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

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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

Group Two - Thinned riparian buffer adjacent to clearcut harvest units

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.

Additional Literature Cited in this Section

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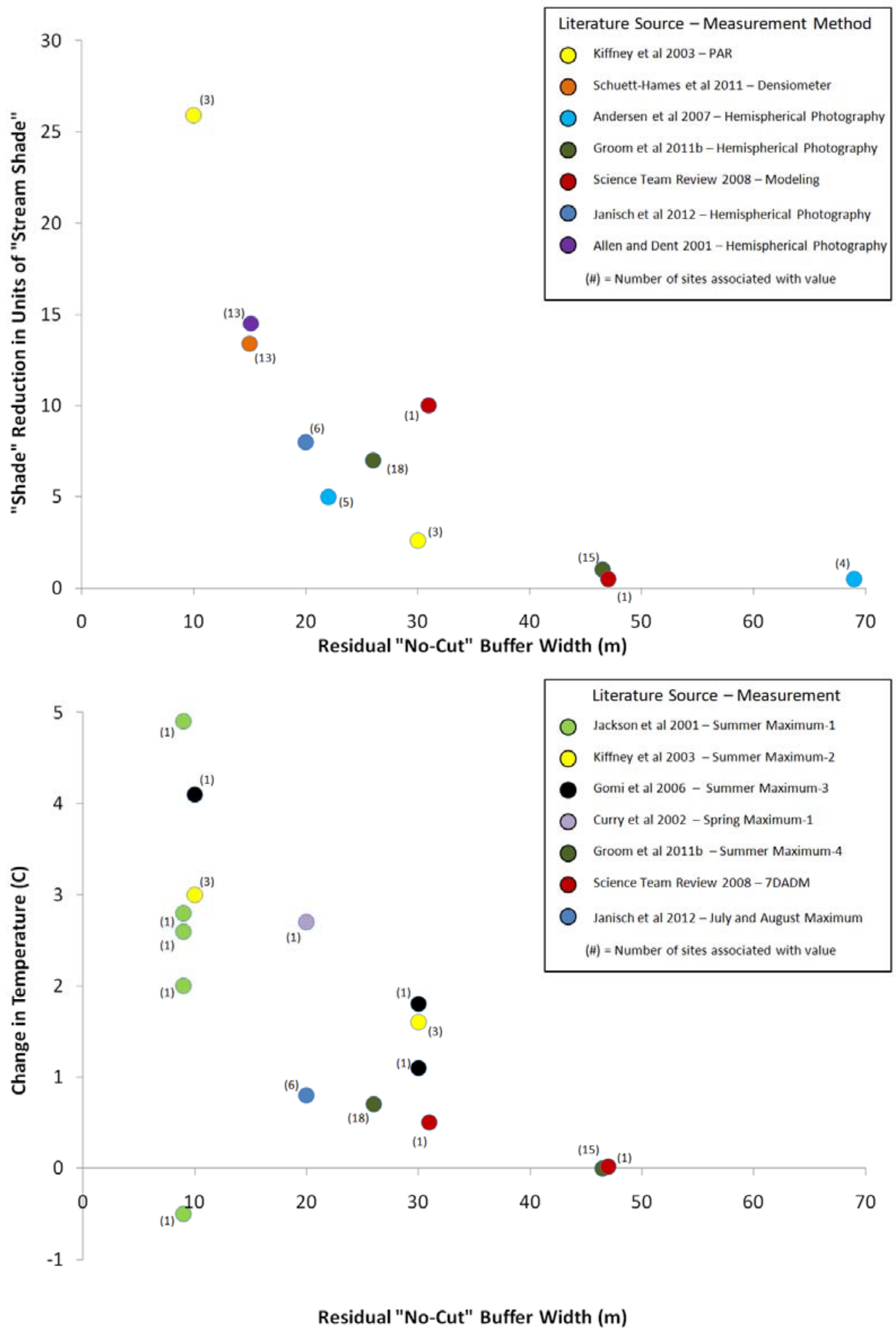

Figure 1. Observed shade and temperature response associated with “no-cut” riparian buffers with adjacent clearcut harvest.

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

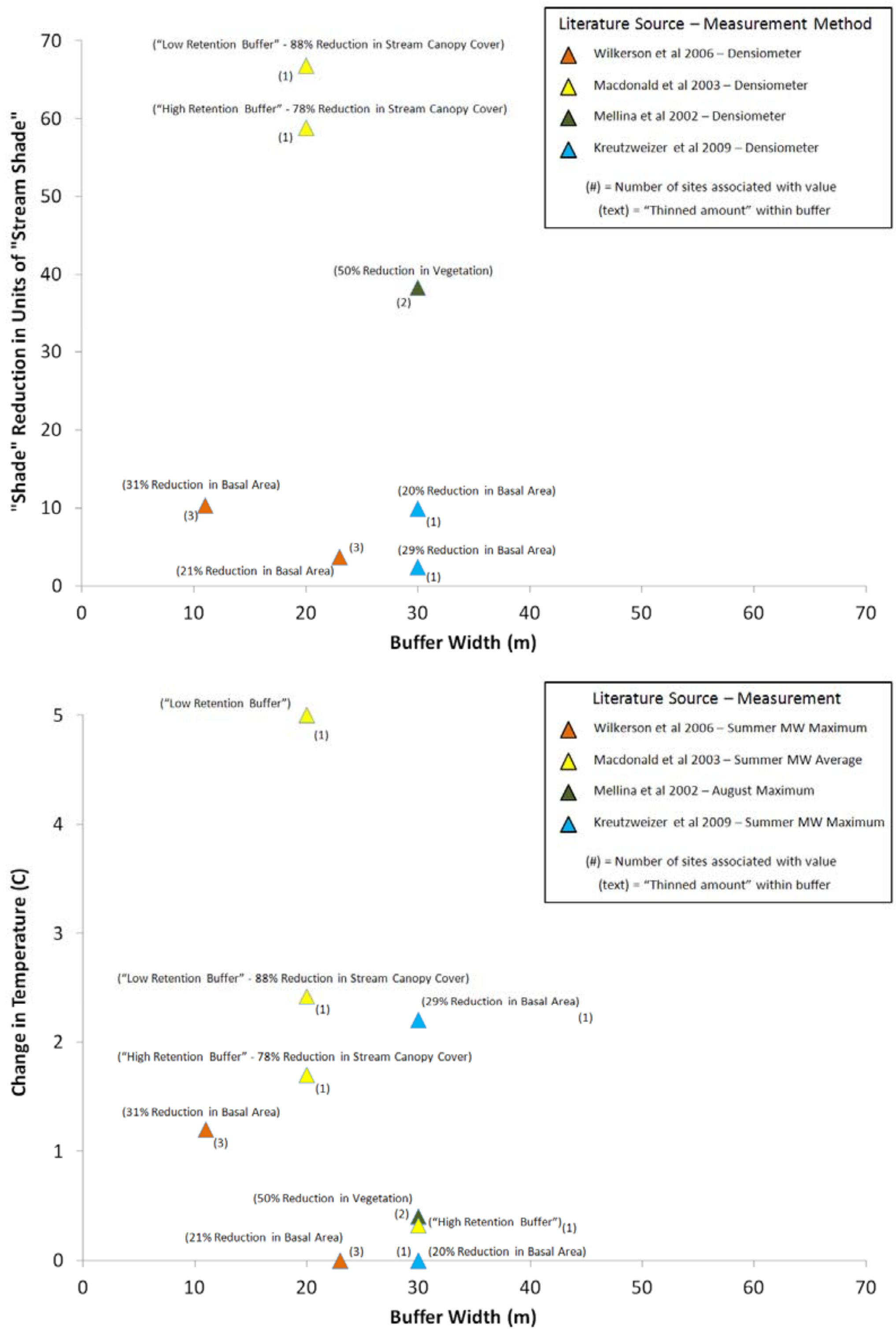

Figure 2. Observed shade and temperature response associated with "thinned" riparian buffers with adjacent clearcut harvest.

(MW = Mean Weekly)