Oregon Forest Industries Council
P.O.Box 12826
Salem, Oregon 97309-0826

WFPA
Washington Forest Protection Association
724 Columbia Street, N.W., Suite 250
Olympia, Washington 98501

June 5, 2000

EPA Region 10
Mailstop: OW-134
1200 S.W. 6th Avenue
Seattle, WA 98101

Attention: Dru Keenan, EPA Office of Water

Subject: Information and Studies Relevant to Temperature, Salmonids, and Water Quality

Dear Ms. Keenan:

The Oregon Forest Industries Council (OFIC) and Washington Forest Protection Association (WFPA), on behalf of our many members in the forest industry, jointly offer the attached information and studies on temperature, salmonids, and water quality as requested by EPA Region 10 by notice issued April 20, 2000. Industrial private forest landowners have been at the forefront of research into water temperature patterns, as well as the response of aquatic biota to changes in temperature. We believe it is vital that this information and its implications for temperature standards be fully incorporated into the Regional Temperature Critieria Guidance Project. Thus, OFIC and WFPA recommend that the following key findings be incorporated into the development of regional temperature standards:

- ***Stream temperatures and aquatic biota vary over space and time.*** Stream temperature patterns vary in response to stream size, drainage area, elevation, geographical location, prevailing climatic conditions, aspect, potential riparian vegetation, etc. (Lewis et al. 2000). Aquatic biota varies across the region, and along longitudinal gradients within a stream system, in response to temperature and other variables (Vannote et al. 1980).
- ***Streams have unique temperature signatures.*** Each stream reach has its own temperature "signature" reflecting its specific environment and flow character (Zwieniecki and Newton 1999). This "signature" or natural baseline is crucial to assessing whether and how much the stream temperature may be affected by natural and human disturbances, and to help guide management actions as needed.
- ***Warming is not strictly cumulative as water flows downstream.*** Progressive increases in water temperature with distance downstream are often erroneously ascribed to cumulative warming from upstream reaches. Although controllable anthropogenic influences can affect temperature on a reach by reach basis, water

temperature increases with increasing distance downstream under natural conditions (Adams and Sullivan 1989; CH2M HILL et al. 1999; Lewis et al. 2000). Downstream warming reflects several physical factors that change as streams increase in size. For example, air temperatures increase with decreasing elevation, cooler groundwater is a continually decreasing portion of streamflow volume, and riparian vegetation has the ability to shade less of the progressively widening stream channel.

- ***Riparian vegetation has little influence on water temperatures in wider streams.*** Research has shown that at a "threshold distance" at approximately 40-70 km from the watershed divide, mean water temperature equals mean air temperature. At this point, rivers are too wide for riparian vegetation to provide effective shade and river depth is sufficient that thermal inertia is large (Adams and Sullivan 1989; Lewis et al. 2000).

- ***In smaller streams, temperature perturbations usually do not persist far downstream.*** Because water temperature naturally adjusts to the local environmental conditions of each reach water passes through, in addition to the effects of continually changing solar radiation and air temperature during the daily cycle, there is a spatial limit to the influence of upstream reaches on the water temperature of downstream reaches (Adams and Sullivan 1989, 1990). For example, for streams with a wetted width of 3 m or less at low flow, an equilibrium condition is reached where the downstream temperature is stabilized within approximately 1 to 4 km, irrespective of upstream water temperature. Beyond this distance, upstream water temperature essentially has no effect because the stream has sufficient time to respond to the surrounding environmental conditions. In addition, research has shown that disturbed stream temperatures can return even more quickly (within about 100-300 m) to a natural temperature "signature" as soon as the stream again encounters riparian shade (Caldwell et al. 1991; Zwieniecki and Newton 1999; Newton and Zwieniecki 1996). For a small stream flowing at one cubic foot per second or faster, water temperature typically re-equilibrates within minutes. In other words, after an adequate distance of flow within a shaded reach, the stream temperature at a downstream location will reflect the ambient environmental conditions regardless of the upstream perturbation—demonstrating it is independent of the upstream temperature.

- ***In smaller streams, riparian shade is a factor that influences water temperature, but conservative, overly risk-averse riparian management area widths and tree heights are not required to control temperatures.*** Riparian vegetation density has a substantial effect on water temperature in small streams only as the riparian vegetation density nears zero (Brosofske et al. 1997). Densities producing canopy cover greater than about 30 percent produce minimal additional cooling, indicating that riparian forests can be actively managed without adverse effects on water temperature as long as sufficient canopy density is retained to maintain effective shade levels. For streams with a wetted width of 3 m or less at low flow, riparian management area widths greater than 15 m and tree heights greater than about 25 m have relatively little influence on further cooling of water temperatures (Zwieniecki and Newton 1999; CH2M HILL et al. 1999).

- ***Temperature effects on salmonids depend on genetic strains within the same species.*** The eyed-egg to 90-day post-hatch survival of Arctic char—reared at a gradually increasing temperature regime from 6 °C to 12 °C—show significant differences among strains in temperature-influenced survival. For example, the Fraser River strain showed 86 percent survival, whereas the Yukon char strain showed 95 percent survival (Bebak et al. 2000). Also, egg hatching success is significantly different between strains—90-97 percent for the Fraser River char and 98-99 percent for the Yukon char.
- ***Temperature effects on salmonids depend on acclimation temperature.*** Research has shown that the effect of water temperature depends on the temperature conditions to which the fish are acclimated. For example, Hokanson and others (1977) demonstrated that the maximum preferred temperature for juvenile salmonids increased as baseline temperature conditions to which the fish were acclimated increased. Also, Bebak and others (2000) showed that, with acclimation, lower egg to post-hatch survival for Arctic char increased by 20-30 percent. Thus, the temperature standard or criteria should account for variations in the natural temperature regimes to which fish are accustomed.
- ***Temperature effects on salmonids depend on duration of exposure.*** Research has shown that effects from temperature depend on the duration of exposure. For example, Kubicek (1977) determined that chinook salmon in the Eel River, California could withstand temperatures previously considered lethal for a duration of about 1.5 hours without apparent harm. Hokanson and others (1977) demonstrated in lab studies that there is no significant difference in the health of trout exposed to a fluctuating diel temperature regime with high maximum temperatures compared with trout exposed only to constant temperatures at the same overall daily mean temperature. Thus, the standard or criteria should include guidance on duration and frequency, as well as magnitude, of acceptable temperature events.
- ***Temperature effects on salmonids depend on food rations.*** Research has shown that food availability can ameliorate temperature-related negative impacts to fish production and growth. For example, Bisson and others (1988) found that growth and production of coho salmon in streams within the Mt. St. Helens eruption zone were high despite summer temperatures well above ranges considered optimal for fish growth. This high level of growth was correlated with high levels of food availability in these streams. Thus, the standards or criteria should account for the natural productivity of systems where fish reside.
- ***Criteria development should recognize that one size does not fit all.*** Temperature criteria development should account for what's naturally achievable, and the specific spatial and temporal needs of biota. The physical and biological variability within

and between stream systems makes the application of a single, universal temperature standard difficult or inappropriate. Therefore, temperature standards, whether narrative or numeric, should reflect the variability of streams and the biological resources they support.

As the Regional Temperature Critieria Guidance Project assesses this and other information, we recommend that several attributes be considered and incorporated into any developed criteria. The criteria should:

- Be based on specifically-cited, scientifically-based research findings.
- Address variation in the natural "signature" of temperatures in streams, and provide guidance on variations from their natural regime that may be allowable without impairment of beneficial uses.
- Go beyond a one-size-fits-all temperature magnitude standard, and recognize that processes that control temperatures and natural temperature "signatures" vary across the landscape by distance downstream, geographic location, elevation, aspect, groundwater inflow, stream depth, stream width, streamflow, etc.
- Go beyond a single numeric or narrative temperature magnitude standard, and establish criteria that recognize and incorporate frequency and duration of temperature events. An exception process should be included to further address limited duration temperature situations where the criteria cannot be maintained.
- Be cautious in ascribing cumulative effects and recognize that warming is not strictly cumulative downstream, but adjusts to new equilibrium conditions.
- Reflect that forestry's role in water quality is not to mitigate for the effects of downstream polluters, and recognize that the influences of forest management are limited by the physics of heat flow and the resistance and resilience of biological ecosystem components.
- Recognize that the temperature conditions preferred by salmonids vary depending on species, life stage, geographic region, acclimation temperature, duration of exposure, and food supply.
- Be measurable, implementable, and easy to understand.

As requested in your April 20, 2000 notice, we attach an annotated bibliography and two (2) copies of a number of documents that provide important information relating to water temperature and salmonids. Please call us if you have questions or need additional information or clarification on these materials.

Sincerely,

Jim McCauley
Director of Water and Forest Regulation
Oregon Forest Industries Council

Ann Goos
Director of Environmental Affairs
Washington Forest Protection Association

Enclosures: Annotated Bibliography of Information and Studies Relevant to Temperature, Salmonids, and Water Quality
Copies of Documents Cited in the Annotated Bibliography

Annotated Bibliography of Information and Studies Relevant to Temperature, Salmonids, and Water Quality

Annotated Bibliography:

Information and Studies Relevant to Temperature, Salmonids, and Water Quality

This annotated bibliography of *Information and Studies Relevant to Temperature, Salmonids, and Water Quality* has been prepared in response to the April 20, 2000 request by the US EPA Region 10; the States of Oregon, Washington, and Idaho; and the US Fish and Wildlife Service and the National Marine Fisheries Service. It was prepared as a joint effort of the Oregon Forest Industries Council, the Washington Forest Protection Association, and their members.

The information and studies are relevant to the interagency regional temperature criteria guidance development project. All are believed to be pertinent to the regional temperature criteria guidance that US EPA expects to deliver to states and tribes, and any proposed revisions by US EPA to temperature standards in the Pacific Northwest. None of the information and studies included in this annotated bibliography is included in the Literature List currently in possession of the project's Technical Workgroup.

The annotated bibliography is organized primarily by the six categories of information that are of special interest to US EPA Region 10:

1. Physiological response of salmonids to water temperature.
2. Behavioral responses of salmonids to water temperature.
3. Changes in salmonid population distributions attributable to changes in water temperature.
4. Multiple stressors that may interact with water temperature to affect salmonids.
5. Expected patterns of water temperature across space and time at multiple scales and anthropogenic changes thereto (including cumulative effects).
6. Measurement and monitoring of water temperature.

Within each of the six information categories, information and studies are listed by title. Each contribution contains:

1. A complete bibliographic citation.
2. A statement of the objectives or subjects addressed.
3. A summary of the significant findings.
4. A conclusion suggesting the relevance of the information to the regional temperature criteria guidance development project.

Full copies of cited papers, reports, and pertinent excerpts are included in a separate attachment.

OFIC

WFPA

Physiological Response of Salmonids to Water Temperature

1. **Summer Production of Coho Salmon Stocked in Mount St. Helens Streams 3-6 Years after the 1980 Eruption.**
   Bisson, P. A., Jennifer L. Nielsen, and James W. Ward.
   1988.
   Transactions of the American Fisheries Society 117:322-335.

   Objective:

   i. Measure growth and production of fish in streams impacted by the Mt. St. Helens eruption.

   ii. Develop an understanding of relationships between fish and their habitats in highly disturbed systems.

   Key Findings:

   - Growth and production of coho salmon stocked in three streams within the area impacted by the Mt. St. Helens eruption were measured.
   - Average daily maximum temperatures during the summer were well above the ranges considered optimal for fish growth, and sometimes exceeded incipient lethal temperatures identified in laboratory studies.
   - In spite of exposure to temperatures widely considered to be detrimental to fish, growth and production of coho salmon in the study streams were equal to or greater than what has been observed in more typical conditions.
   - High levels of food availability in the streams appeared to ameliorate any temperature-related negative impacts to growth.

   Relevancy:

   1. Conclusions about negative impacts to fish from elevated water temperature derived from laboratory studies cannot reliably be extrapolated to streams.
   2. Fish growth and production is not only a result of temperature regime, but food availability, too.

2. **Summer water temperature conditions on the Eel River system, with reference to salmon and trout.**
   Kubicek, P.F.
   1977.
   Master's Thesis. Humboldt State University, Arcata, CA.

Objective:

i. To determine, from a water quality standpoint, the locations and amount of suitable habitat to native anadromous and resident salmonids in the mainstem Eel River system during summer.

Key Findings:

- Water temperatures were measured synoptically at 179 stations and continuously at 30 stations in the Eel River during the summer of 1973.
- Suitability classes were derived from a comprehensive review of the literature taking into account lethal and preferred temperatures, and thermal exposure resistance times, reported in the literature.
- The river was classified into stream segments having "lethal," "marginal," or "satisfactory" temperature suitability:
  - Lethal. Stream sections reaching a maximum temperature of 28 ^{o}C for at least 100 continuous minutes.
  - Marginal. Stream sections reaching a maximum temperature of 26.5 ^{o}C for at least 100 continuous minutes.
  - Satisfactory. Stream sections reaching a maximum temperature of less than 26.5 ^{o}C.
- Of the total of 444 miles surveyed, 44 percent were classified as lethal, 22 percent classified as marginal, and 34 percent classified as satisfactory.
- Observations of the distribution and abundance of salmonids in the river supported the temperature classification system.

Relevancy:

1. This research shows that effects from temperature depend on the duration of exposure.
2. Temperature criteria should include guidance on duration and frequency, as well as magnitude, of acceptable temperature events.

3. **Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams.**
   Bilby, R.E. and P.A. Bisson.
   1992.
   Can. J. Fish. Aquat. Sci. 49:540-551.

   Emigration and production of hatchery coho salmon (*Oncorhynchus kisutch*) stocked in streams draining and old growth and a clear-cut watershed.
   Bilby, R.E. and P.A. Bisson.
   1987.
   Can. J. Fish. Aquat. Sci. 44:1397-1407.

   Objective:

   i. Evaluate the influence of riparian canopy removal on stream productivity.

   ii. Assessed factors determining stream productivity in streams with and without riparian canopy.

   Key Findings:

   - These two companion papers were produced from studies in the upper Deschutes River, Washington.
   - Growth and production of fish were compared along harvested and unharvested forested streams.
   - Increased food availability attributed to increased autochthonous production in stream at the harvested site resulted in higher fish growth and production relative to the stream at the unharvested site.
   - Assessments of optimal conditions for salmonid habitat productivity need to include consideration of the role of autochthonous production in regulating food availability.

   Relevancy:

   1. Increases solar inputs can result in increased fish production due to corresponding increases in autochthonous production.

4. **Salmonid populations in logged and unlogged stream sections of western Washington.**
Bisson, Peter A. and James R. Sedell.
1982.
Weyerhaeuser Technical Report.

Objective:

i. To characterize fish production in streams adjacent to unbuffered and forested riparian areas.

Findings:

- This study compared fish production in adjacent stream reaches with and without riparian canopy cover.
- Salmonid biomass averaged 1.5 times greater in stream reaches adjacent to timber harvest than in streams adjacent to unlogged reaches.
- Increased solar inputs were believed to be responsible for higher production in the unshaded reaches.

Relevancy:

1. Increased fish production are consistently observed in unshaded streams.

5. **Stream temperature and aquatic habitat: Fisheries and forestry interactions.**
Beschta. R.L., R. E. Bilby, G. W. Brown, T. D. Hofstra and L. B. Holtby.
1987.
In: E.O. Salo and T.W. Cundy (eds.). Streamside Management: Forestry and Fish Interactions. Inst. Forest Resour., U. of Washington, Seattle, WA. Contrib. No. 57.

Objective:

i. Synthesis of available literature.

Key Findings:

- Groundwater inputs influence temperature in small streams.
- Temperature is highly variable, and is influenced by the physical setting.
- Buffers are effective in maintaining appropriate stream temperatures for given site conditions.
- Increases in solar inputs can result in both elevated temperature and primary production.
- Fish production can increase in response to increased solar inputs.

Relevancy:

1. Summary and review of available literature on processes influencing stream temperature regime, fish and temperature interactions.

6. **Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout.**
Hokanson, K.E., C.F. Kleiner, and T.W. Thorslund.
1977.
J. Fish. Res. Bd. Can. 34:639-648.

Objective:

i. The purpose of this study was to test the assumption that the average fluctuating water temperature causes the same biological response as an equal constant temperature.

Key Findings:

- Specific growth and mortality rates of juvenile rainbow trout were determined for 50 days at seven constant temperatures between 8 and 22 ^{o}C, and six diel temperature fluctuations (following sine curve of amplitude $\pm$ 3.8 ^{o}C) with mean temperatures from 12 to 22 ^{o}C.
- The upper incipient lethal temperature was found to be 25.6 ^{o}C for trout acclimated to 16 ^{o}C.
- A yield model was developed to describe the effects of temperature on production over time, and to facilitate comparison of treatment responses.
- The results indicate that, in fluctuating temperature conditions, the trout do not respond to mean temperature, but to a value between the mean and maximum daily temperature.

Relevancy:

1. Derivation of temperature standards must take into account the magnitude of temperature variations of the particular natural environment to which the standard applies.
2. Acclimation to fluctuating temperatures, rather than a constant temperature, should be assessed in future studies in setting appropriate temperature standards.

7. **An analysis of the effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria.** [Draft]
Sullivan, Kathleen, Douglas J. Martin, Richard D. Cardwell, John Toll, and Steven Duke. 2000.
Sustainable Ecosystems Institute, Portland, OR. Technical Report.

Objective:

i. To select biologically-based temperature thresholds to protect salmonids.

Findings:

- A risk-based approach that considers both magnitude and duration of temperatures can be used effectively to quantitatively determine biologically-based temperature criteria.
- By applying quantitative methods developed in the report to a wide range of temperature regimes measured in natural streams in Washington, it was found that direct mortality from high temperatures was unlikely because temperatures high enough to cause mortality are either never observed, or occur over periods of time too short to cause death.
- Effects on salmonid growth from long-term exposure to ambient temperatures in natural streams in Washington were quantitatively assessed using a simplified bioenergetics approach developed in the report. The analysis found that growth predicted from ambient temperatures is somewhat less than the maximum potential growth assuming optimal temperatures in all streams regardless of temperature regime, because no stream experienced optimal temperature all of the time. Generally, the effect of temperature regime on growth was quite low in the range of streams studied, although growth effects were evident in streams with higher temperatures.
- Threshold temperature criteria could be identified for salmonid species based on effects on growth of chronic exposure to temperature during the summer season.

Relevancy:

1. Results suggest that quantitative analysis of growth effects can be determined with reasonably simple methods that can be applied at specific sites or at a regional scale to identify appropriate temperature thresholds.
2. Criteria derived in this manner are similar to those developed in a USEPA paper in 1977, and currently found in Washington and Oregon criteria.

Behavioral Responses of Salmonids to Water Temperature

1. **Stream temperature considerations in the development of Plum Creek's Native Fish Habitat Conservation Plan.**
   Sugden, B.D., T.W. Hillman, J.E. Caldwell, and R.J. Ryel.
   1998.
   Plum Creek Native Fish Habitat Conservation Plan Technical Report #12. Plum Creek Timber Company, Columbia Falls, MT.

   Objectives:

   i. This report addresses several questions related to the management of riparian areas for maintenance of stream temperatures suitable for native fish in the 1.7 million-acre Plum Creek Timber Company's Habitat Conservation Planning Area.

   ii. Review temperature requirements of native fish in the Planning Area, including bull trout.

   iii. Review effects of winter conditions on trout in ice-covered streams.

   Key Findings:

   - Literature review indicates that bull trout spawning can occur in water temperatures ranging from 4°C to 12°C.
   - Reviewed field studies indicate that optimal juvenile bull trout rearing requirements fall between 10°C and 15°C. This range appears to be colder than for other native salmonids in the area. While optimal temperatures appear cool, juveniles have been found in water ranging from 4°C to 20.5°C.
   - The literature suggests that introduced brook trout interact with native bull trout, although these studies are mostly correlative. However, the authors could not find where the literature demonstrates that temperature influences the outcome of interactions between the two species.

   Relevancy:

   1. Based on the review of available literature, existing temperature standards for bull trout in Idaho and Oregon appear to be on the lower end of the optimal range of bull trout. This could be deleterious to bull trout.

Changes in Salmonid Population Distributions Attributable to Changes in Water Temperature

1. **Summer water temperature conditions on the Eel River system, with reference to salmon and trout.**
   Kubicek, P.F.
   1977.
   Master's Thesis. Humboldt State University, Arcata, CA.

   Objective:
   i. To determine, from a water quality standpoint, the locations and amount of suitable habitat to native anadromous and resident salmonids in the mainstem Eel River system during summer.

   Key Findings:
   - Water temperatures were measured synoptically at 179 stations and continuously at 30 stations in the Eel River during the summer of 1973.
   - Suitability classes were derived from a comprehensive review of the literature taking into account lethal and preferred temperatures, and thermal exposure resistance times, reported in the literature.
   - The river was classified into stream segments having "lethal," "marginal," or "satisfactory" temperature suitability:
     - Lethal. Stream sections reaching a maximum temperature of 28 °C for at least 100 continuous minutes.
     - Marginal. Stream sections reaching a maximum temperature of 26.5 °C for at least 100 continuous minutes.
     - Satisfactory. Stream sections reaching a maximum temperature of less than 26.5 °C.
   - Of the total of 444 miles surveyed, 44 percent were classified as lethal, 22 percent classified as marginal, and 34 percent classified as satisfactory.
   - Observations of the distribution and abundance of salmonids in the river supported the temperature classification system.

   Relevancy:
   1. This research shows that effects from temperature depend on the duration of exposure.
   2. Temperature criteria should include guidance on duration and frequency, as well as magnitude, of acceptable temperature events.

Multiple Stressors that May Interact with Water Temperature to Affect Salmonids

1. **FEMAT riparian process effectiveness curves: What is science-based and what is subjective judgement?**
   CH2M HILL and Western Watershed Analysts.
   1999.
   Oregon Forest Industries Council, Salem, OR.

   Objectives:
   i. To review the scientific evidence behind the riparian shade effectiveness curve—shade as a function of distance from stream channels—that was presented in the federal Forest Ecosystem Management Assessment Team report.

   ii. To propose refinements to the FEMAT riparian shade effectiveness curves based on the best available science.

   Key Findings:
   - Neither the scientific source nor the technical basis of the FEMAT shade effectiveness curve could be independently verified. Data and curves from FEMAT-referenced studies do not fit the published FEMAT shade relationship.
   - Three relevant scientific studies based on empirical data indicate that the FEMAT shade effectiveness curve should rise more sharply with distance from the stream channel; that is, the FEMAT curve underestimates the shade contribution from stream-adjacent riparian vegetation.
   - Independent scientific studies show that approximately 80 percent of full shade effectiveness occurs within a distance equal to one-half the height of a site-potential tree, and 90 percent of shade effectiveness occurs within a distance of 0.7 tree height.
   - Site-specific factors affecting shade effectiveness include vegetation density, height of vegetation, orientation of the stream, stream width, and latitude and time of year.

   Relevancy:
   1. Any generalized shade-distance relationship should be used with caution. The FEMAT shade curve should not be used in any application. The shade-distance relationship needs to be as accurate as possible to illustrate riparian vegetation effectiveness for shade, for use within any modeling procedure, for use in TMDL allocations, or for use in water quality management plans to address temperature.

2. **Evaluation of Oregon DEQ's Temperature Modeling and TMDL Process.**
CH2M HILL, Western Watershed Analysts, and T.N. Adams Consulting. 1999.
Oregon Forest Industries Council, Salem, OR.

Objectives:

i. To evaluate the structure and performance of Heat Source (Version 5.5), the Oregon Department of Environmental Quality's stream temperature model.

ii. To review the temperature model's use in developing a draft temperature TMDL for the Upper Grand Ronde River Sub-Basin in Oregon.

Key Findings:

- *Heat Source* is a reach-based stream temperature model; its algorithms and results appear to adequately represent thermal processes in segments of large streams.
- *Heat Source* confirmed that mainstem water temperatures essentially are independent of conditions in the smaller forested tributaries upstream.
- For medium-sized streams, the model is most sensitive to three input variables: buffer height, stream depth, and air temperature. Beyond threshold values, increases in buffer height and stream depth failed to influence downstream temperature significantly. Air temperature had a much greater effect on downstream water temperature than upstream water temperature.
- Sensitivity tests indicate the model reasonably predicts temperature conditions in small forested stream segments, with several caveats.
- The model demonstrates that downstream temperatures return to normal, given sufficient time and distance to reach equilibrium (even after exposure to solar radiation far in excess of that allowed by the Oregon Forest Practices Act Water Protection Rules).

Relevancy:

1. The ODEQ model does not indicate that tall, wide forested riparian buffers are essential for providing shade to most forested tributaries narrower than 10' wide.
2. Any temperature increases under the current Oregon Forest Practices Rules are likely to be small and localized.
3. Water temperature increases are not persistent and will rapidly move toward an equilibrium with their environment.
4. Managed forested riparian buffers can withstand partial harvest without compromising stream temperature.

3. **Evaluation of shade effects on water temperature of tributaries and the mainstem of the Grande Ronde River using Oregon DEQ's *Heat Source* temperature model.**
Western Watershed Analysts and CH2M HILL.
2000.
Oregon Forest Industries Council, Salem, OR.

Objectives:

i. To model an entire tributary drainage as realistically as possible under several different riparian vegetation scenarios to determine if riparian buffer vegetation could be reduced to less than site-potential tree height, less than 30 m width, and / or less than 80 percent density without violating applicable water quality standards.

ii. To review the Oregon Department of Environmental Quality's (ODEQ) methodology for determining site-potential vegetation height and density by physiographic unit.

iii. To review ODEQ's methodology for allocating solar loading and effective shade based on physiographic unit, stream width, and stream aspect.

Key Findings:

- Riparian vegetation conditions can be selectively manipulated in tributary drainages without violating water quality standards in the tributaries and without further increases in maximum water temperatures in the mainstem of the Grande Ronde.
- ODEQ's methodology for determining site-potential vegetation dimensions ignores the substantial variability of achievable conditions that are commonly found in forest riparian areas, and is not a realistic representation of true forest conditions.
- ODEQ's methodology for allocating solar loading and effective shade does not provide realistic achievable representations of potential effective shade because the procedures to determine riparian vegetation height are flawed.

Relevancy:

1. It is recommended that ODEQ eliminate the requirement for shade levels based on site-potential vegetation, and instead require only the level of shade necessary to maintain local and downstream reach temperatures at or below the applicable water temperature standards, or the level of shade achievable at the individual stream reach, whichever is less.
2. The *Heat Source* model can be used to estimate the required levels of shade, or simpler canopy / elevation / temperature models could be developed to provide these estimates.

4. **Review of the Scientific Foundations of the *Forests and Fish* Plan.**
CH2M HILL.
2000.
Washington Forest Protection Association, Olympia, WA.

Objectives:

i. To review the scientific foundations for the proposed Washington forest practices rules contained in the Forests and Fish Report.

ii. To assess the probable effectiveness of the Forests and Fish Report for protecting fish habitat and water quality on non-federal, non-tribal forestlands in the State of Washington.

Key Findings:

- The *Forests and Fish* shade management prescriptions would provide near-maximum levels of shade to streams—levels that approach or exceed the amounts provided by mature forests. These may be less than the maximum potential shading, but would maintain water temperatures at or below state water quality standards in most situations where it currently exists.
- Water temperature in perennial non-fish-habitat reaches of streams may increase over limited distances as a result of staggered shade retention zones, but these changes are not expected to affect beneficial uses of downstream fish-habitat waters because strategic watershed locations would be shaded and stream temperatures would relax toward equilibrium with the surrounding environment.
- The *Forests and Fish* plan's riparian strategy for managing shade and its effect on heat energy is consistent with the concept of diminishing marginal returns. Approximately 70 percent of the total shade delivered to stream channels originates within 50 feet of the channel. Only 10 percent of the total shade delivered to the stream is derived from beyond 50 feet. The remaining 20 percent shade is unachievable, even under old-growth riparian stand conditions.

Relevancy:

1. The report provides a detailed literature review of riparian vegetation and streamside shade relationships.
2. Information is provided for evaluating the effect of various riparian vegetation management regimes and their contributions to shade and the regulation of water temperature.

5. **Effect of water temperature on survival of eyed eggs and alevins of Arctic char.**
   Bebak, J., J.A. Hankins and S.T. Summerfelt.
   2000.
   North American Journal of Aquaculture 62:139-143.

   Objectives:
   i. To determine hatching success and post-hatch survival of two different genetic strains of Arctic char.

   Key Findings:
   - Temperature effects on salmonids depend on genetic strains of the same species.
   - Significant differences were observed in the eyed-egg to 90-day post-hatch survival of Arctic char reared at a gradually increasing temperature regime from 6 ^{o}C to 12 ^{o}C—86 percent survival for the Fraser River strain versus 95 percent survival for the Yukon char strain.
   - Egg hatching success also was significantly different between strains—90-97 percent for the Fraser River char strain, and 98-99 percent for the Yukon char strain.
   - Significantly lower egg to post-hatch survival was observed for Arctic char reared only at 12 ^{o}C (no gradual acclimation from 6 ^{o}C as noted above)—73 percent for the Fraser River char versus 65 percent for the Yukon char. Without acclimation, survivals were 20-30 percent lower.
   - Hatching success was 90% or more at all temperature regimes tested.
   - Post-hatch survival varied from 78 to 97 percent among the different salmonid strains.

   Relevancy:
   1. The genetic strains of salmonids appear to influence hatching success under varying temperature regimes.

6. **Growth of stunted Arctic char after transfer to a commercial rearing system.**
Udedal, O., T.G. Heggberget, and G.E. Grande.
1994.
Transactions of the American Fisheries Society 123:423-429.

Objectives:

i. To determine specific growth rates of wild-caught salmonids following exposure to varying temperature regimes.

Key Findings:

- Wild-caught Arctic char were reared in the laboratory in a 12 week experiment.
- Seasonal water temperatures ranged from under 5 ^{o}C to over 20 ^{o}C.
- Survival was 94 percent and most of the mortality took place at temperatures over 20 ^{o}C.

Relevancy:

1. The range of water temperature affects salmonid acclimation and survival.
2. Temperature effects on salmonids depend on duration of exposure.

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Expected Patterns of Water Temperature across Space and Time at Multiple Scales and Anthropogenic Changes Thereto (including Cumulative Effects)

1. **Physics of forest stream heating: 1) A simple model.**
   Adams, Terry and Kathleen O. Sullivan.
   1989.
   Weyerhaeuser Technical Report 044-5002/89/1
   [Also published as Timber/Fish/Wildlife document TFW-WQ3-90-007.]

   Objective:

   i. Develop a simple and effective physical model to describe stream temperature in terms of daily mean temperature and fluctuations about the mean.

   Key Findings:

   - Stream heating is influenced by the interaction of broad regional climatic patterns and local conditions.
   - Daily mean water temperature is always near daily mean air temperature when stream is in equilibrium with environment. This indicates that solar insolation has little influence on the daily mean temperature after initial transient heating period. However, fluctuations around the mean are strongly influenced by solar insolation, riparian vegetation and diurnal air temperature fluctuations.
   - Stream depth affects both response time and magnitude of fluctuations in stream temperature.
   - Groundwater influx is an important factor in the temperature of small streams.

   Relevancy:

   1. Different types of temperature metrics (e.g., mean daily temperature or fluctuations about the mean) show different responses to regional and local conditions.
   2. Local environmental factors such as shade strongly influence stream temperature fluctuations in small streams. Stream temperature in large streams fluctuate less and show less response to local environmental factors such as shade. Daily mean temperatures in large streams respond more to average basin air temperatures.
   3. The strong relationship identified between daily mean water temperature and daily mean air temperature indicates that stream temperatures will vary regionally according to local climate regimes.

2. **Physics of stream heating: 2) An analysis of temperature patterns in stream environments based on physical principles and field data.**
Sullivan, Kathleen and Terry Adams.
1991.
Weyerhaeuser Technical Report 044-5002/89/2.

Objectives:

i. Establish a more global understanding of the basic physics of stream heating.

ii. Identify the fundamental environmental parameters determining stream heating.

iii. Demonstrate their broad application in describing temperature regimes of streams.

Key Findings:

- Stream heating is influenced by the interaction of broad regional climatic patterns and local conditions. Analysis of field data from a variety of streams in Oregon and Washington indicates that daily mean water temperature equilibrates with and is always near air temperature regardless of stream size.
- There is some location in the basin where the stream is of sufficient size where the influence of riparian canopy and groundwater on water temperature is negligible. At this threshold distance, water temperature is primarily related to air temperature. This finding is supported by recent work by Mohseni and Stefan (1999) who also found that "after a long travel time…the memory of the upstream temperature is lost and only weather determines water temperature."

Relevancy:

1. Stream shading has a stronger influence on stream temperature in small streams, while temperatures in large streams are primarily influenced by air temperature.
2. The most important factors regulating stream temperature are:
   - Air temperature.
   - Stream depth.
   - Groundwater inflow.
   - Riparian conditions.

Supporting Literature:

Mohseni, O. and H.G. Stefan. 1999. Stream temperature/air temperature relationship: a physical interpretation. Journal of Hydrology 218:128-141.

3. **Evaluation of downstream temperature effects on Type 4/5 waters.**
Caldwell, J., K. Doughty and K. Sullivan.
1991.
TFW-WQ5-91-004.

Objectives:

i. Characterize temperature regimes in Type 4 waters (small non-fish bearing streams) of Washington.

ii. Assess the magnitude and extent of downstream effects related to water temperatures of upstream Type 4 waters.

iii. Provide recommendations for management of riparian areas on Type 4 waters relevant to potential downstream temperature impacts.

Key Findings:

- Small streams respond dynamically to local conditions (e.g., shade, groundwater, air temperature). Logging debris and shrubs provide substantial shade to small streams.
- The downstream influence of small streams to larger, fish-bearing streams is limited to approximately 150 m beyond the water type interface.
- There is a maximum equilibrium temperature above which water temperatures will not increase even though air temperatures do.

Relevancy:

1. Stream temperature increases from timber harvest along small non-fish streams have a negligible effect on downstream fish-bearing streams.

4. **Effectiveness of eastside (Washington) target shade rule.**
   Glass, Domoni.
   2000.
   Boise Cascade Corporation, Boise, ID. [Unpublished Report].

Objective:

i. Evaluate the effectiveness of streamside shade requirements specified by the Washington forest practices shade rule methodology in predicting compliance with water temperature standards.

Key Findings:

- Application of the shade rule methodology was adequate to maintain stream temperature at or below standards for 95 to 96 percent of the 155 streams sampled.
- Application of the rule methodology provided more shade that was needed to maintain stream at temperature standards at 20 to 25 percent of the sample locations.
- For eastern Washington streams studied, the shade rule methodology was found to be effective for predicting the amount of shade needed to maintain stream temperatures at least as cool as required by current water quality standards.

Relevancy:

1. Riparian forest stand canopy closure can be used as a guide to ensure that sufficient shade is retained to maintain stream temperature standards when the canopy values are applied using a regional predictive model that uses elevation as an independent variable.

5. **Stream temperature considerations in the development of Plum Creek's Native Fish Habitat Conservation Plan.**
Sugden, B.D., T.W. Hillman, J.E. Caldwell, and R.J. Ryel.
1998.
Plum Creek Native Fish Habitat Conservation Plan Technical Report #12.
Plum Creek Timber Company, Columbia Falls, MT.

Objectives:

i. This report addresses several questions related to the management of riparian areas for maintenance of stream temperatures suitable for native fish in the 1.7 million-acre Plum Creek Timber Company Habitat Conservation Planning Area.

ii. Discuss the potential influence of small streams on downstream fish-bearing waters.

iii. Study canopy cover before and after timber harvest along ten streams in Montana and Idaho.

Key Findings:

- Available literature suggests that small streams would be expected to equilibrate with surrounding conditions within 500 feet.
- Small non-fish-bearing streams are not expected to materially influence the temperatures of larger fish-bearing streams unless they constitute a significant part of the flow to fish-bearing streams.
- Measurement of ten sites before and after harvest in western Montana and northern Idaho found that mean canopy cover decreased from 67% to 62% after harvest.

Relevancy:

1. Except where they constitute a large fraction of the flow to a fish-bearing stream, small streams are unlikely to significantly affect downstream temperatures. Where they do constitute a substantial fraction of the discharge to a fish-bearing stream, research on equilibrium distances suggest that providing shade on the lower 500 feet of these streams would be an effect conservation strategy.
2. Existing state forest practices regulations lead to the retention of a large fraction of the pre-harvest canopy over streams. This would be expected to largely control direct-beam shortwave radiation inputs to streams, thus minimizing adverse temperature increases associated with harvesting.

6. **Temperature and streamflow regulation by streamside cover.**
Newton, M. and M. Zwieniecki.
1996.
Final Report to Oregon Department of Forestry. Oregon Department of Forestry Salem, OR.

Objective:

i. Sixteen stream systems were studied to determine whether current rules for forestry Best Management Practices (BMPs) for standard harvesting and hardwood conversion units near streams are adequate for protection against excessive warming of streams (i.e., >64 ^{o}F), and also whether features of streams and various elements of hydrologic systems explain the patterns of temperature fluctuation observed.

Key Findings:

- Warming patterns occurred under conditions where warming would be expected in fully covered streams.
- The *expected* rate of warming provides a useful index of whether the observed warming is excessive.
- On the average, in-unit warming was slightly greater than expected if fully covered.
- Within 480 feet downstream from the unit, the average temperature was almost identical with expected for covered streams. Thus, the net warming occurring in units was very slight, and was localized.
- No cumulative effect was demonstrable.
- Streams with buffers designed to intercept direct sunlight only showed negligible warming in or below units, despite major openings.

Relevancy:

1. Several factors apparently reduce the innate tendency for streams to warm.
2. Substantial transpiration removes water from the streams.
3. Most of the removal by transpiration occurs during the time of day that water is warmest, and this temporal bias by transpiration leads to a loss of heat from the stream.
4. The baseflow that supplies most of summer discharge is cold, i.e., about 53.6 ^{o}F.
5. At least partly because of the transpirational removals, flow does not increase with downstream movement in proportion to basin area, and much of what occurs in the stream channel at any given point is of relatively local cool sources.

7. **Influence of streamside cover and stream features on temperature trends in forested streams in Oregon.**
   Zwieniecki, M. and Newton, M.
   1999.
   Western Journal of Applied Forestry. 14(2):106-113.

   Objective:

   i. To assess whether streamside cover of streams and various stream features explain the patterns of temperature fluctuation observed.

   Key Findings:

   - Timber harvesting along low elevation western Oregon streams with riparian buffers (8.6 to 30.5 m wide) was followed by little direct local effect on water temperature.
   - A study of 14 streams demonstrated that all have a tendency to warm with downstream direction even under full forest cover.
   - After the natural warming trend of the stream water was accounted for, water at slightly higher temperatures within the buffered clearcut zones cooled to the trend line of temperature by 150 m downstream.

   Relevancy:

   1. Estimating the net temperature effect associated with management practices requires use of a warming trend line as the norm for fully covered forests because of the natural warming trends in streams with decreasing elevation.

8. **Regional assessment of stream temperatures across northern California and their relationship to various landscape-level and site-specific attributes.**
Lewis, T.E., D.W. Lamphear, D.R. McCanne, A.S. Webb, J.P. Krieter, and W.D. Conroy.
2000.
Forest Science Project, Humboldt State University Foundation, Arcata, CA. Technical Report.

Objective:

i. Characterize water temperature regimes and factors across a broad geographic area in northern California using continuous temperature data from streams throughout northern California.

Key Findings:

- Watersheds that are predominately coastal have cooler air temperatures whereas those that have a southeasterly to northwesterly orientation show strong thermal gradients.
- Water temperatures have a tendency to increase with increasing distance from the watershed divide and with increasing drainage area.
- Water temperature near the source is the coolest, normally close to groundwater temperature.
- The "threshold distance" concept, that is the distance from the watershed divide at which streams become too wide for riparian vegetation to provide adequate shading, was explored empirically using the continuous temperature data from streams throughout northern California.
- The data suggests that 70 km is the approximate theoretical maximum threshold distance.

Relevancy:

1. A single temperature standard is difficult to apply to a broad region, because streams differ markedly in size, drainage area, elevation, geographical location, prevailing climatic conditions, aspect, riparian vegetation, etc.
2. Streams in diverse settings behave very differently, and temperature standards, whether numeric or narrative, should reflect these differences.

9. **Harvesting effects on microclimatic gradients from small streams to uplands in western Washington.**
Brosofske, K.D., J. Chen, R.J. Naiman, and J.F. Franklin.
1997.
Ecological Applications 7(4):1188-1200.

Objective:

i. To characterize microclimatic gradients across riparian ecosystems of small streams under various forest structural conditions.

Key Findings:

- Regression analyses between stream water temperature and microclimatic variables in the surrounding area revealed that wind speed, relative humidity, and solar radiation had little or no relationship with stream temperature.
- Air and surface temperatures had intermediate effects on water temperature.
- Soil temperature appears to exert a strong influence on water temperature, especially where forest vegetation was present.

Relevancy:

1. Air and surface temperatures, and groundwater influences, appear to be the controlling variables affecting water temperature of small streams.
2. Vegetation, as it affects wind speed, relative humidity, and solar radiation, has relatively little or no affect on stream water temperature.
3. Riparian vegetation density has a substantial effect on water temperature in small streams only as the riparian vegetation density nears zero.

Measurement and Monitoring of Water Temperature

1. **Stream temperature considerations in the development of Plum Creek's Native Fish Habitat Conservation Plan.**
   Sugden, B.D., T.W. Hillman, J.E. Caldwell, and R.J. Ryel.
   1998.
   Plum Creek Native Fish Habitat Conservation Plan Technical Report #12.
   Plum Creek Timber Company, Columbia Falls, MT.

   Objectives:
   i. This report addresses several questions related to the management of riparian areas for maintenance of stream temperatures suitable for native fish in the 1.7 million-acre Plum Creek Timber Company Habitat Conservation Planning Area.
   ii. Develop a predictive stream temperature model for western Montana and northern Idaho.

   Key Findings:
   - Significant relationships were found among all combinations of temperature metrics evaluated. Pearson correlation coefficients consistently exceeded 0.89 for all possible combinations of temperature metrics. In addition, relationships were linear. Simple linear regression models explained 84% to 99% of the variability between independent and dependent temperature metrics.
   - Data taken from 100 streams in western Montana and northern Idaho was used to develop a linear regression model that predicted Maximum Weekly Maximum Temperature (MWMT) and Maximum Weekly Average Temperature (MWAT) as a function of upstream canopy cover, elevation, and the Palmer Drought Severity Index. Combinations of these independent variables explained between 49% and 77% of the variability in maximum stream temperature.

   Relevancy:
   1. Maximum stream temperatures can be reasonably predicted based on elevation and canopy cover.
   2. Such a model could be used in reach-scale timber harvest design to ensure maintenance of a desired maximum water temperature.
   3. This model also could be used to estimate the natural temperature capabilities of streams.

2. **Huckleberry Creek Recovery Monitoring.**
Fransen, Brian, et al.
1986-Present. [Ongoing Research]
Weyerhaeuser Corporation, Federal Way, WA.

Objective:

i. Monitoring of the physical habitat, hydrology, and fish populations in Huckleberry Creek, a tributary to the Deschutes River in western Washington, was initiated in 1986. In 1990, a significant storm event resulted in a large debris torrent that traveled approximately one mile downstream of the initiation point. Resulting alteration of riparian vegetation and in-stream habitat dramatically changed the physical environment for fish communities within the stream reach affected by the debris torrent. A downstream reach was relatively unaffected by the debris torrent with the exception of the influence of elevated stream temperature from the upstream reach.

Key Findings:

- Stream temperature, physical habitat, and fish communities within both reaches have been monitored.
- Stream temperatures demonstrate a clear trend in recovery toward pre-disturbance levels.
- Channel unit surveys indicate that physical habitat recovery processes are creating conditions similar to pre-disturbance condition.
- Fish production after the event increased within the reach affected by the debris torrent immediately following the event.

Relevancy:

1. The study is providing information on the physical and biological recovery processes of Huckleberry Creek after a debris torrent.
2. Evaluations of longer-term trends in fish community and habitat response are ongoing.
3. Results are being summarized and can be made available to the temperature criteria guidance development project upon request.

3. **St. Helens Recovery Monitoring.**
Fransen, Brian, et al.
1988-Present. [Ongoing Research]
Weyerhaeuser Corporation, Federal Way, WA.

Objective:

i. To continue to monitor fish populations, temperature, and physical habitat within the three study streams assessed in the earlier research publication by Bisson et al. (1988).

Key Findings:

- Although this recent research has not yet been summarized in written form, the data suggests that the three study streams continue to exhibit relatively high fish production.
- Summer stream temperatures continue to moderate as riparian vegetation matures.
- Trends in physical habitat recovery vary by site characteristics and the severity of the initial disturbance.

Relevancy:

1. The study continues to provide information on the physical and biological recovery processes of three stream affected by the Mt. St. Helens eruption.
2. Evaluations of long-term trends in fish community and habitat response are ongoing.
3. Results are being summarized and can be made available to the regional temperature criteria guidance development project upon request.

4. **Johnson Creek Recovery Monitoring.**
   Fransen, Brian, et al.
   1986-Present. [Ongoing Research]
   Weyerhaeuser Corporation, Federal Way, WA.

Objective:

i. To monitor stream temperature and fish populations were monitored following a debris torrent in Johnson Creek, Oregon.

Key Findings:

- Stream temperatures returned to ranges within water quality standards seven years following the debris torrent.
- Rapid riparian vegetation growth was largely responsible for restoring water temperatures.
- Fish populations were assessed during five consecutive years and demonstrated relatively high productivity.

Relevancy:

1. Study is providing information on the physical and biological recovery processes of Johnson Creek after a debris torrent.
2. Evaluations of long-term trends in fish community and habitat response are ongoing.
3. Results are being summarized and can be made available to the temperature criteria guidance development project upon request.

5. **Rayonier Temperature Data—E/W Humptulips Watershed Analysis.**
Dieu, Julie J. and Douglas Martin.
1998. [Ongoing Monitoring]
Rayonier Corporation, Hoquiam, WA.

Objective:

i. To monitor stream temperature at the E/W Humptulips Watershed for Washington watershed analysis.

Key Findings:

- Compiled temperature data collected by the USDA Forest Service over a period of many years, and collected new thermograph data during the summer of 1998.
- These data and summaries are available from Fish Habitat Analyst Dr. Doug Martin (Martin Environmental, 2103 N. 62nd Street, Seattle, WA 98103; 260-528-1696; martin1696@aol.com).
- Using the model described in Sullivan et al. (Unpublished manuscript), Dr. Martin calculated the Reduction in Maximum Growth (RMG) for eight thermograph stations in the E/W Humptulips Watershed from the data collected in 1998.

Relevancy:

1. Study is providing information on the influences of water temperature on salmonid growth.
2. Results are being summarized and can be made available to the temperature criteria guidance development project upon request.

6. **Rayonier Temperature Data—E/W Dickey Watershed Analysis.**
Dieu, Julie J. and Douglas Martin.
1997. [Ongoing Monitoring]
Rayonier Corporation and Quileute Tribe, Hoquiam, WA.

Objective:

i. To monitor stream temperature at the E/W Dickey Watershed Administrative Units for Washington watershed analysis.

Key Findings:

- Data were collected during the summer of 1997 throughout the E/W Dickey Watershed Administrative Units by the Quileute Tribe as part of a cooperative watershed analysis.
- Parts of the E/W Dickey Watershed experience very high temperatures and very significant diurnal fluctuations (e.g., highs of 20-24 °C with 12 °C diurnal fluctuations).
- The Dickey Watershed is the third highest coho smolt producer per square mile in Washington State.
- Summaries of these data are available from Dr. Julie Dieu (unfortunately, due to hard drive crashes and personnel changes at Quileute Natural Resources, the original data are lost). Appropriate portions of the E/W Dickey Watershed Analysis are also available from Dr. J. Dieu (Rayonier, P.O. Box 200, Hoquiam, WA 98550; 360-538-4581; Julie_dieu@rayonier.com).

Relevancy:

1. Study is providing information on the influences of water temperature on salmonids.
2. Results are being summarized and can be made available to the temperature criteria guidance development project upon request.

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7. **Rayonier Temperature Data—Middle Palix River and its Tributaries.**
Dieu, Julie J. and Douglas Martin.
1998. [Ongoing Monitoring]
Rayonier Corporation, Hoquiam, WA.

Objective:

i. To monitor stream temperature at the Middle Palix River and its tributaries for Washington watershed analysis.

Key Findings:

- Data were collected during the summer of 1998 in several, carefully selected locations in the Middle Palix River and its tributaries.
- Temperatures in the Middle Palix River appear to be controlled by inputs of abundant, deep groundwater.
- It is rare for temperatures to exceed 13 °C (even when grab samples have been taken in unshaded wetland channels during the late afternoons of the hottest weeks in August), and diurnal fluctuations are almost always less than 1 °C.
- Although excellent coho rearing habitat appears plentiful in the Middle Palix River, coho smolt production is quite low.
- The only anadromous species that occurs in abundance in the Middle Palix River is chum, whose fry rear in the extended estuarine environment of Willapa Bay.

Relevancy:

1. These data are interesting, especially in contrast with the E/W Dickey Watershed Analysis results, because the two watersheds are physiographically similar, but differ strongly in smolt production. They both have gentle, coastal topography, numerous wetlands and very low-gradient streams.
2. It would be interesting to calculate the Reduction in Maximum Growth (RMG) from these stations to see if naturally cold temperatures in the Middle Palix River are limiting fish growth.
3. Dr. Dieu can provide appropriate portions of the Palix Watershed Analysis and the thermograph data to the temperature criteria guidance development project upon request.

Information and Studies Relevant to Temperature, Salmonids, and Water Quality
June 5, 2000
Enclosure

Copies of Documents Cited
in the Annotated Bibliography