INDEPENDENT MULTIDISCIPLINARY SCIENCE TEAM (IMST)

State of Oregon

December 8, 2000

The Honorable John A. Kitzhaber
Governor of Oregon
State Capitol
Salem OR 97310

The Honorable Brady Adams
Oregon Senate President
State Capitol
Salem OR 97310

The Honorable Lynn Snodgrass
Oregon House Speaker
State Capitol
Salem OR 97310

Enclosed is the IMST report of a scientific workshop that we conducted on influences of human activities on stream temperature and the existence of cold-water fishes, in particular salmonids, in streams with elevated temperatures.

The workshop was organized to identify technical points of agreement, disagreement, and gaps in our scientific information about these two topics. It is particularly noteworthy that points of agreement and gaps in scientific evidence were identified for both questions, but participants identified no substantial points of disagreement. All participants agreed that this indicates that the areas of disagreement and debate about influences of human activities on stream temperature and occurrences of salmonids in streams with elevated temperatures are based primarily on concerns about application, regulation, and management rather than disagreements about scientific evidence.

The IMST organized this workshop to inform its work on the IMST Stream Temperature Report. This topic has been the center of contentious debate throughout Oregon and has raised many questions about the Water Quality Standards. Participation in the workshop was limited to a relatively small number (22 invited participants with 16 attending, plus 5 members of the IMST) of invited technical specialists. We limited participation to ensure a manageable size and to facilitate the productive work of the group. Inevitably, when limiting participant numbers, some qualified individuals or the organizations they represent are left out, and that was the case for this workshop as well. However, IMST selected invitees to represent a cross section of a disciplinary expertise (forestry, rangeland management, urban management, fisheries, and hydrology), experience, and perspective.

Workshop participants and invitees who were unable to attend the workshop were asked to review and comment a draft of this report. IMST revised the report to reflect comments and suggestions, as we felt appropriate. Participants did not review the revised report. This document is an IMST report of the discussions and findings of the workshop, not an interpretation of workshop findings.

In addition to this report, IMST has established a public record of the workshop. The Record is maintained by the Oregon Watershed Enhancement Board and includes:

- Audio tapes of the plenary sessions and group discussions
- Video tapes of the plenary sessions
- Papers prepared by Matthew Boyd (Oregon Department of Environmental Quality) and Dale McCullough (Columbia River Inter-Tribal Fish Commission) in support of their presentations made at the workshop
- Final comments made by participants of what they felt were the most important points to capture in the workshop report
- Comments on the review draft of this report submitted by workshop participants and invitees not able to attend

IMST has found that scientific workshops of this type are valuable for identifying and clarifying the technical and scientific aspects of issues relevant to the mission of the Oregon Plan for Salmon and Watersheds. Reports of these workshops are solely the responsibility of the IMST and are our summary of the workshop discussions.

IMST will produce a report on the technical basis for Oregon Temperature Standard and implementation of actions related to stream temperature for recovery of salmon and watersheds. This report of the workshop will provide important technical information for the IMST report.

I hope this information will be helpful as work on the Oregon Plan for Salmon and Watersheds continues.

Sincerely Yours,

Logan A. Norris, Chair
Independent Multidisciplinary Science Team

LAN:grs

cc: IMST
Joint Legislative Committee on Stream Restoration and Species Recovery
Workshop Participants and Invitees

Influences of Human Activity on Stream Temperatures and Existence of Cold-Water Fish in Streams with Elevated Temperature: Report of a Workshop

Independent Multidisciplinary Science Team
Corvallis, OR
October 5-6, 2000

Technical Report 2000-2

A report of the
Independent Multidisciplinary Science Team,
Oregon Plan for Salmon and Watersheds

November 8, 2000

Members of IMST
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Citation: Independent Multidisciplinary Science Team. 2000. Influences of Human Activity on Stream Temperatures and Existence of Cold-Water Fish in Streams with Elevated Temperature: Report of a Workshop. Technical Report 2000-2 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board. Salem, Oregon.

Acknowledgements

The IMST would like to thank Randy Wildman for his assistance in organizing the workshop and Glenda Serpa for her administrative support to the workshop and report. We are grateful to Kathleen Maas-Hebner for her contributions to writing and producing the report. We also thank D. Eric Hanson, Suzie Peck, Cathleen Rose, and Cynthia Taylor for their technical writing assistance.

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Executive Summary

The Independent Multidisciplinary Science Team (IMST) convened a panel of experts on stream temperature and fish ecology on October 5-6, 2000 for a scientific workshop on human influences on stream temperature and responses by salmonids. The workshop was designed to review and discuss scientifically credible data and publications about 1) factors related to human activity that influence stream temperature and 2) behavioral, physical, and ecological mechanisms of cold water fish species for existing in streams with elevated temperatures. The goal of the workshop was to review empirical evidence and to identify points of agreement, disagreement, and knowledge gaps within the scientific community concerning the factors that influence stream temperature and fish responses to elevated temperatures. This information will assist the IMST in preparing a broader temperature report on Oregon's stream temperature water quality standards and their implementation.

This report is prepared by the IMST. It was reviewed by workshop participants and revised by the IMST accordingly. The report includes abstracts of plenary presentations on factors that influence stream temperatures and fish responses, and the results of group discussions. The workshop participants focused on three main questions and were asked to list statements of agreement and disagreement, and to identify gaps in the scientific knowledge related to each question:

- How and where does riparian vegetation influence stream temperature?
- Do other changes in streams cause increases in stream temperature?
- How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?

The workshop participants provided answers to the questions in the form of bullets. The answers below represent the IMST's summation of the workshop findings and were reviewed by the participants. Several gaps in the scientific basis for specific questions or relationships were identified. The participants found no areas of disagreement for which technical information was available. They noted that any disagreements were not related to scientific interpretation, but were based on concerns or opinions about application, regulation, and management.

How and where does riparian vegetation influence stream temperature?

The influence of riparian vegetation on stream temperature is cumulative and complex, varying by site, over time, and across regions. Riparian vegetation can directly affect stream temperature by intercepting solar radiation and reducing stream heating. The influence of riparian shade in controlling temperature declines as streams widen in downstream reaches, but the role of riparian vegetation in providing water quality and fish habitat benefits continues to be important. Besides providing shade, riparian vegetation can also indirectly affect stream temperature by influencing microclimate, affecting channel morphology, affecting stream flow, influencing wind speed, affecting humidity, affecting soil temperature, using water, influencing air temperature, enhancing infiltration, and influencing thermal radiation. It is critical to know the site potential to understand what vegetation a site can support. There is not a good scientific understanding of how much vegetation shading is required to affect stream temperature.

This lack of understanding may be due to the spatial and temporal variability in landscape components, and the resulting variability in both the direct and indirect influences of vegetation on stream temperature. Therefore, it is difficult to generalize about the effects of vegetation on stream temperature.

Do other changes in streams cause increases in stream temperature?

The answer to this question is yes, other physical changes in the stream system can modify stream temperatures. Stream temperature is a product of complex interactions between geomorphology, soil, hydrology, vegetation, and climate within a watershed. Changes in these factors will result in changes in stream temperature. Human activities influence stream temperature by affecting one or more of four major components: riparian vegetation, channel morphology, hydrology, and surface/subsurface interactions. Stream systems vary substantially across the landscape, and site-specific information is critical to understanding stream temperature responses to human activities.

How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?

Workshop participants identified several mechanisms that might explain the ability of fish populations to exist at higher than expected temperatures. The first mechanism was that the fish may have physiological adaptations to survive exposures to high temperatures. A second possibility was that stream habitats may contain cooler microhabitats that fish can occupy as refuge from higher temperatures. A third consideration is that ecological interactions may be different under differing thermal conditions resulting, for example, in changes in disease virulence or cumulative effects of stressors. Finally, since substantial differences exist between laboratory and field studies, it is difficult to apply results of laboratory studies to fish responses in the field. It is important to note that these proposed mechanisms are speculative and, as the list of gaps indicates, substantial experimental work is required to establish their influences on fish in different stream systems.

Workshop Summary

Workshop participants recognized gaps in the available science. Additional knowledge about human influences on stream temperatures and, consequently, influences on cold-water fish populations, will improve our ability to prevent further degradation of stream habitat and will enhance efforts geared towards the recovery of depressed fish populations. Even with these gaps, there was enough agreement on factors that influence stream temperature to indicate information is available to start developing and implementing management practices that are designed to reduce stream warming. It was suggested that managers should consider riparian vegetation, channel morphology, and hydrology, and should account for site differences.

Introduction

The Independent Multidisciplinary Science Team (IMST) convened a panel of experts on stream temperature and fish ecology in Corvallis, Oregon on October 5-6, 2000 for a scientific workshop on human influences on stream temperature and responses by salmonids (Agenda, Appendix 1). The workshop was designed to review and discuss scientifically credible data and publications about 1) factors related to human activity that influence stream temperature and 2) behavioral, physical, and ecological mechanisms of cold water fish species for existing in streams with elevated temperatures. The goal of the workshop was to review empirical evidence and to identify points of agreement, disagreement, and knowledge gaps within the scientific community concerning the factors that influence stream temperature and fish responses to elevated temperatures. This information will assist the IMST in preparing a broader temperature report on Oregon's stream temperature water quality standards and their implementation.

This report includes abstracts of plenary presentations (provided by the speaker unless noted otherwise) on factors that influence stream temperatures and fish responses, and the results of group discussions. The workshop participants focused on three main questions:

- How and where does riparian vegetation influence stream temperature?
- Do other changes in streams cause increases in stream temperature?
- How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?

The IMST conducted the workshop and active participation was limited to invited participants and IMST members (Appendix 2). Participants were selected on the basis of their scientific expertise and experience in the Pacific Northwest to include a variety of scientific perspectives from several disciplines (forestry, rangeland management, urban management, fisheries, and hydrology). The goal was to keep the group small enough to ensure productive discussion, but this may have resulted in some other individuals with appropriate expertise being excluded. Invited speakers were asked to present information to give all participants a common frame of reference and to be a catalyst for the ensuing discussions. Participants were asked to provide the IMST with citations for empirical scientific studies and these are included in the report.

The participants were provided with an initial agenda to serve as a suggestion of how to proceed for the rest of workshop. The group decided to keep the proposed questions and focus on a few topics as one group and not break into smaller workgroups. On Day One, participants first discussed "How and where does riparian vegetation influence stream temperature?" focusing on the influence of vegetation and the longitudinal basis for the influence of vegetation. Afterward they discussed "Do other changes in streams cause increases in stream temperature?" focusing on physical processes or changes other than vegetation. On Day Two, participants discussed "How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?" and focused on the technical basis for fish population performance at temperatures higher than those observed in laboratory or field studies and potential reasons for these discrepancies.

This is a report prepared by the IMST summarizing the workshop. It is not intended as the position of the IMST on these topics, but is simply intended to capture points of agreements and disagreements of the participants and the outputs of the workshop process. All invited workshop participants reviewed a draft of the workshop report, and IMST incorporated their reviews into the final workshop report. This report includes the speakers' abstracts of their presentations, a summary of group discussions and statements of agreement, disagreement, and knowledge gaps listed by the participants during the workshop, and a list of recommended citations.

The presentations and group discussions were recorded on audio and video tapes. The workshop was open to the public and consistent with Oregon Public Meetings law. The Record of this workshop includes this report, audio and video tapes, final statements provided by participants, post-workshop papers written by two speakers and post-workshop comments by some participants. These are available through the Oregon Watershed Enhancement Board Office in Salem (contact Bev Goodreau (503) 986-0187).

Presenters Abstracts

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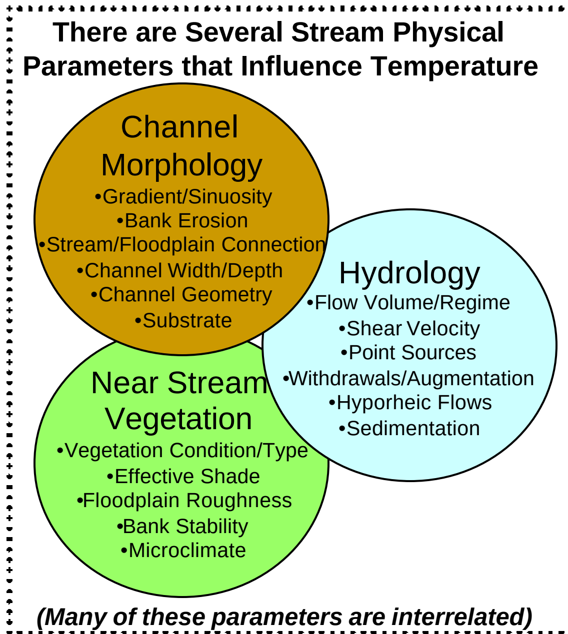
<u>Dominant Human Influences on Stream Temperature</u>
The overriding intent of the Oregon stream temperature standard is to minimize human related stream warming. An overview of the parameters that affect stream temperature should include near stream vegetation, channel morphology and hydrologic parameters. Many of these stream parameters are interrelated (i.e. the condition of one may impact one or more of the other parameters). These parameters affect the **stream thermal budget** and the **heat transfer mechanisms** to varying degrees. Stream temperature dynamics are further complicated when these parameters are evaluated on a watershed or sub-basin scale. For example, near stream vegetation can have considerable variability in both the longitudinal and transverse directions relative to the stream. Other parameters such as the stream microclimate can have a diurnal and seasonal temporal component as well as spatial variability. The current analytical approaches developed for stream temperature consider all of these parameters and rely on ground level and remotely sensed spatial data. To understand temperature on a landscape scale is a difficult and often resource intensive task. Stream temperature analysis is an evolving science that has made significant strides since the early pioneering work of George Brown in the late 1960's. The next decade will surely bring about analytical advancements and improved understanding of stream temperature dynamics in both spatial and temporal scales.



A far easier question to answer is that of the dominant human related causes of stream warming. To this end, Brown (1969) has largely answered this question. His studies demonstrate that the stream temperature regime is highly sensitive to the solar radiation portion of the energy budget and stream flow volume, both of which can be affected by human land use activities.

Recall Equation 2 - Rate Change in Temperature Caused by Heat Energy Thermodynamics,

$$\frac{\partial T}{\partial t} = \left(\frac{Ax_i \cdot \Phi_i}{\rho \cdot c_p \cdot V_i} \right),$$

For simplicity, this expression can be simplified to temperature change as a function of heat energy exchange per flow volume.

$$\Delta T_w \propto \frac{\Delta \text{Heat} \quad \text{Energy}}{\text{Flow} \quad \text{Volume}}$$

Using this simple expression, it becomes apparent that stream temperature change is a function of the total heat energy transfer and flow volume. To isolate the human influence on this expression, the task then becomes to associate the human influence on the stream thermal budget and/or flow volume.

1. **Stream Thermal Budget** – What are the dominant human increases in heat transfer to a stream? The solar radiation component of the stream thermal budget is often the most significant heating term and can be highly influenced by human related activity. Decreased levels of stream shade increase solar radiation loading to a stream. Vegetation physical characteristics control the shadow length cast across the stream surface and the timing of the shadow. Channel width determines the shadow length necessary to shade the stream surface. Near stream vegetation and channel width are sometimes interrelated in that stream bank erosion rates can be a function of near stream vegetation condition. **Human activities that change the type or condition of near stream vegetation to levels that result in decreased stream surface shading will likely have a warming effect on stream temperature.**

2. **Flow Volume** - It follows that large volume streams are less responsive to temperature change, and conversely, low flow streams will exhibit greater temperature sensitivity. Specifically, stream flow volume will affect the wetted channel dimensions (width and depth), flow velocity (and travel time) and the stream assimilative capacity. **Human related reductions in flow volume can have a significant influence of stream temperature dynamics, most likely increasing diurnal variability in stream temperature.**

DEQ recently completed a temperature analysis for the Umatilla River Sub-Basin (ODEQ 2000). The current condition near stream vegetation was mapped and sampled to derive vegetation type and condition. Channel width was also mapped and sampled. Stream surface shade was simulated and compared to measured ground level and remotely sensed data for accuracy. Stream surface shade levels were moderate in the upper watershed and poor in the middle and lower portions of the watershed. Potential near stream vegetation and channel morphology conditions were developed and used to simulate shade levels that would be expected under “system potential conditions.” Effective shade improved to moderate levels throughout the upper and middle watershed, while lower levels persisted in the lower portions of the watershed.

A mass balance was used to develop a current condition stream flow volume. From this flow profile, maximum potential flows (no withdrawals with augmentation) and natural river flows (no withdrawals and no augmentation) were estimated. It should be noted that the Umatilla River is augmented by over 200 cfs at Pendleton. Nearly all of this augmented water plus the instream base flow is withdrawn from the Umatilla River before the Columbia River confluence.

The results of the Umatilla River stream temperature analysis are as follows (ODEQ 2000):

- Stream temperature simulations demonstrate that when shade is increased (to levels that reflect no human disturbance to near stream vegetation and channel width) that the Umatilla River maintains cooler daily maximum, daily minimum and daily mean stream temperatures throughout the entire mainstem length.

- Increased stream flow volumes (via decreased instream water withdrawals) are necessary to maintain cooler stream temperatures in the lower mainstem (mouth to river mile 27). Natural stream flows (simulated with no human related withdrawals or augmentation) helped moderate stream temperatures in this portion of the Umatilla.

Maximum daily stream temperature distributions shift from a current condition of over 50% of the mainstem above the incipient thermal limit to 100% of the mainstem below the incipient thermal limit when potential shade and natural stream flows were simulated. In essence, the results from Brown (1969) are confirmed. Stream shading and stream flow are the dominant human related influence on stream temperature in the Umatilla River.

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1. The energy that heats streams is the net balance of may inputs and outputs. Algebraically:

$$S = R_{net} + A - LE - C$$

where R_{net} = net radiation (net solar and net long wave)
A = advective heat (e.g., groundwater)
LE = evaporation to atmosphere
C = sensible heat transfer to atmosphere.

2. By day, net radiation is the dominant and driving term.

3. There are relatively few studies where many components of the energy balance have been measured (George Brown's work is a pioneering classic), and none that I know of where all have been measured (C and LE are usually crudely estimated).

4. Gaps in our knowledge:

1) Quantification of shading in relation to riparian structure (could make better use of models in literature (e.g., row crops)
2) Radiation effects of incised channels and other topography (canyons)
3) Storage of heat by conduction into streambeds (moderates daily water temperature range)
4) Measurement of LE and C in semi-arid environments when streams are like small oases. These environments may induce large LE and transfer more sensible heat to streams than most models predict.
5) Influence of riparian structure on wind speed (relevant for LE and C).

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<u>Physical Factors that Influence Stream Temperatures within the Range of the Coho Salmon in Northern California</u>

Status and Trends in aquatic and terrestrial ecological resources are products of a patchwork of federal, state, Native American, and private lands. This patchwork can be seen quite vividly if one looks at Land Stewardship Allocations in range of coho salmon in Northern California. The allocation is split almost equally between private lands and state/federal, and Native American lands. With each stewardship come different land management directives that could be considered treatments. Here is a map aggregated by California Planning Watersheds showing the predominant treatment that is in place in each watershed in terms of land management. The predominant treatment depends on the major land steward in the watershed. To understand what options are available for the maintenance and restoration of desired beneficial uses of surface waters in watersheds and basins, and across the entire range of the coho salmon in Northern California we must understand temporal and spatial distribution of the diversity of land management treatments that are in effect.

Data were acquired from about 1,300 sites across Northern California and captured into a georeferenced database for meta-analysis. We have over 3 million temperature records and additional landscape-level and site-specific attributes data in our ORACLE database. Data were submitted to us by timber companies, state agencies, the USDA Forest Service, BLM, Redwood National Park, and the Natural Resources Conservation Service. The final data set is about 50/50, private lands data and public lands data. Sites were distributed from the Oregon border to as far south as Santa Cruz and as far east as the Sierras. The area of interest was restricted to the range of the coho salmon in California.

One environmental constraint that imposes limitations on what stream temperature can actually be attained is air temperature. We acquired a spatial air temperature coverage from Oregon State University that was developed using the Parameter Regression on Independent Slopes Model (PRISM). With this data we were able to develop a good picture of the spatial air temperature regimes across the study area. This maps shows 30-yr long-term PRISM average maximum air temperatures for the hydrologic units that comprise the coho range. Some basins are quite warm, especially those in the interior. Stream temperatures reflected this. Streams in coastal basins exhibited cooler water temperatures. Using the PRISM air temperature data we also estimated groundwater temperature. It is believed that groundwater temperature is within 2 or 3 degrees Celsius of the average annual air temperature. Using the PRISM air temperature data we are able to construct a spatial coverage of estimated groundwater temperature. We are acquiring well monitoring data from the USGS to validate these estimates.

What is the areal extent of the cooling influence of the coast? This is like asking 'where's the fog zone?' Using the PRISM data we calculated the steepest rate of change in air temperature and were able to define the zone of coastal influence (ZCI). Comparing streams inside and outside of the ZCI we found that streams inside the ZCI were significantly cooler.

The cooling influence of the coastal zone was seen in the Eel River basin. Mainstem temperatures reached over 30EC in the middle reaches, but near the coast, a marked decrease in mainstem water temperature was observed. This is quite remarkable, given the thermal inertia of such a large volume of water. Cooling or warming influences of tributaries on mainstem temperatures was noted. The amount of cooling or warming was a function of the relative contribution of the tributary's flow to the mainstem. (Brown's mixing equation).

The Gualala River drainage is an interesting case study. It has two mainstems that lie predominantly in the ZCI and three large systems that originate outside of the ZCI. The ZCI-out streams generally exhibited a decrease in water temperature upon entering the ZCI. The stream systems that lie entirely inside of the ZCI still exhibited a typical longitudinal warming in the downstream direction.

It has been shown in stream systems around the world that water temperature tends to increase in a longitudinal direction. However, some of our findings suggest that in near coastal areas, stream temperatures may exhibit a decrease in the downstream direction.

Brown and Brazier showed a decrease with increasing stream size in the effectiveness of buffer strips for controlling stream temperature. We plotted our 1998 canopy data from about 330 sites versus the natural log of distance from the watershed divide and found that at about 70 km from the watershed divide, canopy values drop below 20 to 30%. Stream temperature is more a function of air temperature in a system that is too wide for riparian shading. However, we must remember that both air and water temperature are both greatly influenced by solar radiation.

Comparing tributary sites with greater than 75% canopy we found that in two hydrologic units (HUCs), the Mad River - Redwood Creek and Big- Ten Mile - Garcia HUCs, longitudinal trend lines sites inside and outside of the zone of coastal influence are parallel, with both showing a warming trend in the downstream direction, but with ZCI-out sites being warmer.

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Physical factors that influence stream temperature

Stream temperature and the physical factors that can influence it have become a political and emotional set of issues in Oregon. I believe that we can reach consensus on a list of physical factors that could influence energy inputs in natural stream settings. However a listing alone will not address the needs of this group, the Oregon plan, or the associated regulatory programs that are being developed and implemented across the state. This group should also attempt to describe the conditions necessary for a physical factor to contribute a significant influence on stream temperature.

Most successful land management efforts include the development of management prescriptions based upon site-specific data. The IMST report should acknowledge that state- and basin-wide plans, based upon the generic influence of physical factors on stream temperature, will lack the ability to predict site specific conditions or responses. In other words, this process needs to reflect site potential limitations.

To illustrate let me describe a portion of a basin-wide study in the Burnt River drainage in NE Oregon. We are currently completing two 2-yr studies and have a third study under way that address the question of Burnt River site potential. These studies support a basin-wide study involving both stream temperature modeling and field studies.

The river segment of interest is located in sagebrush steppe with the lands adjacent to the river supporting wet meadow, meadow, and sodic meadow plant communities. In this example the modeling effort looked at a wide range of potential factors that could influence stream temperature. As a point of illustration the model identified that vegetation shade in excess of 70% would be needed to influence river temperatures. However site specific information that would limit or modify model projections was not being reflected in the model. As a result, model inputs were modified to reflect limiting soil and plant population attributes and the potential for shading was reduced dramatically.

In conclusion, we have embarked on a statewide planning program. The need for understanding physical factors that influence stream temperature has been correctly identified and generic conclusions formulated. However, the application of that knowledge to the land must be tempered using screens that evaluate land capability and suitability.

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Studies of the relationship of shade to water temperature in a controlled environment indicated a linear relationship, i.e. differential temperature change between unshaded and shaded water was proportional to the amount of shade present. At the same time a multitude of factors simultaneously influence change in water temperature. Empirical studies of several streams in eastern Oregon indicated comparatively little influence of shade on stream temperature. Streams with the highest level of canopy cover often heat at a higher rate than streams with little or no cover. Temperature of water in flowing streams is a result of a complex series of interactions and there is probably **no single driving factor** that operates across all situations.

An example of the influence of subsurface water on temperature was presented. With no input of subsurface water the stream water temperature warmed as the water flowed downstream. With the implementation of subsurface irrigation the net warming trend was eliminated and stream temperature cooled as the water flowed downstream.

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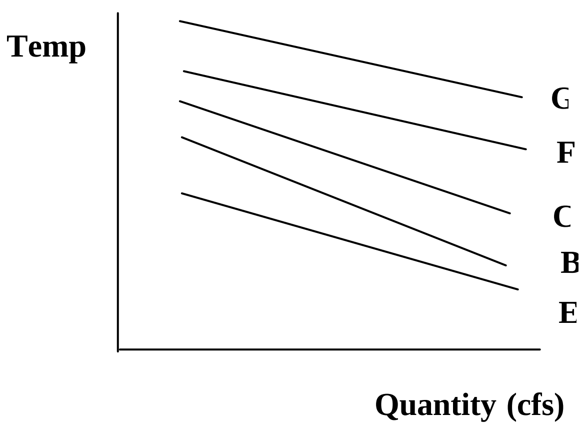
Channel Potential: The Need to Know

Aldo Leopold in his novel, A Sand County Almanac, stated, "A science of land health needs, first of all, a base datum of normality, a picture of how healthy land maintains itself as an organism."

How do we quantitatively determine the current condition of the channel of interest and of greater concern how do we determine potential? To adequately address the issues of water quality and to prudently invest limited monetary resources toward restoration of channels a broadly accepted methodology for assessing stream channel potential and departure from potential needs to be developed. Following is a brief outline of a proposed methodology.

Rosgen (1996) asserts that the physical appearance and operational character of the present day river is a product of the adjustment of the channel's boundaries to the magnitude of stream flow and sediment produced from it's associated catchment. The specific characteristics of a given river are further modified by the influence of channel materials, basin relief, and other features of valley morphology along with the local influence of erosion and sediment deposition. Extensive research has shown that natural channels attempt to maintain a dynamic equilibrium between sediment loads and the energy available for streamflow to perform work (Lane 1957, Leopold and Wolman 1957, Heede 1986, Harvey and Watson 1986, Schumm 1977, Leopold 1994). A channel determined to be in a state of dynamic equilibrium has the ability to maintain, over time, its dimension, pattern, and profile in such a manner that it is neither aggrading nor degrading and is able to transport without adverse effects the flows and detritus of its catchment. Rosgen (1996) refers to dynamic equilibrium as "morphologic stability". Natural streams that are stable, and self-maintained, and whose physical and biological function is at an optimum are said to be operating at their full potential. **A major obstacle for studying streams is to determine, quantitatively, how well their current condition matches their potential** (Rosgen 1996). Stream potential has been described in terms of "Proper Functioning Condition" (USDI Bureau of Land Management 1993) and "Desired Future Condition" (USDA Forest Service 1992, Bauer and Burton 1993). Visual characteristics, while useful, are frequently interpreted differently by different people or by the same person at a different time. In addition, many streams have been degraded for so long that the degraded conditions have become associated with natural or baseline conditions. Rosgen's stream classification system and channel assessment protocol provides a quantitative measurement of the degree to which existing conditions differ from an accepted range of morphological attributes documented for different stream types. The following diagram is an attempt to incorporate Rosgen's method into a conceptual model depicting expectations for stream temperature as a function of stream type.

I believe the scientific community must determine a methodology for assessing stream potential that is quantifiable and credible. Effort is needed to build a database of stream type reference reaches by hydro-physiographic region and to measure water quality parameters within the specified reference reaches. This data set would provide the template for assessing potential and departure from potential of other channels located in the same hydro-physiographic region. Restoration and management decisions could then be made on the basis of sound scientific knowledge instead of qualitative characteristics that are open for public criticism.



Pattern: plan view
- meander length, belt width
- radius of curvature
- sinuosity

Dimensions: cross-section
- width, depth, entrenchment
- channel materials

Profile: longitudinal profile
- channel slope, riffle/pool sequences, riffle/pool depth, facet slope

1. Locate and measure reference reaches within ecological provinces or hydro-physiographic regions.

2. Monitor temperature patterns within reference reaches

3. Riparian assessment of reference reach using riparian community typing and greenline methodologies (Winward 2000)

4. Provides baseline data for determining departure both of the physical and biological attributes of the channel

Dale McCullough
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My intent for my talk was to limit the number of figures shown but to connect physical model of stream temperatures, laboratory and field measures of thermal effects on salmon, the distribution of a salmon population on a watershed scale, and estimates of production at a watershed scale. This is a lot of material to try to link together, especially in six figures, but the adequacy of a temperature standard cannot be judged solely by the level of protection brought about at a single reach. It must involve consideration of what is biologically optimal for salmonid species and how far downstream those conditions can be expressed in each mainstem river and its tributaries.

Work by Theurer et al. (1985) on the Tucannon River showing thermal recovery that is possible there by simply restoring potential streamside vegetation on the mainstem and restoring channel morphology. The Tucannon example indicates that if a mean July temperature of 20ºC is taken as the ultimate limit to chinook distribution (i.e., the point at which abundance goes to zero), there are currently 40 km of the lower mainstem producing no fish. Under the restored condition this entire stream length is usable for fish production.

In terms of fish abundance, Theurer et al.'s (1985) estimates of juvenile and adult numbers for the river system under the current and restored condition. These estimates were made considering only the direct effect of thermal restoration and the stream area involved, not other habitat factors that might also be restored in conjunction with riparian and channel morphology recovery.

Next, I showed a figure on temperature requirements of spring chinook that I had developed for our technical committee work in the 1994 Oregon triennial temperature review (McCullough 1999). This diagram illustrates the time span of various life stages during the year and the temperature requirements. I won't try to thoroughly describe the contents of this figure. However, the important point is that the figure shows temperature ranges that provide high survival for each life stage. In the case of adult migration, the range shown indicates temperatures generally associated with successful migration. This is contrasted with temperatures inhibiting migration (a threshold temperature). In the egg stage, the temperature range indicated provides high survival. However, it must be remembered that accumulated thermal units must be appropriate for correct emergence timing so even though temperatures may provide high incubation survival, the incubation thermal regime is also critical. For the juvenile stage, an optimal growth range is identified. In addition, the growth limits are shown. Growth limits are specific to acclimation temperature and food availability. Those growth limits depicted are at full ration. It is also important to recognize that at any life stage there will be multiple effects.

At a temperature of 15.5ºC a disease threshold is identified. Above this the probability of mortality from warm-water diseases becomes increasingly greater. Pre-spawning holding in spring chinook can be a stage critical to survival. Spring chinook must migrate upstream to cool waters to spend the summer prior to the fall spawning period. Highest survival and greatest readiness for spawning (maturity) is ensured within a limited temperature range. Fish forced to hold in warm streams (or refugia that are marginally better than ambient conditions) can be impaired in a number of ways. Gametes in maturing fish can be damaged by high water temperature in holding waters, thus lowering viability or impairing future embryo or alevin development. A threshold temperature exists that inhibits spawning activity. In addition, the limited spawning that might occur in the vicinity of this threshold would be accompanied by significant egg mortality (unless intragravel water temperatures are significantly lower). Egg fertilization at temperatures above this threshold impair embryo survival, even if the eggs are subsequently covered by gravel. Temperatures just above the migration blockage temperature begin to kill adults, based on evidence from laboratory tests. In the mainstem Columbia with its system of reservoirs, temperature regimes are very similar to laboratory temperature regimes (i.e., nearly constant) and prolonged at high levels, making it fairly logical to extrapolate to the field.

It is important to point out that incipient lethal temperatures identified for juveniles are dependent upon the acclimation temperature in relation to an exposure temperature. The ultimate upper incipient lethal temperature (UUILT) is that temperature that kills 50% of the test fish in a constant temperature laboratory test within a 24-h period, when fish were acclimated to the highest temperature that allowed the maximum degree of thermal tolerance. This is an important issue because it cannot be assumed that fish in the wild are always most effectively acclimated to high exposure temperatures. This is surely the case when fish enter a river from the ocean or pass from a mainstem river into a tributary that may be warmer (e.g., from the Columbia into the Snake River).

Another issue of significance is that the UUILT for juvenile chinook is approximately 3ºC higher than for adults. There can be a tendency to use values such as the UUILT for the juvenile life stage and apply it to all situations. However, this is not conservative of adults. State of health is also critical. Diseased fish are known to perform less successfully in laboratory tests. Also, if fish are not fully acclimated to exposure temperature conditions, mortalities can exceed predicted levels.

Brett et al. (1982) showed the optimum growth temperatures for chinook under various feeding regimes, from full ration to 60% of full ration. Feeding at the 60% level was considered by Brett et al. to be most representative of field conditions. Given this feeding level, the temperature that is optimum for growth declines dramatically. This same effect of feeding level on growth optimum was described in great detail by Elliott (1994) for brown trout (also see McCullough 1999 for a description). These studies point out that we must be very cautious in assuming that fish growth will be adequate in the field under certain temperature ranges.

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Information on temperature and fish physiology were presented and differences between field and laboratory results were discussed. When water temperature is increased, fish activity and biological and chemical reactions also increase. Warmer temperatures favor pathogens. Field observations suggest fish have three main responses to high water temperatures; emigration, selection of favorable microhabitats, and selective mortality. Laboratory observations of fish are not similar to those made in the field because laboratory fish are stressed (unnatural habitat and thermal regimes) Interactions between fish are altered when dead fish are left with live fish and feeding and social interactions are changed when fish can not escape from the group. Laboratory experiments tend to underestimate thermal tolerances by fish and field studies can overestimate tolerances by not accounting for changes in disease resistance, reproductive fitness, or the loss of genetic variation. (Abstract prepared by IMST)

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Fish responses to higher temperatures were presented from a community perspective. Two studies were discussed. The first study examined the influence of water temperature on the interactions between steelhead and redside shiners (Reeves et al. 1987). One study discussed was the Carnation Creek Experimental Watershed Study which monitored steelhead, cutthroat trout, and coho salmon after clearcut logging. Stream temperatures increased after logging (Holtby 1988). As a result coho emerged earlier, grew faster because there was an increase in benthic organisms, the coho left the streams earlier which lead to a decrease in ocean survival. (Abstract prepared by IMST)

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Healthy populations of anadromous fish are the exception rather than the rule in Oregon. Currently there are 11 species of anadromous fish listed as threatened or endangered under the federal Endangered Species Act that spawn in Oregon, and several more that migrate through the state. Population growth rates are negative for most of these species. For those species that rear in freshwater, there is significant mortality in the early life stages. This underscores the importance of fresh water habitat to species persistence, particularly during periods of poor ocean productivity, and provides opportunities to increase population growth rates by reducing mortality during early life stages. Preliminary data collected by the National Marine Fisheries Service (NMFS, Feist et al. unpublished) indicate that certain fresh water habitat conditions affect spawner abundance for Snake River spring/summer chinook. Spawner abundance appears to be negatively correlated with mean annual daily maximum air temperature (water temperature data not available). In its recovery planning efforts, NMFS will seek to reduce mortality from human disturbance at multiple life stages by addressing habitat, harvest, hatcheries, and fish passage issues.

Workshop Discussion Background

The group determined the final statement of questions and designed the discussion process. On the first day the group felt that the three suggested breakout group topics (influence of vegetation, longitudinal basis for influence of vegetation, and effects of discharge and channel dimensions) were not clearly independent. For both days, participants decided to discuss topics as a group and not split into smaller workgroups.

The group was asked to clarify the potential impacts of human activities on stream temperature and how other factors may interact to affect the stream temperature response to the human activities. They were also asked to focus on the science and leave policy related matters (e.g., development of management practices or regulations) to the policy makers.

The group felt that the issue of stream temperature and how it can be affected by human activities and the environment is very complex and the individual factors have varying influences at any given time or place. Temperatures vary in time and space and are the result of the cumulative impacts of factors in the environment through which a stream flows and along its entire length. Knowledge of the processes that influence stream temperature is important in understanding, predicting, and evaluating what may or is occurring at a given site.

The following information was recommended by the workshop participants to describe the complex nature of stream temperature dynamics and to define some terminology used for the reader.

Stream temperature is a function of latitude, elevation, season, time of day, rate and depth of flow, stream width, vegetation cover and other physical shading effects (e.g., canyon walls).

> "As water flows downstream, its temperature will continue to change as a result of several factors that make up the heat balance of water. The net rate of gain (stream heating) or loss (stream cooling) as a stream moves through the environment is the algebraic sum of net radiation, evaporation, convection, conduction, and advection. Net radiation is generally dominated by the amount of direct-beam solar radiation that reaches a streams surface. Heat gain or loss from evaporation and convection depends on the vapor pressure and temperature gradients, respectively, between the water surface and the air immediately above the surface. Wind speed at the air-water interface is also an important controlling variable. Conduction of heat between the water in the stream and the streambed depends on the type of material that makes up the bed. Bedrock channels are more efficient than gravel-bed channels at conducting heat. Advection is the result of heat exchange as tributaries or groundwater or different temperatures mixes with the main streamflow, and can either increase or decrease stream temperature.
>
> Channel characteristics and morphology also influence the amount of heat gain or loss of a stream. The surface area over which energy transfers take place is important: wide streams receive more energy

> than narrow ones. Discharge is another significant variable: for the same surface area and energy input, the temperature change expected of a high-discharge stream will be less than that of a low-discharge stream. In other words, for a give rate of net input, the change in temperature of a stream is directly proportional to surface area and inversely proportional to discharge." (Beschta et al. 1987)

Shade is cover (vegetation or other structure such as canyon walls) that intercepts direct solar radiation. Stream cover is generally the layers of vegetation (such as trees, shrubs, and other overhanging vegetation) that are over the stream or immediately adjacent to the wetted channel. Stream shade is the percentage of that cover that casts a shadow on the stream.

Thermal environment is the total amount of energy inputs and outputs surrounding an object. For streams, the thermal environment is the summation of energy inputs (sources of heating) and outputs (mechanisms for cooling) from the sun, incoming and outgoing longwave radiation, land, stream bed, and air.

Site potential is the combination of environmental conditions that affect the type of vegetation at a particular place. Environmental conditions include soil type, drainage, slope, and climate.

Temperature equilibrium is a concept where water temperature responds to meteorological conditions. The net rate of heat exchange is the sum of radiative processes, evaporation, and conduction at the water/air interface. The rate of heat exchange is a function of the difference between actual water temperature and an equilibrium temperature at which the net rate of heat exchange would be zero. The equilibrium temperature changes in response to varying meteorological conditions and water temperature moves continuously toward the constantly changing equilibrium temperature (Edinger et al. 1968).

Hyporheic zone is the area under a stream channel or floodplain that contributes water to the stream. Hyporheic flow, also called interstitial flow, is water/subsurface flow between the water table and surface water flow. The source of hyphoreic flow can be from the channel itself.

Vegetation and Physical Influences on Stream Temperature

The goal of this work session was to identify, based on scientifically accepted data, the factors related to human activity that can affect stream temperature. Workshop participants addressed the questions: “How and where does riparian vegetation influence stream temperature?” and “Do other changes in streams cause increases in stream temperature?”

Participants began by identifying points of agreement about the effects of solar radiation on stream temperature, and defining some important concepts in regard to stream temperature change. Solar radiation is the principal source of energy that causes stream heating, and is the driver of many environmental factors that can influence stream temperature. Participants also recognized the importance of evaluating environmental influences on temperature at a landscape scale because the environmental factors that influence stream temperature vary over space and time. At any given point and at any specific time, stream temperature is the result of a complex suite of environmental factors that transform solar energy and re-emit it as heat energy within the environment. The interactions and effects of these environmental factors are cumulative and complex, and vary by site, over time, and across regions. Knowledge of the mechanisms and processes that drive stream heating and operate across the landscape provide information for site-specific applications of this general knowledge.

Participants agreed that human activities influence stream temperature by affecting four major components in the physical environment, each of which have important influences on stream temperature. These four components include riparian vegetation, channel morphology, hydrology, and surface/subsurface interactions.

The following sections summarize the participants’ discussion by listing identified points of agreement about stream temperature change, the effects of solar radiation and landscape factors, and the ways in which riparian vegetation, channel morphology, hydrology and surface/subsurface factors influence stream temperature. All workshop participants agreed to the bullets listed under "Agreements" and "Disagreements". In addition, "Gaps in the science" were identified. **It is important to note that any of the statements listed below, when viewed individually, oversimplify the complexities of environmental factors and processes that influence temperature. Therefore, it is important to consider them as a whole to begin to understand their complex interactions and effects on stream temperature.**

Agreements

<u>Solar Radiation</u>

- Solar radiation influences both air and water temperature.
- Solar radiation is the principal energy source that causes stream heating.
- Direct absorption of solar radiation by the stream and the streambed warms water; interception of solar radiation by vegetation reduces potential for warming.

- Shading (vegetative and/or topographic cover) reduces direct solar radiation loading.

- Shading (vegetative and/or topographic) of the water surface reduces potential stream heating.

Landscape Scale Factors

- The factors that human activities can affect to influence stream temperatures are vegetation, stream flow (hydrology), channel morphology, and subsurface/surface interactions (factors are not listed in order of importance).

- The influence of vegetation on stream temperature decreases with increasing channel width.

- The type of vegetation and its influence on temperature varies over time.

- A landscape context is needed for prioritizing work (evaluation of condition, establishing site potential, and remedial measures of variables) at the site level.

- Understanding site differences depends on an understanding of basic processes.

- It is very difficult to measure evaporation and convection across a spatially and temporally variable landscape.

- Streams tend to heat in the downstream direction.

- Stream temperature reflects the thermal environment.

- The thermal environment is determined by atmospheric and terrestrial factors in the vicinity of the stream, including thermal radiation, solar radiation, air temperature, wind speed, relative humidity, streambed temperature, and mass transfer between surface and subsurface.

- Channel geomorphology and valley landforms change longitudinally in a river network, and these changes alter the relative influence of energy balance factors. These combine to produce a longitudinal temperature pattern or signature for a stream.

- Temperatures vary in time and space and are the result of the cumulative impacts of factors in the environment through which the stream flows, and along its entire length.

Stream Temperature Change

- Stream temperature tends to move toward equilibrium temperatures based on the energy balance, which is a function of several variables. As these variables change in time and space, the energy balance and the equilibrium temperatures also change.

- Assuming solar radiation is attenuated, a stream moving through a warmer thermal environment will heat and a stream moving through a cooler thermal environment will cool.

- Since the gradient of change is larger between cool water and the thermal environment than for warm water and the same environment; in summer, shade is more effective in controlling the rate of heating in cooler water than warmer water. In other words, it is more efficient ecologically to use shade to protect cool water from warming than to attempt to cool water that has already warmed.

Riparian Vegetation

- The influence of riparian vegetation varies by site. The potential kind and amount of riparian vegetation varies by site according to site characteristics (i.e. site potential).

- Vegetation is an important influence on microclimate, which may affect stream temperature if it sufficiently changes the stream environment.

- Shading of the riparian area and the water surface affects the microclimate, which may reduce stream heating.

- Riparian vegetation influences other aspects of the thermal environment of streams other than simply intercepting solar radiation. Other potential functions of riparian vegetation:
  - Influencing microclimate
  - Augmenting subsurface flow
  - Influencing wind speed
  - Influences longwave (thermal) radiation
  - Affecting humidity
  - Affecting soil temperature
  - Using water
  - Influencing air temperature
  - Enhancing infiltration
  - Impacting channel morphology with large wood and other vegetation
  - Influencing base flow (and possibly influcencing hyporheic exchange)
  - Adding to bank stability (roots provide cohesion and aboveground structure to dissipate energy)
  - Influencing long wave (thermal) radiation
  - Roots (of woody and herbaceous plants) are important structural components that influence channel morphology and flood plain function.

Hydrology and Surface/Subsurface Interactions

- Longitudinal patterns of temperature change depend on tributary inputs from major tributaries or combinations of many small tributaries.

- Any land use development (urban, roads, agriculture, etc) that reduces ground water inflow contributes to a summer time stream temperature increase.

- Influences of tributary, ground water, or hyporheic flows on stream temperature are a function of the volume and temperature of the flows relative to the stream into which they flow.

- Conditions of and connections to floodplains and watersheds are important in considering the contribution of ground water to streams and its impact on stream temperature.

Channel Dimension / Geomorphology Factors

- The change in temperature is a function of energy input, water surface area and discharge. ($\Delta T = E \times A / Q$; where ΔT = temperature change, E = energy, A = area, and Q = discharge).

- An increase in the surface area/volume ratio (or width/depth ratio) increases the rate of temperature change when there is a constant input of energy.

- Channel geomorphology and valley landforms change longitudinally in a river network and can change the factors that influence stream temperature.

Disagreements

No disagreements were listed by the participants.

Gaps in Knowledge

Climate Change

- Understanding how global climate change may affect precipitation, stream discharge, and stream temperature.

Stream Temperature Change

- Understanding the causes of the rate of stream temperature change in shaded reaches.

- Understanding the influence of heat conduction into the streambed on stream temperature.

- To improve temperature prediction confidence at the reach scale, we need additional studies to understand processes in the stream energy balance (radiative transfer, evaporation, convection, and advection of heat in the atmosphere, conduction of heat in the streambed), particularly in eastside semi-arid environments.

Riparian Vegetation

- Understanding how much vegetation is required to change the thermal environment and stream temperature.

Landscape Factors

- Heat transfer from convection and evaporation (the role of air movement over water) is not understood at the landscape level. It is very difficult to measure these factors.
- We do not have a process for understanding and determining site potential on a long-term basis or how it changes over time.
- How much localized heating is transferred downstream and for what distance can it be detected?

Technical Factors

- There are a variety of techniques available to measuring shade on water and it can be difficult to integrate or compare data collected by different methods.

Hydrology

- Understanding the relationships between hyporheic flow and stream temperature.
- Understanding how water applied to the soil surface can contribute to ground water inputs to streams, and how this affects stream temperature. For example:
    - At what distance from the stream can water applied to soil affect ground water inputs and/or temperature?
    - What are the impacts of on stream systems and biota?
- Understanding how the source of water in channels (snow melt, rain, etc) affects base flow, temperature, or other factors.

Geomorphology

- Understanding how stream channel incision or aggradation impacts ground water, stream temperature, and riparian communities.

Fish Ecology and Responses to Stream Temperature

During the second day, the biological factors that account for status of fish populations in relation to stream temperature were presented during the workshop and discussed by the workshop participants. The major question for this discussion was "How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?"

The group felt that general statements could be produced relating to this issue. However, certain aspects of the question needed further clarification before more specific answers would be valid. The participants agreed that a definition of "healthy" fish populations should be developed and they generated a list of criteria to define the condition of the fish populations. They were also concerned about the validity of reports of fish at stream temperatures higher than expected. Some concerns were also raised regarding the direct application of laboratory measurements to actual performance of fish populations in the wild.

In spite of these concerns, the workshop participants reached agreement on several factors that could help explain why fish populations occur in streams at higher than expected temperatures. Much of this agreement, however, was based on scientific conjecture rather than experimental data. Therefore, they also identified gaps in the information base which, when filled, would improve our ability to interpret what is happening in natural fish populations with regard to temperature and why.

The discussion of fish ecology was organized according to aspects of the interaction between fish and temperature in the field and in the lab. It began with a list of features postulated to characterize the health of a fish population. The gaps in knowledge about fish biology in the laboratory and field are combined, since these related primarily to field-derived information, and the application of laboratory results to field situations. Workshop participants found no areas of technical disagreement.

Defining a "healthy population"

A healthy population is characterized by the following: It has

1) the capacity to persist or grow through time and across its range,

2) components that can occupy all available and suitable habitats and maintain its distribution in time and space,

3) an adequate number of individuals (abundance) to maintain itself through perturbations and environmental stresses,

4) adequate variation in life histories and genotypes,

5) the presence of all life history stages at some time and some place within its overall distribution,

6) ability to perform in all life history functions and have the ability to continue life history functions through time and space, and to persist through disturbance events and environmental stresses,

7) enough fish to perform ecological functions (e.g., nutrient supply, food supply for predators)

8) ability to deal with multiple sources of mortality (e.g., disease, predation, fishting)

Agreements

Agreements on potential factors that could explain why fish may occur in warmer stream waters than expected.

Credibility of anecdotal or research observations

Observers, both scientists and the public, may note the occurrence or performance of fish at temperature higher than research results from laboratory or field would predict. This may result from 1) inadequacies of scientific information or 2) limitations of the observations or perceptions of the observers. The workshop participants identified several sources for such discrepancies.

- Definition of health is critical to resolving fish-temperature issues. Simple occurrence alone does not indicate a healthy population.

- Point observations alone do not indicate healthy populations. Fish can respond to thermal stress by changing distributions, and occurrence at a point may not reflect the status of populations with the stream reach or network.

- Seasonal observations alone may not indicate habitat use at time of maximum temperatures. Fish may be able to tolerate short periods of elevated temperature but the consequences of the stress may occur at other times.

- Anecdotal information and personal memories are embraced rather than empirical observations.

- Observations are simply incorrect.

Population responses

- Genetic variation or unique local, physiological adaptations may exist to allow some fish to tolerate elevated temperatures.

- The range of temperatures that fish populations can tolerate may be wider than we realize.

- Physiological performance of individuals in a population varies and some individuals may be able to tolerate temperatures above specified limits.

- There may be delayed thermal effects on adult fecundity or gamete variability

Habitat use

- Cold water refugia (such as deep pools; water entering from subsurface flow, input from springs, or tributaries which haven't mixed with surface stream flow) may be available to fish along a stream reach.

- Excessive temperature may temporarily crowd fish into marginal habitats that are incapable of supporting fish over the long-term.

Duration of heat stress

- Diel variations of temperatures may moderate effects of high maximum temperatures (i.e., length of exposure or cumulative exposures may be an important component of consequence of exposure).

Interaction with other factors

- Food availability can be an important factor in how fish respond to temperature changes.

    - Environmental stressors other than temperature may be relatively low.

    - Simultaneous exposure to secondary stressors may affect how a fish or population responds to elevated water temperatures. Secondary stressors can include:

        - Cumulative exposure to high temperatures,
        - Disease,
        - Inter/intraspecific competition,
        - Predation,
        - Lack of available cold water refugia (they disappear or distribution changes).

- Other components of the biological community may be more severely affected by environmental stresses so that their impact on the fish may not be as severe as when stresses are lower.

Laboratory observations

- Laboratory fish can be subject to unnatural stressors that could impact their reaction to temperature.

- Laboratory fish are subject to different social interactions than wild fish, which may affect
their reaction to temperature.

- Conditions can be relatively artificial with respect to acclimation (e.g., experimental unit, tank, feeding, light, noise, or temperature) and experiments are relatively short-term.

- Death is often the measured endpoint in the laboratory, whereas in the field, changes in abundance and/or distribution or delayed death (all of which can be more difficult to observe) tend to be the endpoints.

- Laboratory fish may be screened for disease with diseased fish excluded from the study.

- Genetic stock of laboratory fish is selected and may not reflect the range of variability in the wild gene pool.

- Laboratory fish are well-fed and pampered compared to wild fish; laboratory fish may not be exposed to stressors such as predation, interspecific competition, and pollutants.

- In the lab, behavioral mechanisms for coping with stressors are limited.

Disagreements

No disagreements were listed by the participants.

Gaps in Knowledge

- In Oregon, we have more information on riparian vegetation, stream flow, stream morphology, and stream temperature, than we have on fish populations, life history stages, and fish responses to temperature.

- Data on the location of healthy populations are unavailable. This limitation provides few opportunities to match population and temperature data or other variables.

- We lack the ability to separate effects of temperature from other stressors when they occur simultaneously.

- We are unable to accurately determine the effects of cumulative exposure to temperatures above the optimal range on growth and survival.

- We have not determined how the delayed effects of high temperature exposure may affect fish (or their future condition).

- The spatial and temporal distribution and abundance of cold-water refugia are not well known.

- The impact of fish concentrating at cold-water refugia and how it may change or increase their risk for predation or disease has yet to be determined.

- We need to develop temperature metrics to better reflect cumulative exposure and effects of diel fluctuations in temperature.

- We need to be able to link measurements of the thermal environment to thermal effects on biological systems.

- We need to determine how to measure health of a fish population.

- We lack information on complex thermal effects across the range of species and life history stages.

- We are not able to quantitatively interpret laboratory data to be able to compare with or apply it to field situations.

Workshop Conclusions

The focus of the workshop was on the technical and scientific basis of factors that can influence stream temperature, particularly those that can be modified by human activity, and on responses by cold-water fishes to elevated stream temperatures. The participants were asked to discuss and answer three questions: How and where does riparian vegetation influence stream temperature? Do other changes in streams cause increases in stream temperature? How can apparently healthy fish populations exist in streams with temperatures higher than lab and field studies would indicate as healthy? The participants listed statements of agreement and disagreement, and gaps in our knowledge for each question.

It is important to note that any of the statements listed in the report, when viewed individually, oversimplify the complexities of environmental factors and processes that influence temperature. Therefore, it is important to consider them as a whole in order to begin to understand their complex interactions and effects on stream temperature.

The workshop participants provided plausible answers to the questions in the form of bullets. The answers below represent IMST's summation of the workshop findings and were reviewed by the participants. Several gaps in the scientific basis for specific questions or relationships were identified. The participants found no areas of disagreement for which technical information was available. They noted that any disagreements were not related to scientific interpretation but were based on concerns or opinions about application, regulation, and management.

How and where does riparian vegetation influence stream temperature?

The influence of riparian vegetation on stream temperature is cumulative and complex, varying by site, over time, and across regions. Riparian vegetation can directly affect stream temperature by intercepting solar radiation and reducing stream heating. The influence of riparian shade in controlling temperature declines as streams widen in downstream reaches, but the role of riparian vegetation in providing water quality and fish habitat benefits continues to be important. Besides providing shade, riparian vegetation can also indirectly affect stream temperature by influencing microclimate, affecting channel morphology, affecting stream flow, influencing wind speed, affecting humidity, affecting soil temperature, using water, influencing air temperature, enhancing infiltration, and influencing thermal radiation. It is critical to know the site potential to understand what vegetation a site can support. There is not a good scientific understanding of how much vegetation shading is required to affect stream temperature This lack of understanding may be due to the spatial and temporal variability in landscape components, and the resulting variability in both the direct and indirect influences of vegetation on stream temperature. Therefore, it is difficult to generalize about the effects of vegetation on stream temperature.

Do other changes in streams cause increases in stream temperature?

The answer to this question is yes, other physical changes in the stream system can modify stream temperatures. Some of these changes are a result of human activity while others are not. Stream temperature is a product of complex interactions between geomorphology, soil, hydrology, vegetation, and climate within a watershed. Changes in these factors will result in changes in stream temperature. Human activities influence stream temperature by affecting one or more of four major components: riparian vegetation, channel morphology, hydrology, and surface/subsurface interactions. Stream systems vary substantially across the landscape, and site-specific information is critical to understanding stream temperature responses to human activities.

How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?

Workshop participants identified several mechanisms that might explain the ability of fish populations to exist at higher than expected temperatures. The first mechanism was that the fish may have physiological adaptations to survive exposures to high temperatures. A second possibility was that stream habitats may contain cooler microhabitats that fish can occupy as refuge from higher temperatures. A third consideration is that ecological interactions may be different under differing thermal conditions resulting for example in changes in disease virulence or cumulative effects of stressors. Finally, since substantial differences exist between laboratory and field studies, it is difficult to apply results of laboratory studies to fish responses in the field. It is important to note that these proposed mechanisms are speculative and, as the list of gaps indicates, substantial experimental work is required to establish their influences on fish in different stream systems

Workshop Summary

Workshop participants recognized gaps in the available science. Additional knowledge about human influences on stream temperatures and, consequently, influences on cold-water fish populations, will improve our ability to prevent further degradation of stream habitat and will enhance efforts geared towards the recovery of depressed fish populations. Even with these gaps, there was enough agreement on factors that influence stream temperature to indicate information is available to start developing and implementing management practices that are designed to reduce stream warming. It was suggested that managers should consider riparian vegetation, channel morphology, and hydrology, and should account for site differences.

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Appendix 1.

Workshop Agenda

IMST Workshop Agenda

Stream Temperature
LaSells Stewart Center
Oregon State University
October 5-6, 2000

Thursday, October 5th

8:30 Welcome workshop panelists and identify the purpose and products of the workshop

Major questions:
How and where does riparian vegetation influence stream temperature?
Do other changes in streams cause increases in stream temperature?

Reports on physical factors that influence stream temperature
9:00 Matt Boyd and Mike Unsworth
9:30 Tim Lewis
9:45 Larry Larson, Bill Krueger and Tamzen Stringham

10:30 Break

11:00 Discussion of major factors related to human activity that influence stream temperature and questions to be explored

12:00 Lunch provided for panelists

1:00 Discussion of influence of vegetation and longitudinal basis for influence of vegetation. Identify major points of agreement, disagreement, and knowledge gaps.

3:00 Break

3:30 Discussion of geomorphology and effects of discharge and channel dimension. Identify major points of agreement, disagreement, and knowledge gaps.

5:30 Adjourn

Friday, October 6th

8:30 Review and identify points of unanimity or consensus from Thursday's discussions.

Major question:
How can apparently healthy fish populations exist in streams with temperatures higher than laboratory and field studies would indicate as healthy?

10:00 Break

Reports on biological factors that account for status of fish populations

10:30 Dale McCullough
10:45 Carl Schreck
11:00 Gordon Reeves
11:15 Jeff Lockwood

12:00 Lunch provided for panelists

1:00 Discuss technical basis for population performance at temperatures above those observed in individual laboratory or field studies. Identify major points of agreement, disagreement, and knowledge gaps.

3:00 Break

3:30 Discuss major factors responsible for population performance at temperatures above standard

4:30 Adjourn

Appendix 2.

Workshop Participants

Workshop Participants

Borman, Mike	Dept. of Rangeland Resources, Oregon State University
Boyd, Matt	Oregon Department of Environmental Quality
Brown, George	Dept. of Forest Engineering, Oregon State University
Dent, Liz	Oregon Department of Forestry
Johnson, Sherri	Dept. of Fisheries and Wildlife, Oregon State University
Krueger, Bill	Dept. of Rangeland Resources, Oregon State University
Larson, Larry	Dept. of Rangeland Resources, Oregon State University
Lockwood, Jeff	National Marine Fisheries Service
McCullough, Dale	Columbia River Inter-Tribal Fish Commission
Miner, Ron	Dept. of Bioresource Engineering, Oregon State University
Reeves, Gordie	US Forest Service, Pacific Northwest Research Station
Schreck, Carl	Or. Coop. Fishery Res. Unit, Dept. of Fisheries and Wildlife, Oregon State University
Stringham, Tamzen	Dept. of Rangeland Resources, Oregon State University
Sturdevant, Debra	Oregon Department of Environmental Quality
Timothy Lewis	Forest Science Project, Humboldt State University Foundation
Unsworth, Mike	Center for Analysis and Environmental Change, Oregon State University

Independent Multidisciplinary Science Team members present

Norris, Logan	Team Chair, Dept. of Forest Science, Oregon State University
Buckhouse, John	Dept. of Rangeland Resources, Oregon State University
Elmore, Wayne	Bureau of Land Management, US Dept. of Interior
Gregory, Stan	Dept. of Fisheries and Wildlife, Oregon State University
Pearcy, Bill	College of Oceanic and Atmospheric Sciences, Oregon State University

Invited participants unable to attend the workshop but were given the opportunity to review the draft manuscript

Berman, Cara	Environmental Protection Agency
Beschta, Bob	Dept. of Forest Engineering, Oregon State University
Dunham, Jason	US Forest Service, Rocky Mountain Research Station
Li, Hiram	Or. Coop. Fishery Res. Unit, Dept. of Fisheries and Wildlife, Oregon State University
Moore, Jim	Dept. of Bioresource Engineering, Oregon State University
Tate, Ken	Dept. of Agronomy and Range Sciences, University of California