Predicting Effects of Climate Change on Aquatic Ecosystems in the Great Northern Landscape: Combining Vulnerability Assessments, Landscape Genomics, and Modeling for Conservation

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Agency Partners: U.S. Geological Survey, The University of Montana, Crown Mangers Partnership, Flathead Basin Commission, Glacier National Park, U.S. Forest Service, U.S. Fish & Wildlife Service, Montana Fish, Wildlife & Parks, Confederated Salish and Kootenai Tribes, Montana State University

Project Summary:

Global climate change is expected to dramatically impact the structure and function of freshwater systems, yet no studies have comprehensively assessed the potential effects of climate change on aquatic ecosystems in the Great Northern Landscape. The proposed research aims to build on an existing climate change research project focused on hydrologic and thermal effects on foodwebs, native salmonids (threatened bull trout and westslope cutthroat trout), and lotic habitats in the transboundary (US and Canada) Flathead River system. The project will apply new and existing techniques for combining downscaled climate spatial data with fine-scale aquatic species vulnerability assessments (invertebrates→fish), population genetic data and remotely sensed riparian and aquatic habitat analysis. Results may be used to identify populations and habitats most susceptible to the impacts of climate change; develop monitoring and evaluation programs; inform future research needs; and develop conservation delivery options in response to climate change and other stressors (e.g., habitat loss and invasive species) that are often complicated or exacerbated by climate change.

Need for Project:

Climate change poses a serious threat to natural resources, biodiversity, and ecosystem services in the United States (Botkin et al. 2007) and especially in the Rocky Mountain Ecoregion (Hauer et al. 1997). Increasingly, natural resource managers require scientifically robust and regionally relevant information on climate change and associated variability to assess key impacts and species sensitivities to future climate conditions. Global climate change is expected to dramatically impact the structure and function of freshwater aquatic ecosystems. Regional climate change in the interior West is expected to result in increased stream temperatures, modify hydrologic regimes, and increase the amount and frequency of disturbance events (Pederson et al. 2010). These climatic changes combined with species-specific tolerances to regime extremes (e.g., critical temperature thresholds) will likely result in significant changes in the distribution, abundance, and genetic diversity of many aquatic species (Hall et al 1992), particularly inland salmonids (Rahel et al. 1996, Rieman et al. 2007; Haak et al. *In-press*). Therefore, an understanding of the potential impacts of climate change on aquatic ecosystems is needed to develop and implement pro-active conservation, recovery, and management programs at regional and watershed scales in the Great Northern Landscape Conservation Cooperative (GNLCC).

The Crown of the Continent Ecosystem (CCE) is considered one of the largest, most pristine, intact, and biodiverse ecosystems in North America (UNESCO 2010). The CCE is located at the narrowest point in the Rocky Mountain cordillera where four main climatic zones converge – Arctic/boreal, Alpine, Pacific temperate and Eastern grasslands. There are reported to be more than 1,200 species of vascular plants, 70 species of mammals, including all North America's native carnivores, 270 species of birds and 25 species of fish among an aquatic life richer than any place in the Rockies between the Yukon and Mexico including 400-600 species of aquatic insects, many of which are endemic and rare. On the western boundary of the CCE, is the Transboundary Flathead Watershed, a significant portion of which forms Waterton-Glacier International Peace Park, a World Heritage Site and Biosphere Reserve. The Transboundary Flathead River (North Fork) originates in British Columbia and flows into Montana and is considered one of America's wildest and most biodiverse river systems. Its water quality is pristine, it harbors abundant and diverse aquatic life, and it has long been recognized as a range-wide stronghold for two hallmark native fish species, the bull trout (*Salvelinus confluentus*), listed as a threatened species under the Endangered Species Act, and the westslope cutthroat trout (*Oncorhynchus clarkii lewisi*), a species of special concern.

Since the mid 1970's, however, this globally unique river ecosystem has been continuously threatened by British Columbia plans of strip mining for coal and industrial development. In 2007, British Petroleum announced plans for coal-bed methane development in the basin. The swift and successful response included three elements: a careful scientific analysis, a fact-finding mission that respected the scientific input, and a productive diplomatic relationship that resulted in policy changes (Hauer and Muhlfeld 2010). In September 2009, a joint United Nations Educational, Scientific, and Cultural Organization (UNESCO)/International Union for Conservation of Nature fact-finding mission visited the Flathead in Montana and British Columbia and their report concluded that mining in the Flathead would be "incompatible" with Waterton-Glacier as a World Heritage Site (UNESCO 2010). Furthermore, the report stated that future research and conservation should focus on addressing the compounding issues associated with global climate change: *"The Flathead is regarded as one of the last of America's remaining wild rivers and of global ecological significance….and recognizing the clear evidence for ecological and environmental stress under changing climatic regimes, specific programs of management and associated monitoring and research should be developed to combat climate change impacts. Adaptive management strategies should give emphasis to enhancing the resilience and capacity of wildlife and plants in adjusting to changing environmental conditions".*

Salmonids and aquatic invertebrates provide an excellent early warning indicator of climate warming because their body temperature is dependent on the temperature of their surroundings, and they have characteristically narrow tolerances of thermal fluctuation (Williams et al. 2009). Bull and cutthroat trout require the coldest water temperatures of any native northwest salmonid, clean stream bottoms for spawning and rearing. Many aquatic insects have very narrow thermal tolerance and are highly habitat-specific in their distributions. Among the salmonids, complex habitats built from the connections between river, lake, and headwater streams support annual spawning and feeding migrations; unique behaviors that maintain genetic diversity and adaptive potential.

As the CCE (and indeed all of the Great Northern Landscape) undergoes rapid change as the regional climate continues to modulate with strong trends toward a warmer-drier regime, understanding how climate change will influence habitat for various sensitive aquatic species is critical for pro-active conservation and recovery programs for "at risk" populations and critical habitats in the Great Northern LCC. There is an urgent need to collect and assimilate historical and contemporary climate and aquatic species information and conduct vulnerability assessments for fish and invertebrate populations and habitats most susceptible to the potential impacts of climate change in the GNLCC. Further, there is a need to develop population and habitat models to enhance conservation and responses to climate change and other existing stressors (e.g., land-use and invasive species). Additionally, there is a need to identify biologically meaningful physiological thresholds (e.g., temperature) to inform vulnerability assessments.

Current climate research in the Flathead system provides an ideal opportunity to build on this framework to include vulnerability assessments on trends and connectivity of rare and sensitive macroinvertebrate species in this heterogenous watershed. Results may be used to identify populations and habitats most susceptible to the impacts of climate change; develop monitoring and evaluation programs; inform future research needs; and develop conservation delivery options in response to climate change and other stressors (habitat loss and invasive species) with broad application that reaches beyond the Flathead system in the GNLCC. Indeed, the Transboundary Flathead and the ongoing research, policy applications, and political complexities has many of the elements specifically coherent with the goals and objectives of the GNLCC; thus, the proposed activities described herein can be viewed as a unique opportunity to set a strong pace for future GNLCC development.

Overarching Goals:

We propose a regional assessment of aquatic species vulnerabilities and responses to climate change as the basis for adaptive management for aquatic ecosystems in the Great Northern LCC, using the Transboundary Flathead Ecosystem as a case example. This region encompasses a complex mix of federal, state, tribal, and private lands in the US and federal, provincial and private lands in Canada. The complex suite of ownerships, international relations, and agency objectives establish their own set of challenges; however, all will experience a similar range of climatic (e.g., long-term drought and declining snow pack) and non-climatic (e.g., habitat fragmentation, shifting land- and water use patterns, and invasive species) changes requiring coordinated management and planning.

Role of Existing Climate Change-Related Projects - Global climate change in the GNLCC region is likely to increase air and water temperatures, increase the risk of catastrophic fire, and change the timing and quantity of water available from snowpack. To better understand and assess potential effects of climate change on aquatic ecosystems, habitat, foodwebs and native salmonids in the Northern Rocky Mountains, we will build the research agenda for this project on a platform of collaborative and supporting research.

Foodwebs – We are completing a freshwater invertebrate analysis of stream and river sites that were particularly at risk to the effects of the proposed coal mining in the headwaters of the Tranboundary Flathead in Canada (*Environmental Assessment of Baseline Conditions and Evaluation: Glacier National Park and the Flathead Basin Threatened by Coal Mine and*

Coalbed Methane Development, R. Hauer, PI). Data and analysis from that effort leads into the objectives of this project. Thus, we will build upon existing methodologies and additionally link directly with the sampling protocols of the fish component of the project (given below). This is particularly important as we develop spatially-explicit temperature and hydrologic models of stream response to climate change. The objectives of the ongoing research are to: (1) synthesize current data on the distribution and abundance of stream invertebrates; (2) work with the fish component to compile all current and historic data for water temperature, air temperature, flow and precipitation; (3) map the distributions of key-indicator species in a GIS framework.

Fish - We will use and build upon existing methodologies and climate change outputs from a USGS fine-scale modeling project in the upper Flathead River system (*The Potential Influence of Changing Climate on the Persistence of Native Salmonids at Risk*, C. Muhlfeld, Co-PI). The fine-scale submodels use high resolution, site-specific data in a spatially-explicit geographic information system (GIS) framework to examine risk associated with increasing temperatures, modified hydrologic regimes, and disturbance events for threatened bull trout and westslope cutthroat trout. The objectives of this ongoing research are to: (1) synthesize current data on the distribution and temperature requirements of native bull and cutthroat trout; (2) compile all current and historic data for water temperature, air temperature, flow and precipitation, and their relationships to biotic and abiotic covariates; (3) assess the relationship of these factors and the distribution (occurrence) of each focal species; (4) map the current fish distributions, temperatures and habitats in a GIS framework; (5) explore the distributions of thermally and hydrologically suitable habitat for each species and life history type under various climate change scenarios; and (6) identify populations and species that are at greater risk of extirpation in the face of climate change.

Aquatic and Riparian Habitat – We have developed advanced techniques for the analysis of riparian habitat and river hydraulics and habitat using high resolution (5 – 10cm) airborne remote sensing imagery and tools developed specifically for the CCE during specific NSF-funded research and development. We will build upon these methodologies to integrate specific climate-change outputs for this project. The objectives of the on-going research are to 1) acquire the remote sensing imagery for the North Fork corridor from headwaters to the confluence of the Middle Fork., 2) integrate the imagery into a GIS framework, and 3) develop riparian and hydraulic habitat maps along the North Fork Corridor. (We are including imagery and analysis/classification of that imagery in Appendix A of this proposal as an illustration of the new methodologies in remote sensing employed by this research team).

Specific Research Objectives:

Through this project we propose to build on these three existing research components (Foodwebs, Fish, Aquatic and Riparian Habitat) by incorporating the following objectives:

(1) Develop vulnerability assessments for rare and sensitive macroinvertebrates in the Flathead system, which will produce climate projections for a host of aquatic biota at multiple trophic levels in the food web (e.g., ecosystem approach);
(2) Apply new and existing techniques for combining downscaled climate spatial data with population genetic data to monitor and predict effects of climate change on connectivity, gene flow, and persistence for bull trout and westslope cutthroat trout populations;
(3) Assess the physiological thresholds (e.g., temperature and flow tolerances) and responses of these aquatic organisms (fish and key-indicator invertebrates) using controlled laboratory experiments in an artificial stream at the Bozeman Fish Technology Center.
(4) Extend the remote sensing from the North Fork river corridor to headwater tributaries where much of the connectivity and response to variation in thermal and hydrologic regimes will be played out.

Objective 1: Vulnerability assessments for rare and sensitive macroinvertebrates - Understanding how climate change will influence macroinvertebrate populations, their persistence and vulnerability to invasive species (e.g., zebra mussel), and the adaptability of species to thermal and hydrologic change. Maintaining macroinvertebrate populations requires preservation specific habitats that will be under threat from the expected changes in climate. While it is likely that the most abundant of stream habitats will persist, the habitats that are relatively rare and sustained by snowpack and slow hydrologic regime release are at great risk. We will need a landscape level assessment combining existing data from the BC headwaters, GNP, and additional lands on the west side of the NF to resolve regional sustainability of a bio-diverse foodweb.

Our objective is to develop and apply novel techniques for linking downscaled and spatially explicit climate data to the specific distributions of key-indicator species. Outputs from both the high-resolution GCM regionalized to the GNLCC will be linked with the habitat remote sensing data to derive distribution analysis and spatially-explicit forecastings of macroinvertebrate response to projected climate change.

Objective 2: Landscape genomics - Understanding how climate change will influence population persistence, connectivity (both demographic and genetic connectivity), and invasive species is increasingly urgent for management and restoration of interior species of native salmonids. Maintaining populations and their adaptive potential requires preservation of life history variation, connectivity corridors among populations, and genetic variation within and among populations. Genetic connectivity (gene flow) can now be assessed with great precision for both 'neutral' and adaptive gene markers. This genetic variation can subsequently be associated with physical and environmental features at increasingly fine spatial scales to model and predict spread of neutral and adaptive alleles across landscapes and river networks (Luikart et al. 2003).

Our general objective is to develop and apply novel techniques for combining downscaled climate spatial data with population genetic data to monitor and predict effects of climate change on connectivity and persistence for bull trout and westslope cutthroat trout populations in the Flathead system that are sensitive to climate change. Outputs from high-resolution GCM data (S. Hostetler, USGS) and fine-scale climate models will be used with novel genetic markers (in adaptive genes) in populations of native trout in the Flathead River system. Specifically, the proposed analysis will provide spatially-explicit connectivity (gene flow and dispersal) models, standardized genetic monitoring tools, and information immediately useful to managers about where barriers (thermal and hydrological) and disturbances (wildfire, debris flows) are likely arise and fragment populations. These models, tools, and information are crucially needed to predict and prevent population extirpations, introgressive hybridization, and replacement of native tout populations with invasive trout. This research will inform restoration programs in the context of climate change, including the control/suppression of nonnative fish species, protection of aboriginal populations, and by improving habitat conditions to improve the survival and the long-term persistence of critical populations.

Objective 3: Physiological assessments - Temperature, flow, and photoperiod are the primary environmental cues that entrain the timing of gamete maturation and the spawning cycle of fishes. Our understanding of the relative importance of each of these environmental drivers and the magnitude of each driver required to elicit gametogenesis and a spawning event in bull and cutthroat trout is limited. Water temperature has been found to strongly influence survival, growth, and competitive ability (e.g. Selong et al., 2001; Bear et al., 2007), as well as the distribution and population status of westslope cutthroat trout (Muhlfeld et al. 2009). However, the physiological thresholds and well-defined photoperiod, temperature and flow tolerances related to successful gametogenesis and spawning have not been determined for these species. Understanding the physiological responses and sensitivity (i.e. shifts in gametogenesis and spawning time, spawning success, developmental rates of embryo and larvae, and ultimately recruitment success) of these species to predicted changes in temperature and flow with an associated forecasted shift in photoperiod is paramount in our efforts to predict climate change effects on habitat and the adaptive potential of fish populations.

Objective 4: Remote Sensing of Habitat - Fundamental to understanding the distribution and abundance of species and their potential response to climate change is quantifying biophysical space (habitat) used by species or (among highly motile species) in different life stages that promotes successful growth and reproduction. Conservation biologists sometimes refer to locally adapted populations with habitat-specific distributions or life cycles as ecologically significant units. However, habitats are constantly changing as units within a changing landscape. Physical and biological attributes of a landscape vary in time and space and interact to determine quantity and quality of specific habitat. Sufficient habitat is required for species to persist in a landscape and, of course, a given landscape is composed of multiple gradients and species responses. Often feedback mechanisms are complex and nonlinear, making habitat for each species in the landscape very difficult to define. Nonetheless, quantifying habitat for species in very specific spatial and temporal terms is fundamental to conservation of biodiversity.

The objectives in this component of the proposed project are to: 1) quantify, in a spatially explicit way, stream channel habitats (e.g., riffles, runs, pools), various riparian habitats (e.g., forest, shrub and wetland complexes), and potential sites of subsurface habitats of low and high hydraulic conductance of ground water (e.g., the hyporheic zone); 2)link these habitat markers specifically to the distribution of foodweb species and the the distribution of the various critical life histories of bull and cutthroat trout (especially within the context of their genomic variation); and 3) link trajectories of habitat change (persistence or spatial change) with the regionally downscaled climate models. Understanding the processes and the habitat structure associated with critical habitats of the Transboundary Flathead will be crucial in any long-term diagnosis of effects due to climate change.

Methods:

Overview of methodological approachs - We will structure this project to perfectly dovetail with our currently funded NPS projects (Hauer) and USGS (Muhlfeld) projects under the NCCWSC underway in the Transboundary Flathead Basin. We will also use the outputs of regional climate models (e.g., RegCM3) that simulate climate resolutions of 50 and ~12 km using existing statistically downscaled data of some subset of the AR4 IPCC global model output (S. Hostetler, USGS). We have also developed hydrologic, thermal, and geomorphic models to downscale climate effects to stream habitats in each basin, and have developed biological models that predict trout population attributes from stream habitat. When coupled with our proposed stream corridor/hydraulics habitat analysis through our remote sensing (refer to Appendix A), we will have direct linkage between the downscaled climate models, the habitats that lead to specific thermal and hydrologic regimes, and the geospatial analysis of the distribution and abundance of those habitats. We will also use these climate models to predict changes in habitat distributions and risks posed to trout and key-indicator invertebrate populations throughout stream networks of the Transboundary Flathead Basin for a range of plausible climate scenarios. These data will be combined with new genetic data of the two fish species using spatially-explicit 'landscape genomic' modeling approaches (Manel et al. 2003; Kalinowski et al. 2008) to project effects of climate change on trout.

Approach of Objective 1: Macroinvertebrate vulnerability assessment- Our research will 1) link in novel ways species distributions with climate and habitat model output, 2) identify spatially-explicit temperature and flow models that lead to habitat change, and 3) provide future casting scenarios that allow analysis and synthesis of management actions that may enhance sustainability of stream foodwebs. We propose to integrate our invertebrate distribution data by incorporating biological information on key-indicator, rare and sensitive species with both the downscaled climate models and the remote sensing habitat analysis. [We will also incorporate the invertebrate data from the NPS Vital Signs project in GNP (Schweiger and Hauer in prep). Over 300 species of macroinvertebrates from the three aquatic insect orders Plecoptera (stoneflies), Trichoptera (caddisflies) and Ephemeroptera (mayflies) occur in the Flathead system. This extremely high aquatic biodiversity is unparalleled anywhere in the Rocky Mountains from New Mexico to the Yukon. Many of these species are endemic to the CCE. Climate change posses are real threat to the biodiversity of the aquatic foodweb in streams as thermal, hydrologic and riparian habitat changes in response to fundamental drivers.

Approach of Objective 2: Landscape genomics - Our research will 1) develop novel standardized DNA markers in important functional genes genome-wide using SNPs, 2) using existing DNA samples and genotype bull trout and westslope cutthroat trout, 3) identify spatially-explicit temperature and flow models that best correlate with connectivity and hybridization, and finally (4) predict where future barriers and corridors are likely to exist by using simulations of movement of individuals across forecasted future stream networks using movement rules validated using current and past connectivity models. We will develop DNA markers in neutral and adaptive genes using 1000s of SNPs (single nucleotide polymorphisms) for population genetics and identification of hybrids in bull trout, cutthroat trout, and rainbow trout . This development is feasible within 6 months because collaborators are currently conducting large-scale SNP discovery using genomics technologies. Enormous advantages of SNP data over microsatellite data (which are currently widely used) is that SNP data can be easily compared and standardized among laboratories (microsatellites cannot), SNPs can be found in adaptive genes and genotyped at far lower cost. Next, we will genotype 100-200 SNPs from fish from existing contemporary samples. Samples will be relatively evenly-distributed across the stream networks so that novel individual-based genetic analyses can be conducted along with traditional population-based landscape. Third, we will identify models best explaining connectivity and hybridization. To identify stream and climate features that influence genetic variation, gene flow, and hybridization, we will calculate correlations between genetic variables (e.g., variation, genetic distances) and the stream cost-distances between all pairs of individuals for each of many alternative stream movement/resistance hypotheses (i.e. models). Models with highest support will be used to project effects of climate change on gene flow and hybridization. Finally, we will project effects of climate change on connectivity, hybridization and persistence. To forecast how future stream and climate changes will alter connectivity, hybridization, and persistence, we will use available projections of future stream characteristics (flow, temperature etc.) to parameterize resistance surfaces on which individual fish will move according to the movement costs identified in models from Task 3. We will use individual-based spatially-explicit computer simulations models as we have developed and described in recent work (Landguth and Cushman 2009; Kalinowski et al. 2008).

Approach of Objective 3: Physiological assessments - Artificial stream channels have been used successfully to spawn salmonids and sturgeon and determine spawning behavior and habitat requirements (Berejikian 2000, 2001; Kynard et al. *In press*). An artificial stream will be built at the Bozeman Fish Technology Center that will allow control of water temperature (8-22°C), flow (0 – 175 cm/s), and photoperiod. The stream will be approximately 1.5 m wide, 20 m circumference with a center wall (island) separating the river channels. Water velocity will be created and controlled using a combination of propeller-driven water propulsion systems, pumps and water jet propulsion systems, eductors, and louvers. Substrate composition will mimic those in the headwaters habitats of our species of interest. This artificial stream will allow us to determine the physiological responses to physical changes (e.g. flow and temperature) to their environment under various photoperiod regimes. We will determine the relative importance of these environmental drivers and over time will be able to look at the adaptive potential of fish populations to habitat alterations resulting from climate change. As bull trout are fall spawners, trials will be initiated in the fall of 2010.

Approach of Objective 4: Remote Sensing of Riparian and Aquatic Habitat -

We have developed over the past 5 years the technology of collecting and processing airborne remotely sensed data (ARS) for the purpose of habitat evaluation and analysis. Airborne remotely sensed data are collected with ultra-high resolution multispectral imagery system deployed from the FLBS/UM research aircraft Cessna 185. We will collect imagery in mid-summer for land cover classification. A combination of supervised and unsupervised classifications will be used to produce a land cover map for each study reach (see Appendix A). First, an unsupervised classification will be used to discriminate between vegetative cover and non-vegetative cover (i.e. vegetation vs cobble and water). This will be followed by a supervised classification approach for the vegetative cover. To help discriminate among different vegetation types, homogeneous stands of the varying cover types (e.g., cottonwood, willow, water, cobble, dry grass) are identified and associated with specific spectral signatures. These specific imagery signatures are used as "training areas" to classify the image into the different land cover types. Mean spectral signatures are calculated for each cover type and subsequently used in a supervised classification. Using the spectral signatures, the Mixed Tune Matched Filtering (MTMF) algorithm in ENVI (RSI 2000) is then applied to the vegetative component of the imagery to discriminate the varying vegetation types. For each reach, a final land cover map is produced consisting of dominant cover types (i.e., water, cobble, deciduous – predominately cottonwood, willow, mixed grasses, dry grasses, and shadows).

This method of classifying vegetation is a significant departure from approaches involving digitizing and photo-interpretation. We are able to take this approach to conduct an integrated supervised and unsupervised classification because of the application of the spectral imagery allowing vegetation specific differentiation. We are also then able to conduct various analyses on the vegetation coverage of the riparian corridor that would not otherwise be feasible using traditional photo-interpretation methods. Remotely sensed data of stream segments will be analyzed for vegetation complexity and patterns of patch types and corridors linkage with foodweb and fish species use. All ARS data will be processed at FLBS GIS lab.

Deliverables:

- High resolution climate data sets produced by our regional climate models (2011)
- High resolution (<1m) habitat classification and analysis of selected and representative stream reaches (from alpine to valley floor)
- Fine scale species distribution modeling with supportive data with scenarios for agency conservation strategies and conservation efforts (2011)
- Data sharing in the GNLCC [Data will be made available to resource managers dealing with aquatic systems, including the Crown Managers Partnership, USGS, FWS, USFS, BLM, state management agencies, and private organizations (e.g., Trout Unlimited) (2011-2014)]
- Species-specific decision support tools (Bayes nets) will be made available from the USGS fish-climate project that will incorporate our results. These will be portable, and

designed to permit fish managers to quickly and efficiently assess extinction risk and the outcome of management actions (2012)
- Workshops to present the results and decision support tools to managers and provide hands-on training (2012-)
- Multiple peer reviewed publication(s) of the study (2010-2)

Overview Budget

2010 Budget*

	FY2010
1. Operation Expenses	
Genetic Analyses (SNPs development)	15,000
Invertebrate Analysis	20,000
Travel	5,000
2. Supplies and Equipment	5,000
3. Salaries	
Climate Modeler	35,000
Remote Sensing GIS	20,000
4. Direct costs	100,000
5. Indirect costs (DOI or CESU rate 17%)	17,000
TOTAL (with indirect costs)	117,000
6. Major equipment**	25,000
Total Project Costs	142,000

***2010 Budget:**

- This is an ongoing research project and is expected to take at least five years (2010-2014) to finish.
- Funding is requested for 2010 and is intended to begin the additional work specified herein.
- Budgets are expected to increase in subsequent years.
- The objectives and budget specified herein shall be cooperatively supported by approximately $500K funding to Hauer on the North Fork 2005-09 including ~$100K of existing funding (2010) as direct cooperative to the 2010 funding period requested in this budget; and, approximately $125K/year funding to Muhlfeld, also as direct cooperative to the funding period requested in this budget. [Summary: we have in hand for 2010 approximately $225K as cooperative matching funds from other federal sources to provide much of the framework for the proposed components of the project described herein]
- The budget provided here are as costs within large categories. Detailed budgeting will need to be completed between the funding agency and the CESU recipients.

**This is a major equipment cost that stays with the USF&W, but is a component of the cooperative project described here.

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