Fire and Fish Dynamics in a Changing Climate

Lisa Holsinger and Robert Keane

Wildland fire is a natural disturbance that affects the distribution and abundance of native fishes in the Rocky Mountain West (Rieman and others 2003). Fire can remove riparian vegetation, increasing direct solar radiation to the stream surface and leading to warmer summer water temperatures (fig. 1). Fire can also consume vegetation and organic biomass on the forest floor, changing hydrologic flows, stream quality, and fish habitat suitability.

Many native fish species, such as bull trout (*Salvelinus confluentus)* and cutthroat trout (*Oncorhynchus clarkii*), have evolved with fire, and their populations are resilient to fire's effects given adequate connectivity to robust population segments elsewhere in a basin. This resiliency, however, has been reduced in many watersheds through stream habitat loss and degradation and the invasion of nonnative fishes (e.g., brook trout, *Salvelinus fontinalis,* and brown trout, *Salmo trutta*) that better tolerate warmer water temperatures and threaten native fish persistence through displacement and hybridization.

Forecasting the long-term effects of climate change and fire on water temperatures and native fish populations requires an understanding of fire dynamics—the size, distribution, frequency, and severity of

Lisa Holsinger and Robert Keane are research ecologists with the Forest Service, Rocky Mountain Research Station Fire Sciences Lab, in Missoula, MT.

Male bull trout in East Fork Bitterroot River basin. Photo: Aubree Benson, Forest Service.

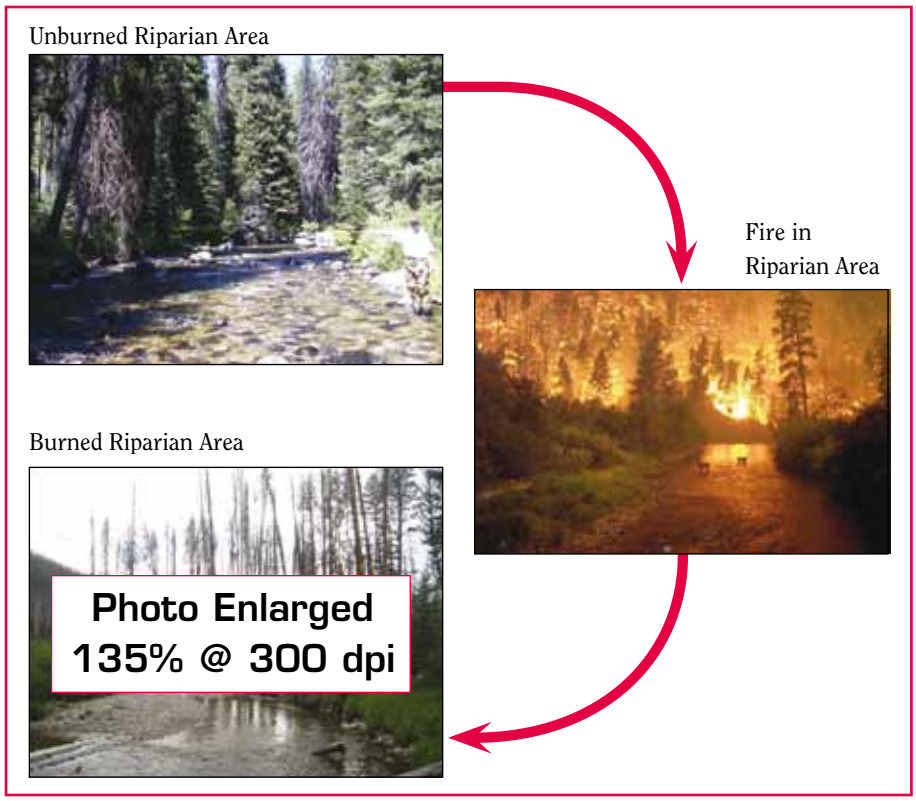

Figure 1—*Fire disturbance can affect stream temperatures by removing canopy shading.*

fires across a landscape—as well as the extent and location of changes in riparian forest structure and the time necessary for riparian stands to recover. It will also depend on the distributions of native and non-native fishes and their responses to changes in water temperature.

To evaluate such fire and fish population dynamics, we are using a landscape fire succession simulation model called Fire-BGCv2, linked to a stream temperature model, to predict bull trout persistence and changes in fish communities. Analyses of model simulation outputs allow us to examine how temporal and spatial changes in water temperature and fish distributions are influenced by fire and landscape characteristics. This information will provide the ability to predict potential thresholds in fire risk and the scales at which to expect recovery in stream temperatures and fish communities, in both time and space, under various fire and climate regimes across the landscape. Given that climate change appears to be affecting both fire patterns (Westerling and others 2006) and air temperature (a good predictor of water temperature), tools that assist managers in predicting changes in the distribution of fire and the influence of fire management on native fishes are a critical need.

Study Site

We chose to apply our simulation modeling to the East Fork Bitterroot River basin in west-central Montana due to the extensive data available for the area on fire and fish (fig. 2). The upper portion of this basin is a core conservation area for bull trout (MFWP 1998), and a rich spatial dataset describing burn severity and extent was developed following the 2000 and 2007 wildfires in the basin. Also, Montana Fish, Wildlife, and Parks and the Forest Service have collected long-term data on the effects of those fires on stream temperatures and fish communities.

> Many native fish species, such as bull trout and cutthroat trout, have evolved with fire, and their populations are resilient to fire's effects.

Modeling Approach

Forest-Fire Succession

We are using a spatially explicit fire ecosystem model called Fire-BGCv2 to simulate fire and forest succession (Keane and others 1996, 1997, 1999) (fig. 3). FireBGCv2 integrates vegetation succession, fire behavior and effects, and climate conditions. More specifically, the model simulates the flow of carbon, nitrogen, and water across various ecosystem components to calculate individual tree growth in the basin. The driving variables for these processes are taken from daily weather. Fire behavior and its effects are incorporated by linking a spatial fire simulation model to Fire-BGCv2 and simulating fire ignition, spread, and effects across landscapes using inputs such as topography, vegetation, weather, and fuelbed characteristics.

In 2009, we collected upland and riparian habitat data describing forest structure and composition to calibrate the Fire-BGCv2 model to the East Fork Bitterroot River basin. We also acquired records from a nearby weather station with data from 1955 to present, as well as 98-foot (30-m) spatial data describing soil composition and distribution, topography, stream networks, and fire history.

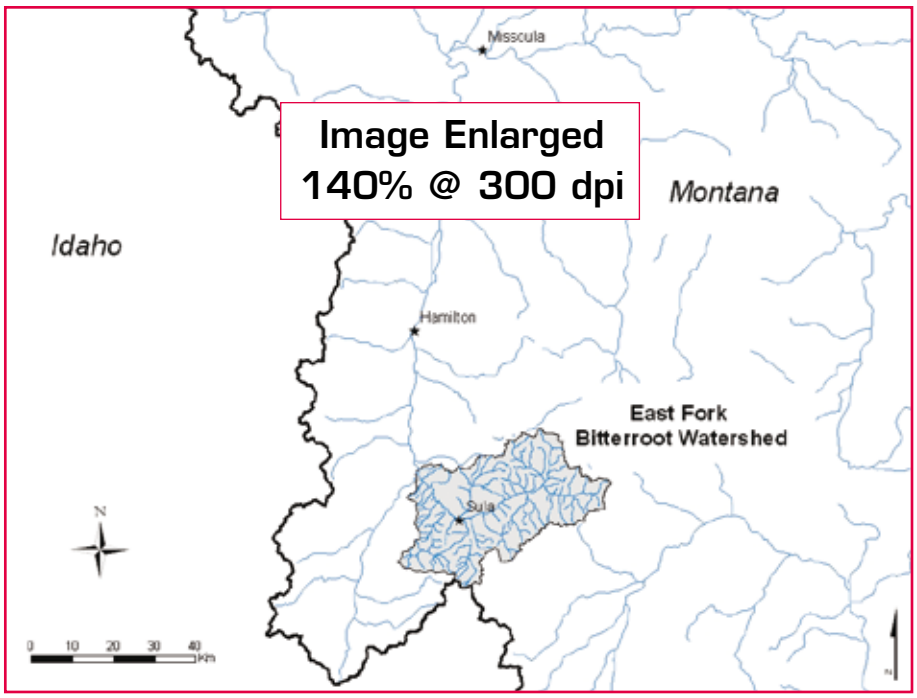

Figure 2—*East Fork Bitterroot River basin.*

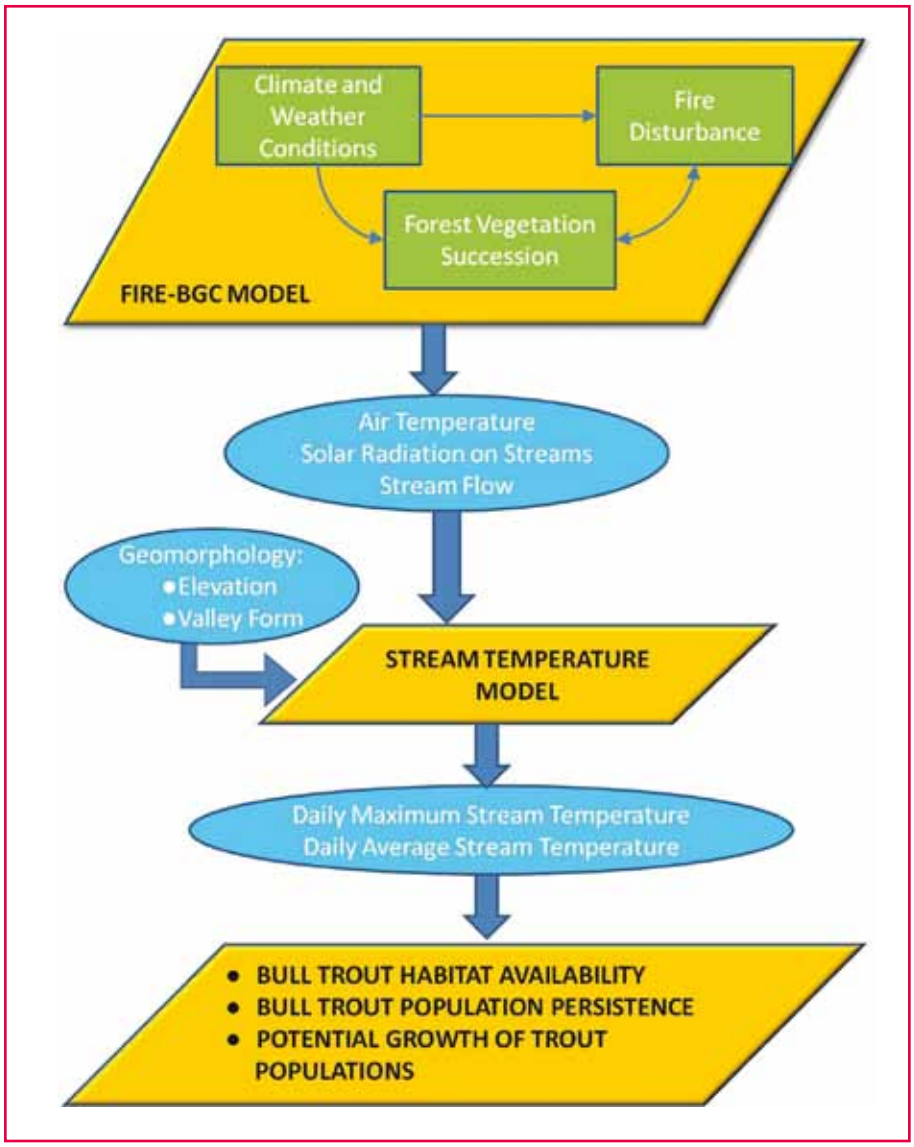

Figure 3—*Overview of the Fire-BGCv2 simulation model, modified to predict stream temperature and fish population dynamics.*

Stream Temperature

We developed a quantitative model that predicts water temperature for the East Fork Bitterroot River basin based on methods used for the Boise River (Isaak and others 2010). After calibrating Fire-BGCv2 to the East Fork Bitterroot, we ran model simulations for the basin to develop a suite of potential predictor variables of stream temperature. We compared these variables to stream temperature data collected for 19 locations across the basin and found that the best predictors for stream temperature were air temperature, stream flow, elevation, solar radiation reaching the stream, stream channel slope, and the area within the drainage basin that contributes water to streamflow. Using these variables, we created a stream temperature prediction equation and embedded it into Fire-BGCv2 to predict water temperatures across the entire watershed with a relatively high accuracy ($R^2 = 0.78$ for average daily stream temperatures; $R^2 = 0.71$ for maximum daily stream temperatures).

We hope to identify what fire and landscape characteristics pose higher risks to bull trout populations to help aid in their conservation and management under current and possible future climates.

Planned Model Simulations and Anticipated Results

We will run model simulations to explore the long-term effects of climate change and fire management on stream temperatures and aquatic species in the East Fork Bitterroot River basin. We will model historical climate, two climate conditions commonly predicted under climate change (warmer-wetter, hotter-drier), and two fire management scenarios (fire exclusion and prescribed burning), as follows:

1. **Historical climate** to describe conditions that streams historically experienced—**with historical fire regime** and **with fire exclusion** to simulate the effects of active wildfire suppression.
2. **Future warm/wet climate—with fire exclusion,** and **with fuels management** where fuels are treated to reduce fire ignition and spread potential.
3. Future hot/dry climate—**with fire exclusion** and **with fuels management.**

Each scenario will produce a time series on stream temperature and fire disturbance related to specific areas of the watershed, which we

can relate to aspects of fish population dynamics in terms of bull trout persistence and native versus nonnative trout community composition. For bull trout, their distribution has been correlated to maximum summer water temperature and stream habitat patch size (Dunham and others 2003). Using predictions from our stream temperature model, we will estimate the total habitat patch size and number of available habitat patches available for bull trout under each climate scenario. Assuming large patches greater than 24,700 acres (10,000 ha) will support local populations with a high probability of persistence and small patches less than 12,350 acres (5,000 ha) will not (Rieman and others 2007), we can estimate how each climate scenario may change bull trout survival in the East Fork Bitterroot River basin.

To evaluate the balance of native versus nonnative trout populations, we will evaluate shifts in stream temperature distribution across the East Fork Bitterroot basin with each simulation scenario and determine whether these shifts affect fish community composition. More specifically, we will use energetic models that predict potential growth for westslope cutthroat trout, rainbow trout, brook trout, brown trout, and bull trout based on average daily stream temperature. Using these potential growth rate equations, we can measure habitat quality for each of the native and nonnative trout species and forecast shifts in the extent and location of high-quality habitat for these species across the basin.

By exploring a variety of fire regimes for each climate simulation scenario, we anticipate a suite of results, presented in bullets below, which should prove useful in understanding the impacts of fire on native and nonnative fish populations under current and a changing climate.

- We expect the probability of bull trout persistence to vary in each of our climate and fire management scenarios as a function of increasing fire frequency, magnitude, and severity (fig. 4). If this is true, our key next questions will be to evaluate: (1) where we should focus conservation efforts (e.g., higher elevation areas where stream temperatures may be cooler?) and (2) whether fuel treatment alters the outcomes.
- We also anticipate identifying thresholds at which the frequency of area burned becomes detrimental to bull trout populations based on the minimum habitat area needed for population persistence (fig. 5). Based on these

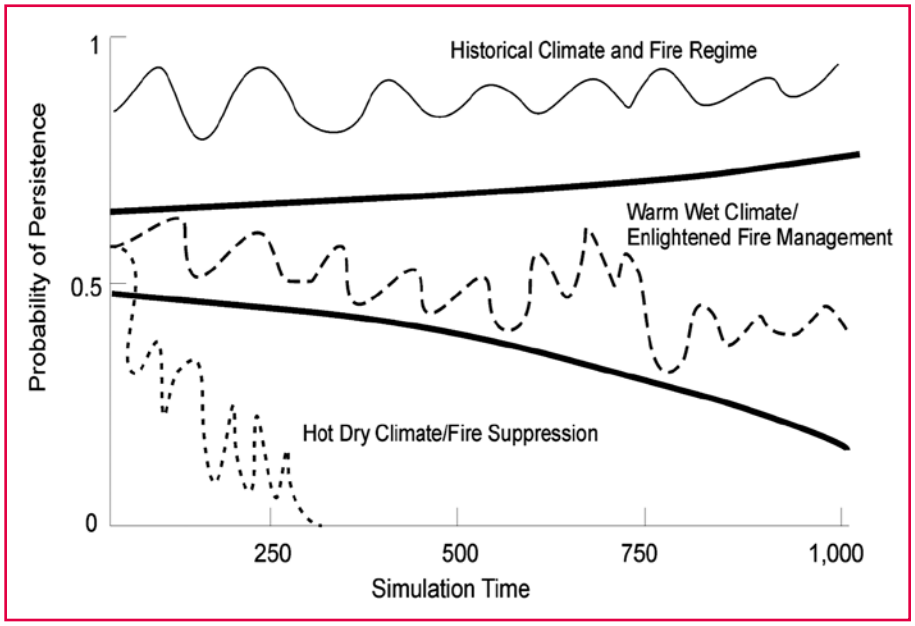

Figure 4—*Potential outcomes from simulations where bull trout persistence probability is evaluated (where 1 represents 100 percent survival and 0 is extinction) under various climate and fire scenarios.*

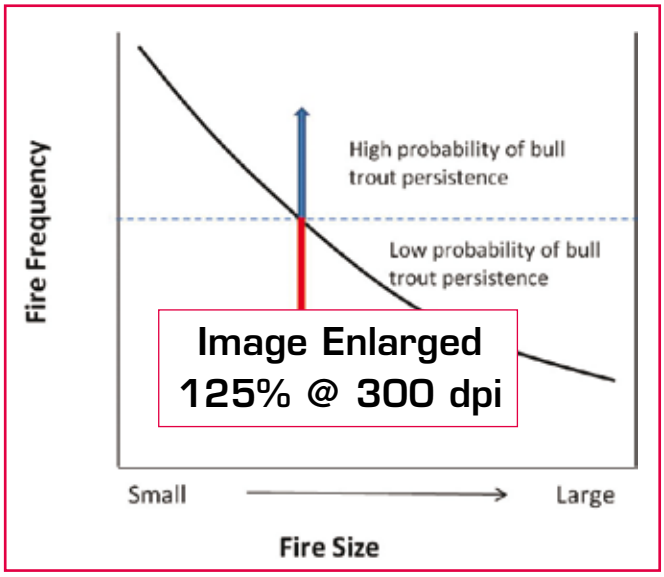

Figure 5—*Potential relationship of fire size and frequency where the dotted line across the curve represents the critical point where either persistence in bull trout is likely or extinction is predicted.*

thresholds, we will evaluate which factors, such as fire severity, fire size, vegetation, or fuels, result in large-scale, long-term changes in fish communities to better understand under what circumstances one might consider fire or fuel management.

- Similarly, we expect burn severity and fire size to affect fish populations. We expect large, high severity fires to have strong impacts on stream temperature and fish populations, depending on the amount of riparian area burned, and we expect little change with low severity burns (fig. 6). The magnitude and scale of response in mixed severity fires will likely be variable, depending on fire and landscape characteristics (fire behavior, topography, vegetation).
- Finally, we will evaluate the relationship of fire size and severity to the stream distance from burns at which temperatures become suitable for bull trout (fig. 7). We anticipate that stream distance appropriate for bull trout will increase with increasing fire size and severity.

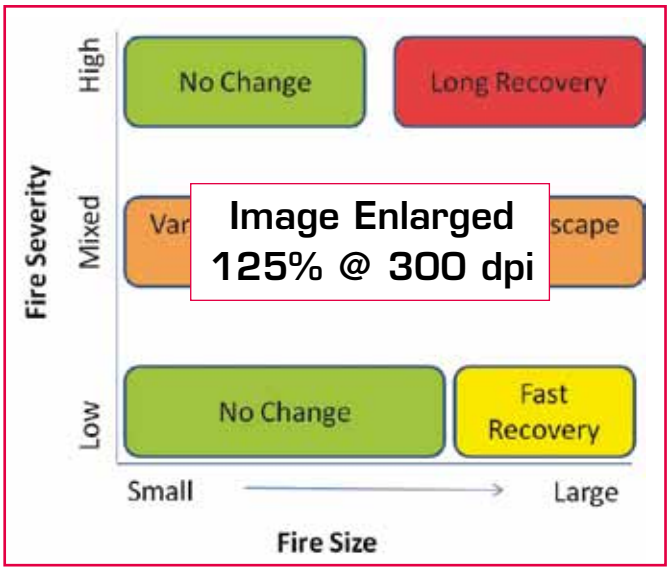

Figure 6—*Range of fire sizes and severity and the expected effects on native bull trout and cutthroat trout populations.*

Figure 7—*Possible relationship of fire size to the stream distance from those fires where stream temperatures become suitable for bull trout.*

At this stage, we are poised to begin our simulations and expect to be reviewing simulation results by summer 2011. Our goal is to develop information that offers a comprehensive approach for understanding how the occurrence and persistence of bull trout may vary with changing climate regimes. In particular, we hope to identify what fire and landscape characteristics pose higher risks to bull trout populations to help aid in their conservation and management under current and possible future climates.

References

Dunham, J.; Rieman, B.; Chandler, G. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. North American Journal of Fisheries Management. 23: 894–904.

Isaak, D.J.; Luce, C.; Rieman, B.E.; Nagel, D.; Peterson, E.; Horan, D.; Parkes, S.; Chandler, G. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. Ecological Applications. 20(5): 1350–1371.

Keane, R.; Ryan, K.; Running, S. 1996. Simulating effects of fire on northern Rocky Mountain landscapes using the ecological process model FIRE-BGC. Tree Physiology. 16(3): 319–331.

Keane, R.; Hardy, C.; Ryan, K.; Finney, M. 1997. Simulating effects of fire management on gaseous emissions from future landscapes of Glacier National Park, Montana, USA. World Resource Review. 9:177–205

Keane, R.E.; Morgan, P.; White, J.D. 1999. Temporal pattern of ecosystem processes on simulated landscapes of Glacier National Park, USA. Landscape Ecology. 14: 311–329.

Rieman, B.; Lee, D.; Burns, D.; Gresswell, R.; Young, M.; Stowell, R.; Rinne, J.; Howell, P. 2003. Status of native fishes in the western United States and issues for fire and fuels management. Forest Ecology and Management. 178: 197–211.

Rieman, B.; Isaak, D.; Adams, S.; Horan, D.; Nagel, D.; Luce, C. 2007. Anticipated climate warming effects on bull trout habitats and populations across the Interior Columbia River Basin. Transactions of the American Fisheries Society. 136: 1552–1565.

Westerling, A.; Hidalgo, H.; Cayan, D.; Swetnam, T. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science. 313: 940–943.