Regardless of the range of large wood sizes targeted, site-specific information on forest stands on both banks and stream conditions, in conjunction with forest growth and stream wood recruitment models, are required to estimate the site-specific effect of thinning on instream wood loads.

Non-Conventional Thinning Prescriptions That Increase Instream Dead Wood

As we identified in the thinning section above, it is possible to increasing dead wood delivery to streams when thinning. This is accomplished by actively dropping tree boles into the stream during thinning operations. Such dead wood restoration thinning would immediately increase the amount of wood in the channel, which should provide benefits to fishes and other aquatic organisms.

We explored this management option by modeling the amount of instream wood that would result from directionally falling or pulling over trees in the stand and compared this to the amount of wood that would be expected to be found in the stream without thinning the stand (Figure 14). The amount of wood increased above the "no thin" level immediately after the entry in all of the options of wood additions. However, the cumulative total amount of wood expected in the stream over 100 years relative to the unthinned stand varied depending on the amount of wood delivered (Table 1). Adding less than or equal to10% of the wood that would be removed during thinning produced less wood in the channel than the unthinned option. When less than or 15% of the thinned trees were tipped at each entry, the total amount of dead wood in the channel exceeded the unthinned scenario. This analysis of tree-felling into streams during thinning is very preliminary and needs further examination.

Table 1. *Percent difference in the volume of in-channel wood between an unthinned stand and one in which varying percent of trees were directionally felled or tipped into the channel (See Figure 14). The modeled stand was thinned from 400 to 90 trees/acre and there were two entries (year 2015 and year 2045). Wood input from only one bank was considered.*

Percent of trees felled or tripped into the stream	Time period (simulation year) when wood volume production curves for treated untreated stands cross in Figure 14.	Percent difference in total volume of wood produced relative to the unthinned stand
Thin, no tip	N/A	-43
5	2055-60	-17
10	2065-70	-4
15	2070-75	7
20	2075-80	14
25	2080-85	18

Large Diameter Trees And Distance From Stream

While the importance of large diameter wood to stream and riparian ecosystems has been well established (Harmon et al. 1986), creating additional very large diameter trees may also be important because recruitment of large wood into streams depends on bole diameters at heights that correspond to the distance of the tree from the stream. For example, to deliver a 20" diameter bole (the minimum pool forming diameter for a 60 foot wide stream) from a 160 foot tall tree that is 60 feet away from a stream would require a tree greater than 30" dbh. Thinning with dead wood creation can meet short-term needs and accelerate production of very large diameter (greater than 40" dbh) dead wood. This could be important near larger streams where conifers are separated from a stream by a band of alders or shrubs and large conifer bole inputs must come from trees that are 30 to 50 or more feet away from the stream.

Instream Wood Recruitment From Sources Outside The Thinned Stand

The relative effects of thinning a stand on instream wood recruitment should be assessed with knowledge of wood in the stream and recruitment from the opposite bank as well as upstream sources (see Landscape section below). Unless both banks have the same initial vegetative conditions and slope features, the wood delivery potential will vary between the banks. Most, if not all, of the current assessment of thinning effects have only considered impacts from one bank. Conclusions about the effects of thinning on instream wood recruitment at a site may not accurately reflect the potential impacts of thinning unless both banks have similar conditions and are treated the same. Assessing the relative effect of riparian thinning on instream wood loads at the site and over the long term requires an estimation of the likely wood recruitment that will occur from the opposite bank, the wood recruitment that will occur from upstream transport, and the rate of decay and downstream transport of wood from the site. Tools such as the model Streamwood can be used in combination with a forest growth model to make such assessments and predict the relative effect of a riparian thinning treatment. However, the model is data intensive, requiring knowledge of stand conditions and planned future silvicultural treatments for riparian forests at and upstream of the site (Meleason 2001, Meleason et al. 2003). The model also requires estimates of stream size, gradient, existing wood load, and flood frequency. Though data intensive, such modeling would provide a strong analytical justification for evaluating proposed riparian thinning relative to management objectives.

Overview Of Instream Wood Recruitment Processes And Functions

General Mechanisms And Pattern of Wood Recruitment To Streams

Wood recruitment to streams occurs either from near-stream tree mortality events (e.g. bank erosion, windthrow or windsnap) or from upstream landslides and debris flows. At a watershed scale, near-stream inputs are relatively regular in space and time while landslides and debris flows are episodic, adding large amounts of wood to low-gradient streams, but also removing large amounts of wood from higher gradient streams. Upslope, episodic delivery can account for a substantial portion (up to 80%) of the large wood in small to mid-sized streams (Reeves et al. 2003, Bigelow et al. 2007) in mountainous setting. Near-stream recruitment is the dominant source (up to 100%) in low gradient streams with floodplains. Topographic features of a watershed influence the relative contribution of upslope sources of wood. Steeper, more highly dissected watersheds will likely have a greater proportion of wood coming from upslope sources than will watersheds that are less dissected or steep (Martin and Benda 2001). However, in any watershed only a small subset of the upslope channels will deliver wood to valley floors and fish-bearing streams via debris flows.

It is not possible to fully understand or predict the effects of riparian forest management on wood delivery without considering both near-stream and episodic (upslope) processes. The wood found in forested streams in coastal areas of the Pacific Northwest originates from both sources and either source may be dominant depending on physiographic setting and location in the channel network. However, the spatial distribution of wood from these two sources is substantially different as is the function. Near-stream wood recruitment tends to be more evenly distributed throughout a drainage network, whereas episodic landslides tend to create large concentrations of wood at tributary junctions, which contributes to habitat complexity and ecological productivity (Bigelow et al. 2007). The presence of large wood in debris flows slows the speed of the flow and reduces the run-out distance of debris flows on the valley floors (Lancaster et al. 2003). Stream-side sources of wood can provide the largest key pieces to streams, and contribute to gravel storage that converts bedrock reaches to alluvial reaches, and create smaller, more numerous pools, and create habitat complexity (Montgomery et al. 1996, Bigelow et al. 2007). Both types of wood delivery are necessary for functioning and productive stream ecosystems.

The variable sources and delivery processes of dead wood to streams has implications for assessing the effects of thinning on wood delivery to fish-bearing streams. The magnitude of the effects of streamside silviculture (either positive or negative) relative to amount and size of wood delivered to streams will vary depending on stream type and location in a drainage network. For example, wood delivered to most streams that are high in the drainage network will not ultimately be delivered to fish-bearing streams that are low in the drainage network. However, some small and intermittent streams will be key sources of wood to larger streams. It is not possible to characterize the effects of thinning on delivery of wood to fish-bearing streams from nonfish-bearing streams without knowledge of stream type and stream network context as well as the condition of the vegetation where thinning is proposed. Potential impacts of riparian thinning on anadromous fish habitats are much less in forests along headwater streams that have a low potential to deliver wood and sediment to fish-bearing streams. Thinning in such riparian forests could focus on achieving other Aquatic Conservation Strategy (ACS) goals (e.g. see Table 2).

Table 2. *Potential ecological outcomes of Riparian Thinning in Relation to Aquatic Conservation Strategy Objectives (See NWFP, 1994).*

Aquatic Conservation Strategy Objectives for Forest Service and BLM-administered lands within the range of the northern spotted owl will be managed to:	Range of outcomes	
1. Maintain and restore the distribution, diversity, and complexity of watershed and landscape-scale features to ensure protection of the aquatic systems to which species, populations and communities are uniquely adapted.	Where landscapes are dominated by dense, young conifer stands (e.g. Douglas-fir plantations), thinning can help increase the long-term diversity of forest patch types by accelerating the development of variable density stands with large diameter trees	Where landscapes already have a diversity of stand types, thinning can decrease landscape-level stand diversity by creating stands that are all the same (i.e. low density stands of large diameter trees).
2. Maintain and restore spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include floodplains, wetlands, upslope areas, headwater tributaries, and intact refugia. These network connections must provide chemically and physically unobstructed routes to areas critical for fulfilling life history requirements of aquatic and riparian-dependent species.	If young, high density conifer stands interfere with the movement of riparian-dependent species, then thinning can improve connectivity between habitats of riparian-dependent species. Thinning that increases wood loads to streams can improve connectivity for aquatic species.	Thinning that reduces snag and down wood abundances of a size that are important to species (e.g. see Table 4) may interfere with both the movement of species and the utilization of riparian and aquatic habitat by certain species (e.g. salmonids). If thinning alters microclimates it may interfere with the movement of species sensitive to temperature and humidity (e.g. herpetofauna).
3. Maintain and restore the physical integrity of the aquatic system, including shorelines, banks, and bottom configurations.	Thinning that increases wood loads to streams can help maintain and restore the physical integrity of stream beds.	Removal of trees adjacent to shorelines and banks and construction/maintenance of roads used to access thinning sites can affect the integrity of aquatic systems and their shorelines and banks. Thinning that reduces wood loads to streams can delay recovery of the physical integrity of stream beds.
4. Maintain and restore water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain within the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian	Thinning adjacent to streams may reduce shade and increase stream temperatures which can improve growth of instream organisms such as benthic invertebrates and fishes	Thinning can increase stream temperatures beyond a level that supports healthy aquatic and riparian ecosystems.

communities.

5. Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.	Thinning that increases dead wood loads to streams can help maintain and restore natural sediment regimes in aquatic systems	Thinning that reduces wood loads in streams can reduce sediment storage and affect transport rates.
6. Maintain and restore in-stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing. The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.	Thinning that increases dead wood loads to streams, riparian areas and wetlands can help sustain such habitat.	Thinning that reduces dead wood loads in both low- and high-gradient streams can delay recovery of natural patterns of sediment and wood storage and transport and nutrient processing.
7. Maintain and restore the timing, variability, and duration of floodplain inundation and water table elevation in meadows and wetlands.	Thinning that increases dead wood loads to streams can increase floodplain inundation, by creating jams and other instream obstructions	Thinning that reduces wood loads in low-gradient streams can lead to channel incision and reduced floodplain inundation.
8. Maintain and restore the species composition and structural diversity of plant communities in riparian areas and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.	Thinning can increase the diversity and biomass of understory plants. If shade-tolerant tree species become established, this helps increase structural diversity by creating a multi-tiered canopy. Thinning that increases dead wood loads in streams and riparian areas can help to sustain physical complexity	Thinning can reduce the future supplies of snags and large dead down and decomposing wood on the forest floor and in aquatic systems and thus delay the recovery of physically complex aquatic, riparian and terrestrial habitat. A lack of large wood in streams can also reduce channel migration and potentially lead to channel incision and habitat simplification. Thinning can affect the forest microclimate and the thermal regime of aquatic systems

9. Maintain and restore habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.	Thinning can increase the biomass and diversity of understory vegetation. Thinning can create stands of variably spaced overstory trees with thick limbs that are used for nesting by marbled murrelets and can provide habitat for a diverse arboreal, epiphytic community	Thinning can reduce the future supplies of snags and large dead down and decomposing wood on the forest floor and in aquatic systems and thus delay the recovery of habitat essential to numerous aquatic, riparian-dependent and terrestrial vertebrates, invertebrates, plants and fungi. Also, the roads used to access thinned stands may provide access routes for diseases, exotic species and other undesirable species

Wood Size And Function In Streams

Studies of sizes and functions of wood of in Pacific Northwest streams have examined three key attributes: (1) minimum diameter of wood needed to independently form a pool (Beechie et al. 2000), (2) median diameter of pieces in unlogged Coast Range streams in SW Washington (which coincidentally is similar to the median diameter of pool-forming pieces in second growth forests) (Bilby and Ward 1989), and (3) key piece sizes; those that are unlikely to move during a flood and are needed to anchor wood jams (Figure 15) (Abbe et al. 1996, Montgomery et al. 1996, Fox and Bolton 2007). The size of wood increases with channel width for each functional attribute. Hence, judging the effects of thinning on recruitment of wood to streams depends in part on the size of the stream next to the thinned riparian stand, as well as the size of future instream wood being targeted. In general, more wood creates more pools in streams, up to a point at which pool formation is maximized and additional wood does not increase pool area or numbers (Montgomery et al. 1995, Beechie and Sibley 1997) (Figure 16). Rosenfeld and Huato (2003) found a similar relation for streams in coastal streams in British Columbia. The relation between wood and pools was statistically significant but wood only accounted for 11% of the variation in pool spacing, suggesting that other factors likely also influence pool abundance. Previous studies show that this relationship holds in both low and moderate gradient streams but that it is stronger in moderate gradient streams (Montgomery et al. 1995, Beechie and Sibley 1997).

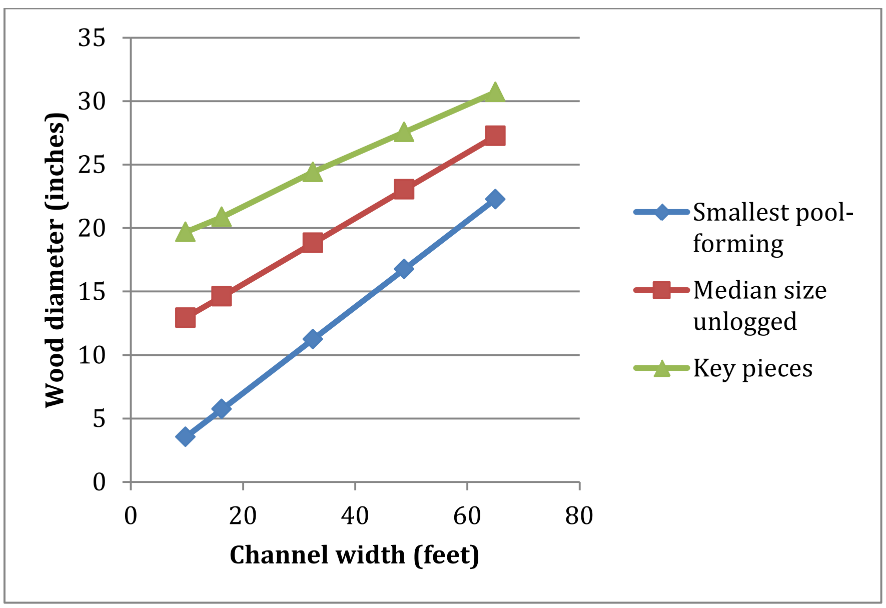


Figure 15. *Examples of variation in functional wood sizes as a function of channel width (based on data in Bilby and Ward (1989) for median size of wood in unlogged streams Beechie and Sibley (1997) for smallest pool-forming, and Washington Forest Practice Board (1995) for key pieces.*

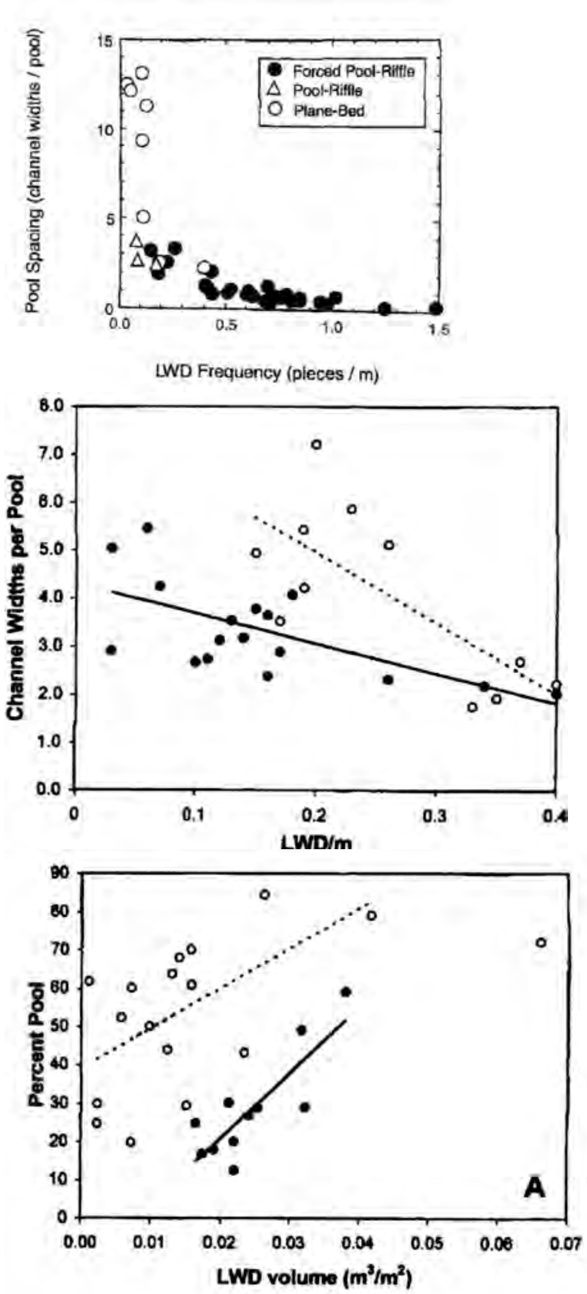


Figure 16. *Pool formation by wood in low and moderate gradient channels. Upper panel from Montgomery et al 1995, lower and middle panels from Beechie and Sibley 1997. Upper panel illustrates strong relationship between wood and pools up to about 0.5 pieces/m, and little influence at wood abundance greater than 0.5 pieces/m (Montgomery et al 1995). Middle panel illustrates difference between pool spacing in low and moderate gradient channels, and lower panel illustrates difference between percent pool in low and moderate gradient channels (Beechie and Sibley 1997). Open circles are moderate gradient channels and filled circles are low gradient channels. Note difference in x-axis scales between upper and middle panels.*

The size of wood that can create a pool is directly related to stream size but the potential to form pools in a channel of a given size increases with piece size (Rosenfeld and Huato 2003). For example, Rosenfeld and Huato (2003) found that on average only 6% of the pieces of wood 6-12" (15-30 cm) in diameter formed pools in smaller streams in British Columbia, but 42% of pieces greater than 24" (61 cm) in diameter formed pools (Figure 17). They also modeled pool abundance as a function of number and sizes of wood pieces and found that the removal (from the stream) of the largest pieces (larger than 24” or 61 cm) caused the greatest decrease in pool abundance compared to removal of smaller pieces (Figure 18). Thus, assessments of the impact of thinning should consider the range of sizes of wood that will be delivered.

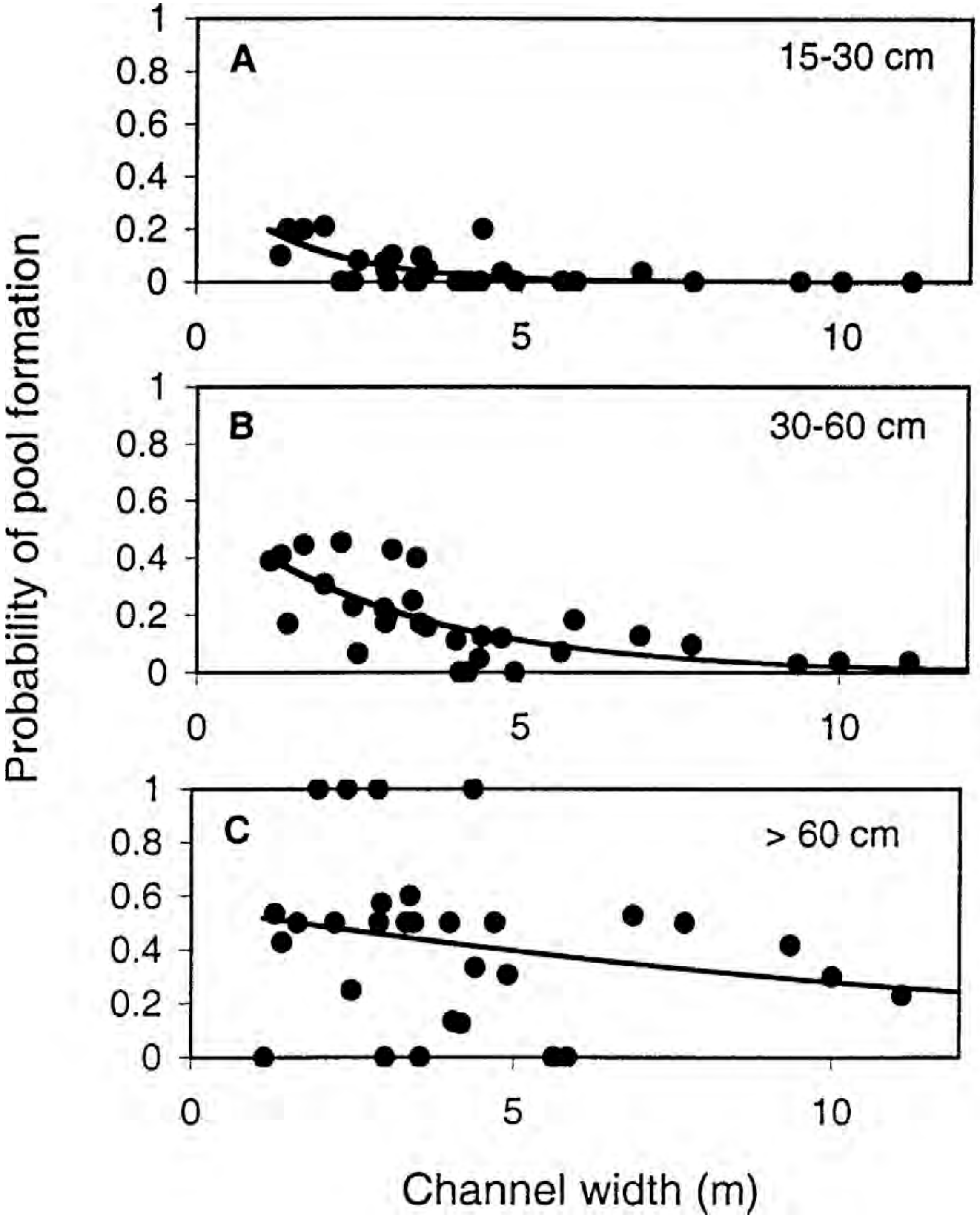


Figure 17. *Probability of pool formation as a negative exponential function of bank-full channel width for LWD of the following diameters: (A) 15 to 30 cm (P 5 0.42 3 2.71(–0.69 · width)), (B) 30 to 60 cm (P 5 0.57 3 2.71(–*

0.33 · width)), and (C) greater than 60 cm (P 5 0.56 3 2.71(–0.07 · width)). Solid lines represent the fitted functions. (From: Rosenfeld and Huato 2003.)

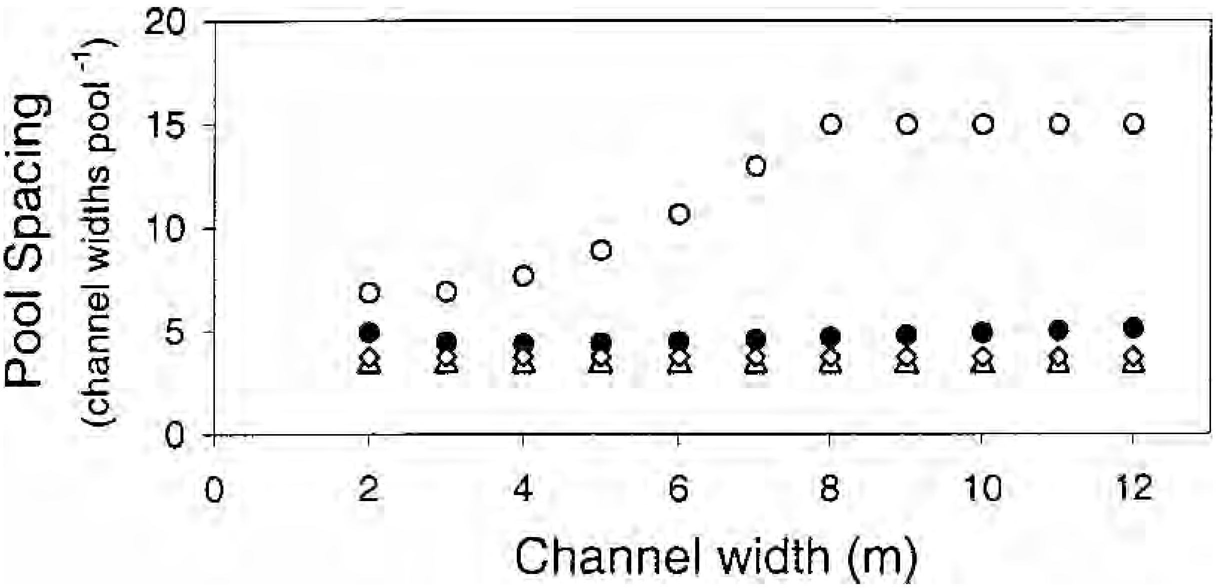


Figure 18. *Modeled pool spacing plotted against channel width, where pool spacing was calculated as a power function of total LWD abundance (pool spacing 5 2.67 3 (LWD/m)20.33) either with all diameter classes included (triangles) or with the largest diameter class removed (diamonds). The solid circles show the pool spacing predicted by the diameter-specific probability model (equation 1 in text) with all diameter classes of LWD included; the open circles show the predicted pool spacing with the largest diameter class (greater than 60 cm) removed. (From: Rosenfeld and Huato 2003.)*

Wood of a size that can independently form pools is not the only ecologically important size of wood in streams. Larger pieces can serve as stable key members that create instream obstructions and form wood jams by racking up numerous smaller pieces of wood that are mobile during high flows. Such wood jams typically consist of a wide range of wood sizes, with the larger sizes creating stability, and the smaller sizes filling the interstices of the jam, helping to store sediment and forcing water over the tops of jams, creating plunge or scour pools (Bilby and Ward 1989, May and Gresswell 2003, May and Gresswell 2004). Sediment stored above wood jams creates areas of stable vegetated surfaces along the channel (Jackson and Sturm 2002). The latter may also be areas of hyporheic flows, which can help to cool streams and may provide other important ecological functions, as has been observed for larger streams (Stanford and Ward 1988, Jackson and Sturm 2002, Johnson 2004). Wood jams containing a range of wood sizes, particularly in small streams, provide for other functions including sediment sorting, energy dissipation, habitat for benthic organisms, nutrient and organic material retention and cycling and the creation of low-gradient alluvial habitat in otherwise steep, bedrock-dominated reaches (Bilby 1981, Bilby and Ward 1989, Montgomery et al. 1996).

Effects Of Tree Species Composition On Instream Wood Quality And Quantity

Hardwood trees, such as red alder and big leaf maple are common components of riparian zones in western Oregon and other parts of the Pacific Northwest (Nierenberg and Hibbs 2000, Hibbs and Bower 2001). In the Pacific Northwest, hardwoods do not achieve the combination of diameter, length, strength, longevity and rootwad size of the conifers (Alden 1995, Alden 1997) but they can, nonetheless, provide wood that can create habitat in streams and riparian areas over the short-term, up to 70 years (Andrus et al. 1988, Beechie et al. 2000). In smaller streams, they may form accumulations by serving as the key piece, and like all pieces of instream wood, are most stable when they have root wads attached rather than being broken or bucked into pieces (Abbe et al. 1996, Braudrick and Grant 2000, Abbe and Montgomery 2003). Their effectiveness in forming pools is directly related to bole size relative to both the size of the stream and position within the stream (Bilby and Ward 1989, Abbe et al. 1996). Hardwoods can also be important components of coarse wood accumulations in larger streams, particularly when coniferous key pieces are present (Hyatt 1998, Collins et al. 2002). However, hardwood longevity is limited because they deteriorate more quickly than conifers, particularly when exposed to air (Harmon et al. 1986, Bilby et al. 1999, Bilby 2003). Thus, they may be important in the short-term for improving instream habitat, but conifers are needed for longer-lasting, long-term improvements.

Watershed-Scale Perspectives

Much knowledge about vegetation manipulation and aquatic and landscape ecology has been developed since the Northwest Forest Plan was enacted in 1994, and alternative approaches for designing management of riparian areas are emerging (Harris 1999, Rot et al. 2000, Reeves et al. 2003, Hughes et al. 2005). The management of a particular location depends on the "context" of that location (Kondolf et al. 2003, Montgomery and Bolton 2003) and many restoration efforts fail because of the reliance on "off-the-shelf" and one-size-fits all concepts and designs rather than on an understanding of specific features and capabilities of the location of interest (Kondolf et al. 2003). Recent scientific advances suggest that effective aquatic conservation practices should be tailored to the specific features and characteristics of the location of interest as illustrated in Table 3 (Beechie et al. 2010).

Table 3. *This table illustrates how the ecological consequences of wood recruitment are expected to vary with physiographic setting and stream type. Thinning with bole removal will likely reduce total wood recruitment to streams, but could reduce the time required to get greater than 40" dead trees by approximately a decade (see Figures 1-3). While simulated thinning effects on dead wood production are the same regardless of setting, the ecological consequences to streams vary depending on stream characteristics. Note that in this example, we are not considering effects on temperature, riparian or terrestrial ecosystems. Nor are we considering potential ecological effects of road systems that are needed to support the management actions.*

Physiographic Setting	Ecological effects for instream wood at the site	Ecological effects for wood recruitment in coho salmon streams
Coho salmon stream with low wood abundance	Pool-forming wood and key pieces for small streams (i.e., <50 feet wide) are typically 17-28 inches (Figure 15), so heavy thinning could delay recruitment of wood large enough to form pools for a century or more if both banks are treated similarly.	Same as for wood recruitment at the site
Small, steep headwater streams that have been scoured to bedrock by debris flows.	Wood sizes required to store sediment and remain stable in small steep streams such as these are typically >36 inches, so decreased time to recruitment of >36 inch wood may hasten	Where delivery of large wood to coho streams by debris flow is possible, the eventual increase in large wood may alter delivery rates of large wood and sediment to downstream coho salmon habitats

	recovery of sediment storage (though the recruitment of very large wood will still likely be 60 to 100 years away even with thinning, depending on the model used to predict recovery time).	for several decades at some point in the future.
Small, steep headwater streams without debris flow potential	Thinning may decrease recruitment of <36 inch wood in small streams could will likely delay accumulation of stored sediments (< 36 inch wood can store sediment in small streams). However, thinning and leaving some boles could accelerate recruitment of wood.	By definition, these streams have a low potential to deliver wood to coho streams so thinning in these headwaters streams will likely have little influence on wood loads in coho streams.

It is now widely recognized that variation in geomorphic setting of the stream or reach supports fish species habitat diversity (Benda et al. 2004, Burnett et al. 2007, Beechie et al. 2010). Variation depends on channel gradient and size, and the ratio of the valley width relative to the size of the active channel. Intrinsic potential (IP) is a measure of the capability of a given stream or stream segment to potentially provide suitable habitat for a given fish species (Burnett et al. 2007).

A watershed-scale perspective on wood recruitment is needed to restore wood loadings in streams in the Oregon Coast Range. Small, headwater streams can be important sources of wood that can be in key components of fish habitat in fish-bearing streams (Reeves et al. 2003, Bigelow et al. 2007). The model NetMap (http://www.netmaptools.org/taxonomy/term/21) is capable of identifying the streams that are the most likely sources of wood. Figure 19 illustrates how management of riparian reserves might vary, depending on the context of the particular location. Factors to consider in determining the specific management scheme could include the intrinsic potential (see Burnett et al. 2007) and potential for thermal loading and erosion at the location. Areas of management option 1, which correspond to the first row of Table 3, are ecologically productive or sensitive areas. Management activities in these areas could be relatively conservative to maintain or enhance the key ecological processes that affect the quantity and quality of aquatic habitat. Areas of management option 2 are portions of the fish-bearing network that are less ecologically productive (e.g. low intrinsic potential for any fish species) or less sensitive (e.g. not likely to warm because of topographic shading or orientation). A greater range of ACS-related management activities could occur here.

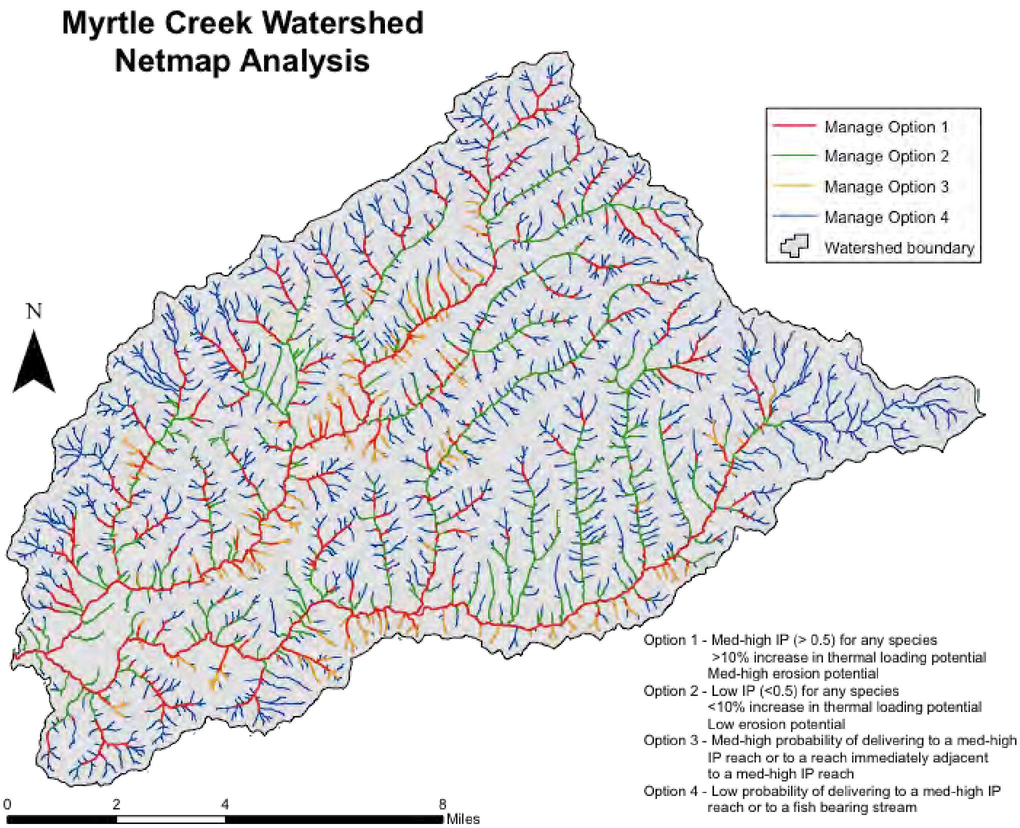


Figure. 19. *An example of potential strata of areas of varying relative ecological sensitivity and productivity in which options for riparian management could be developed. See the text for more detail.*

Streams with management options 3 and 4 in Figure 19 are in the non-fish bearing portions of the stream network. Those in option 3 represent the second row in Table 3 and are potential sources of large wood and sediment for the fish-bearing portion of the network. Riparian management could be directed towards the development of large key pieces of dead wood to help form jams that could store sediment (Montgomery et al. 1996), and smaller pieces of wood in the channel for eventual delivery to fish-bearing streams when debris flows occur (May and Gresswell 2003, May and Gresswell 2004). Streams in option 4 are not as strongly connected to the fish-bearing portion of the network but could be sources of cold-water inputs to larger streams, sites of storage and processing of organic material, or habitat for amphibians and other aquatic organisms.

A decision support framework that recognizes the inherent variation in stream networks and riparian areas, and identifies appropriate management actions for a specific set of circumstances could be developed to guide management. Such an approach is illustrated in Figure 19. This approach would require identification of the selected characteristics of a site, and the application of a given set of management options that are specific to that site. Site features could include intrinsic potential, thermal loading potential, the location of headwater streams that have a strong potential to deliver wood to the location of interest, riparian stand condition and the species for which the stream and riparian areas are being managed. The first three parameters could be determined using NetMap.

Overview of Dead Wood Functions in Terrestrial Environments and the Effects of Thinning

Use Of Large Dead Wood By Terrestrial Species

There is voluminous literature on the role of dead wood in terrestrial ecosystems. Dead wood in the form of snags or down wood is utilized by numerous plants, animals and fungi and its presence is a signature feature of late-successional forests. Different species prefer different sizes, densities and decay classes of snags and down wood. Comprehensive information on the size and density of snags and down wood utilized by different species are available at the USFS DecAID web site (http://www.fs.fed.us/r6/nr/wildlife/decaid/) and other sources. Below we briefly summarize what is known about dead wood use by terrestrial species including fauna, flora and fungi.

The literature available from DecAID, suggests that relations between snag size and use has been documented for a number of species, particularly cavity nesting birds and bats. DecAID uses the density of snags greater than 25 cm and greater than50 cm as important metrics for assessing the suitability of snag habitat for numerous species. Studies relating down wood and species use (e.g. herpetofauna or small mammals) usually measure down wood as a percent of the cover on the forest floor, and relations between species use and a specific size of large wood are less clear. DecAID suggests that wood cover of about 20% will be sufficient for most species, and that the down wood should generally be at least 30 cm to 50 cm in diameter, or larger. The process of tree fall can be important too. As trees fall, they break branches and scar the boles of nearby trees. This creates structural irregularities which can provide important habitat such as nesting and roosting platforms and nesting cavities.

Numerous terrestrial vertebrates are associated with large dead wood, ranging in size from 13 cm to greater than 200 cm diameter, however, the average diameter of dead wood used ranges from 53 cm to 123 cm. Table 4 provides examples of specific sizes of dead wood and live trees associated with vertebrate species found in older forests (cf. Bunnell et al. 1999, Bunnell and Houde 2010). A number of forest vertebrates are also positively associated with the percent cover of all dead wood on the forest floor, often defined as logs greater than 10 cm or greater than 30 cm diameter (Marcot et al. 2010). Large diameter snags or down wood are used in a number of ways that vary by species (Table 4). Such uses include nesting, denning, resting, foraging and roosting. Several small mammals, such as the northern flying squirrel form the prey base for the Endangered Species Act (ESA) listed spotted owl and are among the species associated with abundant large dead standing and down wood. This presumably, is why spotted owls prefer to forage in stands with abundant standing and fallen dead wood (Table 2, North et al. 1999). The fruiting bodies of hypogeous fungi are a food source of northern flying squirrels and are also associated with down logs, suggesting that there are complex, indirect paths through which dead wood supports spotted owls (Amaranthus et al. 1994, Carey 2000).

Table 4. *Examples of species of Pacific coastal forests use of large diameter dead wood and live trees in aquatic and terrestrial habitats, with an emphasis on ESA-listed species (salmonids, the northern spotted owl (and its prey base) and the marbled murrelet). Size range numbers refer to bole diameter breast height (dbh), unless otherwise noted (cf. Bunnell et al. 1999, Bunnell and Houde 2010).*

Species	Wood Type	Function	Size Range	Avg diam (cm)	Avg L or Ht (m)	References
Onchorynchus, *Salmo*, and *Salvelinus* (salmonids) and other aquatic species	Instream CWD	Forms pools independently, in the absence of other wood or obstructions	0.15-0.75 m diameter for streams with bankfull widths between 4-23 m according to the equation: Diameter = 0.028*BFW + 0.0057	-	-	Beechie and Sibley 1997
salmonids and other aquatic species	Instream CWD	Independently stable during large floods. "Key" piece forms jams	Varies with stream size: wood piece volumes from 1.0-10.8 m3 for streams 1-100 m wide.	-	-	Fox and Bolton 2007
salmonids and other aquatic species	Instream CWD	Independently stable during large floods. "Key" piece forms jams	Varies with stream size: wood diameters from 40-70 cm and lengths from 8-24 m for streams 1-20 m wide.	-	-	WFPB 1995
salmonids and other aquatic species	Instream CWD	Stablize valley spanning jams in high gradient channels	60-200 cm diameter	-	-	Montgomery et al. 1996
salmonids and other aquatic species	Instream CWD	accumulates on larger “key” pieces to form debris jams	> 10 cm dbh, 2 m length	-	-	Bilby 1980, Bilby and Ward 1989,
Strix occidentalis (northern spotted owl)	CWD	Preferred foraging areas	foraging positively related to all CWD volumes, and big log (dbh >50 cm and L > 8m) volumes and densities	-	-	North 1999
G. sabrinus (northern flying squirrel), *Neotamias townsendii* (Townsend's chipmunk)	CWD	Preferred habitat for NSO prey species	12% cover of large wood	-	-	Carey 1995
Myotis lucifugus (little brown myotis)	CWD	Roosting	-	55	8	Bunnell and Houde 2010
Martes pennanti (fisher)	CWD	Resting	50-200	95		Zielinski et al. 2004
Martes americana (marten)	CWD	Denning	-	53	-	Ruggerio 1998

M. americana	CWD	Resting	-	66	17	Bull and Heater 2000
Ursus americanus (black bear)	CWD	Denning	-	108	17	Bull et al. 2000
U. americanus	CWD	Denning	-	123		Davis 1992
Ensatina eschscholtzii	CWD	General habitat	0-800 m3/ha, density=0.11*(CWD Volume)^0.66	-	-	Butts and McComb 2000
Ensatina eschscholtzii	CWD	General habitat	91% of observations related to CWD	-	-	Bury and Corn 1988
Aneides ferreus (clouded salamander)	CWD	General habitat	84% of observations related to CWD	-	-	Bury and Corn 1988
Batrachoseps wrightorum (slender salmander)	CWD	General habitat	64% of observations related to CWD	-	-	Bury and Corn 1988
S. occidentalis	Snags	Preferred foraging areas	vol > 142 m3/ha, 70% of snag volume was from snags > 50 cm dbh. 15 large snags >50 cm/ha in medium and high use areas	86	-	North 1999
G. sabrinus (northern flying squirrel), *Neotamias townsendii* (Townsend's chipmunk)	Snags	Preferred habitat for NSO prey species	23 large (>50 cm) snag/ha	-	-	Carey 1995
Myotis californicus (California myotis)	Snags	Roosting	-	56	27	Brigham et al. 1997
Myotis volans (Long-legged myotis)	Snags	Roosting	95% CI = 83-110	97	38	Ormsbee and McComb 1998
Myotis thysanodes (Fringed myotis)	Snags	Roosting	58.5-167	121	41	Weller and Zabel 2001
M. americana	Snags	Denning	-	55	-	Ruggerio 1999
M. pennanti	Snags	Resting	66-200	119		Zielinski et al. 2004
Colaptes auratus (common flicker)	Snags	Cavity nesting	36-112 cm	61	11	Mannan et al. 1980
Dryocopus pileatus (pileated woodpecker)	Snags	Cavity nesting	46-172 cm	78	15	Mannan et al. 1980
Picoides villosus (hairy woodpecker)	Snags	Cavity nesting	48-172 cm	92	18	Mannan et al. 1980
Sphyrapicus varius (sapsucker)	Snags	Cavity nesting	56-216 cm	101	17	Mannan et al. 1980

Sitta canadensis (nuthatch)	Snags	Cavity nesting	74-185 cm	118	28	Mannan et al. 1980
Oecile rufescens (chickadee)	Snags	Cavity nesting	53-160 cm	103	18	Mannan et al. 1980
C. auratus	Snags	Foraging	19-167 cm	95	23	Mannan et al. 1980
D. pileatus	Snags	Foraging	20-185 cm	103	30	Mannan et al. 1980
P. villosus	Snags	Foraging	13-173 cm	62	20	Mannan et al. 1980
S. occidentalis	Live trees	Platform nesting	36-179 cm dbh	106	42	Forsman 1984
S. occidentalis	Live trees	Cavity nesting	74-205 cm dbh	135	38	Forsman 1984
S. occidentalis	Live trees	Roosting	Range of means: 15-115 cm, varies with location and weather	83	-	Forsman 1984
S. occidentalis	Live trees	Dispersal habitat	> 40% canopy cover of trees > 28 cm dbh	-	-	USFS 2010
Brachyramphus marmoratus (marbled murrelet)	Live trees	Platform nesting	large trees > 82 cm dbh comprising > 10% of the canopy cover	-	-	Meyer and Miller 2002
B. marmoratus	Live trees	Platform nesting	dominated by conifers > 50 cm dbh	-	-	Ripple et al. 2003
B. marmoratus	Live trees	Platform nesting	mean dbh of trees > 77 cm (OR) or > 91cm (CA)	-	-	Meyer et al. 2002
B. marmoratus	Live trees	Platform nesting	> 70% crown closure from trees > 53 cm dbh (WA)	-	-	Raphael 2002a
B. marmoratus	Live trees	Platform nesting	key predictors of nest sites: total # trees > 90 cm	-	-	Perez-Comas and Skalski 1996
B. marmoratus	Live trees	Platform nesting	high density of trees > 80 cm within 50 m of nest	-	-	Rodway and Regehr 2002
B. marmoratus	Live trees	Platform nesting	-	110	32	Hamer and Meekins 1999
B. marmoratus	Live trees	Platform nesting	49-533 cm dbh, range of means, varies with location	116-278	51-73	Hamer and Nelson 1995
M. americana	Live trees	Resting	-	61	25	Bull and Heater 2000
M. pennanti	Live Trees	Resting	35-205	125		Zielinski et al. 2004
U. americanus	Live Trees	Denning	-	112	24	Bull et al. 2000
U. americanus	Live Trees	Denning	-	159		Davis 1992

Though species association with specific sizes of large dead wood are known (Table 4), mechanistically speaking, the reasons why a particular species is associated with a particular size class of dead wood are not always well understood (cf. Bunnell et al. 1999). Potential functions provided by large dead terrestrial wood that would not occur in smaller dead wood includes temperature (hot and cold) and humidity refugia (Ruggiero et al. 1998, Kluber et al. 2009), large internal cavity volumes for nests and dens (Bull et al. 2000, Zielinski et al. 2004), cavities between the bark and bole (Bunnell et al. 2002), and sustained structural integrity, particularly during advanced stages of decay (Mannan et al. 1980). For some species, the size of the dead wood may not matter so much as the mechanism by which the tree died and what happened to the tree while it was alive. As an example, the slow death of a tree by heart rot creates a large cavity that is useful as a denning site for several species (e.g. black bear, fisher and marten *M. americana*), suggesting that variation in the mechanisms of tree death is another consideration for the maintenance of biodiversity (Bunnell and Houde 2010).

Dead wood also affects plant composition, successional dynamics, and forest structure. The light gap formed when the tree falls allow understory vegetation to grow, including shade-tolerant trees, which helps to form a multi-tiered canopy. As the fallen bole decays it creates an elevated organic substrate (i.e. a “nurse” log), which is an important establishment site for conifer species such as Sitka spruce and western hemlock (Harmon and Franklin 1989). This function is especially important for maintaining a conifer component in moist, hardwood and shrub dominated riparian forests. Thus, large diameter wood recruitment into stream-adjacent alder forests may be essential to ensure that these forests can re-establish a conifer component over the long-term, which in turn can become an important source of large diameter coniferous wood to streams.

Many nonvertebrate species in forest ecosystems are associated with dead wood. Though size preferences are not well understood for most of them, many are associated with dead wood across a wide range of sizes, including wood less than 30 cm diameter. Species groups that utilize dead wood include fungi, lichen, bryophytes, mosses, invertebrates and vascular plants (reviewed in Bunnell and Houde 2010). Within these groups are hundreds of species that are dead wood obligates or are predominantly found on dead wood. The loss of dead wood in managed forests has been associated with a decline in biological diversity for many of these species groups (Jonsson et al. 2005, Davies et al. 2008, Bunnell and Houde 2010). In terms of considering management options for the purpose of maintaining and restoring biological diversity, it would be helpful to better understand how such species are affected by the size, abundance and quality of dead wood, and in particular, which species prefer large diameter dead wood.

Dead wood can affect soil moisture and is important for fungi. Down wood has a high pore volume and thus can serve as moisture reservoirs and provide persistent microsites that aid in forest recovery after prolonged drought or fire (Amaranthus et al. 1989). For example, in one study in southwest Oregon, down logs provided considerable rooting and mycorrhizal activity, and mean moisture content (157%) was 25 times greater than mean soil moisture (6%) (Amaranthus et al. 1989). In forests of western North America, decomposing wood occurs in the organic humus horizon of soils and, indeed, throughout the entire soil horizon (Harvey et al. 1976a, Harvey et al. 1976b). Down wood is also a major source of mychorrizal fungi (Amaranthus et al. 1996). In dry environments, decaying wood retains moisture and serves as important reservoirs of such fungal activity during dry summer months (Harvey et al. 1976a, Harvey et al. 1976b).

Thinning And Development Of Structurally Complex Forests With Large Dead Wood

Biodiversity declines in conifer forests have led to experimental and management efforts to accelerate the development of old forest structure, especially large live and dead wood in young, simplified stands that are a legacy of past commercial harvest activities (Davis et al. 2006, Puettmann et al. 2009, Bauhus et al. 2010). The approaches (e.g. active vs. passive management) for restoring dead wood and the structural complexity for terrestrial and aquatic biodiversity are a subject of ongoing discussion and active research (Beechie et al. 2000, Puettmann et al. 2009, Bauhus et al. 2010, Bunnell and Houde 2010, Marcot et al. 2010). Several researchers have proposed that restoration in young stands be done with variable density thinning (Carey 2006) and ecological forestry (Franklin et al. 2007). Variable density thinning is being applied in many plantations in national forests in Oregon (Stuart Johnston personal communication). The rationale for such thinning is that it will accelerate the development of large live trees and create structural and compositional heterogenity that fosters increased biodiversity in homogeneous young stands (Muir et al. 2002, Garman et al. 2003, Davis et al. 2006). Thinning young forests with variable density thinning creates canopy gaps, another structural attribute of older forests that is often missing in dense young stands (Spies 1989). If active management can accelerate the development of old forest structure, then the restoration of biologically diverse aquatic and terrestrial communities could also be accelerated (Puettmann et al. 2009, Bauhus et al. 2010).

It is well established in the literature that thinning young Douglas-fir stands can increase the diameter growth rates of the remaining live trees (Tappeiner et al. 2007). In one of the longest experiments in the region, a 35 year study of thinning effects, the average growth of surviving trees in thinned plots was 165% greater than in unthinned plots (Marshall and Curtis 2002). However, the increases in diameter growth from thinning may not apply equally to all individuals, especially for the largest trees in the stand which may be under less competition from neighbors. (e.g. Davis et al. 2006). Although we may have a relatively good understanding of the effects of thinning on the growth of surviving trees in young stands, that is not the case for the effects of thinning on dead wood dynamics. Currently, there are few long-term (e.g. greater than 50 years) data sets with which to assess the long-term impacts of thinning on snag and down wood dynamics (Bunnell and Houde 2010, Marcot et al. 2010). Forest growth models can be used to assess the long-term effects of thinning on deadwood production in terrestrial ecosystems but only one study by Garman et al. (2003) has examined effects of thinning on dead wood (see page 3). The simulations and state of knowledge that we presented earlier in the report for riparian forests (see pages 3-4) are also relevant to understanding the effects of thinning on dead wood in terrestrial forests and we do not repeat them here.

Additional Considerations

As stated in the introduction, the amount and recruitment of dead wood in forests and streams is difficult to predict and function of many factors. We have attempted to answer the wood recruitment question that was posed to us and discuss some of these factors that affect this answer. However, there are other important aspects restoring habitat for salmonids that we do not address including:

- Recognizing how the inherent dynamics of forests and streams affect habitat quality and ecosystem functions over time
- Characterizing how management effects vary with spatial and temporal scale—we have focused primarily on stand/site-level effects in this summary
- Putting wood recruitment into a broader ecological context, e.g. its role in stream habitat relative to other factors (e.g. boulders).

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III. Effects of Riparian Thinning on Marbled Murrelets and Northern Spotted Owls

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Background

Despite having different missions and mandates, the agencies share the common goal of improving ecosystem function. To that end, the ICS requests the SRT's consideration and thoughts regarding the following topics related to overall ecosystem function.

- Identify data critical in evaluating tradeoffs between short term and long term positive or negative effects of various riparian thinning treatments on fish and riparian/ stream ecosystems.
- Characterize the relationship between "no-cut" stream buffer width and management goals to accelerate recovery of forest structural conditions beneficial to federally listed terrestrial species.

Ecosystem Function

This section on ecosystem function has at least two facets to consider: (1) the effects of thinning on other (non-salmonid) threatened and endangered species (the northern spotted owl and marbled murrelet), and (2) effects on the overall system structure and composition relative to late-successional forests and related ecological goals. In the sections below we address these two areas with the knowledge that "ecosystem function" has many meanings to different people depending on their background and experience. The nature of the above questions and answers in this document do not allow for a complete coverage of all of the facets of ecosystem function. Consequently, the sections below focus on the status and habitat associations of terrestrial threatened and endangered species (i.e., northern spotted owls, marbled murrelets) which are important in the ecosystem. We also provide information on what is known about the effects of forest thinning on marbled murrelets and northern spotted owls.

Marbled Murrelet

The marbled murrelet was listed federally as a threatened and endangered species by the U.S. Department of Interior, Fish and Wildlife Service, in 1992 in the states of Washington, Oregon, and California. The species is also listed as threatened or endangered at the state (Washington, Oregon, California) and provincial level (British Columbia). The main reasons for the listings were loss of terrestrial habitat for nesting and declining populations in the marine environment. The species along with northern spotted owls and the numerous salmon stocks has been the focus of much controversy over the management and conservation of late-successional forests in the

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Pacific Northwest. The geographic range of marbled murrelets spans the nearshore marine environment from central California, Oregon, Washington, British Columbia (Canada), southeast Alaska and the Aleutian Islands, Alaska. The species is like most seabirds in that it spends most of its time in the marine environment foraging on small fish, resting, and preening. However, it is a solitary nester and flies up to 80km (50mi) inland to nest in old conifer forests. This unique behavior of nesting in conifer forests is where many of the conservation challenges arise for the species in the terrestrial environment (McShane et al. 2004).

Like most seabirds, marbled murrelets are a K-selected species. They have a low reproductive rate, with 1 egg produced per year and limited renesting attempts after nesting failures. They do not mature until they are 2-5 years old, and adult survival rates range from 80-95% per year. Effective conservation of marbled murrelets requires the ability to detect adverse changes in demography as quickly as possible, determination of the cause(s) of these changes, and early implementation of effective conservation actions. Their life history characteristics of using both the marine and terrestrial environments make conservation measures doubly challenging (McShane et al. 2004).

Terrestrial habitat for nesting is the important feature of their life history, and it includes older-aged forests, primarily mature and old-growth conifer stands within 80 km of the Pacific Ocean (McShane et al. 2004). However, they also use younger (>60 years) forests for nesting that have mistletoe, other deformities, or squirrel nests for nesting platforms (Nelson and Wilson 2001). Their nesting attempts are often unsuccessful due to forest fragmentation and the associated increase in abundance of their primary predators (jays, crows, and ravens). Eggs are laid on large lateral limbs, generally with large quantities of moss. They do not build nests but merely scratch out depressions in the moss in which to lay their egg. Consequently, large lateral limbs with large quantities of epiphytic moss seem to be the features that provide the characteristics that they need for nesting. Their nests also tend to have much overhead cover, and they have a high fidelity to nest stands and nest sites from one year to the next. They will nest in younger trees that have deformities or squirrel nests that act as nesting platforms but this is an exception to their general behavioral patterns. Most murrelet nests have been found in low elevation wet coniferous forests, apparently because of the greater abundance of moss and platforms in those areas. Although murrelets will nest throughout watersheds, fewer nests are found on ridgetops or areas with high wind, because platforms and moss cover are less abundant there (McShane et al. 2004). Murrelets are known to build nests near natural edges, such as those found along streams, wetlands, canopy gaps, forest clearings and avalanche chutes (McShane et al. 2004). However, proximity to forest edges also increases predation risk, and there are conflicting data as to whether proximity to forest edges increases or decreases nesting success (McShane et al. 2004). The main threats to marbled murrelets and their terrestrial habitat are the loss and fragmentation of habitat and predation of their nests by corvids (i.e., jay, crows, and ravens). Of the nesting attempts that fail, predation is responsible for >78% of the failures. In addition, predation rates appear to be higher in smaller more fragmented forests than in larger less fragmented stands of conifers. Threats to the species in the marine environment include oil spills, lack of prey, and entanglement in gill-nets (McShane et al. 2004). The effects of fishing by humans on prey species of murrelets are not well understood.

Currently, marbled murrelets are managed under the Northwest Forest Plan for the conservation of late-successional forests. There are also state plans and Habitat Conservation Plans for the species in California and Washington but none in Oregon, which is an important deficiency. A recent 5-year review of the species' status by the U.S. Fish & Wildlife Service (McShane et al. 2004) concluded that (1) significant improvements are needed in the amount and distribution of nesting habitat, (2) ongoing logging on state and private lands in suitable and occupied murrelet habitat is threatening nesting habitat, (3) ongoing thinning on all lands with no consideration for the effects on stand microclimate or increases in predators is a potential problem, and (4) no state conservation plan or Forest Practice Rules exist for Oregon. Populations are declining between 4-7% per year (McShane et al. 2004), so maintaining all suitable habitat and creating new habitat will be important to their long-term survival. In addition, regulation in Oregon will be mandatory for survival of the species in that state.

There are data on stand densities and other features from nest sites that have been used for nesting by murrelets but they are based on a very small sample of nests (McShane et al. 2004, Grenier and Nelson 1995), so little can be concluded about preferences or selection of these sites. They will nest in all conifer tree species, and one nest was found in a red alder. They generally nest in the middle of the live crown of a tree, so they prefer areas in the tree that provide lots of overhead cover. Most nests have >80% cover above the nest branch (McShane et al. 2004). They nest in all areas throughout a watershed but most nests are found at lower elevations often near natural forest edges, such as those found along streams. Edges may provide murrelets easier access to their nests (McShane et al. 2004:87-88), but may also increase predation risk. Also, murrelets frequently use lower elevation wet forests that provide an abundance of epiphytes as wetter areas generally have more suitable platforms based on a higher abundance of moss (Nelson et al. 2003). Very few nests are on ridgetops because they are drier (and thus less moss) and more prone to windthrow, so there are fewer nesting platforms. Most nesting sites in coastal Oregon occur < 3,400 feet.

Effects of thinning on marbled murrelet nesting habitat

Thinning of young (< 80 years old) forests is thought to accelerate the development of marbled murrelet nesting habitat because widely spaced trees extend their limbs after thinning to fill in the newly formed canopy gaps, and the limbs presumably increase in diameter as well. Thus, over the long term, thinning may increase the rate of development and density of large diameter limbs in overstory trees that are of a size ideal for marbled murrelet nesting (e.g. see Table 4.3.2 in McShane et al. 2004). However, this is an untested prediction that needs additional study, and managers also must consider the potential short-term negative effects of thinning young forests compared to the long-term potential positive effects. The negative effects of thinning appear to be the creation of forest stand characteristics (i.e., increase in forest fragmentation, shrub abundance and canopy gaps) that favor higher abundances of species (jays, crows, ravens) that prey on murrelet nests. Exact relationships between canopy gaps or understory biomass and predator abundance is not well known, so this is an area that needs further study, so all the potential effects of thinning on nesting success of marbled murrelets can be considered. Marbled murrelets nests that are near un-natural forest edges (e.g. roads and forest harvest boundaries) may be less successful than those found in forest interiors, so thinning operations designed to improve marbled murrelet nesting sites will likely be less detrimental if located >50 m from occupied or historical nesting areas (e.g. see section 4.5.6.2 in McShane et al. 2004). Because of sustained low recruitment and severe population declines of murrelet populations, thinning near occupied sites should proceed with caution until results from studies on the potential negative effects are known.

There are a number of stand characteristics consistently associated with murrelet nesting sites (Table 1). These characteristics include tall and large diameter trees, numerous nesting platforms, vertical canopy heterogeneity (e.g. canopy dominants rising above the average tree height) and canopy gaps. Basic physiological responses of conifers to increased sunlight resulting from the removal of nearby trees suggests that thinning should accelerate the development of some of these characteristics, but exact silvicultural approaches for attaining this structure have yet to be determined. In addition, there is no experimental evidence to suggest that the overall structure of thinned stands will result in higher levels of murrelet nests, nesting success, or that thinning will even increase the number of potential nesting platforms relative to unthinned stands. As such, thinning operations designed to accelerate the development of murrelet nesting habitat relative to natural processes should be considered experimental and monitored accordingly.

Guidelines from the USFWS

The USFWS does not have any specific guidelines for management of habitat for marbled murrelets (B. Tuerier, pers. comm.). The recovery plan for the murrelet states that habitat for the species is expected to be provided in the riparian reserves as specified under the Northwest Forest Plan. Consequently, management of areas proposed for thinning would be under the guidelines of the Northwest Forest Plan, and specific recommendations, if any, may be found in the recovery plan for the species (B. Tuerier, pers. commun.).

Northern Spotted Owl

The northern spotted owl was listed as a Threatened species by the U.S. Department of Interior in 1990 after two decades of debate and court proceedings over the issue. The main reasons for the listing were loss of habitat and the lack of regulatory mechanisms to protect their critical habitat. Since that time the subspecies has become the icon for management and conservation of late-successional forests throughout its geographic range in Washington, Oregon, northern California, and British Columbia. Because of its importance in this issue, it is one of the most researched and well-known owl species in the world. It has been the subject of many long-term demographic studies (Forsman et al. 1996, Anthony et al. 2006, Forsman et al. 2011). There have also been many studies on their habitat associations, home range attributes, behavior, diet and population genetics, all of which have provided valuable information about habitat needs and population stability. The subspecies preys upon medium to small-sized mammals throughout most of its geographic range. Northern flying squirrels and woodrats comprise the bulk of the diet in most localities (see below). The subspecies is long-lived, with an average life span of 8-9 years and longevity up to 23 years in the wild. Spotted owls have high survival rates as breeding adults and typically produce 1-2 young when they nest, which is about once every two years (Forsman et al. 2011). Consequently, they are a K-selected species with high site and mate fidelity. They are also highly territorial around their nesting areas and occupy these areas all year.

Northern spotted owls are associated with mature and old-growth forests throughout most of their geographic range (Thomas et al. 1990). Through radiotelemetry studies of their movement patterns it has been determined that they have very large home ranges which often overlap the home ranges of their neighbors (Forsman et al. 1984). A review of several but not all telemetry studies indicates that the subspecies selects or uses mature and old growth forests for foraging and roosting where such forests are available (Table 1). These same studies also indicated that northern spotted owls avoid young or medium aged forests in most parts of their geographic range (Table 1). Exceptions to this generality exist in northern California where the subspecies often occurs in relatively young mixed-species forests of Douglas-fir, redwood, California bay, and tanoak that have high densities of woodrats (Diller And Thome 1999). The subspecies also derives demographic fitness from its association with late-successional forests. For example, Bart and Forsman (1992) noted that spotted owls that occupied home ranges that had >40% old forest produced more young than owls that occupied home ranges with < 40% old forest. In addition, three studies that examined relationships between survival and habitat characteristics of home ranges found that survival rates of breeding adults were positively related to the amount of older forests around their core nesting areas (Dugger et al. 2005; Fig. 1) or the amount of old forests within their home ranges (Franklin et al. 2000, Olson et al. 2004: Figs. 2-3). Consequently, demographic performance and fitness of northern spotted owls are dependent on the amount of older forests around their nesting centers or within their home range. In addition, the dynamics of spotted owl populations are most sensitive to changes in adult survival rates (Noon and Biles 1990), so recent declines in survival rates have caused much concern for the status of their populations (Forsman et al. 2011).

Northern spotted owls are also associated with riparian areas, which is relevant to thinning of young forests in these areas (McDonald et al. 2006, Glenn et al. 2004). The association with riparian areas has been determined with the use of radiotelemetry studies of their movements and habitat use, which have shown that owls use riparian areas more than their proportional availability across the landscape. There have been at least three hypotheses proposed for the disproportionate use of riparian areas: (1) riparian areas provide more favorable thermoregulatory conditions (Barrows 1981); (2) prey species are more abundant in riparian areas (Carey et al. 1992 1999); and (3) fire severity has been lower in riparian areas resulting in the retention of structural complexity (Reeves et al. 2006). There is some support for all three of these hypotheses so they all likely have some influence over the use of riparian areas by northern spotted owls.

Northern spotted owls are obligate predators on medium- to small-sized mammals throughout their geographic range, and northern flying squirrels comprise the majority of the diet in most areas (Table 2). Woodrats and red tree voles are more prominent in the diet in the southern portion of the owl's range, whereas deer mice and red-backed voles are more common in the diet in the northern part of their range. These species of mammals have been studied in some detail, so there is a fair amount of information on their habitat associations and diets. Most importantly, several of the mammal species in the spotted owl's diet consume large amounts of hypogeous fungi (Maser et al. 1978), so fungi form the basis of an important food chain in coniferous forests. Hypogeous fungi form a symbiotic relationship with the roots of conifers whereby they provide a number of micronutrients to the trees that are otherwise unavailable. The food chain from fungi to small mammals to spotted owls (and many other predators) is, therefore, an important functional relationship in coniferous forests. Unfortunately, we know very little about the effect of thinning of young or old forests on this food chain and northern spotted owls. However, we do know that thinning of mature forests in the northern Coast Range of Oregon had a significant effect on species composition and biomass of hypogeous fungi (Gomez et al. 2003), hypogeous fungi and small mammals are associated with coarse woody debris (Gomez et al. 2003, McComb 2003), the abundance and survival of flying squirrels is associated with biomass of hypogeous fungi (Gomez et al. 2005, Lemkuhl et al. 2004), and thinning of a mature forest resulted in an expansion of the nonbreeding home range and a shift in the cores use areas of a male spotted owl (Meimann et al. 2003). The results of these studies suggest that this food chain is intricately tied to dead wood and hypogeous fungi in older coniferous forests. In addition, two recent studies have found that thinning in young forests virtually eliminated flying squirrels in the short term (Wilson 2010, Manning et al. 2012). Taken together, the above studies suggest that thinning in young forests has a short-term negative effect on spotted owls, but the long-term effects of thinning in young forests on spotted owls and their prey are unclear. This is an area where there needs to be a focus on monitoring and research on the effects of thinning on spotted owls and their prey.

Effects of thinning on forest structure important to spotted owls

The effects of thinning forests on habitat use of spotted owls have not been thoroughly studied, and the results of studies have not been in agreement in all cases. Historically, many of the forest management practices (i.e., clearcuts, shelterwood cuts, heavy commercial thinning) used in the Pacific Northwest have had negative effects on spotted owls (Forsman et al. 1984, Zabel et al. 1995, Buchanan et al. 1995, Hicks et al. 1999, Meimann et al. 2003). In most of these studies, the data collected on thinning were incidental to other research objectives, or there were only a few owls potentially affected by the harvest operations. Among the studies that reported spotted owl responses to thinning or other timber harvest activities, four studies (Forsman et al. 1984, King 1993, Hicks et al. 1999, Meiman et al. 2003) found spotted owls were displaced by harvest near the nest or activity center. Forsman et al. (1984) suggested that negative effects (decreased reproduction, site abandonment) of thinning or selective harvest were most likely associated with higher-intensity thinning, timber harvest close to the nesting areas, and the nest site had low amounts of suitable habitat. Similarly, Meimann et al. (2003) reported that a male spotted owl expanded his home range and shifted foraging and roosting away from a recently thinned forest, which was located close to the nest tree. They recommended that harvest operations not be conducted near nest sites. Given the small number of studies and small number of owls involved in the above studies, firm conclusions about the effects of thinning on habitat use by spotted owls are elusive, so this is an area where more monitoring and research needed.

Several studies have indicated that forest thinning can temporarily (e.g., up to 20 years) reduce the availability of hypogeous fungi, which are key foods for northern flying squirrels and other small mammals on which spotted owls depend (Waters et al. 1994, Colgan et al. 1999, Luoma et al. 2003, Gomez et al. 2003, Meyer et al. 2005). In addition, Carey (2000) found lower abundances of flying squirrels in recently-thinned (within 10 years) stands in western

Washington than in stands that were clear-cut 50 years ago. Wilson (2010) also reported that most thinning is likely to suppress populations of flying squirrels for several decades, but the long-term effects of variable density thinning on squirrels have not been studies and are unknown.

Effects of commercial thinning on spotted owl prey

Another important consideration is the effect of vegetation management on spotted owl prey species, particularly northern flying squirrels, dusky-footed woodrats, bushy-tailed woodrats, and other small mammals. Most birds of prey are limited by or influenced greatly by abundance of their prey species (Newton 1979), so this is an important consideration. There is actually a lot of published information on the effects of commercial thinning on spotted owl prey, particularly northern flying squirrels, red-backed voles, woodrats, and red tree voles. The published literature indicates that commercial thinning has negative effects on abundance of flying squirrels (Carey 2000; Manning et al. 2012; Wilson 2010; Gomez et al. 2005; Waters and Zabel et al. 1994, Waters et al. 2000) within the range of the spotted owl, and these effects may last up to 15 years or longer (Wilson 2010). Other studies in northeastern Oregon (Bull et al. 2004), southern British Columbia (Herbers et al. 2007, Ransome et al. 2004), coastal British Columbia (Ransome and Sullivan 2002), Ontario (Holloway and Malcolm 2006), and the Sierra Nevada Mountains of California (Meyer et al. 2007, Waters and Zabel 1995) have shown similar negative effects of commercial thinning on abundance of northern flying squirrels, so these negative effects on northern flying squirrels have been documented for other forest types in other U.S. states and Canadian provinces. Based on these publications, it is safe to say that commercial thinning within the range of the northern spotted owl will have a negative effect on abundance of northern flying squirrels. Northern flying squirrels are the owl's primary prey by number and biomass throughout most of their range; consequently, there is little doubt that commercial thinning will have a negative effect on abundance of flying squirrels as prey for spotted owls. In addition, commercial thinning has negative effects on the abundance of red-backed voles (Suzuki and Hayes 2003, Manning unpublished data), which is also an important prey species for the owl. There has not been as much research on the effects of commercial thinning on red tree voles because this species is extremely difficult to study because of its arboreal activity patterns. However, this species lives in the forest canopy and feeds exclusively on needles of Douglas-fir, so thinning activities will most likely have negative effects on this prey species (Forsman, person. comm.). Forests where red tree voles have been studied (Swingle and Forsman 2009) and later thinned do not support tree vole populations (E. Forsman, person comm.). Mixed results have also been reported in studies that examined effects of thinning on woodrats.

The long-term benefits of thinning in young plantations to create forests with characteristics of late-successional forests (e.g. large diameter standing and down wood) may outweigh any short-term negative effects on owls or their prey. However, as the age of forests selected for thinning increases, the short-term negative effects of such activities will likely increase and the benefits decrease. The Northwest Forest Plan specified a maximum age of 80 years for forests that are slated for thinning. The reasons for this guideline were that (1) it was unclear if thinning could actually accelerate the rate at which naturally regenerated mature forests developed old forest conditions, and (2) spotted owls forage in mature forests, and thinning of these forests will likely reduce their quality as spotted owl habitat both in the short and long term. If these young forests are not currently good foraging habitat, they are gradually developing late-successional characteristics that will provide foraging habitat in the near future. Consequently, thinning in riparian forests >80 years old or any younger forests where thinning is not likely to accelerate the development of late-successional forest structure is not recommended.

Guidelines from the USFWS

The USFWS does not have any specific guidelines for managing habitat for northern spotted owls in Riparian Reserves as designated under the Northwest Forest Plan (B. White, pers. comm.). However, there is some limited guidance on thinning in the Late-Successional Reserves in the Recovery Plan for the species (U.S. Fish and Wildlife Service 2011). Under Recovery Action 6, the Plan states: "In moist forests managed for spotted owl habitat, land managers should implement silvicultural techniques in plantations, overstocked stands, and modified younger stands to accelerate the development of structural complexity and biological diversity that will benefit spotted owl recovery". However, this prediction is speculation, and it needs to be tested with a good system of monitoring and research. Land managers should implement treatments in the Late-Successional Reserves per the Standards and Guides of the Northwest Forest Plan.

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Table 1. (A) Habitat characteristics of 10 occupied marbled murrelet nests in the Oregon Coast Range and (B) Habitat characteristics of 30 occupied marbled murrelet nests in the Siuslaw National Forest (from Grenier and Nelson 1995).

Table 1A. Stand characteristics of 10 murrelet nest sites in the Oregon Coast Range

Characteristic	mean	se	Range
TPH > 10 cm dbh	349.8	24.1	208.8-565.2
TPH > 46 cm dbh	131.9	15	10.2-269.9
TPH > 81 cm dbh	55.7	6.8	15.3-127.3
dbh > 10 cm	43.8	0.9	10-206
dbh > 46 cm	80.6	1.3	46-206
dbh > 81 cm	109.3	1.7	81-206
snag dbh (cm)	57.8	2.7	10.5-187
total snags per hectare	54	9.3	5.1-142.6
Distance to stream (m)	310	98.3	0-1000

Table 1B. Stand characteristics of 30 murrelet nest sites in the Siuslaw National Forest, Oregon

Characteristic	mean	se	Range
TPH total	253	nd	nd
TPH total, dominants	107.3	nd	nd
TPH total co-dominants	53.4	nd	nd
TPH total mid-story	92.3	nd	nd
TPH DF > 81 cm dbh	27.9	2.82	3-57
dbh all trees	60.8	nd	nd
dbh, dominants	89.7	nd	nd
dbh, co-dominants	59.2	nd	nd
dbh, mid-story	33.4	nd	nd
Canopy closure (%)	63.7	3.2	16-83
Canopy ht (m)	55.4	1.53	37-69

Table 2. Selection or avoidance of different forest types, as reported in seven different radiotelemetry studies of habitat use by northern spotted owls showing their association with mature and old-growth forests and avoidance of young forests.

	Forest Type[1]				
Data source	Non-forest	Sapling-Pole	Young	Mature	Old-growth
Forsman et al. (1984)	-	-	-/ns	-/ns/+	+
Carey et al. (1990)	-	-	-/ns	ns	+
Carey et al. (1992)	-	-	-/ns	ns/+	+
Zabel et al. 1995	-	-/ns	-/ns	ns	ns
Forsman et al. (2005)	-	-	-/ns	ns/+	+
Hamer et al. (2007)	-/ns	-/ns	-/ns	-/ns/+	ns/+
Glenn et al. (2004)	-	-	-	+	NA

[1]Meaning of symbols: "-" indicates that the forest type was avoided (i.e. used less than its proportional availability in the home range area). "NS" indicates that analyses were not statistically significant, and a "+" indicates that the forest type was selected (i.e. used more than its proportional availability in the home range area). "NA" indicates that the forest type was not available in the study area.

Table 3. Percent of different prey species in the diet of northern spotted owls in Oregon, subdivided by geographic region, 1970-2001 (adapted from Forsman et al. 2001). All values are percent of prey numbers in regurgitated pellets as opposed to percent of prey biomass.

	Coast Ranges			Interior SW	Cascade Mtns		
Species	North	Cent.	South		North	Cent.	East
Lagomorph	0.8	3.6	4.6	2.6	0.0	4.7	4.3
Flying Sqrl	48.4	49.5	36.0	28.2	52.1	34.7	41.1
Gophers	2.6	0.6	0.1	5.4	0.0	4.8	5.1
Deer Mouse	17.3	10.5	6.2	4.9	0.0	6.4	4.0
Woodrat	11.8	7.1	18.2	27.8	2.3	9.6	5.1
R-B Vole	0.0	2.2	2.8	6.8	26.9	10.7	12.0
Tree Vole	4.9	12.7	18.2	2.6	0.0	8.1	0.0
Misc Mammals	9.1	7.7	7.9	11.7	4.8	13.7	9.0
Other	5.2	6.1	6.0	10.1	13.9	7.4	19.5
Totals	100	100	100	100	100	100	100

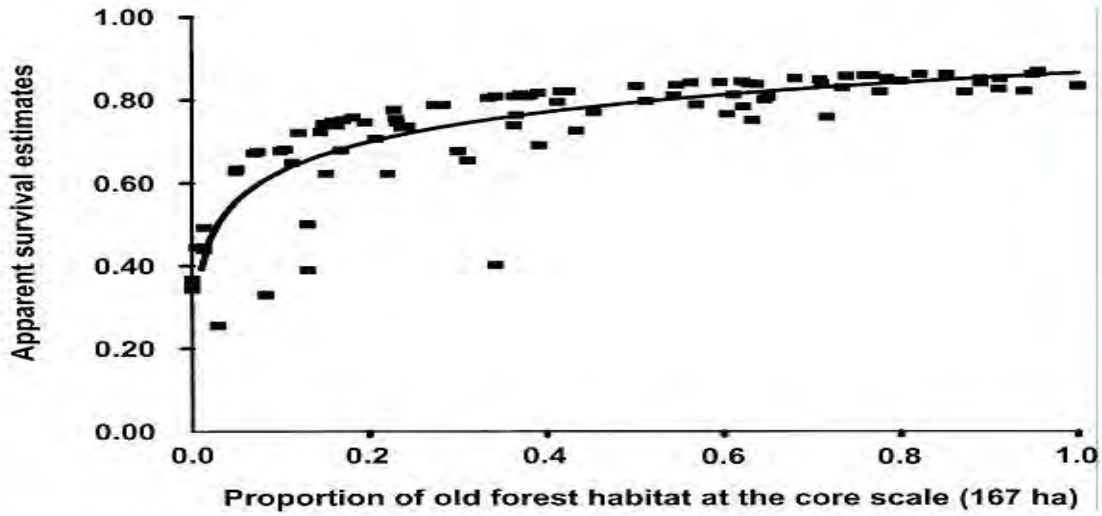

FIGURE 3. Estimates of apparent survival from the best model including the pseudothreshold structure of old forest habitat at the core scale (pt_cOFall) and the mean-centered quadratic form of nonhabitat (q_rNONall) at the ring plotted against the proportion of old forest habitat available at the core scale. Survival estimates were generated for each Northern Spotted Owl territory used in the survival analysis (n = 97) for southern Oregon (1990–1995).

Figure 1. Relationship between survival rates or northern spotted owls and the amount of old forest habitat around their core nesting areas in southern Oregon, 1990-1995 (Dugger et al. 2005).

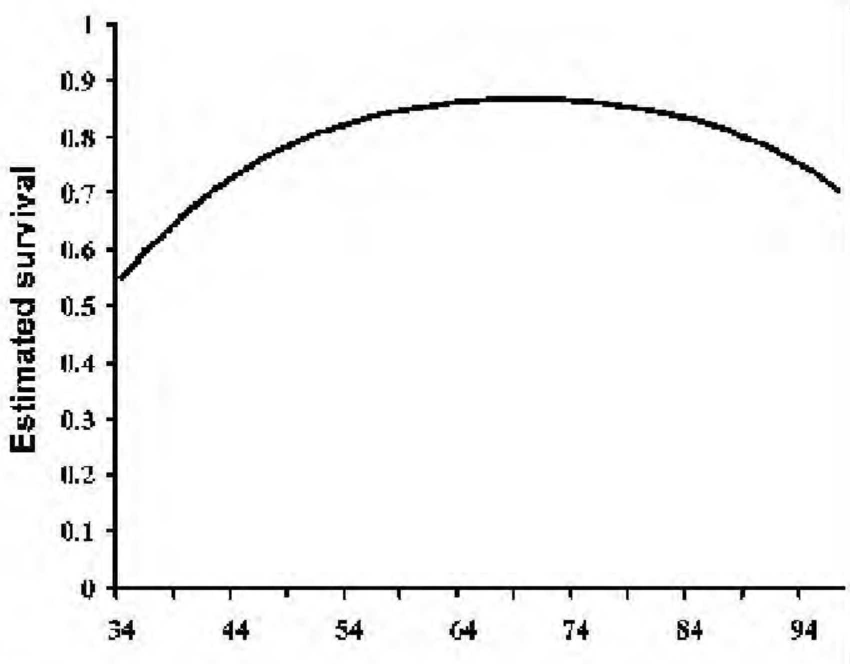

Fig. 2. Estimated survival for northern spotted owls on the Roseburg study area, Oregon, USA, 1988–1999, from the landscape pattern model with percentage of old and mid-seral conifer within a 1,500-m circle centered on owl activity centers.

Figure 2. Relationship between survival rates of northern spotted owls and the percentage of old and mid-seral conifer forests in their activity centers in western Oregon, 1988-1999 (Olson et al. 2004).

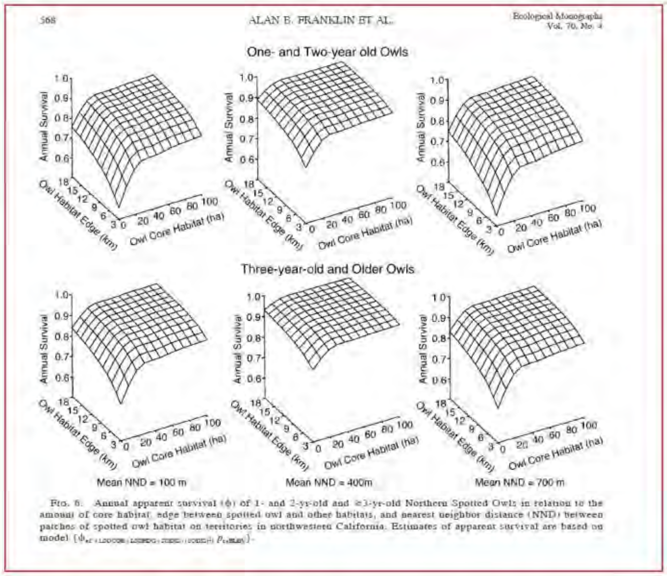

FIG. 6. Annual apparent survival (φ) of 1- and 2-yr-old and ≥3-yr-old Northern Spotted Owls in relation to the amount of core habitat, edge between spotted owl and other habitats, and nearest neighbor distance (NND) between patches of spotted owl habitat on territories in northwestern California. Estimates of apparent survival are based on model {φ[illegible] p[illegible]}.

Figure 3. The relationships between survival rates of breeding spotted owls and the amount of habitat in their core nesting areas in northern California from Franklin et al. (2000).

II. Effects of Riparian Management Strategies on Stream Temperature

Science Review Team Temperature Subgroup

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Background

The Science Roundtable Team (SRT) of technical experts was requested by the Interagency Coordinating Subgroup (ICS) to evaluate models that predict changes in shade and stream temperature as a result of the removal of trees in riparian areas. The management concern is that stream temperature in the summer may increase as a result of riparian management activities and negatively affect coldwater fishes, including salmon, trout, and associated aquatic ecosystems. The area of interest includes conifer forests of the Oregon Coast Range, but the findings of the SRT are intended to be applicable to a broader range of forests in western Oregon and Washington. The ICS requested information on what is known and not known about the effects on shade and water temperature of various riparian management strategies that employ no-cut buffers of various widths and thinning of trees at different intensities. In contrast to the well-documented impacts of clearcuts on shade and stream temperature, the effects of partial cutting and removal of trees in riparian areas have not been well studied and are more difficult to predict than the effects of clearcuts. Mechanistic models that predict changes in stream temperature as a result of increases or decreases in solar radiation provide a foundation for addressing the questions posed by the ICS, and empirical studies provide additional insights into the complexities of applying these models in the field. In this document, we summarize pertinent scientific theory and empirical studies to address the following tasks specified by the ICS:

> *Define the effects of various riparian management strategies on stream function, with a focus on temperature.*
>
> - *Describe effects associated with "no cut" buffers of various widths and alternative thinning regimes (e.g., skips and gaps, different thinning intensities).*
> - *Characterize the distance at which thinning affects downstream temperature.*
> - *Describe how unstable landforms and existing riparian roads can affect the conclusions reached in the above analysis.*

To address the management concerns outlined by the ICS, we focus on stream temperature during the summer when reductions in shade due to the removal of trees could potentially cause increases in the maximum or average daily temperature that exceed the thermal tolerances of aquatic organisms (Beschta et al. 1987). We begin by defining the physical factors that influence the thermal regime of streams, and then we specifically examine the scientific literature that describes the effects associated with alternative riparian management strategies. We then explain the complexities of determining downstream impacts of riparian management strategies in the stream network. We also identify special considerations for evaluating these effects in the context of landslides and roads in riparian areas. Finally, we identify areas of uncertainty that make it difficult to predict the effects of various riparian management strategies without extensive knowledge of factors that are difficult to quantify and expensive to measure in the field.

Factors influencing stream temperature

Stream temperature is influenced by multiple anthropogenic and non-anthropogenic factors that occur above the water surface, in the streambed, within the water column, and in the surrounding landscape (Poole and Berman 2001, Caissie 2006) (**Figure 1**). These factors can be grouped in four general categories: (1) atmospheric conditions, (2) the streambed, (3) stream discharge, and (4) topography (Caissie 2006). The interactions among these factors make predicting changes in stream temperature response to human alteration of the landscape a challenging task, particularly if precise estimates of thermal impacts are required to inform management decisions (Johnson 2003; Hester and Doyle 2011).

Heat exchange processes in streams

The interactions among factors that influence water temperature in streams are complex, but the actual physics of stream heating can be summarized relatively simply as exchanges of energy at the air/water surface and at the streambed/water interface (**Figure 2**). The relative importance of the various heat exchange processes in **Figure 2** varies with respect to the factors identified in **Figure 1**. However, solar radiation is generally the dominant component of the energy budget in terms of heat gain (Moore and Wondzell 2005, Cassie 2006). Inputs of heat energy from solar radiation can be large compared to the losses associated with heat exchange. Therefore, most of the solar energy is stored in the stream, thereby causing an increase in water temperature in a downstream direction. Accordingly, the most efficient method to maintain low stream temperatures is to reduce heat loading from solar radiation. Shade prevents stream warming by reducing inputs of heat energy from solar radiation.

The removal of heat energy from the stream requires heat exchange of the water with the surrounding environment through which energy moves out of the "warm" stream via processes associated with the second law of thermodynamics (i.e., energy travels from high to low concentrations). Inputs of cold water from the streambed, seepage areas on the stream bank, and tributaries can be large components of the net energy budget and can help cool the stream on hot summer days if they are sufficiently large relative to the stream discharge (Wondzell 2012). Energy gained from solar radiation also leaves the stream through long-wave radiation, evaporation, convection (air and water), and conduction (air, water, streambed) (**Figure 1)** (Caissie 2006).

Stream temperature and riparian management strategies

The effects of riparian vegetation on shade and stream temperature have been studied extensively, and it is generally accepted that removing trees in riparian areas reduces the amount of shade which leads to increases in thermal loading to the stream (Moore and Wondzell 2005).

This increase in thermal loading from direct solar radiation after the removal of shade may or may not lead to measurable increases in stream temperature depending on the net effect of the multiple factors described in the following sections.

What are factors are most relevant?

We focus on shade and the factors that influence its spatial extent, temporal duration, and quality. The primary factors that influence shade are riparian vegetation (Groom et al, 2011b) and the surrounding terrain (Allen et al. 2007). Note that riparian vegetation, upland shading, and aspect (i.e., stream orientation) are grouped under the general category of topography because both trees and the surrounding landscape constitute vertical structure that affects the transmission of solar radiation to the stream (**Figure 1**). We also consider (1) the physical characteristics of the stream itself and how they affect heat flux at the water surface, and (2) the role of direct transfer of energy to and from the stream through groundwater, tributary inflow, and hyporheic exchange.

Why are these factors important?

Although many other factors affect stream temperature (**Figure 1**), we focused on (1) shade, (2) heat flux at the water surface, and (3) groundwater–surface water interactions because these factors are often directly associated with riparian management activities (Webb et al. 2008). Other factors are not addressed because (1) they are difficult to measure in the field and incorporate into predictive models, and (2) they compose a relatively small part of the heat budget in the streams that are most likely to be encountered in the forested landscapes pertinent to this report (Johnson 2003).

Shade in riparian areas

In order to assess the ability of riparian vegetation to create effective shade over a stream, three characteristics of the “shade” need to be evaluated: (1) spatial extent, (2) temporal duration, and (3) quality. Shade spatial extent is the spatial area over which a shadow is cast over a stream. Shade temporal duration is the length of time during which a portion of stream is shaded. Shade quality is a function of the canopy density (including the stems), where lower canopy density is associated with lower shade quality. The removal or modification of trees in riparian areas can affect the spatial extent, temporal duration, and quality of shade on a stream.

Vegetation height and topography

The height of the vegetation directly influences the spatial extent of shade. On flat ground, the distance over which a tree can cast a shadow during the summer in the Pacific Northwest varies from approximately 50-200% of the tree height, depending on the time of day (see discussion below on temporal variability). Depending on sun angle and tree height, there is a threshold distance from the stream at which shadows from even the tallest trees will no longer reach the stream from mid-day to late afternoon when thermal loading from solar radiation is greatest. Wherever streambanks are higher than the stream, the effective height of vegetation includes not just the height of the tree but also the elevation of its base above the stream. Thus, shadow length is longer for vegetation located on streambanks above the stream. In steep, narrow headwater catchments, a large proportion of shade may be created by topographic relief alone; however, at broader scales, and at most locations within a watershed, the largest component of shade is typically derived from riparian vegetation (Allen et al. 2007, Allen 2008). Because shade conditions in streams are a function of shade produced by the vegetation and shade produced from topography, both factors must be considered in evaluating potential effects of removing trees in riparian areas.

Density of vegetation

The density of vegetation in riparian areas affects shade and thermal loading to a stream due to the penetration of solar radiation through gaps in the canopy and among the branches and stems (Brazier and Brown 1973, DeWalle 2010). Riparian stands with few trees and low canopy and branch density reduce shade quality. The removal of vegetation through "thinning" activities results in an initial lowering of the vegetation density in the riparian stand. In low-density stands (i.e., more open stands), wider buffers can compensate for decreased canopy density and help achieve the same shade quality as would be achieved given similar vegetation with a closer spacing of trees.

Width of buffer

The width of the band of vegetation along the stream bank influences the amount of solar radiation that reaches the stream. Wide buffers create more shade than narrow buffers, as measured by angular canopy density (Brazier and Brown 1973, Wooldridge and Stern 1979, Steinblums et al. 1984, Beschta, et al. 1987). However, there is a high degree of variability in this relationship, particularly at narrower buffer widths where the effect on shade is greatest. For instance, data from Brazier and Brown (1973) and Steinblums et al. (1984) indicate that a 15-m buffer width might provide anywhere from 18 to 80% shading (**Figure 3**). In addition, these studies also showed that 75-90% shade can be achieved with a wide range of buffer widths, ranging from approximately 9 to 43 m. The high variability in buffer width and shade condition is a function of the many variables that influence the amount of shade produced by riparian vegetation. As described above, low-density stands with limited vertical distribution of branches and foliage may require wider buffer widths to produce the same amount of shade as high-density stands.

Temporal variability

Shade duration is dependent on day of the year and the height and distance at which the shade-producing feature is located from the stream. Shade duration can be calculated based on physical attributes of the tree (i.e., height and distance to stream) and the location of the sun in the sky, which varies daily and seasonally, and the azimuth of the stream. The intensity of solar radiation on the surface of the earth also varies daily and seasonally based on the vertical angle of the sun in the sky. The shadow length from riparian vegetation is the shortest at mid-day when the sun is high in the sky, and the shadow length increases during other parts of the day as the sun is lower in the sky. In the Pacific Northwest, the greatest amount of energy generally occurs between the hours of 10:00 to 14:00 and in July and August (Beschta et al 1987). However, heat loading from solar radiation during other periods of the day constitutes a significant part of the energy budget (~40%) and therefore is influential on stream temperature. Tools that are typically used to measure and model solar radiation incorporate both the surrounding topography (e.g., aspect and elevation) as well as daily and seasonal variation (Moore et al. 2005, Allen et al. 2007, Boyd and Kasper 2003). These methods provide estimates of total shortwave energy for a given day or time period. Such estimates of total shortwave energy are necessary in order to compare the thermal impacts of riparian management scenarios.

Stream channel dimensions and heat flux at the water surface

The effect of solar radiation at the stream surface on water temperature depends on stream width, and depth, and the flow velocity (Beschta et al. 1987, Sullivan et al. 1990). For a given stream discharge, a shallower, wider stream will heat up faster than a deeper, narrower stream, so it is important to consider the morphology of the channel itself in determining the potential effects of increased solar radiation resulting from riparian management strategies. Furthermore, the exchange of heat energy to the stream from solar radiation depends on the length of stream that is exposed and the time that it takes for water to pass through that area (i.e., a function of velocity). The shadow length associated with a short tree might be sufficient to "cast a shadow" over a narrow stream channel, but this same tree may be insufficient to shade a wider stream channel. Accordingly, stream width is an important factor to consider in determining thermal loading associated with a particular riparian stand.

Groundwater and surface water interactions

Groundwater inputs, tributary inflow, and hyporheic exchange can directly influence stream temperature because they involve advective transfer of relatively cool or warm water to the stream. The size of the effect is a function of the amount of water entering (or exchanged with) the stream relative to the stream discharge (Johnson and Jones 2000, Story et al. 2003, Wondzell 2006, Wondzell 2012) and the difference in temperature between the stream and the inflowing water. For example, small amounts of cold water can have large effects on stream temperature in warm streams if they are large relative to the size of the receiving stream's discharge or if they are very cold relative to the receiving stream's temperature. Such cold-water inputs can be distinct point sources (e.g., groundwater seeps), or they can be diffuse (e.g., hyporheic exchange) (Poole and Berman 2001; Poole et al. 2001, Wondzell 2012). If the net effect of these inputs over a given stream distance is large relative to the stream discharge, they can have significant effects on downstream reaches. Thus, the magnitude of temperature response associated with riparian management is directly related to these processes, which can either increase or decrease stream temperature.

Effects associated with riparian management strategies

Removal of trees in riparian areas increases shortwave thermal loading to streams through its effects on (1) shade quality (i.e., thinning of the stand to reduce the stand density), and (2) shade temporal duration (i.e., reducing the average vegetation height as a result of thinning from "above") (Groom et al 2001b). The specific shade response to tree removal depends on pre-harvest vegetation, including its composition, structure, and location relative to the stream, and on the number and location of trees that are removed. Therefore, specific trends described below only provide *approximate* guidelines of shade conditions associated with various buffer conditions given the variability of conditions in the forests pertinent to this report. In addition, the effects of riparian management on stream temperature are even more variable (Moore et al. 2005a, Moore et al. 2005b, Moore and Wondzell 2005, Janisch et al. 2012).

No-cut buffers adjacent to clearcut harvest units

Substantial effects on shade have been observed with "no-cut" buffers ranging from 20 to 30 m (Brosofske et al. 1997, Kiffney et al. 2003, Groom et al. 2011b), and small effects were observed in studies that examined "no-cut" buffers 46 m wide (Science Team Review 2008, Groom et al. 2011a). For "no-cut" buffer widths of 46-69 m, the effects of tree removal on shade and temperature were either not detected or were minimal (Anderson et al. 2007, Science Team Review 2008, Groom et al. 2011a, Groom et al. 2011b) (**Figure 4**). The limited response observed in these studies can be attributed to the lack of trees that were capable of casting a shadow >46 m during most of the day in the summer (Leinenbach 2011; Appendix C of this document). Reductions in shade and increases in stream temperature were more apparent at ~30 m "no-cut" buffer widths, as compared to the 46-69 m wide buffers, but the magnitude and direction of response was highly variable for both shade and stream temperature (Kiffney et al. 2003, Gomi et al. 2006, Science Team Review 2008, Groom et al. 2011a, Groom et al. 2011b). At "no-cut" buffer widths of <20 m, there were pronounced reductions in shade and increases in temperature, as compared to wider buffer widths. The most dramatic effects were observed at the narrowest buffer widths (≤10 m) (Jackson et al. 2001, Curry et al. 2002, Kiffney et al. 2003, Gomi et al. 2006, Anderson et al. 2007).

Thinning in riparian buffers adjacent to clearcut harvest units

Reductions in shade and increases in stream temperature were associated with thinning activities occurring within riparian buffers, along with the narrowing of the buffer (Mellina et al. 2002, Macdonald et al. 2003, Wilkerson et al. 2006, Science Team Review 2008, Kreutzweiser et al. 2009) (**Figure 5**). However, the response varied from no effects to large effects which appeared to be related to differences in the intensity of thinning, with stronger effects associated with higher thinning intensities. However, the limited number of studies that have specifically evaluated thinning in riparian buffers makes it difficult to generalize, particularly given the many different possible combinations of thinning intensity and buffer width.

No-cut buffers adjacent to thinning harvest units

The width of the inner "no-cut" riparian buffer was shown to affect the potential consequences of thinning in the "outer" buffer regions, with wider "no-cut" buffers resulting in lower reductions in stream shade conditions (Anderson et al. 2007, Science Team Review 2008, Park et al 2008) (**Table 1**). In addition, the canopy density of the inner "no-cut" buffer zone appeared to have an ameliorating effect on thinning activities within the "outer" thinning buffer zone, with higher "protection" associated with greater canopy densities in the inner zone. Finally, higher residual vegetation densities within the "outer" thinning zone were shown to result in less shade loss. Once again, the limited number of studies that have specifically evaluated these buffer conditions make it difficult to generalize, particularly given the many different possible combinations of thinning intensity, buffer widths, and stream sizes.

Other associated effects

Secondary effects of thinning in riparian areas can potentially reduce shade and potentially lead to increases in stream temperature. For example, trees that are left after thinning may be vulnerable to blowdown (Chan et al. 2006), which has been shown to decrease shade and increase stream temperatures (MacDonald et al. 2003). Similarly, “no-touch” riparian buffers have also been shown to be vulnerable to windthrow following harvest activities (Jackson et al. 2007), resulting in much lower stream shade conditions (Schuett-Hames et al. 2011). Windthrow effects can be long term. For example, windthrow was shown to impede the “recovery” of stand density (i.e., shade conditions) for over eight years following both “heavy” and “moderate” thinning treatments (Curtis Relative Density [RD] of 8.3 and 16.0, respectively), but recovery was observed over the same period in “lightly” thinned stands (RD of 27.8). Secondary effects of thinning and associated road building on microclimate, sediment loads to the stream, and subsurface drainage patterns adjacent to riparian areas are poorly understood but may influence advective transfer and heat exchange in water that enters the stream as shallow groundwater (Story et al. 2003, Brosofske et al. 1997, Anderson et al. 2007).

Potential downstream effects

The spatial extent to which riparian management affects stream temperature downstream of harvest units depends on the spatial context of the stream reach in terms of hydrology and geomorphology and how these factors interact in the stream heat budget (Poole et al. 2001, Johnson 2003). For example, in stream reaches with cold tributary inflows and groundwater inputs that constitute a large percentage of the stream discharge (i.e., “gaining” reaches), the distance may be short to bring the temperature back down to what it would have been prior to the reduction in shade resulting from the removal of trees (Story et al. 2003). Similarly, reaches with extensive hyporheic exchange (Wondzell 2006, Wondzell 2012) via the streambed and floodplain may show no effects of increased solar radiation on stream temperature (Janisch et al. 2012). In contrast, bedrock-dominated stream channels are likely to require very long recovery distances because they are not buffered by hyporheic exchange (Johnson and Jones 2000). Thus, it is not possible to characterize the exact distance at which thinning activities will affect downstream temperature without accounting for all of the factors that influence stream temperature. However, the rate of heat loss via convection and evaporation at the surface of small streams is very slow, as compared to the heat exchange rate associated with solar radiation loading. Therefore, the heat added to a stream by the sun will not be readily dissipated, and the distance over which elevated temperatures may extend downstream may be much longer than the length of the “treatment”.

Considerations for unstable landforms and existing roads

In riparian areas with unstable landforms and existing roads, precautions are necessary to ensure that enough shade will be available in the event of future landslides that could remove forest vegetation and reduce shade on the stream. Thus, the removal of shade needs to be evaluated on the basis of how much shade is currently present because further riparian management activities in a “disturbed” stand can have a larger impact on shade conditions than what would be expected from the same level of disturbance in an “undisturbed” stand (Chan et al. 2004b). Disturbed stands that have been subjected to tree removal before thinning activities may already have low canopy density, and hence already provide limited shade. Furthermore, the removal of trees on unstable slopes may lead to increased vulnerability of neighboring trees to windthrow and landslides, which both can lead to reductions in shade and potential increases in stream temperature (Pollock et al. 2009). All kinds of landslides can topple and remove trees and, therefore, have the potential to reduce canopy density and shade (Oregon Department of Geology and Mineral Resources 2008). Debris flows are also of concern because they often remove stream- adjacent trees, alluvium, wood and soil along the debris flow track, creating a wide, shallow and generally featureless bedrock channel. Riparian shade is removed, the growth of future stream-adjacent trees is inhibited because soil is lacking, the cooling effect of hyporheic exchange is minimized because there is no alluvium, and the potential for future accumulations of alluvium is reduced because there is little large wood in the system to retain alluvium, and there are no large riparian trees to provide large wood (Montgomery 1997, Pollock et al. 2009). Depositional areas from debris flows also have the potential to inundate riparian floodplain forests with water and sediment and cause increased tree mortality. Thus, where debris flows and landslides have occurred, the effects on stream temperature may last for centuries.

Although estimates of impacts of thinning near existing roads and unstable landforms need to be conservative to account for potential future losses of shade, it may be very difficult to weigh the advantages and disadvantages of such thinning activities within the broader context of landscape disturbance and its role in aquatic ecosystems (Reeves et al. 1995, Montgomery 1997). For example, landslides and debris flows can reduce shade, but may provide large accumulations of wood and sediment, which can have variable effects on stream geomorphology, depending on the location and condition of the pre-existing habitat where deposition occurs (May and Gresswell 2003). Thus, in the context of landscape management, there are multiple physical effects of landslides and debris flows that need to be considered, and these effects vary with landscape position.

What is not known or uncertain

Extensive research on the effects of forest management on shade and stream temperature provides a foundation for predicting the effects of thinning in riparian areas. However, because the effects of thinning are lesser in magnitude compared to complete removal of riparian vegetation, landscape context (e.g., geology, geomorphology, and hydrology) plays a greater role and can make it more difficult to determine cause and effect (Thompson 2005). Furthermore, thinning may occur at different intensities and in various spatial configurations which may be difficult to model and evaluate experimentally.

There are no examples of studies in the literature on the effects of riparian thinning on stream temperature that match the specific characteristics of management activities likely to occur in riparian areas on federal forest lands. Field studies that can address these challenges may require watershed-scale, long-term manipulative experiments to detect effects over spatial and temporal scales that are relevant to the ecological, hydrological, and geomorphological processes of interest. However, shorter-term studies that evaluate potential effects of thinning intensity and buffer width on shade and stream temperature can be conducted by substituting space for time (Pickett 1989) in which sites representing a wide range of thinning intensities and buffer widths are examined in relation to the relative amounts of shade that they produce. Although the results of such studies cannot elucidate causal relationships, they would still provide a foundation for evaluating potential downstream cooling distances in riparian areas under various thinning scenarios. These field studies could be designed to test hypotheses about where downstream cooling distances would be expected to be long or short. Recently available technologies such as lidar remote sensing, thermal IR remote sensing, and distributed temperature sensing could be used to better quantify shade and evaluate stream temperature response to various thinning treatments (Lutz et al. 2012, Torgersen et al. 2012).

Spatially explicit models and landscape analysis tools that consider many different factors at multiple spatial and temporal scales may be used to evaluate potential cumulative effects of riparian management scenarios (Cissel et al. 1999, Benda et al. 2007). However, these landscape analysis tools need to be better integrated with stream temperature models (see Allen et al. 2007). Many different models exist for predicting stream temperature response to changes in shade; for descriptions of these models and their relative strengths and weaknesses, see Caissie 2006, Allen et al. 2007, Chapter 2 in Allen 2008, Webb et al. 2008, and Torgersen et al. 2012. The most commonly applied stream temperature model in western Oregon is HeatSource (Boyd and Kasper 2003), which was developed by the Oregon Department of Environmental Quality and the U.S. Environmental Protection Agency. This model has been used effectively to evaluate effects of shade on water temperature in streams of various sizes and types, and it is currently the most accessible stream temperature modeling tool for land managers because of the availability of technical support from government agencies. A limitation of HeatSource and most other stream temperature models is that they require data on the physical and hydrological characteristics of the stream (width, depth, and velocity) which may be difficult to acquire in the field, particularly in forested streams that may be inaccessible due to dense vegetation, steep topography, and a lack of roads.

Another modeling tool that is increasingly used by federal forest managers is NetMap (Benda et al. 2007; www.netmaptools.org). It is important to note, however, that NetMap does not predict stream temperature; it provides information only on spatial variability of thermal loading as a function of shade from trees (based on tree height and buffer width) and/or the surrounding topography. NetMap has immense potential for evaluating the potential effects of riparian thinning on thermal loading across landscapes; however, these predictions may be limited by the data on forest structure (i.e., stem and canopy density) and topography (e.g., digital elevation models) on which the model is based (see Appendix D on the appropriate use of geospatial data and models in resource management). It is possible that tools such as NetMap will provide more precise estimates of thermal loading based on lidar-derived high-resolution measurements of forest structure and topography; however, these datasets are not widely available. Field studies are needed to "ground-truth" NetMap predictions of thermal loading in varied landscape settings and with different spatial scales of forest structure and topographic data (e.g., 1-5-m lidar data versus 10- and 30-m digital elevation models).

Field studies as well as the spatially explicit modeling and landscape analysis tools described above are needed to address the following uncertainties associated with predicting the effects of thinning in riparian areas on shade and stream temperature:

Effects of thinning intensity and "skips and gaps"

The intensity of thinning activities has an impact on the amount of shade produced by the riparian stand. Thinning from "below" (i.e., removing small trees) primarily affects shade quality by increasing the transmission of solar radiation from the side, whereas thinning from "above" by removing large trees that cast long shadows most likely affects both shade quality and duration. Implementing a "skips and gaps" thinning scheme (i.e., leaving patches of undisturbed riparian forest along the stream) may reduce shade conditions and potentially increase stream temperature; however, this scenario may have less of an impact if the cut patches are located farther away from the stream. Additional field studies and spatially explicit modeling in a variety of forest and hydrological settings are needed in this area.

Groundwater and hyporheic exchange

Tools and techniques for measuring the vertical and horizontal structure of forest vegetation and the underlying ground surface are advancing rapidly (e.g., ground-based and airborne lidar), and it is likely that within the next decade, it will be possible to develop highly detailed shade models for entire small watersheds. Such information may solve many of the problems associated with measuring the transmission of solar radiation through the forest to the stream. However, the most significant challenge to predicting the effects of thinning in riparian areas is the lack of information on processes below the water surface and in the floodplain. This problem has been addressed in modeling of stream temperature in larger rivers by using remote sensing of water temperature to identify thermal anomalies associated with groundwater and surface water interactions which then can be incorporated into a spatially explicit stream temperature model (Boyd and Kasper 2003). Unfortunately, airborne remote sensing of water temperature is not possible in small forest streams where dense overhanging vegetation may block the view of the stream. Thus, in these streams, it will be necessary to use in situ methods and hydrologic modeling to quantify thermal heterogeneity in water temperature associated with groundwater inputs and hyporheic exchange. With the recent dramatic improvements in stream temperature sensor technology (e.g., mobile probes and temperature-sensitive fiber-optic cable), it is now possible to quantify thermal heterogeneity in small streams at relatively low cost. These new techniques are capable of mapping stream temperature at a fine spatial resolution (1 m) over several kilometers and can be used to improve the accuracy and precision of (1) models that predict potential effects of riparian thinning on stream temperature and (2) monitoring of water temperature in response to riparian forest management.

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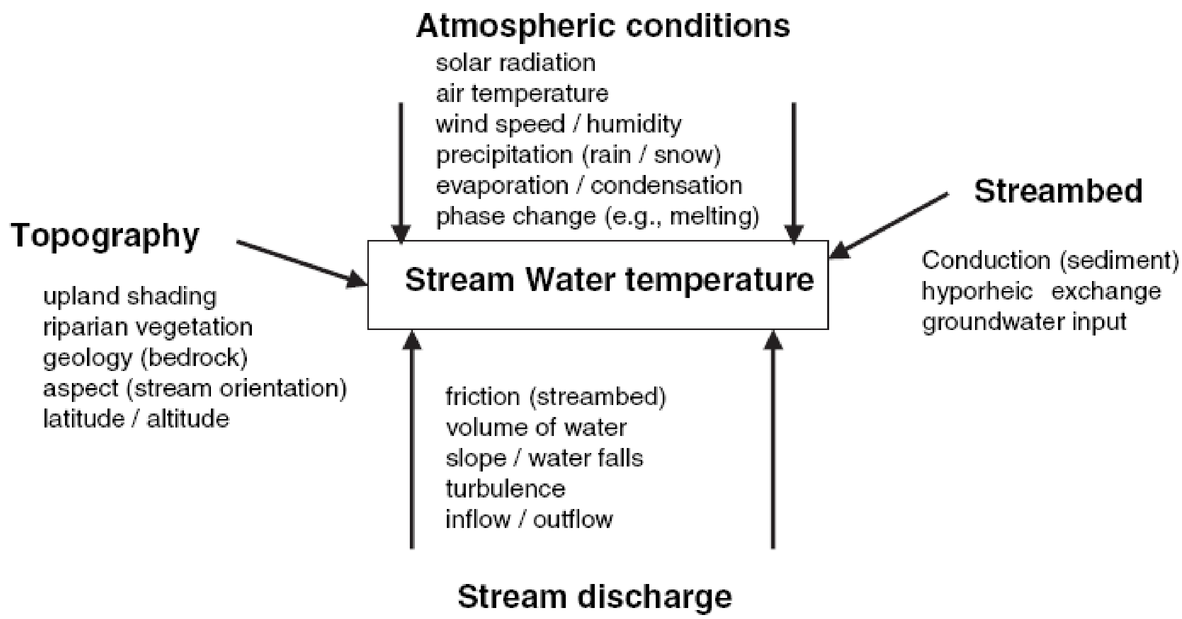

Figure 1. Factors influencing the thermal regime of rivers and streams (Caissie 2006).

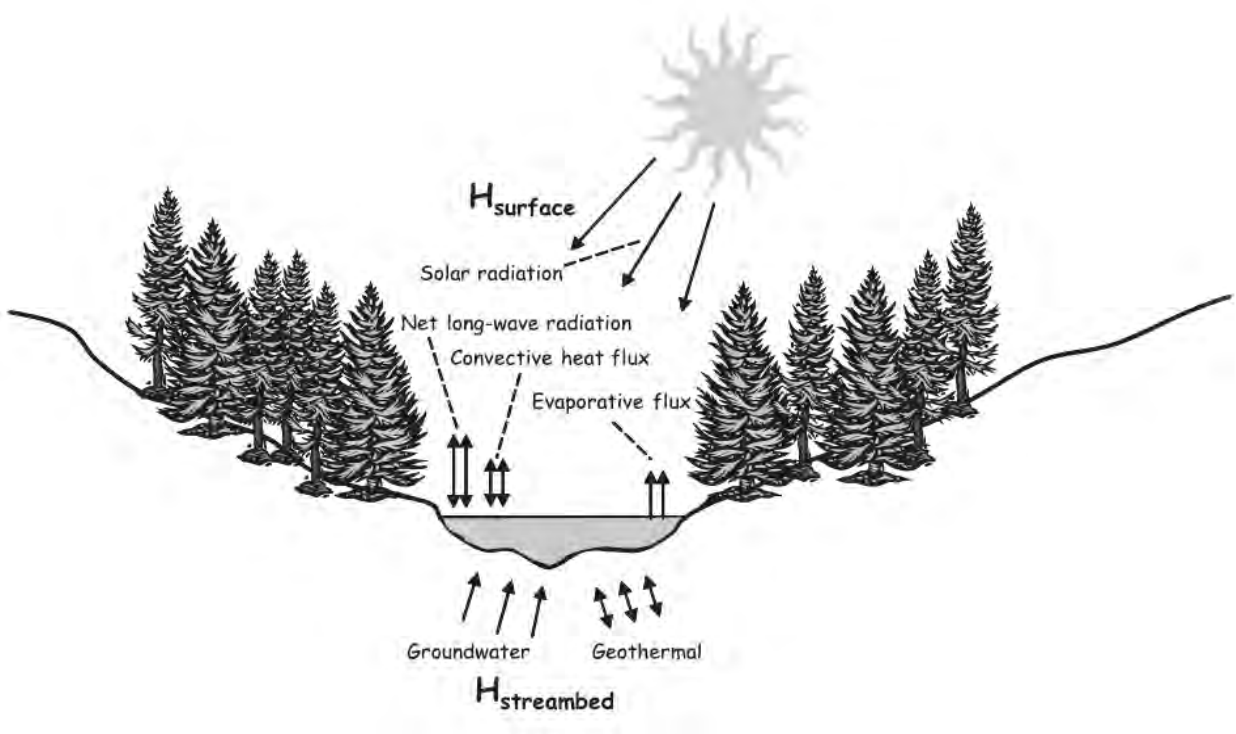

Figure 2. River and stream heat exchange processes (Caissie 2006).

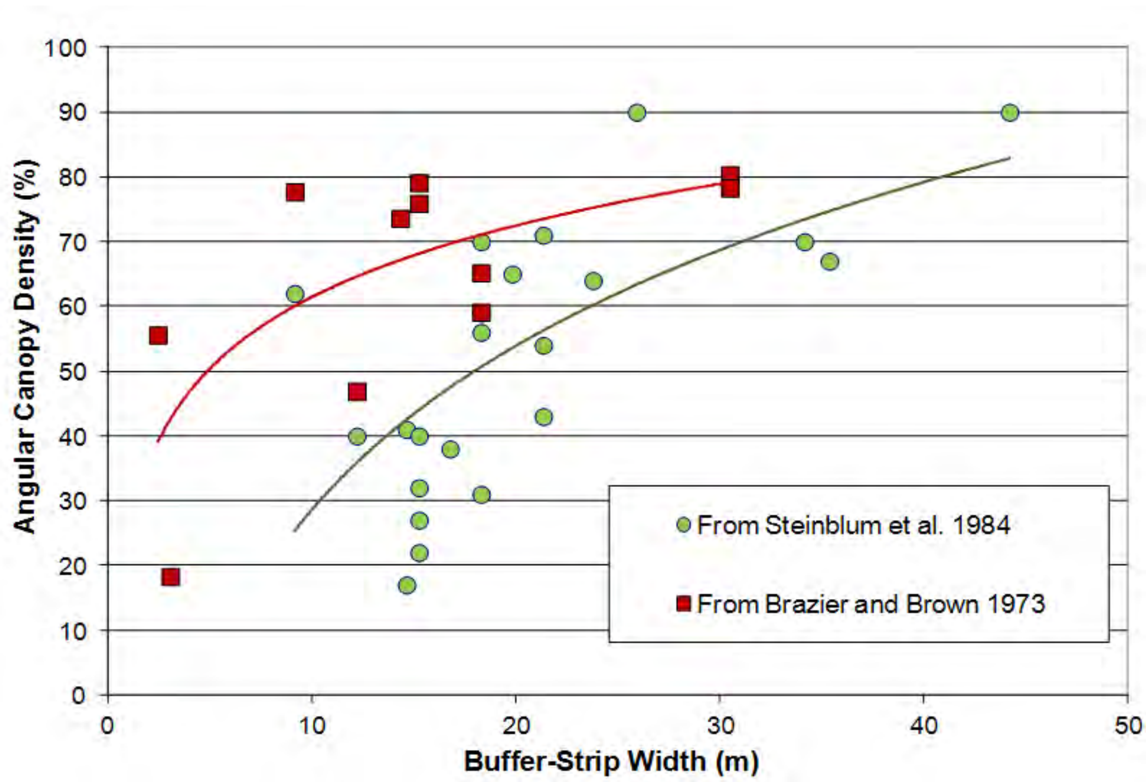

Figure 3. Relationship between angular canopy density (ACD) and riparian buffer width.

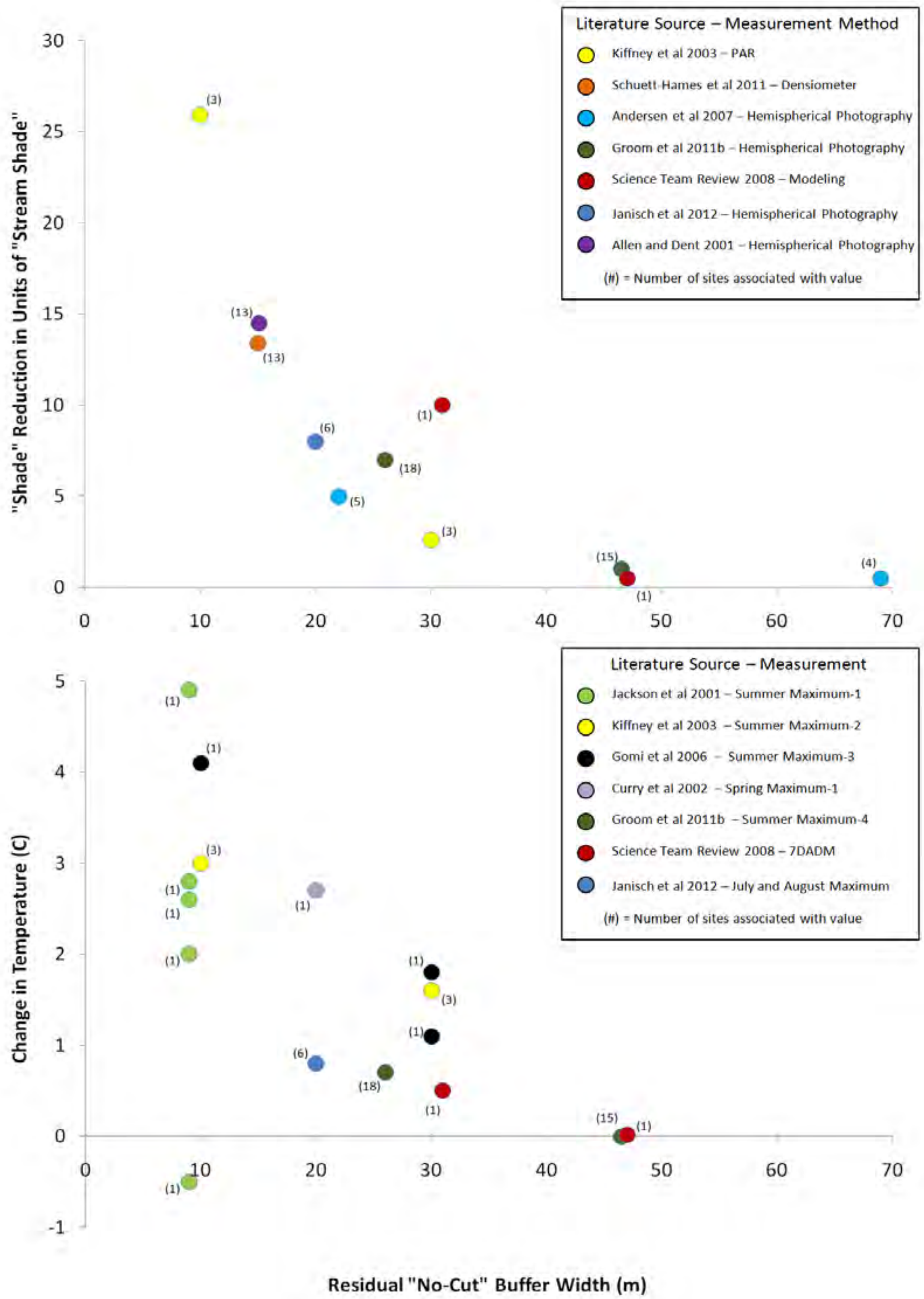

Figure 4. Observed "shade" and temperature response associated with "no-cut" riparian buffers with adjacent clearcut harvest. Note that many of these studies evaluated correlates of shade (e.g, canopy density) as opposed to direct measurements of shade. Corresponding references and measurement methods and types are listed in the legend. Abbreviations: PAR = photosynthetically active radiation; 7DADM = seven-day moving average of daily maximum temperature.

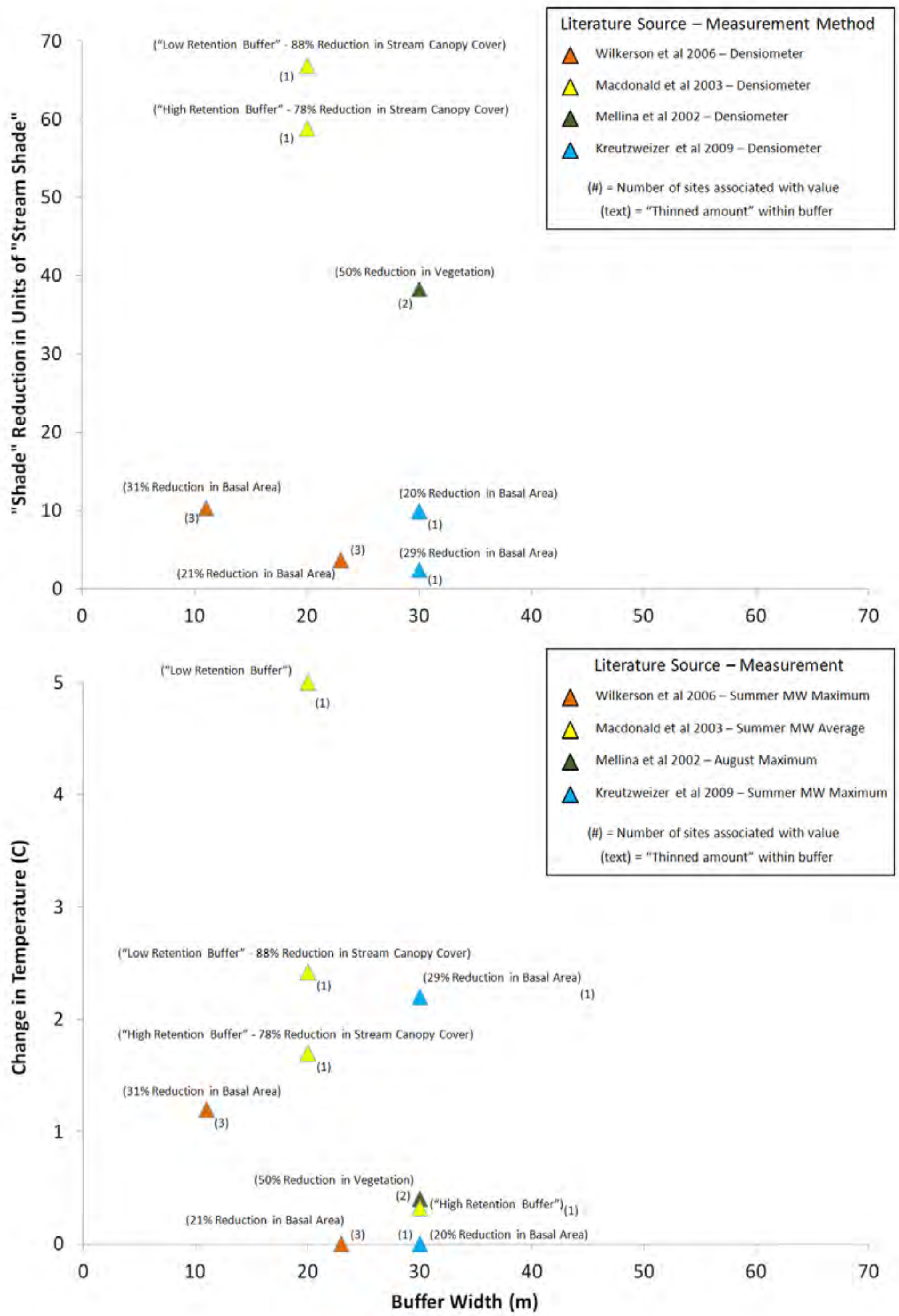

Figure 5. Observed "shade" and temperature response associated with "thinned" riparian buffers with adjacent clearcut harvest. Corresponding references and measurement methods and types are listed in the legend. Abbreviation: MW = mean weekly.

Table 1. Observed shade and temperature response associated with "no-cut" buffers adjacent to "thinned" harvest units.

Total distance (m)	Inner "No-touch" zone distance (m)	Inner "no-touch" zone stand condition	Outer "thinned" zone distance (m)	Thinning target	Resulting units of "shade" reduction	Resulting temperature change (°C)	Number of sites	Source
120	22	500-750 tph	98	198 tph	≈ 2.5% Open Sky	Not Measured	4	Anderson et al. 2007
120	9	500-750 tph	111	198 tph	5% Open Sky	Not Measured	5	Anderson et al. 2007
46	18	65-80% CC	27	50% CC	4 ES	0.2 7DADM	1	ODEQ Memorandum 2008
31	18	65-80% CC	12	50% CC	12 ES	0.6 7DADM	1	Science Team Review 2008
55	24	530 tph	31	321 tph	-0.9 and 0.7 ACD [1]	Not Measured	1	Park et al. 2008
55	18	530 tph	37	321 tph	-0.3 and 0.2 ACD	Not Measured	1	Park et al. 2008
55	12	530 tph	43	321 tph	1.8 and 2.0 ACD	Not Measured	1	Park et al. 2008
55	6	530 tph	49	321 tph	2.9 and 9.3 ACD	Not Measured	1	Park et al. 2008

Abbreviations: tph = trees per hectare; CC = riparian canopy cover (planar view); 7DADM = seven day moving average of daily maximum stream temperature; ACD = angular canopy density.
[1] Harvest activities occurred on only one stream bank in this study (Park et al. 2008), whereas the other studies had harvest activities on both stream banks. Accordingly, a doubling of the "shade" results associated with Park et al. (2008) would allow for a more direct comparison of results with the other studies.

Metric conversions

Meters	Feet	Meters	Feet	Meters	Feet	Meters	Feet
1	3	34	112	67	220	**100**	**328**
2	7	35	115	68	223	101	331
3	10	36	118	69	226	102	335
4	13	37	121	**70**	**230**	103	338
5	16	38	125	71	233	104	341
6	20	39	128	72	236	105	344
7	23	**40**	**131**	73	239	106	348
8	26	41	134	74	243	107	351
9	30	42	138	75	246	108	354
10	**33**	43	141	76	249	109	358
11	36	44	144	77	253	**110**	**361**
12	39	45	148	78	256	111	364
13	43	46	151	79	259	112	367
14	46	47	154	**80**	**262**	113	371
15	49	48	157	81	266	114	374
16	52	49	161	82	269	115	377
17	56	**50**	**164**	83	272	116	380
18	59	51	167	84	276	117	384
19	62	52	171	85	279	118	387
20	**66**	53	174	86	282	119	390
21	69	54	177	87	285	**120**	**394**
22	72	55	180	88	289	121	397
23	75	56	184	89	292	122	400
24	79	57	187	**90**	**295**	123	403
25	82	58	190	91	298	124	407
26	85	59	194	92	302	125	410
27	89	**60**	**197**	93	305	126	413
28	92	61	200	94	308	127	417
29	95	62	203	95	312	128	420
30	**98**	63	207	96	315	129	423
31	102	64	210	97	318	**130**	**426**
32	105	65	213	98	321	131	430
33	108	66	216	99	325	132	433

Appendix A – Synopsis of Literature Describing the Effects of Riparian Management on Stream Shade and Stream Temperature

Peter Leinenbach - USEPA Region 10

Included in this literature review were original studies conducted on forest lands that used a BACI (Before-After/Control-Impact) design to investigated the effects of riparian buffers on stream shade and temperature conditions. Specifically, studies that included monitoring of both before and after treatment, and studies with untreated control sites were included in this review. In addition, only studies with a defined riparian buffer were included in the review; That is, studies that only investigated the effects of clearcut harvest up to the stream's wetted edge. Finally, only studies that described forested conditions in North America (i.e., latitude between 40^{o}N and 55^{o}N), with an emphasis on streams in the Pacific Northwest, were included in this effort.

This appendix is separated into three sections.

The first section lists the individual studies included in this synopsis. The studies are grouped into four categories based on: (1) field studies; (2) field studies with "warm" headwater conditions; (3) stream shade and stream modeling studies; and (4) riparian management studies (i.e., these studies did not emphasize effects on stream shade and water temperature response).

The second section lists stream shade and temperature response reported in these studies. The information is presented in tables and it is categorized into three groups: (1) "No-cut" riparian buffer adjacent to clearcut harvest units; (2) Thinned riparian buffer adjacent to clearcut harvest units; and (3) "No-cut" riparian buffer adjacent to thinned riparian harvest units.

The third sections presents results associated with group 4 listed above (i.e., riparian management studies).

Section One – Listing of Studies

The studies are grouped into four groups.

The **first group** of studies are ***field efforts*** which investigated stream shade and temperature responses resulting from harvest activities at various "no-cut" buffer widths and thinned buffer regimes.

Group 1

1.1 - Variable Buffer Widths and Water Quality – Ripstream Project – 1
Groom J. D., L. Dent, L. and Madsen. 2011a. Stream temperature change detection for state and private forests in the Oregon Coast Range. *Water Resources Research* 47

1.2 - Variable Buffer Widths and Water Quality – Ripstream Project – 2
Groom J. D., L. Dent, L. Madsen, J. Fleuret. 2011b. Response of western Oregon (USA) stream temperatures to contemporary forest management. *Forest Ecology and Management* 262(8):1618–1629.

1.3 - Vegetation Buffers and Water Quality – Coast Range of Washington Study
Jackson, C.R., C.A. Sturm, and J.M. Ward. 2001. Timber harvest impacts on small headwater stream channels in the Coast Ranges of Washington. *JAWRA* 37(6):1533–1549.

1.4 - Variable Buffer Widths and Water Quality – Malcolm Knapp Research Forest Study – 1
Kiffney, P. M., J. S. Richardson, J. P. Bull. 2003. Responses of periphyton and insect consumers to experimental manipulation of riparian buffer width along headwater streams. *Journal of the American Water Resources Association* 40:1060-1076.

1.5 - Variable Buffer Widths and Water Quality – Malcolm Knapp Research Forest Study – 2
Gomi T., D. Moore, and A.S. Dhakal. 2006. Headwater stream temperature response to clear-cut harvesting with different riparian treatments, coastal British Columbia. *Water Resour. Res.* 42:W08437.

1.6 - Variable Buffer Widths and Water Quality – Westside Type N Buffer Study – CEMR
Schuett-Hames., D., A. Roorbach, and R. Conrad. 2011. Results of the Westside Type N Buffer Characteristics, Integrity and Function Study – CEMR Final Report. December 14, 2011 cc

1.7 - Variable Buffer Widths and Water Quality – Rogue River Siskiyou National Forest Study
Park., C., C. McCammon, and J. Brazier. 2008. Draft Report - Changes to Angular Canopy Density from Thinning with Varying No Treatment Widths in a Riparian Area as Measured Using Digital Photography and Light Histograms.

1.8 - Variable Buffer Widths/Thinnings and Water Quality – Stuart-Takla Study
Macdonald, J.S., E.A. MacIsaac, and H.E. Herunter. 2003. The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. *Can. J. For. Res*. 33(8): 1371–1382.

1.9 - Variable Buffer Widths/Thinnings and Water Quality – Western Maine Project
Wilkerson E., J.M. Hagan, D. Siegel, and A.A. Whitman. 2006. The Effectiveness of Different Buffer Widths for Protecting Headwater Stream Temperature in Maine. *Forest Science* 52(3):221–231.

1.10 - Vegetation Buffers and Water Quality – Washington Headwater Stream Study

Janisch J.E., S.M. Wondzell, and W.J. Ehinger. 2012. Headwater stream temperature: Interpreting response after logging, with and without riparian buffers, Washington, USA. *Forest Ecology and Management* doi:10.1016/j.foreco.2011.12.035.

1.11 - Vegetation Buffers and Water Quality – Oregon Department of Forestry Stream Shade Study

Allen M., and L. Dent. 2001. Shade Conditions Over Forested Streams In the Blue Mountain and Coast Range Georegions of Oregon – ODF Technical Report #13.

The **second group** is similar to the first group except that the headwater condition associated with these studies were dramatically influenced by "warm" water sources as a result of lakes, ponds and/or impoundments. Accordingly, the elevated headwater temperature resulted in a "cooling" effect in the pre-harvest stream reach as the river re-entered forested conditions (i.e., in these forested areas there was high levels of shade, and potentially cool ground water). In other words, the effects of the harvest activities are "muted" by the natural occurring "cooling" phenomenon within these reaches. Thus, caution should be used to compare the relative magnitude of effects associated with harvest activities with this group and that with Group 1 study results.

Group 2

2.1 - Riparian Thinning with "Warm" Headwater Conditions – North Central B.C. Project

Mellina. E., R.D. Moore, S.G. Hinch, J. S. Macdonald. 2002. Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. *Can. J. Aquat. Sci.* 59:1886–1900.

2.2 - Riparian Thinning with "Warm" Headwater Conditions – White River Harvest Impact Project

Kreutzweiser, D. P., S. S. Capell, and S.B. Holmes (2009). Stream temperature responses to partial-harvest logging in riparian buffers of boreal mixedwood forest watersheds. *Can. J. For. Res.* 39:497–506.

2.3 - Riparian Buffer with "Warm" Headwater Conditions – Copper Lake Watershed Study

Curry R.A., D. A. Scruton, and K. SD. Clarke. 2002. The thermal regimes of brook trout incubation habitats and evidence of changes during forestry operations. *Can. J. For. Res.* 32: 1200–1207.

The **third group** of studies are ***modeling efforts*** which investigated the effect of riparian buffer conditions on stream shade and water temperature conditions. Water quality modeling provides an excellent tool to investigate the relationship between riparian vegetation, stream shade, and the resulting temperature condition. The Canton Creek modeling effort verified simulated base conditions with empirical data sets for surface and instream temperature and therefore represent a potential pseudo-BACI design. The other modeling efforts in this group were essentially sensitivity analyses.

Group 3

3.1 - Stream Shade Modeling – Effects of Riparian Buffer Width, Density and Height
DeWalle, David R., 2010. Modeling Stream Shade: Riparian Buffer Height and Density as Important as Buffer Width. ***Journal of the American Water Resources Association*** (JAWRA) 46(2):323-333.

3.2 - Stream Shade Modeling – Potential Shadow Length Associated with Riparian Vegetation
Leinenbach, P, 2011. Technical analysis associated with this project to assess the potential shadow length associated with Riparian vegetation

3.3 - Stream Shade and Temperature Modeling - Variable Buffer Widths/Thinnings and Water Quality
Science Team Review. 2008. Western Oregon Plan Revision Draft Environmental Impact Statement – Science Team Review - www.blm.gov/or/plans/wopr/files/Science_Team_Review_DEIS.pdf

3.4 - Stream Shade and Temperature Modeling - Variable Buffer Widths/Thinnings and Water Quality
Oregon Department of Environmental Quality Memorandum. 2008. Modeling result reporting document – Evaluation WOPR FEIS Riparian Area Land Use Allocation. Obtained from Ryan Mitchie at ODEQ.

3.5 - Stream Shade and Temperature Modeling - Variable Buffer Widths and Water Quality
Cristea N., and J. Janisch. 2007. Modeling the Effects of Riparian Buffer Width on Effective Shade and Stream Temperature. *Washington Department of Ecology* Publication No. 07-03-028:1–64.

The **fourth group** of studies are field efforts which investigated the condition of the riparian stand resulting from both clearcut and thinning activities. Although these studies did not emphasize effects on stream shade and water temperature response, valuable attributes were measured during these efforts (i.e., air temperature and solar loading at the stream surface and within the harvest buffers, and resulting buffer canopy cover associated with harvest activities).

Group 4

4.1 - Effects of Riparian Thinning - Density Management Study – 1

Chan S., P. Anderson, J. Cissel, L. Larson, and C. Thompson. 2004a. Variable density management in Riparian Reserves: lessons learned from an operational study in managed forests of western Oregon, USA. ***For. Snow Landsc. Res*** 78(1/2):151-172.

4.2 - Effects of Riparian Thinning - Density Management Study – 2

Chan S., D. Larson, and P. Anderson. 2004b. Microclimate Pattern Associated with Density Management and Riparian Buffers – An Interim Report on the Riparian Buffer Component of the Density Management Studies.

4.3 - Effects of Riparian Thinning - Density Management Study – 3

Anderson P. D., D. J. Larson, and S.S Chan. 2007. Riparian Buffer and Density Management Influences on Microclimate of Young Headwater Forests of Western Oregon ***Forest Science*** 53(2):254-269.

4.4 - Effects of Riparian Thinning Over Time - Oregon Coast Range Project

Chan S.S., D.J. Larson, K. G. Maas-Herner, W.H. Emmingham, S. R. Johnston, and D. A. Mikowski. 2006. Overstory and understory development in thinned and underplanted Oregon Coast Range Douglas-fir stands. ***Can. J. For. Res.*** 36:2696-2711.

4.5 – Effects of Riparian Harvest on Microclimate Gradients –Western Washington

Brosofske, K.D., J. Chen, R.J. Niaman, J.F. Franklin. 1997. Harvesting Effects on Microclimatic gradients from Small Streams to Uplands in Western Washington. *Ecological Applications* 7(4):1188-1200.

4.6 – Effects of Riparian Harvest on Blowdown – Coast Range of Washington Study

Jackson, C.R., D.P. Batzer, S.S. Cross, S.M. Haggerty and C.A. Sturm. 2007. Headwater Streams and Timber Harvest: Channel, Macroinvertibrate, and Amphibian Response and Recovery. *Forest Science* 53(2):356–370.

Section Two - Summary of Stream Shade and Stream Temperature Response

Summary information is presented in tables and it is categorized into three groups: (1) "No-cut" riparian buffer adjacent to clearcut harvest units; (2) Thinned riparian buffer adjacent to clearcut harvest units; and (3) "No-cut" riparian buffer adjacent to thinned riparian harvest units.

Group One – "No-cut" riparian buffer adjacent to clearcut harvest units

There are five general buffer width categories associated with these harvest studies: 46m (150 feet), 30 m (100 ft), 20 m (66 ft), 15 m (50 ft), and 10 m (33 ft). The stream shade and temperature response was highly variable within each group, however the magnitude of change increased as the "no-cut" buffer width decreased. The least amount of effect was associated with the widest "no-cut" buffer width (i.e., 150 ft), and the largest was observed with the narrowest "no-cut" buffer width (i.e., 33 ft). Results for this group are illustrated in **Figure 1**.

46m "no-cut" riparian buffer adjacent to clearcut harvest units

There were very little reported changes in shade and temperature conditions associated with 47m (150ft) "no-cut" buffers.

Buffer Dimensions	Shade Response	Temperature Response	Source
47m no-cut buffer width (average condition) (n= 15 sites)	Little difference in shade was found for these sites (mean change in Shade from 90% to 89%).	These sites did not exhibit exceedance rates of the PCW criteria that differed from preharvest, control, or downstream rates (i.e., 5%). Observed temperature changes at these sites were as frequently positive as negative: The average observed maximum change at these sites was 0.0 °C.	*1.1 Groom et al 2011a* *1.2 Groom et al 2011b*
46m no-cut buffer (modeled condition)	Very little shade reduction was observed associated with the 46 m "no-cut" buffer (maximum reduction was 1 unit of percent shade).	Very little (less than 0.1 C) increase in water temperature was observed for the 46 m "no-cut" buffer.	*3.3 Science Team Review, 2008*
69m no-cut buffer (Site Potential Tree Height)	The 69m no-cut buffer, with a patch clearcut outside of this zone, did not result in a significantly different light condition over the stream.	Not Reported	*4.3 Anderson et al., 2007*

30m "no-cut" riparian buffer adjacent to clearcut harvest units

Stream shade conditions have been shown to decrease up-to 10 units of shade with a 30m (100ft) riparian buffer. Similarly, Kiffney observed that solar flux (PAR) increased by 5 times over control conditions with a 30 meter buffer. Stream temperature response ranges from around 0.5 to 1.8*C. Groom et al 2001b observed an increase in maximum temperature pre-harvest to post-harvest for sites that exhibited an absolute change in shade of > 6%; otherwise, directionality appears to fluctuate.

Buffer Dimensions	Shade Response	Temperature Response	Source
26m no-cut buffer width (average condition) (n= 18 sites)	Post-harvest stream shade values differed significantly from pre-harvest values (mean change in Shade from 85% to 78%). Authors observed an increase in maximum temperature pre-harvest to post-harvest for sites that exhibited an absolute change in shade of > 6%; otherwise, directionality appears to fluctuate.	Pre-harvest to post-harvest temperatures increased on average by 0.7 °C with an observed range of response from −0.9 to 2.5 °C. In addition, mean temperatures increased by 0.37 C, minimum temperatures by 0.13 C, and diel fluctuation increased by 0.58 C. Timber harvested on these sites had a 40.1% probability that the daily maximum temperature response will be >0.3 C (i.e., exceed the Protect Cold Water (PCW) criteria).	*1.1 Groom et al 2011a* *1.2 Groom et al 2011b*
30m no-cut buffer width (n = 3 sites)	Compared with controls mean solar flux (i.e., photosynthetically active radiation – PAR) reaching the stream was 5 times greater. This corresponds with an approximate reduction of 3 units of shade as compared to the control.	Compared with controls, mean daily maximum summer water temperatures increased by 1.6*C. Authors concluded that "our observations suggest that additional light penetration comes through the sides of the buffer" and that there was a significant relationship between light levels and buffer width along small streams.	*1.4 Kiffney et al., 2003*
30m no-cut buffer width (n = 2 sites)	Not Presented	The two 30 m buffer sites resulted in a 1.1 and 1.8 C increase of the daily maximum temperatures: 1.8 C treatment effect was statistically significant, but the 1.1 C treatment effect was not.	*1.5 Gomi et al., 2006*
30m no-cut buffer width (modeled condition)	The 31 m no-cut buffer had shade reductions of over 10 units at several locations, while other areas had only minimum reductions (i.e. 1 unit of percent shade). There were many more areas with 1 unit of shade reduction than was observed for the 46 m no-cut buffer.	The 31 m no-cut buffer produced changes in stream temperature in excess of 0.5° C at one location along Canton Creek, and temperature increases of over 0.2 C at several other locations.	*3.3 Science Team Review, 2008*

20m "no-cut" riparian buffer adjacent to clearcut harvest units

One study showed summer temperature increased and shade decreased following harvest activities. Another study showed a spring temperature increase following harvest activities (the study did not report on summer temperature conditions). Another study showed that stream shade conditions were statistically lower for 22m wide "no-cut" buffers, as compared to controls.

Buffer Dimensions	Shade Response	Temperature Response	Source
20m "no-cut" buffer width (n = 6 site)	Stream shade decrease on average from 94% to 86% for the continuously buffered treatment reaches.	Temperature response was highest at the start of the evaluation period (i.e., July) and decreased in latter parts of the summer. The July-August average temperature change for the three post-treatment years was 0.8 ^{o}C, and the estimated average July 1st temperature change for the three post-treatment years was 1.1 ^{o}C. The authors concluded that overall, the area of surface water exposed to the ambient environment best explained aggregated temperature response. Shorter stream segment lengths were associated with coarse-substrate channels and shorter exposure lengths, and these streams tended to be thermally unresponsive to management.	*1.10 Janisch et al., 2012*
20m no-cut buffer width on one side of the stream (n = 1 site)	Authors stated that "there was forest buffer zone to protect the stream from solar loading" associated with the 20m buffer stream. However, there was no information to support this claim.	Harvest reaches were downstream of lakes and therefore stream temperatures entering the reach are elevated. Because this study was focusing on affects to brook trout, the evaluation period was fall, winter, and spring. Summer period results were not presented. Compared to control reach, spring stream temperatures in 20m buffer increased by an average of 2.7 *C in the three years following treatment activities. Authors speculate the warming of stream water in the 20 m buffer stream suggests "the mechanism of temperature change was related to groundwater flow to the stream and not direct solar inputs, i.e., there was forest buffer zone to protect the stream from solar radiation." That is, temperature increases are a result of elevated surface temperature associated with the clearcut zones warming up the groundwater which enters the stream.	*2.3 Curry et al., 2002*
22m no-cut buffer (average condition) with patch treatment outside of this zone (n = 5 sites)	The variable buffer (i.e., 22m) patch treatment resulted in a significantly lower canopy cover condition over the stream (p = 0.002) (Increased about 5 units of percent visible sky.).	Not Reported	*4.3 Anderson et al., 2007*

15m "no-cut" riparian buffer adjacent to clearcut harvest units

Shade conditions were lower at this "no-cut" buffer width. In addition, the effects of windthrow in the years following the harvest activities were shown to result in dramatically lower overhead shade conditions. Stream temperatures were also shown to increase as the "no-cut" buffer width was decreased from 75 ft to 50 ft.

Buffer Dimensions	Shade Response	Temperature Response	Source
15m (50 ft) "no-cut" buffer width (n = 13 sites)	The first year following harvest stream shade decreased by 13.4 units of shade. Mean overhead shade conditions five years after harvest was about 30 units of shade lower than the reference reaches in stands with large amount of tree mortality due to windthrow (An average mortality of 68.3% for 3 sites). Mean overhead shade conditions five years after harvest was about 10-13 units of shade lower than the reference reaches in stands without a large amount of tree mortality due to windthrow (An average mortality of 15% for 10 sites).	Not Presented	*1.6 Schuett-Hames et al., 2011*
15m (49.6 ft) "no-cut" buffer width (n = 13 sites)	The average shade measured at the unharvested sites in the Coast Range was 89 % (i.e., 95, 85, 89, 93, and 83). The average difference in shade conditions associated with the 13 no-cut streams in the Oregon Coast Range was 14.5 units of shade, ranging from 4 to 27 units.	Not Presented	*1.11 Allen and Dent, 2001*
15m (50ft) no-cut buffer width (modeled condition)	As the riparian buffer width was reduced from 23 m to 15 m, stream shade was reduced by 4 to 8 units of shade for a 3m wide stream channel.	For a 3 m wide stream channel after 472m stream channel distance, stream temperatures in creased between 0.11 and 0.17 C as the riparian buffer width was reduced from 23 m to 15 m.	*3.5 Cristea and Janish, 2007*

10m "no-cut" riparian buffer adjacent to clearcut harvest units

Large temperature increases (ranging from 2 to 5*C) were associated with 10m wide "no-cut" buffers. Light penetrating from the sides of the riparian buffer were cited as potential causes for these temperature increases (Kiffney et al., 2003 and Jackson et al., 2007[1]). Kiffney et al (2003) reported that the solar flux associated with 10m buffers increased 16 times greater than control un-harvested conditions, which corresponds to an approximate reduction of 26 units of shade as compared to the control.

Buffer Dimensions	Shade Response	Temperature Response	Source
8m to 10m "no-cut" buffer width (n = 5 sites)	Not Presented	Four of the five buffered streams became warmer (+2.0, 2.6, 2.8 and 4.9 C), and one became slightly cooler (-0.5 C) (Site 17E). The year following harvest at Site 17E had blowdown of some of the riparian vegetation, which buried 29% of the sample reach. This covering up of the stream channel confounded the temperature response for this sample reach (added additional shade), and thus it could be expected that the response temperature may have been warmer without the blowdown vegetation lying on top of 29% of the stream reach length.	*1.3 Jackson et al, 2001*
10m "no-cut" buffer width (n = 3 sites)	Compared with controls mean solar flux (i.e., photosynthetically active radiation – PAR) reaching the stream was 16 times greater. This corresponds with an approximate reduction of 25.9 units of shade as compared to the control.	Compared with controls, mean daily maximum summer water temperatures increased by 3.0*C. Authors concluded that "our observations suggest that additional light penetration comes through the sides of the buffer" and that there was a significant relationship between light levels and buffer width along small streams.	*1.4 Kiffney et al., 2003*
10m "no-cut" buffer width (n = 1 site)	Not Presented	The summer daily maximum temperature increased 4.1 C for the 10m buffer site, which indicated a significant treatment effect.	*1.5 Gomi et al., 2006*
9m (30ft) "no-cut" buffer width (modeled condition)	As the riparian buffer width was reduced from 23 m to 9 m on a 3 m wide stream, stream shade was reduced by 12 to 16 units of shade.	For a 3 m wide stream channel after 472m stream channel distance, stream temperatures in creased between 0.27 and 0.33 C as the riparian buffer width was reduced from 23 m to 9 m.	*3.5 Cristea and Janish, 2007*

[1] Jackson, C.R., D.P. Batzer, S.S. Cross, S.M. Haggerty and C.A. Sturm. 2007. Headwater Streams and Timber Harvest: Channel, Macroinvertibrate, and Amphibian Response and Recovery. *Forest Science* 53(2):356–370

<u>Group Two - Thinned riparian buffer adjacent to clearcut harvest units</u>

There are three general buffer width categories associated with these harvest studies: 30 m (100 ft), 20 m (66 ft), and 10 m (33 ft). Similar to results associated with the Group One, stream shade and temperature response was highly variable within each group, and the magnitude of change increased as the “thinned” buffer width decreased. The least amount of effect was associated with the wider “thinned” buffer width, and the largest was observed with the narrower “thinned” buffer width. In addition, greater thinning intensities generally resulted in larger shade reductions and greater temperature increases. Results for this group are illustrated in **Figure 2**.

30m thinned riparian buffer adjacent to clearcut harvest units

Maximum stream temperature response was shown to increase by 0.4*C (Mellina et al 2002) and by 4.4*C at one site in another study (Kreutzweiser et al., 2009). The authors in the first study concluded that the modest changes (compared with literature values) may reflect the effect of warm headwater temperatures on the temperature response associated with this thinned buffer. The authors in the second study reported that the large initial temperature response was a consequence of upslope harvest disturbance affecting groundwater inflow.

Buffer Dimensions	Shade Response	Temperature Response	Source
30m thinned buffer width (All mature commercial timber (>15 cm dbh for lodgepole pine and >20 cm dbh for spruce and subalpine fir) within a 30 m buffer surrounding the stream (n = 2 sites)	Following harvest, canopy cover over the stream decreased from 88% to 50%.	Relative to pre-harvest patterns, maximum temperatures for the two treatment streams increased by a net average of 0.4 C, and diurnal fluctuations increase by a net average of 1.1 C. The authors concluded that these are modest changes (compared with literature values) may reflect the effect of headwater lakes on outlet stream temperature.	*2.1 Mellina et al., 2002*
30m (to 100m) thinned buffer width (Basal area was reduced by 20.4% (Site WR1), 28.6% (WR2), and 10.8% (WR6). There was a 5 m no entry zone.) (n = 3 sites)	Site WR1 had a 12% reduction of canopy cover but no increase in ambient light (PAR) reaching the stream surface. WR2 had no detectable change in canopy cover removed but average light reaching the stream surface increase (but not significantly). Canopy density and PAR were not measured for site WR6.	Instream temperature downstream of WR 2 increased by around 4.4 C in the first post-logging year. Stream temperatures at WR1 became more variable following harvest, but were within the range of “preharvest weekly temperatures”. Stream temperatures at WR6 were elevated in one of the three post-harvest monitoring years. All streams originated from beaver ponds and flowed downstream through the harvest or reference blocks. Accordingly, all sites exhibited as much as 6-8 C of cooling in the forested reaches over the 240-600m distances between upstream pond outflows and downstream locations.	*2.2 Kreutzweiser et al., 2009*

20m thinned riparian buffer adjacent to clearcut harvest units

Temperature response was highly variable from no response to a 0.5 to 4*C response. The study which did not show a response (Wilkerson et al 2006) did not have a large reduction in stream shade following treatment (from 94 pre-harvest to 90 post-harvest). The post harvest canopy cover levels are still very high (≥ 90%) and therefore solar loading is low at these locations. The other study indicated that subsequent riparian vegetation blowdown dramatically reduced shade conditions and temperatures subsequently increased as a result of this blowdown (Macdonald et al., 2003). Finally, results associated with this study indicated that greater thinning intensities resulted in larger shade reductions and temperature increases.

Buffer Dimensions	Shade Response	Temperature Response	Source
20m thinned buffer width (remove all merchantable timber (>15 cm and >20 cm dbh for pine and spruce-pine respectively) within **20m** of stream, 2) High Retention Buffer – Remove all large merchantable timber > 30 cm dbh within the **20-30m** zone) (n = 4 sites – 2 each)	Canopy density conditions over the stream were shown to decrease following harvest activities, from an average condition of 76 in the control group, to 17 and 9 percent canopy density for "High" Retention buffer (B3) and "Low" Retention buffer (B5), respectively.	The authors concluded that summer stream temperatures clearly increased following forest harvesting and found that water temperatures were still elevated 5 years following treatment for all riparian buffers used in the analysis. Summer maximum mean weekly temperature increased by an average of 2.4*C and 5 *C for the "low" retention buffers. For the "high" retention buffers, summer maximum mean weekly temperature increased by an average of 0.3*C and 1.7 *C. Several years of blowdown associated with the second listed high retention buffer and patch retention buffer increased the temperature response from this treatment. Before the blowdown event, this buffer had a temperature increase of over 1 C for the weekly average temperature condition, and it increased to near 2 C following the blowdown events. The other high retention buffer in this study had around a 0.5 C temperature increase following harvest: This reach was the largest stream, and had very little stream length exposed to cutblocks (375 m).	*1.8 Macdonald et al., 2003*
23m thinned buffer width (**thinning target of 13.7 m^2/ha**) (n = 3 sites)	Canopy closure only slightly reduced following harvesting efforts for the 23m thinned buffers (Average canopy cover was 94 before treatment and 90 following treatment.)	They did not report a temperature increase associated with the 23 m and partial harvest buffers. They speculated that high subsurface groundwater flow significantly mitigated the effects of canopy removal by slowing temperature increases.	*1.9 Wilkerson et al., 2006*

10m thinned riparian buffer adjacent to clearcut harvest units

Shade (percent canopy cover) was reduced by 10 units and temperatures subsequently increased by 1.4 C.

Buffer Dimensions	Shade Response	Temperature Response	Source
11 m thinned buffer (thinning target of 13.7 m^2/ha) (n = 5 sites)	Canopy closure was reduced following harvesting efforts for the 11m thinned buffers (Average canopy cover was 94 before treatment and 84 following treatment.)	The temperature increase associated with the 11m buffer ranged from 1.0 to 1.4 C.	*1.9 Wilkerson et al., 2006*

Group Three - "No-cut" riparian buffer adjacent to thinned riparian harvest units

The table on the following page presents summary information associated with these riparian management studies. There are several interrelated factors which influences the amount of shade produced by these buffer conditions: (1) the total distance associated with the Inner "no-cut" zone and the Outer "thinned" zone; (2) the distance associated with the Inner "no-cut" zone; (3) vegetation density within the "no-cut" zone; (4) the distance associated with the Outer "thinned" zone; and (5) the amount of vegetation remaining within the Outer "thinned" zone following harvesting activities.

The width of the inner "no-cut" riparian buffer was shown to affect the potential consequences of thinning in the "outer" buffer regions, with wider "no-cut" buffers resulting in lower reductions in stream shade conditions (Anderson et al. 2007, Science Team Review 2008, Park et al 2008). In addition, the vegetation density of the inner "no-cut" buffer zone appeared to have an ameliorating effect on thinning activities within the "outer" thinning buffer zone, with higher "protection" associated with greater vegetation densities in the inner zone. Finally, higher residual vegetation densities within the "outer" thinning zone were shown to result in less shade loss. Once again, the limited number of studies that have specifically evaluated these buffer conditions make it difficult to generalize, particularly given the many different possible combinations of thinning intensity and buffer width.

Observed Shade and Temperature Response Associated With "No-Cut" Buffers Adjacent to "Thinned" Harvest Units								
Total Distance (m)	Inner "No-Cut" Zone Distance (m)	Inner "No-Cut" Zone Stand Condition	Outer "Thinned" Zone Distance (m)	Thinning Target	Resulting Units of "Shade" Reduction	Resulting Temperature Change (*C)	Number of Sites	Source
120	22	500-750 tph	98	198 tph	≈ 2.5% Open Sky	Not Measured	4	Anderson et al 2007
120	9	500-750 tph	111	198 tph	5% Open Sky	Not Measured	5	Anderson et al 2007
46	18	65-80% CC	27	50% CC	4 ES	0.2 7DADM	1	ODEQ Memorandum 2008
31	18	65-80% CC	12	50% CC	12 ES	0.6 7DADM	1	Science Team Review 2008
55	24	530 tph	31	321 tph	-0.9 and 0.7 ACD[2]	Not Measured	1	Park et al 2008
55	18	530 tph	37	321 tph	-0.3 and 0.2 ACD	Not Measured	1	Park et al 2008
55	12	530 tph	43	321 tph	1.8 and 2.0 ACD	Not Measured	1	Park et al 2008
55	6	530 tph	49	321 tph	2.9 and 9.3 ACD	Not Measured	1	Park et al 2008

tph = trees per hectare; CC = Riparian Canopy Cover (Planar View); 7DADM = seven day moving average of daily maximum stream temperature; ACD = Angular Canopy Density

[2] Harvest activates occurred on only one stream bank in this study (Park et al 2008), while the other two studies had harvest activities on both stream banks. Accordingly, a doubling of the "Shade" results associated with Park et al 2008 would allow for a more direct comparison of results with the other studies.

Section Three – Summary of Riparian Management Studies

The table below presents a summary of the “Shade” response associated with riparian thinning

Buffer/Treatment	Vegetation Response	Shade Response	Source
Thin riparian stands to 200 tph	Thinning to 200 tph decreased stand density by up to 70% (i.e., unthinned controls had 500 to 700 tph).	Thinning to 200 tph increased available light from 10 to 16 units of shade (i.e., 13–19% in the unthinned buffer to about 29% within the thinned buffer). Light values indicate that upland thinning to 200 tph increases available light within the first **20 m** of the adjacent riparian buffer. Thus, the authors conclude that thinning may result in some significant (but potentially transitory) changes in stand light and microclimate conditions.	*4.1 Chan et al., 2004a*
Thin riparian stand to various levels	Not Presented	Commercial thinning substantially increased understory light when stand density was decreased to a basal area (BA) less than 120 ft^2/ac, or in other terms, below a relative density (RD) of 30. At BA ≥ 160 ft^2/ac, and RD ≥40, light levels average about 10% of open conditions, similar to those of unthinned stands.	*4.2 Chan et al., 2004b*
Four Treatment Groups: (1) Unthinned (≈550 trees/ha (i.e., tph)); (2) light thinning (≈250 tph); (3) moderate thinning (≈140 tph); and (4) heavy thinning (≈70 tph).	Thinning reduced basal area (BA) by 51%, 67%, and 84% in lightly, moderately, and heavily thinned stands, respectively. Tree densities in thinned stands were reduced in the moderate and heavily thinned stands by windthrow and stem breakage during severe winter storms in the first 4 years of the study.	Immediately after thinning, % skylight through the canopy ranged from 2% in unthinned stands to 48% in heavily thinned stands. After 8 years, % skylight in lightly thinned stands was similar to levels in unthinned stands, and % skylight in moderately thinned stands had diminished to levels similar to those in lightly thinned stands just after thinning. Percent skylight for the moderate and heavy thinned stands was elevated above unthinned stand conditions for the eight year period associated with this study.	*4.4 Chan et al., 2006*

Thinning riparian vegetation from 600 tph to 200 tph increased “view to sky” by 10 units (19% to 29%) (Chan et al., 2004a). This reduced vegetation levels has a direct effect on shade potential through a reduction in canopy density (DeWalle 2010). The authors also reported that light availability increased up to 20m from the thinning activities. The “view to sky” was shown to be maintained within riparian stands at various stand conditions, but below a certain level (i.e., ≤ 40 Residual Density (RD)) the percent view to sky was shown to increase, dramatically so below a RD of 30 (Chan et al 2004b). Once again, this has implications on the amount of shade produced by the riparian stand. At higher RD levels, riparian vegetation removal does not have a subsequent response in canopy density, and subsequently it does not have a large affect on shade conditions. In other words, the same amount of harvest from a stand with a lower initial RD will result in greater reduction in shade production.

In a separate study Chan et al (2006) found that a “light” forest thin (RD of 28 and tph of 252) increased skylight (%) around 12 units (i.e., from around 2% pre-harvest condition to 14% following harvest). (Preharvest condition was a RD of 54 and tph of 547.) This corresponds closely with the results associated the previous two reports: Thinning trees to around a 200 tph (or 30 RD) results in around a ten unit increase of open sky.

Chan et al (2006) also observed that skylight conditions were reduced dramatically with a “Moderate” (RD of 16) and “Heavy” (RD of 8) thin conditions, from around 2% skylight in pre-harvest condition to 29% to 44% following harvest, respectively. Once again, this follows the results of the previous two reports: Thinning below a RD of 30 results in a dramatically increasing “Open Sky” condition.

Eight years following treatment, the “light” thin stand had recovered skylight conditions (i.e., around 6%). However, both the “moderate” thin (RD 16) and “heavy” thin (RD 8) condition did not have a recovery of the percent skylight condition (Chan et al 2006). Shoal (2002) reported that thinning to a RD (Curtis) of 35 to 40 minimized excessive blowdown for Douglas-fir forest stands in the Olympic National Forest. It appears that the low RD conditions in the “Moderate” and “Heavy” thinning, which potentially resulted in the stand being more susceptible stand to blowdown, may have been a factor in the increased percent skylight in the subsequent years. Accordingly, from a shade production perspective, it is important to reduce both the current low canopy cover conditions, along with the potential low conditions in subsequent years as a result of blowdown.

Steinblums et al (1984) reported that trees which are susceptible to windthrow tend to be lost during the first few years following harvest. Jackson et al (2007) reported that windthrow two years following the creation of a 10m “no-cut” buffer resulted in a loss of 33 to 64% of buffered trees with attendant effects on canopy cover. MacDonald et al (2003) reported three successive years of riparian vegetation loss from windthrow on a 20m wide thinned buffer. They measured reduced shade conditions, which resulted in an increase in stream temperatures (≈1 C degree temperature increase), as a direct response to this riparian vegetation loss. Pollock and Kennard (1998) reported that narrow streamside buffers (< 23m) have a much higher probability of suffering appreciable mortality from windthrow than forests with wider buffers. Similarly, Grizzel and Wolff (1998) observed that, on average, windthrow affected 33 percent of buffer trees and ranged from 2 to 92 percent across the 40 sites (average buffer width of 26m). Finally, Schuett-Hames et al (2011) observed an average windthrow loss of 68% in several stands with a buffer width of 15m, which resulted in an additional loss of 20 units of shade on the stream.

Accordingly, the residual density of the thinned buffer, along with the width of the buffer, need to be maintained at a sufficient level to reduce the potential effects of windthrow of the riparian vegetation over time.

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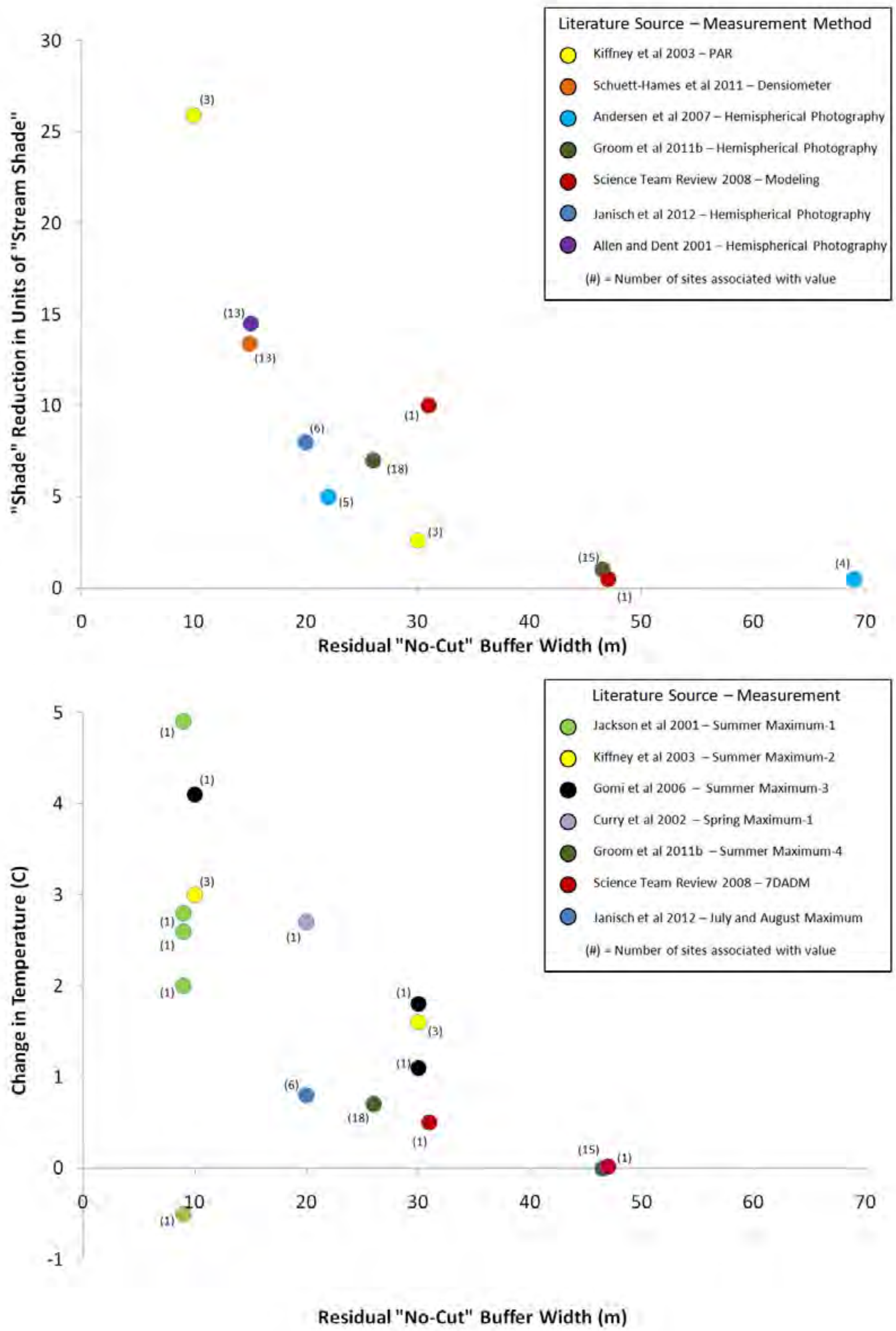


Figure 1. Observed shade and temperature response associated with "no-cut" riparian buffers with adjacent clearcut harvest.

(PAR = Photosynthetically Active Radiation; 7DADM = seven day moving average of daily maximum temperature)

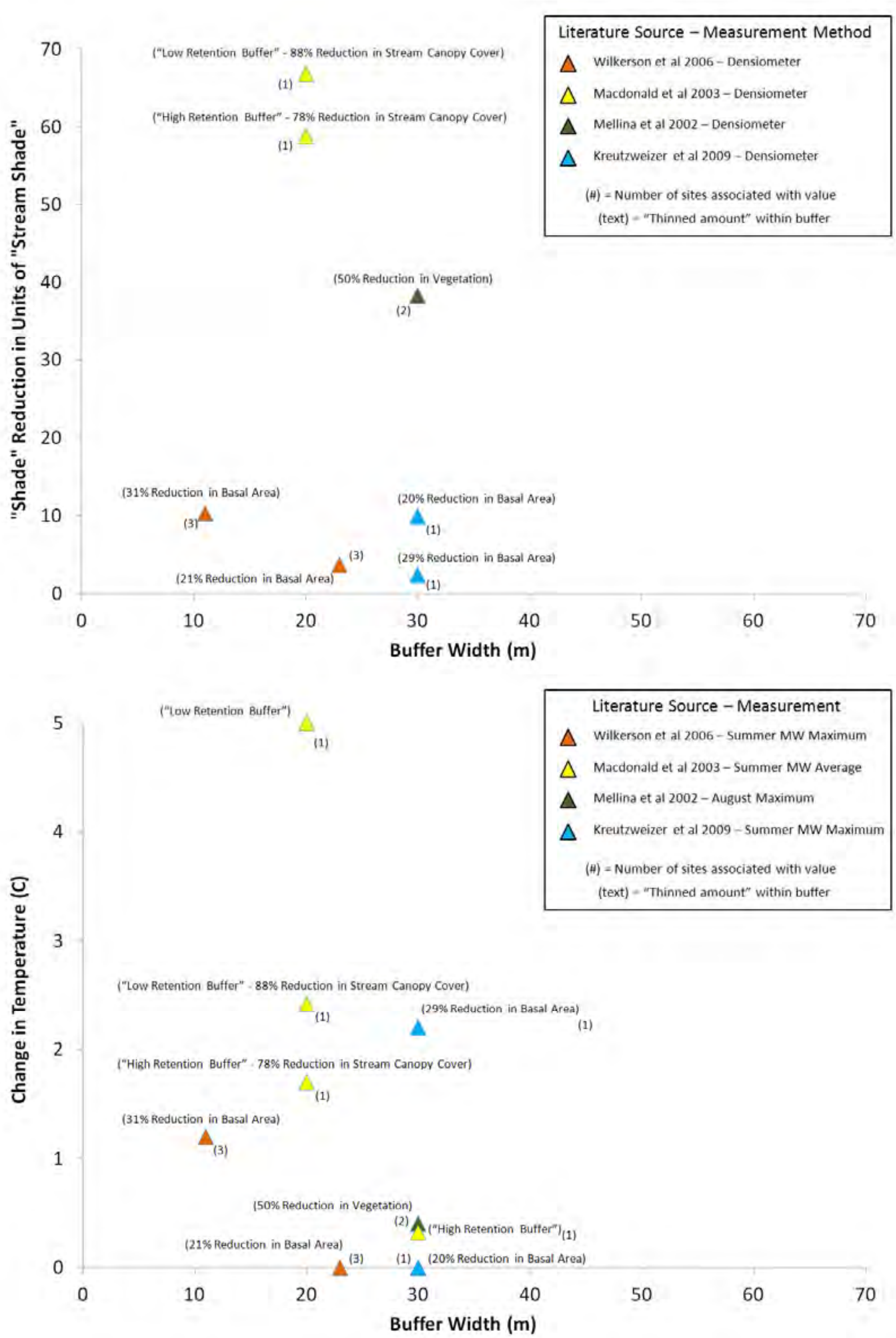


Figure 2. Observed shade and temperature response associated with "thinned" riparian buffers with adjacent clearcut harvest.

(MW = Mean Weekly)

Appendix B – Consolidated Summary of Literature Describing the Effects of Riparian Management on Stream Shade and Stream Temperature

Peter Leinenbach - USEPA Region 10

Project	*Buffer/Harvest*	Vegetation Response	"Shade" Response	Water Temperature Response
1.1 and 1.2 - Variable Buffer Widths and Water Quality Ripstream Project – 1 and 2 Oregon Coast Range *Groom et al., 2011a* *and* *Groom et al., 2011b*	*18 "Private" Sites – Average "no-touch" buffer of **26m**, and clearcut harvests were generally outside of this zone. Four sites had harvest only on one bank of the river. Average treatment length for "Private" sites was 600 m.* *15 "State" Sites - Average "no-touch" buffer of **47m**, and thinning was the dominate harvest activities outside of this zone. Thirteen sites had harvest on only one bank of the river. Average treatment length for "State" sites was 800 m.* *Two years of pre-harvest and two years of post-harvest data was used in this analysis.*	Average "Private" site post-harvest basal area were reduced by around half (i.e., Pre-harvest levels were 43 m^2/ha and post-harvest levels were 25 m^2/ha). Average post-treatment buffer basal area (m^2/ha) for "State" sites was 42, which is an increase over pre-harvest levels (i.e., Pre-harvest levels were 41 m^2/ha).	"Private" site post-harvest stream shade values differed significantly from pre-harvest values (mean change in Shade from 85% to 78%); however, very little difference was found for "State" site stream shade values (mean change in Shade from 90% to 89%). The shade model BasalXHeight which included parameters for basal area per hectare (BAPH), tree height, and their interaction was best-supported: Its model weight (ω = 1.00) indicated strong relative support for this model and virtually no support for the remaining models. Accordingly, stream shade conditions were shown to be a function of tree height and stand density (i.e., basal area - BAPH). Sites with wider uncut buffers, or fewer stream banks harvested had greater basal area (i.e., BAPH). Sites with higher basal area within 30 m of the stream resulted in higher post-harvest shade.	Authors observed an increase in maximum temperature pre-harvest to post-harvest for sites that exhibited an absolute change in shade of > 6%; otherwise, directionality appears to fluctuate. "Private" sites pre-harvest to post-harvest temperatures increased on average by 0.7 °C with an observed range of response from −0.9 to 2.5 °C. In addition, mean temperatures increased by 0.37 C, minimum temperatures by 0.13 C, and diel fluctuation increased by 0.58 C. Timber harvested on "Private" sites had a 40.1% probability that the daily maximum temperature response will be >0.3 C (i.e., exceed the Protect Cold Water (PCW) criteria). "State" forest riparian stands did not exhibit exceedance rates of the PCW criteria that differed from preharvest, control, or downstream rates (i.e., 5%). Observed temperature changes at "State" sites were as frequently positive as negative: The average observed maximum change at "State" sites was 0.0 °C, however there were several sites with temperature increases near 1.5 °C due to harvest activities.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.3 - Vegetation Buffers and Water Quality Coast Range of Washington Study Coast Range of Washington State *Jackson et al., 2001*	Four stand conditions: (1) No adjacent harvest (reference stream), (2) standard clearcut, (3) full riparian buffer, and (4) a non-merchantable harvest (There was very little non-merchantable vegetation so these effectively became clearcut harvest.). Widths of buffers applied to the buffered streams were dictated by operational considerations and the widths of the linear buffers ranges from 8 to 10 meters on each side of the channel. The stream length harvested was not presented. It appears that there was two years of water temperature data collect - one year of pre-harvest data and one year of post-harvest data.	Not Presented	Not Presented	Streams with no buffer did not have a statistically significant temperature response as a result of the streams being buried by a layer of slash that was deposited over these streams. Four of the five buffered streams became warmer (+2.0, 2.6, 2.8 and 4.9 C), and one became slightly cooler (-0.5 C) (Site 17E). The year following harvest at Site 17E had blowdown of some of the riparian vegetation, which buried 29% of the sample reach. This covering up of the stream channel confounded the temperature response for this sample reach (added additional shade), and thus it could be expected that the response temperature may have been warmer without the blowdown vegetation lying on top of 29% of the stream reach length. Temperature recovery is not observable because there was only one year of post harvest data. However, "significant" blowdown was observed in the year following this study period (2000), indicating that temperatures may have increased due to potentially elevated solar loading from the low shade levels following blowdown of the riparian vegetation.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.4 - Variable Buffer Widths and Water Quality Malcolm Knapp Research Forest Study - 1 Coastal British Columbia (**49^{o} Latitude**) *Kiffney et al., 2003*	Riparian no-touch buffer widths were **10m** and **30m**. There were control (no harvest) and a zero meter buffer (clearcut to stream). Stream treatment length ranged from 215 to 650 meters. Appears to have pre-harvest data and one year of post-harvest data collection.	Not Presented	Mean solar flux (i.e., photosynthetically active radiation – PAR) reaching the stream with a clear-cut (zero meters), 10-m, and 30-m treatment buffers were 58, 16, and 5 times greater than compared with the control, respectively. This corresponds with an approximate reduction of 3 and 26 units of shade associated with the 30 m and 10 m buffers, respectively, as compared to the control. Authors concluded that "our observations suggest that additional light penetration comes through the sides of the buffer" and that there was a significant relationship between light levels and buffer width along small streams.	Compared with controls, mean daily maximum summer water temperatures increased by 1.6, 3.0, and 4.8 degrees Celsius for the 30 m, 10 m and zero meter (clearcut) harvest treatments, respectively.
1.5 - Variable Buffer Widths and Water Quality Malcolm Knapp Research Forest Study - 2 Coastal British Columbia (**49^{o} Latitude**) *Gomi et al., 2006*	Riparian no-touch buffer widths were **10m** and **30m**. There were control (no harvest) and a zero meter buffer (clearcut to stream). Stream treatment length ranged from 215 to 650 meters. **The sites used in this analysis were similar to that of Kiffney et al., 2003.** Time line was six years: Two years of pre- harvest, and post-harvest was four years.	Not presented for buffered streams.	Not Presented	The summer daily maximum temperature increased 4.1 C for the 10m buffer site, which indicated a significant treatment effect. The two 30 m buffer sites resulted in a 1.1 and 1.8 C increase of the daily maximum temperatures: 1.8 C treatment effect was statistically significant, but the 1.1 C treatment effect was not.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.6 - Variable Buffer Widths and Water Quality Westside Type N Buffer Study – CEMR Western Washington *Schuett-Hames et al., 2011*	Eight sites had clear-cut harvest to the edge of the stream (clear-cut patches), thirteen had 50 foot wide no-cut buffers on both sides of the stream (50-ft buffers), and three had circular no-cut buffers with a 56 foot radius around the perennial initiation point (PIP buffers). An un-harvested reference reach was located in close proximity to each treatment site (not within 100 feet of the treatment site). Stream treatment length was a minimum of 300 ft. Standing tree data were collected in 2006 (three years after harvest), and in 2008 (five years after harvest).	In 50 ft buffered stands with minimum windthrow induced mortality (n=10), mean tree mortality for these buffers was 15%, and the mean density of live trees was 140 trees/acre five years after harvest (range 59-247). In 50 ft buffer stands with high windthrow induced mortality (n=3), mean tree mortality was 68.3% for these buffers over the five year period, and exceeded 90% in one case. The mean density of the remaining live trees was 62.8 trees/acre.	The first year following harvest stream shade decreased 13.4 shade units. In 50 ft buffered stands with minimum windthrow induced mortality (n=10), overhead shade in this group of buffers was 10-13 units of shade less than the reference reaches five years after harvest activities. In 50 ft buffer stands with high windthrow induced mortality (n=3), mean overhead shade five years after harvest was about 30 units of shade lower than the reference reaches five years after harvest activities.	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.7 - Variable Buffer Widths and Water Quality Rogue River Siskiyou National Forest Study Rogue River Siskiyou National Forest, Oregon *Park et al., 2008*	Thinning maintained the dominate trees and removed 80 to 100 stems per acre. Various "no-touch" buffer widths were maintained (i.e., 20, 40, 60, and 80 feet) with thinning occurring outside of this zone to distance of 180 ft from the stream. Stream treatment length for each treatment was 100 ft. It appears that Angular Canopy Density (ACD) values were collected soon after thinning activities	Reduced the stems per acre from around 220 to between 120 and 140 within the "thinned" zone.	Thinning the stand from 220 stems per acre to around 120 to 140 stems per acre increased the Angular Canopy Density (ACD) over the stream by 14% in one plot and 24% in another plot (Each treatment had two reported plot values). ACD reductions were observed for at least one plot at each of the "no-touch" buffer widths (up to 80 feet). The magnitude of decrease was lower as the "no-touch" buffer width increased, with average reductions in ACD near zero with a "no-touch buffer" of 60 feet.	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.8 - Variable Buffer Widths/Thinnings and Water Quality Stuart-Takla Fisheries-Forestry Interaction Study Interior sub-boreal forests of northern British Columbia (**55^{o} Latitude**) *Macdonald et al., 2003*	Three harvest conditions: 1) Low Retention Buffer – remove all merchantable timber (>15 cm and >20 cm dbh for pine and spruce-pine respectively) within **20 m** of stream, 2) High Retention Buffer – Remove all large merchantable timber > 30 cm dbh within the **20-30m** zone and 3) Patch cut – a high-retention along the lower 60% of the stream and removal of all riparian vegetation in the upper 40% of the watershed. Forest harvest actions outside of these buffer areas were not presented. Stream treatment length ranged from 185 to 810 meters. There are two reaches for the low and high retention buffers, and three control (unharvested) reaches. There was around 2 years of pre-harvest data, and 5 years of post harvest data.	Not Presented	Canopy density conditions over the stream were shown to decrease following harvest activities, from an average condition of 76 in the control group, to 17 and 9 percent canopy density for "High" Retention buffer (B3) and "Low" Retention buffer (B5), respectively.	The authors concluded that summer stream temperatures clearly increased following forest harvesting and found that water temperatures were still elevated 5 years following treatment for all riparian buffers used in the analysis. Summer maximum mean weekly temperature increased by an average of 2.4*C and 5 *C for the "low" retention buffers. For the "high" retention buffers, summer maximum mean weekly temperature increased by an average of 0.3*C and 1.7 *C. Several years of blowdown associated with the second listed high retention buffer and patch retention buffer increased the temperature response from this treatment. Before the blowdown event, this buffer had a temperature increase of over 1 C for the weekly average temperature condition, and it increased to near 2 C following the blowdown events. The other high retention buffer in this study had around a 0.5 C temperature increase following harvest: This reach was the largest stream, and had very little stream length exposed to cutblocks (375 m). No temperature recover was observed after five years.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.9 - Variable Buffer Widths/Thinnings and Water Quality Western Maine Project Western Maine (45° Latitude) *Wilkerson et al., 2006*	Fifteen streams were assigned to one of five treatments: (1) clearcut with no stream buffer (less than 6.8 m^2/ha residual basal area); (2) a thinned 11-m buffer (thinning target of 13.7 m^2/ha) and clearcut outside of this zone; (3) a thinned 23-m buffer (thinning target of 13.7 m^2/ha) and clearcut outside of this zone; (4) partial cuts with no designated buffer (retaining at least 13.7 m^2/ha residual basal area in the harvest zone); and (5) un-harvested controls. Stream treatment length was 300m and was on both sides of the stream. There were three replicates of each treatment. Time line was 3 years: one year of pre-harvest data and two years of post-harvest data.	Basal area values associated with "clearcut harvest" stands in this study were reduced to levels well below the minimum target (retain at least 6.9 m^2/ha). The basal associated with the partial-harvest treatment ranged from 14.0 to 18.9 m^2/ha. Thinning targets associated with the buffered streams (11 m and 23-m) exceeded the 13.8^2/ha target in 5 of the 6 streams (only one was slightly below 13.5^2/ha).	Canopy closure measured in the middle of the stream channel was reduced by average of 11% in the 11m group (i.e., average canopy cover was 94 before treatment and 84 following treatment), and 4% the 23m group (Average canopy cover was 94 before treatment and 90 following treatment.).	The temperature increase associated with the 11m buffer ranged from 1.0 to 1.4 C. They did not report a temperature increase associated with the 23 m and partial harvest buffers. They speculated that high subsurface groundwater flow significantly mitigated the effects of canopy removal by slowing temperature increases. No apparent temperature recovery was observed after 3 years.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.10 - Vegetation Buffers and Water Quality Washington Headwater Stream Study Western Washington (46.5° Latitude) *Janisch et al., 2012*	In small forested watershed (< 9 ha) the following three treatments were applied: (1) clearcut (n=5); (2) continuous buffered (n= 6); and (3) patch-buffered streams (n=5). In all three treatments, the upland portions of the catchments were clearcut harvested so that these treatments differed only in the way the riparian zone was harvested. The buffer width associated with the continuous buffer treatment was 20 meters on both side of the stream. The average stream treatment length for continuous buffer streams was 279 m, however only 43% of the stream length (on average) was observed to be flowing in the first post harvest year. There were 6 continuous buffer treatment sites, each with a paired reference site. A seven year monitoring period (2002-2008), with three years of post harvest temperature data collection activities.	Not Presented	Stream shade was calculated from hemispherical photography, and included both canopy and topography. Stream shade averaged 94% over the stream channel before logging and did not differ significantly between reference and treatment reaches. Stream shade in reference sites did not change substantially (average = 94%) after logging activities occurred in the other sample reaches. Stream shade decrease to 86% on average for the continuous buffer treatment reaches. This corresponds to an average reduction of 8 units of stream "shade" associated with this treatment.	For continuous buffered catchments, temperature changes were significantly greater than zero ($\alpha = 0.05$) in the first two post-treatment years. In the third post-treatment year, the magnitude of the temperature change estimated from the statistical model was significantly different for most of the monitoring period, however it was shown to not be significantly different from zero after Julian day 228 (≈15th August) (It is important to point out that the absolute temperature response is still greater than zero during this last two week period). Temperature response was highest at the start of the evaluation period (i.e., July) and decreased in latter parts of the summer. The July-August average temperature change for the three post-treatment years for the continuous buffered streams was 0.8 °C, and the estimated average July 1st temperature change for the three post-treatment years was 1.1 °C. The authors concluded that overall, the area of surface water exposed to the ambient environment best explained aggregated temperature response. Shorter stream segment lengths were associated with coarse-substrate channels and shorter exposure lengths, and these streams tended to be thermally unresponsive to management activities.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
1.11 - Vegetation Buffers and Water Quality Oregon Department of Forestry Stream Shade Study Coast Range of Oregon (45^{o} Latitude) *Allen and Dent, 2001*	The 13 sites in the Coast Range managed with a "no-cut" buffer had an average "no-cut" buffer width of 49.6 feet (15 m). Clearcut harvest occurred outside of this no-cut zone. The average stream width for these sites was 6.6 feet, and ranged from 3.2 to 12.8 feet. The plot had a minimum length of 500 feet and maximum length of 1000 feet. Unharvested stand data were collected at sites adjacent, or in close proximity, to harvested stands in order to sample shade conditions that may have existed prior to entry. A time line was not presented	Not Presented	The average shade measured at the unharvested sites in the Coast Range was 89 % (i.e., 95, 85, 89, 93, and 83). The average difference in shade conditions associated with the 13 no-cut streams in the Oregon Coast Range was 14.5 units of shade, ranging from 4 to 27 units.	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
2.1 - Riparian Thinning with "Warm" Headwater Conditions North Central British Columbia Project North-Central British Columbia (55^{o} – Latitude) *Mellina et al., 2002*	Three small, lake headed, forest streams. Two sites (118/16 and 118/48) had thinning out of all mature commercial timber (>15 cm dbh for lodgepole pine and >20 cm dbh for spruce and subalpine fir) within a 30 m buffer surrounding the stream and clearcut occurred outside of this zone. The third site was an unharvested control. Stream treatment length was 607 m and 372 m for the treatment reaches and 430 m for the unharvested reach. The time line was four years: One year of pre-harvest data, and three years of post-harvest data.	Harvesting removed around 50% of streamside vegetation.	Following harvest, canopy cover over the stream decreased from 88% to 48% and 51% for sites 118/16and 118/48, respectively.	Maximum stream temperatures and diurnal fluctuations increased as a result of harvesting, but the magnitude of change was lower than expected because the water entering the treatment reach was warm lake water discharge. Relative to pre-harvest patterns, maximum temperatures for the two treatment streams increased by a net average of 0.4 C, and diurnal fluctuations increase by a net average of 1.1 C. The authors concluded that these are modest changes (compared with literature values) may reflect the effect of headwater lakes on outlet stream temperature. The dominate downstream cooling observed both before and after harvest was attributed to the combination of warm source temperature associated with the lakes and the strong cooling effect of ground water inflow through the clear-cut, as well as the residual shade provided by the partially logged riparian buffer. No apparent temperature recovery was observed over three years.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
2.2 - Riparian Thinning with "Warm" Headwater Conditions White River Riparian Harvesting Impacts Project Boreal Shield near White River, Ontario (**48° Latitude**) *Kreutzweiser et al., 2009*	Thirty to 100m wide riparian buffers were "thinned" to basal area reduction of 20.4% (Site WR1), 28.6% (WR2), and 10.8% (WR6). (It is important to note that the preharvest basal area volume was not presented.) There was a 5 m no entry zone. These levels were assessed by postlogging measurements of residual trees and stumps. Three sites had not been previously been logged and serve as reference conditions. Stream treatment length was 600 m (WR1), 840 m (WR2) and 550m (WR6). Site WR6 was harvested during the second year so there was only one year of preharvest data for this site, and three years of post-harvest data. The other two harvest sites (WR1 and WR2) had two years of pre-harvest data and two years of post-harvest data.	Thirty to 100m wide riparian buffers were "thinned" to basal area reduction of 20.4% (Site WR1), 28.6% (WR2), and 10.8% (WR6). (It is important to note that the preharvest basal area volume was not presented.)	Site WR1 (20.4% of basal area removed) had a 12% reduction of canopy cover but no increase in ambient light (PAR) reaching the stream surface. WR2 (28.6% of basal area removed) had no detectable change in canopy cover removed but average light reaching the stream surface increase (but not significantly). Canopy density and PAR were not measured for site WR6 because the "logging occurred in only small sections of one side of the stream, and mature streamside trees at WR6 tended to be further removed from the stream edges than at WR1 or WR2."	All streams originated from beaver ponds and flowed downstream through the harvest or reference blocks. Accordingly, all sites exhibited as much as 6-8 C of cooling in the forested reaches over the 240-600m distances between upstream pond outflows and downstream locations during the monitoring period. This is an expected condition (Mellina et al., 2002: Story et al., 2003). The only site that had reduced cooling during the post harvest summer period was WR2 (28.6% of basal area removed). The authors inferred that is possible that shallow groundwater inflow temperatures were elevated by increase solar radiation and soil warming in the upland clearcut and parts of the riparian forest around this site. Instream temperature downstream of WR 2 (28.6% of basal area removed) increased by around 4.4 C in the first post-logging year. Temperatures returned to pre-harvest levels by the second post-harvest year. Stream temperatures at WR1 (20.4% of basal area removed) became more variable following harvest, but were within the range of "preharvest weekly temperatures". Stream temperatures at WR6 (10.8% of basal area removed) were elevated in one of the three post-harvest monitoring years. The authors summarized that the temperature impacts were not observed on the second post harvest year.

Project	Buffer/Harvest	Vegetation Response	“Shade” Response	Water Temperature Response
2.3 - Riparian Buffer with “Warm” Headwater Conditions Copper Lake Watershed Study Western Newfoundland, Canada (48.5^{o} Latitude) *Curry et al., 2002*	19 ha were harvested in one stream without a buffer strip (Site T1-1). A harvest area of 33 ha with a 20 m buffer strip was applied to another stream. The 20m buffer strip was primarily on one side of the stream (Site T1-2). There was a control (no harvest) watershed. Time line was five years (1993 through 1997). Harvest occurred November 1994 through January 1995, along with June and July 1996.	Not Presented	Authors stated that “there was forest buffer zone to protect the stream from solar loading” associated with the 20m buffer stream. However, there was no information to support this claim.	Harvest reaches were downstream of lakes and therefore stream temperatures entering the reach are elevated. Because this study was focusing on affects to brook trout, the evaluation period was fall, winter, and spring. Summer period results were not presented. Stream temperatures trends in the control (no harvest) basin paralleled air-temperature trends. Compared to control reach, spring stream temperatures in 20m buffer increased by an average of 2.7 *C in the three years following treatment activities. Authors speculate the warming of stream water in the 20 m buffer stream suggests “the mechanism of temperature change was related to groundwater flow to the stream and not direct solar inputs, i.e., there was forest buffer zone to protect the stream from solar radiation.” That is, temperature increases are a result of elevated surface temperature associated with the clearcut zones warming up the groundwater which enters the stream. The authors observed a temperature recover in the last year of the study, however it appeared that the spring period during this last year was an extremely cool period (i.e., the clearcut harvest treatment reach was cooler than pre-harvest temperature conditions.)

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
3.1 - Stream Shade Modeling Effects of Riparian Buffer Width, Density and Height Modeled shade conditions 40°N Latitude *DeWalle., 2010*	Not specifically outlined in the analysis. The riparian buffer was modified to illustrate the effects of various buffer attributes and resulting shade conditions.	Input parameter in model	Vegetation on the north bank buffer of an east-west aspect stream can produce up to 30% of the daily shade occurring on the stream surface. The **density** of the buffer is one of the most important controls on buffer shading. Relatively high shading was only achieved with the high buffer densities. Shading by vegetation along a stream increased as **buffer width** was increased. Shading is primarily associated with the top of the vegetation (i.e., shadow length) at narrower buffer widths. Outside of this "inner" zone, sunlight traveling through the side of the buffer increases in importance towards shade production. Stream shading increased rapidly with increased **buffer height**. Shading is primarily associated with the side of the vegetation at shorter vegetation heights. Outside of this "inner" zone, sunlight traveling through the top of the vegetation (i.e., shadow length) increases in importance towards shade production.	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
3.2 - Stream Shade Modeling Potential Shadow Length Associated with Riparian Vegetation Modeled shade conditions 45.7°N Latitude *Leinenbach, 2011*	Not specifically outlined in the analysis. Vegetation height was modified to illustrate the potential shadow length associated with various tree height conditions at various hillslope angles and at various months of the year along a stream situated at a latitude of 45.7°N.	Input parameter in model	Results indicate that a tree located on a flat hillslope along the stream **within a distance of its height** can be influential on shade production (i.e., the shadow length associated with the tree is long enough to reach the stream), and ultimately on stream temperature during the summer period (July/August). However, there are commonly occurring situations which trees outside of this distance can contribute to shade production (For example, a 100 foot tall tree located on a hillslope of 20 degrees can cast a 169 foot long shadow at 4 PM during the late summer.).	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
3.3 and 3.4 - Stream Shade and Temperature Modeling Variable Buffer Widths/Thinnings and Water Quality Western Washington (**46.65° Latitude**) *Science Team Review, 2008* *and* *ODEQ Memorandum, 2008*	Four buffer conditions were evaluated for BLM administered lands along Canton Creek, Oregon (North Umpqua Basin): (1) A 46 m (150 ft) no-touch buffer width; (2) A 31 m (100 ft) no-touch buffer width; (3) A 31 m variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 13 m (40 ft) 50% canopy cover outside of the "no-touch" zone); and (4) A 46 m variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 28 m (90 ft) 50% canopy cover outside of the "no-touch" zone). Clearcut occurred outside of this zone. Pre-thinning canopy cover associated with large conifers was 80%. Calculated shade conditions associated with the various buffer combinations were modeled for shade and temperature response using Heat Source 7.0.	Input parameter in model	Very little shade reduction was observed associated with the 46 m "no-touch" buffer (maximum reduction was 1 unit of percent shade). The 31 m no-touch buffer had shade reductions of over 10 units at several locations, while other areas had only minimum reductions (i.e. 1 unit of percent shade). There were many more areas with 1 unit of shade reduction than was observed for the 46 m no-touch buffer. The 31 m variable retention buffer had shade reduction of over 12 units of shade at several locations along the river, with two regions of the river approaching a reduction of 20 units of shade. There were many more areas with 1 unit of shade reduction than was observed for the 46 m and 31 m no-touch buffers. The 46 m variable retention buffer had shade reductions of around 4 units at several locations along the river. There were many more areas with 1 unit of shade reduction than was observed for the 46 m no-touch buffer.	Temperature response was expressed as the maximum change in the seven day average of the maximum daily temperature during the modeling period (July 12th through July 31st). Very little (less than 0.1 C) increase in water temperature was observed for the 46 m "no-touch" buffer. The 31 m no-touch buffer produced changes in stream temperature in excess of 0.5° C at one location along Canton Creek, and temperature increases of over 0.2 C at several other locations. The 31 m variable retention buffer produced changes in stream temperature in excess of 0.6° C at one location along Canton Creek, and temperature increases of over 0.2 C at several other locations. The 46 m variable retention buffer produced changes in stream temperature approaching 0.2° C.

Project	Buffer/Harvest	Vegetation Response	“Shade” Response	Water Temperature Response
3.5 - Stream Shade and Temperature Modeling Variable Buffer Widths and Water Quality Western Washington (**46.65° Latitude**) *Cristea and Janish, 2007*	Variable “no-touch” buffer widths were tested (i.e., **9m**, **15m**, and **23m**) with a vegetation height of 15 m. Harvest unit on only one side of the stream. Angular canopy density for each buffer width condition was estimated using two models (Brazier and Brown, 1973; Steinblums et al., 1984), which was used as an estimate of canopy cover condition in the “Shade.xls” model. Calculated shade conditions associated with the various channel width and buffer combinations were modeled for temperature response using QUAL2Kw.	Input parameter in model	As the riparian buffer width was reduced from 23 m to 15 m, stream shade was reduced by 4 to 8 units of shade for a 3m wide stream channel. As the riparian buffer width was reduced from 23 m to 9 m on a 3 m wide stream, stream shade was reduced by 12 to 16 units of shade.	For a 3 m wide stream channel after 472m stream channel distance, stream temperatures in creased between 0.11 and 0.17 C as the riparian buffer width was reduced from 23 m to 15 m. For a 3 m wide stream channel after 472m stream channel distance, stream temperatures in creased between 0.27 and 0.33 C as the riparian buffer width was reduced from 23 m to 9 m. Temperature results associated with the 6m channel indicate that the “shadow length” from the 15 m tall vegetation was not sufficient to cast a proper shadow across the stream leading to very low shade conditions. Accordingly, despite greater shade conditions associated with the wider riparian buffers, the temperature response was muted in the 6m stream channel. In other words, shade levels for the 6m stream are low for all buffer width conditions and therefore stream temperature increases are high for all scenarios.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
4.1 - Effects of Riparian Thinning Riparian Buffer Component of the Density Management Studies Project - 1 Oregon Coast Range and west side of the Cascade Mountains in western Oregon. *Chan et al., 2004a*	Thinning treatments include: 1) Unthinned control – 500 to 750 trees per ha (tph) greater than 12.7 cm dbh. 2) High density retention – 70 to 75% of area thinned to 300 tph, 25 to 30% unthinned Riparian Reserves or leave islands. 3) Moderate density retention – 60 to 65% thinned to 200 tph, 25 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings. 4) Variable density retention.	Thinning to 200 tph decreased stand density by up to 70% (i.e., unthinned controls had 500 to 700 tph).	Thinning to 200 tph increased available light from 10 to 16 units of shade in the buffer (i.e., 13–19% in the unthinned buffer to about 29% within the thinned buffer). Light values indicate that upland thinning to 200 tph increases available light within the first **20 m** of the adjacent riparian buffer. Thus, the authors conclude that thinning may result in some significant (but potentially transitory) changes in stand light and microclimate conditions.	Not Presented
4.2 - Effects of Riparian Thinning Riparian Buffer Component of the Density Management Studies Project - 2 Oregon Coast Range and west side of the Cascade Mountains in western Oregon. *Chan et al., 2004b*	See above for Chan et al., 2004a	Not Presented	Commercial thinning substantially increased understory light when stand density was decreased to a basal area (BA) less than 120 ft^2/ac, or in other terms, below a relative density (RD) of 30. At BA ≥ 160 ft^2/ac, and RD ≥40, light levels average about 10% of open conditions, similar to those of unthinned stands.	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
4.3 - Effects of Riparian Thinning Riparian Buffer Component of the Density Management Studies Project - 3 Oregon Coast Range and west side of the Cascade Mountains in western Oregon. *Anderson et al., 2007*	Three types of unharvested buffers were bounded by riparian harvest: (1) Streamside retention buffers (SR) – average **9 m** wide, which consisted of retaining all trees having a portion of their crown extending directly over the stream; (2) Variable width buffers (VB) – averaged **22m** wide, with an minimum buffer of 12m from the stream center and maximum width up to 32m; and (3) One site potential tree height buffer (B1) – **69m**, and ranging from 53 to 73 meters. There were two harvest activities occurring outside of the buffer zone: (1) patch opening (i.e., small (0.4-ha) clearcut harvest); and (2) thinning to a density of 198 trees per hectare (tph). (Unharvested controls reaches had around 500 to 750 tph (Chan et al., 2004)).	Basal areas of the thinned treatments were relatively constant over distance in the upslope, treated portions of the transects. Basal area reductions associated with the 0.4 ha patch treatments were observed.	Clearcut harvest outside of the 69m no-touch buffer ("B1-P") did not result in a significantly different light condition over the stream than the unharvested condition ("UT") and appears to be decreasing less than 1 unit of percent visible sky. Clearcut harvest outside of the 22m no-touch buffer ("VB-P") resulted in significantly higher light conditions over the stream ($p = 0.002$), increasing 5.1 units of percent visible sky.	None reported *Maximum **air** temperature above the stream for the SRT was similar to that of the thinned upslope and were 4 C warmer than observed for streams with unharvested stands. This indicates that the stream center and buffer microclimates were essentially the same as the upslope in the thinned stand. Although statistically insignificant, temperature maximum of the SRT treatment exceeded that for untreated stands by 4.5°C. Temperature increases above the stream associated with thinning retaining buffers of 22 m width (VBT) were approximately 1°C and statistically insignificant. Maximum soil and air temperatures were associated with the 0.4 ha circular patch openings for the patch sites and were the highest for all monitoring sites.*

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
4.4 - Effects of Riparian Thinning Over Time Oregon Coast Range Project Oregon Coast Range. *Chan et al., 2006*	Four Treatment Groups: (1) Unthinned (≈550 trees/ha (i.e., tph)); (2) light thinning (≈250 tph); (3) moderate thinning (≈150 tph); and (4) heavy thinning (≈75 tph). Stands were monitored over an eight year period.	Thinning reduced basal area (BA) by 51%, 67%, and 84% in lightly, moderately, and heavily thinned stands, respectively. Tree densities in thinned stands were reduced in the moderate and heavily thinned stands by windthrow and stem breakage during severe winter storms in the first 4 years of the study.	Immediately after thinning, % skylight through the canopy ranged from 2% in unthinned stands to 48% in heavily thinned stands. After 8 years, % skylight in lightly thinned stands was similar to levels in unthinned stands, and % skylight in moderately thinned stands had diminished to levels similar to those in lightly thinned stands just after thinning. Percent skylight for the moderate and heavy thinned stands was elevated above unthinned stand conditions for the eight year period associated with this study.	Not Presented

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
4.5 – Effects of Riparian Harvest on Microclimate Gradients Microclimate Gradients in Western Washington Study Western Washington State *Brosofske et al., 1997*	Variable no cut riparian buffer width: 23m (and 17m on other bank), 17m(23m), 25m (60m), 60m (25m), and 60m (25m). One year of pre-harvest and one year of post-harvest data collection.	Not Presented	Solar radiation and relative humidity did appear to have some association with buffer width. Edge influences appeared to allow solar load to penetrate the forest buffer and affect stream microclimate. Accordingly, the authors surmise that as the buffer widens the amount of solar radiation able to penetrate the vegetation and reach the stream station would decrease.	They did not find any relationship between water temperature and buffer width. It is important to point out that the temperature response associated with each treatment was not presented so it is not possible to determine the exact impact of various riparian buffer widths on stream temperature. Observe a strong influence of soil temperature in the surrounding land area on water temperature, even for sites well away from the stream. The authors concluded that this suggests that activity in the watershed up to or more than 180 m away may affect the stream even when a buffer strip is left intact. Authors conclude that a buffer at least 45 m on each side of the stream is necessary to maintain a natural riparian microclimatic environment along the stream.

Project	Buffer/Harvest	Vegetation Response	"Shade" Response	Water Temperature Response
4.6 – Effects of Riparian Harvest on Blowdown Coast Range of Washington Study Coast Range of Washington State *Jackson et al., 2007*	Four stand conditions: (1) No adjacent harvest (reference stream), (2) standard clearcut, (3) full riparian buffer, and (4) a non-merchantable harvest (There was very little non-merchantable vegetation so these effectively became clearcut harvest.). Widths of buffers applied to the buffered streams were dictated by operational considerations and the widths of the linear buffers ranges from 8 to 10 meters on each side of the channel. The stream length harvested was not presented.	Buffer blowdown was extensive in 2001 (two years following harvest activities associated with buffered streams). Blowdown ranged from 33 to 64% of buffered trees with attendant effects on canopy cover. After blowdown, the newly fallen trees either spanned the channels or lay beside the channels, so blow down trees were not adding woody debris to the channels or altering channel structure at the time of the study.	Not Presented	See *Jackson et al, 2001*

Appendix C – Annotated Bibliography of Literature Describing the Effects of Riparian Management on Stream Shade and Stream Temperature

Peter Leinenbach – USEPA Region 10

1.1 - Variable Buffer Widths and Water Quality – Ripstream Project - 1

Groom J. D., L. Dent, L. and Madsen. 2011a. Stream temperature change detection for state and private forests in the Oregon Coast Range. *Water Resources Research* 47

Location: Western Oregon coast range (45^{o} Latitude)

Abstract: Oregon's forested coastal watersheds support important cold-water fisheries of salmon and steelhead (Oncorhynchus spp.) as well as forestry-dependent local economies. Riparian timber harvest restrictions in Oregon and elsewhere are designed to protect stream habitat characteristics while enabling upland timber harvest. We present an assessment of riparian leave tree rule effectiveness at protecting streams from temperature increases in the Oregon Coast Range. We evaluated temperature responses to timber harvest at 33 privately owned and state forest sites with Oregon's water quality temperature antidegradation standard, the Protecting Cold Water (PCW) criterion. At each site we evaluated stream temperature patterns before and after harvest upstream, within, and downstream of harvest units. We developed a method for detecting stream temperature change between years that adhered as closely as possible to Oregon's water quality rule language. The procedure provided an exceedance history across sites that allowed us to quantify background and treatment (timber harvest) PCW exceedance rates. For streams adjacent to harvested areas on privately owned lands, preharvest to postharvest year comparisons exhibited a 40% probability of exceedance. Sites managed according to the more stringent state forest riparian standards did not exhibit exceedance rates that differed from preharvest, control, or downstream rates (5%). These results will inform policy discussion regarding the sufficiency of Oregon's forest practices regulation at protecting stream temperature. The analysis process itself may assist other states and countries in developing and evaluating their forest management and water quality antidegradation regulations.

Riparian Stand and Harvest Conditions:

Sites: Thirty three (33) first and third order streams on 18 private sites and on 15 State forest sites.

Stand Conditions: Dominated by Douglas fir and red alder. Forest stands were 50-70 years old and were fire- or harvest regenerated. Mean measured tree height was 25.7 m. Sites with evidence of debris torrent or beaver disturbance were excluded. Pre-treatment buffer basal area (m^2/ha) was 41 and 43 for state and private sites, respectively.

Stream Conditions: First to third order streams. Average BFW was 4.6 and 4.1 meters for state and private sites, respectively. Average wetted width was 2.3 and 2.0 meters for state and private sites, respectively.

Harvest conditions: There was an upstream control reach for each sample reach (average length of 684 m). There was also a downstream "recovery" reach for many of these sites. Average "no touch" buffer width for the private sites was 26 m (85 ft), and ranged from 14 to 36 m (The reported mean distance was 31m and was defined as "the perpendicular distance from the stream bank to the first stump encountered within 10 m of the observer, measured every 60 m along the treatment reach." It was assumed that, on average, that the perpendicular distance of the stump to the stream will be 5 meters further from the stream than the observer (i.e., 31 m – 5 m = 26 m).). Using a similar calculation, the average "no touch" buffer width for the state sites was 46.8 m (154 ft), and ranged from 20 to 56 m. Thirteen (13) of the 15 State sites had harvest on only one bank of the river, and 4 of the 18 private sites had harvest on only one bank of the river.

Stream Length Logged: Average treatment length was 800 and 600 meters for state and private sites, respectively. Minimum treatment length target was 300m.

Time line: 2002 through 2008 - Two years of preharvest data and five years of post harvest data. Temperature analysis was limited to all of the pre-harvest data (two years for most sites and more at others) and two years of post-harvest data.

Summary of Results:

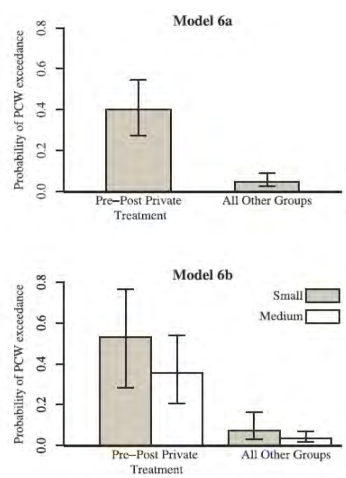


Figure 5. Point estimates for the two best supported mixed effects logistic regression models (±95% CI). Point estimates represent the probability of each comparison type exceeding the PCW. Model 6a allowed preharvest to post-harvest year-pair comparisons for private treatment reaches (PPPT) to differ from all other comparison types combined (all other groups). Model 6b is similar in formulation to model 6a except that it additionally allowed small streams to differ from medium streams.

This is the initial article in 2011 from Groom et al which describes the results associated with the Ripstream project. The project determined that timber harvested along medium or small fish-bearing streams on private lands resulted in a 40.1% probability that a preharvest to postharvest comparison of 2 years of data will detect a temperature increase of >0.3 C (i.e., violate the **Protecting Cold Water (PCW) criterion**: The PCW criteria is defined as "Anthropogenic activities are not permitted to increase stream temperature by more than 0.3 C above its ambient temperature."). State forest riparian stands did not exhibit exceedance rates that differed from preharvest, control, or downstream rates (i.e., 5%).

The authors did not report on temperature recovery.

1.2 - Variable Buffer Widths and Water Quality – Ripstream Project - 2

Groom J. D., L. Dent, L. Madsen, J. Fleuret. 2011b. Response of western Oregon (USA) stream temperatures to contemporary forest management. *Forest Ecology and Management* 262(8):1618–1629.

Location: Western Oregon coast range (45^o Latitude)

Abstract: A replicated before–after-control-impact study was used to test effectiveness of Oregon's (USA) riparian protection measures at minimizing increases in summer stream temperature associated with timber harvest. Sites were located on private and state forest land. Practices on private forests require riparian management areas around fish-bearing streams; state forest's prescriptions are similar but wider. Overall we found no change in maximum temperatures for state forest streams while private sites increased pre-harvest to post-harvest on average by 0.7 °C with an observed range of response from −0.9 to 2.5 °C. The observed increases are less than changes observed with historic management practices. The observed changes in stream temperature were most strongly correlated with shade levels measured before and after harvest. Treatment reach length, stream gradient, and changes in the upstream reach stream temperature were additionally useful in explaining treatment reach temperature change. Our models indicated that maximum, mean, minimum, and diel fluctuations in summer stream temperature increased with a reduction in shade, longer treatment reaches, and low gradient. Shade was best predicted by riparian basal area and tree height. Findings suggest that riparian protection measures that maintain higher shade such as the state forests were more likely to maintain stream temperatures similar to control conditions.

Riparian Stand and Harvest Conditions:

Sites: Thirty three (33) first and third order streams on 18 private sites and on 15 State forest sites.

Stand Conditions: Dominated by Douglas fir and red alder. Forest stands were 50-70 years old and were fire- or harvest regenerated. Mean measured tree height was 25.7 m. Sites with evidence of debris torrent or beaver disturbance were excluded. Pre-treatment buffer basal area (m^2/ha) was 41 and 43 for state and private sites, respectively.

Stream Conditions: First and third order streams. Average BFW was 4.6 and 4.1 meters for state and private sites, respectively. Average wetted width was 2.3 and 2.0 meters for state and private sites, respectively.

Harvest conditions: There was an upstream control reach for each sample reach (average length of 684 m). There was also a downstream "recovery" reach for many of these sites. Average "no touch" buffer width for the private sites was 26 m (85 ft), and ranged from 14 to 36 m (The reported mean distance was 31m and was defined as "the perpendicular distance from the stream bank to the first stump encountered within 10 m of the observer, measured every 60 m along the treatment reach." It was assumed that, on average, that the perpendicular distance of the stump to the stream will be 5 meters further from the stream than the observer (i.e., 31 m – 5 m = 26 m).). Using a similar calculation, the average "no touch" buffer width for the state sites was 46.8 m (154 ft), and ranged from 20 to 56 m. Thirteen (13) of the 15 State sites had harvest on only one bank of the river, and 4 of the 18 private sites had harvest on only one bank of the river.

<u>Stream Length Logged:</u> Average treatment length was 800 and 600 meters for state and private sites, respectively. Minimum treatment length target was 300m.
<u>Time line:</u> 2002 through 2008 - Two years of preharvest data and five years of post harvest data. Temperature analysis was limited to all of the pre-harvest data (two years for most sites and more at others) and two years of post-harvest data.

Summary of Results:

Table 5
Mean and range values for State and Private independent variables and site characteristics. Values are calculated from 15 State sites and 18 Private sites. Pre and Post refer to measurements taken preharvest or postharvest. For Shade ranges see Fig. 4; basal area and trees per hectare are BAPH and TPH, respectively.

Variable	State		Private	
	Mean	Range	Mean	Range
Gradient (%)	6.5	1.5–13.2	6.4	1.0–17.5
treatment Length (km)	0.8	0.3–1.5	0.6	0.3–1.8
Elevation (m)	350	160–570	300	3–900
Watershed area (ha)	222	72–593	208	27–626
Crown ratio	0.43	0.30–0.56	0.40	0.26–0.57
Buffer width (m)[a]	51.8	25–61	31	19–41
Bankfull width (m)	4.6	2.7–7.9	4.1	2.2–7
Wetted width (m)	2.3	1.3–3.7	2.0	1.0–3.0
Thalweg (cm)	17	9–30	15	8–24
Basal area (m /ha)				
Pre-harvest	41	19–74	43	23–73
Post-harvest	42	25–73	25	11–40
Trees per ha				
TPH pre	368	147–665	465	196–664
TPH post	387	128–645	270	111–429
Tree height (m)	26	17–37	25	18–31

[a] Means reported in Groom et al. (2011); 95% CI for State sites = 45.6 m, 58.0 m; 95% CI for Private sites = 26.7 m, 35.3 m.

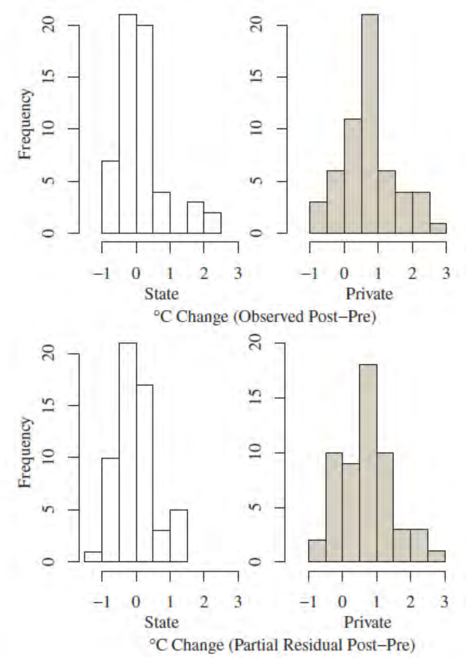


Fig. 6. Within-site pairwise differences in temperature change between post-harvest and pre-harvest values for Maximum observed data and partial residuals. Observed values are presented individually in Fig. 3. Partial-residual values represent observed values but control for site treatment reach length, upstream control temperature change, and stream gradient.

<u>Vegetation Response -</u> Average post-treatment buffer **basal area** (m^2/ha) for state sites was 42, which is an increase over pre-harvest levels (i.e., Pre-harvest levels were 41 m^2/ha). This result was most likely a result of two factors: 1) the "no-touch" buffer associated with state sites was 51.8 m, and 2) Only limited selective harvest occurred outside of this zone at many of these sites. Average private site post-harvest basal area were reduced by around half (i.e., Pre-harvest levels were 43 m^2/ha and post-harvest levels were 25 m^2/ha). Reductions at private sites may be occurring for two reasons: 1) The average "no-touch" buffer zone width was 26 m; and 2) Harvest activities outside of this zone were all "clearcut". Thus, basal area reductions following harvest is primarily a result of vegetation removal in the outer zone of the riparian zone (The riparian area was defined in this study as a 170 ft (53 m) distance from the stream, which corresponds to the riparian management area (RMA)).

<u>Stream Shade Response -</u> Private site post-harvest **stream shade** values differed significantly from pre-harvest values (mean change in Shade from 85% to 78%); however, only a small difference was observed for state site stream shade values (mean change in Shade from 90% to 89%). The shade model BasalXHeight which included parameters for basal area per hectare (BAPH), tree height, and their

interaction was best-supported: Its model weight (ω = 1.00) indicated strong relative support for this model and virtually no support for the remaining models. (BAPH and Height variables were calculated by using vegetation plot data from the edge of the bank to a perpendicular distance of 30 m, a distance at which they surmise that tree canopies have likely ceased to influence stream shade during daily periods of the greatest radiation intensity (mean measured tree height = 25.7 m).) Accordingly, stream shade conditions were shown to be a function of tree height and stand density (i.e., basal area - BAPH). Between 68% and 75% of variability in post-harvest shade may be accounted for by basal area within 30 m of the stream, tree height, and possibly blowdown. Sites with wider uncut buffers, or fewer stream banks harvested had greater basal area (i.e., BAPH). Sites with higher basal area within 30 m of the stream resulted in higher post-harvest shade.

<u>Stream Temperature Response -</u> The authors determined that maximum, Average, Minimum, and Diel Fluctuation **stream temperatures** increased as a consequence of timber harvest. Particularly, ranking models determined that by far the most critical driver for stream temperature change was shade. In addition, they generally observed an increase in maximum temperature pre-harvest to post-harvest for sites that exhibited an absolute change in shade of > 6%; otherwise, directionality appears to fluctuate.

A comparison of within-site changes in ***maximum temperatures*** from pre-harvest to post-harvest indicated an overall increase in Private site temperatures while observed changes at State sites were as frequently positive as negative: The average observed maximum change at State sites was 0.0 °C (range = −0.89 to 2.27 °C); and the average observed maximum temperature change at Private sites averaged 0.73 °C (range = −0.87 to 2.50 °C), and Private sites exhibited a greater frequency of post-harvest increases from 0.5 to 2.5 °C compared to State sites. They repeated this comparison while controlling for the effects of control reach temperature change, treatment reach length, and gradient by plotting differences in partial residuals from the Maximum temperature model Grad_Shade (each datum = model residuals + predicted effect of Shade). They found that State site differences became less extreme for positive increases (<1.5 °C) while private comparisons appeared to occupy the same range of responses. Using a linear mixed effects model ("HarvestPrivate") the authors determined that maximum temperatures at Private sites increased ***relative to State sites*** on average by 0.71 C, mean temperatures increased by 0.37 C, Minimum temperatures by 0.13 C, and Diel Fluctuation increased by 0.58 C.

The authors did not report on temperature recovery.

1.3 - Vegetation Buffers and Water Quality – Coast Range of Washington Study

Jackson, C.R., C.A. Sturm, and J.M. Ward. 2001. Timber harvest impacts on small headwater stream channels in the Coast Ranges of Washington. *JAWRA* 37(6):1533–1549.

Location: Coast Range, Washington

Abstract: We evaluated changes in channel habitat distributions, particle-size distributions of bed material, and stream temperatures in a total of 15 first-or second-order streams within and nearby four planned commercial timber harvest units prior to and following timber harvest. Four of the 15 stream basins were not harvested, and these streams served as references. Three streams were cut with unthinned riparian buffers; one was cut with a partial buffer; one was cut with a buffer of non-merchantable trees; and the remaining six basins were clearcut to the channel edge. In the clearcut streams, logging debris covered or buried 98 percent of the channel length to an average depth of 0.94 meters. The slash trapped fine sediment in the channel by inhibiting fluvial transport, and the average percentage of fines increased from 12 percent to 44 percent. The trees along buffered streams served as a fence to keep out logging debris during the first summer following timber harvest. Particle size distributions and habitat distributions in the buffered and reference streams were largely unchanged from the pre-harvest to post-harvest surveys. The debris that buried the clearcut streams effectively shaded most of these streams and protected them from temperature increases. These surveys have documented immediate channel changes due to timber harvest, but channel conditions will evolve over time as the slash decays and becomes redistributed and as new vegetation develops on the channel margins.

Riparian Stand and Harvest Conditions:

Sites: fifteen first and second order streams in the coast range of Western Washington. Four of the 15 streams basins were not harvested, and these streams served as references. Four for each harvest type ("Reference", clearcut, full buffer, and non-merchantable buffer)

Stand Conditions: Not described

Stream Conditions: 1st and 2nd order streams

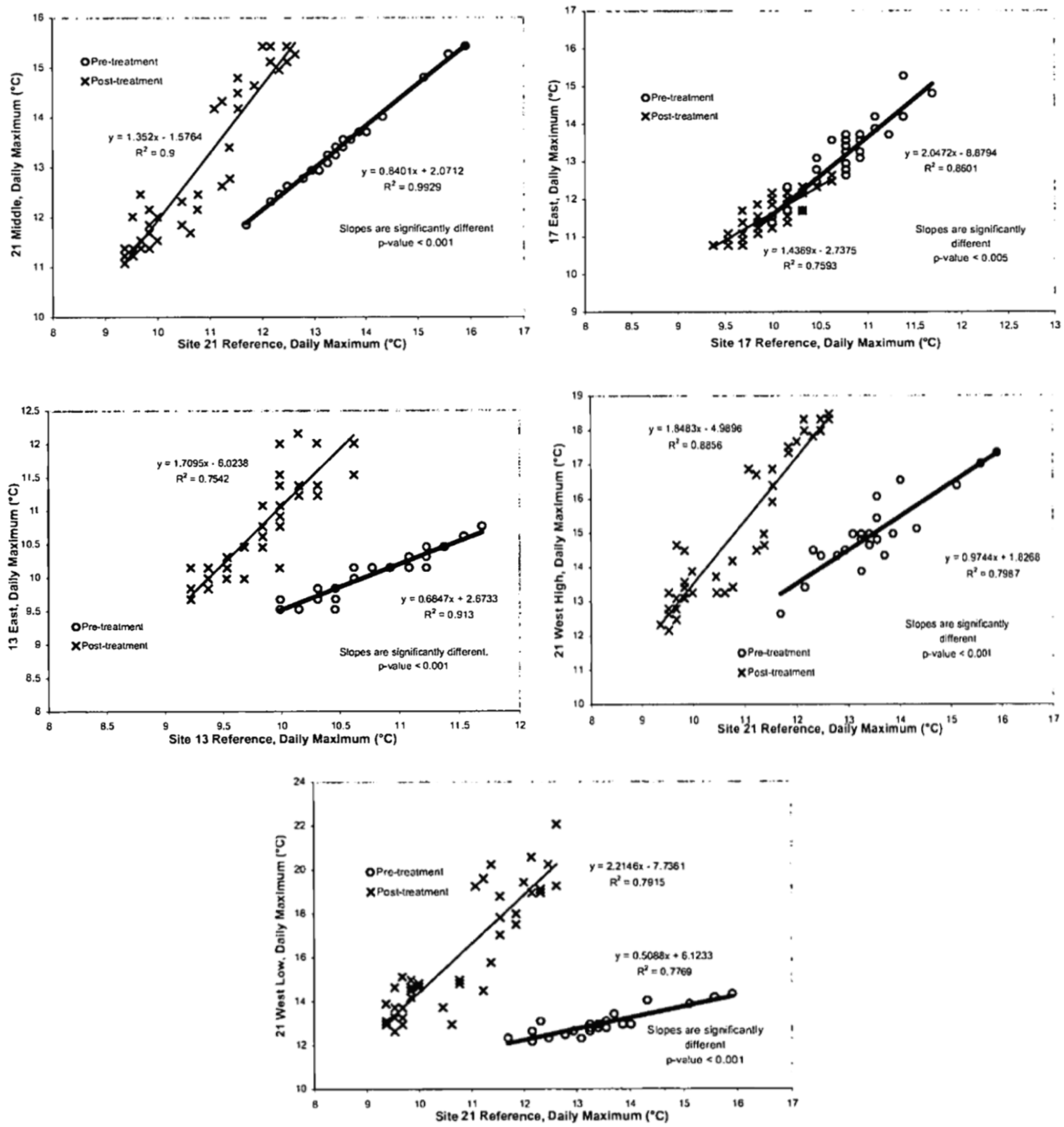
Harvest conditions: No adjacent harvest (reference stream), standard clearcut, full riparian buffer and a non-merchantable harvest (There was very little non-merchantable vegetation so these effectively became clearcut harvest.). Widths of buffers applied to the buffered streams were dictated by operational considerations, and the buffer widths were around 8 to 10 meters on each side of the stream.

Stream Length Logged: Not described

Time line: Two years of water temperature data – one pre and one post-harvest

Summary of Results:

Streams with no buffer did not have a statistically significant temperature response as a result of the streams being buried by a layer of slash that was deposited over these streams. Four of the five buffered streams became warmer (+2.0, 2.6, 2.8 and 4.9 C), and one became slightly cooler (-0.5 C) (Site 17E). The year following harvest at Site 17E had blowdown of some of the riparian vegetation, which buried 29% of the sample reach. This covering up of the stream channel confounded the temperature response for this sample reach (added additional shade), and thus it could be expected that the response temperature may have been warmer without the blowdown vegetation lying on top of 29% of the stream reach length.



Temperature recovery is not observable because there was only one year of post harvest data. However, “significant” blowdown was observed in the year following this study period (2000), indicating that temperatures may have increased due to potentially elevated solar loading from the low shade levels following blowdown of the riparian vegetation. In a follow-up study, Jackson et al 2007 reported that blowdown ranged from 33 to 64% of buffered trees with attendant effects on canopy cover.

1.4 - Variable Buffer Widths and Water Quality – Malcolm Knapp Research Forest Study - 1

Kiffney, P. M., J. S. Richardson, J. P. Bull. 2003. Responses of periphyton and insect consumers to experimental manipulation of riparian buffer width along headwater streams. *Journal of the American Water Resources Association* 40:1060-1076.

Location: Coastal British Columbia (49^{o} Latitude)

Abstract: Riparian trees regulate aquatic ecosystem processes, such as inputs of light, organic matter and nutrients, that can be altered dramatically when these trees are harvested. Riparian buffers (uncut strips of vegetation) are widely used to mitigate the impact of clear-cut logging on aquatic ecosystems but there have been few experimental assessments of their effectiveness. Forests along 13 headwater stream reaches in south-western British Columbia, Canada, were clear-cut in 1998, creating three riparian buffer treatments (30-m buffer, 10-m buffer and clear-cut to the stream edge), or left as uncut controls, each treatment having three or four replicates. We predicted that periphyton biomass and insect consumers would increase as buffer width decreased, because of increased solar flux. We used two complementary studies to test this prediction. In one study, we compared benthic communities before and after logging in all 13 streams; a second study focused on periphyton and insect colonization dynamics over 6-week periods in each of four seasons in four streams, one in each treatment. Photosynthetically active radiation, and mean and maximum water temperature, increased as buffer width narrowed. Periphyton biomass, periphyton inorganic mass and Chironomidae abundance also increased as buffer width narrowed, with the largest differences occurring in the clear-cut and 10-m buffer treatments. Photosynthetically active radiation, water temperature, periphyton biomass and periphyton inorganic mass were significantly greater in the 30-m buffer treatment than in controls during some seasons. We have shown that a gradient of riparian buffer widths created a gradient in light and temperature that led to non-linear increases in periphyton biomass and insect abundance. For example, Chironomidae abundance was generally greater in the 10-m and 30-m buffer treatments than in controls, whereas this was not always the case in the clear-cut treatment. This pattern may be due to the high sediment content of the periphyton mat in the clear-cut treatment, which potentially limited the response of some insects to increased food resources. Overall, our results indicate that uncut riparian buffers of 30-m or more on both sides of the stream were needed to limit biotic and abiotic changes associated with clear-cut logging in headwater, forested watersheds.

Riparian Stand and Harvest Conditions:

Sites: 13 headwater streams in South-Western British Columbia, Canada.

Stand Conditions: 550-650 trees/ha, average dbh 40 cm, average height 45 m, average age 70 years, and western hemlock, western red cedar, and Douglas-fir were the dominate species.

Stream Conditions: headwater streams

Harvest conditions: Riparian no-touch buffer widths of 10m and 30m, zero m, and control (unharvested).

Stream Length Logged: Ranged from 215 to 650 meters

Time line: Pre-harvest data and one year of post-harvest data collection.

Summary of Results:

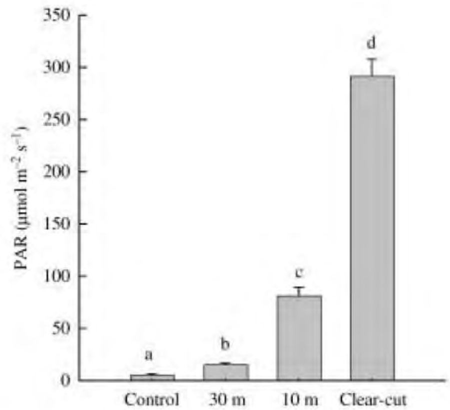


Fig. 2. Mean (1 SD) annual PAR (400–700 nm) measured in each treatment the first year after logging. Means with the same letter were not statistically different based on the within-season comparison.

Mean solar flux (Photosynthetically active radiation – PAR) reaching streams with clear-cut (zero meters), 10-m, and 30-m buffers was 58, 16, and 5 times greater, respectively compared to the control sites. This corresponds with an approximate reduction of 2.6 and 25.9 units of shade associated with the 30 m and 10 m buffers, respectively, as compared to the control. Authors concluded that "our observations suggest that additional light penetration comes through the sides of the buffer" and that there was a significant relationship between light levels and buffer width along small streams. Compared with controls, mean daily maximum summer water temperatures increased by 1.6, 3.0, and 4.8 degrees Celsius for the 30 m, 10 m and zero meter (clearcut) harvest treatments, respectively.

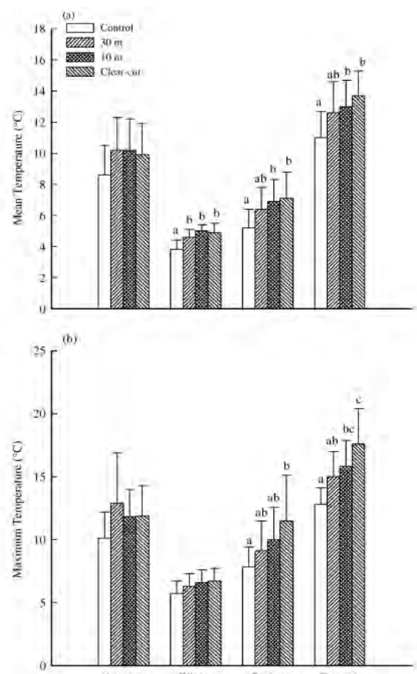


Fig. 3. Mean (1 SD) (a) daily and (b) maximum daily water temperature in each riparian treatment in each season the first year after logging. Means with the same letter were not statistically different based on the within-season comparison.

1.5 - Variable Buffer Widths and Water Quality – Malcolm Knapp Research Forest Study - 2

Gomi T., D. Moore, and A.S. Dhakal. 2006. Headwater stream temperature response to clear-cut harvesting with different riparian treatments, coastal British Columbia. *Water Resour. Res.* 42:W08437.

Location: Coastal British Columbia (49^{o} Latitude)

Abstract: A 6-year study document the effects of clear-cut harvesting with and without riparian buffers (10m and 30m wide) on headwater stream temperature in coastal British Columbia. The experiment involved a replicated paired catchment design. Pretreatment calibration relations between treatment and control streams were fitted using theme series of daily minimum, mean, and maximum temperature. Generalized least squares (GLS) regression was used to account for auto correlation in the residuals. While water temperature in streams with 10 and 30 m buffers did not exhibit marked warming, daily maximum temperature in summer increased by up to 2 – 8 C in the streams with no buffer. The effectiveness of the buffers may have been maximized by the north-south orientation of the streams, which meant that the streams would be well shaded from late morning to early afternoon by the overhead canopy, even under the 10 m buffer. The variation in response for the no-buffer treatments is consistent with the differences in channel morphology that influence their exposure to solar radiation and their depth. Relations between treatment effect and daily maximum air temperature suggested that recovery toward pre-harvest temperature conditions occurring, with rates appearing to vary with stream and by season

Riparian Stand and Harvest Conditions:

Sites: Ten locations: Three control sites, four sites at zero buffer, one site at 10m buffer, and two sites at 30m buffer.

Stand Conditions: Not presented (from Kiffney et al., 2003 - 550-650 trees/ha, average dbh 40 cm, average height 45 m, average age 70 years, and western hemlock, western red cedar, and Douglas-fir were the dominate species.)

Stream Conditions: BFW ranged from 0.5 to 4.0 meters

Harvest conditions: Riparian buffer width 10m, 30m (No logging in riparian buffers.) and zero meter buffers.

Stream Length Logged: 215 to 650 meters

Time line: Six Years: Two years pre- harvest, and post-harvest was four years.

Summary of Results:

The sites used in this analysis were similar to that of Kiffney et al., 2003. They had to remove two 10m and one 30m treatment streams in the study because these sites had less than one year of pre-treatment stream temperature data. This left only one 10 m, and two 30m buffered streams for this study. Treatment effects from harvesting were most strongly expressed for daily maximum temperature, particularly in summer. The summer daily maximum temperature increased 4.1 C for the 10m buffer, which indicated a significant treatment effect. The 30 m buffers resulted in a 1.1 and 1.8 C increase of the daily maximum temperatures: 1.8 C treatment effect was statistically significant, but the 1.1 C treatment effect was not.

Temperature recovery rates were not presented for the riparian buffered streams.

1.6 - Variable Buffer Widths and Water Quality – Westside Type N Buffer Study – CEMR

Schuett-Hames., D., A. Roorbach, and R. Conrad. 2011. Results of the Westside Type N Buffer Characteristics, Integrity and Function Study – CEMR Final Report. December 14, 2011

Location: Western Washington

Executive Summary Conclusions: This study provides insights into the harvest unit-scale effects of the westside Type Np riparian prescriptions on riparian stand condition, and riparian processes and functions including tree fall, wood recruitment, channel debris, shade, and soil disturbance. The nature and magnitude of responses varied, depending on whether the reaches were clear-cut or buffered, and in the case of the buffered reaches, on the magnitude of post-harvest disturbance from wind-throw. The study evaluated prescription effectiveness by comparing the treatments with unharvested reference sites of similar age. Since many of the FFR resource objectives for Type Np streams are intended to protect amphibians and downstream fish and water quality, the results of this study do not provide a complete story of prescription effectiveness. Combining the results of this study with sub-basin scale studies that examine the effects of the prescription on aquatic organisms and exports of heat, sediment and nutrients to fish-bearing streams will provide a more complete assessment of prescription effectiveness.

Riparian Stand and Harvest Conditions:

Sites: 24 non-fish bearing headwater streams in the western hemlock zone of western Washington

Stand Conditions: Randomly selected sites to provide an unbiased estimate of variability associated with the prescriptions when applied in an operational timber harvest setting under a range of site conditions across western Washington. Mean common tree height was 95 feet, and ranged from 60 to 128 feet. The mean site index was 122.

Stream Conditions: Mean bankfull width was 6 feet, and ranged from 3.1 to 11.4 feet.

Harvest conditions: Eight sites had clear-cut harvest to the edge of the stream (clear-cut patches), thirteen had 50 foot wide no-cut buffers on both sides of the stream (50-ft buffers), and three had circular no-cut buffers with a 56 foot radius around the perennial initiation point (PIP buffers). An un-harvested reference reach was located in close proximity to each treatment site (not within 100 feet of the treatment site).

Stream Length Logged: Both sides of a Type Np stream had to be harvested under the westside Type Np riparian buffer prescriptions for at least 300 ft (except for circular perennial initiation point buffers) without a stream adjacent road.

Time line: Data were collected one year after harvest (2004), again in 2006 (three years after harvest), and in 2008 (five years after harvest).

Summary of Results:

The first year following harvest stream shade decreased 13.4 units of shade for the 13 sites with a 50-ft buffer.

In the years following harvest, tree mortality rates exceeded 50% at three of the 50-ft buffer sites. Mean tree mortality was 68.3% for these buffers over the five year period, and exceeded 90% in one case. The mean density of the remaining live trees was 62.8 trees/acre. The channels received a large pulse of LWD input from wind-thrown trees, however most wood was suspended over or spanning the channel and mortality has reduced the supply of trees available to provide future LWD. Mean overhead shade five years after harvest was about 30 units of shade lower than the reference reaches; however cover from understory plants and channel debris increased. Soil disturbance from uprooted trees in the first five years after harvest was over five times the rate for the reference reaches, but most root-pits did not deliver sediment.

The majority of 50-ft buffers (10 of 13) had tree mortality rates less than 33% over the five year post-harvest period. Mean tree mortality for these buffers was 15%, and the mean density of live trees was 140 trees/acre five years after harvest (range 59-247). Overhead shade in this group of buffers was reported 10-13 units of shade less than the reference reaches. These buffers had minimal soil disturbance from uprooted trees in the first five years after harvest.

Table 49. Descriptive statistics for stream shade metrics by patch type; one year (2004), three years (2006) and five years (2008) after harvest.

Patch Type	n	Overhead Cover (viewed from stream)		Percentage of Channel Obscured by Understory Plant Cover	
		Mean	SD[1]	Mean	SD[1]
2004					
Reference	14	89.3 %	4.4 %	14.3 %	8.3 %
50-ft buffer	13	75.9 %	15.7 %	28.9 %	16.8 %
Clear-cut	8	12.0 %	12.7 %	17.8 %	13.1 %
PIP buffer	3	54.9 %	21.2 %	37.3 %	26.4 %
2006					
Reference	13	93.3 %	4.9 %	13.3 %	4.7 %
50-ft buffer	12	80.8 %	19.9 %	31.3 %	20.2 %
Clear-cut	7	14.0 %	14.4 %	38.7 %	31.1 %
PIP buffer	3	65.0 %	13.2 %	29.4 %	14.6 %
2008					
Reference	14	90.2 %	4.6 %	16.0 %	16.8 %
50-ft buffer	13	80.6 %	15.7 %	34.7 %	21.0 %
Clear-cut	8	36.5 %	27.6 %	41.2 %	24.4 %
PIP buffer	3	61.7 %	21.4 %	47.4 %	38.1 %

[1] SD = standard deviation

1.7 - Variable Buffer Widths and Water Quality – Rogue River Siskiyou National Forest Study

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Park., C., C. McCammon, and J. Brazier. 2008. Draft Report - Changes to Angular Canopy Density from Thinning with Varying No Treatment Widths in a Riparian Area as Measured Using Digital Photography and Light Histograms.

Location: Rogue River Siskiyou National Forest, Oregon

Abstract: A study was conducted on the Rogue River Siskiyou National Forest measuring changes in Angular Canopy Density (ACD) as a result of thinning in a riparian stand. The study established varying widths of no treatment riparian buffers and measured ACD before and after thinning. The intent of the study was to add to the 1972 Brazier and Brown ACD data set and to apply the specified no-treatment widths defined by Table 3 of the Northwest Forest Plan Temperature Strategy (NFPTS) to verify that ACD remains unchanged after thinning. Digital photography was used to generate light histograms to measure ACD. The study site was clearcut in the early 1960s and was planted with Douglas-fir. The trees were 40 years old, 95 feet tall on a slope less than 30 percent and the trees were over dense and in need of overstory thinning. Thinning to the stream without a no-treatment buffer reduced ACD by 14% to 24%. As expected as the width of the no-treatment buffer increased, the loss of ACD was reduced. There was no change in ACD before and after the thinning treatment with a no treatment buffer of 50 feet. This validates the specified no-treatment width recommended in Table 3 of the NFPTS for the tree height and percent hill slope of the study site.

Riparian Stand and Harvest Conditions:

Sites: One stream with various stream buffer management scenarios applied at different locations

Stand Conditions: The study site, clearcut in the early 1960s and planted with Douglas-fir, had trees 40 years old, 95 feet tall on a slope less than 10 percent. The trees were 220 stems per acre. The stand was 98% Douglas-fir with a small mix of alder and cedar.

Stream Conditions: Not directly described in the draft report, however an image in the report indicate that the bankfull width is narrow (≈< 3 feet).

Harvest conditions: Thinning maintained the dominate trees and removed 80 to 100 stems per acre. Various "no-touch" buffer widths were maintained (i.e., 20, 40, 60, and 80 feet) with thinning occurring outside of this zone to distance of 180 ft from the stream.

Stream Length Logged: One hundred feet

Time line: Not specified

Summary of Results:

Thinning the stand from 220 stems per acre to around 120 to 140 stems per acre increased the Angular Canopy Density (ACD) over the stream by 14% in one plot and 24% in another plot (Each treatment had two reported plot values). ACD reductions were observed for at least one plot at each of the "no-touch" buffer widths (up to 80 feet). The magnitude of decrease was lower as the "no-touch" buffer width increased, with average reductions in ACD near zero with a "no-touch buffer" of 60 feet.

1.8 - Variable Buffer Widths/Thinnings and Water Quality – Stuart-Takla Study

Macdonald, J.S., E.A. MacIsaac, and H.E. Herunter. 2003. The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. *Can. J. For. Res*. 33(8): 1371–1382.

Location: Interior sub-boreal forests of northern British Columbia (55^{o} Latitude)

Abstract: Stream temperature impacts resulting from forest harvesting in riparian areas have been documented in a number of locations in North America. As part of the Stuart–Takla Fisheries–Forestry Interaction Project, we have investigated the influence of three variable-retention riparian harvesting prescriptions on temperatures in first-order streams in the interior sub-boreal forests of northern British Columbia. Prescriptions were designed to represent a range of possible harvesting options outlined by the Forest Practices Code of B.C., or associated best management practice guidelines. Five years after the completion of harvesting treatments, temperatures remained four to six degrees warmer, and diurnal temperature variation remained higher than in the control streams regardless of treatment. Initially, the high-retention treatment acted to mitigate the temperature effects of the harvesting, but 3 successive years of windthrow was antecedent to reduced canopy density and equivalent temperature impacts. We speculate that late autumn reversals in the impacts of forest harvesting also occur. Temperature impacts in this study remained within the tolerance limits of local biota. However, even modest temperature changes could alter insect production, egg incubation, fish rearing, migration timing, and susceptibility to disease, and the effects of large changes to daily temperature range are not well understood.

Riparian Stand and Harvest Conditions:

Sites: Eight first order streams in British Columbia Canada. Five harvested streams were compared to 3 control streams

Stand Conditions: Sub-Boreal Spruce biogeoclimatic zone (Engelmann Spruce Subalpine Fir zone at high elevations)

Stream Conditions: BFW range 0.6 to 3.2 meters

Harvest conditions: Three harvest conditions: 1) Low Retention Buffer – remove all merchantable timber (>15 cm and >20 cm dbh for pine and spruce-pine respectively) within 20 m of stream, 2) High Retention Buffer – Remove all large merchantable timber > 30 cm dbh within the 20-30m zone and 3) Patch cut – a high-retention along the lower 60% of the stream and removal of all riparian vegetation in the upper 40% of the watershed. Forest harvest actions outside of these buffer areas were not presented.

Stream Length Logged: 185 m to 810 m

Time line: 1.5 years before and 5 years after harvest

Summary of Results:

The authors concluded that summer stream temperatures clearly increased following forest harvesting and found that water temperatures were still elevated 5 years following treatment for all riparian buffers used in the analysis.

Canopy density conditions over the stream were shown to decrease following harvest activities, from an average condition of 76 in the control group, to 17 and 9 percent canopy density for “High” Retention buffer (B3) and “Low” Retention buffer (B5), respectively.

Summer maximum mean weekly temperature increased by an average of 2.4*C and 5 *C for the “low” retention buffers. For the “high” retention buffers, summer maximum mean weekly temperature increased by an average of 0.3*C and 1.7 *C. Several years of blowdown associated with the second listed high retention buffer and patch retention buffer increased the temperature response from this treatment. Before the blowdown event, this buffer had a temperature increase of over 1 C for the weekly average temperature condition, and it increased to near 2 C following the blowdown events. The other high retention buffer in this study had around a 0.5 C temperature increase following harvest: This reach was the largest stream, and had very little stream length exposed to cutblocks (375 m).

No temperature recover was observed after five years and windthrow in the years following harvest had resulted in higher stream temperatures.

1.9 - Variable Buffer Widths/Thinnings and Water Quality – Western Maine Project

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Wilkerson E., J.M. Hagan, D. Siegel, and A.A. Whitman. 2006. The Effectiveness of Different Buffer Widths for Protecting Headwater Stream Temperature in Maine. *Forest Science* 52(3):221–231.

Location: Western Maine (45° Latitude)

Abstract: We evaluated the effect of timber harvesting on summer water temperature in first-order headwater streams in western Maine. Fifteen streams were assigned to one of five treatments: (1) clearcutting with no stream buffer; (2) clearcutting with 11-m, partially harvest buffers, both sides; (3) clearcutting with 23-m, partially harvested buffers; (4) partial cuts with no designated buffer; and (5) un-harvested controls. Over a 3-year period we measured summer water temperature hourly before and after harvesting, above and below the harvest zone. Streams without a buffer showed the greatest increase in mean weekly maximum temperatures following harvesting (1.4-4.4 C). Stream with an 11-m buffer showed minor, but not significant, increases (1.0-1.4 C). Streams with a 23-m buffer, partial harvest treatment, and control streams showed no changes following harvest. The mean weekly maximum temperatures never exceeded the thermal stress limit for brook trout (25 C) in any treatment group. The mean daily temperature fluctuations for streams without buffers increased from 1.5 C/day to 3.8 C/day, while with 11-m buffers fluctuations increased nonsignificantly by 0.5-0.7 C/day. Water temperatures 100 m below the harvest zone in the no-buffer treatment were elevated above pre-harvest levels. We concluded that water temperature in small headwater streams is protected from the effects of clearcutting by an 11-m buffer (with >60% canopy retention).

Riparian Stand and Harvest Conditions:

Sites: 15 Study Streams

Stand Conditions: No harvest within the last 20 years. Trees at least 15 m tall and mature closed-canopy cover (>85%).

Stream Conditions: Headwater streams draining small watersheds. Mean BFW – 1.9 to 4.2 m.

Harvest conditions: Fifteen streams were assigned to one of five treatments: (1) clearcut with no stream buffer (less than 6.8 m^2/ha residual basal area); (2) a thinned 11-m buffer (thinning target of 13.7 m^2/ha) and clearcut outside of this zone; (3) a thinned 23-m buffer (thinning target of 13.7 m^2/ha) and clearcut outside of this zone; (4) partial cuts with no designated buffer (retaining at least 13.7 m^2/ha residual basal area in the harvest zone); and (5) un-harvested controls. There were three replicates of each treatment.

Stream Length Logged: 300m and was on both sides of the stream

Time line: 3 years – 2001 (Pre-harvest) and Postharvest (2002 and 2003)

Summary of Results:

Vegetation Response - Basal area values associated with "Clearcut harvest" stands in this study were reduced to levels well below the minimum target (retain at least 6.9 m^2/ha). The basal associated with the partial-harvest treatment ranged from 14.0 to 18.9 m^2/ha. Thinning targets associated with the buffered streams (11 m and 23-m) exceeded the 13.8^2/ha target in 5 of the 6 streams (only one was slightly below 13.5^2/ha).

<u>Stream Shade Response -</u> Canopy cover measured in the middle of the stream channel was reduced following harvesting efforts for the 11m thinned buffers (Average canopy cover was 94 before treatment and 84 following treatment.) Canopy closure reduced by 4 units following harvesting efforts for the 23m thinned buffers (Average canopy cover was 94 before treatment and 90 following treatment.)

<u>Stream Temperature Response -</u> The temperature increase associated with the 11m buffer ranged from 1.0 to 1.4 C. They did not report a temperature increase associated with the 23 m and partial harvest buffers. They speculated that t high subsurface groundwater flow significantly mitigated the effects of canopy removal by slowing temperature increases.

No apparent temperature recovery was observed after 3 years.

Table 3. Average (minimum, maximum) basal area and canopy closure for preharvest year (2001) and the first postharvest year (2002) for each of the 15 study streams

		Cut block basal area Mean (min, max) m^2/ha		Riparian buffer basal area Mean (min, max) m^2/ha		% Canopy closure Mean (min, max)	
Stream	Treatment	Preharvest 2001	Postharvest 2002	Preharvest 2001	Postharvest 2002	Preharvest 2001	Postharvest 2002
Kibby	0 m	23.9 (7.8, 46.8)	1.5 (0.0, 6.2)	30.1 (26.5, 32.7)	0.0 (0.0, 0.0)	95 (81, 99)	1 (0, 4)
Pierce 1	0 m	28.6 (6.2, 49.9)	1.3 (0.0, 12.5)	22.9 (9.4, 37.4)	3.6 (1.6, 6.2)	97 (90, 99)	37 (4, 80)
Skinner 1	0 m	25.9 (10.9, 40.0)	2.1 (0.0, 9.4)	22.3 (17.2, 28.1)	3.1 (0.0, 6.2)	95 (88, 98)	27 (2,88)
Bald Mt.	11 m	22.0 (6.2, 35.9)	0.0 (0.0, 0.0)	24.9 (15.6, 39.0)	15.1 (10.9, 18.7)	98 (86, 99)	84 (60, 93)
Caratunk	11 m	33.9 (20.3, 51.5)	1.7 (0.0, 9.4)	19.2 (10.9, 34.3)	13.5 (9.4, 18.7)	91 (53, 99)	92 (68, 98)
Skinner 2	11 m	26.0 (10.9, 39.0)	1.9 (0.0, 9.4)	21.8 (17.2, 28.1)	16.6 (0.0, 31.2)	93 (2, 99)	75 (3, 97)
Mass 2	23 m	32.7 (12.5, 54.6)	0.7 (0.0, 3.1)	29.6 (18.7, 42.1)	24.9 (15.6, 34.3)	95 (89, 98)	91 (83, 95)
Roxbury	23 m	21.8 (0.0, 34.3)	1.1 (0.0, 6.2)	21.3 (15.6, 28.1)	19.2 (15.6, 21.8)	96 (92, 99)	94 (89, 98)
Sanderson	23 m	20.4 (3.1, 42.1)	1.0 (0.0, 9.4)	24.9 (18.7, 29.6)	15.6 (9.4, 18.7)	91 (79, 98)	86 (58, 98)
Mass 1	Partial	24.3 (3.1, 48.3)	18.9 (3.1, 37.4)	17.2 (9.4, 24.9)	14.0 (6.2, 21.8)	96 (86, 99)	96 (88, 99)
Pierce 2	Partial	25.1 (12.5, 40.5)	14.9 (3.1, 37.4)	24.9 (17.2, 29.6)	16.1 (14.0, 18.7)	96 (93, 99)	91 (71, 98)
UpCup	Partial	33.8 (14.0, 59.3)	16.1 (3.1, 51.5)	22.3 (17.2, 29.6)	17.2 (12.5, 21.8)	87 (59, 98)	82 (49, 98)
Appleton	Control	22.3 (6.2, 37.4)	21.3 (6.2, 34.3)	14.6 (3.1, 21.8)	15.1 (3.1, 21.8)	93 (66, 99)	90 (68, 99)
Bryant	Control	23.1 (10.9, 32.7)	24.1 (14.0, 37.4)	19.2 (18.7, 20.3)	19.2 (15.6, 21.8)	97 (90, 99)	96 (94, 97)
Dud	Control	24.5 (12.5, 37.4)	23.8 (6.2, 34.3)	18.7 (14.0, 24.9)	19.8 (15.6, 28.1)	94 (76, 100)	92 (50, 100)

1.10 - Vegetation Buffers and Water Quality – Washington Headwater Stream Study

Janisch J.E., S.M. Wondzell, and W.J. Ehinger. 2012. Headwater stream temperature: Interpreting response after logging, with and without riparian buffers, Washington, USA. *Forest Ecology and Management* doi:10.1016/j.foreco.2011.12.035.

Location: Western Washington (46.5^o Latitude)

Abstract: We examined stream temperature response to forest harvest in small (<9 ha) forested headwater catchments in western Washington, USA over a seven year period (2002–2008). These streams have very low discharge in late summer (mean≈ 0.3 L s^{-1}) and many become spatially intermittent. We used a before–after, control-impacted (BACI) study design to contrast the effect of clearcut logging with two riparian buffer designs, a continuous buffer and a patch buffer. We focused on maximum daily temperature throughout July and August, expecting to see large temperature increases in the clearcut streams (n = 5), much smaller increases in the continuously buffered streams (n = 6), with the patch-buffered streams (n = 5) intermediate. Statistical analyses indicated that all treatments resulted in significant (α= 0.05) increases in stream temperature. In the first year after logging, daily maximum temperatures during July and August increased in clearcut catchments by an average of 1.5 ^oC (range 0.2–3.6 ^oC), in patch-buffered catchments by 0.6 C (range 0.1–1.2 ^oC), and in continuously-buffered catchments by 1.1 ^oC (range 0.0–2.8 ^oC). Temperature responses were highly variable within treatments and, contrary to our expectations, stream temperature increases were small and did not follow expected trends among the treatment types. We conducted further analyses in an attempt to identify variables controlling the magnitude of post-harvest treatment responses. These analyses showed that the amount of canopy cover retained in the riparian buffer was not a strong explanatory variable. Instead, spatially intermittent streams with short surface-flowing extent above the monitoring station and usually characterized by coarse-textured streambed sediment tended to be thermally unresponsive. In contrast, streams with longer surface-flowing extent above the monitoring station and streams with substantial stream-adjacent wetlands, both of which were usually characterized by fine-textured streambed sediment, were thermally responsive. Overall, the area of surface water exposed to the ambient environment seemed to best explain our aggregate results. Results from our study suggest that very small headwater streams may be fundamentally different than many larger streams because factors other than shade from the overstory tree canopy can have sufficient influence on stream energy budgets to strongly moderate stream temperatures even following complete removal of the overstory canopy.

Riparian Stand and Harvest Conditions:

Sites**:** Five streams with clearcut harvest, six streams with continuously buffer streams, and five stream with patch-buffered streams.

Stand Conditions: Even aged stands ranging from 50 to 100 years, dominated by Douglas-fir and western hemlock. Conifers in all catchments were approximately 40 m tall. The forest canopy was closed, and was "providing dense shade throughout the catchment before logging". Red alder was the dominant hardwood species, and was more common in riparian areas.

Stream Conditions: Headwater streams draining small watersheds (average of 4.9 hectare size for continuous buffered streams). Mean BFW for the continuous buffered streams was 0.6 m, and the flow rate was around 0.01 cfs (i.e., 0.3 Ls^{-1}) in the late summer. The valley floor associated with these sites was generally only a few meters wide and often the bankfull stream channel occupied the fully width of the valley floor.

Harvest conditions: In small forested watershed (< 9 ha) the following three treatments were applied: (1) clearcut (n=5); (2) continuous buffered (n= 6); and (3) patch-buffered streams (n=5). In all three treatments, the upland portions of the catchments were clearcut harvested so that these treatments differed only in the way the riparian zone was harvested. The continuous riparian buffers reported in this study range from 10 to 15 meters on each side of the stream. Correspondences with the lead author of this study clarified the following widths of the continuous "no-touch" buffer: The no-touch buffer widths were variable, but on average the continuously buffered streams were around 20 meters on each side of the stream (estimated by the lead author through the use of aerial imagery). For patch buffers, portions of the riparian forest approximately 50-110 m long were retained in distinct patches along some portions of the headwater stream channel, with the remaining riparian area clearcut harvest. There was substantial variation in the locations of the patch treatments. For clearcut treatments, overstory trees were harvested from the catchment, including the entire riparian zone.

Stream Length Logged: The mean stream length of continuous buffered treatment streams was 279 meters, however only 43% of the stream length (on average) was observed to be flowing in the first post harvest year.

Time line: A seven year monitoring period (2002-2008), with three years of post harvest temperature data collection activities.

Summary of Results:

Stream Shade Response – Stream shade was calculated from hemispherical photography, and included both canopy and topography. Shade averaged 94% over the stream channel before logging and measured shade did not differ significantly between reference and treatment reaches. Stream shade in reference sites did not change substantially (average = 94%) after logging activities. Stream shade decrease on average to 86% for the continuous buffer treatment reaches. This corresponds to an average reduction of 8 units of stream "shade" associated with this treatment.

Stream Temperature Response – The temperature statistic used in this analysis was maximum daily temperature averaged over July and August. For continuous buffered catchments, temperature changes were significantly greater than zero (α = 0.05) in the first two post-treatment years. In the third post-treatment year, the magnitude of the temperature change estimated from the statistical model was significantly different for most of the monitoring period but not significantly different from zero after Julian day 228 (≈15th August). However, the absolute temperature response is still greater than zero during the last two weeks of the monitoring period. The July –August average temperature change for the three post-treatment years for the continuous buffered streams was 0.8 ^oC (i.e., (1.06+0.89+0.38)/3 = 0.8 ^oC). Temperature response was highest at the start of the evaluation period (i.e., July) and decreased in latter parts of the summer (i.e., July 1st average temperature response was approximately 1.3 ^oC, 1.1 ^oC and 0.8 ^oC in post-treatment year one, two and three, respectively). Accordingly, the estimated average July 1st temperature change for the three post-treatment years was 1.1 ^oC.

Table 2
Mean response of each treatment group in each post-logging year. A debris flow removed all riparian understory vegetation from one patch-buffered catchment between Years 2 and 3, leading to large temperature increases, so we also present treatment group means for patch-buffered catchments with that outlier removed from the calculation of temperature response in all three post-treatment years.

Treatment	Temperature response (°C)		
	Year 1	Year 2	Year 3
Continuous buffer	1.06	0.89	0.38
Patch buffer	0.61	0.67	0.91
Clearcut harvest	1.53	1.10	0.84
Patch buffer with outlier removed	0.73	0.72	0.16

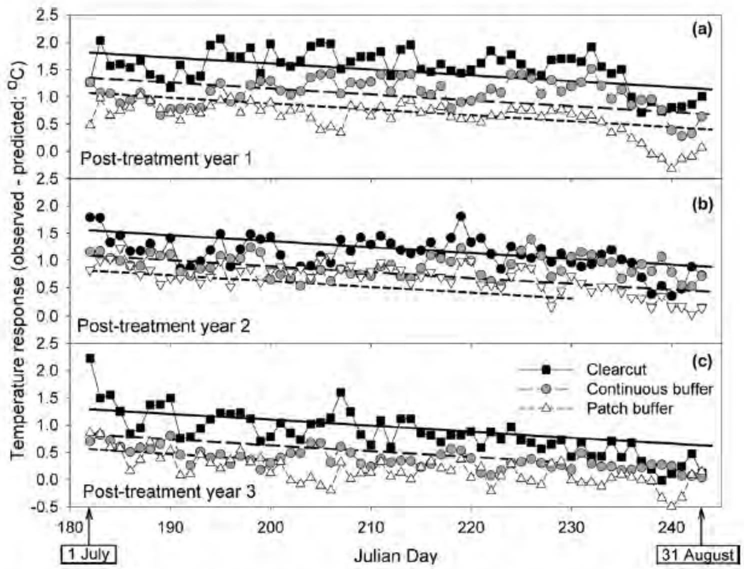

Fig. 4. Fit of the repeated-measures statistical model to the observed changes in stream temperature. Points represent the change in maximum stream temperature for each day of July and August, averaged over all catchments within a treatment group. The bold lines are the temperatures predicted from the statistical model where treatment, years post-treatment, and day of year were all fixed effects. These lines are only drawn for the dates over which the statistical model indicated a significant effect (i.e., stream temperatures were significantly different from 0.0 °C, $\alpha = 0.05$). Sample sizes per year for the clearcut, continuous, and patch treatments, respectively, were (A) Year 1: 5, 6, 5; (B) Year 2: 5, 6, 5; (C) Year 3: 3, 5, 5.

The observed variability of temperature response among catchments of the continuous buffer catchments, ranged from 0 to 2.8 °C in the first year after logging. Wetted stream length was shown to be a significant factor influencing the temperature response associated with riparian treatments, with greater responses associated with longer wetted stream lengths. In addition, the type of substrate was also shown to be a significant factor influencing temperature response, with a low response associated with coarse-substrate channels, and a large response associated streams with fine-texture streambed sediments. Shorter stream segment lengths were associated with coarse-substrate channels. The authors concluded that overall, the area of surface water exposed to the ambient environment best explained aggregated temperature response.

Temperature response successively decreased in the three years following the treatment; however there was still a significant response in temperature at post-harvest year 3.

1.11 - Vegetation Buffers and Water Quality – Oregon Department of Forestry Stream Shade Study

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Allen M., and L. Dent. 2001. Shade Conditions Over Forested Streams In the Blue Mountain and Coast Range Georegions of Oregon – ODF Technical Report #13.

Location: Coast Range of Oregon (45° Latitude)

Synopsis: The Oregon Department of Forestry implemented a shade monitoring project in basins within the north coast and northeastern regions of Oregon (ODF Blue Mountain and Coast Range georegions). Discussions in this document will focus on sites associated with the Coast Range georegion. Data were collected on both harvested stream reaches and those with no recent history of harvest. One goal of this project was to determine the range of shade levels provided over streams under varying forest management scenarios. A second goal was to investigate possible links between site and stand characteristics and shade. The authors stated that the results from the Coast Range georegion are most appropriately applied to sites managed with a no-cut buffer.

Riparian Stand and Harvest Conditions:

Sites**:** 30 sites in the Coast Range of Oregon, of which 16 sites were managed with a "no-cut" buffer (however only 13 of these sites had both shade and buffer width data collect at them).

Stand Conditions: Riparian areas are typically dominated by an alder overstory and a salmonberry/sword fern understory. Riparian conifer species typically include western hemlock, western redcedar, and/or Sitka spruce. Douglas-fir is more prevalent farther away from the stream. Pre-harvest stand ages averaged 65 years.

Stream Conditions: The average stream width was 6.6 feet, and ranged from 3.2 to 12.8 feet.

Harvest conditions: The 13 sites in the Coast Range managed with a "no-cut" buffer had an average "no-cut" buffer width of 49.3 feet (15 m). Clearcut harvest occurred outside of this no-cut zone. Unharvested stand data were collected at sites adjacent, or in close proximity, to harvested stands in order to sample shade conditions that may have existed prior to entry. In order to collect data on a wide range of unharvested stands, this sample includes both young, intensively managed areas, as well as older stands.

Stream Length Logged: The plot had a minimum length of 500 feet and maximum length of 1000 feet.

Time line: Not described

Summary of Results:

Stream Shade Response - Thirteen of 16 no-cut sites in the Coast Range georegion had both shade measurements (collected by hemispherical photography at 3 feet over the stream surface) and the buffer width measurements. Buffer width was defined as the distance from the highwater mark to the first cut tree measured every 200 feet along the sample reach. The black circles on Figure 11 in the ODF report (shown below) depict these 13 no-cut sites for the Coast Range.

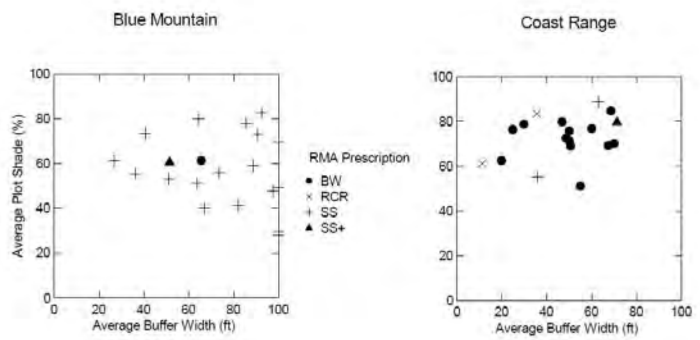
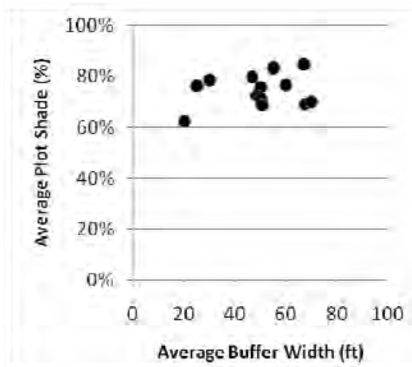


Figure 11. Average Plot Shade by average buffer width and RMA prescription for each georegion. SS = Site-Specific Prescription, SS+ = average buffer widths contain values that exceed 100 feet, BW = No-Cut Buffer, RCR = Riparian Conifer Restoration. Note: Only 38 sites had buffer width data.

Information for these 13 sites was obtained from Appendix A and B in this ODF technical report, along with the Microsoft Access database associated with this project (USEPA partially funded this project and the project database was a project deliverable). The image below illustrates this information for the 13 no-cut Coast Range sites. There is a difference in shade conditions at one of the sites presented below – The Microsoft Access database verified all of the information within Appendix A and B of this ODF technical report, except for this one shade measurement.



These 13 sites were located along small (11 sites) and medium (2 sites) stream size classes. The average stream width for these sites was 6.6 feet, and ranged from 3.2 to 12.8 feet. There were five small and medium sized unharvested streams in the Coast Range. The average shade measured at these unharvested sites was 89 % (i.e., 95, 85, 89, 93, and 83). The average difference in shade conditions associated with these 13 no-cut streams in the Oregon Coast Range was 14.5 units of shade, ranging from 4 to 27 units. The response would have been 16 units of shade reduction without the shade measurement correction described above.

<u>Stream Temperature Response -</u> Not measured

2.1 - Riparian Thinning with "Warm" Headwater Conditions – North Central B.C. Project

Mellina. E., R.D. Moore, S.G. Hinch, J. S. Macdonald. 2002. Stream temperature responses to clearcut logging in British Columbia: the moderating influences of groundwater and headwater lakes. *Can. J. Aquat. Sci.* 59:1886–1900.

Location: North-Central British Columbia (55^{o} – Latitude)

Abstract: Although the future timber supply in the northern hemisphere is expected to come from boreal and subboreal forest, little research has been conducted in these regions that examines the temperature responses of small, lake-headed streams to streamside timber harvesting. We examined the temperature patterns of two subboreal outlet streams in north-central British Columbia for 1 year before and 3 years after clearcut logging and found only modest changes (averaging 0.05-1.1 C) with respect to summer daily maximum and minimum temperatures, diurnal fluctuations, and stream cooling. A multi-stream comparative survey conducted in the same geographic region revealed that streams headed by small lakes or swamps tended to cool as they flowed downstream, and headwater streams warmed, regardless of whether or not timber harvesting took place. Stream cooling was attributed to a combination of warm outlet temperatures (promoted by the presence of the lakes) and cold groundwater inflows. A regression model revealed that summertime downstream warming or cooling in headwater and outlet streams could be predicted by upstream maximum summer temperatures and canopy cover. Lentic water bodies and groundwater inflows are important determinants of stream temperature patterns in subboreal forests and may subsequently moderate their responses to streamside harvesting.

Riparian Stand and Harvest Conditions:

Sites: Three small, lake headed, forested streams. Two streams were harvested and one was a no-cut control.

Stand Conditions: Located in subboreal spruce biogeoclimatic zone. Canopy cover > 70%.

Stream Conditions: Three small, lake headed, forested streams, <2 m BFW, headed by a small (<20 ha), relatively shallow lake.

Harvest conditions: Two sites (118/16 and 118/48) had thinning out all mature commercial timber (>15 cm dbh for lodgepole pine and >20 cm dbh for spruce and subalpine fir) within a 30 m buffer surrounding the stream and clearcut occurred outside of this zone. The third site was an unharvested control. Harvested 40 ha and 36 ha around the stream, representing 13 to 9% of the drainage area at the downstream sites.

Stream Length Logged: 607 m and 372 m for the treatment reaches and 430 m for the unharvested reach.

Time line: Four year – one year pre-harvest, and three years of post-harvest data.

Summary of Results:

Harvesting removed around 50% of streamside vegetation. Following harvest, canopy cover over the stream decreased from 88% to 48% and 51% for sites 118/16and 118/48, respectively.

Maximum stream temperatures and diurnal fluctuations increased as a result of harvesting, but the magnitude of change was lower than expected because the water entering the treatment reach was warm lake water discharge and therefore the treatment reach was a “cooling” reach.

Relative to pre-harvest patterns, maximum temperatures for the two treatment streams increased by a net average of 0.4 C, and diurnal fluctuations increase by a net average of 1.1 C. The authors concluded that these are modest changes (compared with literature values) may reflect the effect of headwater lakes on outlet stream temperature.

The dominate downstream cooling observed both before and after harvest was attributed to the combination of warm source temperature associated with the lakes and the strong cooling effect of ground water inflow through the clear-cut, as well as the residual shade provided by the partially logged riparian buffer.

No apparent temperature recovery was observed over three years.

2.2 - Riparian Thinning with "Warm" Headwater Conditions – White River Harvest Impact Project

Kreutzweiser, D. P., S. S. Capell, and S.B. Holmes (2009). Stream temperature responses to partial-harvest logging in riparian buffers of boreal mixedwood forest watersheds. *Can. J. For. Res.* 39:497–506.

Location: Ontario, Canada (48^o Latitude)

Abstract: As part of a larger study to examine the operational feasibility, ecological benefits, and environmental impacts of partial-harvest logging in riparian buffers along boreal mixedwood forest streams, we determined the effects on summer stream temperatures. Three logged study reaches were compared with three reference reaches over two prelogging and two postlogging summers. Partial-harvest logging resulted in an average removal of 10%, 20%, and 28% of the basal area from riparian buffers at the three logged sites. At the two more intensively logged sites, there were small (<10%) reductions in canopy cover (P = 0.024) and no significant changes in light at stream surfaces (P> 0.18). There were no measurable impacts on stream temperatures at two of the three logged sites. At the most intensively logged site, daily maximum temperatures were significantly higher (~4°C) for about 6 weeks in the first summer after logging than in prelogging years or at the reference sites (P< 0.001). Temperature increases were attributed to a logging-induced temporary disruption of cool water inputs from ground disturbance in a lateral-input seep area. Our results indicate that partial-harvest logging in riparian buffers of boreal mixedwood forest streams can sustain effective canopy cover and mitigate logging-induced water temperature increases.

Riparian Stand and Harvest Conditions:

Sites: Six sites - Three sites had not been previously been logged and serve as reference conditions. Three sites were logged.

Stand Conditions: Boreal mixwoods, defined as various proportions of least two of five species: white spruce, black spruce, balsam fir, trembling aspen, and white birch. Six study blocks located with a 120 km2 area. Reference sites had not been previously logged, although not discussed, it could be assumed that the "harvest" were in similar condition.

Stream Conditions: All streams originated from beaver ponds and flowed downstream through the harvest or reference blocks. Stream-reach length (distances between the beaver pond and bottom of the study reach) ranged from 240 to 600 m. Average BFW ranged from 2.6 to 6.4 meters. During the summer, wetted widths were 30-50% of the BFWs. None of the beaver ponds were "headwater" ponds.

Harvest conditions: Thirty to 100m wide riparian buffers were "thinned" to basal area reduction of 20.4% (Site WR1), 28.6% (WR2), and 10.8% (WR6) (It is important to note that the preharvest basal area volume was not presented.). There was a 5 m no entry zone. These levels were assessed by postlogging measurements of residual trees and stumps.

Stream Length Logged: 600 m, 840m and 550m.

Time line: Four years – Site WR6 was harvested during the second year so there was only one year of preharvest data for this site, and three years of post-harvest data. The other two harvest sites (WR1 and WR2) had two years of pre-harvest data and two years of post-harvest data.

Summary of Results:

All streams originated from beaver ponds and flowed downstream through the harvest or reference blocks. Accordingly, all sites exhibited as much as 6-8 C of cooling in the forested reaches over the 240-600m distances between upstream pond outflows and downstream locations during the monitoring period. This is an expected condition (Mellina et al., 2002: Story et al., 2003). The only site that had reduced cooling during the post harvest summer period was WR2 (28.6% of basal area removed). The authors inferred that is possible that shallow groundwater inflow temperatures were elevated by increase solar radiation and soil warming in the upland clearcut and parts of the riparian forest around this site.

Site WR1 (20.4% of basal area removed) had a 12% reduction of canopy cover but no increase in ambient light (PAR) reaching the stream surface. WR2 (28.6% of basal area removed) had no detectable change in canopy cover removed but average light reaching the stream surface increase (but not significantly). Canopy density and PAR were not measured for site WR6 because the "logging occurred in only small sections of one side of the stream, and mature streamside trees at WR6 tended to be further removed from the stream edges than at WR1 or WR2."

Instream temperature downstream of WR 2 (28.6% of basal area removed) increased by around 4.4 C in the first post-logging year. Temperatures returned to pre-harvest levels by the second post-harvest year. Stream temperatures at WR1 (20.4% of basal area removed) became more variable following harvest, but were within the range of "preharvest weekly temperatures". Stream temperatures at WR6 (10.8% of basal area removed) were elevated in one of the three post-harvest monitoring years.

The authors summarized that the temperature impacts were not observed on the second post harvest year (i.e., the last year of the study).

2.3 - Riparian Buffer with "Warm" Headwater Conditions – Copper Lake Watershed Study

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Curry R.A., D. A. Scruton, and K. SD. Clarke. 2002. The thermal regimes of brook trout incubation habitats and evidence of changes during forestry operations. *Can. J. For. Res.* 32: 1200–1207.

Location: Western Newfoundland, Canada (48.5^{o} Latitude)

Abstract: The thermal regimes in streambed substrate used by brook trout, *Salvelimus fontinalis* Mitchell, for incubation of embryos were examined in reference and treatment (0- and 20-m riparian buffer strips) streams in a clear-cut harvested, northern temperate forest of western Newfoundland. In these streams, incubation habitats (redds) were primarily composed of down welling surface waters with variable but minor mixing of upwelling groundwater. The result in incubation temperature were cold (<1 C) and surface water temperatures were accurate predictors of red temperatures. Both treatment streams displayed evidence of warming in the fall and spring of the 2 years beginning the year of initial harvesting. The increase was most pronounced in the stream without a riparian buffer strip. Clear-cut harvesting with and without a riparian buffer strip altered the thermal regime of surface water and the hyporheic zone in this northern temperate forest where, in addition to salmonid incubation, many biological processes take place. The potential for impacts on stream ecosystems is estimated to be high for the managed forest of the region. Future studies should strive to enhance our understanding of the hydrological connections between forests and streams on this landscape to determine the full effects of timber harvesting on the hydrology and biology of a watershed and its streams.

Riparian Stand and Harvest Conditions:

Sites: Four headwater streams originating from ponds/marshes.

Stand Conditions: Northern temperate forest dominated by balsam fir and black spruce.

Stream Conditions: Headwater streams that range from 2.5 to 5.0 m wide. Upstream areas are pond/march systems and therefore the boundary temperatures are elevated.

Harvest conditions: 19 ha were harvested in one stream without a buffer strip (Site T1-1). A harvest area of 33 ha with a 20 m buffer strip was applied to another stream. The 20m buffer strip was primarily on one side of the stream (Site T1-2). There was a control (no harvest) watershed.

Stream Length Logged: Not Provided

Time line: Five Years - 1993 through 1997. Harvest occurred November 1994 through January 1995, along with June and July 1996.

Summary of Results:

Harvest reaches were downstream of lakes and therefore stream temperatures entering the reach are elevated.

Because this study was focusing on affects to brook trout, the evaluation period was fall, winter, and spring. Summer period results were not presented.

Stream temperatures trends in the control (no harvest) basin paralleled air-temperature trends.

Compared to control reach, spring stream temperatures in 20m buffer increased by an average of 2.7 *C in the three years following treatment activities. Authors speculate the warming of stream water in the

20 m buffer stream suggests “the mechanism of temperature change was related to groundwater flow to the stream and not direct solar inputs, i.e., there was forest buffer zone to protect the stream from solar radiation.” That is, temperature increases are a result of elevated surface temperature associated with the clearcut zones warming up the groundwater which enters the stream.

The authors observed a temperature recover in the last year of the study, however it appeared that the spring period during this last year was an extremely cool period (i.e., the clearcut harvest treatment reach was cooler than pre-harvest temperature conditions.)

3.1 Stream Shade Modeling – Effects of Riparian Buffer Width, Density and Height

DeWalle, David R., 2010. Modeling Stream Shade: Riparian Buffer Height and Density as Important as Buffer Width. ***Journal of the American Water Resources Association*** (JAWRA) 46(2):323-333.

Location: Modeled shade conditions (40^{o}N Latitude)

Abstract: A theoretical model was developed to explore impacts of varying buffer zone characteristics on shading of small streams using a path-length form of Beer's law to represent the transmission of direct beam solar radiation through vegetation. Impacts of varying buffer zone height, width, and radiation extinction coefficients (surrogate for buffer density) on shading were determined for E-W and N-S stream azimuths in infinitely long stream sections at 40°N on the summer solstice. Increases in buffer width produced little additional shading beyond buffer widths of 6-7 m for E-W streams due to shifts in solar beam pathway from the sides to the tops of the buffers. Buffers on the north bank of E-W streams produced 30% of daily shade, while the south-bank buffer produced 70% of total daily shade. For N-S streams an optimum buffer width was less-clearly defined, but a buffer width of about 18-20 m produced about 85-90% of total predicted shade. The model results supported past field studies showing buffer widths of 9-11 m were sufficient for stream temperature control. Regardless of stream azimuth, increases in buffer height and extinction coefficient (buffer density) were found to substantially increase shading up to the maximum tree height and stand density likely encountered in the field. Model results suggest that at least 80% shade on small streams up to 6-m wide can be achieved in mid-latitudes with relatively narrow 12-m wide buffers, regardless of stream azimuth, as long as buffers are tall (≈30 m) and dense (leaf area index ≈6). Although wide buffers may be preferred to provide other benefits, results suggest that increasing buffer widths beyond about 12 m will have a limited effect on stream shade at mid-latitudes and that greater emphasis should be placed on the creation of dense, tall buffers to maximize stream shading.

Riparian Stand and Harvest Conditions:

Sites: Sensitivity analysis of shade production for a theoretical stream at a 40^{o}N Latitude

Stand Conditions: 30 m tall trees (variable height for the tree height modeling)

Stream Conditions: 3 m wide BFW, which results a buffer height ⁄ stream width ratio = 10 (This was used in order to produce results where the majority of energy reaching the stream centerline was transmitted by vegetation.) Variable stream aspects were modeled.

Harvest conditions: The riparian buffer was modified to illustrate the effects of various buffer attributes and resulting shade conditions.

Stream Length Logged: None

Time line: One day – summer solstice

Summary of Results:

Although the magnitude and response and the shape of the relationship might be different from field measurements, the general principles still apply: 1) vegetation closer to the stream has a greater potential to provide shade (i.e., the tree behind tree principle), and that 2) there are different intrinsic potential for shade production for streams with different aspects, but these differences vary depending on the season.

Vegetation on the north bank buffer of an east-west aspect stream can produce up to 30% of the daily shade occurring on the stream surface.

<u>Stream Shade and Buffer Density</u> –

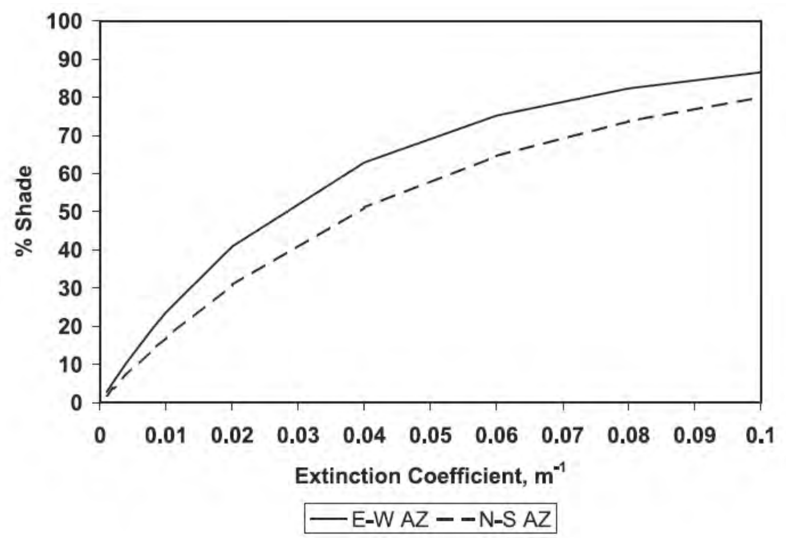


FIGURE 9. Effects of Increasing Radiation Extinction Coefficients (surrogate for buffer density) in Beer's Law (Equation 1) on Shading by Buffer Zones for Two Stream Azimuths at 40°N on the Summer Solstice. Conditions represent a small 3-m wide stream shaded by a 12-m wide and 30-m tall buffer.

The authors reported that model results suggest that buffer density is one of the most important controls on buffer shading. Relatively high shading was only achieved with the high buffer densities.

The author noted that Beer's law (used in the model in this study to estimate radiation transition through the vegetation) may underestimate total shading by buffers, as dense natural forests are known to produce >90% shading.

Stream Shade and Buffer Width –

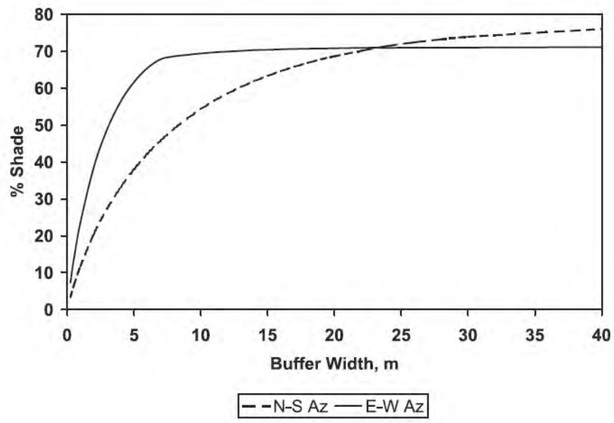
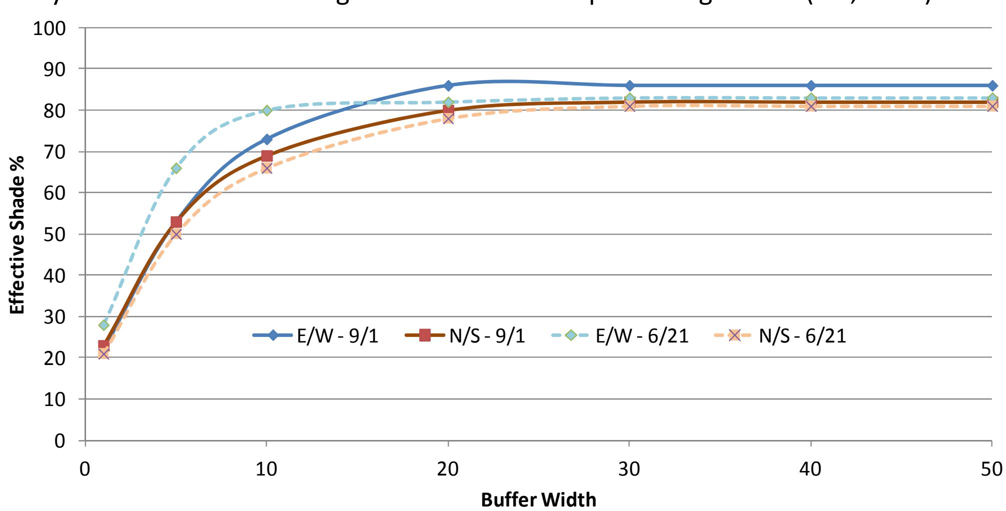
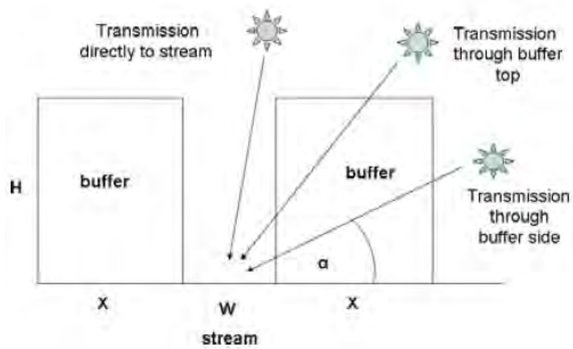


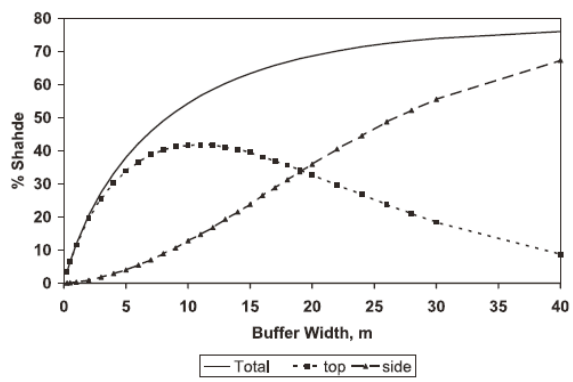
FIGURE 3. Effects of Increasing Buffer Width on Shading for Two Stream Azimuths at 40°N on the Summer Solstice. Shading with increasing buffer width indicated an optimum width of about 6-7 m for E-W azimuth stream, whereas an optimum width was less clearly defined for a N-S stream. Conditions represent a small 3-m wide stream shaded by 30-m tall vegetation with an average extinction coefficient of 0.05 m^{-1} in Equation (1).

Shading by vegetation along a N-S aspect stream gradually increased as buffer width was increased, with 88% of the total occurring in the first 18-20 meters of buffer. The "outer" buffer from 20 meters to 30 m was responsible for the remaining of the shade production (12%). Alternatively, shading by vegetation along an E-W aspect stream increased relatively rapidly for the model scenario used in his study. The author concluded that buffer widths of only about 6-7 m were needed to and further increases in buffer width up to about 30 m had little additional effect. It is important to point out that the modeling period was summer solstice. It is also important to point out that the distance associated shade production in an E-W stream becomes similar to a N-S stream as the sun is located lower in the sky during the later summer period (see image below). (Shade values in the image below were calculated using the Washington Ecology shade model - www.ecy.wa.gov/programs/eap/models.html, using 30m tall trees, canopy density of 85%, and BFW of 3.0m). In both scenarios, buffers wider than 30 meters resulted in very little change in stream shade conditions and are directly related with shade length of the modeled riparian vegetation (i.e., 30 m).



For N-S aspect streams, shading is primarily associated with the top of the vegetation (i.e., shadow length) at narrower buffer widths (< 10 meters). Beyond a 10m buffer width, sunlight traveling through the side of the buffer increases in importance towards shade production. When sunlight travels through the side of the buffer, the density of the buffer become important toward shade production. At around an 18 m buffer width, shade associate with side part of the buffer becomes the dominant shade producing feature.





Overall for E-W streams, the north-bank buffer accounted for 30% of the total shading, and south-bank buffer accounted for the remaining 70%. Shading patterns were similar to trends just described, however the transition between a top dominated vs. side dominated shading system was around an 8 m buffer width. Once again these scenarios are for the summer solstice and results would be expected to different in later summer periods.

Stream Shade and Buffer Height -

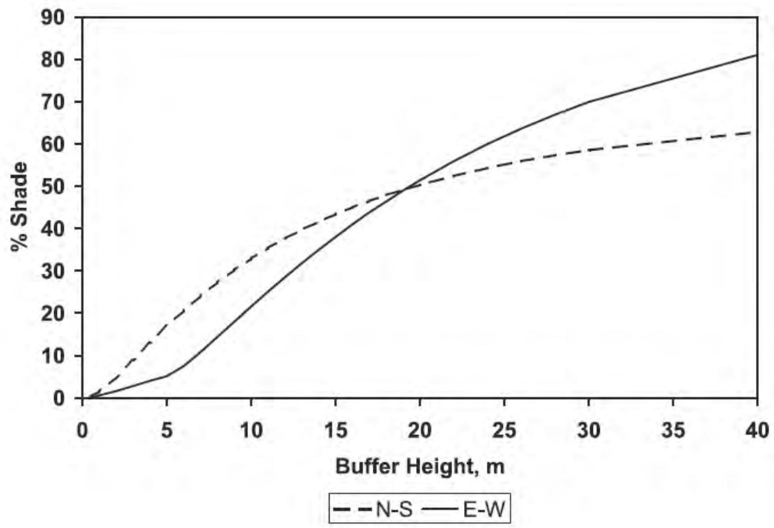


FIGURE 6. Effects of Increasing Buffer Height on Shading for Two Stream Azimuths at 40°N on the Summer Solstice. Shading increased rapidly up to heights of 30-40 m regardless of stream azimuth. Conditions represent a small 3-m wide stream shaded by a 12-m wide buffer with an average extinction coefficient of 0.05 m^{-1} in Equation (1).

Stream shading increased rapidly with increased buffer height regardless of stream azimuth. In contrast to shading due to buffer width changes, increased buffer height for N-S streams gradually increases shading along solar tracks through the tops of buffers and becomes dominant after a height of about 19 m. A similar trend was observed for an E-W stream except the transition from side dominated to top dominated occurred at around 6 meters.

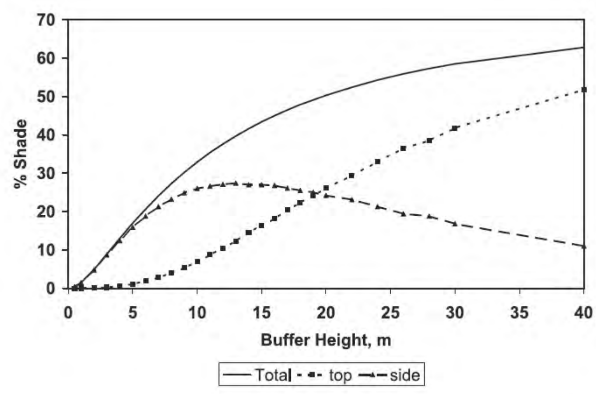


FIGURE 7. Shading Along Solar Tracks Through the Sides and Tops of Riparian Buffers on Both Banks of a N-S Azimuth Stream as Buffer Height Increased. In contrast to trends shown in Figure 3 for buffer width changes, importance of shading along solar tracks through the top of buffers gradually dominated and shading for tracks through buffer sides gradually diminished as buffer height increased. Conditions are otherwise similar to those represented in Figure 6.

3.2 Stream Shade Modeling – Potential Shadow Length Associated with Riparian Vegetation

Leinenbach, P, 2011. Technical analysis associated with this project to assess the potential shadow length associated with Riparian vegetation

Location: Modeled shadow length of riparian vegetation (45.7°N Latitude)

Abstract (Synopsis): Results indicate that a tree located on a flat hillslope along the stream **within a distance of its height** can be influential on shade production (i.e., the shadow length associated with the tree is long enough to reach the stream), and ultimately on stream temperature during the summer period (July/August). However, there are commonly occurring situations which trees outside of this distance can contribute to shade production (For example, a 100 foot tall tree located on a hillslope of 20 degrees can cast a 169 foot long shadow at 4 PM during the late summer.).

Riparian Stand and Harvest Conditions:

Sites: Sensitivity analysis of shadow length associated with vegetation at a 45.7°N Latitude

Stand Conditions: Variable tree height

Stream Conditions: Not Relevant (Only determining shadow length)

Harvest conditions: Not Relevant (Only determining shadow length)

Stream Length Logged: None

Time line: Estimates during the spring, summer, and fall period.

Summary of Results:

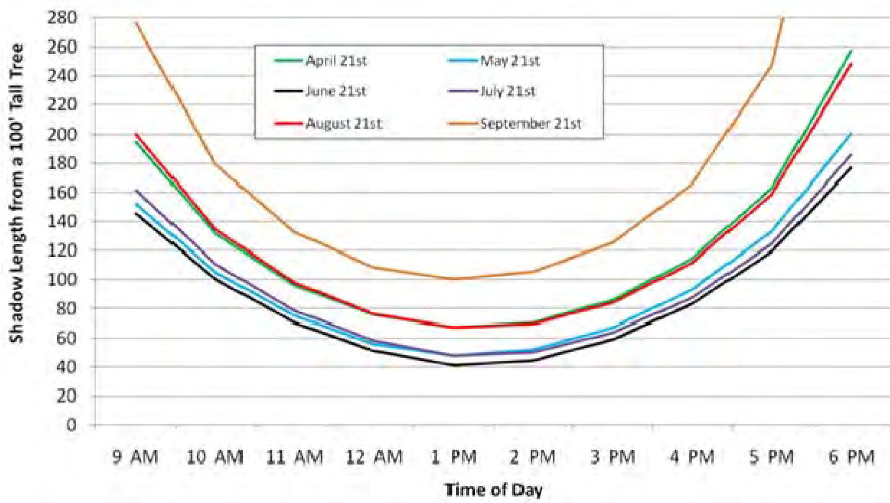
The distance of a shadow cast by a tree can be estimated by the following trigonometric equation[1]:

$$Shadow\ Length = \frac{Tree\ Height * \cos(Hillslope\ Angle)}{\tan(Sun\ Angle - Hillslope\ Angle)} - Tree\ Height * \sin(Hillslope\ Angle)$$

Solving this equation provides insight into the distance from a stream a tree could potentially provide stream shade. The tree will not have any effect of stream shade production when it is located further away from the stream than the calculated shadow length. The figure below shows that the shadow distance associated with a 100’ tall tree varies throughout the course of the day, along with the season[2]. The shadow distance increases as the sun is lower in the sky during the mid morning (9 am to 11 am) and mid afternoon (2 pm to 4 pm) periods. The figure also indicates that shadow lengths are longer during late spring and late summer, than during the summer equinox.

[1] See Attachment A below for the derivation of this equation.

[2] The “Altitude of the Sun” reference location associated with analysis was within the Tillamook Forest and the model used to determine the “Altitude of the Sun” (i.e., SolRad) was obtained from Washington Ecology’s TMDL model webpage - http://www.ecy.wa.gov/programs/eap/models.html



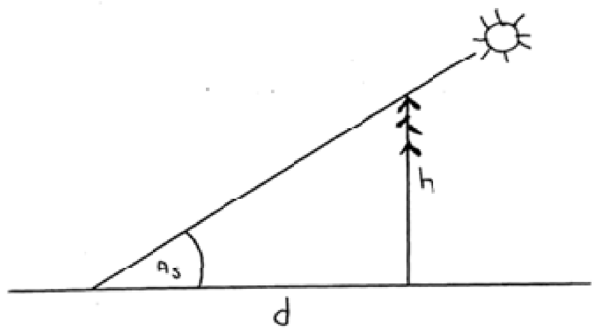
Stream temperatures are often at a maximum during the July to August period and therefore stream shade is particularly important at this time[3]. The table below presents the average shade length associated with riparian vegetation during these summer months. On a flat stream bank, the shadow length can equal the height of the tree in the afternoon, when stream temperatures are often at their daily maximum and potential solar heat loading is still high (i.e., 4 pm conditions). The table below also shows that the shadow length increases for vegetation located on sloped stream banks.

Average July 21st and August 21st shadow length (feet) associated various tree height conditions.										
Height of Tree	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm
Flat Hillslope										
20	36	25	18	13	11	12	15	20	28	43
40	72	49	35	27	23	24	30	40	57	87
60	108	74	53	40	34	36	44	60	85	130
80	145	98	71	54	46	48	59	80	113	174
100	181	123	88	67	57	60	74	100	142	217
120	217	147	106	81	69	72	89	120	170	260
140	253	172	124	94	80	84	104	140	198	304
20 Degree Hillslope										
20	120	48	28	19	16	16	22	34	64	334
40	240	96	56	38	31	33	44	68	129	668
60	360	143	84	57	47	49	65	101	193	1002
80	480	191	112	76	62	66	87	135	257	1336
100	599	239	140	95	78	82	109	169	321	1669
120	719	287	167	115	94	99	131	203	386	2003
140	839	335	195	134	109	115	152	237	450	2337

[3] July and August (and sometimes September) conditions are often associated with low stream flows, long days, and warm air temperatures, which can result in high stream temperatures. Therefore, rivers/streams often have lower assimilative capacity for the addition of heat loads.

Attachment A – Estimating Shadow Distances

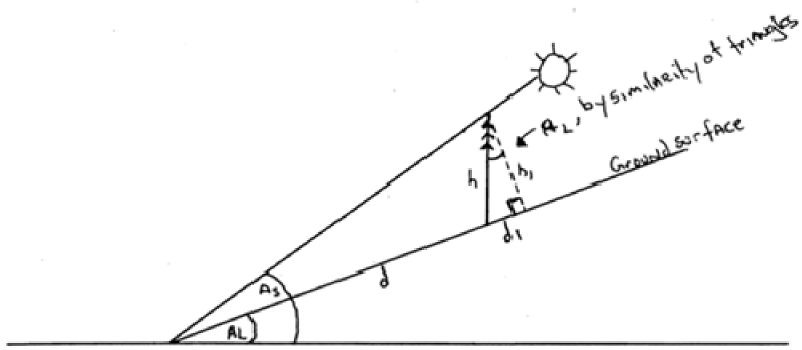
Case 1: Ground has Zero Slope



A_S = sun angle, h = tree height, and d = shadow distance

$$\tan(A_S) = \frac{h}{d} \Rightarrow d = \frac{h}{\tan\,(A_S)}$$

Case 2: Ground is sloped, with a slope angle = A_L and assume that the tree grows vertically



A_S = sun angle above the horizon, not the ground surface, h_1 = height of the line drawn from the tree tip, perpendicular to the ground, and d_1 = distance from interception of that line with the ground, to the base of the tree.

Using the same argument as in Case 1,

$$\tan(A_S - A_L) = \frac{h_1}{(d_1 + d)}$$

Solve this for d, the shadow distance:

$$d = \frac{h}{\tan{(A_S - A_L)}} - d_1$$

Since,

$$h_1 = h * \cos(A_L)\ and\ d_1 = h * \sin(A_L)$$

Thus,

$$d = \frac{h * \cos(A_L)}{\tan(A_S - A_L)} - h * \sin(A_L)$$

In other words,

$$Shadow\ Length = \frac{Tree\ Height * \cos(Hillslope\ Angle)}{\tan(Sun\ Angle - Hillslope\ Angle)} - Tree\ Height * \sin(Hillslope\ Angle)$$

Note: When A_L = 0 (flat ground), this equation reduces to Case 1, because sin(0) = 0, and cos(0) = 1

3.3 Stream Shade and Temperature Modeling - Variable Buffer Widths/Thinnings and Water Quality

Science Team Review. 2008. Western Oregon Plan Revision Draft Environmental Impact Statement – Science Team Review. http://www.blm.gov/or/plans/wopr/files/Science_Team_Review_DEIS.pdf

Location: Water quality modeling of Canton Creek, North Umpqua Basin, Western Oregon

Abstract (Synopsis):

The ODEQ evaluated the Western Oregon Plan Revision (WOPR) Alternatives using the mathematical model Heat Source Version 7.0. Heat Source simulates open channel hydraulics, flow routing, heat transfer, effective shade, and stream temperatures. Modeling was performed for a stream segment roughly 18 km in length. Modeling simulated base conditions were verified with empirical data sets for surface and instream temperature. Alternatives varied vegetation only.

This simulation suggested that for this reference stream segment (i.e., Canton Creek): (1) Current (baseline) conditions are 1-2° C above "natural thermal potential" conditions; (2) A 46 m (150 ft) no-touch buffer width produced only very small changes in stream temperature; (3) A 31 m (100 ft) no-touch buffer width produced changes in stream temperature in excess of 0.5° C; (4) and a 31 m (100 ft) variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 12 m (40 ft) 50% canopy cover outside of the "no-touch" zone) produced changes in stream temperature in excess of 0.6° C. Stream temperatures are expressed as the maximum change in the seven day average of the maximum daily temperature during the modeling period (July 12th through July 31st).
Shade and temperature response to buffer width changes was site was highly variable along the stream reach.

Riparian Stand and Harvest Conditions:

Sites: Canton Creek, North Umpqua Basin, Western Oregon

Stand Conditions: "System Potential Vegetation" which represented riparian vegetation at a mature state. The authors acknowledged that natural disturbance would reduce system potential vegetation and that it is not possible for an entire stream to be at its maximum potential everywhere, all the time. In this analysis system potential vegetation was disturbed by modeling a 50 year interval historical disturbance regime. The severity of disturbance ranged from low to very high. Pre-thinning canopy associated with large conifers is 80%.

Stream Conditions: 3rd order stream

Harvest conditions: A 46 m (150 ft) no-touch buffer width, a 31 m (100 ft) no-touch buffer width, and a 31 m (100 ft) variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 12 m (40 ft) 50% canopy cover outside of this zone).

Stream Length Logged: BLM administered land along the riparian zone of Canton Creek (Approximately 5 kilometers)

Time line: Simulation for July 12-31.

Summary of Results:

The 46 m (150 ft) no-touch buffer width produced only very small changes in stream shade and temperature.

Figure 8. Temperature increase due to harvest on all BLM administered land managed according to Alternative 1.

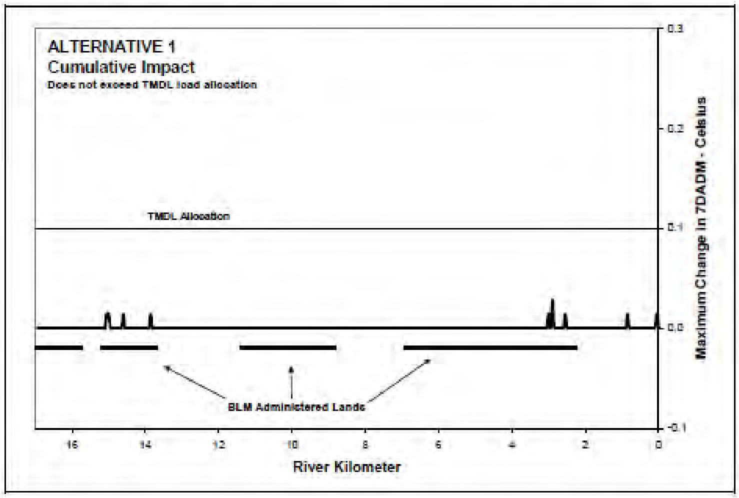
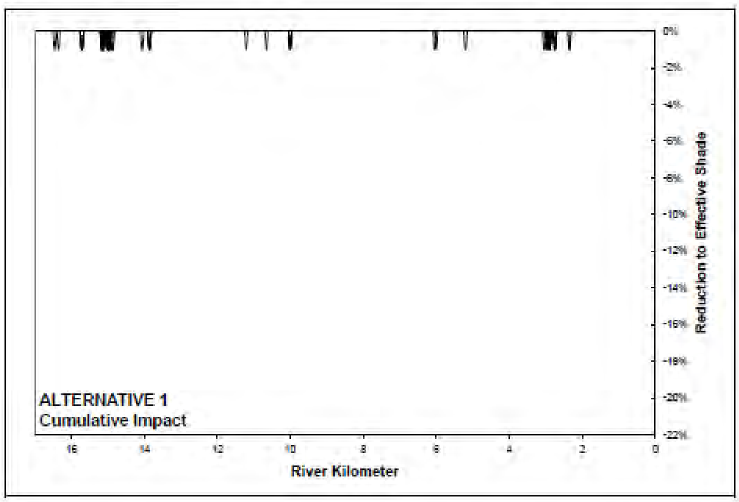


Figure 9 Reduction to effective shade due to harvest on all BLM administered land managed according to Alternative 1.



The 31 m (100 ft) no-touch buffer had shade reductions of over 10 units at several locations, while other areas had only minimum reductions (i.e. 1 unit of percent shade). There were many more areas with only 1 unit of shade reduction than as observed for the 46 m no-touch buffer.

The 31 m no-touch buffer produced changes in stream temperature in excess of 0.5° C, expressed as the maximum change in the seven day average of the maximum daily temperature during the modeling period (July 12th through July 31st). In addition, temperature increases of over 0.2 C were observed at several other locations.

Figure 14 Temperature increase due to harvest on all BLM administered land and managed with 100 ft buffers.

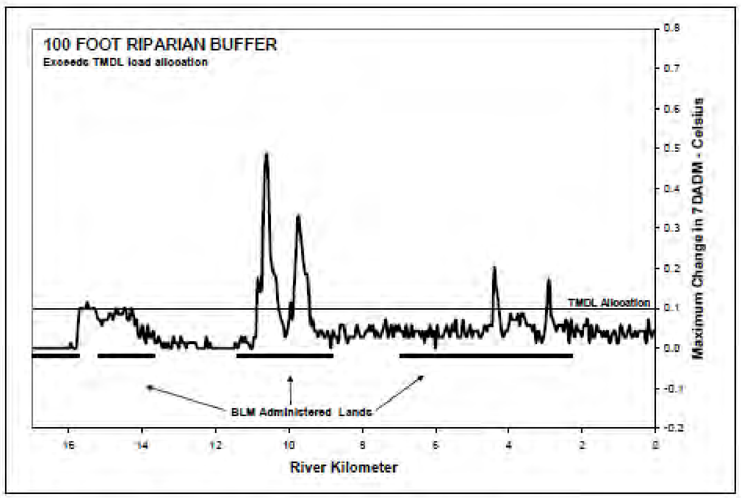
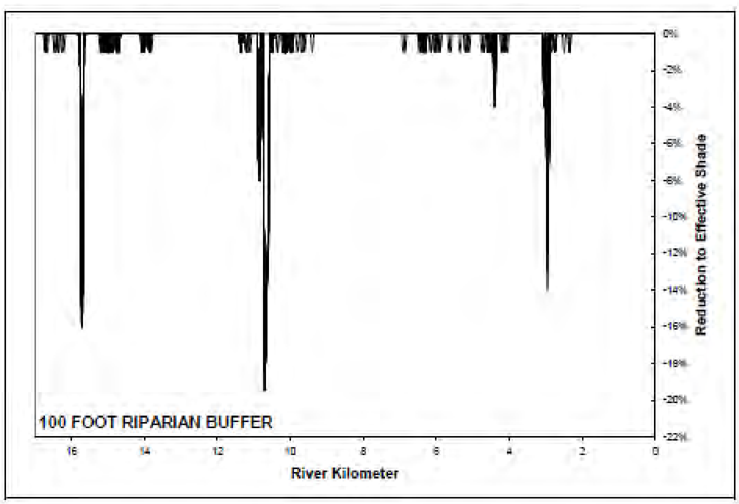


Figure 15 Change to effective shade due to harvest on all BLM administered land



The 31 m (100 ft) variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 13 m (40 ft) 50% canopy cover outside of the "no-touch" zone) had shade reduction of over 12 at several locations along the river, with two regions of the river approaching a reduction of 20 units of shade There were many more areas with only 1 unit of shade reduction than as observed for the 46 m and 31 m no-touch buffers.

A 31 m variable retention buffer produced changes in stream temperature in excess of 0.6° C, expressed as the maximum change in the seven day average of the maximum daily temperature during the modeling period (July 12th through July 31st). In addition, temperature increases of over 0.2 C were observed at several other locations.

Figure 12 Temperature increase due to harvest on all BLM administered land managed according to Alternative 2

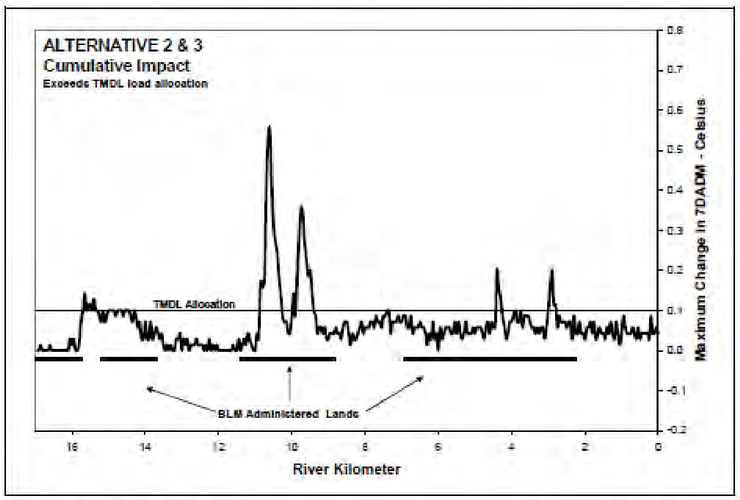
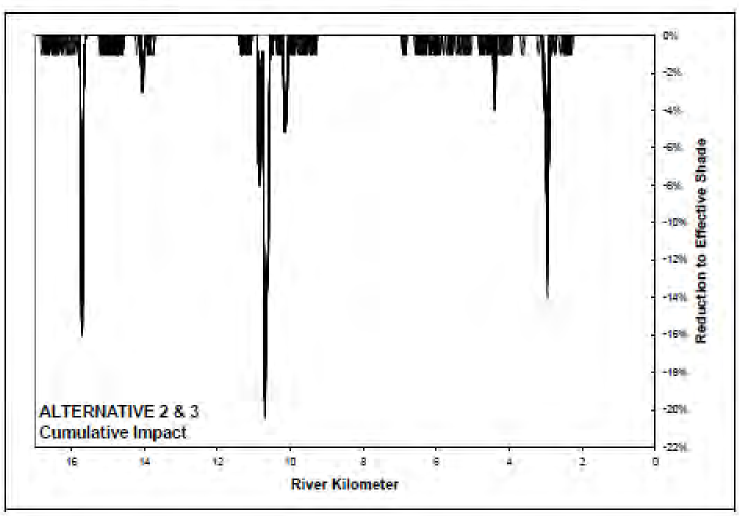


Figure 13. Reduction to effective shade due to harvest on all BLM administered land managed according to Alternative 2.



3.4 Stream Shade and Temperature Modeling - Variable Buffer Widths/Thinnings and Water Quality

Oregon Department of Environmental Quality Memorandum. 2008. Modeling result reporting document – Evaluation WOPR FEIS Riparian Area Land Use Allocation. Obtained from Ryan Mitchie at ODEQ.

Location: Water quality modeling of Canton Creek, North Umpqua Basin, Western Oregon

Abstract (Synopsis):

The ODEQ evaluated the Western Oregon Plan Revision (WOPR) Alternatives using the mathematical model Heat Source Version 7.0. Heat Source simulates open channel hydraulics, flow routing, heat transfer, effective shade, and stream temperatures. Modeling was performed for a stream segment roughly 18 km in length. Modeling simulated base conditions were verified with empirical data sets for surface and instream temperature. Alternatives varied vegetation only.

This simulation suggested that for this reference stream segment (i.e., Canton Creek): (a) A 46 m (150 ft) variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 28 m (90 ft) 50% canopy cover outside of the "no-touch" zone) produced changes in stream temperature approaching 0.2° C. Stream temperatures are expressed as the maximum change in the seven day average of the maximum daily temperature during the modeling period (July 12th through July 31st).
Shade and temperature response to buffer width changes was site was highly variable along the stream reach.

Riparian Stand and Harvest Conditions:

Sites: Canton Creek, North Umpqua Basin, Western Oregon

Stand Conditions: "System Potential Vegetation" which represented riparian vegetation at a mature state. The authors acknowledged that natural disturbance would reduce system potential vegetation and that it is not possible for an entire stream to be at its maximum potential everywhere, all the time. In this analysis system potential vegetation was disturbed by modeling a 50 year interval historical disturbance regime. The severity of disturbance ranged from low to very high. Pre-thinning canopy associated with large conifers is 80%.

Stream Conditions: 3rd order stream

Harvest conditions: A 46 m (150 ft) variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 28 m (90 ft) 50% canopy cover outside of the "no-touch" zone).

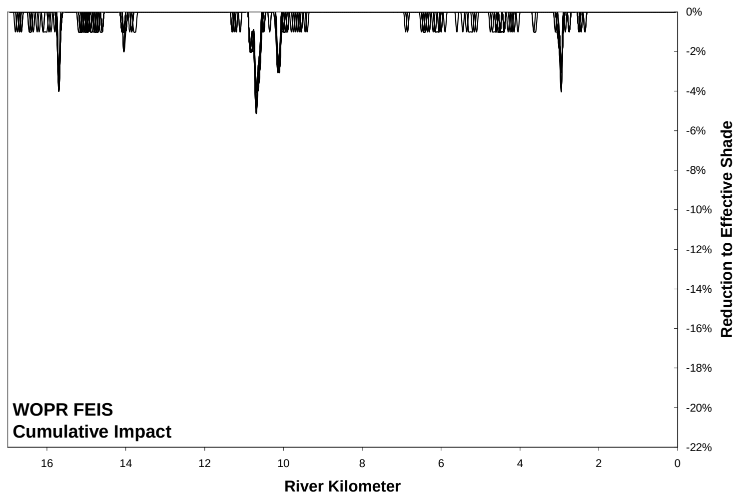
Stream Length Logged: BLM administered land along the riparian zone of Canton Creek (Approximately 5 kilometers)

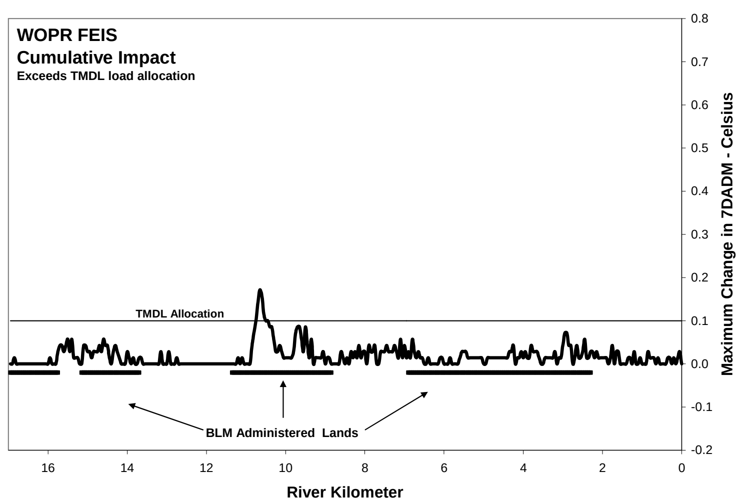
Time line: Simulation for July 12-31.

Summary of Results:

The 46 m (150 ft) variable retention buffer (i.e., 18 m (60 ft) no-touch buffer, with a 28 m (90 ft) 50% canopy cover outside of the "no-touch" zone) had shade reductions of around 4 units at several locations along the river. There were many more areas with only 1 unit of shade reduction than observed for the 46 m "no-touch" buffer.

The 46 m variable retention buffer produced changes in stream temperature approaching 0.2° C, expressed as the maximum change in the seven day average of the maximum daily temperature during the modeling period (July 12th through July 31st).





3.5 Stream Shade and Temperature Modeling - Variable Buffer Widths and Water Quality

Cristea N., and J. Janisch. 2007. Modeling the Effects of Riparian Buffer Width on Effective Shade and Stream Temperature. *Washington Department of Ecology* Publication No. 07-03-028:1–64.

Location: Water quality modeling for streams in Western Washington

Abstract: To evaluate the effects of converting riparian hardwood-dominated stands to coniferous-dominated stands on western Washington stream temperatures, we combined a shade model and water quality model to explore the stream heating potentials of three buffer-width scenarios. Changing one variable at a time, we then ran a series of model simulations for various buffer-width (30-75 feet) and harvest-length (500-1500 feet) scenarios. Results of each simulation were expressed as the change in maximum daily temperature relative to the unharvested state (i.e., upstream boundary condition).

When a 500-foot harvest unit and 50-foot buffer were then applied to our model channel, the downstream temperature of the 10-foot-wide stream increased 0.13°C relative to the upstream state. Temperature continued to rise as harvest-unit length increased, with the 1500-feet-long unit showing the most change (+0.36°C, or approximately +0.12°C per 500 feet of harvest length). Wider buffers (75 feet), in contrast, continued to dampen temperature increases for the 10-foot stream, even at a harvest-unit length of 1500 feet. Results for the 20-foot-wide stream showed a similar pattern, but temperature increases in response to harvest-unit length were higher: 0.15°C (500 feet) – 0.60°C (1500 feet), or about 0.18°C per 500 feet of harvest length. Temperature of the 10-foot-wide stream was more sensitive to buffer width than the 20-foot-wide stream. In contrast, all buffer scenarios cooled the 20-foot-wide stream less effectively, with predicted downstream temperatures converging somewhat when harvest-unit length reached 1000 feet. Inferences vary depending on the shade curve used.
Overall, results indicated that, for the stream scenarios analyzed, riparian vegetation and harvest-unit length exerted greatest control on stream temperature at lower flow rates. Conditions favoring high daily maximum stream temperatures include: shallow and wide streams, north-south channel orientation, low groundwater influx or hyporheic exchange with the channel, and low gradient.

Riparian Stand and Harvest Conditions:

Sites: Modeled streams which were designed to represent streams in western Washington (46.65° Latitude).

Stand Conditions: Represent baseline stand condition for red alder (50 ft tall). Assumed uniformed canopy closure in buffer, and a uniformed buffer width.

Stream Conditions: Variable stream widths (10 ft and 20 ft), and stream aspects (zero, 45 and 90).

Harvest conditions: Variable “no-touch” buffer widths were tested (i.e., 30ft, 50 ft, and 75 ft) with a vegetation height of 50 feet tall (represents baseline stand condition for red alder). Harvest unit on only one side of the stream. Angular canopy density for each buffer width condition was estimated using two models (Brazier and Brown, 1973; Steinblums et al., 1984), which was used as an estimate of canopy cover condition in the “Shade.xls” model. Shade conditions associated with the various channel width and buffer combinations were modeled for temperature response using QUAL2Kw.

Buffer Width (feet)	Angular Canopy Density (%)	
	Brazier and Brown, 1973	Steinblums et al., 1984
30	55	30
50	70	45
75	75	60

Stream Length Logged: Fiver Lengths – 500 ft, 750 ft, 1000 ft, 1250 ft, and 1500 ft
Time line: Modeled August 1st

Summary of Results:

Effective Shade – The effect of riparian density has a very dramatic effect on stream shade conditions for both 10- and 20 foot wide streams. N-S aspect stream channels have the lowest shade conditions during mid day which is associated with maximum air temperatures and solar loading is near the daily peak values. E-W aspect streams may experience a “double sunrise and sunset”: One daily maximum solar loading in the early morning; and the other maximum solar loading in the late afternoon.

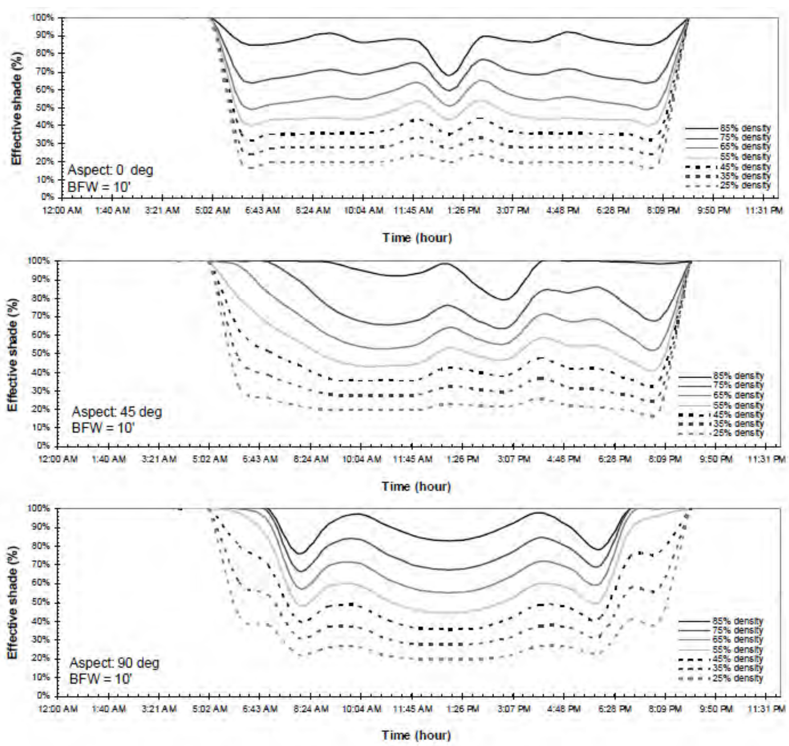


Figure 7. Daily effective shade for three channel orientations provided by a 120-foot buffer of canopy cover varying from 25% to 85%. Channel width is 10 feet.

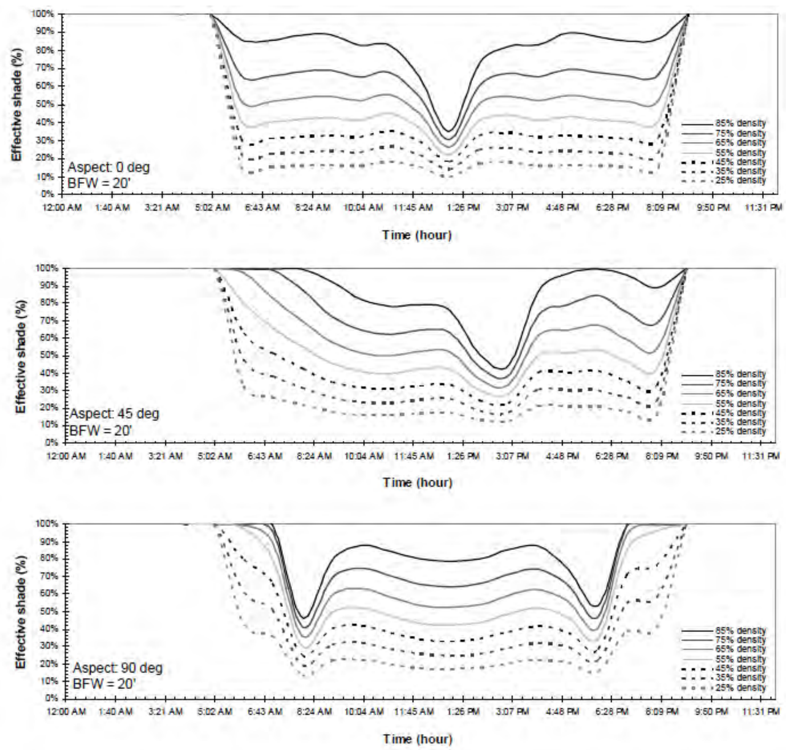


Figure 8. Daily effective shade for three channel orientations provided by a 120-foot buffer of canopy cover varying from 25% to 85%. Channel width is 20 feet.

<u>Stream Temperature</u> –

The baseline vegetation conditions used in the temperature modeling scenarios was a 50' tall tree. The canopy cover associated with the modeling was calculated using two different canopy cover models (Brazier and Brown (1973) and Steinblums et al. (1984)). There were two channel widths in the analysis. Effective shade conditions were calculated for each of these scenarios, and was an input parameter into the temperature model (Qual2kw).

Channel Width (feet)	Riparian Buffer Differences	Brazier and Brown (1973) Canopy Cover (CC) Model		Steinblums et al. (1984) Canopy Cover (CC) Model	
		Shade Change	Temperature Change (A 1500' long channel)	Shade Change	Temperature Change (A 1500' long channel)
10	23m to 15 m	4	0.11 C	8	0.17 C
	23m to 9 m	12	0.27 C	16	0.33 C
20	23m to 15 m	5	0.01 C	10	0.04 C
	23m to 9 m	16	0.05 C	18	0.21 C

Canopy density was shown to be more influential on **stream temperature** response in the narrow 10 ft channel, than it was observed for the wider channels (20 ft).

For a 10 foot wide stream channel, stream temperatures in creased between 0.11 and 0.17 C as the riparian buffer width was reduced from 23 m to 15 m for a 472 m channel length. The corresponding change in shade conditions was 4 to 8 units of shade reduction, respectively. As riparian buffers width was reduced from 23 m to 9 m for a 472 m channel length, stream temperatures increase from 0.27 to 0.33 C. The corresponding change in shade conditions was 12 to 16 units of shade reduction, respectively.

Temperature results associated with the 20ft channel indicate that the “shadow length” from the 50’ tall vegetation was not sufficient to cast a proper shadow across the stream leading to very low shade conditions (see image below). Accordingly, despite greater shade conditions associated with the wider riparian buffers, the temperature response was muted in the 20ft stream channel. In other words, shade levels for the 20ft stream are low for all buffer width conditions and therefore stream temperature increases are high for all scenarios.

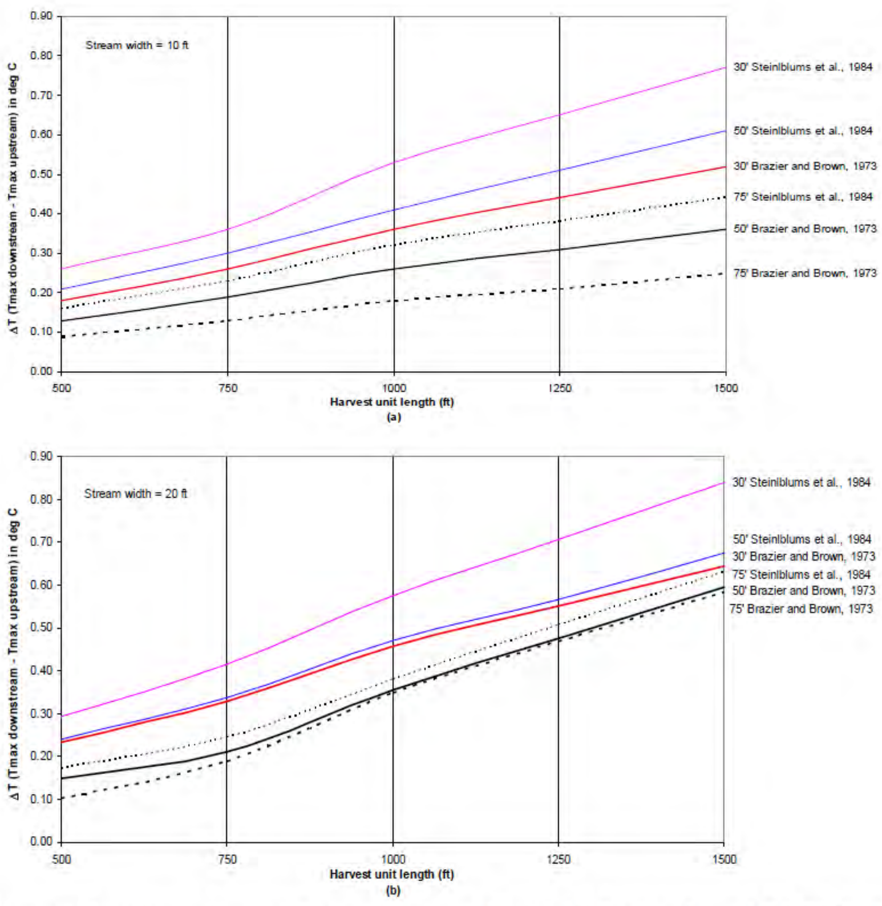


Figure 11. Stream temperature response in the (a) 10-foot-wide and (b) 20-foot-wide streams for different buffer widths and shading curves.

4.1 - Effects of Riparian Thinning - Density Management Study - 1

Chan S., P. Anderson, J. Cissel, L. Larson, and C. Thompson. 2004a. Variable density management in Riparian Reserves: lessons learned from an operational study in managed forests of western Oregon, USA. ***For. Snow Landsc. Res*** 78(1/2):151-172.

Location: Western Oregon

Abstract:

A large-scale operational study has been undertaken to investigate variable density management in conjunction with riparian buffers as a means to accelerate development of late-seral habitat, facilitate rare species management, and maintain riparian functions in 40–70 year-old headwater forests in western Oregon, USA. Upland variable retention treatments include matrices of four thinning intensities embedded with patch openings and leave islands. Additionally, four types of streamside buffer delineation are being examined. The study includes 13 sites, each averaging about 100 hectares. Metrics of stand structure and development, microclimate, aquatic ecology, invertebrate populations and biology, lichens, and bryophytes, are being evaluated with respect to overstory thinning, patch openings and riparian buffer treatments. Results of this study can contribute to a development of riparian buffer delineations based on ecological functions and linkages to upland forest conditions.
Early findings suggest that the near-stream riparian environment provides critical functions and habitat for diverse populations of organisms. Using large, operational experimental plots we are able to demonstrate statistically significant initial responses to a complex suite of treatments for selected vegetation and environment parameters. It remains to be determined if the experimental design will be robust for long-term temporal trends in vegetation and microclimate, or synthesis with companion studies focusing on invertebrates or aquatic-dependent fauna. Meaningful interdisciplinary inferences are more likely achieved if integration is explicitly incorporated into study design and implementation, rather than post-study component synthesis. Conducting a large-scale interdisciplinary study with adaptive management implications requires a strong commitment to collaboration between management and research partners.

Riparian Stand and Harvest Conditions:

Sites: The DMS includes 12 sites dispersed among BLM lands in both the Coast Range and the west-side of the Cascade Mountains in western Oregon. On seven sites, the prescribed thinning treatments were first entries to the regenerating stands. Thinning treatments were applied to an additional five sites that had been previously thinned.

Stand Conditions: Characteristics of 40-to70 year old forests on BLM lands throughout western Oregon.

Stream Conditions: Not specifically presented but assume similar to Anderson et al (2007) description - First and 2nd order streams and active channel ranged from 0.2 to 3.7 m (averaged 1.1 m). Nearly 70% of the streams were summer intermittent.

Harvest conditions: The Density Management Study (DMS) consists of four thinning treatments, each applied to 20 ha or larger treatment units within 80 ha or larger sites. The thinning treatments include: 1) Unthinned control – 500 to 750 trees per ha (tph) greater than 12.7 cm dbh. 2) High density retention – 70 to 75% of area thinned to 300 tph, 25 to 30% unthinned Riparian Reserves or leave islands. 3)

Moderate density retention – 60 to 65% thinned to 200 tph, 25 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings. 4) Variable density retention – 10% thinned to 100 tph, 25 to 30% thinned to 200 tph, 25 to 30% thinned to 300 tph, 20 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings.

Stream Length Logged: Not specifically presented but assume similar to Anderson et al (2007) description - Variable – results summarized from 40 transects and results for each transect was a discrete value (i.e., there was no cumulative effect).
Time line: None presented

Summary of Results:

This is an initial document associate with the Density Management Study describing the first year of data.

Thinning to 200 tph decreased stand density by up to 70%, but only increased available light from 13–19% in the unthinned buffer to about 29% in the thinned buffer. The increase in light (~10% absolute increase) associated with heavy thinning to 200 tph is small relative to the number of trees removed. Light values derived from the hemispherical canopy images indicate that upland thinning to 200 tph increases available light within the first 20 m of the adjacent riparian buffer. Thus, thinning may result in some significant (but potentially transitory) changes in stand light and microclimate conditions.

4.2 - Effects of Riparian Thinning - Density Management Study - 2

Chan S., D. Larson, and P. Anderson. 2004b. Microclimate Pattern Associated with Density Management and Riparian Buffers – An Interim Report on the Riparian Buffer Component of the Density Management Studies.

Location: Western Oregon

Abstract:

Riparian Stand and Harvest Conditions: (assumed similar to that of Chan et al 2004b)

Sites: The DMS includes 12 sites dispersed among BLM lands in both the Coast Range and the west-side of the Cascade Mountains in western Oregon. On seven sites, the prescribed thinning treatments were first entries to the regenerating stands. Thinning treatments were applied to an additional five sites that had been previously thinned.

Stand Conditions: Characteristics of 40-to70 year old forests on BLM lands throughout western Oregon.

Stream Conditions: Not specifically presented but assume similar to Anderson et al (2007) description - First and 2nd order streams and active channel ranged from 0.2 to 3.7 m (averaged 1.1 m). Nearly 70% of the streams were summer intermittent.

Harvest conditions: The Density Management Study (DMS) consists of four thinning treatments, each applied to 20 ha or larger treatment units within 80 ha or larger sites. The thinning treatments include (Fig. 3): 1) Unthinned control – 500 to 750 trees per ha (tph) greater than 12.7 cm dbh. 2) High density retention – 70 to 75% of area thinned to 300 tph, 25 to 30% unthinned Riparian Reserves or leave islands. 3) Moderate density retention – 60 to 65% thinned to 200 tph, 25 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings. 4) Variable density retention – 10% thinned to 100 tph, 25 to 30% thinned to 200 tph, 25 to 30% thinned to 300 tph, 20 to 30% unthinned Riparian Reserves or leave islands, 10% circular patch openings.

Stream Length Logged: Not specifically presented but assume similar to Anderson et al (2007) description - Variable – results summarized from 40 transects and results for each transect was a discrete value (i.e., there was no cumulative effect).

Time line: None presented

Summary of Results:

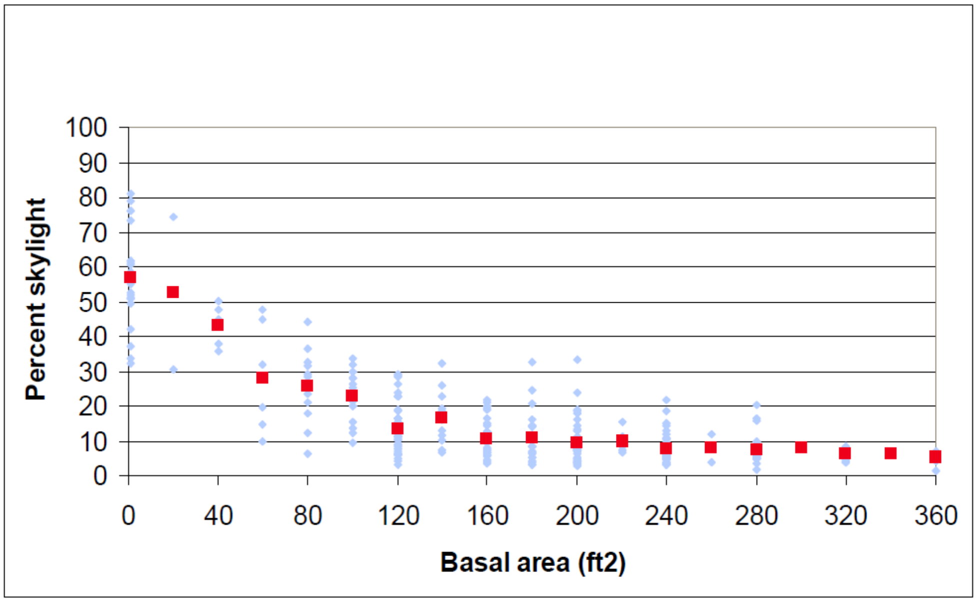


Figure 7a. Basal area and corresponding percent skylight derived from 6 Density Management Study sites during summer conditions. Scatter points represent individual plot values while squares represent means.

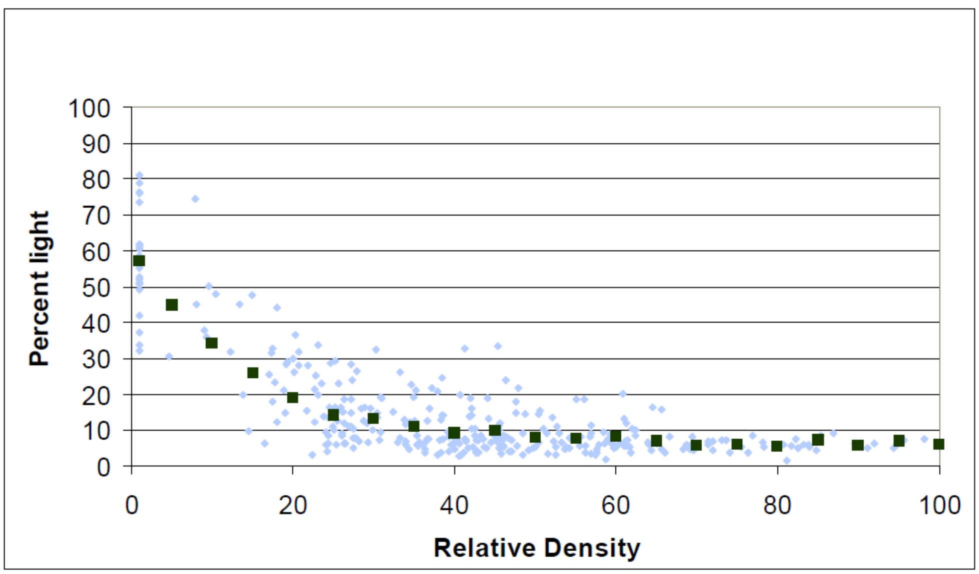


Figure 7b. Percent skylight in relation to Curtis' Relative Density. Derived from six Density Management Study sites during summer conditions. Scatter points represent individual plot values while squares represent means.

Commercial thinning substantially increased understory light when stand density was decreased to a basal area (BA) less than 120 ft^2/ac, or in other terms, below a relative density (RD) of 30. At BA ≥ 160 ft^2/ac, and RD ≥40, light levels average about 10% of open conditions, similar to those of unthinned stands. The corresponding BA of 120 and 160 ft^2/ac, in units of m^2/ha, is 28 and 37, respectively.

4.3 - Effects of Riparian Thinning - Density Management Study - 3

Anderson P. D., D. J. Larson, and S.S Chan. 2007. Riparian Buffer and Density Management Influences on Microclimate of Young Headwater Forests of Western Oregon ***Forest Science*** 53(2):254-269.

Location: Western Oregon

Abstract: Thinning of 30- to 70-year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) stands is a common silvicultural activity on federal forest lands of the Pacific Northwest, United States. Empirical relationships among riparian functions, silvicultural treatments, and different riparian buffer widths are not well documented for small headwater streams. We investigated buffer width and density management effects on riparian microclimates of headwater streams in western Oregon. Spatial variations in stand density, canopy cover, and microclimate were measured along transects extending from stream center upslope into thinned stands, patch openings, or unthinned stands, with riparian buffers ranging from <5 m up to 150 m width. For treated stands, summer mean daily air and soil temperature maxima increased, and mean daily humidity minima decreased with distance from stream. Microclimate gradients were strongest within 10 m of stream center, a distinct area of stream influence within broader riparian areas. Thinning resulted in subtle changes in microclimate as mean air temperature maxima were 1 to 4°C higher than in unthinned stands. With buffers 15 m or greater width, daily maximum air temperature above stream center was less than 1°C greater, and daily minimum relative humidity was less than 5% lower than for unthinned stands. In contrast, air temperatures were significantly warmer within patch openings (+6 to +9°C), and within buffers adjacent to patch openings (+3°C) than within unthinned stands. Buffers of widths defined by the transition from riparian to upland vegetation or topographic slope breaks appear sufficient to mitigate the impacts of upslope thinning on the microclimate above headwater streams.

Riparian Stand and Harvest Conditions:

Sites: Five sites – Four along the Oregon Coast Range, and one site in the western edge of the Cascade Range in Oregon. In total, data from 40 transects distributed among 26 reaches across five sites were used in the analysis.

Stand Conditions: All sites were within the western hemlock vegetation zone and Douglas-fir dominated the 45- to 65 year old forests. Other vegetation in the stands included western hemlock and western red cedar. Basal area in unthinned stands ranged from about 44 to 58 m^2/ha.

Stream Conditions: First and 2nd order streams and active channel ranged from 0.2 to 3.7 m (averaged 1.1 m). Nearly 70% of the streams were summer intermittent.

Harvest conditions: There were two no-cut buffer treatments with clearcut harvest occurring outside of this inner zone: 1) “B1-P”– The no-cut buffer width average 69m; and 2) “VB-P” - The no-cut buffer width average 22m wide. There were several no-cut buffer treatments with thinning activities occurring outside of this inner zone: 1) “B1-T” (average 69m inner zone no-cut width); 2) “VB-T” (average 22m inner zone no-cut width); and “SR-T” (average 9m inner zone no-cut width). Thinning was to a density of 198 tree per hectare (tph). Unharvested controls reaches had around 500 to 750 tph (Chan et al., 2004). Unharvested control treatments were also included in the study (“UT”).

Stream Length Logged: Variable – results summarized from 40 transects and results for each transect was a discrete value (i.e., there was no cumulative effect).
Time line: None presented

Summary of Results:

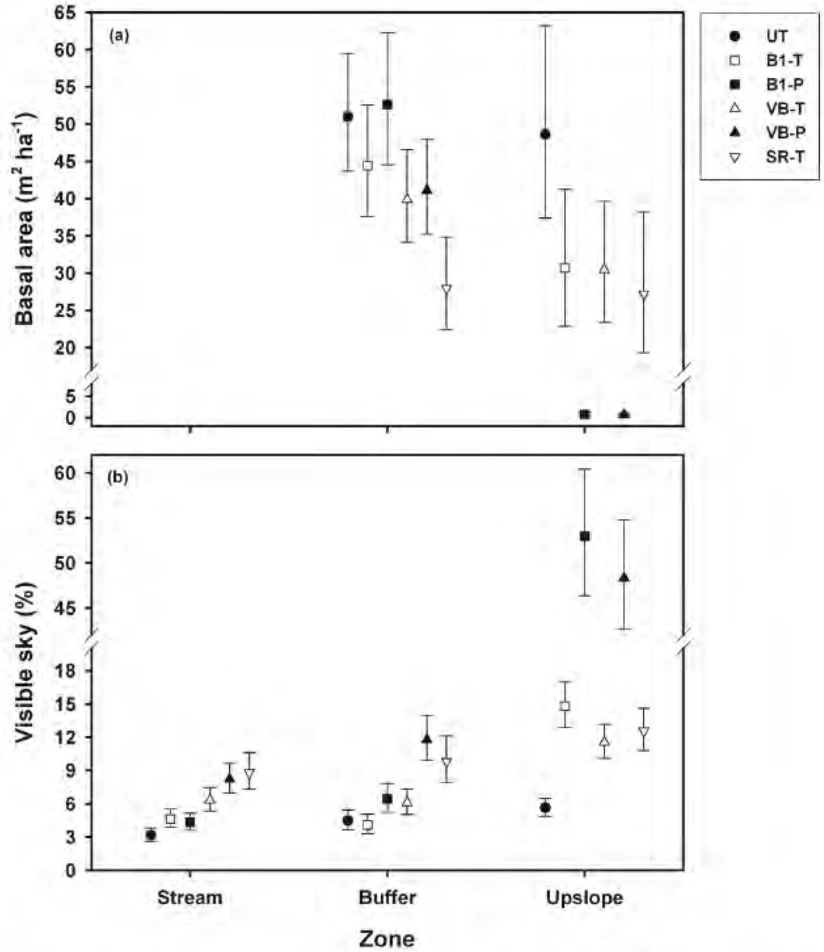


Figure 3. Treatment least-squares means (±1 standard error) for (a) basal area and (b) percentage visible sky as measured over stream center, within buffers, and within the upslope stands. Means and confidence intervals for n = four to five observations. Values are back-transformed from model estimates based on log-transformed data.

Stream Shade Response - Clearcut harvest outside of the 69m no-touch buffer ("B1-P") did not result in a significantly different light condition over the stream than the unharvested condition ("UT") and appears to be decreasing less than 1 unit of percent visible sky.

Clearcut harvest outside of the 22m no-touch buffer ("VB-P") resulted in significantly higher light conditions over the stream (p = 0.002), increasing 5.1 units of percent visible sky.

Stream Temperature Response - Not measured

4.4 - Effects of Riparian Thinning Over Time - Oregon Coast Range Project

Chan S.S., D.J. Larson, K. G. Maas-Herner, W.H. Emmingham, S. R. Johnston, and D. A. Mikowski. 2006. Overstory and understory development in thinned and underplanted Oregon Coast Range Douglas-fir stands. ***Can. J. For. Res.*** 36:2696-2711.

Location: Oregon Coast Range

Abstract: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests managed for timber in western Oregon frequently lack structure and diversity associated with old-growth forests. We examined thinning effects on overstory and understory development for 8 years after treatment. Three 30- to 33-year-old Oregon Coast Range plantations were partitioned into four overstory treatments: unthinned (~550 trees/ha) and lightly (~250 trees/ha), moderately (~150 trees/ha), and heavily (~75 trees/ha) thinned. Within each overstory treatment, two understory treatments were established: underplanted with Douglas-fir and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) or not underplanted. Thinning increased overstory stem growth, crown expansion, and retained crown length. Thinned overstory canopies began to close rapidly the third year after thinning, decreasing % skylight by approximately 2%/year, whereas % skylight in unthinned stands increased slightly. All seedlings planted in unthinned stands died, whereas eighth year survival in thinned stands averaged 88%. Natural regeneration densities and distributions were highly variable. Understory shrub cover was reduced by harvesting disturbance but recovered by the fifth year. Thinning increased understory plant species diversity, and no shrub species were lost. Thinning to low densities and underplanting has the potential to accelerate development of multilayered stands characteristic of old-growth Douglas-fir forests.

Riparian Stand and Harvest Conditions:

Sites: Three forest blocks in the Oregon Coast Range

Stand Conditions: Thirty to 35 year old Douglas-fir plantation on highly productive sites on the west slope of the Oregon Coast Range

Stream Conditions: Not Available

Harvest conditions: (1) Unthinned (≈550 trees/ha (i.e., tph)); (2) light thinning (≈250 tph); (3) moderate thinning (≈150 tph); and heavy thinning (≈75 tph).

Stream Length Logged: Not Available

Time line: Eight years since thinning activities

Summary of Results:

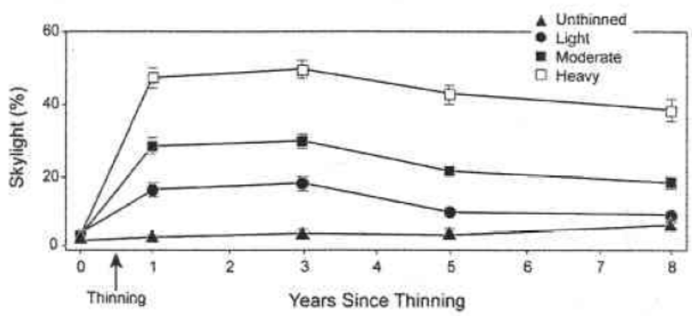
Thinning reduced basal area (BA) by 51%, 67%, and 84% in lightly, moderately, and heavily thinned stands, respectively. Tree densities in thinned stands were reduced in the moderate and heavily thinned stands by windthrow and stem breakage during severe winter storms in the first 4 years of the study. Immediately after thinning, % skylight through the canopy ranged from 2% in unthinned stands to 48% in heavily thinned stands. After 8 years, % skylight in lightly thinned stands was similar to levels in unthinned stands, and % skylight in moderately thinned stands had diminished to levels similar to those in lightly thinned stands just after thinning. Percent skylight for the moderate and heavy thinned stands were elevated above unthinned stand conditions for the eight year period associated with this study.

Table 2. Stand densities before thinning, immediately after thinning (year 1), and 4 and 8 years after thinning.

		Mean density (95% CI)				% Change	
Density measure	Treatment	Prethinning	Year 1	Year 4	Year 8	Years 1–4	Years 5–8
Trees/ha	Unthinned	547 (493–601)	547 (493–601)	510 (454–568)	496 (435–558)	–6.8	–0.3
	Light	686 (556–816)	252 (225–279)	244 (215–274)	242 (212–273)	–3.2	–0.8
	Moderate	598 (512–683)	138 (120–156)	128 (119–138)	126 (117–136)	–7.2	–1.6
	Heavy	671 (526–816)	72 (68–77)	70 (64–75)	68 (63–73)	–2.8	–2.9
Basal area (m^2/ha)	Unthinned	44 (40–47)	44 (40–47)	45 (40–51)	49 (44–54)	2.3	8.9
	Light	47 (43–50)	23 (21–26)	27 (23–31)	31 (27–35)	17.4	14.8
	Moderate	43 (39–46)	14 (11–16)	15 (13–18)	18 (16–21)	7.1	20.0
	Heavy	45 (40–50)	7 (6–8)	8 (7–9)	10 (8–13)	14.3	25.0
Relative density[a]	Unthinned	7.7 (7.2–8.2)	7.7 (7.2–8.2)	7.8 (6.9–8.7)	8.2 (7.4–9.0)	1.3	5.1
	Light	8.6 (7.7–9.4)	4.0 (3.6–4.3)	4.4 (3.8–5.0)	4.9 (4.3–5.5)	10.0	11.4
	Moderate	7.7 (7.0– 8.4)	2.3 (1.9–2.7)	2.4 (2.0–2.8)	2.8 (2.4–3.1)	4.3	16.7
	Heavy	8.3 (7.2–9.4)	1.2 (1.1–1.3)	1.3 (1.1–1.5)	1.6 (1.3–1.9)	8.3	23.1

Note: The percentage of change in density was calculated for the first 4 years (years 1–4) and the second 4 years (years 5–8) post-thinning.
[a]Relative density = $(BA/QMD)^{0.5}$, where BA is the basal area (m^2/ha) and QMD is the quadratic mean stand diameter (cm; Curtis 1982); RD (Imperial) = 6.945 28 × RD (metric).

Fig. 4. Changes over 8 years in % skylight through the canopy by thinning treatment. Error bars are 95% confidence intervals. Data points are slightly offset for presentation.



Example of % Skylight for 1 and 8 years after thinning within each stand.		
	Post-thin	Year 8
Unthinned (≈ 550 tph)	2%	6%
Light thin (≈ 250 tph)	14%	8%
Moderate thin (≈ 150 tph)	29%	16%
Heavy (≈ 75 tph)	44%	26%

4.5 – Effects of Riparian Harvest on Microclimate Gradients –Western Washington

Brosofske, K.D., J. Chen, R.J. Niaman, J.F. Franklin. 1997. Harvesting Effects on Microclimatic gradients from Small Streams to Uplands in Western Washington. *Ecological Applications* 7(4):1188-1200.

Location: Western Washington

Abstract: Riparian zones are vital components of the landscape. Much attention has been focused on the question of how wide a buffer is needed to protect the original riparian environment. We sampled five streams 2-4 m wide and associated riparian ecosystems before and after clearcutting in western Washington. Buffers ranging from 17 to 72 m wide were left intact at all sites when harvesting. Our objectives were: (1) to characterize pre-harvest microclimatic gradients across riparian ecosystems, from the stream to the upland; (2) to identify effects of harvesting on these gradients; and (3) to describe effects of buffer width and near-stream microclimate on stream microclimate. Six weather stations measuring air temperature, soil temperature, surface air temperature, relative humidity, short-wave solar radiation, and wind speed were installed along transects running across the stream and into the upland, and two reference stations were established, one in an upland clearcut and one in an upland interior forest. Pairwise comparison tests were used to evaluate statistical differences between stations along transects for determination of gradient extent. Pre-harvest riparian gradients existed for all variables except solar radiation and wind speed, and values generally approached forest interior values within 31-62 m from the stream. After harvesting, microclimate values at the buffer edge and each subsequent location toward the upland began to approximate clearcut values instead of forest interior values, indicating an interruption or elimination of the stream-upland gradient. In addition, regression analyses showed that stream microclimate was affected to some degree by buffer width and microclimate in the surrounding area. We conclude that a buffer at least 45 m on each side of the stream is necessary to maintain a natural riparian microclimatic environment along the streams in our study, which were characterized by moderate to steep slopes, 70-80% overstory coverage (predominantly Douglas-fir and western hemlock), and a regional climate typified by hot, dry summers and mild, wet winters. This buffer width estimate is probably low, however, since it assumes that gradients stabilize within 30 m from the stream and that upslope edge effects extend no more than 15 m into the buffer (a low estimate based on other studies). Depending on the variable, required widths may extend up to 300 m, which is significantly greater than standard widths currently in use in the region (i.e., ∼10-90 m). Our results indicate that even some of the more conservative standard buffer widths may not be adequate for preserving an unaltered microclimate near some streams. Additional site-specific data are needed for different site conditions in order to determine whether generalizations can be made regarding near-stream microclimate.

Riparian Stand and Harvest Conditions:

Sites: Five streams in three locations in Western Washington

Stand Conditions: Canopy cover was 70-80%, Douglas Fir, western hemlock

Stream Condition: width ranged - 2-4 meters

Harvest conditions: Variable no cut riparian buffer width: 23m (and 17m on other bank), 17m(23m), 25m (60m), 60m (25m), and 60m (25m).

Stream Length Logged: Not relevant
Time line: One year of pre-harvest and one year of post-harvest data collection

Summary of Results:

They found that solar radiation and relative humidity did appear to have some association with buffer width. Edge influences appeared to allow solar load to penetrate the forest buffer and affect stream microclimate. Accordingly, they surmise that as the buffer widens the amount of solar radiation able to penetrate the vegetation and reach the stream station would decrease.

They did not find any relationship between water temperature and buffer width. The water temperature response associated with each treatment was not presented so it is not possible to determine the impact of various riparian buffer widths on stream temperature.

They observe a strong influence of soil temperature in the surrounding land area on water temperature, even for sites well away from the stream. They concluded that this suggests that activity in the watershed up to or more than 180 m away may affect stream microclimate even when a buffer strip is left intact.

Authors conclude that a buffer at least 45 m on each side of the stream is necessary to maintain a natural riparian microclimatic environment along the stream.

4.6 - Effects of Riparian Harvest on Blowdown – Coast Range of Washington Study

Jackson, C.R., D.P. Batzer, S.S. Cross, S.M. Haggerty and C.A. Sturm. 2007. Headwater Streams and Timber Harvest: Channel, Macroinvertibrate, and Amphibian Response and Recovery. *Forest Science* 53(2):356–370.

Location: Coast Range, Washington

Abstract: Abiotic and biotic responses of 15 first-order streams to timber harvest were monitored at four sites in Washington's Coast Ranges (six watersheds clearcut to streambanks; four clearcut with stream buffers; and four references). Surveys of geomorphology, macroinvertebrates, and amphibians were conducted in 1998 (baseline), 1999 (immediately postharvest), 2000 (macroinvertebrates only) and 2001. Logging slash immediately covered or buried clearcut channels with 0.5 to 2 meters of slash, increasing roughness and trapping fine sediments, and slash still dominated channel conditions in 2001 when fine sediment fractions remained elevated relative to reference streams. In buffered and reference streams, particle size distributions were almost unchanged. Buffer blowdown was extensive (33% to 64%); increased light stimulated streamside vegetation. In 1999, clearcut streams supported higher macroinvertebrate densities of collectors and shredders, likely due to increased detrital resources. Collector response persisted into 2001, and new responses included higher overall macroinvertebrate biomass in buffered streams. No macroinvertebrate groups declined significantly in the three summers after harvest. Clearcutting to stream channels appeared to have short-term negative effects on local giant salamander and tailed frog populations but not torrent salamanders.

Riparian Stand and Harvest Conditions:

Sites: fifteen first and second order streams in the coast range of Western Washington. Four of the 15 streams basins were not harvested, and these streams served as references. Four for each harvest type ("Reference", clearcut, full buffer, and non-merchantable buffer)

Stand Conditions: Not described

Stream Conditions: 1st and 2nd order streams

Harvest conditions: No adjacent harvest (reference stream), standard clearcut, full riparian buffer and a non-merchantable harvest (There was very little non-merchantable vegetation so these effectively became clearcut harvest.). Widths of buffers applied to the buffered streams were dictated by operational considerations, and the buffer widths were around 8 to 10 meters on each side of the stream.

Stream Length Logged: Not described

Time line: Two years of water temperature data – one pre and one post-harvest

Summary of Results:

This study was a follow-up to the Jackson et al., 2001 which described the immediate effects of harvest activities on stream channel and riparian conditions on small headwater streams. The salient information provided in this new study concerns the effects of blowdown on the buffer stand condition in years following harvest activities. Buffer blowdown was extensive in 2001 (two years following harvest activities associated with buffered streams). Blowdown ranged from 33 to 64% of buffered trees with attendant effects on canopy cover. After blowdown, the newly fallen trees either spanned the channels or lay beside the channels, so blow down trees were not adding woody debris to the channels or altering channel structure at the time of the study.

Table 4. Summary of buffer blowdown and canopy cover as measured by a spherical densitometer

Stream	Buffer type	Blowdown (2001) (%)	Canopy cover[1] (%)		
			1998 (pre)	1999	2001
21W	Non-merchantable	44	90	65	10
21M	Full	52	93	15[2]	15[2]
17E	Full	33	92	51	35
13E	Full	64	87	23	72[3]
12E	Partial (within buffer of fish-bearing stream)	42 32 along fish-bearing stream	95	NM	90

[1] These canopy cover estimates should be used with caution. The densitometer readings were taken within the survey section. However, both the buffers and the blowdown of the buffers were patchy, so these numbers are not an average for the whole stream.
[2] The buffer on 21M was much wider and denser downstream of the survey reach where these densitometer measurements were taken.
[3] Canopy coverage on 13E in 2001 was provided by dense scrub-shrub vegetation growing adjacent to the channel. On this stream the channel-adjacent herbaceous vegetation had grown to a height of 2 meters in many places.

Use of Geospatial Data and Models in Natural Resource Management

By Lee Benda

20 July 2012

GIS data: Advantages and limitations

During the last decade, there has been a proliferation of geospatial data in natural resource management including in the disciplines of forestry, fishery management, geology, geomorphology, hydrology, wildfire and climate change (Miller 2003, Wing and Bettinger 2008). Geographical information system (GIS) data and associated model output are only as good as the measurement technologies from which they are derived (e.g., aerial photographs, satellite imagery, laser altimetry, field surveys, digitizing, etc.). Important attributes about GIS data include their spatial (three dimensional) resolution (90 m, 10 m, and <10 m), accuracy, and precision. In addition, GIS information derived from predictive numerical models is also only as good as the model and the data that go into the model.

GIS data used in natural resource management can include hillslope gradients, aspects, stream networks, stream gradients, vegetation and other watershed features. In general, across the western U. S., 10-m digital elevation models (DEMs) are used within GIS-based numerical models to derive these and other watershed attributes such as slope stability, debris flow potential, and channel and fish habitat characteristics (Benda et al. 2007, Burnett et al. 2007). Forest growth models (FVS, Zelig, ORGANON) that use plot- scale field data are used to create predictions about stand structure over time. These model predictions, as well as others that use a single year's remote sensed data on stand structure, can be used to forecast the recruitment of wood to channels (using yet other models), and those predictions can be used to predict changes to fish habitat quality and abundance.

It is important to remember that GIS raster or cell-based data are relatively 'coarse grained' which means that data, such as vegetation type, is represented by square cells with sides of length, for example 90 m or 10 m with cell areas of 8100 m^2 or 100 m^2, respectively. These types of data are not accurate down to a more human scale of meters (e.g., while standing in the field); an exception is GIS information that utilizes sub-meter resolution LIDAR. Forest data at coarse scales are generalized, or averaged, and thus GIS information of forest structure will be only accurate in an averaged sense. Nevertheless, this type of coarse-grained information could be used effectively to plan timber harvest and or forest restoration activities across a large watershed over the next 50 years.

Another type of GIS information is vector (line) data such as stream channels that are derived either from digitizing paper (USGS) maps or from numerical models that use DEMs and roads (typically digitized from paper maps or aerial photographs). The accuracy of stream lines depends on the accuracy of the original map product (such as U.S.G.S. 1:24,000-scale topographic maps or the resolution of DEMs). If channel network extraction models are used

(Miller and Burnett 2007), the accuracy of the delineated channel network will be much better using 10-m versus 90-m digital elevation data. Similarly, the stream attributes so derived (e.g., gradient, floodplain width, orientation, etc.) will also depend on the DEM resolution and on the robustness of the numerical model itself. For example, if the delineated channel segments are 100 m in length, then the predicted channel gradients will be an average over that length scale.

The spatial accuracy of road lines is dependent on the care with which the locations of roads were digitized from maps or photos. The attributes that are extracted from roads, such as road gradients and drainage points, are also dependent on the digitizing accuracy.

Given the necessary coarse grain and, thus, approximate nature of most GIS data and numerical model predictions, **the relative difference among values** (whether grid cells, lines, points or polygons) **is likely more accurate compared to the absolute value of any single data point**. For instance, predictions of slope stability typically reveal a large range of failure potential across a watershed. The value of any site specific prediction (pixel scale) is only a rough approximation of reality (because of model limitations and uncertainty in governing parameters). The relative difference between areas of high and low instability, however, can provide a more accurate accounting of hillslope stability (or erosion potential) across a watershed and this type of knowledge is suitable for planning purposes.

Watershed- to landscape-scale GIS information about topography, stream networks, forest vegetation, erosion potential, and aquatic habitat has provided an unprecedented ability to consider entire watersheds (and landscapes) in the implementation of forestry and fishery management (Spies and Johnson 2007), and also to quantitatively forecast outcomes, including cumulative effects of forest practices (Dunne et al. 2001). Prior to advanced GIS, numerical models, and computer technology, this capability did not exist. Given the limitations of GIS information and associated numerical models, but also the advantages of these information systems, it is important to ask the following question: **How do resource managers and analysts apply geospatial data and models in their day-to-day work?**

GIS data and the resource manager

The obvious advantage of GIS for land use managers is its ability to provide spatial information at watershed and landscape scales and thus to provide the 'big picture' of where certain watershed attributes are located and how they relate (spatially) to other attributes (see www.netmaptools.org for numerous examples; Benda et al. 2007). For instance, where are the unstable hillslopes located and are they in close proximity to the best aquatic habitats? Where is the most fire prone vegetation located with respect to the most erosion prone soils, and where do these areas overlap with sensitive fish habitats? Which segments of roads are located on unstable ground, and if a failure occurs, could it enter a fish bearing stream? Thus, first and foremost, land managers use GIS information, analysis, and associated model predictions for screening (e.g., to get the big picture) and for watershed scale planning. For instance, when planning stream or road restoration, GIS maps of potential impacts of roads on aquatic habitats can be used to prioritize field surveys.

One key recommendation is that **as management plans built with GIS support are implemented, site-specific information (at the scale of an individual timber harvest plan or an individual stream reach restoration project) should be collected to fine tune management activities (or the projection of effects) in specific areas**, and thus plans should be adjusted as necessary. For example, **GIS information and analysis tools could be used to forecast forest growth and the effects of thinning on future forest stand structure, which affects shade from solar radiation and the amount and size distribution of wood in streams**. To offset the predicted reduction of wood in streams due to thinning in riparian areas, other models are used to forecast how trees directionally felled into streams will increase wood storage and hence improve fish habitats across entire watersheds. This type of GIS analysis can support the development of forest plans and their evaluation across entire watersheds. **When specific components of the management plan are implemented** (for example, thinning along a certain stretch of stream), then **a field reconnaissance or more detailed field measurements should be obtained to determine the exact structure of the forest stand to make more detailed site specific harvest (and tree felling) prescriptions at that site**. In other words, after the *planning stage* that utilized GIS information (and associated model forecasts), the *implementation phase* will require some type of validation step, that might include collecting site-specific information (on existing forest structure and aquatic habitat condition) to make adjustments as necessary to the management activities.

The same recommendation also applies to the use of GIS information in other activities involving riparian management, slope stability, road restoration, and wildfire risk assessment. Consider slope failure potential and the use of GIS information. Increasingly, management planning is taking place at the watershed scale (or at the scale of an entire national forest). Thus, there is a need to consider slope stability conditions at that scale to help guide placement of harvest units for a 10-year forest plan. First, we accept the premise that the application of one or more slope stability models utilizing 10-m DEMS provide acceptable results (Montgomery and Dietrich 1994, Miller and Burnett 2007). From a watershed scale perspective, a map of slope stability indicates where the unstable areas are located and their proximity to roads, stream channels, or high quality fish habitat. This information can be used to plan placement of new forest roads (or conversely locations where to abandon roads) and to plan forest harvest or forest restoration activities. In other words, **watershed-scale maps are important guides to watershed-scale forest management planning**.

How does GIS information, or associated modeling results about slope stability, get used in project specific planning? If geologists were asked to review or help design the placement of a forest road on a particular hillslope, the watershed-scale GIS maps would be very useful as a guide or screening tool, allowing them to see the big picture (e.g., the physical characteristics of a single hillslope compared to all the other surrounding hillslopes in the vicinity). **At the project level, more site-specific information is needed**. Is the hillslope sufficiently steep to be of concern (e.g., is the GIS information on slope gradient accurate)? Are there other instability features such as slope convergence, evidence of previous failures or ground cracking? What is the likelihood of a failure, and would the associated sediment would impact important resources, including sensitive fish habitats? **It is likely that the remotely sensed data and model predictions would match, approximately, what is found in the field**. However, attributes such as evidence of previous failures would not be included in model predictions, but they can help with a final determination.

Summary

For land use analysts and planners, it is important to understand the limits in accuracy and precision of GIS information, including data derived from remote sensing, field surveys, or digitizing, and from numerical models. Although GIS information is often approximate and coarse grained (particularly if derived from remote sensing and numerical model predictions), it offers unprecedented ability to plan (and evaluate through modeling) watershed-scale plans for forestry, restoration, road rehabilitation, conservation, wildfire planning, and to consider climate change impacts. For example, a GIS map of fish habitat quality can be used to prioritize where analysts will go into the field to plan inventory, monitoring, and restoration projects.

When implementing such plans at the scale of individual hillsides, stream reaches, or road segments (e.g., timber harvest, fuel treatments, forest restoration-thinning, placement of wood in streams for restoration, and road maintenance or abandonment), site-specific information should be obtained on the relevant parameters (e.g., forest stand condition, channel characteristics, hillslope conditions, and road attributes and conditions). Once field observations or data have been collected, site-specific management prescriptions can be tailored or modified as necessary from the original predictions made using GIS information. In that way, GIS information and field information are compatible, and when used together, they provide a robust method for implementing forest management or fishery management at scales ranging from the watershed down to the particular hillside, stream reach, or road segment.

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