

Rec'd 9/14/07



**Brian J. Johnson**  
*Director, California Water Project*  
*Trout Unlimited Staff Attorney*

September 14, 2007

Ms. Tam Doduc, Chair  
and Members of the Board  
State Water Resources Control Board  
1001 I Street  
Sacramento, CA 95814

**Re: Comments for SWRCB Workshop: Water Policy Through A Carbon Lens**

Dear Ms. Doduc and Members of the Board:

On behalf of Trout Unlimited (TU), I submit the following comments on water policy through a carbon lens. Thank you for the chance to contribute to this important subject.

We appreciate your leadership in bringing forward a discussion on the relationship between water management decisions, energy, and climate. As many of your panelists noted, water policy decisions have profound implications for climate change, for at least two reasons: because water use decisions influence the amount of energy consumed in the state; and because water use decisions influence the ability of natural systems to respond to global warming.

With respect to the first, I won't restate the information presented by the Pacific Institute, NRDC, Bob Wilkinson and many others, except to say that we strongly agree with the conclusion that it is past time for California to factor energy and climate consequences into its decisions on water use, and past time to factor impacts on water supplies and aquatic resources into its decisions on energy production and consumption.

I write today to suggest a few ways that the SWRCB's water policy decisions can begin to provide a better response to climate change. I am also attaching two documents that develop our recommendations in more detail. First, I am attaching testimony by Dr. Jack Williams, Senior Scientist, Trout Unlimited, before the Subcommittee of Water and Power, Energy and Natural Resources Committee of the United States Senate, on June 6, 2007.<sup>1</sup> Second, I am attaching a manuscript prepared by Dr. Williams and others at TU entitled "Climate Change and Western Trout: Strategies for Restoring Resistance and Resilience in Native Populations." A summary of our recommendations follows.

<sup>1</sup> Prior to working for TU, Mr. Williams served in a number of research and management positions in the federal government, including Science Advisor to the Director of the BLM, Endangered Species Specialist for the U.S. Fish and Wildlife Service, National Fisheries Program Manager for the Bureau of Land Management (BLM), Deputy Forest Supervisor on the Boise National Forest, and Forest Supervisor on the Rogue River and Siskiyou national forests. He is also an Adjunct Professor at Southern Oregon University.

TU has developed six strategies to strengthen the *resistance* (ability to withstand environmental change) and *resilience* (ability to rebound after environmental disturbance) of trout and salmon populations. These strategies are part of the *Protect-Reconnect-Restore-Sustain* model of fisheries conservation. That model focuses on protection of our best remaining habitats and populations, reconnection of stream systems by removing instream barriers and reestablishing instream flows, the restoration of vital main-stem river and riparian habitats, and the ability to sustain those efforts for future generations.

- Strategy 1: Protect remaining core habitat areas. It is vital that remaining salmon and trout strongholds as well as watersheds that produce reliable supplies of cold water are protected.
- Strategy 2: Maintain genetic and life history diversity. Higher levels of genetic and life history diversity enable populations to better adapt to future environmental change.
- Strategy 3: Increase size and extent of existing populations. Many populations of native trout have been pushed into upper elevation streams by non-native species. Climate change will diminish these upstream habitats as snowpacks decrease and droughts become more frequent and severe. The only options for these fish are to expand into remaining downstream habitat or perish.
- Strategy 4: Minimize outside stressors. Climate change will further stress stream systems and watersheds that have already been pushed to their limits. Reducing existing sources of stress, such as competition with non-native or hatchery fish, disease, increased water extraction, or impacts from mining, grazing and unsustainable timber harvests will help keep these systems from ecological collapse.
- Strategy 5: Manage at watershed scales to reconnect stream systems. We should identify and reconnect important stream systems that have been disconnected by construction of dams, water diversions, and other dewatering processes.
- Strategy 6: Monitor, evaluate and employ adaptive management. It is important to adequately fund monitoring programs and maintain the ability to modify management strategies in the face of changing conditions and new information.

It is worth emphasizing that Strategy 5, in particular, guides much of TU's work on water law reform for the purpose of protecting stream flows. It is especially compatible with the proposal for a "watershed approach" (also known as "Streamflow Stewardship") that emerged from our North Coast Water Rights working group, and with our recommendations for the upcoming AB 2121 Instream Flow Policy.

We look forward to continued collaboration with your agency and the NCWR working group on those matters. In the meantime, if you or your staff have any questions or would like to discuss this question, please give me a call.

Ms. Tam Doduc, Chair  
Members of the Board  
September 14, 2007

Page 3 of 3

Sincerely,

A handwritten signature in black ink, appearing to read "BJ Johnson", written over a horizontal line.

Brian J. Johnson  
Director, California Water Project  
Trout Unlimited



---

**Statement of Dr. Jack Williams  
Senior Scientist, Trout Unlimited**

**Before the**

**Subcommittee of Water and Power  
Energy and Natural Resources Committee  
United States Senate**

**June 6, 2007**

Mr. Chairman, Members of the Committee, I appreciate the opportunity to appear before you today to provide Trout Unlimited's perspective on the impacts of climate change on our nation's water supply, related impacts to trout and salmon populations, as well as strategies that we believe can be important in responding to the very serious threat that climate change poses to these valuable resources.

Trout Unlimited (TU) is the nation's largest coldwater fisheries conservation organization dedicated to the protection and restoration of our nation's trout and salmon, and the watersheds that sustain them. Our goal is to restore robust populations of native and wild coldwater fishes so that future generations can enjoy these resources. TU has more than 160,000 members organized into 450 chapters across the country. Our members generally are trout and salmon anglers who give back to the resources they love by voluntarily contributing substantial amounts of their personal time and energy to fisheries habitat protection and restoration on public and private lands. The average TU chapter donates 1,000 hours of volunteer time on an annual basis.

My name is Jack Williams and I serve as Senior Scientist for Trout Unlimited. Prior to working for TU, I was privileged to serve in a number of research and management positions in the federal government, including Endangered Species Specialist for the U.S. Fish and Wildlife Service, National Fisheries Program Manager for the Bureau of Land Management (BLM), Science Advisor to the Director of the BLM, Deputy Forest Supervisor on the Boise National Forest, and Forest Supervisor on the Rogue River and Siskiyou national forests. I have also served as a Professor at Southern Oregon University and retain the title of Adjunct Professor at that institution.

Trout Unlimited is very concerned about the impacts of climate change on our water and fisheries resources. During the past year, a team of TU scientists and geographic information specialists have modeled the impacts of climate change on coldwater fishes, reviewed available scientific literature, and prepared articles on the impacts of climate change for our members. In addition, TU has polled hunters and

anglers across the country to determine their level of interest and concerns about how climate change is likely to impact their recreational pursuits. Furthermore, we have developed a series of strategies, that if implemented, we believe will substantially increase the resistance and resilience to climate change impacts in our nation's salmon and trout streams.

I would like to briefly describe the impacts from climate change on our trout and salmon resources and their habitats and then proceed to describe our strategies to increase resistance and resilience to these impacts.

### *Impacts to Trout and Salmon Resources*

There is a clear scientific consensus that climate change will have major and negative implications to our nation's hydrology and river systems. Numerous peer-reviewed studies have predicted broad declines in trout and salmon populations as well. U.S. Forest Service scientists have predicted that between 53 and 97% of wild trout populations are likely to be eliminated from the Appalachian Mountains because of warming climate. Losses of western trout populations may be as high as 64%. Most studies of Pacific Coast salmon predict losses of 20-40% by the year 2050. The bad news about the salmon models is that they may actually be optimistic predictions because they focus on freshwater conditions and do not consider the complexity and uncertainty of changing ocean environments.

Although some regions will fare better than others and the timing and severity of impacts is somewhat uncertain, the overall need for concern should be clear. Based on review of the relevant literature and research, the following impacts from climate change are likely to occur: increased stream temperatures, increased evaporation rates, earlier spring runoff, reduced snowpack, higher winter flows and lower summer flows in most streams, greater storm intensity and increased frequency of floods, drought and wildfires, and rising sea levels. Erosion rates will increase as will polluted runoff from our cities and agricultural areas. One of the most significant bottom lines for fisheries and other water users is that stream flows are likely to be even lower during future summers than they have been in the past.

While some consequences of climate change are highly predictable others are not. Beginning in 2002, a "dead zone" of very low dissolved oxygen has appeared each year off the Oregon coast. Unlike other oceanic dead zones, this one is not attributable to pollution or other human impact that has been identified. Rather, it is caused by changes in ocean currents and upwelling that is in turn, controlled by weather patterns. In 2006, the dead zone covered 1,235 square miles, an area the size of Rhode Island. According to Oregon State University Professor Jane Lubchenco, "we are beginning to think there has been some sort of fundamental change in ocean

conditions off the West Coast.” The changes appear consistent with wind patterns modified by climate change.

The Oregon coast changes bring up another important concern: climate change is not just a problem of the future, but is a growing concern of the present. Our climate already is rapidly changing and we currently are seeing impacts to our stream systems and aquatic communities. For instance, because of warmer stream flows and earlier peak runoff, mayflies and other aquatic insects are emerging earlier in Rocky Mountain streams. Earlier emergence of aquatic insects means that females are smaller in body size and produce fewer eggs than would insects that emerge later. Such changes may seem minor but could have cascading implications to fish populations that depend on mayflies, caddisflies, stoneflies and other aquatic insects as their primary food supplies.

At TU we have modeled impacts of climate change on Colorado River cutthroat trout in Utah, Wyoming and Colorado; Bonneville cutthroat trout in Idaho, Utah, Wyoming and Nevada; and westslope cutthroat trout in Idaho, Montana, Oregon and Washington. In 5 of the 8 major river drainages where Colorado River cutthroat trout occur, most populations already are below adequate habitat thresholds and will be further stressed by climate change impacts. The same situation is true for 2 of 4 geographic management areas of Bonneville cutthroat trout. Most remaining populations of both subspecies are restricted to small, headwater streams, which will feel the brunt of climate change impacts due to declining snowpacks, drought and wildfire. Westslope cutthroat trout fare somewhat better because of existing strongholds in National Forest wilderness areas. Nonetheless, populations of westslope cutthroat continue to be invaded by non-native rainbow trout that hybridize with the cutthroat and eliminate the native gene pool.

Depending on the climate model used, most salmon populations in the Pacific Northwest are expected to decline by 20 to 40% by the year 2050. In California, where temperatures already pose a significant source of stress for fisheries, greater declines are likely.

Unless immediate action is taken to restore resistance and resiliency to climate change impacts, stream conditions will degrade and many more of our native trout and salmon may soon warrant the protection of the Endangered Species Act. Let me outline what can be done to alleviate at least some of the adverse impacts of climate change on the nation's trout and salmon populations.

#### *Strategies to Increase the Resistance and Resilience to Climate Change Impacts*

Trout Unlimited works primarily to implement what we refer to as the Protect-Reconnect-Restore model of fishery sustainability. This process emphasizes

protection of our best remaining habitats and populations, reconnecting stream systems by removing instream barriers and reestablishing flows, and restoring vital lower-elevation rivers. I will describe six strategies for dealing with a rapidly changing climate that fit this model. These strategies are consistent with the best available science and have been proven to be effective in on-the-ground application. Our primary goal in suggesting these strategies is to increase the resistance to climate change impacts in our natural systems and to enable fish populations and their habitats to rebound more completely once they are disturbed by flood, drought and wildfire that will accompany a warming environment.

Furthermore, it is important to realize that these actions must be implemented strategically to achieve success. That is, for each evolutionarily significant unit of salmon, or each large river basin with trout, we need to identify the best subset of opportunities for protection, reconnection, and restoration. We must carefully choose those areas for restoration where we can make the most immediate and lasting impact.

**Strategy 1: Protect remaining core habitat areas.** It is vital that remaining salmon and trout strongholds as well as watersheds that produce reliable supplies of cold water be protected from additional disturbance. Watersheds that currently support large and robust populations of native fisheries should be protected from new dam and road development. Simply stated, it is more biologically sound and cost effective to protect existing population strongholds than attempt to restore them once they have been disturbed.

**Strategy 2: Maintain genetic and life history diversity.** Higher levels of genetic diversity enable populations to better adapt to future environmental change. For example, scientists at the University of Washington have demonstrated that large numbers of separate spawning populations of sockeye salmon in Alaska's Bristol Bay have been the key to maintaining that robust fishery in the face of changing freshwater and marine conditions. Under certain conditions, one set of stocks will be favored and produce abundant offspring; when conditions shift, a different group of populations will be favored. It is simply a matter of maintaining all the genetic pieces to maximize adaptability.

Life history diversity also is critical. In western cutthroat trout, for example, most populations are resident stream forms that are restricted to single tributaries. But, restoring migratory populations expands habitat options, produces bigger fish, and allows remaining individuals more opportunities to find suitable habitats as stream conditions and flows change.

**Strategy 3: Increase size and extent of existing populations.** Currently, many populations of native trout in the West have been pushed into upper elevation streams as non-native species have been introduced downstream. We know that at least 5 miles of continuous high quality habitat are necessary to ensure the likelihood

that each trout population will persist for many generations. The populations already are being squeezed from downstream reaches. Climate change will squeeze them from upstream as snowpacks diminish and precipitation patterns change. The options for these fish are to expand into remaining downstream habitat or perish. But for downstream expansion to be possible, non-native fishes must be removed and habitats restored.

**Strategy 4: Minimize outside stressors.** In many ways, the impacts of climate change will bring additional stress to stream systems and watersheds that already have been pushed to their ecological limits. We may not be able to slow the immediate impacts of a changing climate, but we can identify and remove or mitigate existing sources of stress. Too many roads, poorly constructed culverts, and poor livestock practices are a few examples of existing stressors that can be fixed. Watersheds that are in a healthy condition will be better able to withstand the stress of climate-imposed impacts and rebound from disturbances.

We know basic improvements in water quality, restoration of riparian habitats, and restoration of stream channel complexity will improve habitats and create refuges from warm water by forming deeper and more shaded pools of cool water. This appears just as true for small mountain streams in New Mexico or Montana as it does for larger river systems in coastal areas of Oregon and Washington.

**Strategy 5: Manage at watershed scales to reconnect stream systems.** Many existing stream systems have been disconnected by construction of dams, water diversions, and other dewatering processes. We should identify and reconnect the hydrology in those areas that are most likely to provide for long-term survival of trout and salmon. In some cases, this may be as easy as replacing poorly designed culverts with small bridges that allow upstream and downstream movement of fish and spawning gravels.

**Strategy 6: Monitor, evaluate and employ adaptive management.** As noted earlier, our ecosystems are complex and some impacts of climate change are difficult to predict with certainty. Therefore, it is important to adequately fund monitoring programs and maintain the ability to modify our management approach in the face of changing conditions and new information. We must listen to what the land is telling us as climate shifts.

### *Conclusion*

In conclusion, we find that climate change poses a serious and imminent threat to our nation's water and stream resources and to the trout and salmon populations they support. Further, we believe that the impacts of a rapidly changing



climate are already manifesting themselves through changes in precipitation regimes and snowmelt patterns, warmer weather and increasing drought, reduced snowpacks and earlier stream runoff, reduced stream flows in the summer, and a greater threat from disturbance processes such as drought, flood and wildfire.

Despite these significant challenges posed by a rapidly changing climate, we believe there are many reasonable and proven actions, such as the strategies described herein, that can be taken immediately to reduce the threats to our coldwater fishery resources. We strongly believe that our actions must be based on the principles of conservation biology and restoration ecology.

The long-term health of our rivers and watersheds must have priority over any quick fixes. We are highly skeptical of any attempts to channelize streams or dam headwaters in an effort to control flows and floods. Rather, we advocate healthy streams and floodplains that are more able to absorb higher energies associated with floods and also are more likely to slowly release water and maintain flows during summer and autumn.

Many of our existing trout and salmon face an increased risk of extinction. It is important to make investments in protection and restoration of our streams, riparian areas and watersheds during the current and coming years while the debates and discussions concerning our energy policies and carbon footprint move forward. By making such basic investments in the health of our watersheds, we will insure the persistence of our most valuable salmon and trout populations and buy the time needed to deal with the larger problem of reducing our carbon footprint.

Thank you again for the opportunity to testify today. I look forward to answering any questions that you may have.

# Climate Change and Western Trout: Strategies for Restoring Resistance and Resilience in Native Populations

Manuscript in review. 2007.  
Wild Trout IX Proceedings

Jack E. Williams<sup>1</sup>, Amy L. Haak<sup>2</sup>, Helen M. Neville<sup>3</sup>,  
Warren T. Colyer<sup>4</sup>, and Nathaniel G. Gillespie<sup>5</sup>

<sup>1</sup>Trout Unlimited, 329 Crater Lake Avenue, Medford, OR 97504; <sup>2</sup>Trout Unlimited, 910 W. Main Street, Suite 342, Boise, ID 83702; <sup>3</sup>Trout Unlimited, 1020 W. Main Street, Suite 440, Boise, ID 83702; <sup>4</sup>Trout Unlimited, 249 South 100 West, Providence, UT 84332; <sup>5</sup>Trout Unlimited, 1300 N. 17<sup>th</sup> Street, Suite 500, Arlington, VA 22209.

---

**ABSTRACT**— Global warming and associated climate change will cause unprecedented environmental challenges for coldwater-dependent fishes. We model three future conditions expected to impact western trout populations most severely – warmer summer temperatures, increased winter flooding, and increased wildfires – to identify those subwatersheds and river basins where three cutthroat trout subspecies are likely to be at greatest risk. Many isolated and smaller Bonneville cutthroat populations, particularly those at lower elevations, will face increased risk from higher stream temperature and winter flooding. Lowest risk areas for this subspecies occur in the Bear River basin. Colorado River cutthroat populations will be at low risk in the Upper Green, however, all other basins include subwatersheds at moderate to high risk. Current westslope cutthroat populations are in relatively better condition but approximately one-third face high risk from increased winter flooding. We argue that management agencies should meet these threats with accelerated and strategically located actions that restore resistance and resilience to climate change in native trout populations and their habitats by protecting best remaining populations, increasing population size and habitat in isolated populations, reducing outside habitat stressors, reconnecting habitats, and restoring migratory life histories. Control of non-native salmonids should accompany these efforts. Given future uncertainty of climate change impacts and non-native species expansion, more consistent monitoring and dedication to adaptive management principles are critical.

---

## INTRODUCTION

Rapid global warming and associated climate change are likely to have significant negative impacts on most native trout populations. As ectotherms, trout physiology is directly regulated by temperature and their life history stage-specific habitat requirements make them vulnerable to the many changes predicted to occur in aquatic habitats because of climate change (Rahel et al. 1996; Poff et al. 2002; Ficke et al. 2005). Native trout species are already struggling in the face of wide-scale habitat degradation, fragmentation, and the introduction of non-native species (Dunham et al. 2002; Lee et al. 1997). Many of these existing threats are likely to be compounded by the effects of climate change.

Perhaps the most pervasive change associated with climate change is a warming of the Earth's surface. During the late 20<sup>th</sup> century, the Earth's average surface air temperature rose 0.6°C, a

rate unprecedented in the past 1,000 years (Mote et al. 2005). Warming air temperatures will cause numerous fundamental environmental changes, including increased stream and lake temperatures and increased evaporation rates. This will reduce annual snowpack and reduce water storage in mid to lower elevation watersheds (Barnett et al. 2004). Precipitation changes are also predicted to result in peak flows occurring earlier in the year and longer, lower base flows (Barnett et al. 2004; Ficke et al. 2005). In general, disturbance events such as floods, drought, and wildfire will increase as climate change progresses (Poff 2002; McKenzie et al. 2004).

Although the general trends are clear, physical characteristics of the catchment, such as topography, vegetation, and orientation, will influence impacts to local watersheds and populations. Also important in determining local impacts will be existing stressors, such as road densities and livestock grazing. The presence of non-native fishes will add still more complexity and uncertainty. Nonetheless, the effects of a rapidly changing climate are already beginning to manifest themselves. Harper and Peckarsky (2006), for instance, report earlier mayfly and other aquatic insect emergences in Rocky Mountain streams because of reduced snowpack and earlier peak runoff during the past decade.

In this paper, we present our analysis of climate change impacts – increased summer temperature, increased flood risk, and increased wildfire risk – on three subspecies of native trout in the western U.S., and suggest management strategies that will help restore resistance and resilience within populations to climate change. Despite the likely negative implications of climate change to western trout, we remain hopeful. Our hope rests on our ability to implement ecologically based restoration strategies that have proven effective for trout populations and their watersheds. We argue that strategic implementation of such strategies will increase the likelihood that native trout populations will persist in the future, even if this future is characterized by rapid environmental change. Salmonids evolved in highly dynamic environments and have substantial dispersal abilities that will aid in their survival if provided reasonable assistance.

## METHODS

Our analysis models three elements of environmental change that are widely predicted to result from global warming and are likely to affect coldwater fish adversely.

1. Increased summer water temperature resulting from an increase in air temperature.
2. Larger and more frequent winter flood events resulting from an increase in rain on snow as warm mid-winter air masses become more common.
3. More frequent wildfire where longer, hotter, and drier summers aggravate a situation that is already volatile due to past management practices.

The analyses were conducted at the subwatershed scale in a GIS environment. For each factor, each subwatershed was scored as low, moderate, or high risk for adverse environmental affects on coldwater fish populations. A composite map of the three elements was projected across the current distribution of Bonneville, Colorado River, and westslope cutthroat trout in order to identify populations that are the most vulnerable to global warming induced environmental change.

### Summer Temperature

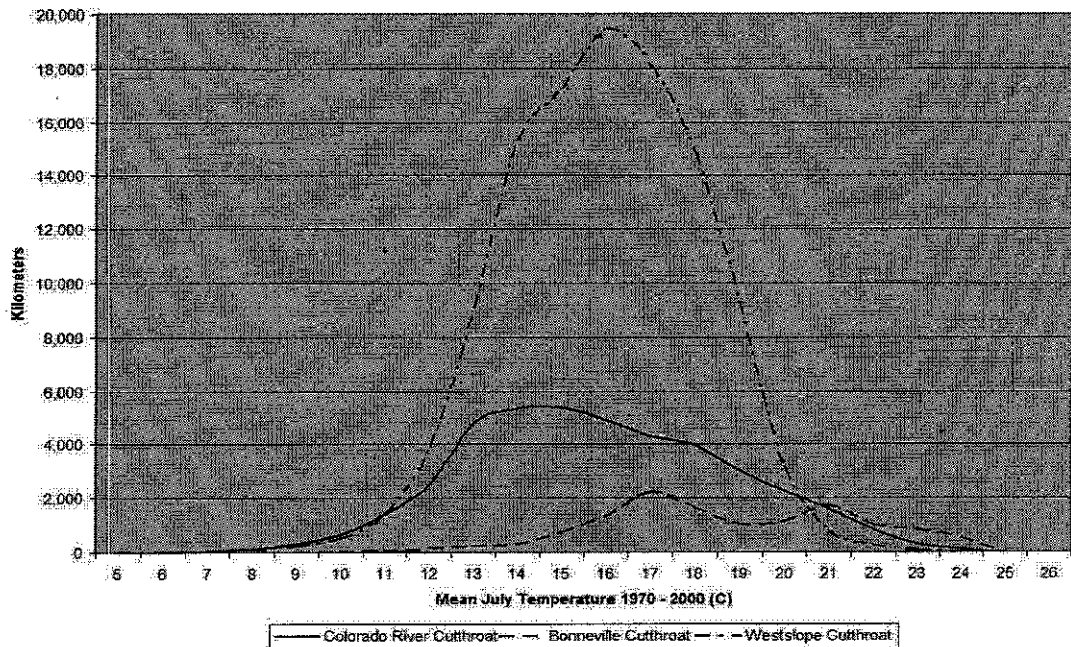
The strong correlation between air temperature and water temperature and the lack of regional temperature data for streams and lakes makes air temperature a practical indicator for modeling environmental change across large geographic areas (Rahel 2002). We apply the methods of Rahel et al. (1996) who used changes in mean July air temperature to model habitat loss due to

global warming for a coldwater guild of brown, rainbow, brook and cutthroat trout in the Rocky Mountains. Analyzing average daily July temperature seems appropriate because this is typically the hottest month in the Rocky Mountains.

The PRISM Group in the Oregon Climate Service at Oregon State University (PRISM 2007) recently published a series of national data sets of average monthly minimum and maximum temperatures from 1970 to 2000 at a resolution of 800 meters. We averaged the minimum and maximum July temperatures for this 30-year period to establish a baseline from which to model change.

Before modeling the affects of increasing temperature, it was first necessary to determine the thermal limits for each of the three species evaluated that incorporate species-specific adaptations to local environmental conditions. This was accomplished through a comparison of the historic distribution (in kilometers of habitat) for each species and mean July temperature (Figure 1).

Less than 1% of the total distribution for westslope and Colorado River cutthroat was found in streams with an average July air temperature greater than 22°C. In contrast, nearly 20% (1,400 km) of the historic distribution of Bonneville cutthroat was associated with a mean July air temperature greater than 22°C. The thermal distribution of Bonneville cutthroat was bimodal, as opposed to the bell curve exhibited by the other two species' distributions. The warmer second peak may be associated with an extensive network of lower elevation valley bottoms that historically contained Bonneville cutthroat trout populations.



**Figure 1. Historic distribution of Colorado River, Bonneville, and westslope cutthroat trout as measured in kilometers of stream habitat relative to July air temperature.**

Based on this analysis, an upper thermal limit of 22° C was applied to westslope and Colorado River cutthroat while 24° C was used for Bonneville cutthroat. We also identified a 'marginal' temperature range for each species that was within thermal limits but was on the upper end of the respective habitat curve. This marginal habitat range for westslope and Colorado River cutthroat was defined as 19° C - 22° C and for Bonneville cutthroat as 22° C - 24° C. Any temperatures less than the lower end of these ranges were considered thermally suitable.

Our analysis of global warming impacts on thermal suitability applied a 3° C temperature increase to the 1970-2000 mean July air temperatures. This increase has been projected as the most likely scenario for the American West within this century (Climate Impacts Group 2004). An area-weighted average temperature under the global warming scenario was calculated for each subwatershed within the species' ranges. Using the species-specific 'suitable', 'marginal' and 'unsuitable' temperature break points previously defined, each subwatershed was then scored for the level of risk to local populations from increased summer air temperatures: 1 (suitable, low risk), 2 (marginal, moderate risk), or 3 (unsuitable, high risk).

### Increased Flood Risk

Hamlet and Lettenmaier (in review) modeled uncharacteristic winter flood events for basins of the Pacific Northwest as a result of global warming. Their analysis recognized three types of winter precipitation regimes for basins in the Pacific Northwest: rain dominant, snow dominant, and transient. Winter flooding in rain dominant basins is a function of the individual storm event and the size and runoff characteristics of the catchment. Snow dominant basins do not typically flood in mid-winter but rather flooding occurs later as spring run-off. Transient basins, where both rain and snowstorms occur, are the primary location of significant mid-winter flooding events. The magnitude of the flood event is dependent on the intensity and duration of the rainstorm and the antecedent snow pack.

Given the uncertainty of climate models with regard to future precipitation patterns, it is not possible currently to model increased flood risk as a function of changes in precipitation amounts. However, warmer winter temperatures will likely result in increased winter flooding due to increases in rain on snow events as snow dominant watersheds shift to transient precipitation regimes.

Our analysis of uncharacteristic winter flooding due to global warming assumed the same 3° C temperature increase used in our model of thermal impacts. For winter flooding we used mid-winter temperatures (January - March) as our baseline. We again relied on the PRISM average monthly minimum and maximum temperatures for 1970 - 2000. These data sets were processed to establish a mid-winter average temperature across the ranges of our three species of interest.

In addition to temperature data, we also acquired average annual and monthly precipitation data for the same time period. For each subwatershed, the area weighted mean of three variables was calculated: annual precipitation, winter precipitation, and winter temperature. Subwatersheds where the three months of winter precipitation comprised less than 25% of the annual precipitation were classified as having a non-winter dominant precipitation regime and therefore were at low risk for uncharacteristic winter flooding.

Once the subwatersheds dominated by winter precipitation were identified, we classified them by type: rain, snow, or transient using the data on mean winter air temperature. We assumed that subwatersheds with a mean winter temperature less than -1° C were snow dominant while those with a mean winter temperature greater than +1° C were rain dominant. The remainder of the subwatersheds was classified as transient.

A 3° C temperature increase was added to the current winter mean and the subwatersheds were reclassified. The change in basin type between current temperatures and the global warming

scenario served as the basis for scoring the risk of uncharacteristic winter flooding. The highest score was assigned to subwatersheds that change from snow dominant to transient or rain dominant. Subwatersheds that change from transient to rain were assigned a moderate risk score because they would be likely to experience more flood events (and currently are) in the near term as they continue to receive some snow along with an increasing frequency of warm mid-winter storm events until they ultimately become rain dominant. Once this occurs, the winter flood risk may actually decline since there will no longer be an antecedent snow pack to contribute to high run-off. Subwatersheds that remain as either snow or rain dominant, or are non-winter precipitation dominant, received the lowest risk score.

#### **Increased Wildfire Risk**

Recognizing that fire is a part of the western landscape and fire risk will continue to increase as predicted under a warming climate, the increased wildfire risk analysis sought to identify areas at greatest risk for uncharacteristic wildfire. Several factors contribute to increased risk for uncharacteristic wildfire, including changes in fuel loads, and vegetation type, composition, and structure. Past land management practices have resulted in the removal of large, fire-resistant native conifers and the spread of invasive, and highly flammable, species such as cheatgrass, resulting in an increase in the frequency, duration, and intensity of western wildfires (DellaSala et al. 2004).

In order to identify those areas that have been the most altered and are therefore at greatest risk for uncharacteristic fires, we used the Fire Regime Condition Class Departure Index developed by the Forest Service LANDFIRE program. The Index uses a scale of 0 – 100% to depict departure from the presumed historical vegetation reference conditions incorporating plant composition, structure, and disturbance regimes (Hann et al. 2004). Area weighted means of the departure index were calculated for each subwatershed and grouped into three classes of risk: low is less than 50% departure, moderate is 51 – 75% departure, and high risk is greater than 75% departure.

#### **Composite Climate Risk**

The subwatershed risks for each of the three elements (increased summer temperature, increased flood risk, and increased wildfire risk) were combined to generate a composite score for risk of habitat loss due to environmental change from global warming. Each subwatershed was scored as low, moderate, or high risk based on the highest score from each of the three elements modeled and then evaluated against the current distribution of each subspecies. This allowed us to quantify potential habitat loss due to global warming and identify populations at greatest risk.

### **RESULTS**

#### **Bonneville Cutthroat Trout**

For a 3° C increase in temperatures predicted with climate change, 77% of subwatersheds with existing populations were modeled to be at moderate or high composite risk for Bonneville cutthroat trout (Table 1). A disproportionately large share of remaining habitat was projected to face thermal challenges in the West Desert and Southern Bonneville basins, where many remaining populations already are fragmented and occupy small stream segments. Stream habitats in the Bear River and Northern Bonneville basins were mostly at lower risk for thermal problems except along the lower-elevation western flanks of those basins.

Areas of moderate to high risk for winter flooding were modeled to occur primarily in the Southern Bonneville and Northern Bonneville basins. Much of the West Desert will be in moderate risk while much of the Bear River and eastern portions of the Northern Bonneville basins are likely to remain as snow-form precipitation and therefore at low risk of increased winter flooding. Wildfire models suggest that highest risk areas are found in the lower elevations

of the Bear River and Southern Bonneville basins. In general, the composite risk analysis showed that most of the West Desert, Southern Bonneville, and Northern Bonneville basins were in the moderate to high-risk range. Only populations in the extreme eastern portion of the Northern Bonneville basin, and most of the Bear River basin were modeled to be at low risk (Figure 2).

	Increased Summer Temperature			Increased Flooding			Increased Wildfire			Composite Risk		
	High	Mod	Low	High	Mod	Low	High	Mod	Low	High	Mod	Low
Bonneville	8	16	76	48	7	45	13	37	50	57	20	23
Colorado River	5	23	72	12	0	88	1	20	79	14	27	59
Westslope	3	35	62	31	7	62	3	42	55	36	31	33

**Table 1. Percent of currently occupied subwatersheds in low, moderate, and high risk category for each of the climate change factors.**

#### Colorado River Cutthroat Trout

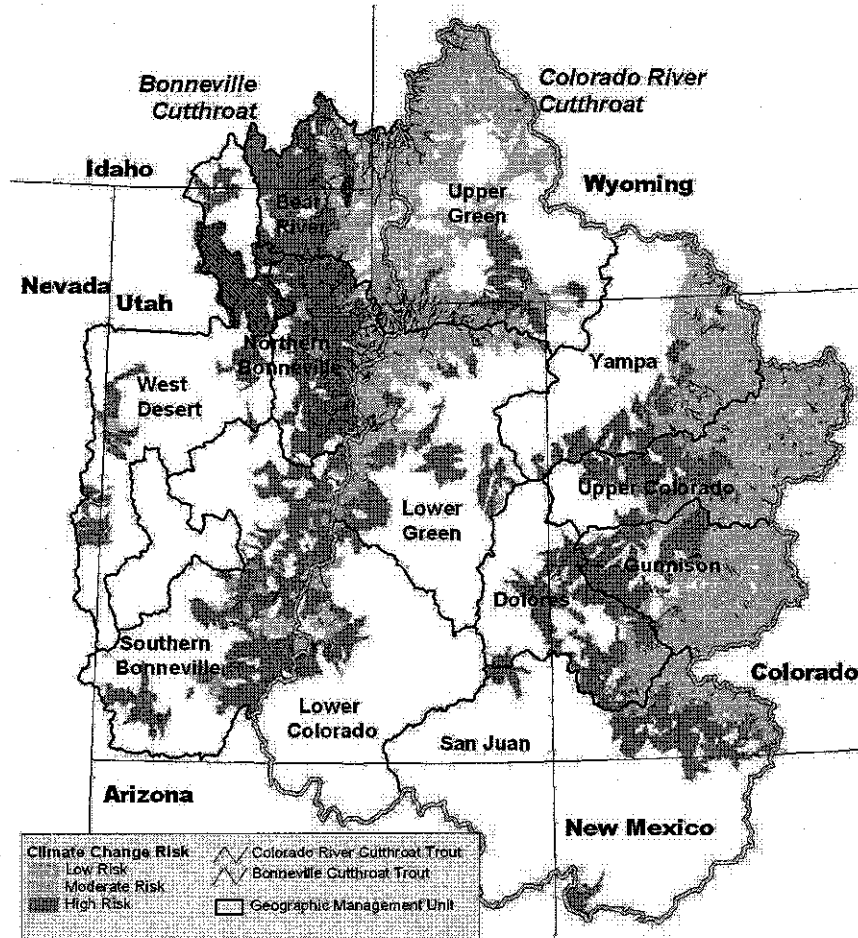
Colorado River cutthroat trout are more isolated in headwater tributaries that are less susceptible to thermal changes. Historically, 89% of stream habitat occupied by Colorado River cutthroat trout was less than or equal to 19°C, and this percentage decreases only to 72% with the 3°C increase projected from climate change. Twenty-eight percent of currently occupied subwatersheds were likely to be at thermal risk with the 3°C increase (23% of subwatersheds occur in 19-22°C range, and 5% in greater than 22°C). All basins will be affected by increased temperature but a greater relative impact is likely in the Upper Colorado, Gunnison, Yampa, and Dolores basins.

Increased risk for winter flooding was identified in habitats at lower elevations within the Lower Green, Yampa, Upper Colorado, Gunnison, Dolores, Lower Colorado, and San Juan basins. All of the Upper Green and higher elevation habitats all other basins were modeled at low risk for increased flooding. Increased wildfire risk was generally lower and more scattered within the range of Colorado River cutthroat trout, but those basins in the eastern portion of the range had a higher percentage of subwatersheds in the moderate and high risk categories. In general, the composite risk analysis showed mostly low risk in the Upper Green basin. Higher elevation zones of other basins were mostly in low risk categories despite increased risk for wildfire in scattered subwatersheds (Figure 2).

#### Westslope Cutthroat Trout

When the 3°C temperature increase was applied to the 1970-2000 mean July temperatures, westslope cutthroat trout show 3% of subwatersheds within the current range at high risk from increased temperatures and 35% at moderate risk (Table 1). Current westslope cutthroat trout populations are less fragmented and occupy many lower elevation streams that are moderately vulnerable to temperature increases over the next century. Most thermal risks occur in the Upper Missouri, Clearwater, and Coeur d'Alene basins, as well as the Oregon portions of the range.

Most existing habitat in the Salmon and much of the Clark Fork Basin was modeled at low risk from summer temperature increase.



**Figure 2. Composite climate change risks for Bonneville and Colorado River cutthroat trout.** Subwatersheds within historic and current range were scored as low, moderate, or high risk. The range for the Colorado River cutthroat trout is outlined by double line; the range of the Bonneville cutthroat trout is shown to the left.

High risk from winter flooding was identified in 31% of the current range, especially within the Clearwater, Coeur d'Alene, Clark Fork, Kootenai basins, as well as those portions of the range in Washington and Oregon. Remaining basins were primarily at low risk from flooding. Increased risk from wildfire was more variable, but at high risk levels in much of the Flathead, Upper Missouri, and Middle Missouri basins. In the composite risk analysis, the Salmon and Madison basins were at the lowest composite risk to climate change impacts. Highest risk areas were modeled in the Flathead, northeastern portions of the Upper Missouri, northern portions of the Middle Missouri, and much of the range in Washington. The Clearwater, Coeur d'Alene, Kootenai, western portions of the Clark Fork, and the range in Oregon were mostly in the moderate or high composite risk categories (Figure 3).



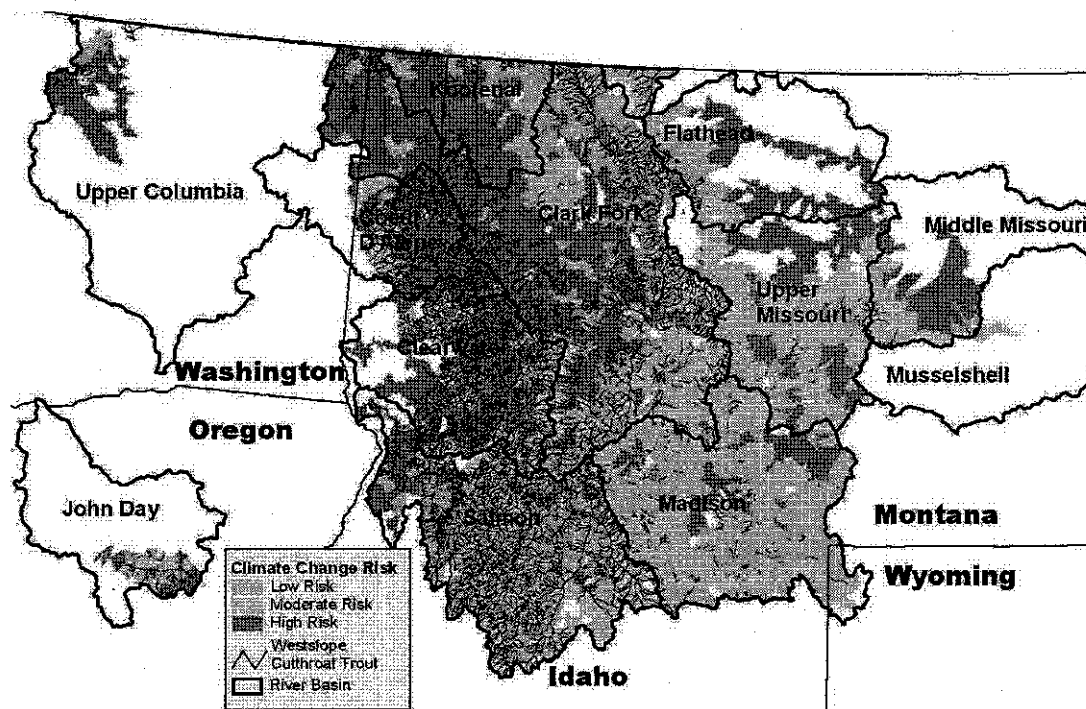


Figure 3. Composite climate risk map historic and current range for westslope cutthroat trout that combines risk of increased summer temperature, winter flooding, and wildfire.

For all subspecies, local stream-specific impacts were unpredictable in our analysis because of the scale of the data and the categorization by subwatershed. Nonetheless, many subwatersheds and larger river basins were identified at high risk of significant impacts to stream populations from climate change events. This does not mean that restoration efforts should be abandoned from these regions. Much to the contrary, our analysis illuminates those regions that should receive immediate actions to expand habitats and populations – that is, restore resistance and resilience to climate change – so that the genetic, life history, and population diversity within these subspecies can be maintained in the face of a rapidly changing climate.

#### Strategies to Restore Resistance and Resilience

While we may not be able to stop a rapidly changing climate, we can implement measures designed to increase the likelihood of native trout persistence. We describe six strategies that draw on existing and proven methodologies and will increase the ability of habitat and populations to withstand rapid environmental change (**resistance**), and improve the ability of habitats and populations to rebound after disturbance (**resilience**). These strategies generally fit within what can be described as a “protect-reconnect-restore” model of fisheries sustainability, where emphasis is to **protect** the best remaining habitats and populations, **reconnect** fragmented habitats by removing in-stream barriers and reestablishing in-stream flows, and **restore** vital mainstem river and riparian habitats. Trout Unlimited has encouraged implementation of these strategies as a contingency plan to prepare for future climate change impacts.

#### Strategy 1: Protect remaining population and habitat strongholds

The first rule of strategic restoration is to protect remaining core strongholds (Frissell 1997; Williams et al. 1997). Existing trout strongholds should be maintained in high quality condition

as these areas will have the greatest likelihood of resisting climate change and will be key to future population expansions. Similarly, watersheds that produce reliable supplies of cold water should be protected, as these areas will be key to maintenance of suitable downstream conditions.

**Strategy 2: Maintain genetic and life history diversity**

Genetic and life history diversity help buffer populations against environmental changes by allowing populations to maintain broad suites of behavioral characteristics, increasing the likelihood that some individuals will be better adapted to novel conditions (Schlosser and Angermeier 1995). Restoring life history diversity, especially migratory forms, serves the dual purpose of maintaining genetic diversity and increasing the ability of a population to explore and colonize habitats that had recovered from earlier disturbance (Dunham et al. 2003; Colyer et al. 2005; Neville et al. 2006). Larger, migratory individuals also have higher fecundities and therefore are better able to resist outside stressors such as non-native species.

**Strategy 3: Increase size and extent of existing populations**

Small, fragmented populations are at greater risk of extinction because of habitat limitations as well as demographic and environmental variability (Hilderbrand and Kershner 2000; Rieman and Allendorf 2001). Many populations of native trout have been relegated to smaller, upper elevation streams by degraded downstream habitat and advances from non-native salmonids. Climate change is likely to exacerbate these threats by increasing environmental variability and reducing suitable water quality and quantity (Poff 2002; Poff et al. 2002). Populations occurring over larger geographic areas, or greater stream-lengths, will be more stable and more resistant to local extinction.

**Strategy 4: Minimize outside stressors**

For many watersheds, climate change will add stress to drainages that are already impacted by a multitude of anthropogenic disturbances such as roads, overgrazing by livestock, poor timber harvest practices, off-road vehicle use, mining, pollution, and agriculture. The cumulative effect of climate change impacts may deteriorate some watersheds to the point that they will not be able to rebound following disturbance events, or may move watershed conditions to new and reduced-integrity thresholds following floods, drought, wildfire, or other major changes. Restoration of natural conditions and ecological processes will improve the ability of populations to rebound after catastrophic events, including increased floods, particularly when focused on restoring riparian habitats, floodplains, and reconnecting streams to larger river systems (Williams and Williams 2004).

**Strategy 5: Manage at watershed scales to reconnect stream systems**

Restoring connectivity within and among watersheds by removing barriers to dispersal or by restoring in-stream flows will facilitate the recovery of migratory life histories, and increase the likelihood of fish finding suitable habitat conditions. Restoring connectivity in watersheds helps to reverse the habitat fragmentation and isolation of small populations, often cited as principal causes of population loss among coldwater fishes (Dunham et al. 1997; Hilderbrand and Kershner 2000). As waters warm in response to climate change, increasing access to suitable habitat conditions will become critical to survival for many populations. However, because non-native species can expand as connectivity increases, site-specific decisions will have to be made that weigh this factor among potential gains (Fausch et al. 2006).

**Strategy 6: Increase monitoring and improve adaptive management**

Langston (1995) appropriately characterized successful adaptive management as "listening to the land," with managers being responsive to monitoring results and acting on new knowledge by modifying management programs appropriately. Climate change will add variability to natural

systems that are already exceedingly complex and subject to synergistic effects of human actions that further confound management. Non-native species and pathogens are present in many watersheds harboring native trout and the response of these animals to climate change may be particularly hard to predict. If carefully designed, monitoring programs should be valuable in unraveling the complexities that climate change will add to natural systems (Kershner 1997).

### Conclusion

The impacts of climate change on western trout populations and particularly native trout will be significant. Many of the current ranges of these fishes already have been greatly reduced from historic conditions. For example, based on subwatersheds, Colorado River cutthroat trout occupy 18% of their historic range, Bonneville cutthroat trout 37% and westslope cutthroat trout 56%. Yet our modeling shows significant portions of this remaining range at high risk from climate change (57% of Bonneville cutthroat trout range is at high climate change risk, 14% of Colorado River cutthroat trout, 36% westslope cutthroat trout). Modeling increased risk factors can help identify those areas where existing populations are at greatest risk and where restoration and reintroduction efforts should be expanded. These models can be useful in determining how climate change may compound current stresses, and in developing strategies to protect, reconnect and restore populations of Bonneville cutthroat, westslope cutthroat and Colorado River cutthroat trout. Monitoring will be critical in understanding local stream impacts appropriately placing streams within broader basin-wide strategies.

### ACKNOWLEDGEMENTS

Matt Barney and Matt Mayfield (Conservation Geography) provided excellent support in climate change modeling and map preparation. Discussions with Chris Wood (TU) and Brian Barr (National Center for Conservation Science and Policy) assisted our analysis and manuscript preparation. This research was supported by the William and Flora Hewlett Foundation, Wildlife Management Institute, TU's Coldwater Conservation Fund, and Kenneth Woodcock.

### REFERENCES

- Barnett, T., R. Malone, W. Pennell, D. Stammer, B. Semtner, and W. Washington. 2004. The effects of climate change on water resources in the West: introduction and overview. *Climatic Change* 62:1-11.
- Climate Impacts Group. 2004. Overview of the climate change impacts in the U.S. Pacific Northwest. Climate Impacts Group, University of Washington. Available online at [www.cses.washington.edu/cig](http://www.cses.washington.edu/cig).
- Colyer, W. T., R. H. Hilderbrand, and J. L. Kershner. 2005. Movements of fluvial Bonneville cutthroat trout in the Thomas Fork of the Bear River, Idaho-Wyoming. *North American Journal of Fisheries Management* 25:954-963.
- DellaSala, D. A., J. E. Williams, C. Deacon Williams, and J. F. Franklin. 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. *Conservation Biology* 18:976-986.
- Dunham, J. B., G. L. Vinyard, and B. E. Rieman. 1997. Habitat fragmentation and extinction risk of Lahontan cutthroat trout. *North American Journal of Fisheries Management* 17:1126-1133.
- Dunham, J. B., S. B. Adams, R. E. Schroeter, and D. C. Novinger. 2002. Alien invasions in aquatic ecosystems: toward an understanding of brook trout invasions and their potential impacts on inland cutthroat trout in western North America. *Reviews in Fish Biology and Fisheries* 12:373-391.
- Dunham, J. B., M. K. Young, R. E. Gresswell, and B. E. Rieman. 2003. Effects of fire on fish populations: landscape perspectives on persistence of native fishes and nonnative fish invasion. *Forest Ecology and Management* 178:183-196.
- Fausch, K. D., B. E. Rieman, M. K. Young, and J. B. Dunham. 2006. Strategies for conserving native salmonid populations at risk from nonnative fish invasions: tradeoffs in using barriers to upstream movement. U. S. D. A. Forest Service General Technical Report RMRS-GTR-174, Fort Collins, Colorado.

- Ficke, A. A., C. A. Myrick, and L. J. Hansen. 2005. Potential impacts of global climate change on freshwater fishes. World Wide Fund for Nature, Gland, Switzerland.
- Frissell, C. A. 1997. Ecological principles. Pages 96-115 in J. E. Williams, C. A. Wood, and M. P. Dombeck, editors. *Watershed restoration: principles and practices*. American Fisheries Society, Bethesda, Maryland.
- Hamlet, A. F. and D. P. Lettenmaier. In review. Effects of 20<sup>th</sup> Century warming and climate variability on flood risk in the western U.S. Climate Impacts Group, University of Washington.
- Hann, W., A. Shlisky, D. Havlina, K. Schon, S. Barrett, T. DeMeo, K. Pohl, J. Menakis, D. Hamilton, J. Jones, and M. Levesque. 2004. Interagency fire regime condition class guidebook. Interagency and The Nature Conservancy fire regime condition class website. Available online at [www.frcc.gov](http://www.frcc.gov).
- Harper, M. P. and B. L. Peckarsky. 2006. Emergence clues of a mayfly in a high-altitude stream ecosystem: potential response to climate change. *Ecological Applications* 16:612-621.
- Hilderbrand, R. H. and J. L. Kershner. 2000. Conserving inland cutthroat trout in small streams: how much habitat is enough? *North American Journal of Fisheries Management* 20:513-520.
- Kershner, J. L. 1997. Monitoring and adaptive management. Pages 116-131 in J. E. Williams, C. A. Wood, and M. P. Dombeck, editors. *Watershed restoration: principles and practices*. American Fisheries Society, Bethesda, Maryland.
- Langston, N. 1995. *Forest dreams, forest nightmares: the paradox of old growth in the Inland West*. University of Washington Press, Seattle.
- Lee, D. C., J. R. Sedell, B. E. Rieman, R. F. Thurow, and J. E. Williams. 1997. Broad-scale assessment of aquatic species and habitats. Pages 1057-1496 in T. M. Quigley and S. J. Arbelbide, technical editors. *An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins: Volume III*. U. S. D. A. Forest Service General Technical Report PNW-GTR-405.
- McKenzie, D., Z. Gedalof, D. L. Peterson, and P. Mote. 2004. Climate change, wildfire, and conservation. *Conservation Biology* 18:890-902.
- Mote, P. W., A. K. Snover, W. Whitley Binder, A. F. Hamlet, and N. J. Mantua. 2005. *Uncertain future: climate change and its effects on Puget Sound – foundation document*. Climate Impacts Group, University of Washington, Seattle.
- Neville, H. M., J. B. Dunham, and M. M. Peacock. 2006. Landscape attributes and life history variability shape genetic structure of trout populations in a stream network. *Landscape Ecology* 21:901-916.
- Poff, N. L. 2002. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions Royal Society of London* 360:1497-1510.
- Poff, N. L., M. M. Brinson, and J. W. Day. 2002. *Aquatic ecosystems and global climate change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States*. Pew Center on Global Climate Change, Arlington, Virginia.
- PRISM. 2007. PRISM Group, Oregon Climate Service, Oregon State University, Corvallis. Available online at <http://prism.oregonstate.edu/>.
- Rieman, B. E. and F. W. Allendorf. 2001. Effective population size and genetic conservation criteria for bull trout. *North American Journal of Fisheries Management* 21:756-764.
- Rahel, F. J. 2002. Using current biogeographical limits to predict fish distributions following climate change. Pages 99-109 in N. A. McGinn, editor. *Fisheries in a changing climate*. American Fisheries Society Symposium 32, Bethesda, Maryland.
- Rahel, F. J., C. J. Keleher, and J. L. Anderson. 1996. Potential habitat loss and population fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: response to climate warming. *Limnology and Oceanography* 41:1116-1123.
- Schlosser, I. J. and P. L. Angermeier. 1995. Spatial variation in demographic processes of lotic fishes: conceptual models, empirical evidence, and implications for conservation. Pages 392-401 in J. L. Nielsen, editor. *Evolution and the aquatic ecosystem: defining unique units in population conservation*. American Fisheries Society Symposium 17, Bethesda, Maryland.
- Williams, J. E. and C. D. Williams. 2004. Oversimplified habitats and oversimplified solutions in our search for sustainable freshwater fisheries. Pages 67-89 in E. E. Knudsen, D. D. MacDonald, and Y. K. Muirhead, editors. *Sustainable management of North American fisheries*. American Fisheries Society Symposium 43, Bethesda, Maryland.
- Williams, J. E., C. A. Wood, and M. P. Dombeck. 1997. Understanding watershed-scale restoration. Pages 1-13 in J. E. Williams, C. A. Wood, and M. P. Dombeck, editors. *Watershed restoration: principles and practices*. American Fisheries Society, Bethesda, Maryland.