

A Preliminary Study of Streamside Air Temperatures Within the Coast Redwood Zone 2001 to 2003¹

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Abstract

Timber harvest practices must address potential impacts to aquatic and riparian habitats. Stream shading and cool water temperature regimes are important to protect stream-dwelling organisms. We are examining riparian temperature regimes within the coastal redwood area of Mendocino County. Summer temperature gradients are being characterized along fifteen transects set perpendicular to watercourses within four different watersheds. Data loggers record temperature along each transect at pre-determined spatial intervals from the watercourse midpoint. With the exception of a control transect, all watercourses in this study are subject to near-future timber operations. This study is part of a larger program to detect changes in riparian microclimate as a result of timber harvest. Here we examine the relationship between temperature and physiography, and explore different methods of analysis in order to characterize pre-harvest temperature gradients. As with similar studies, we find upslope temperatures increase with distance from the watercourse. The greatest temperature increase per unit distance occurred between the watercourse mid-point station and the 25ft stations on either side. Our analysis indicates the calculated maximum weekly average temperatures (MWAT) may be the best graphical indicator of overall riparian temperature regimes, while the mean maximum weekly temperatures (MMWT) appear more sensitive to physiographic characteristics.

Key words: microclimate, riparian, temperature, timber harvest

Introduction

Few studies have focused on riparian microclimate gradients in California's coastal redwood region (Ledwith 1996). Timber harvesting near watercourses, resulting in changes to canopy structure and composition has the potential to alter water temperature and microclimate regimes of adjacent stream-side areas, especially during warm summer periods (Beechie and others 2000; Brosofske and others 1997; Brown and Krygier 1970; Chen 1991, Chen and others 1992, 1993a, 1993b, 1995; Corner and others 1996, Erman and others 2000, Independent Multidisciplinary Science Team 1999, O'Connell and others 2000, Spence and others 1996). Reduced shade leads to increased water temperatures, which can impair important life requisites and reduce survival rate of salmonids during adult upstream migration, juvenile rearing, and downstream migration of smolts (NMFS 2000). Nearly all of California's salmonid species inhabiting the coastal redwood zone are Federally and/or State listed as threatened or endangered (DFG 2004), thus requiring protective

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measure to be implemented to mitigate the effects of timber harvest related impacts. While changes in biological variables resulting from intensive timber harvest are often difficult to document, changes in air temperature, relative humidity and wind speed appears highly responsive (Chen 1990). Our long term plans are to examine the effects of timber harvest on summer stream temperature and riparian microclimate regimes. In this study, we focus on the first three years of data, documenting temperature gradients across riparian zones prior to timber harvest in coastal Mendocino County. The secondary goal of this research is to analyze the best method of characterizing summer air temperature gradients within and upslope of riparian buffer zones, using the different calculated values of the maximum weekly average temperature (MWAT) and mean maximum weekly temperature (MMWT).

Study Sites

Watercourses selected for this study are within western Mendocino County and discharge into the Pacific Ocean between the towns of Fort Bragg and Mendocino (*fig. 1*). With the exception of a control transect on Russian Gulch within the Russian Gulch State Park, all watercourses in this study are within the Jackson Demonstration State Forest (JDSF). We collected data from the following watersheds: North Fork of the South Fork Noyo River (NFSFN) including a tributary to Brandon Gulch, upper Parlin Creek (tributary to the South Fork Noyo River), Caspar Creek, and Russian Gulch. Stream channel elevations ranged from approximately 356 m (840 ft: Parlin Creek; Transect F) to approximately 49 m (160 ft: Casper Creek; Transect #2). Distance to ocean ranges from 19 km (12 miles: Parlin Creek - Transect F), to four km (2.5 miles; Russian Gulch). Orientation of specific stream reaches varied.

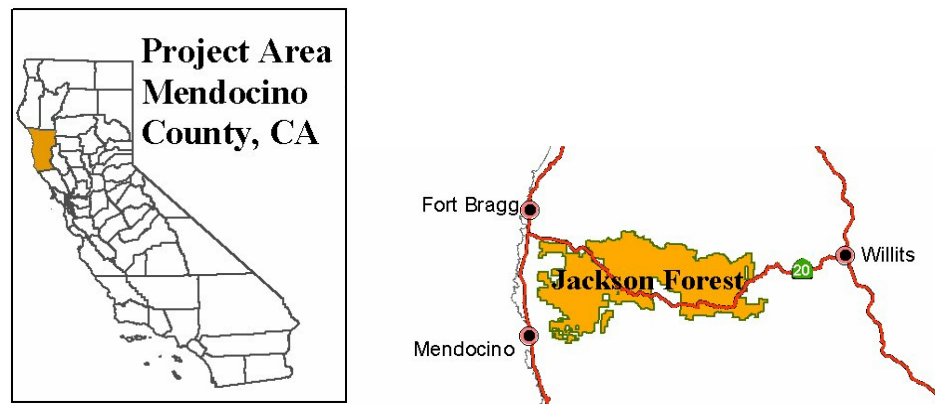


Figure 1—Overview of Jackson Demonstration State Forest (JDSF). Study area is within JDSF, with one control transect located north of Mendocino at Russian Gulch State Park.

Most precipitation in this region occurs in winter. Summer periods are usually warmer and without rainfall. Summer fog commonly intrudes into some study sites and precipitation may occur in the form of fog-drip. Mean annual precipitation at Caspar Creek from 1962 to 1997 was 1,190 mm, with a range of 305 to 2,007 mm. (Henry 1998). Average winter air temperatures are approximately 6.5 °C with minimums reaching 4.5 °C. Average summer air temperatures are approximately 15.5 °C, with average maximums reaching 22.5 °C. Summer discharges at study streams vary from dry to less than 0.5 ft³/second.

Overstory vegetation consists of mature second growth coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and grand fir (*Abies grandis*). Other notable overstory species include tanoak (*Lithocarpus densiflorus*), and red alder (*Alnus rubra*). Understory vegetation includes evergreen and red huckleberry (*Vaccinium ovatum* and *V. parvifolium*), Pacific rhododendron (*Rhododendron macrophyllum*), sword fern (*Polystichum munitum*), and poison oak (*Toxicodendron diversilobum*). In-stream animal species occupying study streams include Pacific giant salamander (*Dicamptodon ensatus*), coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss*), sculpin (*Cottus sp.*), and threespine stickleback (*Gasterosteus aculeatus*). In addition, numerous aquatic invertebrate species are dependant upon streams and adjacent riparian zones.

Methods

We are monitoring summer (May through September) temperature gradients along fifteen transects oriented perpendicular to stream channels. Depending on the watershed, transect location was used to document microclimate conditions along a given reach or to assess differences between units planned for timber harvest and units planned for timber retention. Along each transect, we established up to eleven sampling stations; one at mid-channel with a data logger suspended above the stream channel and another submersed underwater on or near the transect, and the other stations running up each adjacent hillslope (two at each distance) at 7.6 m (25 ft), 22.9 m (75 ft), 45.7 m (150 ft), and up to 91.4 m (300 ft) (*fig. 2*). For sites where timber has been marked for future harvesting, we established additional stations in areas where trees will be removed and in areas where groups of trees will be retained following harvest.

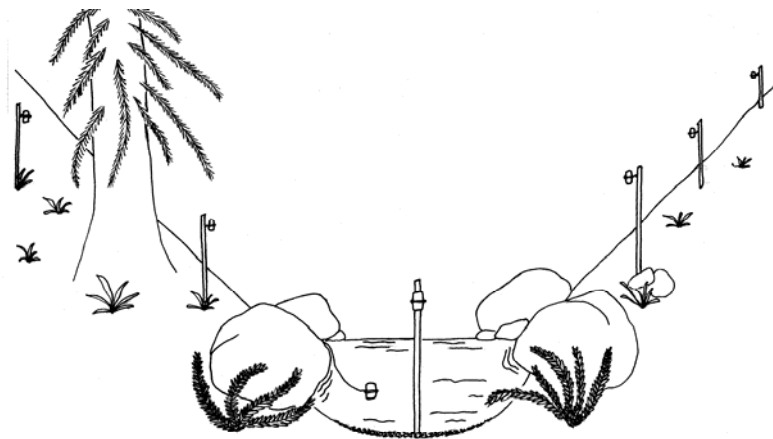


Figure 2—Schematic depicting a transect with temperature data loggers set at mid-channel, 25 ft, 75 ft, and 150 ft on either side of the watercourse. A submersed instream unit is also shown. (Figure by Sheryl Greene 2002)

Of the fifteen transects, eight were established in upper reaches of Parlin Creek, two in the NFSF Noyo drainage, and four in the SF Casper area. A control transect, where no timber harvesting will occur, was established at Russian Gulch within Russian Gulch State Park. Study sites were chosen based on the type and timeframe of timber operations planned for those areas.

For the NFSF Noyo and Parlin Creek sites, we used HOBO[®] H8 data loggers from Onset Computer Company (OCC) to measure and record temperature at each station. The manufacture's specified accuracy is ± 0.7 °C. These were programmed to record temperature at 1 hour intervals from late spring to mid-autumn. All H8 data loggers were housed in OCC's white submersible cases. Terrestrially-located loggers were wired to single wooden stakes measuring 91.4 cm long (three ft), 3.8 cm wide (1.5 inches), and 0.8 cm thick (5/16 or 0.3 inches). Loggers were positioned so case bottoms were 61 cm (two ft) above the ground or water surface. Styrofoam cups, with cut-out ventilation holes, were placed over the casings to insulate them from direct solar radiation.

For the Caspar Creek and Russian Gulch sites, we used HOBO[®] Pro temperature/relative humidity loggers from OCC to measure air temperature and relative humidity at each station. Humidity data was not analyzed for this paper. The manufacture's specified accuracy is ± 0.2 °C. These were programmed to record conditions at 1 hour intervals over 24 hours per day. Pro loggers were housed in OCC's white HOBO[®] solar radiation shields. Each logger was wired to two wooden stakes each measuring 122 cm (four ft) long, 3.8 cm wide (1.5 inches), and 1.6 cm thick (10/16 or 0.6 inches). Pro loggers were positioned so shield bottoms were 75 cm (2.5 ft) above the ground or water surface.

Two metrics of temperature were examined for each station along the transect for each year. The maximum weekly average temperatures (MWAT) was calculated as a moving average temperature for a 168 hour period (seven days) one-hr reading using that interval's value, the preceding 83 values, and the subsequent 84 values (3.5 days). The maximum value of these seven-day moving averages is the MWAT. The mean maximum weekly temperature (MMWT) was calculated using daily maximum temperature values. The MMWT was calculated by averaging each day's value with those of the preceding and subsequent three days (seven values). For each station, the maximum of the seven-day running average maximum temperatures is the MMWT. To assess temperature gradient differentials between mid-channel and upland stations, we used the mathematical differences between the mid-channel and the upland MWAT and MMWT within the same transect in the same year.

Shade, overstory canopy, and aspect were measured at each station to determine their influence on temperature measurements. Shade, or the percentage of available solar energy blocked at each station by canopy and topography, was measured. A Solar Pathfinder[®] using the sun arc for August, the month stream temperatures in the area commonly peak, was employed for this purpose. Overstory canopy was also measured by using a vertical sighting tube at 49 points situated at and around each station along four 24-meter transects centered on the data logger. At each point, canopy was scored as present when the sighting tube encountered canopy. Thus, the canopy at each data logger is indexed to a possible range from zero (no canopy) to 49 (full canopy). The resulting data is useful in mapping "holes" in the canopy. Aspect was measured with a handheld compass at each station.

All transects were established in 2001 after the May 1 summer season began.

Thus, some of the data represents only two of the three years of data, where we are not confident we captured the periods of highest temperature intensity in 2001.

Results

On average, temperatures gradually increased with increasing upslope distance from the watercourse midpoint. MWAT and MMWT values generally escalated with increasing distance from the transect’s mid-channel station. At 7.6 m (25 ft), MWAT values averaged 0.8 °C higher than adjacent channel midpoint MWAT values for the same year. The MMWT values averaged 2.5 °C higher than the mid-channel MMWT for the same transect. At the 22.9 m (75 ft) stations, MWATs averaged 1.2 °C, while MMWTs averaged 2.9 °C above mid-station values. Between the watercourse and the 45.7 m (150 ft) stations, MWATs averaged 1.5 °C and MMWTs 3.5 °C higher. For the transects that had stations between 70.1 m (230 ft) and 91.4 m (300 ft), MWATs averaged 2.0 °C higher, and MMWTs averaged 4.1 °C than transect mid-channel values (fig. 3).

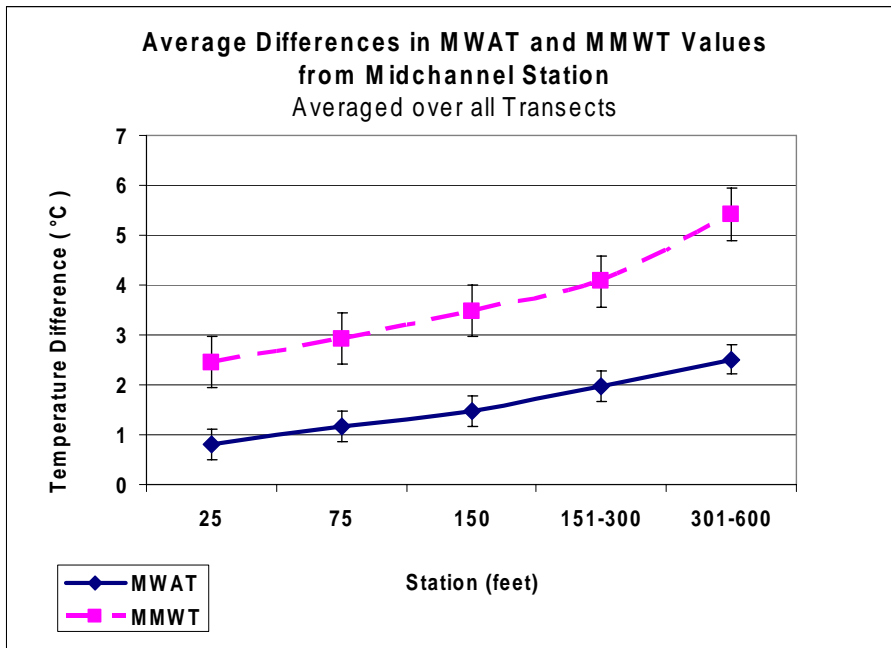


Figure 3—Average differences in the station’s MWAT and MMWT values minus the MWAT and MMWT values of the same transects’ mid-channel station, respectively.

The greatest temperature increase per unit of distance occurred between the mid-channel station and the 25 ft stations on either side. Average MWAT value at the 7.6 m (25 ft) station was 0.81 °C higher than the mid-channel station, giving the slope of the temperature gradient a $(0.81/7.6) = 0.11$ °C/m value. Subsequent temperature gradients between stations decrease. From the 7.6 m (25ft) unit to the 22.9 m (75ft) unit, the MWAT gradient averaged $(1.17-0.81)/(22.9-7.6) = 0.02$ °C/m. The 22.9 m (75 ft) to the 45.7 m (150 ft) gradient has an average slope of 0.01 °C/m. Not every transect included a unit above 45.7 m, thus these slope values were not calculated. MMWT temperature gradient values were 0.32 °C/m, 0.03 °C/m and 0.02 °C/m for 7.6 m, 22.9 m and 45.7 m respectively.

The MWAT and MMWT values were calculated for each station each year. Data used in our analysis represent the highest MWAT and MMWT values achieved for that station in that year. Mathematical differences between MWATs and MMWTs of the upslope stations and the MWATs and MMWTs of the mid-channel station of the same transect in the same year were calculated (*fig. 4*).

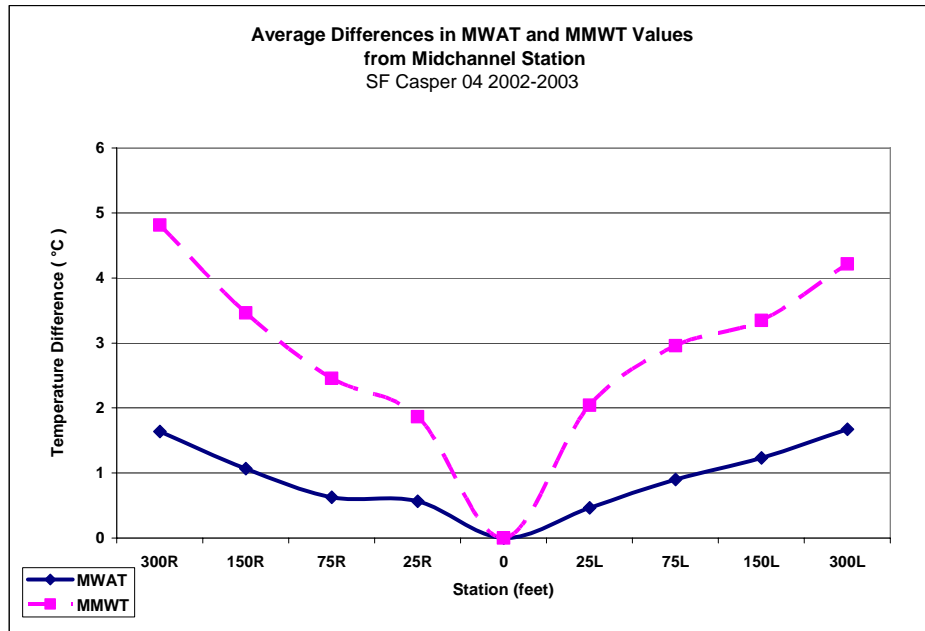


Figure 4—Two seasons of pre-harvest data for one transect. Graphed values are the MWAT and MMWT values at that station, minus the MWAT and MMWT values at the mid-channel (0 ft) station. These differences are then averaged over 2 seasons. Station numbers represent distances from the mid-channel station as well as station orientation [right side (“R”) or left side (“L”), facing downstream].

Observing individual transect graphs, MWAT values generally increased with distance from the watercourse mid-point station. However, in six of fourteen transects, this pattern was slightly altered, with one downslope station measuring slightly higher than its adjacent upslope neighbor. All six MWAT values are within the specified accuracy ranges of the temperature data loggers. MMWT values also generally increased with distance from the mid-channel station, but in eleven of fourteen transects, the gradually increasing pattern was disrupted. On one or both sides of the transect, one downslope unit measured higher temperatures than its upslope adjacent neighbor(s) (*fig. 5*). These are not all within the accuracy ratings for the units. Instead, these ‘atypical’ patterns may be linked to physiography. Canopy, aspect, or environmental placement (such as in a hollow stump or near a road) may influence the temperatures measured at these stations. MMWT values appear to be more sensitive to these physiological characteristics than do MWAT values.

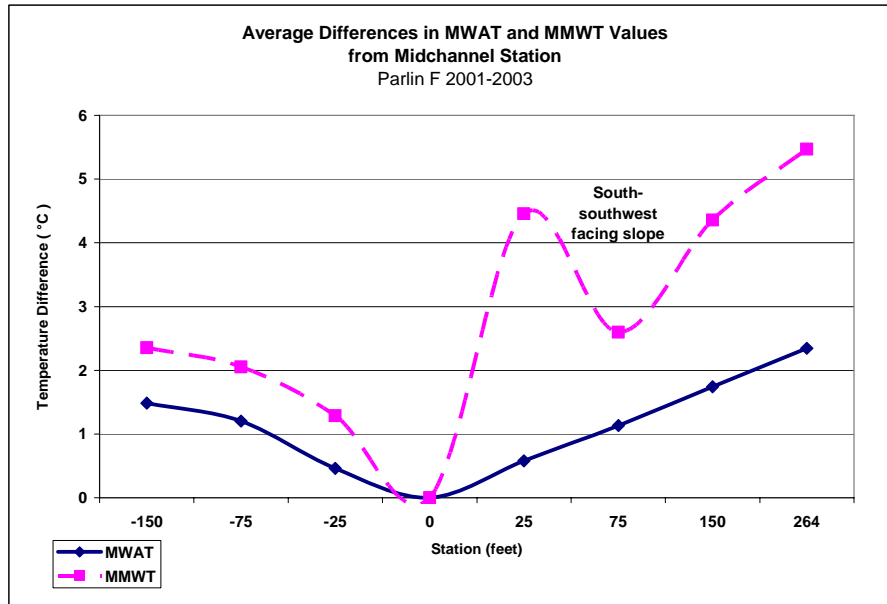


Figure 5—Three seasons of pre-harvest data for one transect. Graphed values are the MWAT and MMWT at that station, minus the MWAT and MMWT values at the mid-channel (0 ft) station. These differences are then averaged over 3 seasons. The station number refers to the data logger’s distance from the mid-channel station, while + designates a station in a (future) harvest area and – designates a station in a non-harvest area.

The fourteen transects were comprised of a graphed total of 116 units. Of these, 19 downslope units measured higher temperatures, and thus had a greater difference in their MMWT values from their midpoint stations, when compared to their upslope adjacent neighbors. This represents approximately 16 percent of the units. Of the 19 units, 13 were on south-facing slopes. This represents approximately 68 percent of the units with atypical relationships. Also 13 of the 19 units had a canopy index equal to or less than 40 (out of 49), and/or a shade measurement of 90 percent or less. Canopy or shade measurements at or below these values usually indicate there is nearby opening or “hole” in the canopy. These are not necessarily the same 13 units as those on south facing slopes, although there is much overlap. Four of the 19 stations receive some measure of direct solar exposure due to being on or at the edge of a road or forest opening. One of the 19 units consistently measuring lower MMWT values than its downslope neighbor arbitrarily resides in a hollow stump, sheltered from direct exposure to wind, heat vectors and solar radiation.

Discussion

To achieve aquatic resource conservation, timber harvest activities must address potential (significant) impacts including reduced canopy, increased summer air temperatures, and reduced humidity. For aquatic habitats, management should address stream shading and conservation of cool water temperature regimes (Welsh and others 2001). Increases in air temperature may promote attendant increases in evapotranspiration rates of riparian vegetation, which could reduce streamflows and extend the dry period for intermittent streams (Ledwith 1996).

As our data suggests, pre-harvest air temperatures rise as distance from mid-channel to upslope areas increase. This is in agreement with similar studies. In Sierra Nevada basins with undisturbed canopy, near stream air temperatures were significantly lower than adjacent uplands (Erman and others 2000). Before timber harvest, stream and riparian areas in Washington are generally characterized by cool air and soil temperatures, high humidity, and low wind speed relative to upland forest interior conditions (Chen and others 1999). Ledwith (1996) found that air temperatures at streams increased with decreasing buffer width in even-aged managed forests in Northwestern California.

The decision to undertake this study was primarily based on the scarcity of information specific to the North Coast redwood region. The region is highly influenced by ocean air currents and seasonal fog conditions, unlike conditions in central Washington or the Sierra Nevada range. The long term goal of this study will be to track potential changes in microclimate in response to un-even aged management practices. Timber harvest practices vary by forest type and are regulated differently by each state. The California Forest Practice Rules (CFPRs) regulate timber harvest activities in California. Several sections of the CFPRs are dedicated to protect aquatic and riparian areas from impacts caused by timber harvest. Despite this, there is significant debate over the size and structure of stream-side riparian zones for buffering harvest related impacts. Key elements defining riparian zones include topography, surface water, soils, vegetation and microclimate (O'Connell and others 2000). To determine the optimum buffer width (one that protects the integrity of the riparian ecosystem while allowing profitable timber harvest), researchers have examined riparian processes as a function of distance from stream channels (Ledwith 1996). Our long term efforts are to examine the microclimate of riparian buffer zones in the coast redwood region, and to characterize changes in microclimate and water temperature due to uneven-aged harvest management as practiced under the CFPRs.

Conclusions

Our preliminary study focused on air temperature regimes across riparian and upslope areas of mature second growth coast redwood forests. In agreement with similar studies, we found that upslope temperatures increased with increasing distance from the watercourse. We also found that physiography can influence these regimes. Temperature gradients are steepest between the watercourse and the 7.6 m (25 ft) stations, and decrease as distance upslope increases. MWAT values are less sensitive to physical characteristics than are MMWT values. MWAT values appear to reflect overall temperature gradients, while MMWT values reflect temperature gradients relative to physiography. The sensitivity of MMWT values may make them more valuable in determining changes in microclimate resulting from timber harvest practices. We plan on continuing to collect summer microclimate data in these areas, both before and after timber is harvested. Humidity monitoring and analysis will be added to the long term study. We also hope to determine the influences of canopy, solar radiation, aspect, and slope on temperature and humidity gradients. Changes in temperature and humidity regimes, as well as changes in canopy and forest structure, will be analyzed to document the magnitude of changes due to un-even aged timber harvest practices in a coastal-influenced area.

References

- Beechie, T.J.; Pess, G.; Kennard, P.; Bilby, R.; Bolton, S. 2000. **Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington streams.** *North American Journal of Fisheries Management* 20: 436-452.
- Brosfokske, K.D.; Chen, J.; Naiman, R.J.; Franklin, J.F. 1997. **Harvesting effects on microclimate gradients from small streams to uplands in western Washington.** *Ecological Applications* 7: 1188-1200.
- Brown, G.W.; Krygier, J.T. 1970. **Effects of clear-cutting on stream temperature.** *Water Resources Research* 6 (4): 1133-1139.
- California Department of Fish & Game (DFG). 2004. **Federal and State Endangered Species Act Status for California Anadrouous Fish as of August 6, 2004.** California. *See* <http://www.dfg.ca.gov/nafwb/index.html>
- Chen, J. 1990. **Microclimatic pattern and basic biological responses at the clearcut edges of old-growth Douglas-fir stands.** *The Northwest Environmental Journal* 6(2): 423-425.
- Chen, J. 1991. **Edge effects: microclimate pattern and biological responses in old-growth Douglas-fir forests.** Seattle, WA: University of Washington; Ph.D. thesis.
- Chen, J.; Franklin, J.F.; Spies, T.A. 1991. **Vegetation responses to edge environments in old-growth Douglas-fir forests.** *Ecological Applications* 2(4): 387-396.
- Chen, J.; Franklin, J.F.; Spies, T.A. 1993a. **An empirical model for predicting diurnal air-temperature gradients from edge into old-growth Douglas-fir forest.** *Ecological Modelling* 67: 179-198.
- Chen, J.; Franklin, J.F.; Spies, T.A. 1993b. **Contrasting microclimates among clearcut, edge, and interior of old growth Douglas-fir forest.** *Agriculture and Forest Meteorology* 63: 219-237.
- Chen, J.; Franklin, J.F.; Spies, T.A. 1995. **Growing-season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests.** *Ecological Applications* 5(1): 74-86.
- Chen, J.; Saunders, S.C.; Crow, T.R.; Naiman, R.J.; Brosfokske, K.D.; Mroz, G.D.; Brookshire, B.L.; Franklin, J.F. 1999. **Microclimate in Forest Ecosystem and Landscape Ecology.** *BioScience* 49(4): 286-297.
- Corner, R.A.; Bassman, J.H.; Moore, B.C. 1996. **Monitoring timber harvest impacts on stream sedimentation; instream vs. upslope methods.** *Western Journal of Applied Forestry* 11(1): 25-32.
- Erman, D.C.; Erman, N.A.; Drury, I.; Greathouse, E.A.; Ransom, B.O. 2000. **Testing variability of riparian temperatures in Sierra Nevada stream basins.** Tahoe National Forest Challenge Cost Share Agreement CCS-05-97-17-019.
- Henry, N. 1998. **Overview of the Caspar Creek Watershed Study.** In: Ziemer, R.S., technical coordinator. *Proceedings of the conference on coastal watersheds: the Caspar Creek Story*; 1998 May 6 1998; Ukiah, CA. Gen. Tech. Rep. PSW-GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 149 p.
- Independent Multidisciplinary Science Team. 1999. **Recovery of wild salmonids in western Oregon forests: Oregon Forest Practices Act Rules and the measures in the Oregon Plan for Salmon and Watersheds.** Technical Report 1999-1 to the Oregon Plan for Salmon and Watersheds, Governor's Natural Resources Office, Salem, OR. 92 p.

- Ledwith, T.S. 1996. **The effects of buffer strip width on air temperature and relative humidity in a stream riparian zone.** Humboldt, CA: Humboldt State University; 88 p. M.S. thesis.
- National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NMFS). 2000. **Salmonid Guidelines for Forestry Practices in California.** California. Available at http://www.krisweb.com/biblio/gen_nmfs_nmfs_2000_sgfp.htm
- O'Connel, M.A.; Hallett, J.G.; West, S.D.; Kelsey, K.A.; Manuwal, D.A.; Pearson, S.F. 2000. **Effectiveness of riparian management zones in providing habitat for wildlife.** Final Report to the Washington Timber, Fish and Wildlife Program; TFW-LWAG-00-001.
- Spence, B.C.; Lomnicky, G.A.; Hughes, R.M.; Novitzki, R.P. 1996. **An ecosystem approach to salmonid conservation.** ManTech Environmental Research Services Corp, Corvallis, OR. Available from the National Marine Fisheries Service. Portland, OR; TR-4501-96-6057.
- Welsh, H.H.; Hodgson, G.R.; Harvey, B.C. 2001. **Distribution of juvenile coho salmon in relation to water temperature in tributaries of the Mattole River, California.** North American Journal of Fisheries Management 21(3): 464-470.