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Issue Paper 2

Salmonid Distributions and Temperature

Prepared as Part of Region 10 Temperature Water Quality Criteria Guidance Development Project

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Abstract

Distributions of native salmonid fish in the Pacific Northwest are strongly tied to temperature conditions in their habitat. Salmonid populations have declined in conjunction with thermal changes and the loss and fragmentation of large and interconnected cold-water habitats. Temperature affects the health of not only individual fish but also entire populations and groups of species. Temperature changes have obvious direct effects, and also interact with other factors to indirectly affect salmonids.

The best way to protect existing populations and restore depleted populations is to create temperature criteria that explicitly consider salmonids' temperature requirements at different times and places. Natural temperature conditions must be preserved whenever possible. Because current fish distributions and populations are significantly reduced from their historical numbers, protection and restoration of their thermal environment must often extend beyond the boundaries of their existing or suitable habitat.

Attempts to set temperature criteria must balance what is known and *not* known about the habitat and biological requirements of salmonids. Full consideration of current and potential fish distribution and habitat, including thorough documentation of assumptions and knowledge gaps, is needed in establishing and implementing temperature criteria to support healthy (viable, productive, and fishable) salmonid populations.

Introduction

Under natural conditions, freshwater salmonid habitat is defined by physical and chemical characteristics of the environment, including water quality, flow, geological and topographic features of the stream and its valley, and cover (National Research Council 1996). Common factors influencing fish distribution include size and accessibility of suitable habitat, connectivity between areas of suitable habitat, biological interactions, and "historical" factors (e.g., postglacial dispersal and geographic barriers) (Matthews 1998). Many of these factors act directly or indirectly with temperature to determine the distribution of a species. This is especially true for cold-water fishes such as salmonids.

This paper is not intended to be an exhaustive review of the status or declines in salmonid populations or distributions. These are widely documented elsewhere. We briefly review some examples of declines in salmonid populations and habitats to provide some context for these issues, but our focus is not on declines per se. Furthermore, this issue paper is not intended to be an exhaustive review of the effects of temperature on salmonid distributions in the Pacific Northwest (see McCullough 1999). Rather, it is intended to describe a basic framework for thinking about salmonid distributions and appropriate biological criteria to protect salmonid populations from adverse effects of altered factors affecting thermal regimes.

This paper describes in a question-and-answer format five main issues related to salmonid distributions and temperature criteria:

1. Definition of a "distribution"
2. Direct effects of temperature
3. Indirect effects of temperature
4. Relevance of scale
5. Importance of unoccupied habitat

What is a "distribution"?

Often, the word "distribution" is used without reference to what is specifically meant. Like any other organism, salmonid fishes (and temperatures) are not distributed equally across landscapes. Within stream basins, limits to fish distributions may be obvious, but even within continuous areas of suitable habitat, discontinuities in distributions may arise (Angermeier et al. in press, Dunham et al. in press).

A common example of "distribution" for animals can be found in popular bird identification and field guides. Distribution maps for birds often cover broad areas. In some cases, ranges of different "races" or recognized subspecies are distinguished. Within these areas, it is obvious that birds do not occur everywhere. For example, a wading bird may only be found in wetland areas, though it is broadly distributed across the continent (because wetlands are broadly distributed). Furthermore, this bird may only be found in particular kinds of wetlands (those with sufficient cover and food to support reproduction). This bird may be found in different areas, depending on the season. Birds may appear in "unusual" habitats while migrating, or may shift habitat use from year to year, depending on climate (wet vs. dry years). Similar analogies apply to salmonid fishes. There are several things to consider when using the term "distribution" for salmonids: ontogenetic variation; life history variation; and historical, contemporary, and potential distribution.

Ontogenetic variation. "Ontogenetic variation" refers to changes in habitat use during the life cycle of an individual. Here, the term "life cycle" refers to the sequence of events (egg → alevin → parr → smolt → juvenile → adult) that must occur within an individual's life for successful reproduction. Ideally, temperature criteria established for salmonids should address spatial and temporal distribution of thermal habitats that protect all life stages.

Habitat requirements vary considerably as salmonids begin their lives as eggs in (or on) the substrate and progress through developmental stages to reproduction as an adult. Different life stages may have different thermal requirements (Magnuson et al. 1979; Physiology issue paper). However, thermal requirements may also overlap considerably among life stages. Furthermore, some life stages are relatively insensitive to temperature whereas others (such as egg incubation) are extremely sensitive (see Physiology issue paper).

Life stage requirements may be tied to specific spatial or temporal frames. Many salmonids' life stages may use certain habitats only on a seasonal or intermittent basis. For example, the timing of migration and spawning for most species is strongly tied to temperature (Bjornn and Reiser 1991).

Often, assessments for salmonids focus on the distribution of areas used for spawning and early rearing (Dunham et al. 2001). Even though the importance of spawning and rearing habitat is obvious, other components of the life cycle may be key to viability or productivity, particularly for species with obligate life histories. Such habitats can include migratory corridors, feeding areas, and seasonal refuges (Northcote 1997). In many species, loss or severe degradation of these habitats can cause extinction even if spawning and rearing habitats are in good condition. An obvious example is extinction of migratory salmonid populations that used spawning habitats now blocked by dams. As of 1991, at least 106 major populations of salmon and steelhead on the West Coast of the United States had become extinct, with inadequate fish passage at dams a primary cause (Nehlsen et al. 1991).

Life history variation. Life history refers to how an individual completes the life cycle. Salmonids may adopt a "resident" or "migratory" life history. Resident fish remain very close to their natal habitats throughout their life cycle, whereas migratory fish use a much broader range of habitat. Each of these broad categories has its own variations. For example, spawning migrations vary by time and location (e.g., summer vs. winter steelhead; fall vs. winter chinook). The length of juvenile residence in natal areas may also be important (e.g., "stream" vs. "ocean" type chinook).

Some species have relatively fixed life cycles and life history patterns (e.g., pink salmon, Groot and Margolis 1991); others exhibit considerable variation or polymorphism (e.g., cutthroat trout). Most Pacific salmon die after spawning, whereas most species of trout and char do not (iteroparous). Some species, subspecies, races, or populations have flexible life histories (referred to as "facultative"); others have fixed life history patterns (referred to as "obligatory") (Rieman and Dunham 1999). Species in the latter category may be less resistant to environmental change.

Historical vs. contemporary vs. potential distribution. Both fish distributions and stream temperatures can be considered in terms of "historical," "contemporary," or "potential" distribution. Historical refers to the distribution of native salmonids before European settlement. Contemporary refers to the present distribution of native salmonids. Potential refers to the distribution of native salmonids we would expect if natural habitat conditions were restored to the fullest extent possible, given the current natural capacity (Ebersole et al. 1997) of the system. In other words, potential distribution allows for the possibility that physical systems have been altered such that historical distributions are no longer attainable. Widespread declines of salmonids observed in most areas

(Nehlsen et al. 1991, Lee et al. 1997, Thurow et al. 1997) suggest that many streams are not currently at their full natural potential or capacity.

A primary concern of managers is protecting or restoring fish distributions that maximize population viability (most recently reviewed by McElhany et al. 2000). Many efforts are under way to define thermal habitat potential using predictive physical models (reviewed by Bartholow 2000). Prediction of physical responses is complex, but is much simpler than predicting biological responses.

Restoration of the physical system (temperature, thermal regime) should be considered together with biological requirements (viability, productivity) of a species. The physical potential of a system constrains what can be achieved biologically. There are four possible scenarios in which physical system potential and biological requirements or potential are considered:

1. System potential attained, biological goal attained. This is the best of all worlds, where protection to maintain existing conditions would be a prudent management option.

2. System potential attained, biological goal **not** attained. This is a situation where nothing can be done to enhance the potential of the natural system to attain a biological goal.

3. System potential **not** attained, biological goal **not** attained. This is a situation where enhancement of system potential could result in a biological benefit.

4. System potential **not** attained, biological goal attained. This is a situation where enhancement of system potential could result in a biological benefit, but the current state of the biological system is satisfactory from a regulatory viewpoint.

It may be difficult to balance the attainment of biological goals versus physical system potential, but the answer is essential to long-term viability and productivity of salmonid populations. In reality, these four scenarios represent extremes along a continuum of biological requirements and physical system potential. In practice, it is much easier to define physical system potential than to define "how much is enough?" from a biological perspective. Thus, it may be difficult to discern different scenarios based on biological requirements. In practice, most management to date has focused on system potential.

Defining of system potential can be challenging. First, it is critical to realize that perspectives on attainment of system potential may depend on scale. For example, a local reach of stream may be at system potential, but part of a larger degraded system in need of restoration. Second, it is difficult, if not impossible, to restore all aquatic habitats to their historic condition. There usually are insufficient data to definitively document "historic" conditions, but even limited information on historic habitat conditions and fish populations can provide a useful perspective. Such determination involves finding what is "irreversible" (e.g., removal of major dams and urban centers) and what can likely be accomplished through basin management.

Examples. The historical and contemporary distributions of resident and anadromous fish have been documented in the Columbia River Basin (CRB) by the Interior Columbia Basin Ecosystem

Management Project (Figures 1 to 7). About 12,452 km of the 16,935 km of streams that originally were accessible are now blocked (Quigley and Arbelbide 1997), including some large subbasins and many smaller watersheds. Other factors contributing to the decline of

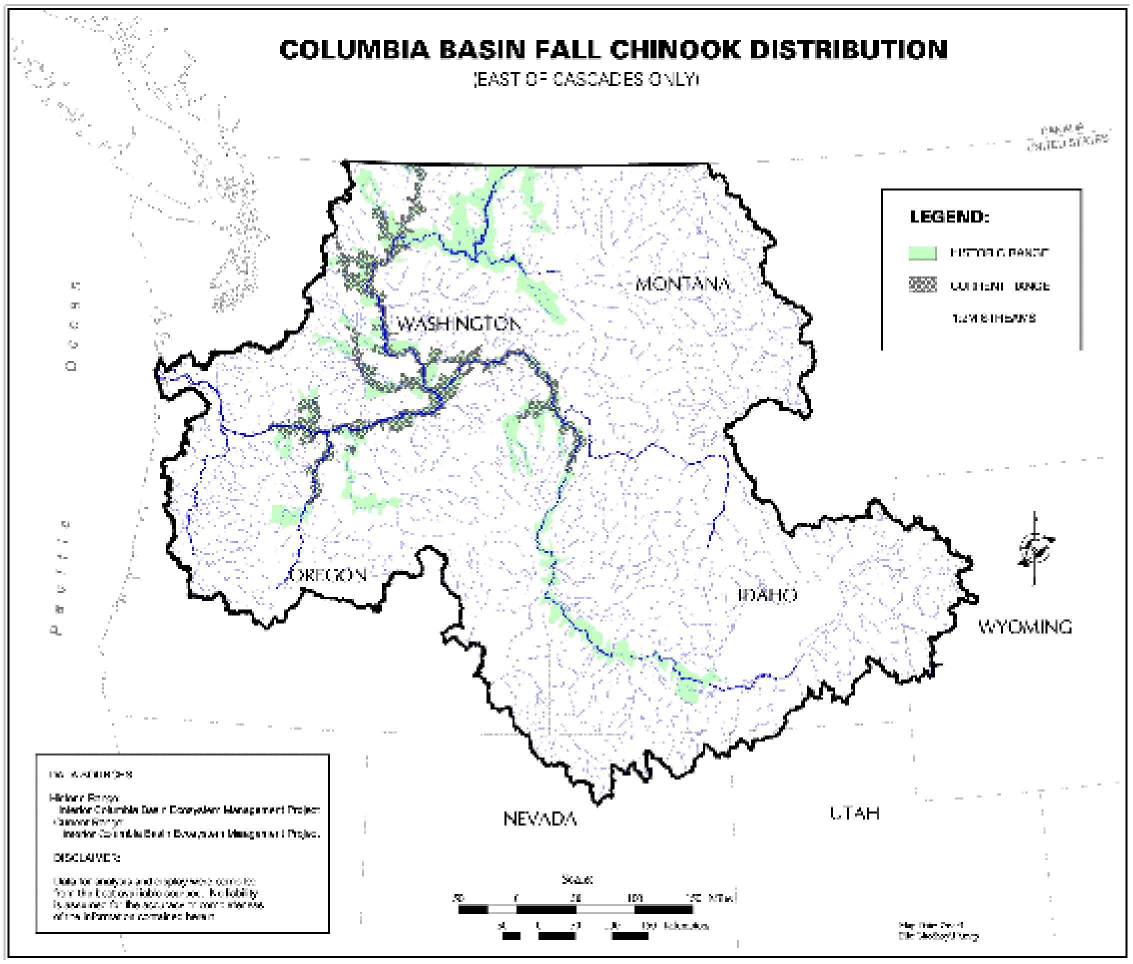

Figure 1. Columbia Basin fall chinook distribution.

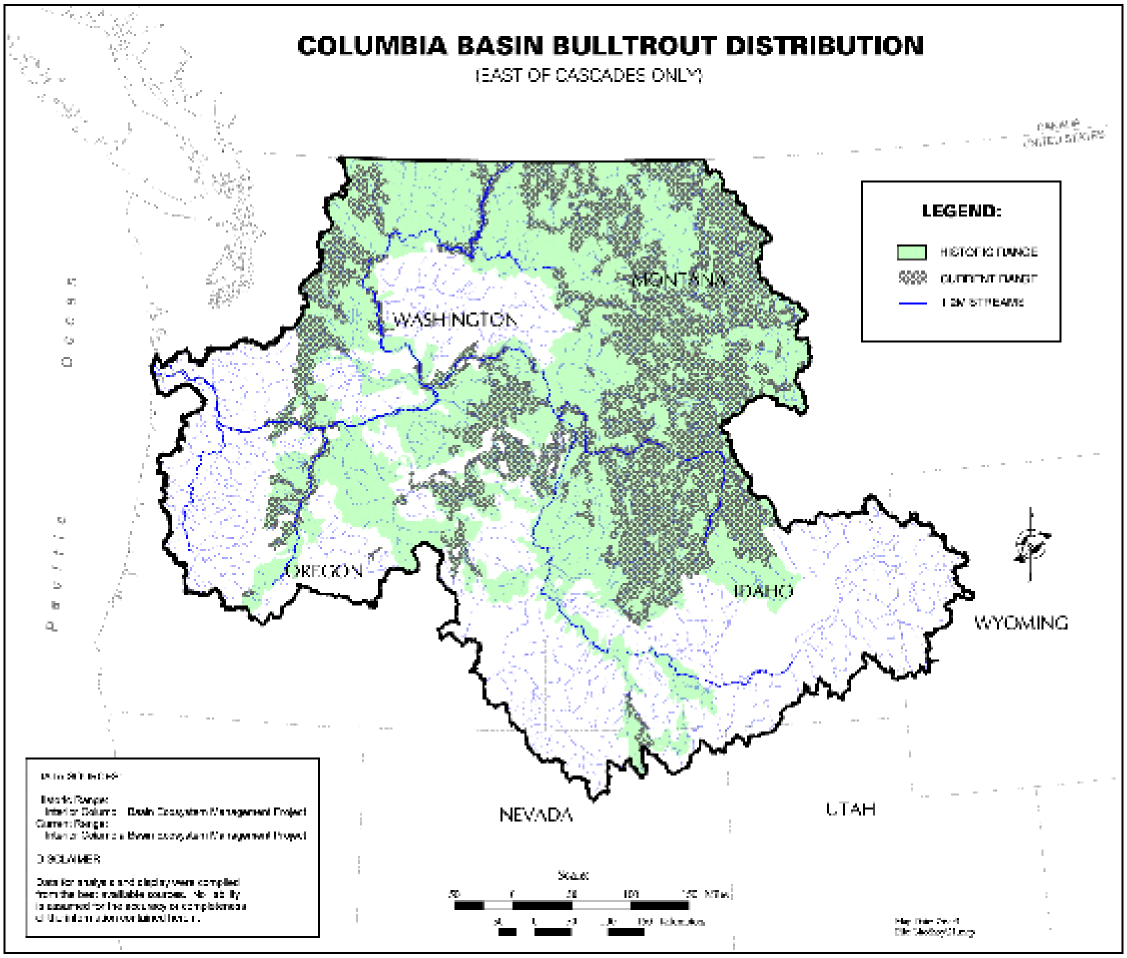

Figure 2. Columbia Basin bulltrout distribution.

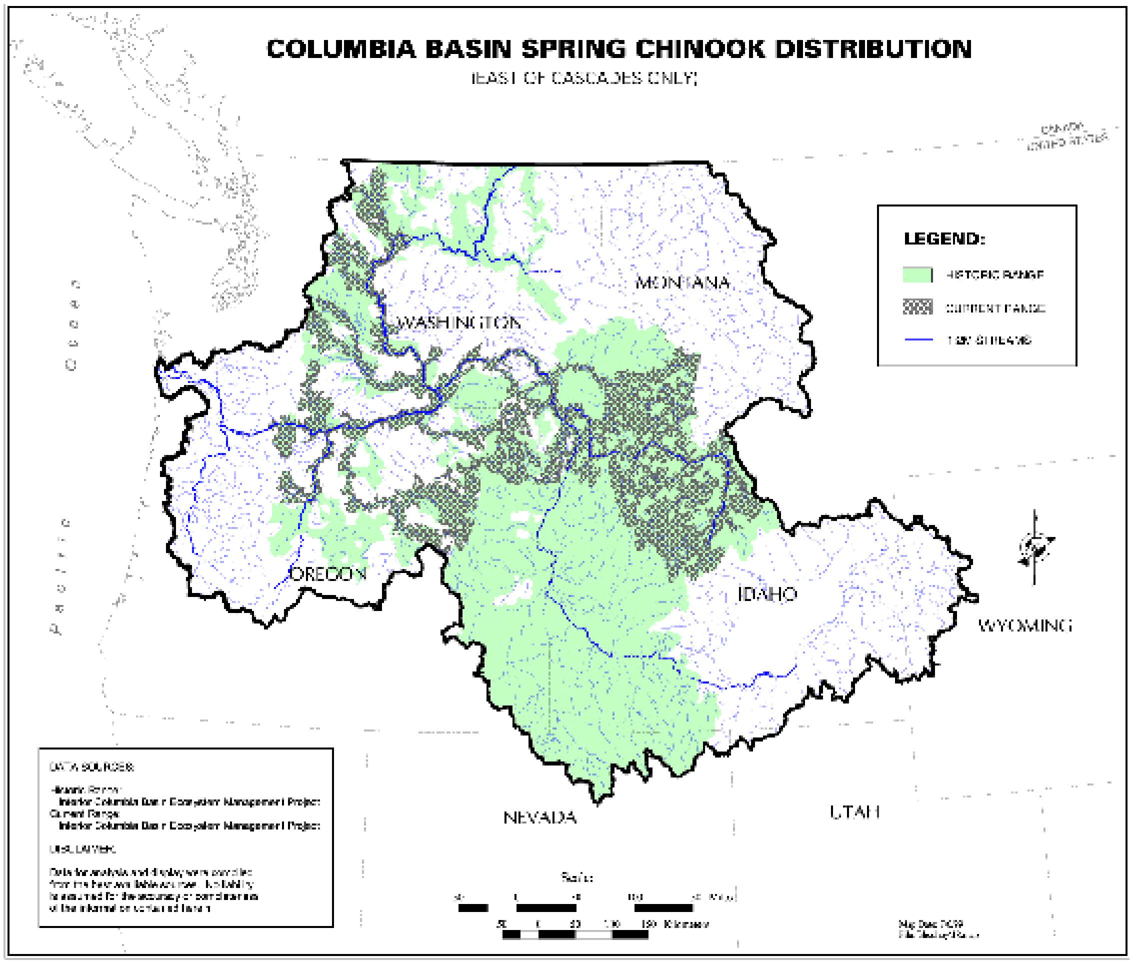

Figure 3. Columbia Basin spring chinook distribution.

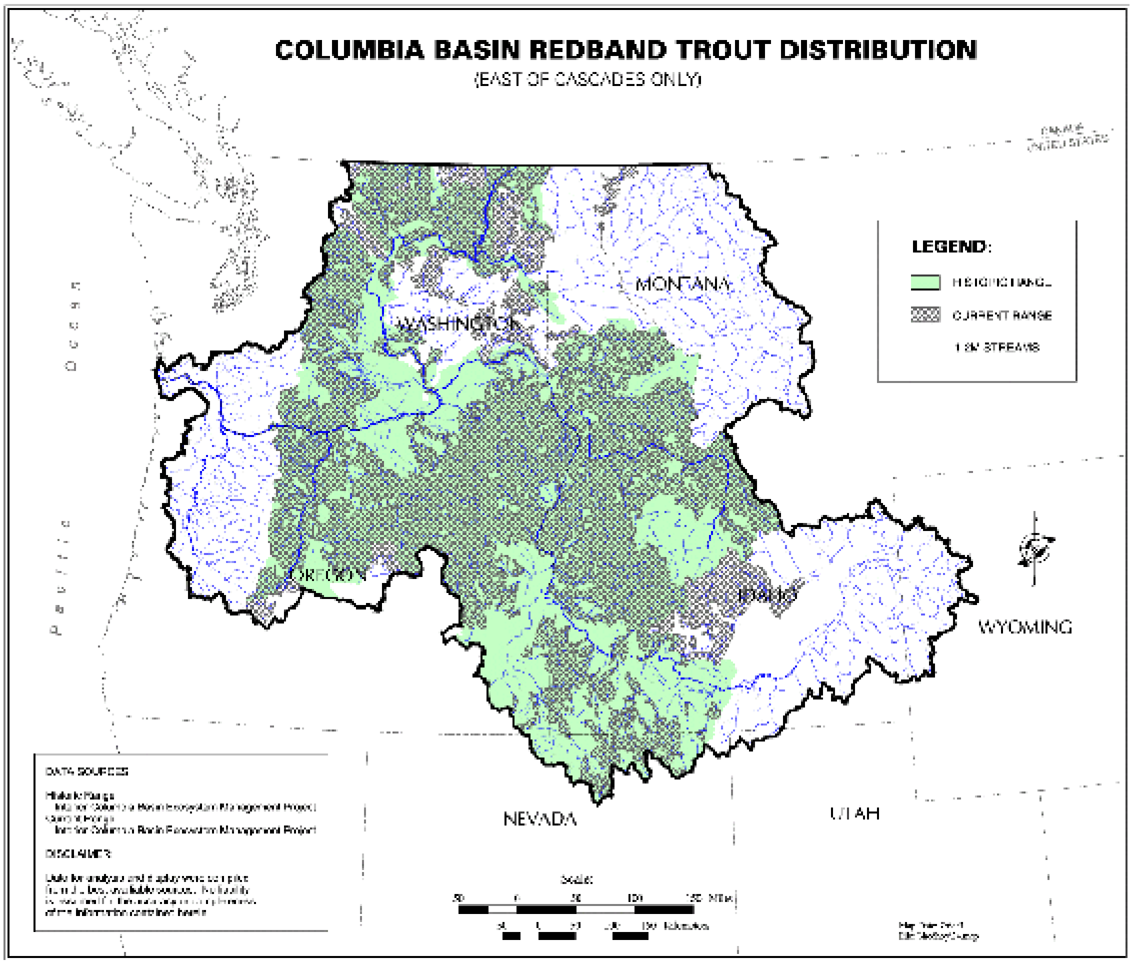

Figure 4. Columbia Basin redband trout distribution.