Project Title: Integrated analysis for management of fire and fuels, terrestrial and aquatic ecological processes, and conservation of sensitive species

Final Report: **JFSP Project Number 05-4-3-15**

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I. Abstract

The potential for fire to negatively impact habitat that supports a threatened or endangered species, either directly or indirectly through phenomena such as debris flows, presents resource managers with a tough choice: treat fuels to reduce the risk of fire but potentially degrade stream habitat or do not treat fuels knowing an uncharacteristic fire could jeopardize fish populations. The purpose of this study was to develop a decision support framework to assist managers in resolving this conundrum. We developed a population persistence model for stream fishes that uses existing GIS data and tools to resolve where and how human impacts and fire-related disturbance may affect stream fish. Using overlaid spatial data we are able to identify places where fire is most likely to produce net ecosystem benefits and areas where existing conditions suggest the need for restoration. The persistence model, that we call Integrating Forests, Fish, and Fire or IF3, can be used to evaluate how fire, as well as pre-fire management, is likely to impact stream habitat and resident fish populations. By melding the results of GIS analysis and persistence modeling we are able to identify areas where pre-fire management actions are likely to benefit fish populations by increasing their resilience to future fire activity. Using persistence as a "currency" of the value of proactive management for ecological resources prioritization provides a defensible means for identifying and prioritizing pre-fire habitat management over large areas. The tools we developed may be used independently or integrated into existing decision-support frameworks, such as the Fire Effects Planning Framework (FEPF; JFSP Project # 99-1-3-16).

II. Background and Purpose

In the western United States thousands of kilometers of streams containing sensitive, threatened, or endangered fishes wind through forest and rangeland where vegetation conditions could support uncharacteristic and potentially catastrophic wildfire. If there is evidence a wildfire could harm stream fish, proactive forest management could reduce risks. Unfortunately, traditional forest management, particularly roads maintained in support of these activities, may harm stream fish populations as well (Furniss et al. 1991). For populations located in forest stands where wildfire hazards suggest the need for proactive management, resource managers face the problem of determining which perturbation is least likely to harm stream fish.

As stewards of public resources, land management agencies conduct management actions with the intent of producing net ecosystem benefits. In the last 20 years, the most notable refinement of this paradigm has been the recognition that fire can be an efficient mechanism for maintaining forest health and suppression, therefore, is not always the most appropriate response to fire ignitions (Miller 2003). It goes without saying wildfire that threatens human lives and infrastructure will continue to be suppressed aggressively because of the relatively straightforward process by which the risk posed by wildfire to humans can be identified and quantified. For forest stands and ecological resources outside of the wildland-urban interface (WUI) terms like value, hazard, risk, threat, and benefit are more difficult to define (Rieman et al. In Review). Regardless of this difficulty, it is imperative resource managers have methods for identifying potential risks and benefits of fire in areas where ecological resources, like sensitive fish populations, may be impacted by wildfire.

The Fire Effects Planning Framework (FEPF; JFSP Project # 99-1-3-16) was designed to provide managers with information about the potential effects of fire activity and fuels treatment in forest stands. A significant contribution of FEPF is an emphasis on identification of potential *benefits* of fire including long-term maintenance of forest health, reduction in potential for future uncharacteristic fire, or maintenance or creation of critical habitat for sensitive species (Black and Opperman 2005). The impetus for the current study was to develop a related set of tools for evaluating risks and benefits of fire to aquatic habitat, particularly locations that support sensitive, threatened, or endangered species.

The major objective of this project was to develop a decision-support model that would help resource managers understand the potential impacts of fire and fire-related disturbances, such as debris flows, to stream fish populations. The resiliency of aquatic populations is determined by population status, the condition of stream habitat before a fire, and the size and intensity of a fire event. The model we developed incorporated these factors in order to estimate the probability an affected population would persist in the wake of a fire event.

A subordinate objective of the study was to apply this model in several fire-prone forests and disseminate the results of our analysis to resource managers. A challenge resource managers face when confronting fire issues outside of WUI is the difficulty of placing a value on ecological resources (Finney 2005). Conceptually post-fire persistence can be viewed as a "currency" of value assuming fish species being evaluated have some form of protected designation. We therefore undertook three case studies in watersheds in Idaho and New Mexico that contain bull trout (*Salvelinus confluentus*) and Gila trout (*Oncorhynchus gilae*). Both species currently receive federal protection under the provisions of the Endangered Species Act and are the object of intensive research, monitoring, and management by state and federal resource management agencies.

The major product of this study is a framework, analogous to FEPF, which allows resource managers to develop an understanding of where and how fire may affect sensitive fish populations within fire-prone forest stands. Persistence model results, as well as the GIS analyses that feed the model may be used independently or in conjunction with FEPF in order to provide resource managers of a comprehensive picture of fire-related management needs in forest stands supporting sensitive aquatic species. Pairing a high-resolution spatial analysis with persistence modeling can assist resource managers in prioritizing proactive habitat management projects, which is an improvement over map-based approaches that do not incorporate potential outcomes of fire or fire-related management on ecological resources.

III. Study Description and Location

The South Fork of the Boise River (hereafter SFBR; Figure 1) was the primary study area for this project. All methods and protocols for GIS-analysis, and persistence model development were based on analysis of the SFBR. We selected the SFBR for several reasons including 1) the presence of bull trout in close proximity to human infrastructure and fire-prone forest stands; 2) abundant physical and biological data; 3) cooperation of Boise and Sawtooth National Forest staff; and 4) no significant fire activity in the last 100 years.

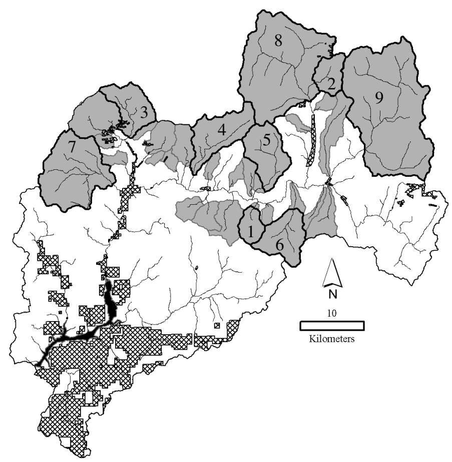

FIG. 1. The South Fork Boise River study area. Bull trout habitat is gray. Occupied bull trout patches are numbered. For this study, all private land (defined by cross-hatching) was classified as WUI but include human settlements, mining claims, and rangelands. In particular large portions of private land in the southern portion of the basin are operating ranches.

The study proceeded in three phases. During phase 1 we developed methods and protocols for a high-resolution, GIS-based analysis of a watershed. Phase 2 was the development of the population persistence model. In Phase 3 we applied the resulting decision-support framework in two additional watersheds.

The primary objective of the GIS analysis was to derive data describing human influence (i.e. roads and culverts), forest condition, aquatic habitat condition, fire-related threats (post-fire stream temperature changes and debris flows), and bull trout population status to be fed into a post-fire persistence model for bull trout. Spatial data describing roads and culverts, forest vegetation, and the size and location of bull trout habitat patches were available. We developed analytical techniques for describing potential post-fire stream temperature changes that could be detrimental to bull trout. We also identified probable initiating areas and transporting channels for post-fire debris flows using empirical rules for debris flow initiation and travel. Detailed descriptions of the methods associated with the GIS analysis can be found in Dare et al., 2009, See Section X *Reports*, below..

The spatial resolution of the GIS analysis was a stream catchment. We defined a catchment as the direct contributing watershed of a single stream segment. We defined stream segments as the section of a stream channel bounded on the upstream and downstream end by a tributary junction (Benda et al. 2004). The average area of a stream catchment in the SFBR was 45 ha and ranged between 10 and 200 ha. For each catchment in the SFBR we identified the following variables:

1) Area (ha)
2) Road density ($ha^{-1} \cdot ha^{2}$)
3) Isolated by a barrier (yes, no)
4) Vegetation composition, based on proportional area of potential vegetation groups.
5) Stream length (km) vulnerable to post-fire temperature increases that would be lethal to bull trout.
6) Probable debris flow initiating area (yes, no)
7) Probable debris flow transporting channel (yes, no)
8) Private land (yes, no; spatial data describing private land was used as surrogate for wildland-urban interface)

Juxtaposing this information with maps of potential and occupied bull trout habitat allowed us to classify the entire watershed into one of three landscape themes: WUI, wildlands, or restoration matrix (sensu Dellasalla et al. 2004). WUI, defined above, was all private land. Conceptually, fire-related management within WUI will always be based on aggressive fuels treatment and fire suppression. Wildlands are areas outside of WUI where terrestrial and aquatic habitat conditions are relatively pristine and potential for uncharacteristic wildfire is limited. Wildfires will likely be allowed to operate freely in wildlands. In between these extremes is a restoration matrix where aquatic habitat, terrestrial habitat, or both would require some form of active restoration before wildfires could be allowed to occur. Identifying these three themes on the landscape is critical to prioritizing potential management actions as well as determining an appropriate response to a fire ignition. Detailed descriptions of the conceptual basis and methods associated with identifying WUI, wildlands, and the restoration matrix can be found in Dare et al., 2009, See Section X *Manuscripts submitted for review*, below.

We built two Bayesian belief networks that estimated persistence probabilities for bull trout population exposed to fire. The models were designed to be used together to estimate persistence under a number of fire-related scenarios (see below). Population persistence was defined as the probability that a patch of stream habitat would support spawning and rearing in the wake of wildfire and post-fire disturbances. The likelihood of patch persistence was modeled as a function of the life-history diversity of the resident population, connectivity to surrounding patches, and patch size and condition. The models were built as Bayesian belief networks a format for decision support models with inherent flexibility and simplicity (Marcot et al. 2006, Pollino et al. 2007, Peterson et al. 2008). We used the belief-network software Netica (Norsys 1998) to build the persistence models.

The two models differed only in the manner in which fire size and severity affected population persistence. In the first (hereafter, Model 1), the vegetation composition of a patch determined probability distributions for fire size and severity based on relations described by Hessburg et al. (2007). Model 1 was intended to emulate the grain of historical fire severity through patch size distributions of fire effects, capturing natural levels and variability of disturbance to which bull trout populations have adapted over time (Dunham et al. 2003). Patch vegetation was not included in the second model (hereafter, Model 2) allowing users to define fire size and severity directly. The purpose of this simplification was to enable users to simulate large and severe wildfires that are statistically improbable based on historical fire size distributions (Alvarado et al. 1998, Hessburg et al. 2007), but may represent extreme events associated with changing climate or fuel accumulations.

We evaluated pre-fire management treatments within each habitat patch using the models. Management treatments we evaluated included 1) reconnecting isolated or fragmented habitat patches by removing barriers; 2) repairing or removing roads in patches where road density could be contributing to fine sediment loads in stream channels; and 3) treating fire-prone terrestrial fuels with varying intensity to limit the size and/or severity of future wildfires within habitat patches (see below). Each treatment produced a change in persistence probability. We documented the magnitude of change in persistence resulting from each treatment in order to evaluate alternative management approaches within each patch.

We evaluated five fuels treatment scenarios in the SFBR using Model 2. In fuels treatment Scenario 1, we assigned a baseline persistence value for each habitat patch in Model 2 based on the assumption that 100 percent of a given patch area would burn at high severity. We then compared this baseline to persistence predictions based on Scenario 2 - 50 percent of patch area burning at mixed severity and 50 percent of patch area burning at high severity; Scenario 3 - 100 percent of patch area burning at mixed severity; Scenario 4 - 50 percent of patch area burning at mixed severity and 50 percent of patch area burning at low severity; and Scenario 5 - 100 percent of patch area burning at low severity. These scenarios constituted a continuum of pre-fire management intensity, whereby fuels treatments would be least intensive under Scenario 1 and progressively more intensive to Scenario 5. Habitat characteristics of the nine occupied spawning patches for which the impact of the five scenarios were evaluated are summarized in Appendix D.

The first external application of the framework developed in the SFBR was in the Gila River watershed in New Mexico. The application in the Gila River was similar to that in the SFBR and involved a catchment-scale analysis of habitat conditions, particularly, habitat patch size and debris flow vulnerability. We generated a map of habitat patches and debris flow vulnerability for Gila trout and calculated post-fire persistence values using the IF3 models.

The second external application of the framework was in Clear Creek, a tributary of the South Fork of the Payette River, in central Idaho. Clear Creek is managed under the jurisdiction of the Boise National Forest's Lowman Ranger District. The District Hydrologist and Fish Biologist requested RMRS assist in the application of the IF^3 models to Clear Creek to identify potential restoration opportunities which may benefit bull trout populations. Clear Creek supports a small population of resident and migratory bull trout. Forest personnel were interested in understanding how fire could affect bull trout in Clear Creek as well as identifying potential fuels treatment opportunities that could minimize the potential for negative impacts of fire to bull trout.

IV. Key Findings

We found large portions of the SFBR, particularly those areas removed from human settlements to be in sufficient condition to be classified as wildlands. Our designation suggests these areas could support normal fire activity that is likely to result in net ecosystem benefits. Most bull trout habitat in the SFBR was classified as wildlands.

The size of the restoration matrix in the SFBR was nearly half the total area of the watershed. Restoration opportunities were most often related to terrestrial vegetation and roads and catchments within the restoration matrix were concentrated in the portions of the basin where human settlements were located. We expect the pattern of human influence and restoration need in the SFBR to be indicative of many watersheds in western North America.

Persistence modeling revealed bull trout populations were not likely to be harmed by fires characteristic of typical disturbance intensities for this watershed. Bull trout populations are likely to be affected by large, high-severity events that could be described as uncharacteristic. Persistence probabilities decreased by 0.10 to 0.50 when large, high-severity fires were simulated using the persistence models.

The potential for post-fire debris flows was widespread in the SFBR but do not appear to threaten bull trout populations in most habitat patches. Modeling suggests debris flows are likely to be restricted to high-elevation stream channels upstream from spawning and rearing habitat used currently by bull trout. Unfortunately, it is possible debris flows could become a significant threat to bull trout if climate change causes and upstream shift in the location of suitable spawning and rearing habitat.

Modeling in the Gila Wilderness Area suggests many habitat patches that support Gila trout are resilient to post-fire disturbances. Additionally, we identified stream channels in other parts of the basin that are candidates for future renovation and introduction of Gila trout. A brief narrative describing the analysis in the Gila River watershed is included in this report.

Bull trout habitat in Clear Creek is concentrated in high-elevation conifer forest that, if it burns, will burn at high intensity. This suggests the need to maintain connectivity to the mainstem of the South Fork of the Payette River in order to insure a migratory component to the population. The presence of a migratory life history will act as a buffer when fire-related disturbances occur near bull trout habitat. Opportunities for translocation of bull trout into other portions of the Clear Creek watershed are limited because of the likelihood of debris flow activity in downstream patches. A detailed report describing the application of the IF3 models in Clear Creek is included with this report.

We identified two pathways by which the results of IF3-based analyses could be integrated into FEPF. The first pathway involves using the high-resolution GIS analysis of aquatic habitat conditions to improve predictions using FEPF, particularly when ecological resources like fish habitat, are threatened by fire. The second pathway involves using the detailed analysis of fire behavior and effects that is part of FEPF to improve the fire component of the IF3 models. A narrative detailing the concepts and mechanics of FEPF integration is included with this report.

V. Management implications

Based on mapping modeling results, we conclude that the coincidence of fire-prone forests and sensitive fish populations does not immediately translate to a conflict between fire-related management needs and species conservation. Our results demonstrate that the potential for fire does not translate directly to risk to fish populations. Large, uncharacteristic fires are likely to have significant impacts; however, large and well-connected populations are still likely to be resilient in the face of these uncharacteristic events.

Proactive management to increase resilience of fish populations can be accomplished in a number of ways. Reconnecting isolated populations increases persistence probabilities substantially. However, we found that the most efficacious management prescription for one patch is not necessarily the best prescription for other patches. For example, in the SFBR we found that reconnecting isolated patches produced the largest increases in persistence probability but in patches fragmented by internal barriers, repairing these barriers produced smaller increases than limiting the size and severity of future fires. Management prescriptions are likely to be site-specific and the IF3-based approach allows decision makers to consider a variety of aquatic and terrestrial management options.

The IF3 framework is appropriate for proactive planning as well as incident-based decision making. From a planning perspective, the IF3 process allows for objective identification of restoration opportunities as well as prioritization decisions based on predicted post-fire persistence. Using the models to game with the results of specific changes in habitat condition or fire activity leads to defensible conclusions about where and how to allocate resources. For incident response IF3 modeling results can inform fire managers about where and how fire activity is likely to affect sensitive stream fish populations. Melding the mapping and persistence results with high-resolution fire analysis in FEPF provides managers with a wealth of information when fires move towards protected aquatic species.

While we did not expressly integrate climate change into the IF3 process the models allow us to explore the implications of increasing stream temperatures on stream fish population persistence. In the SFBR we found debris flow potential to be ubiquitous in high-gradient stream channels located in the upstream portions of bull trout habitat patches. At this time debris flows do not appear to be a significant source of risk to bull trout persistence because their effects are limited to upstream reaches where bull trout are not typically found. Unfortunately, if stream temperatures warm to the point bull trout habitat shifts upstream, debris flows may become a real threat to bull trout in the SFBR and other watersheds. Additional research and monitoring is needed to understand how the size and position of bull trout habitat patches could change and how changes may increase the risk of populations to debris flows.

VI. Ongoing work

See Future work.

VII. Future work

In the next year we will complete a validation study for the empirical rules of debris flow initiation and travel using historical debris flow information collected in the Boise River basin. The results of the validation study will be prepared for submission to a peer-reviewed journal.

In August 2009, we will take part in a 2-day workshop to discuss post-fire remediation within the South Barker Fire perimeter. This workshop is designed to discuss restoration and monitoring needs within the fire perimeter, including potential aquatic restoration actions.

We are developing a manuscript describing the implications of the IF3-based decision support framework for fire management within wilderness areas. At this time the manuscript is untitled but it will be submitted to the International Journal of Wilderness.

VIII. Deliverables Crosswalk

Proposed	Delivered	Status
Manuscript describing reasoning for spatial relationship based analysis instead of temporal integration models	Rieman, B. E., P. F. Hessburg, C. H. Luce, M. R. Dare. In Review. Wildfire and management of forests and native fishes: conflict or opportunity for convergent solutions?	In review for publication in BioScience.
Manuscript describing model logic	Dare, M. R., C. H. Luce, P. F. Hessburg, B. E. Rieman, A. E. Black, C. Miller. In Review. Native fish, fires, and landscape resilience: melding spatial data and decision-support tools to find joint solutions.	In review for publication in Ecological Applications.

Finalized decision support model integrated into FEPF	See Section X. Models, below.	Complete
Applications of decision support model	(1) SFBR, see Section X *Manuscripts submitted for review* below. (2) Gila Wilderness, See Section X *Reports* below. (3) Clear Creek, See Section X *Reports* below.	Complete

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X. Additional Reporting

Peer-review manuscripts:

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Graphics:

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*Models**:

IF3PersistenceModel.neta: Primary persistence model that evaluates fish population persistence based on fire activity modeled using historical fire size and severity distributions.

IF3GamingModel.neta: Secondary persistence model that evaluates fish population persistence based on user-defined fire size and severity. Gaming model used to evaluate large, high-severity fire events.

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*Use of these models requires Netica Bayesian modeling software.

Final Report

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Technology Transfer and Advisory Meetings

April, 2005. Effects of fire on watersheds and fish. Guest Lecture to University of Idaho FOR 426. *C. Luce.*

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September, 2006. Invited presentation of USFS Washington Office entitled "Strategic planning for restoration of aquatic and terrestrial ecosystems." *C. Luce.*

December, 2006. Presentation to USFS Region 6 biologists and hydrologists. *M. Dare.*

January, 2007. Presentation to Idaho Office of Wilderness Society providing project overview and research direction. *M. Dare, C. Luce, B. Rieman*.

January, 2007. Organized workshop for State, Federal, and Academic representatives involved in Gila trout management on Gila National Forest. One-day workshop designed to synthesize information about history and status of Gila trout management in relation to wildfire and non-native invasions. Albuquerque, NM. *M. Dare*.

February, 2007. Presentation to USFS Region 4 biologists and hydrologists. *M. Dare.*

September, 2007. Presentation to J. Cissel, JFSP Program Manager, describing JFSP Project #05-4-3-15. Boise, ID. *M. Dare, C. Luce*.

October, 2007. Met with Lowman Ranger District Hydrologist and Fish Biologist to discuss application of IF3 in Clear Creek, ID. Developed plan for use of IF3 in support of fuels treatment planning in Clear Creek watershed. *M. Dare*.

February, 2008. Met with representative from RMRS Fire, Fuel, and Smoke Science Program, to discuss integrating threats to ecological resources (IF3-based persistence predictions) into RAVAR for application in Region 1 of the USFS. *M. Dare, C. Luce*.

June, 2008. Integration is the Key to Success when Prioritizing Watersheds and Forest Management Actions to Maximize the Potential for "Good" Fire. Presentation to USFS Research Evaluation Team meeting, Boise, ID. *M. Dare*.

July, 2008. Overview of the IF3 Framework for prioritizing watershed restoration. Presentation to National Watershed Condition Class Workshop. Boise National Forest. Boise, ID. *M. Dare, C. Luce*.

August, 2008. Consulted with personnel from the Boise National Forest regarding construction of Bayesian decision support models and application of IF3 decision support model to terrestrial wildlife in the Boise and Payette National Forests. *M Dare, C. Luce*.

September, 2008. Consulted with personnel from Boise National Forest regarding implications of South Barker Fire to stream channels and bull trout populations in Willow Creek. Provided GIS data layers describing predicted extent of post-fire debris flows. *M. Dare.*

October, 2008. Two-day workshop for USFS Rocky Mountain Research Station Director. Described technology transfer of IF3 to Clear Creek, ID. *M. Dare*.

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