Technical Synthesis

Scientific Issues Relating to Temperature Criteria for Salmon, Trout, and Charr Native to the Pacific Northwest

FINAL DRAFT

A summary report submitted to the Policy Workgroup of the

EPA Region 10 Water Temperature Criteria Guidance Project

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Preface

This document is a product of a Technical Workgroup established by the U.S. Environmental Protection Agency (EPA) to assist them in developing temperature criteria guidance for EPA Region 10. The purpose of the EPA guidance is to help Pacific Northwest states and tribes adopt water temperature standards that:

- Meet the biological requirements of native salmonids (Pacific salmon, trout, and charr) species for survival and recovery pursuant to the Endangered Species Act (ESA).
- Provide for the protection and propagation of salmonids under the Clean Water Act (CWA).
- Meet the salmonid rebuilding needs of federal trust responsibilities with treaty tribes.

The project focuses on salmonids because the ESA, CWA, and tribal treaties all require protection and restoration of salmonids. Additionally, this approach is scientifically sound since salmonids can also be viewed as "umbrella species" that are indicators of the biological integrity of aquatic ecosystems in the Pacific Northwest. Where salmonid populations are healthy, habitat conditions are apt to be suitable for other native aquatic species as well.

To provide a scientific foundation for the project, the Technical Workgroup developed five technical summaries on the major physical and biological considerations for developing water temperature standards:

1. thermal effects on salmonid physiology,
2. thermal effects on salmonid behavior,
3. interactions between multiple stressors – thermal and other – affecting salmonids,
4. thermal influences on salmonid distribution, and
5. spatial and temporal variation in patterns of stream temperature.

Each of these summary papers is available on the internet under the "Water" link at the EPA's Region 10 website (http://www.epa.gov/region10/) or by contacting EPA Regional Office in Seattle, WA.

This document is a synthesis of the findings of the technical summaries and begins to discuss the implications of the technical findings for setting a water quality standard for temperature. A panel of experts on salmonid biology and stream temperature provided external, independent peer review of the five underlying technical summaries and this synthesis.

Contents:

Introduction

The distribution, health, and survival of native salmonids (salmon, trout, and charr) and other aquatic species are inextricably linked to water temperature. Temperature exerts its control through its effect on the physiology and behavior of individual organisms. Since salmonids are ectothermic (cold-blooded) organisms, and live under temporally and spatially heterogeneous thermal conditions, water temperature can be thought of as a resource that fish utilize through behavioral means to control body temperature within narrow limits. Water temperatures, in conjunction with adequate flow, food, oxygen, shelter, and other resources, determine habitat suitability for each species. While community composition is shaped by numerous habitat components, each of which can provide optimal or suboptimal conditions, temperature is one of the single most influential determinants of habitat quality. Further, temperature acts synergistically with other environmental stressors, thereby affecting the ability of individual fish to survive and reproduce, and affecting salmonid population viability.

Very high temperatures can cause direct mortality of salmonids. In addition, temperature influences the abundance and well- being of organisms by controlling their metabolic processes. While lethal temperatures do occur in nature and can be locally problematic, temperatures in the range where sublethal effects occur are widespread and probably have the greatest affect on the overall well-being and patterns of occurrence of our native fish populations. As stream temperatures and patterns of heating and cooling (the "thermal regime") change due to land management or other impacts, salmonid fishes are exposed to temperatures outside their physiologic optimum, and fish communities may change drastically (see Distribution technical summary).

Salmonids have developed physiological (see Physiology technical summary) and behavioral (see Behavior technical summary) adaptations to temperature dynamics that allowed them to thrive in the ecologically-diverse rivers and streams of the Pacific Northwest, even though stream temperatures were never optimal in all places and at all times (see Spatio-temporal technical summary). However, human-caused changes to the thermal regime in streams have contributed to habitat conditions that prevent salmonids from continuing to flourish. While many factors have contributed to the decline in native salmonid populations, temperature has played an important role, either directly, or through synergistic interaction with other factors (such as habitat loss and disease).

Project Background

Many laws and regulations govern the use of water in the United States. In the Pacific Northwest, two federal statutes play key roles: the CWA and the ESA. The CWA provides the statutory basis for water quality standards programs and defines broad water quality goals. The ESA was intended to provide a means whereby the ecosystems upon which threatened and endangered species depend may be conserved, and to provide a program for the conservation of such species. Under the ESA, all federal departments are required to conserve threatened and endangered species. Further, under federal treaties with the Columbia River tribes, the federal trust responsibility imposes an obligation on all federal agencies to protect and restore fish and their habitats as necessary to fulfill the intent of the treaties.

The ESA is an important statute in the regulation of water quality, because threatened and endangered salmonids depend on cold, clean water, and because federal agencies are required to cooperate with state and local agencies to resolve water resource issues in concert with conservation of endangered species. The issues of clean water (CWA) and species recovery (ESA) are widespread. Many major watersheds in the region contain streams listed as "water quality limited" due to temperature, and most are important to the recovery of at least one listed salmonid species. Both the CWA and ESA should therefore play complementary roles in the recovery of salmonids in the Pacific Northwest.

Clean Water Act

A water quality standard defines the water quality goals for a water body by designating the use or uses to be made of the water, by setting "criteria" necessary to protect the uses, and by preventing or limiting degradation of water quality through antidegradation provisions. Under section 304(a) of the CWA, EPA publishes water quality criteria that reflect available scientific information on the levels of specific chemicals or parameters for the protection of aquatic life or human health. These criteria are intended to provide protection for all surface waters on a national basis, and may be used by states as a basis for developing enforceable water quality criteria as part of their standards. The criteria are provided as guidance, to assist states and tribes in setting water quality standards.

The foundation for EPA's national criteria for temperature was established by the National Academies of Sciences and Engineering in a review for EPA, *Water Quality Criteria 1972: Report to the U.S. Environmental Protection Agency*. The report focuses on preferred methods and procedures for judging thermal requirements rather than on providing specific numerical values for various species of concern. The report suggests that species and life stages be protected from several levels of negative effects of increased temperature: lethal effects, sublethal effects, habitat exclusion, and reproductive continuity. The report also focused on the importance of establishing upper limits for a maximum weekly average temperature, and on establishing a time-dependent maximum temperature for short exposures. The work was based on the physiological requirements of species and did not take into account the physical aspects of stream or lake systems. EPA later augmented this work and established numeric temperature criteria for certain species including coho and sockeye salmon (EPA 1976).

EPA's 1986 *Quality Criteria for Water* report, as updated in *National Recommended Water Quality Criteria* (EPA 1999), contains summaries of all contaminants and conditions for which EPA has developed criteria recommendations. The criteria serve as guidance to assist states and tribes in adopting water quality standards, as required by section 303(c) of the CWA. Once adopted, states and tribes are to submit the standards to EPA for review and approval or disapproval. EPA reviews the standards to determine compliance with the CWA and implementing regulations and to ensure the criteria associated with the standard are protective of the designated beneficial uses.

Endangered Species Act

When a state proposes a water quality standard that may affect species listed as threatened or endangered populations under the ESA, EPA must consult with the U.S. Fish and Wildlife Service (USFWS) and/or the National Marine Fisheries Service (NMFS) prior to approving the standard, in order to ensure that the proposed standard will not jeopardize the continued existence of a listed species. In order to streamline the process of review and consultation for future water temperature standards in the Pacific Northwest, EPA Region 10 developed a program that allows Oregon, Washington, Idaho, Native American tribal governments, EPA, NMFS, and USFWS to develop guidance jointly for the development of water temperature criteria. All of the participating agencies and tribes hope to use the final product to harmonize the ESA and CWA with respect to water temperature standards, and to help remove water temperature as an impediment to the recovery of imperiled native salmonids.

Treaty Rights and the Trust Responsibility

Through their treaties, tribes reserved the right to fish at all usual and accustomed fishing places and to take a "fair share" of the fish destined to pass to such areas. The Supreme Court has determined that the tribes' fair share is 50 percent of the harvestable fish, unless a moderate living standard can be met with less. Guaranteed by treaty, these tribal fishing rights may only be abrogated by specific congressional legislation – no one may use any method to otherwise deprive treaty fishermen of their right to a fair share of the anadromous fish (those that migrate from streams to the ocean and back).

As trustee of the tribes, the federal government also has the affirmative obligation to safeguard the subject matter of the treaty fishing right – the fish. Thus, federal agencies must use their authorities in a manner that will protect and prevent degradation of the habitat needed to support anadromous fish species. At a minimum, agencies have the duty to refrain from activities that will interfere with the fulfillment of treaty fishing rights. Anything less would amount to a de facto abrogation of Native American treaty rights. Thus, unless federal agencies can demonstrate that treaty fishing rights are presently being fulfilled, they cannot justify approving activities that will cause further degradation of anadromous fish habitat. Similarly, they cannot "balance" their treaty obligations against competing impacts to non-Native Americans or "delay" such obligations in order to minimize those impacts.

The federal trust obligation also mandates that Federal agencies enhance salmonid habitat where necessary to safeguard the fish that underlie the treaty fishing right. Arguably, this Federal trust obligation does not cease once a fish run becomes viable, but must continue to allow for harvestable populations of fish and meaningful fulfillment of the treaty right to take fish.

Project Structure

EPA initiated development of guidance for regional temperature criteria by facilitating a multi-agency effort to accomplish the task. Project participants intend to develop guidance for regional temperature criteria that would be protective of native salmonids; recognizes the natural temperature potential and limitations of streams; could be effectively incorporated by states and tribes in water quality standards programs; and would be endorsed by EPA, USFWS, NMFS, states, and tribes in the Pacific Northwest. Additionally, the participating agencies intend that EPA use the new criteria guidance to evaluate revisions of state and tribal temperature standards, and that states and tribes will use the new criteria guidance to revise their temperature standards. The Technical Workgroup developed a technical interpretation of the project goals (see Appendix A) that articulates the goals in terms of viable salmonid populations, distribution of coldwater habitat to support viable populations, and coldwater habitat support of all life history stages of salmonids.

The individuals involved in the project are employees of tribes and state and federal agencies, and are divided into a technical and a policy workgroup. The Policy Workgroup is comprised of agency/tribal managers and has the ultimate decision-making authority regarding the final form of the guidance. The Technical Workgroup, comprised of agency and tribal scientists, is responsible for developing draft guidance and providing technical review of the Policy Workgroup's final decision.

The participants in this program recognize that water temperature improvement alone will not restore native fish to historic populations; however, water temperature restoration is a necessary component of the protection and restoration of freshwater habitat. For resident salmonid species (those that fulfill their entire life cycle in streams, rivers, and/or lakes), freshwater temperatures are clearly very important. For anadromous salmonids , freshwater temperatures are equally important. Relatively high freshwater survival is necessary to produce sufficient numbers of healthy smolts (young salmon entering the ocean) to ensure that fishable populations of adults will return to streams to spawn. This is particularly important during periods of poor ocean productivity. Also, since mortality is high during the egg to smolt periods in the freshwater and estuarine phases of anadromous salmonid development, reducing mortality during these stages offers significant opportunities for restoration of anadromous fish (Federal Caucus 2000).

How cold must water temperatures be to support salmonids?

Viable populations of native salmonids in the Pacific Northwest need cold water that is both abundant and well-distributed over space and time to meet their freshwater habitat needs (see Physiology, Behavior, Multiple stressors, and Distribution technical summaries). The importance of cold water habitat to salmonids is documented by scientific research (summarized in the Physiology, Behavior, and Multiple stressors technical summaries). The thermal tolerances expressed by salmonid species are markedly colder than for other major groups of fishes, such as centrarchids (e.g., smallmouth bass, perch) and cyprinids (e.g., carp, northern pikeminnow).

Salmonid feeding, growth, resistance to disease, competitive ability, and predator avoidance are influenced by water temperature and are impaired when salmonids are exposed to unsuitable temperatures (see Physiology, Behavior, and Multiple stressors technical summaries). Critical temperature-dependent life stages for salmonids include spawning, egg incubation, emergence, rearing, smoltification, migration, and pre-spawn holding. Any of these salmonid life stages can be present (depending on species and location) during summer months when high water temperatures are most likely to occur in Pacific Northwest streams. Adult fish holding in warm stream reaches are subject to bioenergetic stress and may consume so much of their stored energy that spawning success is impaired. Prolonged holding in water temperatures that are higher than optimal can result in death due to multiple stresses, such as concurrent thermal stress, disease, and energy depletion. Additionally, thermal effects on gametes in holding fish can decrease gamete viability. In salmonids that feed in fresh water as well as for all juveniles, warm temperatures can alter rates of growth and development. In addition, high water temperatures can present thermal barriers to adult and juvenile migrations. If enough fish are affected, the viability of salmonid populations may be threatened.

While individual salmonids may be observed in streams where temperatures exceed laboratory-determined thermal tolerances, these observations alone are not grounds for concluding that warmer streams and rivers can support healthy salmonid populations. Individual fish may stray or be trapped in waters where temperatures are stressful or ultimately lethal. Further, if coldwater pockets (micro-refugia) are available in warm streams, small salmonid populations may be able to persist by exploiting these cold areas for short periods to avoid heat stress (see Behavioral technical summary), even though the majority of habitat in the stream is too warm. Scientific evidence suggests that small increases in temperatures (e.g., 2-3°C) above biologically optimal ranges can begin to reduce salmonid fitness.

Thermal conditions supporting various life stages and biological functions of some salmonids have been studied, primarily in the laboratory setting (Table 1). Although available scientific evidence suggests that *individual fish* are adversely affected by temperatures listed in Table 1. However, there is some uncertainty regarding whether the temperatures listed are cool enough to support viable salmonid *populations* in rivers and streams. Most laboratory studies address single stressors, while providing optimal conditions for other environmental factors, even though temperature does not act independently from all other factors (Table 2, see also Multiple stressors technical summary). For example, when salmonids are fed to satiation, temperatures associated with maximum growth-rates are higher than under conditions of more natural (limited) food supply. Similarly, allowing salmonids to slowly acclimate to warm temperatures in the laboratory will extend their thermal tolerance, yet migrating salmonids may not have time to acclimate in the field.. It is virtually impossible to mimic field conditions in the laboratory, or to disentangle the effects of the multiple, interacting factors in complex natural systems. Because field conditions are in many ways more ecologically complex than laboratory settings, the upper thermal limits for each life stage determined in the laboratory typically will not prevent adverse impacts from multiple stressors in a natural setting. In other words, because most of the temperatures listed in Table 1 are derived from studies that focus on responses of individual fish to temperature, streams may have to provide abundant habitat at somewhat cooler temperatures in order to support viable salmonid populations. However, various salmonid species and life stages show high fitness within a range of water temperatures around *optimum* laboratory-derived temperatures. Thus, rather than focusing on laboratory-derived *maximum* thermal tolerances, laboratory-derived *optimal*

Table 1. Estimates of thermal conditions known to support various life stages and biological functions of bull trout (a species extremely intolerant of warm water) and anadromous (ocean-reared) salmon. These numbers do not represent rigid thresholds, but rather represent temperatures above which adverse effects are more likely to occur. In the interest of simplicity, important differences between various species of anadromous salmon are not reflected in this table and requirements for other salmonids are not listed. Likewise, important differences in how temperatures are expressed are not included (e.g., instantaneous maximums, daily averages, etc.). These numbers are taken from the Physiology technical summary; that summary should be consulted for more detailed discussions and for references to scientific literature that support these numbers.

Consideration	Anadromous Salmon	Bull Trout
Temperature of common summer habitat use	10-17°C	6-12°C
Lethal temperatures (one week exposure)	Adults: >21-22°C Juveniles: >23-24°C	Juveniles: >22-23°C
Adult migration	Blocked: >21-22°C	Cued: 10-13°C
Swimming speed	Reduced: >20°C Optimal: 15-19°C	
Gamete viability during holding	Reduced: >13-16°C	
Disease rates	Severe: >18-20°C Elevated: 14-17°C Minimized: <12-13°C	
Spawning	Initiated: 7-14°C	Initiated: <9°C
Egg incubation	Optimal: 6-10°C	Optimal: 2-6°C
Optimal growth	Unlimited food: 13-19°C Limited food: 10-16°C	Unlimited food: 12-16°C Limited food: 8-12°C
Smoltification	Suppressed: >11-15°C	

temperatures can provide conservative guidance for identifying water temperatures apt to protect salmonids in natural environments. Because there are uncertainties surrounding field and laboratory observations, concurrence between field and laboratory data is especially meaningful.

The scientific research reviewed in the Physiology, Behavior and Multiple-stressor technical summaries shows that salmonids require a diversity of cold water temperatures in streams (Table 1) and that these temperatures must exist at appropriate locations and at appropriate times of the year. While laboratory evidence suggests adult salmon can generally survive a week or more at constant temperatures of 21°C and can often tolerate temperatures as warm as 18°C for prolonged periods under controlled experiments settings, constant temperatures above 16°C have been shown to be intolerable for species such as bull trout. Not only do different species have unique temperature requirements, but individual species have unique temperature requirements for different life stages (spawning, incubation, juvenile growth, seawater adaptation, and adult migration). The times at which those life stages occur is highly variable between streams of our region. In consideration of the available scientific information, it is clear that healthy salmonid populations cannot persist without a variety of cold water temperatures that are well-distributed over space and time (Table 1).

Table 2. Examples of considerations for interpreting laboratory observations of thermal tolerances and preferences for salmonids.

Consideration	Effect	Implication
Acclimation	When salmonids are acclimated to warmer temperatures in the lab, incipient lethal and other threshold temperatures rise to a limited extent	Results from laboratory studies are not directly comparable unless acclimation conditions are the same. In the field, temperatures may vary considerably. In the field, salmonids are assumed to be acclimated to a temperature between the mean and the maximum daily temperature.
Feeding	Feeding to satiation causes optimal growth to occur at higher temperatures than when food is limiting. Food quality and cost of foraging may also be important	In the field, food availability is most typically limited. Thus, laboratory tests where feeding levels are generally at satiation can overestimate suitable temperatures for growth and certain other performances. Also, food quality in the laboratory may differ from foods available in the field, and fish in the field must expend more energy to locate, and capture prey. Foraging costs (energy expenditure) may be reduced considerably under laboratory conditions than under field conditions, thereby reducing stress.
Social interactions	Can mitigate or exacerbate various thermal stresses	Social conditions in the field, especially territoriality, are key components of salmonid population regulation and behavior. Experimental studies seldom consider the role of social factors, which could mitigate or exacerbate responses to stressful temperatures. Unnatural social circumstances in the laboratory include, but are not limited to: possible high fish densities, wild vs. hatchery fish behavior, and altered community age structure. In the field, high fish density or low food availability can result in fish being forced to inhabit marginal thermal habitat. Mixtures of species and age classes can intensify social interactions in the field, whereas lab studies typically use single species and age classes per test.
Physiochemical conditions	Can alter stress response in a number of ways	Artificial lighting, photoperiod, thermal regulation, water chemistry, habitat structure (lab apparatus), cover, etc., may not reflect field conditions and are tied to physiological and behavioral responses to stress. Response may be partially determined by physical features of the experimental apparatus (e.g., horizontal vs. vertical thermal gradient in preference tests).
Handling	Causes additional stress	Repeated handling of fish, invasive procedures, and interaction with apparatus (e.g., tank maintenance), can alter both physiological and behavioral responses to stress.
Fish size/stage	Response may be size, age, or stage-dependent	Most laboratory studies focus on early life stages (e.g., eggs, fry, juveniles). This may not reflect the total life cycle in the wild. For example, adults and emergent fry can be more sensitive to elevated temperature then juveniles.
Exposure	Exposure in lab and field settings may differ	Natural streams have a diurnal range of temperatures and may have cooler areas in pools, tributaries, or where ground water upwells where fish can take refuge from warm temperatures. Fish in a laboratory aquarium cannot escape their test conditions, which may be constant.

How much cold water is necessary to support salmonids? When and where must it exist?

Temperature criteria to protect salmonid fishes have traditionally focused on the question "How warm can water be and still support salmonids?" However, identifying water temperature thresholds is not sufficient to ensure support for viable salmonid populations.[1] It is also important to ask "How much cold water is needed?", and "Where and when must cold water be available?"

Native Pacific salmon, trout, and char have complex life histories (Figure 1) that evolved in the

[1] Viable populations are defined in Appendix A

spatially and temporally dynamic landscapes of the Pacific Northwest (see Distribution technical summary). Accordingly, providing enough cold water at the right places and times to support the recovery of native salmonids will require restoration and protection of natural ecosystem processes and patterns, including thermal regimes and spatial patterns of thermal habitat (see Spatial-temporal technical summary). Thus, our understanding of the biological and physical diversity of natural processes should provide guidance for developing temperature criteria. Maintaining biological diversity and natural system dynamics are important goals when considering how much cold water is necessary, when it is necessary, and where it is necessary.

Biological diversity

The spatial and temporal dynamics of natural thermal regimes lead to variations in life history characteristics (e.g., growth, timing of migration, age at reproduction). These characteristics interact in complex ways to determine individual fitness, and patterns of life history variability, viability, and productivity among populations and species. Within a species, individuals and populations with different life cycles and life histories may fare differently under changing environmental conditions. Variability in life history strategies may therefore confer stability and increased productivity to salmonid populations in naturally variable environments. Alteration of natural thermal regimes may cause populations to decline or important life history variability to be lost (see Spatio-temporal technical summary).

In attempting to set criteria for temperature standards, it may be tempting to focus on specific characteristics of individuals and/or populations (e.g., density of fish, growth, fecundity, or survival) to simplify the task of managing or tracking population dynamics. However, there is considerable risk associated with using these population indices seperately or attempting system-wide maximization of any of these measures because of interaction or feedback among multiple factors. For instance, Holtby (1988) found that logging increased winter water temperature and subsequently the growth of juvenile coho salmon. While this might

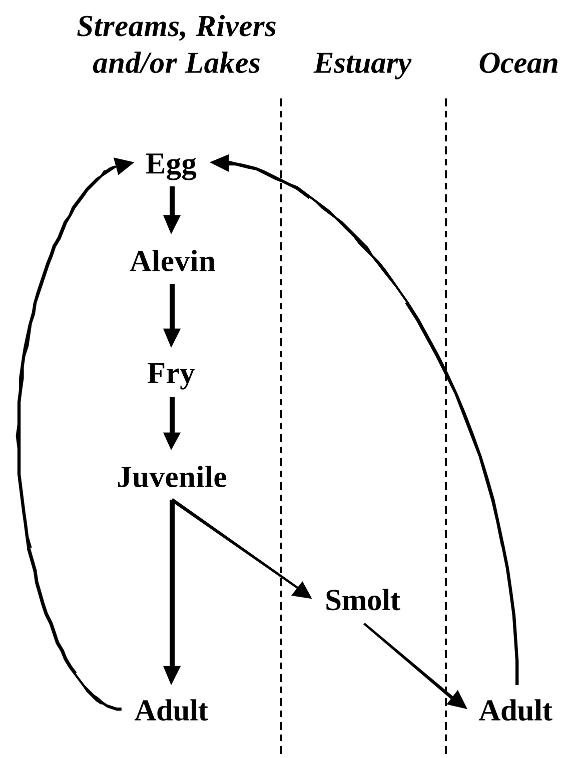

Figure 1. A simplified general sequence of events in the life cycle of salmonid fishes. All salmonids deposit eggs in freshwater (stream or lake) habitats. Depending on temperature and other factors, eggs hatch into alevins (sac fry). Alevins typically remain in or near spawning substrates until the yolk sac is absorbed. Following absorption of the yolk sac, the young are typically referred to as "fry." This stage signifies the initiation of active feeding and development into fully formed juveniles. Juveniles may remain in their natal tributary or lake and mature as adults. This is referred to as a "resident" life history. Known migratory life histories include migrations to non-natal lakes and streams (potadromy) and marine habitats (anadromy). The transition to the marine environment involves complex physiological changes, referred to as "smoltification" in juvenile salmonids. Adults of some species may make repeated transitions between freshwater and marine habitats, however. Migratory behavior varies substantially among species, and within and among local populations, in many cases.

be expected to be beneficial, the increased growth led to earlier migration, reduced marine survival, and an overall reduction in the densities of returning fish. This is not to say that growth should be ignored as an important factor for monitoring salmonid populations. It simply underscores that *single* measures are not effective indicators of overall population status and that attempts to maximize individual measures are associated with high levels of biological risk. In fact, these simplified approaches may reduce rather than preserve natural biological diversity and viability of salmonid populations by focusing attention on specific performance measures at the expense of other important aspects of biological diversity (Lichatowich 1997)

Natural temperature dynamics

Natural landscapes represent a complex mosaic of physical and biological diversity. Ecosystem processes that shape these physical and biological patterns can operate on a number of scales in time or space. A natural thermal regime can be considered in terms of magnitude, frequency, duration, and timing of events (e.g., summer maximum temperatures) and rates of change (i.e., how fast temperatures heat or cool) at different temporal and spatial scales.

Temporal scale. Temporal variation of a thermal regime can be considered in terms of variability among years, within a year (among seasons), within seasons (among days or weeks), and within a single day (among hours) (Figure 2). Thermal regimes affect

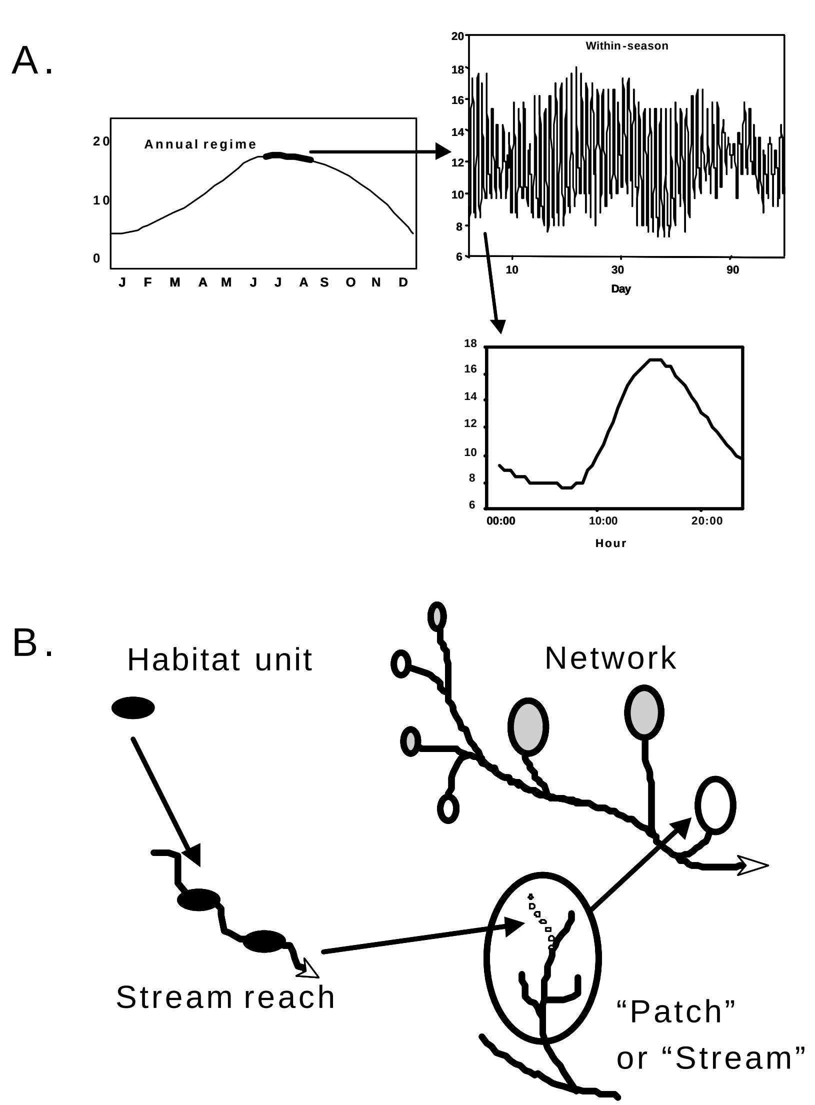

Figure 2. Examples of temporal and spatial variation in thermal regimes. (A) Annual, seasonal, and daily thermal regimes. (B) Different spatial scales where habitat variability is often considered. (see Frissell et al. 1986, Hawkins et al. 1991, Montgomery and Buffington 1998, Dunham et al. 2001).

salmonids at all of these scales (see Spatio-temporal technical summary). Decadal-scale variation in climate and temperature (e.g., El Niño events, Pacific decadal oscillations) may affect long-term patterns of productivity in salmon populations. Within years, the timing and locations of various parts of the salmonid life cycle are linked to seasonal patterns of stream temperature and habitat availability. Smaller-scale weekly or daily variability in temperature also may be important as they affect chronic or acute thermal stress (see Physiology technical summary) and individual behaviors, such as migration, habitat selection, predator avoidance, competition, and behavioral thermoregulation (see Behavior technical summary).

Spatial scale. Spatial pattern is an important part of a thermal regime. Spatial variation can occur within a few meters, such as with pools and riffles, within a larger habitat scale including stream reaches, individual streams, and stream networks (Figure 2). Two important aspects of the spatial distribution of thermal habitat are the size and locations of thermal refuges. For coldwater fish, thermal refuges can be defined as patches of cold water that allow individuals or populations to persist in a thermal regime that ranges (in time or space) outside of the zone of tolerance or preference for a given species. Thermal refuges may range in size from fine scale (e.g., pockets of cold water provided by thermal stratification and localized ground water upwelling to cold side channels and backwaters in alluvial systems) to coarse scale (e.g., thermal variation between headwater creeks to larger main-stem rivers; see Spatio-temporal technical summary).

Landscape context. Protection of fish at specific sites is not sufficient to guarantee the health of a local population. Emerging evidence suggests the health of local populations may depend on the landscape context – specifically, the size, number, connectivity, location, and quality of occupied and unoccupied habitats within which the population lives (see Distribution technical summary). The landscape context refers to the spatial as well as temporal dynamics of habitat change and occupation. Clearly, where habitat is degraded, fish populations will decline and will not recover until the habitat has recovered. In some cases, however, habitat is not just degraded, but a disturbance renders the habitat temporarily unsuitable (e.g. local temperature increases in a portion of a stream network) for salmonid survival. In these cases, although that habitat may ultimately recover, the loss of certain species from the disturbed area can be either temporary or permanent. Species loss is likely to be temporary if other suitable habitats (refuges from disturbance) are: 1) large enough to maintain viable populations of affected fish, and 2) inter-connected to allow emigration from the refuge(s) to the disturbed site when (or if) it recovers from the disturbance. This underscores the fact that not all suitable habitat is necessarily occupied at all times in a dynamic natural landscape. Therefore, protection of currently occupied and unoccupied habitat may be needed to provide a sufficiently large network of well-connected habitat distributed across the landscape (Figure 3). Specific answers to the questions of precisely "how large?" or "how connected?" are only beginning to be addressed as principles of conservation biology are integrated into salmonid ecology (see Distribution technical summary), but evidence suggests that habitat must be widespread and well-connected in order to meet a goal of maintaining viable salmonid populations.

Incorporating thermal regimes

While we do not fully understand how natural ecosystems function, natural conditions serve as models of stream temperature dynamics known to have supported viable salmonid populations. It is difficult to prescribe "appropriate" thermal regimes from inferences about biological conditions or physical conditions alone. Our biological understanding of salmonids has provided important insights into the effects of temperature, but it does not directly address the causes of thermal degradation. Temperature standards that encourage attempts to restore natural thermal dynamics (e.g., address the causes of thermal degradation) provide the highest likelihood of supporting viable salmonid populations.

Ideally, we could reduce thermal degradation by restoring stream temperatures to pre-settlement thermal regimes that historically supported viable

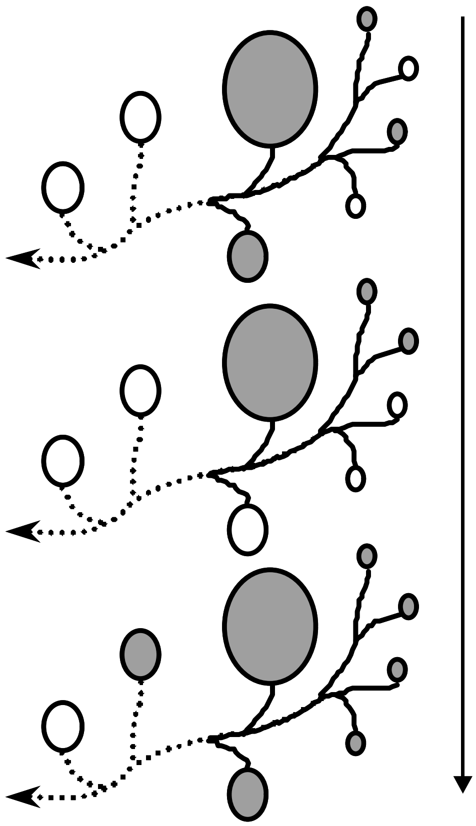

Figure 3. Example of temporal variation in patterns of habitat occupancy by salmonids in a dynamic landscape. Circles represent potential "patches" (Dunham et al., in press) of suitable habitat in a stream network (lines). Filled circles represent occupied habitats, and unfilled circles indicate unoccupied habitats. Temporal variation in stream habitats can change habitat suitability over time, and affect patterns of habitat occupancy. Even if stream conditions remain static, external factors (e.g., ocean productivity cycles) may cause variation in fish populations and habitat occupancy over time. Either will produce patches of potentially suitable, but unoccupied, habitat and a dynamic of local extinction and recolonization by different species (Reeves et al. 1995; Rieman and Dunham 2000).

salmonid populations. However, restoration of historical conditions can be an unreasonable goal given that restoration opportunities may be limited to varying degrees by certain "irreversible" human-caused or natural landscape changes, such as development of major urban centers and volcanic eruptions. Yet, the continuing collapse of salmonid populations suggests that the existing amount and distribution of suitable habitat in the Pacific Northwest is inadequate to maintain viable salmonid populations. Therefore, the Technical Workgroup proposes four actions to help ensure adequate amounts and distributions of cold water to support salmonid populations.

1) Immediately protect remaining suitable habitat from thermal degradation.
2) Restore some amount of thermally degraded habitat; given that thermal degradation in many streams may not be reversible due to policy considerations or social and economic realities, it is likely that most or even all habitat that can be restored will need to be restored in order to support viable populations.
3) Implement restoration across a broad spectrum of habitats from headwaters to ocean because the life histories of salmonids span entire watersheds.
4) Base protection and restoration on natural temperature dynamics to the fullest extent possible. Engineering artificial thermal regimes entails greater uncertainty and risk than attempting to mimic natural processes and patterns.

How do human activities affect stream temperatures?

Water temperature is determined by interactions between the amount of water flowing in the stream, the structural configuration of the stream and riparian zone, and various factors external to the stream/riparian zone (see Spatio-temporal technical summary). In many river basins of the Pacific

Northwest, land management activities have (1) reduced connectivity (i.e., the flow of energy, organisms, and materials) between streams, riparian areas, floodplains, ground water, and uplands; (2) altered floodplain function, wetlands, water tables, and base flows; (3) elevated fine sediment yields, making streams wider and shallower, with fewer pools; (4) reduced instream and riparian large woody debris that traps sediment, stabilizes stream banks, and helps form pools; (5) reduced or eliminated riparian vegetation; and (6) altered peak flow volumes and timing (FEMAT 1993, Henjum et al. 1994, McIntosh et al. 2000, Rhodes et al. 1994, Wissmar et al. 1994, National Research Council 1996, Spence et al. 1996, Oregon Coastal Salmon Restoration Initiative 1997, Quigley and Arbelbide 1997). Thus, human activities can alter stream temperature. Figure 4 shows a schematic representation of a variety of complex interactions that could result in warming of summertime stream temperatures.

Human-caused changes to stream temperature are often hard to quantify, usually because of difficulty determining what the "natural" water temperature would have been in the absence of human-caused degradation. However, scientific research has shown that human activities have the potential to alter thermal regimes (see Spatio-temporal technical summary). Along with changes in mean temperature, more subtle changes in stream temperature may be

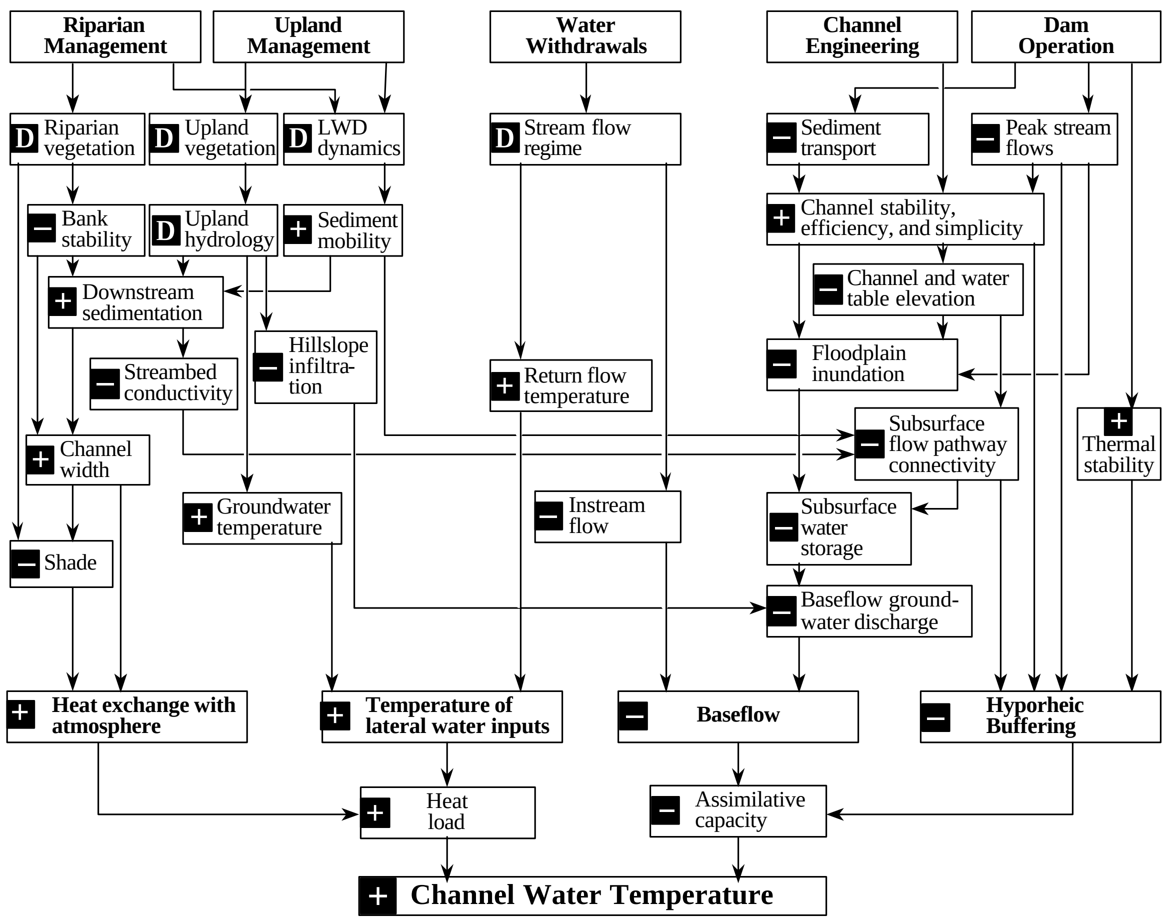

Figure 4. Some pathways of human-caused warming of stream channels (From Poole and Berman, in press.). The symbol "+" indicates an expected increase, "–" an expected decrease, and "Δ" either an expected increase or decrease depending on the specific circumstance or measurement used. Additional arrows and boxes are possible under various conditions.

manifested as changes in temperature extremes, in temperature variation, or in the timing of temperature extremes. Most typically, human-caused degradation simplifies stream structure, which eliminates the coldest water habitats and reduces *spatial* temperature variation within stream reaches. At the same time, human-caused degradation often increases the *daily* and *seasonal* temperature variation in stream reaches by interrupting natural processes that buffer stream temperature such as riparian shade, in-stream flow, and ground water influx. (see Spatio-temporal technical summary). While these effects might seem to offset one another, they instead have a synergistic negative effect on salmonid populations. Increases in daily and seasonal variation expose fish to higher summertime maximum temperatures. At the same time, loss of coldwater habitat that reduces spatial variation within stream reaches precludes salmonids' ability to escape high temperatures or avoid other detrimental physiological and ecological conditions (see Behavior technical summary).

Human influences on stream temperature are inherently cumulative; as the amount and intensity of land-use and river flow regulation increase in a basin, so too does the magnitude of in-stream temperature changes (see Spatio-temporal technical summary). Thus, problematic water temperatures are most apt to occur in basins where urbanization and intensive land-use activities (such as logging and agriculture) are widespread and/or where dams or water withdrawals have substantially altered natural flow regimes. In these basins, more heat is added to streams and the heat accumulates as water moves downstream unless downstream conditions (e.g., riparian vegetation, geomorphology, etc.) effectively allow the accumulated heat to dissipate back out of the stream channel (see Spatio-temporal technical summary). Some streams dissipate added heat effectively, while others retain added heat. The distance over which accumulated heat persists in a stream may range from a few meters to many kilometers. Thus, heat added to cold headwater streams might not create thermally unsuitable salmonid habitat in the headwaters themselves, but may instead contribute to unacceptably warm temperatures farther downstream. In areas where human activities have warmed streams, those same activities often eliminate naturally-occurring thermal refugia (from pockets of cold water in warmer streams to entire watersheds that contain thermally optimal temperature regimes) or isolate such refugia from other suitable thermal habitat. Loss of these important landscape features reduces the ability of salmonids to avoid thermal stress and therefore is apt to decrease survivorship through periods of temperature extremes (see Spatio-temporal and Distribution technical summaries).

How can we contend with scientific uncertainty when establishing temperature criteria?

Developing temperature criteria to protect salmonids is challenging in part because scientific understanding of stream temperature dynamics, salmonid biology/ecology, and their interactions is imperfect. To maximize the potential for success, the process of developing criteria must be founded on scientific information yet be flexible to accommodate scientific uncertainty. Clearly, there are limits to our knowledge. For instance, our knowledge regarding historical distributions of salmonids is extensive, but the details regarding population sizes and habitat utilization within each individual basin is often limited. Data describing historical thermal regimes is extremely scarce and our knowledge of natural distributions of coldwater habitat is imperfect. In addition, we lack the ability to precisely measure or predict the interactions between thermal stress and other biophysical stressors in the freshwater environment. Although salmoind distributions can be correlated with thermal regimes (see Distribution and Behavioral technical summaries), the population responses to changes in thermal regime cannot be precisely specified because a multitude of factors influences salmonid population dynamics. Further, we are uncertain about the precise number and distribution of specific coldwater habitat features (e.g., thermal refugia) needed to restore thermal regimes and support viable populations.

Yet, in spite of these shortcomings, our scientific knowledge is extensive and can provide substantial guidance to the development of temperature criteria. We know salmonids need cold water. We know that much larger salmonid populations occupied a much greater network of northwest streams and rivers only 150 years ago. We know that salmonids evolved to exploit and rely upon the natural thermal regimes of Northwest rivers. We have extensive research showing how the physical structure of streams and rivers influences thermal regimes. We know that many human activities have altered (e.g., warmed) natural thermal regimes extensively. Some major sources of uncertainty and certainty are contrasted in Table 3.

While uncertainty constrains our ability to precisely qualify and quantify the risks associated with different management actions, scientific knowledge has defined many causal relations that exist between the thermal environment, biotic community, and human activities. This certainty affords confidence in the desired outcome of management actions (Tickner et al. 2000). Given uncertainty, we are challenged to make decisions based on what we know, while taking adequate precautions to avoid irretrievable or irreversible mistakes. Thus, in moving forward we must be cautious and conservative, especially when actions may affect threatened or endangered species. When managing natural resources in the face of uncertainty, Ludwig et al. (1993) offered some guiding

Table 3. Examples of uncertainties and certainties associated with determining criteria for water temperature standards based on protecting viable populations of salmonids in the Pacific Northwest.

	Uncertainty	**Certainty**
How Cold	Relationships between lab-derived temperature thresholds and requisite temperatures in the field	Salmonids can experience physiological stresses where water temperatures are not optimal
	Maximum allowable temperatures that will support viable populations	General ranges of water temperatures necessary for survival and reproduction.
	Precise thresholds of harmful temperatures (e.g., see Table 2)	Both lethal and sub-lethal effects affect salmonid survival
	Effects of multiple stressors	Thermal tolerance in salmonids is affected by other stresses and vice versa.
How Much, When and Where?	Mechanisms and dynamics of cumulative effects on stream temperature dynamics	Cumulative effects occur and can result in synergistic temperature changes within in streams subject to multiple disturbances.
	Patterns of environmental variability required to support populations	Complex physical habitat structure creates spatially and temporally diverse coldwater habitats that salmonids have evolved to exploit
	Historical thermal regimes in streams	Salmonid survival requires a variety of cold water temperatures that are well-distributed over space and time.
	Measures of historical fish distribution and trends in fish populations	Salmonid populations have declined precipitously and their distributions have been reduced throughout the region
Human Influence	Data on the alteration of thermal regimes	Thermal regimes have been altered substantially over time; where altered, streams are generally warmer in the summer and more spatially homogeneous
	Exactly what management actions are necessary to protect salmonids	The types of activities affecting stream temperature
	Maximum levels of degradation that will allow salmon to persist	Salmonid populations require a safety buffer in the face of a variable environment

principles: consider a range of alternatives and favor actions that accommodate uncertainties; favor actions that are informative; probe and experiment; monitor results; update assessments and modify policies accordingly; and favor actions that are reversible. Sources of certainty, uncertainty, and related assumptions in any approach to developing temperature criteria must be clearly and completely documented (see Tickner et al. 2000, for examples).

Participants in this project are charged with developing new temperature criteria guidance that will provide sufficient cold water to restore and sustain viable salmonid populations, yet there is no way to determine with certainty *exactly* how cold streams must be, how much coldwater habitat is needed, and what spatial and temporal configurations will be requisite. However, from the certainties listed in Table 3, we can infer several tenets from which criteria robust to uncertainty can be designed.

1) Human actions have caused thermal degradation of aquatic habitats. This is a factor that has contributed to declines in salmonid populations.
2) Existing amounts and/or spatial and temporal distributions of essential habitat, including thermal dynamics thereof, may not be sufficient to support viable salmonid populations.
3) Restoration and protection of thermally suitable habitat will have to address the extent and distribution of water temperatures suitable for salmonids.

While restoration of stream temperature will not be the only action necessary to restore salmonids populations, we conclude that widespread restoration of temperature regimes will favor recovery of salmonids. We further conclude that restoration will require elimination, reduction, or modification of human actions shown to cause thermal degradation; and that temperature criteria will need to define "coldwater habitat" and provide guidance for determining the amount and distribution thereof. Thus, to meet the goals of this project (Appendix A), the available science suggests that salmonid recovery will require more cold water than is currently available, and that the cold water must be well distributed and connected.

As the results of efforts and progress to provide cold, well-connected, and well-distributed aquatic habitat are compiled, and as salmonid populations change in response to those efforts, criteria may be revisited and refined. Yet, in light of scientific uncertainties, the endangered status of salmonids in the Pacific Northwest, and the extent of human alterations to their habitat, it is important to avoid initially underestimating the thermal requirements of salmonids.

Implications for Water Temperature Standards

In concept, a conventional approach to developing water quality standards (such as often used for toxic pollutants) attempts to identify a threshold value that is low enough to avoid risks to aquatic biota. For many parameters, the threshold level is above the range of naturally-occurring conditions in streams. Where this occurs (Figure 5, top), a conventional threshold standard is effective, scientifically defensible, and relatively easy to determine. For water temperature, however, there are several reasons why a single threshold approach to determining water quality criteria can be problematic.

Stream temperatures associated with increased biological risk might occur relatively frequently in some stream reaches under natural conditions (Figure 5, bottom). Natural stream conditions would violate temperature thresholds that were predicated on eliminating biological risk to individual fish. Natural stream temperatures vary across space and time, particularly in large, dynamic landscapes such as the Pacific Northwest. Applying a conventional standard may result in two undesirable consequences illustrated by Figure 6. First, human-caused warming of the best thermal habitat may be allowed where local stream temperatures are naturally below the water quality criterion. Second, streams naturally warmer than the criterion will be identified as candidates for remediation. Salmonids require a variety of cold water temperatures, but a single

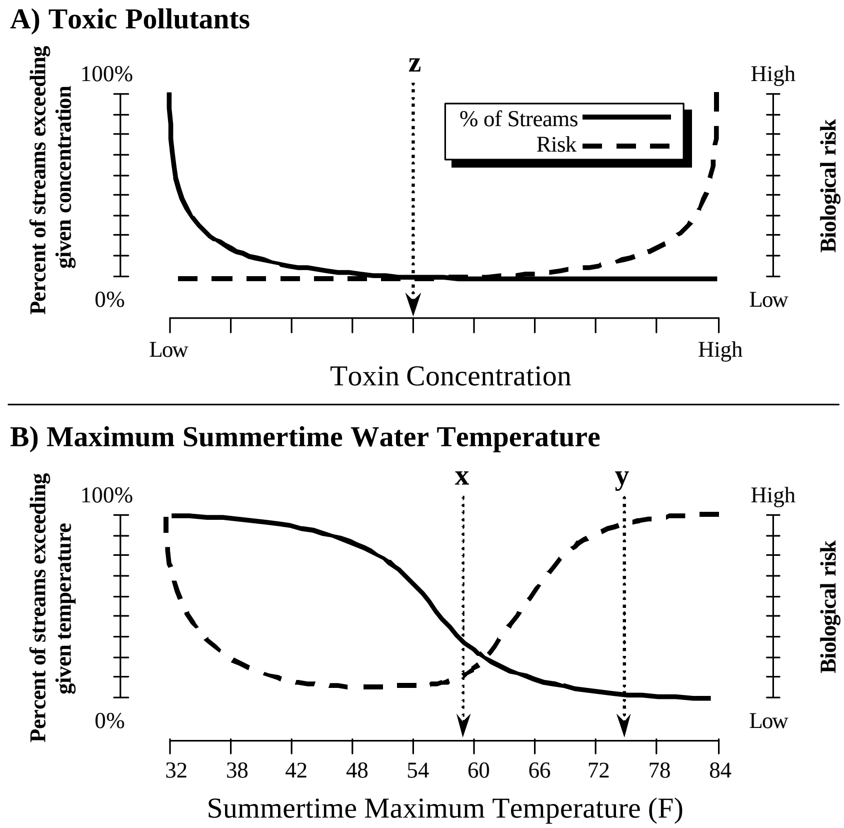

Figure 5. Illustrations of hypothetical relationships between expected frequency of in-stream conditions (in the absence of human-caused degradation) and associated biological risk. In these illustrations, "biological risk" is determined as the risk of negative impacts on individual fish. Top: For some water quality constituents (such as some toxics), conditions with high biological risk are rare in the absence of human-caused degradation. Thus, a single threshold-based water quality standard can be set such that pristine streams are unlikely to violate the standard *and* biological risk is avoided (for instance, line "z"). Bottom: For stream temperature, no such single threshold exists. If a standard is set to avoid substantive risk (for instance, line "x"), temperatures in some streams will not comply with the standard even when human-caused temperature changes have not occurred. If a threshold is set so that virtually all "non-degraded" streams will comply with the standard (for instance, line "y"), fish may be exposed to substantial risk. *NOTE: These graphs are for illustrative purposes only. No temperature data were used to construct temperature frequency curves, nor were laboratory data used to develop risk curves.*

threshold standard does not recognize the diversity of water temperatures needed by various species and over space and time.

Temperature standards are developed primarily to protect aquatic biota as the beneficial use most sensitive to water temperature. Yet, water temperature is the expression of a set of heat transfer processes that are in turn influenced by the physiographic, climatic, and hydrologic variables acting on a particular stream segment. Some of these variables can be altered by human activity and some cannot. Therefore, in setting water temperature standards to protect aquatic biota both the biological and physical processes must be considered. A good standard will protect high-quality habitat and guide restoration of degraded habitat, while recognizing that some naturally warm reaches are also part of the aquatic landscape. It will limit the extent to which the standard may be under-protective in some locations and overly stringent in others.

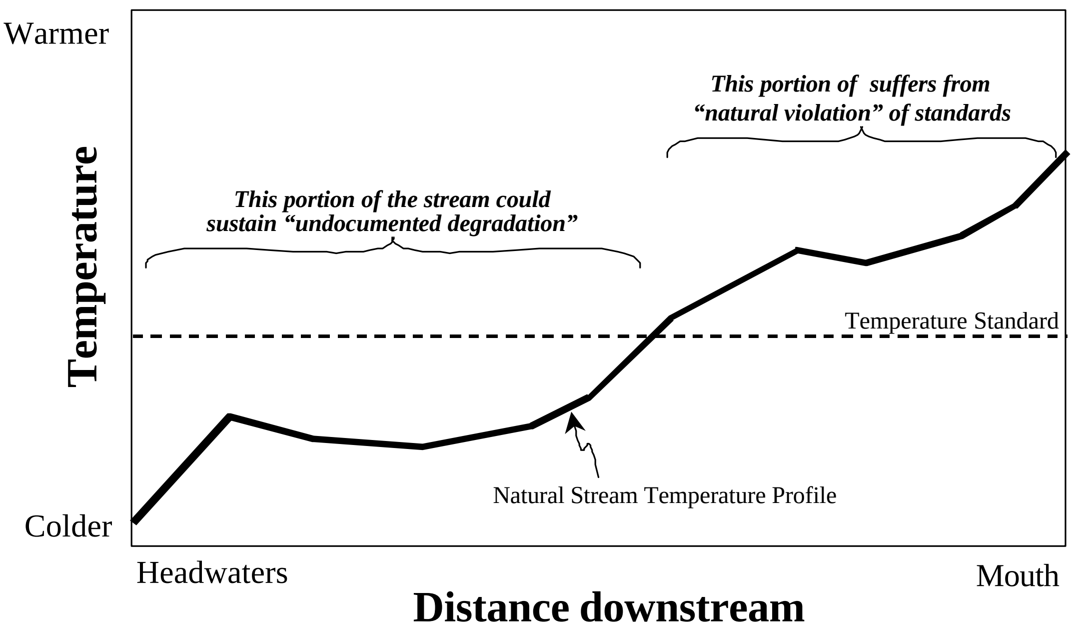

Figure 6. Two difficulties of implementing a single threshold as a temperature standard. First, a single numeric standard may fail to document degradation of the highest quality (coldest) habitat. Second, natural temperatures may violate the standard thus requiring extensive time, effort, and resources in an attempt to determine whether the violation is natural or the result of human-caused temperature changes.

The next task of the Technical Workgroup is to develop conceptual models or frameworks for a temperature standard. In order to avoid the limitations and achieve the objectives described above, the workgroup is analyzing the characteristics of conventionally derived standards and thinking about alternate ways to structure a standard. Described below are possible alternative factors to new standards that the workgroup will consider and evaluate.

<u>Standard development.</u> By convention, water quality standards are designed to remove unacceptable stresses on individual fish. Alternatively, a standard could attempt to describe conditions that would be necessary to maintain viable populations.

<u>Comparison used.</u> The type of comparison used to determine compliance may range from single temperature thresholds to multiple thresholds or even thermal regimes. Single thresholds are individual numbers that are compared to measures of water temperature. Multiple thresholds are groups of thresholds that can be compared across space and/or time to measures of water temperatures. Regimes are compared using metrics that describe the spatial or temporal distribution of temperatures such at mean, range, variance, and timing.

<u>Scientific foundation of numeric values.</u> Numeric values for standards can be determined based on salmonid biology (e.g., lethal or optimal temperatures for salmonids), temperature dynamics of streams (e.g., patterns of heating and cooling), or a combination of both.

<u>Spatial scale of a management unit.</u> For water quality standards, a management unit is the type of geographic unit that is deemed either in or out of compliance with the standard. By convention, individual water bodies, stream reaches, or point locations are used as management units. Alternatively, a management unit could be defined as a basin or sub-basin. As long as enough well-distributed and connected cold water is present, these larger geographic units could be in compliance in spite of naturally warm water at some sites.

Number of measurements. Compliance can be determined based on different measurement conventions: individual samples, multiple samples, or a census of stream temperatures. Each of these conventions is applicable over both space and time. For instance, a temperature census over time is accomplished using a continuous recording data logger. A census over space might be accomplished using a remote sensing technique to map the distribution of water temperatures along the entire river.

Each of the approaches will have a unique set of opportunities and challenges. The flexibility associated with these different approaches may result in criteria that protect the thermal requirements of salmonids while accommodating naturally warm waters. Yet this flexibility could incrementally weaken protections and increase extinction risks. Thus, these alternatives must be considered with caution. The task before the Technical Workgroup is to identify criteria with characteristics that will best ensure the thermal conditions necessary to support viable salmonid population while reducing the instances where naturally warm water is deemed out of compliance.

References

Dunham, J.B., B.E. Rieman, and J.T. Peterson. In Press (2001). Patch-based models to predict species occurrence: lessons from salmonid fishes in streams. In Scott, J.M., Heglund, P. J., Morrison, M., Raphael, M., Haufler, J. and Wall B. (editors). Predicting species occurrences: issues of scale and accuracy. Island Press. Covelo, CA.

EPA. 1976. Quality criteria for water. U.S. Environmental Protection Agency, Washington, DC. 256 pp.

EPA. 1999. National recommended water quality criteria, correction. EPA 822-Z-99-001. U.S. Environmental Protection Agency, Washington, DC.

Federal Caucus (Army Corps of Engineers, Bonneville Power Administration, Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, Environmental Protection Agency, Fish and Wildlife Service, Forest Service, and National Marine Fisheries Service). 2000. Conservation of Columbia Basin fish. Final basinwide salmon recovery strategy. Volume 1. 86 pp. Available Bonneville Power Administration, Portland, OR.

FEMAT. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team (a federal agency consortium), Portland, OR

Henjum, M.G., J.R. Karr, D.L. Bottom, D.A. Perry, J.C. Bednarz, S.G. Wright, S.A. Beckwitt, and E. Beckwitt. Interim protection for late-successional forests, fisheries, and watersheds, national forests east of the Cascade Crest, Oregon and Washington. Eastside Forests Scientific Society Panel, The Wildlife Society Technical Review 94-2, Bethesda, MD.

Holtby, L.B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon *(Oncorhynchus kisutch)*. Canadian Journal of Fisheries and Aquatic Sciences 45: 502-515.

Lichatowich, J. 1997. Evaluating salmon management institutions: the importance of performance measures, temporal scales, and production cycles. Pages 69-87 *in* D.J. Stouder, P.A. Bisson, and R.J. Naiman, (eds.) Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

Ludwig, D., R. Hitborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. Science 260:17-36.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable Salmon Populations and the Recovery of Evolutionarily Significant Units. NOAA Technical Memorandum NMFS-NWFSC-42. U.S. Department of Commerce. Seattle, WA. 156 pp.

McIntosh, B.A., J.R. Sedell, R.F. Thurow, S.E. Clarke, and G.L. Chandler. 2000. Historical changes in pool habitats in the Columbia River basin. Ecological Applications 10(5):1478-1496.

National Academies of Sciences and Engineering). 1972. Water quality criteria 1972: report to the U.S. Environmental Protection Agency. 594 pp.

National Research Council. 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, DC. 452 pp.

Oregon Coastal Salmon Restoration Initiative. 1997. State of Oregon, Salem.

Poole, G. C., and C. H. Berman. In press. An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management.

Quigley, T.M. and S.J. Abbelide. Tech. Eds. 1997. An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: volume 3. Gen. Tech. Rep. PNW-GTR-405. U.S. Forest Service, Portland, OR.

Reeves, G.H., L.E. Benda, K.M. Burnett, P.A. Bisson, and J.R. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. Pages 334-349 *in* J.L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17, Bethesda, MD.

Rieman, B. E. and J.B. Dunham. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9:51-64.

Rhodes, J.J., D.A. McCullough, and F.A. Espinosa, Jr., 1994. A coarse screening process for evaluation of the effects of land management activities on salmon spawning and rearing habitat in ESA consultations. Columbia River Inter-Tribal Fish Commission Technical Report 94-4, Portland, OR.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. An Ecosystem Approach to Salmonid Conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, OR. (Available from the National Marine Fisheries Service, Portland, Oregon.)

Tickner, J., C. Raffensperger, and N. Myers. 2000. The precautionary principle in action, a handbook: first edition. Science and Environmental Health Network, Windsor, North Dakota. 23 pp.

Wissmar, R.C., J.E. Smith, B.A. McIntosh, H.W. Li, G.H. Reeves, and J.R. Sedell. 1994. A history of resource use and disturbance and disturbance in riverine basins of eastern Oregon and Washington (early 1800s-1900s). Northwest Science 68:1-35.

Appendix A: Technical Interpretation of the Project Goals

The following project goals were identified by the Policy Workgroup to guide the Technical Workgroup in development of temperature criteria.

Project Goal Statements (from the Policy Workgroup)

To Develop EPA Regional Temperature Criteria Guidance that:

- Meets the biological requirements of native salmonid species for survival and recovery pursuant to ESA, provides for the restoration and maintenance of surface water temperature to support and protect native salmonids pursuant to the CWA, and meets the salmon rebuilding needs of federal trust responsibilities with treaty tribes
- Recognizes the natural temperature potential and limitations of water bodies
- Can be effectively incorporated by states and tribes in water quality standards programs

The new criteria guidance will be jointly developed by EPA, USFWS, NMFS, States, and Tribes in the Pacific Northwest:

- States and tribes will use the new criteria guidance to revise their temperature standards, if necessary
- EPA and the Services will use the new criteria guidance to evaluate state and tribal standard revisions

Recovery Target (from the Policy Workgroup)

The temperature criteria guidance that would support "sustainable and harvestable levels of salmonids."

To facilitate communication and understanding between the Policy and Technical Workgroup, the Technical Workgroup developed the following interpretation of the project goals based on the literature reviewed in the five technical summaries described in the Preface to this document.

To meet the project goal, the Technical Workgroup believes it is necessary to develop EPA regional temperature criteria guidance that:

- if attained, would provide thermal habitat capable of supporting viable populations[1] (including a surplus for human harvest) of all native salmonids
- protects high quality thermal habitat while minimizing circumstances where compliance would require remediation beyond a system's thermal potential can be implemented and enforced

Thus, temperature criteria should describe thermal regimes that promote the following characteristics of salmonid populations:

Population size is large enough to:

- Maintain genetic and phenotypic diversity[2] over the long term
- Survive environmental variation[3] and catastrophic disturbance
- Provide ecological functions;[4]
- Allow a population surplus that can be harvested by humans

Population growth rate is positive.[5]

Population distributions:

- Are extensive within and across sub-basins;[6]
- Allow full utilization of habitat potential[7] (temporally and spatially) of sub-basins, which allows natural expression of multiple life history strategies[8].
- Are comprised of well-connected[9] sub-populations.

Additionally Temperature criteria should describe thermal regimes that promote the following features of salmonid habitats

- Natural thermal regimes are established across the maximum extent of the landscape.
- Habitats are well-connected.
- Habitat supports all life history stages and strategies.

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[1] The Technical Workgroup defines "viable populations" as those that have characteristics described later in this appendix. See also McElhany et al. (2000) for a more comprehensive discussion of viable salmon populations.

[2] Small population sizes can result in loss of genetic information from the population gene pool such as run timing, age structure, size, fecundity, morphology behavior, and molecular genetic characteristics.

[3] "Environmental variation" includes the natural annual variations that can be summarized statistically. This also includes foreseeable cyclic patterns of climatic change.

[4] Salmon are a keystone species in ecosystems of the PNW. For example, nutrients from carcasses are vital in providing nutrients to riparian vegetation and for the feeding and growth of freshwater biological communities including juvenile salmonids.

[5] Most salmon populations that are currently listed under the ESA have population growth rates (e.g., spawner-spawner ratios) that are extremely depressed and static or are low and declining. Populations can recover only if these population growth rates have ratios of >1.0. A population is only fishable and sustainable if there are more adults returning to the spawning grounds to spawn than are needed to replace the numbers of the parent generation. Also, an excess is needed to compensate for natural fluctuations in environmental conditions throughout the geographic range of the salmon life cycle (including ocean conditions) that lead to periodic fluctuations in survival.

[6] This allows source sub-populations to be maintained so that they contribute to the stability of the overall population by providing centers of high productivity and contributing a source of strays to colonize other habitats within the sub-basin.

[7] Habitat potential is an inherent characteristic of a watershed that has a high level of ecosystem integrity. Elements of the watershed that define its potential include its potential natural vegetation, climate, lithology, geomorphology, biota, hydrology, and soils. These elements interactively set up instream habitat conditions (channel geomorphology, hydrologic regime, water temperature regime, riparian vegetation community types and dynamics, channel substrate characteristics). Given various levels of anthropogenic disturbance to the watershed, alterations to the watershed and/or stream channels and riparian areas can shift the processes that produce in-stream habitats so that they disfavor salmonids. This can come about through alterations in the regimes for large wood input, water temperature, water routing, nutrient input, and sediment. Water temperature regime can be altered by the combined effects of shifts in the woody debris

input, riparian vegetation condition (current state of the vegetation, given all possible states that are defined by its potential), sediment delivery to the channel (affecting intergravel flow, channel morphology, and pool depth and frequency).

[8] A life history strategy is one of the means by which a life cycle can be structured so that life functions are realized. Functions include growth, survival, development, mating, reproduction, incubation, emergence, rearing. When a watershed exhibits a state of high integrity, the ability of the watershed to develop high quality aquatic habitats is great and multiple life history strategies become available for salmonids to complete these functions. Watershed and habitat degradation tend to eliminate many life history strategies (e.g., those strategies that depend upon mainstem rivers, low elevation habitats, floodplain or off-channel habitats).

[9] When sub-populations are well connected, they are capable of interbreeding. This allows better maintenance of genetic integrity in the gene pool because the genes are maintained by a larger, more integrated population. Small, isolated populations with few or poorly connected sub-populations tend to be unstable over time and gradually disappear. They are not resistant to extreme environmental conditions because the entire population can be affected by a single event or disturbance. Populations comprised of well-distributed and connected sub-populations have greater resistance to perturbation because there is lesser likelihood that major portions of the population will be affected by a single event. Likewise, if some life history strategies involve spawning at a different time or in a different location, greater population stability results from this "hedging" against extinction.