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#057

Habitat Enhancement in the Upper Klamath Basin - Completed Projects and Future Opportunities

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Since 2001, River Design Group, Inc. (RDG) has collaborated with resource agencies and landowners to enhance habitat in the Sprague River watershed. Sprague River restoration projects, along with tributary stream restoration and fish passage projects, have followed guidance outlined in the *Master Plan for the Restoration of the Sprague and Sycan Rivers near Beatty, Oregon* as well as other planning documents prepared by U.S. Fish & Wildlife Service, the National Research Council, and Oregon Department of Environmental Quality. Projects have included historical channel reactivation, large wood placement, floodplain revegetation, off-channel habitat enhancement, and livestock management. These activities are intended to improve habitat conditions for target fish species including federally endangered Lost River sucker *Deltistes luxatus* and the shortnose sucker *Chasmistes brevirostris*, and federal species of concern Klamath largescale sucker *Catostomus snyderi* and Klamath redband trout *Oncorhynchus mykiss newberrii*.

In 2009, with funding provided by the Natural Resources Conservation Service, USFWS, and the U.S. Bureau of Reclamation, RDG completed the last of three mainstem Sprague River projects recommended in the *Master Plan*. Each of the three projects included reconstructing historical channel alignments that were abandoned due to channel avulsions. Channel avulsions are common features in the Sprague River corridor and are believed to be related to historical grazing practices, beaver loss due to trapping, and accelerated sediment delivery caused by upstream river straightening. The project designs utilized surface models comprised of merged LiDAR and bathymetry data provided by The Klamath Tribes. One-dimensional hydraulic models, calibrated with known stage-discharge data collected at the USGS Beatty stream gage, were developed to understand existing conditions and evaluate proposed channel hydraulics. Post-project monitoring observations were also applied to improve subsequent projects. The 2009 projects included reactivating 3,700 ft of historical Sprague River channel, installing over 25 large wood habitat structures, revegetation, and filling the existing channel with excavated soils.

In addition to the restoration opportunities on the Sprague River, Fishhole Creek, the largest tributary to the South Fork Sprague River, offers opportunities for restoring fish passage, geomorphic processes, in-stream and riparian habitat, and channel stability. Successful projects have provided many examples of how restoration can be implemented that benefits both the landowner and ecological habitat restoration. Continuing to engage landowners and offering conservation incentives are recommended pathways for expanding ecosystem restoration in the Sprague River watershed.

#109

The Past, Present, and Future of the Williamson River Delta: Big Changes in the Upper Basin

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One of the largest and most significant restoration projects in the Upper Klamath Basin was recently completed on approximately 5,500 acres of the Williamson River Delta. This $8.7 million project was designed to re-establish the

hydrologic connection between Agency Lake, Upper Klamath Lake, the Williamson River and the Williamson River Delta, thereby restoring deltaic wetland ecosystem function to as close to historical condition as feasible for the benefit of two primary objectives: 1) to restore habitat for larval and juvenile Lost River and shortnose suckers, and 2) to improve water quality conditions in Upper Klamath Lake.

In 2006 restoration occurred on the north half of the Delta. Initial steps involved creating a restoration design plan, having construction companies bid on the proposed design, choosing a company to do the earthmoving work, and beginning the process of removing levees, filling toe drains, and recreating historic flow paths through the Delta. Klamath Tribal members monitored all ground disturbing activities to insure that cultural resources were not disturbed. In year one 700,000 cubic yards of material was moved on the north and south halves of the Delta, and restoration proceeded ahead of schedule. In 2007 we used explosives to remove two miles of levee, used mechanical means to remove levees along the Williamson River, and lower the perimeter levees between the main levee breaches to below the high water mark. Over one million cubic yards of material was moved in 2007. In 2008, we moved over 800,000 cubic yards of material, sculpting riparian benches and breaching lakeshore levees on the south half of the Delta. Additional earthwork completed in 2009 helped refined previously work to better achieve the desired outcomes.

We developed a monitoring program to assess the results of this restoration on endangered suckers and water quality in the lake; preliminary results re-affirm that suckers are benefitting from the restored habitats. We believe the long-term benefits of this project will aide in the recovery of the two endangered suckers and lessons learned from this project will help inform future restoration of additional lake-fringe wetlands at the north end of Upper Klamath and Agency Lakes.

The was a project of partners, funded and supported by the National Fish and Wildlife Foundation, Natural Resources Conservation Service, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Oregon Watershed Enhancement Board, North American Wetlands Conservation Council, PacifiCorp, Environmental Protection Agency, Ducks Unlimited and the Klamath Tribes.

#110

Monitoring Fishery Effects of Salmonid Habitat Restoration

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Considerable resources are devoted to salmonid habitat restoration on the Klamath River. Restoration efforts have typically focused on limiting factors such as water quality and fish passage – with considerable attention now being given to dam removal itself. Monitoring is a critical though often under-funded aspect of restoration. Moreover, even though restoration is often intended to enhance salmon populations and fisheries, monitoring (when it does occur) focuses almost exclusively on population effects – or at least on limiting factors affecting populations. In cases where restoration is intended to enhance fisheries, fishery monitoring is also important and should be conducted with the same rigor as physical or biological monitoring. For instance, fishery monitoring should be conducted pre-restoration and not just “after the fact” to provide an adequate basis for comparison. Given the complex nature of fishery behavior, it is also important that monitoring include collection of economic and other data that allow the effects of restoration to be distinguished from other factors that also influence fishery behavior. Ideally monitoring should provide an opportunity to derive “lessons learned” that can be applied to similar restoration projects on other rivers. This presentation discusses data needs for monitoring fishery effects associated with major salmonid restoration projects, existing gaps in such data, and how those gaps might be filled.

#093

Restoration Prior to Dam Removal: the Key to a Low-impact Dam Removal Strategy?

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In early 2009 the California State Coastal Conservancy released a conceptual restoration plan for how a restored Klamath River would look and function after dam removal, prepared by an interdisciplinary team of restoration scientists and engineers. This document included a preliminary plan for what work would be necessary to accomplish successful restoration of the river for the reintroduction of anadromous fish extirpated since dam closure. It involved historical techniques, innovative hydraulic and sediment transport modeling, and site reconnaissance to reconstruct likely geomorphic and ecologic processes and conditions prior to dam closure and assess the likely processes and conditions during and after dam removal. That information was combined with the river restoration planning and implementation experience of the team to develop a comprehensive restoration planning document that includes potential restoration actions and techniques, conceptual restoration plans for each of the three main reservoir areas—including floodplain and in-channel restoration actions, and preliminary cost estimates.

Based on this work and the timeline and details outlined in the recent Klamath Hydroelectric Settlement Agreement, this presentation provides recommendations for immediate (pre-dam removal) restoration actions necessary to achieve successful restoration of the river ecosystem after dam removal. While restoration in the areas submerged by the dams obviously must wait for dam removal, more rapid implementation in non-inundated areas is imperative because of the response time-lag in system conditions relative to the need to provide high-quality habitat in these un-impounded areas immediately after the river is re-opened after dam removal. These actions include measures on the Klamath River in the J.C. Boyle peaking reach, in creeks tributary to the reservoirs, and in key watersheds downstream of Iron Gate Dam. Pre-dam removal action in these areas also supports necessary habitat improvements required to maintain habitat (and aquatic species populations) outside the mainstem of the river. This is important because this habitat and these populations will provide the basis for recovery/repopulation of the mainstem river downstream of Iron Gate after the brief impacts of sediment discharge from dam removal, and will ostensibly be the organisms repopulating the river now inundated by the reservoirs.

#027

Adaptive Management: Lessons from the Everglades, Coastal Louisiana and Missouri River Programs

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The concept of adaptive management (AM) has been around since the 1970's and is being utilized frequently in the planning and implementation of ecosystem restoration and recovery programs. In the most general terms, AM is a structured management approach that links science to decision-making in order to to improve the probability of success. Adaptive management is rooted in sound science and provides a process to address the risk and uncertainty inherent within ecosystem restoration and recovery. Several of the country's largest ecosystem restoration and recovery programs are currently utilizing an AM approach. They include the Louisiana Coastal Area (LCA) Ecosystem Restoration, the Comprehensive Everglades Restoration Plan (CERP), and the Missouri River Recovery Program (MRRP). This presentation will compare and contrast the use of AM by these three programs. The comparison will address such topics as: (1) scale of AM approach; (2) authorities/mandates for use of AM; (3) approach to collaboration and stakeholder engagement; (4) use of scientific information via monitoring, assessment,

and field tests; (5) addressing uncertainty and risk using AM; and (6) linking science to decision-making and management actions. Particular attention will be paid to how lessons learned from the application of AM in these ecosystems could be applied to the Klamath River Basin as they pursue protection of threatened and endangered species and address water management issues.

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#085

A 45-Year Retrospective on Restoration Construction Projects on the Trinity River, California

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Trinity River Restoration Program, Weaverville, CA

Construction projects to facilitate salmon restoration on the Trinity River have changed greatly in form and function since the first restoration efforts began in 1965. These changes have been driven by an evolving understanding of the physical and biological workings of the river, within a backdrop of changing legal mandates and organizational structure.

The early restoration efforts focused on restoring spawning habitat lost due to inundation, in-filling by sand, loss of gravel, and vegetation encroachment. The first restoration effort on the Trinity River was channelization of 4 tributary deltas in 1965 to eliminate delta backwaters (formed by the 1964 storm) that inundated important upstream spawning beds. Fourteen artificial spawning beds were constructed between 1972 and 1976 but had limited success due to continued gravel loss and sand in-filling. From the mid 1970's through the mid 1980's, restoration efforts focused on mechanically removing fine sediment from the mainstem via dredging and ripping the channel bed to loosen the spawning gravels and flush fine sediment. Watershed restoration to reduce fine sediment delivery became a major thrust for restoration activities in the late 1980's and 1990's. During this time period, 18 side channels and 9 "feather edge" pilot projects (with their associated experimental flood flow releases) were constructed in response to a growing recognition of the importance of rearing habitat.

With the signing of the Record of Decision (ROD) in 2000, the Trinity River Restoration Program was restructured with a new focus on encouraging dynamic river processes to restore and maintain adequate salmon habitat. This new approach required revising the operation of Trinity Dam to establish a more natural flood regime, gravel augmentation to replenish the supply lost to the reservoir, mechanical bank rehabilitation construction to destabilize the riparian vegetation on the river banks and create functional floodplains, and continued watershed restoration to minimize fine sediment delivery to the mainstem. Projects since 2004 have evolved to create greater overall diversity by leaving patches of mature vegetation in place, including side channels, islands, and large wood placements, adding micro-topography on floodplain surfaces, and using augmented gravels to both emulate geomorphic features and transport downstream to create new gravel bars. A new vision is emerging on how to design these various features to integrate their function to best support geomorphic processes, riparian regeneration, and salmon recovery.

#121

Restoration Implications of the Holocene History of the Sycan River, Upper Klamath Basin, Oregon

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Understanding how channels, floodplains and other landforms are created is essential to restoration planning, particularly because the present is not "the key to the past" for many rivers. An example is the Sycan River, which drains 1150 km2 within the Sprague River watershed of upper Klamath Basin. Within a few decades or centuries after the Mount Mazama eruption 7660 cal yr BP, the upper Sycan River was impounded by a short-lived dam, probably formed of pumice dunes near the outlet of Sycan Marsh. This dam, upon failure, transformed the lower Sycan River and, to a lesser extent, the Sprague River downstream of the Sycan River confluence. The massive discharge from the outburst flood scoured the clay-dominated floodplain and buried the Sycan Valley with pumiceous sands up to 3.5 m thick, leaving a broad and sloping planar surface composed of coarse pumice sand. The flood also deposited pumiceous sand along 100 km of the Sprague River downstream of the Sycan River confluence and a flood signal is evident in Upper Klamath Lake. After the outburst flood the lower Sycan River has undergone episodes of channel aggradation and incision, resulting in the sand and silt dominated active floodplain of the modern Sycan River which is inset 1 to 4 m below the high surface of the rapidly abandoned Sycan Outburst Flood deposits. These post-flood episodes of incision and aggradation likely owe to climate shifts as well as the intrinsic dynamics associated with significant post-Mazama sediment transport in the pumice mantled watershed. The geomorphic context provided by studies such as this one has implications for understanding current river processes, information vital for establishing attainable restoration objectives. Study results suggest the high planar surface of the Sycan Outburst Flood never acted as an active floodplain for the Sycan River and restoration efforts to return the river to that surface is not a reasonable restoration objective.

Winter warming has had a strong effect on spring snowpack. Apr 1 SWE/Oct-Mar precipitation ratios decrease over time at lower elevation snowcourse sites, suggesting that more winter precipitation is falling as rain rather than snow. The median difference in Apr 1 SWE between two periods, 1945-1976 and 1977-2007, is only 8% at 23 sites >1800m but is 31% at 23 sites <1800m. By contrast, the median difference in Oct-Mar precipitation between 1945-1976 and 1977-2007 at the 20 USHCN sites is only 6%. Our results suggest that snowpack has declined measurably in the Klamath Basin region in the recent decades, especially at elevations less than 1800m. Our findings are consistent with other studies that conclude snowpack reductions are a response to warmer winter temperatures rather than decreased precipitation.

#102

Valley and Stream Habitat Restoration in the Lower Klamath Sub-basin.

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Geomorphic-processed based restoration of coastal valley and stream habitats rely on principles of bio- mimicry and geomorphology, and require collaborative partnerships to affect positive, long-term changes at the landscape scale. In the Lower Klamath Sub-basin, the Yurok Tribe's restoration efforts are guided by research and monitoring of trends in geomorphic processes, habitat condition and use by adult and juvenile salmonids. Recent restoration efforts by the Yurok Tribal Fisheries Program have focused on restoring background wood loading levels in tributaries and increasing the amount and quality of off-channel habitats. Results from several mega-wood loading projects that demonstrate the effectiveness of engineered log jams and bioengineering to create in-stream habitat

complexity, improve side channel and floodplain connectivity, and to store and build riparian soils will be presented. Projects used a range of construction techniques that included a helicopter, heavy equipment, grip hoists and hand labor. Partnerships that involve landowners, funders and an experienced technical team are important to achieve positive project outcomes. However, streamlining onerous permit requirements and improved access to whole tree materials (trees with rootwads, tops, and branches) is needed to support timely on-the-ground implementation and salmon recovery.

#070

Building on the Baseline Assessment: First Year Restoration Discoveries on Big Springs Creek

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Big Springs Creek is a spring-fed creek that supplies over half of the Shasta River's annual flow. The steady influx of cold (~12°C) water that is naturally high in nutrients makes this stream a prime rearing site for salmonids including coho salmon. However, decades of land use activities associated with cattle grazing in and around the stream channel has degraded in-stream and riparian habitat. Recent studies have identified Big Springs Creek as a high priority restoration site in the Shasta Basin.

An ongoing monitoring program was implemented in 2008 to develop a baseline assessment of physical and biological conditions and then track the effects of restoration actions. The baseline assessment identified high temperatures and reduced habitat availability and complexity as the primary impairments. During summer months, water temperatures in the creek peaked above 20°C, at times exceeding 25°C, indicating high rates of heating. Available habitat for coho salmon during summer 2008 was limited to a 15 meter reach at the top of the creek below the Big Springs Dam outlet. Data collected during the 2009 field season monitored the effects of initial passive restoration actions (riparian fencing) that commenced in spring 2009. Preliminary results identify rapid geomorphic, hydraulic, and stream temperature responses to passive restoration actions that resulted in the extensive growth of aquatic macrophytes. Ongoing monitoring will examine whether the effects of vegetation growth are permanent or seasonal.

Given the scope of habitat degradation and the limited funds available for immediate action, a hydrodynamic model was developed to help assess restoration alternatives and identify priority actions. Simulations of present temperature conditions represent the geometries, flows, and vegetative growth observed during the 2008 field season. Several passive and active restoration scenarios were designed to estimate the effects of identified restoration actions on water temperatures in Big Springs Creek after 1, 5, and 20 years. Overall, simulations of long-term restoration suggest that much of Big Springs Creek will experience thermal benefit from both passive and active actions taken on the Shasta Big Springs Ranch and surrounding lands owned by The Nature Conservancy. A comparison of the model results with data gathered during the 2009 field season indicates that initial assumptions about the stream's restoration potential were conservative. The benefits of improved conditions in Big Springs Creek will extend into the Shasta River, expanding potential habitat for coho salmon and other salmonid species.

#024

Update and Design Approach on Urban Stream Restoration Projects Along Yreka and Greenhorn Creeks in the Shasta River Watershed of the Klamath Basin

Thomas F. Hesseldenz

Tom Hesseldenz and Associates, Mount Shasta, CA

Yreka and Greenhorn Creeks flow through the City of Yreka in Siskiyou County, California. They are important spawning tributaries for salmon and steelhead trout, but have been degraded by past gold dredging, loss of accessible floodplain, urban runoff, and in the case of Greenhorn Creek, blockage of fish passage to the upper watershed due to a small dam and reservoir. These creeks are also important spawning gravel sources for the Lower Shasta River. Restoration planning began in 2003, involving proposed floodplain widening along a 1-mile portion of Greenhorn Creek, and funded by a grant from the Siskiyou Resource Advisory Committee (RAC). This project was followed by full design of proposed floodplain widening, funded by a grant from the U.S. Fish and Wildlife Service (FWS). Planning for mitigation of urban runoff impacts to both creeks began in 2006, funded by another grant from the Siskiyou RAC. Design for floodplain widening along a 1/2-mile portion of Yreka Creek began in 2007 and construction was completed in 2008, using 2 California Proposition 40 grants. Greenhorn Creek floodplain widening is scheduled to begin 2010, to be funded in part by FWS. Design is underway for additional floodplain widening along Yreka Creek, funded by a California Proposition 50 grant. Also, a master plan for a 4-mile greenway along Yreka Creek will be updated in 2010 to include floodplain restoration, with funding in hand from FWS and the U.S. Forest Service and proposed additional funding from the Siskiyou RAC. The design approach being taken is to remove tailings and other fill to create wider accessible floodplains next to the creeks, dispose of the spoils nearby but out of the active floodway to minimize hauling costs, re-vegetate widened floodplains, encourage beaver re-colonization, remove invasive exotic plant species, and include stormwater mitigation such as vegetated drainage swales. Widened floodplains will allow fine sediment to settle-out, which will clog porous tailings and restore perennial flows, while also providing topsoil for riparian vegetation. Raising the streams to re-access historic floodplains was deemed to not be feasible due to the urban setting and high collateral ecological impacts. Some of the tailings from floodplain widening may be used for spawning gravel to be injected downstream. Methods of providing anadromous fish passage over or around Greenhorn Dam are also being explored. Restoration design also includes providing ADA-compliant multi-use trails along the creeks for public enjoyment and environmental education.

Water Quality Monitoring and Modeling

#056

Water Management and Water Quality Monitoring at BLM Wood River Wetlands 2007-2009

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The Bureau of Land Management manages a 2,800 acre diked, drained, and subsided peat wetland on the north shore of Agency Lake. BLM initiated management directed at wetland restoration and water quality improvement starting in 1995. Previous studies on the wetland estimated nutrient loading from drainage water prior to restoration activities (Kann and Walker 1999; Snyder and Morace 1997) and nutrient concentrations at pump stations during non-pumping periods (Rykbost and Charlton 2001;Carpenter et al 2009). Between 1996 and 2005, there was little water discharged from the wetland and no monitoring of nutrient discharge from the property. A recent post-restoration study examined standing nutrient loads and characterized seasonal changes in nutrient and water flux

from 2003-2005 (Carpenter et al 2009). The unusually high nutrient concentrations observed late in the growing season were attributed to cumulative evapo-concentration due to curtailment of pumping between 1999 and 2005. Pumping was initiated in 2006 in response wetland water quality concerns and to address hydrologic effects on low emergent vegetative cover throughout the wetland. The purpose of this study was to monitor discharge loads and seasonal water quality trends as related to revised water management regimes and to inform adaptive management of nutrient loads and wetland restoration efforts. Monitoring results between 2007 and 2009 show that nutrient concentrations were high in the spring months relative to nearby surface water sources and were similar to concentrations observed during the time that the property was operated as a cattle ranch. Nutrient concentrations and standing loads were much lower in this study compared to the 2003-2005 study and decreased markedly in the summer and fall, and in subsequent years. Annual total phosphorus (TP) loading to Agency Lake decreased by 80% and total nitrogen (TN) loading decreased by 59% during the study period. Vegetation monitoring indicated that altering the hydrology of the wetland was successful in establishing emergent vegetation cover in areas previously dominated by mudflats and submergent vegetation. Intra and inter annual differences in physical and chemical water quality are presented and compared to data from previous studies on the Wood River Wetlands and to nearby managed wetlands. Inferences are made regarding the affects the recent water management changes in the observed physical and chemical water quality trends within the wetlands.

#041

Modeling Hydrodynamics, Temperature, and Water Quality in Klamath River, from Link River Dam to Keno Dam, Oregon

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The U.S. Geological Survey, Watercourse Engineering, Inc., and the Bureau of Reclamation are working together to build an improved hydrodynamic and water-quality model of the Link River Dam to Keno Dam reach of the Klamath River. Two seasons of extensive data collection and experimental work in 2007 and 2008 were used to improve the current understanding of instream processes in this system and form the basis of this new modeling effort. The model is built with CE-QUAL-W2, a two-dimensional, laterally averaged model that can simulate hydrodynamics and many water quality constituents including temperature, oxygen, nutrients, and algae. Models are first being built and calibrated for the years 2007 and 2008, which have the most extensive datasets. Models also will be built for 2006 and 2009 to examine a wider range of hydrologic conditions and explore the ramifications of developing models with less extensive datasets. Preliminary model results will be compared to data collected from the reach and visualized graphically and with computer animations.

#003

Multi-year Nutrient Budget Dynamics for Iron Gate and Copco Reservoirs, California

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Daily hydrologic and biweekly nutrient data were collected and/or assembled for inflow, outflow, and in-reservoir stations for a Karuk Tribe water quality study of Copco and Iron Gate Reservoirs conducted between May 2005 to December 2007. Mass-balance nutrient budgets were constructed to assess seasonal and annual loading and retention dynamics of nitrogen and phosphorus. Methodological improvements included: 1) flow- and season-based multiple regression models to estimate daily nutrient concentrations, 2) uncertainty estimates for nutrient concentrations and loads, and 3) adjusting inflow concentrations to account for hydropower peaking above Copco.

The combined retention for Iron Gate and Copco Reservoirs was 9±4% of the total phosphorus (TP) inflow over the entire study. Much of the observed retention occurred during winter and spring high flow periods when the percent of TP comprised of particulate P was high. In contrast, during the main reservoir phytoplankton growing season (May 18-September 30) the total combined TP retention was -8%, while for the period encompassing turnover (May 18-December 11) it was 0%. Likely drivers for relatively low to negative retention during the growing season are a high percent of dissolved P in the incoming TP load, which is less likely to settle than particulate phosphorus, and internal loading during anaerobic conditions in the stratified period. Flow-weighted average TP concentrations showed similar patterns to TP retention, with outflow TP concentrations ranging from 73% to 104% of inflow concentrations across the various summary periods.

Over the entire study period, the combined reservoir retention was 13±3% of total nitrogen (TN) inflow. The main reservoir phytoplankton growing season combined TN retention was 23%, while for the period encompassing turnover it was 15%. Higher percent retention during summer months may reflect settling of inflow organic matter and in-reservoir algal material, and/or denitrification. Flow-weighted average TN concentrations showed similar patterns to TN retention, with outflow TN concentrations ranging from 68% to 97% of inflow concentrations across the various summary periods.

Although variation in relative TN and TP retention occurred among years for the various summary periods, inter-annual differences were less than ~10% of inflow, and uncertainty analysis indicates that among-year values were not significantly different.

Overall net retention accounted for a relatively low (11% for TP, and 12% for TN) percentage of inflow on an annual basis, but were generally within the range predicted using models developed from a broad range of lakes and reservoirs that incorporate inflow loading and other hydraulic characteristics.

#032

Scott River Water Balance Model (Understanding Water Quality and Quantity)

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The Siskiyou RCD, Scott River Watershed Council, and local landowners have been working since the late 1990's to develop a Water Balance Model for the Scott River Watershed. It is acknowledged that a better understanding of the hydrology of the watershed is key to developing more effective restoration and water management plans in the Scott River Watershed. Local monitoring of water quality began in the mid-1990's, and has expanded in the past 10 years to include expanded monitoring of water quantity. Pairing of water quality and quantity data will ultimately lead to the development of a comprehensive Scott River Water Balance Model.

One objective of the Water Balance Model has been to develop run-off forecasting abilities to predict in the winter or early spring the potential run-off for the Scott River and tributaries. WaterCourse Engineers Inc, has been very involved in analyzing available hydrologic data and reccommending additional monitoring locations. WCE has developed a preliminary Water Balance Model, Runoff forecast model, and Water Year Types for the Scott River. Since 2007 the RCD and local community has worked closely with U.C Davis and the North Coast Regional Water Quality Control Board to develop a Ground Water Study Plan. This GW Study Plan will identify and collect baseline data useful to develop, evaluate, and assess the design and implementation of water projects and water management alternatives with respect to protecting the needs of anadromous fish, agriculture, and other beneficial uses. The GW study plan will also evaluate the effects of groundwater on health of riparian vegetation, and evaluate cumulative effects of groundwater and surface water use in the Scott River System flows and temperature. In addition, U.C. Davis has been working with the local community to develop a preliminary Groundwater Model for the Scott River Watershed. Ultimately these models will be incorporated, providing a tool to guide local water users and land managers in making the most effective decisions to restore the Scott River Watershed.

This presentation will summarize what has been completed to date, and identify the next steps in the implementation of the Scott River Water Balance Model.

#020

Method Development to Modeling the Shading Provided to the Klamath River and its Tributaries by Vegetation and Geomorphology

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As part of the USGS's River Ecosystems and Science (REMS) project to advance the science of instream flows, a subtask exists to develop research approaches relevant to characterizing the thermal regulation of water and the dynamics of cold water refugia. High temperatures have been shown to have physiological impacts on the performance of anadromous fish species. Various drivers of the presence, variability, and quality of thermal refugia such as hypoheric flows, deep pools and bathymetric factors, thermal stratification of reservoirs, and other broader climatic considerations are being addressed elsewhere in the overall REMS project. This research, however, focuses on developing a conceptual model and methodological techniques to quantify the reduction in insolation load to the Klamath River and select tributaries below Iron Gate Dam provided by riparian and floodplain vegetation, the morphology of the river and its watersheds. Related to multiple scales, initial field-research and GIS/imagery observations resulted in the following postulates: 1) on a vegetation scale, primary seasonal changes will be a result of evergreen conifers that provide shade throughout the year, and deciduous vegetation that provide the majority of shading after it has leafed out; and although generally taller, conifers are often found further from the primary channel, thereby reducing the shading provided, which is exacerbated during the summer months when the zenith angle of the sun is smaller; 2) on a geomorphic channel scale, steep banks can provide local pockets of shading; and 3) on a regional and watershed scale, the orientation of the ridgelines and canyon walls with respect to the azimuth of the sun will be a main driver of shading. Using GIS and remote sensing software packages in concert with the consideration of various sources of newly-collected satellite imagery (i.e. IKONOS and Quickbird), existing ancillary datasets (i.e. 10 m. DEMs, USFS's Land cover mapping and monitoring program vegetation, USGS's National Hydrography Dataset), and selective ground truthing and equipment specifications (i.e. GPS vegetation, pyranometers), conceptual design and preliminary model investigations suggest the potential for further development of a location-specific metric of seasonal shading potential within a riverine system as a result of watershed features.

Integrated Modeling

#156

Overview of SALMOD, a Fish Production Model, in the Secretarial Decision

Sharon G. Campbell

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USGS Ft. Collins Science Center scientists have developed a decision support system model (SIAM) for the Klamath River over the past 10-12 years. The model contains 3 major components: a water balance model, a water quality model, and a fish production model. All of these components are coupled in a Windows interface that allows resource managers to "game" with the model to determine the effects of differing water temperatures and flow conditions on production of fall Chinook salmon. The model has been used for a variety of resource management issues including the FERC relicensing and Settlement Negotiations processes. The upcoming Secretarial Decision

to either remove or retain four hydropower dams along the Klamath River is another opportunity to apply SIAM, specifically the fish production module – SALMOD – to support this process. SALMOD will provide fish production (number of out-migrating fall Chinook salmon) for the mainstem Klamath River from Keno downstream to the Pacific Ocean. SALMOD will be part of several models that will represent the full-life cycle, i.e., both fresh and salt water phases of this anadromous species. The effort is an intense collaboration among Department of Interior agencies, the National Oceanic and Atmospheric Administration, the Tribes, State agencies, universities, and consultants to provide the best available science for the Secretarial Decision.

#157

Conceptual Design and Approach for Modeling Fall-run Chinook Production Post Dam Removal

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As part of the Secretarial Determination, a population dynamics model capable of forecasting annual abundances of fall-run Chinook with uncertainty over a 50 year time frame was requested. In addition, the model should be capable of comparing a status-quo scenario and dams out scenario. The first step in this process was to construct a conceptual model. The conceptual model should have several qualities to be useful: 1) capture the biological processes of interest; 2) capture existing hypotheses about environmental or anthropogenic factors thought to affect the population dynamics; 3) identify sources of data for those factors; 4) identify the pathways for management actions; and 5) if using statistical methods, identify sources of data that can be used as indices of abundance. The conceptual model was presented to stakeholders and has resulted in a conceptual model composed of several components including: an adult migration model, an upper basin production model, an outmigrant mortality model (SALMOD), a retrospective ocean survival model, and a harvest model. Using the conceptual model as a blueprint, a life-stage model (e.g., Leslie-matrix type model) with transition among stages described by stage-specific Beverton-Holt functions is being constructed. The Beverton-Holt function is parameterized with two coefficients, the carrying capacity and the productivity. Each of these two coefficients can be further modeled as a function of environmental driver variables. For example, productivity in the rearing stage may be a function of instream temperature. The conceptual models and progress on translating the conceptual models into a quantitative model capable of meeting the objective of forecasting fall run abundances with uncertainty will be presented.

#155

Evaluating Economic Effects on Fisheries Associated with Klamath Dam Removal

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According to the Klamath Hydroelectric Settlement Agreement, the Secretary of the Interior will determine whether removal of four dams on the Klamath River "1) will advance restoration of the salmonid fisheries of the Klamath Basin, and 2) is in the public interest, which includes but is not limited to consideration of potential impacts on affected local communities and tribes." Among the myriad analyses being prepared to inform the Secretarial Determination are a number of economic studies that focus on the range of human uses and values potentially affected by dam removal. This presentation focuses specifically on the economic analysis as it relates to fishery effects. Topics to be discussed include data requirements, modeling issues and the need for interdisciplinary collaboration.

#095

Effects of Flow Augmentation and Meteorological Conditions on Coho Salmon Production in the Klamath River Basin

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It has been hypothesized that water project operations in the Klamath River basin are a major driver of anadromous fish production. Moreover, fisheries interests have been strong advocates for mainstem flow augmentation to increase abundance of threatened coho salmon. For this reason there was a sincere desire to understand effects of flow and temperature conditions on coho salmon production. Due to the paucity of data in the Basin, a simulation approach was required. We sought to quantify the effects of flow alterations at Iron Gate Dam on coho production in the Lower Klamath River through population life-cycle modeling. For comparison, we also quantified water year-type (wet, moderate and dry) effects on coho. The functional relationships between environmental conditions and coho survival were incorporated into a detailed population model, which was used in conjunction with a hydrodynamic model and water operations model to predict freshwater production of juvenile coho outmigrants. Results suggest that changes in IGD discharge have a limited effect on coho salmon production relative to effects of meteorological conditions. The influence of IGD discharge on mainstem flow and temperature conditions diminishes rapidly downstream due to flow accretion from tributary sources. Furthermore, the majority of juvenile coho production occurs in tributary habitats where temperatures are cooler and velocities more suited for rearing. Proposed changes in river management for fisheries restoration purposes should be viewed within a complete life-cycle context. The effect of river discharge should be quantified in a spatially and temporally explicit manner to properly predict the expected magnitude of fisheries benefit associated with a change in water project operations.

#138

Bioenergetics of Juvenile Chinook and Coho Salmon at Klamath River Tributary Mouths

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Juvenile Chinook and coho salmon occupy cool water associated with Klamath River tributary confluences during mid- to late-summer each year. These areas of cool water influx have been identified as refuges, suggesting these habitats provide refuge from seasonal warm water temperatures in the Klamath River that may be harmful to juvenile salmon. We used bioenergetics modeling to investigate the physiological response of juvenile Chinook and coho salmon to thermal conditions at several Klamath River tributary mouths. Our bioenergetics model for juvenile Chinook salmon was developed from laboratory experiments on Klamath River Chinook salmon, while our model for juvenile coho salmon was developed using laboratory data from coastal populations in Oregon. Modeling investigations focused on generating hypotheses of how juvenile Chinook and coho salmon might benefit physiologically from using tributary mouth habitats or from migrating between tributary mouth and river habitats. Results from these investigations will be used to inform a continuing U. S. Geological Survey effort to model at differing spatial scales within the Klamath River Ecosystem.

Toxic Algae in the Klamath Basin 1

#006

Algae: The Forgotten Half of the Klamath River Phytoplankton

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Although cyanobacteria in the Klamath Hydroelectric Project have received considerable attention, they comprise only 52 percent of the phytoplankton biomass in the Klamath Hydroelectric Project. Diatoms account for 44 percent of the total biomass, and have a significant effect on the biology and nutrient dynamics of the system. Seasonal patterns of diatom growth influence nutrient concentration in the Klamath reservoirs which, in turn, may influence the growth of cyanobacteria. Phytoplankton data collected from the Klamath River and reservoirs in the vicinity of the Klamath Hydroelectric project from 2000-2009 illustrate the distinct spatial, seasonal, and interannual distribution of phytoplankton species. Correlation of phytoplankton growth patterns with changes in nutrient availability may provide some insight into the factors influencing cyanobacterial growth in Copco and Iron Gate reservoirs.

#091

Genetic Analysis of the Population Turnover in the 2007 Copco Reservoir *Microcystis* Bloom that Resulted in Predominantly Non-toxigenic Variants Late in the Season

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Toxic *Microcystis* blooms associated with very high levels of the liver toxin microcystin have occurred in Copco Reservoir on the Klamath River during the last several summers. We have characterized the genetic diversity of *Microcystis* present throughout the 2007 bloom season (June through October) in surface samples taken near the Copco dam. We have determined the DNA sequences of two target loci, *cpcBA* (phycocyanin B/A intergenic region) and ITS (16S/23S ribosomal RNA gene internal transcribed spacer) by constructing clone libraries of PCR products produced with cyanobacterial-specific primer pairs. Based on information from both target loci, distinct sub-populations of *Microcystis* variants (strains) could be distinguished. Distinct strains were present at the early and late ends of the bloom season, with other strains making appearances during the transition period in August. Quantitative PCR was used to quantify the relative gene copy number of *cpcBA* and *mcyB*, one of the genes needed for toxin production, in the Copco Reservoir and UKL samples. We observed a high proportion of toxigenic strains early in the bloom (90% in July), declining to very low levels (<2%) in September and October. A single sampling (21 August) from the water column of Upper Klamath Lake, which suffers blooms that are dominated by *Aphanizomenon*, indicated that its minority *Microcystis* population was genetically related to the early season highly toxigenic population in Copco Reservoir. The August UKL sample indicated the presence of >90% toxigenic *Microcystis*. These studies illustrate the extensive *Microcystis* population changes that can occur within a bloom season. We have also identified *Microcystis* strains whose presence can be monitored with specific genetic techniques to better understand bloom development or to follow remediation efforts.

#147

Nutrient Limitation of Phytoplankton and *Microcystis* Blooms in Copco and Iron Gate Reservoirs

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Large toxin-producing blooms of *Microcystis* are present in the summertime in the Klamath River reservoirs Copco and Iron Gate. Nutrient limitations were investigated in 2007 and 2008 using *in situ* nutrient enrichment experiments, following responses in phytoplankton biomass, abundances of *Microcystis* (using quantitative PCR targeting the phycocyanin intergenic spacer *cpcBA*), and microcystin concentration, to additions of dissolved inorganic nitrogen (DIN) and phosphorus (P), and different forms of N (NH_4^+, NO_3^-, and urea).

The total phytoplankton biomass increased with additions of N both before the onset and during the summertime *Microcystis* blooms, while increases in microcystin concentration were detected in response to additions of either N or P. The data suggest primary N limitation and frequently a secondary P limitation for phytoplankton and *Microcystis* growth prevails in the reservoirs during the summer season. Our data suggest vertical migration of *Microcystis* is a mechanism for nutrient access in the reservoirs during summertime oxygen stratification.

#143

Microcystin Analyses in the Klamath River by ELISA

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Since 2007, the USEPA Region 9 Laboratory has analyzed 1350 surface water samples from the Klamath River for the algae toxin microcystin. The results are used by public health authorities to determine whether the river and reservoirs are safe for recreational use. Analyses are performed using Enzyme-Linked Immunosorbant Assay (ELISA) kits manufactured by Envirologix. This assay was designed as a screening method for drinking water. Our experience indicates that ELISA is also an inexpensive and reliable method for screening surface water samples for recreational use. Modifications to the drinking water method include freezing and sonication for cell lysis, high sample dilutions, and additional Quality Control measures to ensure that data are of known quality.

#146

Evaluation and Comparison of Five Commercial Microcystin Enzyme-Linked Immunosorbent Assays to Liquid Chromatography Tandem Mass Spectrometry Used for Risk Assessment of Inland Waters

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Enzyme-linked immunosorbent assays (ELISAs) are currently (2009) the most common technique used to measure microcystins, a class of cyanotoxins, for risk assessments of inland freshwaters to protect public health. Substantial variation in microcystin results can be observed when comparing multiple ELISA methods and between ELISA and liquid chromatography tandem mass spectrometry (LC/MS/MS) results because of differences in cross-reactivity of microcystin congeners for each respective ELISA and sample congener composition. Inland water samples were analyzed by five commercial microcystin ELISAs and a multi-cyanotoxin LC/MS/MS method. A four parameter calibration curve fit generally provided the greatest precision and accuracy for each ELISA. Four of the five ELISAs exhibited adequate precision for replicate measures of a 0.75 µg/L microcystin-LR standard and for

environmental samples. LC/MS/MS data corrected for cross-reactivity showed a better correlation with the respective ELISA results in three of the remaining four ELISAs with adequate precision than uncorrected LC/MS/MS data. When results from four of the five ELISAs and LC/MS/MS techniques were categorized based on World Health Organization microcystin-LR recreational guidelines, agreement between techniques was observed in most samples. However, detection frequencies and concentrations are not equivalent between each ELISA in most cases.

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#137

Cyanotoxins in Waters of the Klamath Basin: Historical Perspective and Current Risks

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Increasingly, harmful algal blooms (HAB's) are being reported worldwide due to several factors, especially – human development, increasing eutrophication and climate change. HAB organism types include: PSP (paralytic shellfish poisoning), DSP (diarrhetic shellfish poisoning), NSP (neurotoxic shellfish poisoning), ASP (amnesic shellfish poisoning) and CTP (cyanobacteria toxin poisoning). All but CTP organisms are mainly a marine occurrence. CTP's occur in freshwater lakes, ponds, rivers and reservoirs throughout the world. Organisms responsible include an estimated 40 genera but the main ones *are Anabaena, Aphanizomenon, Cylindrospermopsis, Lyngbya, Microcystis, Nostoc and Oscillatoria* (Planktothrix). Cyanobacteria toxins (cyanotoxins) include cytotoxins and biotoxins with biotoxins being responsible for acute lethal, acute, chronic and sub-chronic poisonings of wild/domestic animals and humans. The biotoxins include the neurotoxins; anatoxin-a, anatoxin-a(s) and saxitoxins, the hepatotoxins; microcystins, nodularins and cylindrospermopsin plus the recently discovered neurodegenerative amino acid, β-methyl amino alanine.

The first report of cyanotoxins being produced by Klamath Lake cyanobacteria is from the late 1960's when *Aphanizomenon flos-aquae* was reported to produce a neurotoxic factor. Later work was unable to confirm this report but other species of *Aphanizomenon*, from other geographic locations, are now known to produce paralytic shellfish toxins - the Saxitoxins and cylindrospermopsin. Tests, over the past 25 years have failed to show the presence of anatoxin, cylindrospermopsins or saxitoxins from Klamath Lake cyanobacteria. The only confirmed cyanotoxin in Klamath Lake and Klamath River cyanobacteria is the microcystin group of related heptapeptide liver toxins. The microcystins have become a regular occurrence and environmental risk from cyanobacteria in the Klamath basin. To date the only cyanobacteria confirmed to be a producer of microcystins, in the Klamath Basin, is the colonial waterbloom forming species *Microcystis aeruginosa*. While the presence of *Aphanizomenon flos-aquae* is linked to natural eutrophication in the Klamath Basin, *M. aeruginosa* has been present in Klamath Basin phytoplankton since at least the early 1980's and should be considered an indicator of increased cultural eutrophication. *Microcystis aeruginosa* production of microcysins should be considered the primary risk factor from cyanotoxins in the Klamath Basin-especially Klamath Lake and the Klamath River.

An evaluation of risk assessment of microcystins (i.e. microcystin-LR), in the 1990's by the World Health Organization indicate that a level of 1 µg L-1 should be considered a guideline value for maximum allowable concentration (MAC) based upon an adult consumption of 2 L day-1. Other MAC's for the neurotoxins and cylindrospermopsin will not be set until more basic toxicology and epidemiology are available. In addition the State of Oregon has set a regulatory level of 1 µg g-1 for microcystins in human food supplements produced from Aphanizomenon flos-aquae, in Klamath Lake, and Brazil has set a regulatory level of 1 µg g-1 for microcystins in drinking water supplies. Health authorities from several countries are also evaluating the risks of cynotoxins and are adopting guideline or regulatory levels for microcystins in drinking and recreational waters, and algae food products. The US EPA has listed microcystins, cylindrospermopsin and anatoxin-a as highest priority cyanotoxins, and

saxitoxin(s) and anatoxin-a(s) as medium to high priority. Research is needed to assess the frequency and concentrations with which these cyanotoxins occur in recreational and finished drinking waters. Health research is needed to obtain cyanotoxin dose-response data for establishing Reference Doses (ingested compounds), Reference Concentrations (inhaled compounds) and cancer assessments. Risk management research is needed to assess the efficacy and sustainability of ecological and chemical approaches to freshwater harmful algae bloom control. As part of this need a National Freshwater Harmful Algal Bloom Research Plan (FHABRP) is being developed along with legislation in the form of a Freshwater Harmful Algal Bloom Research & Control Act of 2009 (FHAB Act). Information and discussion of this act is available at: http://www.FreshwaterHABlegislation.com/

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#145

Preliminary Assessment of Cyanotoxin Occurrence in the United States

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Public scrutiny of potential cyanotoxin exposure in lakes and reservoirs used for drinking water supplies and recreation in the United States has increased over the last decade. Media reports of cyanobacterial blooms and human and animal poisonings to cyanotoxin exposure have occurred in at least 32 U.S. States. In August 2006, the U.S. Geological Survey conducted a bloom-targeted cyanotoxin reconnaissance in 23 midwestern U.S. lakes and reservoirs in 4 states. Samples were analyzed by liquid chromatography tandem mass spectrometry (LC/MS/MS) and by enzyme-linked immunosorbent assays (ELISAs) for microcystins, nodularins, cylindrospermopsins; anatoxin-a and lyngbyatoxin-a (LC/MS/MS only), and saxitoxins (ELISA only). Microcystins were detected in all water samples for this study where total concentrations ranged from less than 0.025 µg/L to greater than 17,000 µg/L. The 2nd most frequently detected cyanotoxin was anatoxin-a, being detected in about 30 % of the samples with a maximum concentration of 13 µg/L. In 2007, the U.S. Geological Survey analyzed about 1200 lake and reservoir water samples collected between May and October for microcystins by ELISA with confirmation of a subset of samples by LC/MS/MS in the U.S. Environmental Protection Agency's National Lake Assessment. In contrast to the 2006 Midwestern Lake reconnaissance, water samples for this study were collected from the photic zone at the deepest part of each water body. Preliminary results from this study show that microcystins were present in 32 % of the samples (n=1238) with an average detection concentration of 1.0 µg/L. The results of these two studies demonstrate the wide range in concentrations and the co-occurrence of multiple toxin classes and variants in US lakes and reservoirs. Furthermore, these studies demonstrate the utility of using LC/MS/MS and ELISA to provide multiple lines of evidence to confirm total cyanotoxin exposure.

#106

Multi-year Trends in *Microcystis aeruginosa* and Associated Microcystin Toxin in the Klamath River System: Implications for Public Health Guidelines.

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Copco and Iron Gate Reservoirs located on the Klamath River in Northern California have experienced consistently large toxigenic blooms of *Microcystis aeruginosa* (MSAE) over the past five years, exceeding World Health Organization (WHO) Moderate Probability of Adverse Health Effect Levels for both cell density and toxin by 10 to over 1000 times during July-October. Although both cell density and toxin data indicated that MSAE cells and microcystin were either not detectable or detected at very low levels in the Klamath River directly above the reservoirs, levels of both parameters increased directly below the reservoirs in all years, including accumulation in slow velocity river-edge areas. From a public health perspective these data illustrate that low MSAE or toxin values in open-water (collected in mixed areas of higher velocity) Klamath River samples often translates to values exceeding public health thresholds in river-edge areas.

The four year monitoring program has allowed for the determination of inter- annual and seasonal bloom dynamics, relationships between MSAE cell density and microcystin toxin, as well as between chlorophyll *a* and microcystin. For example, the State of California (SWRCB/OEHHA) public health guidance level of 8 µg/L microcystin had 15% and 20% exceedance probabilities when MSAE cell density was 20,000 cells/ml, and ~25% and ~40% probabilities when MSAE cell density was 40,000 cells/ml for the Jun-Sep and Jun-Aug models, respectively.

Further evaluation of WHO low probability of adverse health effect guideline values of 20,000 cells/ml MSAE and 4 µg/L microcystin as utilized by the CA North Coast Regional Water Quality Control Board for Total Maximum Daily Load calculations, showed that at an MSAE cell density level of 20,000 cells/ml that there were ~35% and 50% probabilities of exceeding 4 µg/L microcystin for the Jun-Sep and Jun-Aug models, respectively. The greater frequency of exceedance observed for the Jun-Aug models reflect both higher absolute microcystin values and higher microcystin toxin to MSAE cell density ratios occurring during that time, and thus provide a more conservative indication of risk with respect to public health.

Agreeing with WHO guidelines relating values of 10 µg/L or greater of chlorophyll to a moderate probability of acute health effects, ~30% and ~25% probabilities of exceeding 20,000 cells/ml MSAE and 4 µg/L microcystin were observed at a chlorophyll *a* level of 10 µg/L in this study. By demonstrating increasing trends in response variables with either increasing CHL or MSAE cell density, the above relationships provide a robust basis for evaluation of public health guidance values for toxic cyanobacteria in the Klamath River system.

#144

Microcystis Blooms in the San Francisco Estuary: Monitoring their Toxicity and Potential Adverse Impacts to Fish Health

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Toxic cyanobacteria are viewed as one of several environmental problems and health hazards for aquatic animals and human beings worldwide. Effective forecasting of algal bloom toxicity requires knowledge on the presence of toxin producing genotypes and the combined effects of environmental conditions that may induce toxin production to lethal levels. In addition, critical food web components such as zooplanktons and pelagic planktivores may be

exposed to cyanotoxins directly by consuming cyanobacteria during harmful algal blooms or indirectly by preying on organisms that have previously ingested or exposed to toxic cyanobacteria. This presentation will discuss the potential relationships between *Microcystis* toxicity, trophic transfer and pelagic fish health in the San Francisco Estuary. Of particular concern is the potential role of *Microcystis* toxins as one of several stressors affecting fish populations that are currently experiencing unprecedented decline in the estuary.

#101

Microcystin Bioaccumulation in Klamath River Fish and Freshwater Mussel Tissue: Implications for Public Health.

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Klamath River fish and freshwater mussel tissues (FWM) were evaluated for cyanotoxins by the California Dept. of Fish and Game Water Pollution Control Laboratory in 2007 and 2009 (FWM only). In 2007, analyses were performed on composite (consisting of 6 yearling fall Chinook) liver, stomach, and fillet samples from the Iron Gate Hatchery, composite and individual freshwater mussel samples (*Gonidea angulata*) from the Klamath River in the Seiad Valley area, as well as yellow perch (both individual fillets and liver composites) collected from Copco and Iron Gate Reservoirs. In 2009, freshwater mussels were evaluated by both the Karuk and Yurok Tribes in locations extending from below Iron Gate Reservoir to the lower river. A variety of known microcystin (MCYST) congeners were analyzed, including MCYST-RR, -LR, -YR, -LA, -LW, -LF, -LY and the demethylated analogues of –RR, and –LR. In addition, in 2009 anatoxin-a, domoic acid, and okadaic acid were also evaluated.

Results for tissue concentration of various MCYST congeners showed some level of bioaccumulation in the majority (85%) of samples tested in 2007, although there was some indication of depuration in November 2007 FWM samples taken after bloom decline. However, unlike 2007, late season FWM samples in 2009 continued to show relatively high levels of MCYST bioaccumulation. Differential uptake of the MCYST congeners occurred both between organisms (fish *vs.* freshwater mussels) and between fish liver *vs.* fish fillets, with only IG Hatchery liver composite samples showing detectable MCYST, while FWM's showed elevated concentrations of MCYST-RR, MCYST-LR MCYST-LR-DM, and MCYST-LA, with MCYST-LR and –LA being the most dominant congeners. Yellow perch fillets were dominated by the demethylated version of MCYST-LR. In contrast, yellow perch livers showed concentrations of both demethylated –LR and –RR, as well as MCYST-LA. FWM samples in 2009 often showed relatively high levels of MCYST bioaccumulation (typically the –LA variant) even when ambient river concentrations were low or below detection.

Comprehensive literature reviews of cyanobacterial toxin accumulation indicate that concentrations of various MCYST congeners in Klamath River fish and FWM tissue exceeded various tolerable daily intake values relevant to public health protection. For example in 2007, MCYST in FWM exceeded the Lifetime TDI guideline for children by 8 to 663x, the Seasonal TDI by 0.8 to 66x, and the Acute TDI by 0.1 to 10.6x. For yellow perch filets, 66% of the samples were greater than 10x (up to 100x) the Lifetime TDI and 1-10x greater than the seasonal TDI, with several samples exceeding the Acute TDI. These trends will be discussed relative to public health protection and State of California guideline values for MCYST in tissue.

Anadromous & Resident Fish 1

#053

Fall Chinook Salmon Escapement and Run Characteristics for the Mainstream Klamath River, 2001 - 2008

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The USFWS, in collaboration with Tribal and state partners, initiated monitoring of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) escapement in the mainstem Klamath River in 1993 using redd survey methods. To improve the accuracy of escapement estimates generated using redd survey data, we conducted carcass surveys of fall-run Chinook salmon within weekly time strata on the Klamath River below Iron Gate Dam during spawning seasons of 2001 through 2008. Carcass survey data were used to estimate escapement using postmortem tag/postmortem recovery methods and to characterize the age and sex composition and spawning success of the run. Unstratified Petersen, stratified Petersen, and Schaefer tag recovery methods were employed to estimate escapement. Our analyses indicate that the unstratified Petersen estimator contains decreased reliance on potential sources of bias compared to the other estimators used. In comparison to redd counts from concurrent redd surveys between Iron Gate Dam and the Shasta River confluence, unstratified Petersen carcass tag recovery methods yielded 3.2 to 4.7 successfully spawned females per observed redd. Redd surveys are still used to estimate escapement between the Shasta River and Indian Creek confluences, where the number of carcasses each year is too sparse for a sufficient carcass-based estimate. According to Kimura-adjusted scale readings and subsequent expansions, jacks (age two fish) represented only 0.1% to 3.9% of the carcasses sampled each season in 2001, 2003 through 2005, and 2007 but 9.4%, 15.8%, and 17.1% in 2002, 2006, and 2008, respectively. Extremely low jack numbers in 2005 boded poor returns in 2006 and 2007 of age 3 and age 4 adults, respectively. Despite low adult estimates in 2006 and 2008, jack estimates were highest, portending good returns of 3 year old spawners in 2007 and 2009 and of 4 year old spawners in 2008 and 2010. Pre-spawn mortalities of females ranged from an unusually high 22.1% in 2005 to a low of 2.7% in 2007. Estimated annual egg deposition by adult females in the study area, calculated from the unstratified Petersen estimates, ranged from 21.1 and 24.5 million (in 2002 and 2003) down to 6.7 and 5.7 million (in 2005 and 2006).

#035

Klamath Basin Lampreys: Critical Uncertainties for Restoration and Management

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The Klamath Basin is home to the highest diversity of lamprey species in the world. These species have a variety of life history strategies from the large anadromous and predatory Pacific lamprey (*Entosphenus tridentatus*) to the small non-predatory Klamath brook lamprey (*Entosphenus lethophagus*). Included in the Klamath Basin lamprey fauna are several endemic species including the smallest extant lamprey, the Miller Lake lamprey (*Entosphenus minimus*). The lampreys of the Klamath Basin also have cultural significance to the Tribes of the Klamath Basin with many of the Lower Basin Tribes actively harvesting Pacific lampreys as part of a subsistence fishery. Despite the importance of the lamprey fauna in the Klamath Basin, little is known about these fishes. Although population monitoring information for any lamprey species on the Pacific coast is sparse, data indicates that populations are at depressed levels and declining. Furthermore, much of the information needed to properly manage and restore these unique species has not been developed. The most studied of the lampreys that occur within the Klamath Basin is the Pacific lamprey. Although the Pacific lamprey is anadromous and sympatric to many Pacific Coast salmonids, current studies demonstrate that their biology and management needs differ dramatically. Some specific examples

include differences in genetic population structure, habitat use, passage needs, bioaccumulation of toxins and more. These differences highlight the need to address the major knowledge gaps and consider lampreys during Klamath Basin restoration planning and implementation.

#065

Population Genetics of Klamath Basin *Oncorhynchus mykiss*

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In the Klamath Basin, the salmonid fish species Oncorhynchus mykiss is present throughout the lower Klamath-Trinity River system as anadromous summer- and winter-run steelhead as well as freshwater resident rainbow trout, all of which are forms of the coastal subspecies O. m. irideus. In addition, redband trout (O. m. newberrii) occur in the upper Klamath Basin. However, compared with the Columbia River to the north, relatively little is known about the relationships among O. mykiss populations within the Klamath River. Although steelhead and other anadromous salmonids historically migrated into the upper Klamath Basin and associated tributaries, the construction of Copco Dam #1 in 1918 and Iron Gate Dam in 1962 stopped all upstream migration of fishes past these barriers. We have conducted population genetic analyses of O. mykiss samples collected throughout the Klamath watershed using data from 18 variable microsatellite loci. Samples included steelhead, rainbow and redband trout, presumably representative of ancestral coastal and inland lineages, as well as samples of O. mykiss from neighboring inland basins. In addition, the Klamath samples were compared with data from O. mykiss populations in other coastal California river systems. Results demonstrate the presence of distinct inland and coastal genetic lineages, as well as divergent lineages represented by samples from the inland lake basins.

#120

Status of Coho Salmon in the Scott and Shasta River Watersheds

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The California Department of Fish and Game has operated video fish counting facilities to enumerate coho salmon (*Oncorhynchus kisutch*) on the Shasta River and Scott River watersheds since 2001 and 2007 respectively. The purpose of these counting facilities is to enumerate abundance and describe the run characteristics of adult coho salmon. Video fish counting operations are initiated each season in the early fall and continue through early January unless high in-stream flows force earlier removal. The total number of coho salmon that entered the Scott River during 2007, 2008 and 2009 was 1,622, 62 and 21 respectively. The total number of coho salmon that entered the Shasta River from 2001 to 2009 has ranged from 9 to 373. The hatchery component of coho salmon in the Scott River is thought to be extremely low, as very few marked fish have ever been recovered in the watershed. The proportion of hatchery origin coho salmon returning to the Shasta River in 2008 and 2009 was estimated to be 73% and 20% respectively. On the Scott River only one data point is available for each cohort, preventing any trend analysis, although it is clear that one of the three brood years is sustaining itself while the remaining two are critically low. All three cohorts on the Shasta River have declined (14%-95%) over the course of the last two generations. Recent counts on two of the three Shasta River cohorts are critically low (<31 individuals). Both the Scott River and Shasta River coho salmon populations are identified in the Southern Oregon Northern California Coho (SONCC) recovery plan as independent core populations, which indicates their high level of importance to the long term success of the ESU. Current data collected from the Shasta River and Scott River counting facilities indicates that both of these important populations are at critically low abundance levels and are facing an extremely high risk of extinction.

#061

The Potential for Integrating Fish Tagging Studies Throughout the Klamath River Basin

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Management and recovery of imperiled fish populations depend on understanding key life history parameters and their roles in regulating population dynamics. Capture-recapture studies offer a reliable way to estimate these parameters including survival, recruitment, population growth rate, movement, and habitat use. Capture-recapture data can be incorporated into a robust modeling framework to evaluate the effects of water management strategies and other environmental factors on fish populations. Severe water quality problems in the Klamath River Basin have led to fisheries concerns in the region and a non-binding conditional agreement to remove four dams separating the upper and lower basins. State, federal, and tribal natural resource agencies throughout the Klamath River watershed are currently using passive integrated transponder (PIT) tags to study various endangered and sport fish populations. Unfortunately, the potential of these studies has often been hampered by low probabilities of re-encountering tagged fish. To ameliorate this problem, researchers have begun using remote underwater PIT tag detection systems to improve data collection efforts. Recent technological advances have improved the feasibility of tagging studies and allow for numerous study design possibilities. These advancements will allow researchers to conduct larger scale studies and ask bigger and better questions that address more complex hypotheses. In order to achieve the full potential of the various tagging studies in the basin, substantial thought should be given to study design, and collaboration among agencies will be required. To facilitate future collaboration, the USGS Klamath Falls Field Station is creating a centralized tagging database for the entire Klamath Basin that will allow storage and retrieval of data. This basin-wide database will simplify and facilitate data-sharing and collaboration among agencies.

Anadromous & Resident Fish 2

#074

Chinook and Coho Salmon Outmigrant Trapping in the Main Stem Klamath River

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The USFWS has been conducting downstream migrant monitoring for juvenile salmonids in the mainstem Klamath River at Big Bar, 10.0 km upstream of Weitchpec, since 1988. Since 1996, that site has been monitored jointly by the USFWS Arcata Fish and Wildlife Office and the Karuk Tribe of California. Since 2000, USFWS, Karuk Tribe, and USGS Fort Collins Science Center have been using rotary screw traps and frame nets to monitor outmigrants of all fish species at three sites on the mainstem Klamath River between Iron Gate Dam and the Scott River confluence: downstream of the Bogus Creek confluence (2002 to present), near the I-5 bridge river crossing , and just upstream of the Kinsman Creek confluence (2002 to present). After very high disease rates were noted in 2003, we also sampled the mainstem Klamath River at Happy Camp and above Orleans in 2004 (Chamberlain and Williamson 2006). Temporal distribution of outmigration, outmigrant length and weight, and production/successful outmigrant estimates of Chinook salmon, based on mark-recapture trap efficiencies are currently in production using techniques recently developed for the Trinity River Restoration Program. Since 2004 we have recorded external symptoms of infection, which generally are not exhibited until late stages of infection. Gill, belly, anus, eye, and skin conditions, in particular, were examined. QPCR (quantitative real-time polymerase chain reaction) assays and histology analyses (of fish that we provided) conducted by the USFWS California-Nevada Fish Health Center

provide more accurate/precise infection rates and relationships to habitat conditions. We intend that these infection rates, by size category and exposure time, observed water temperatures, and locations of disease hotspots, will be included into our young-of-year salmon production model, SALMOD.

#042

Juvenile Coho Salmon Use of Off-Channel Habitats in the Lower Klamath River

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The Yurok Tribal Fisheries Program (YTFP) and the Karuk Tribe Department of Natural Resources (KTDNR) initiated a collaborative study in 2006 to better understand juvenile coho salmon habitat use within the Klamath River mainstem corridor, which encompasses the main river channel and its side channels, off-channel habitats and the lower reaches of tributaries near the Klamath floodplain. Fish sampling efforts have included the use of fyke nets, beach seines, and electro-fishing. Fish marking techniques have been used to document fish movement patterns, estimate fish densities, and assess residence time in several off-estuary slough and lower tributary locations. Marking young-of-the year coho salmon with Passive Integrated Transponder (PIT tags) by KTDNR and YTFP throughout mainstem and tributary habitats has enabled tracking movement and growth of these uniquely numbered fish between the time they are marked and subsequent recapture events. Results indicate that fish migrate substantial distances from natal tributaries and mainstem habitats into off-estuary sloughs and off-channel wetlands beginning with the onset of the first fall freshets. Beaver ponds and similar open-water wetlands appear to provide preferred over-wintering habitat in the Lower Klamath for non-natal juvenile coho salmon. Growth rates of coho rearing in these habitats are substantially greater than those of fish sampled over the same time frame in free-flowing tributary habitats; indicating an advantage these still-water habitats, with relatively warm winter water temperatures, offer compared to winter habitat conditions in natal inland streams. PIT-tagged coho from throughout the basin are consistently captured in these types of off-channel habitats, indicating that they play a key role in the growth and survival of coho salmon from throughout the Klamath Basin. Life –stage habitat requirements and spatial distribution of these habitats seem to determine migratory behavior of juvenile coho. Information regarding the importance of off-channel/beaver pond habitats is guiding our restoration efforts in the Lower-Klamath Basin.

#096

Juvenile Coho Life History Tactics Utilizing the Mid-Klamath River Corridor with Linkages Between Inland and Coastal Riverine Habitats

Toz Soto

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The Karuk Tribal Fisheries Program (KTFP) and the Yurok Tribal Fisheries Program (YTFP) initiated a collaborative study in 2006 to better understand juvenile coho salmon habitat use within the Klamath River mainstem corridor. The mainstem corridor encompasses the main river channel and its side channels, off-channel habitats and the lower reaches of tributaries in close proximity to the Klamath floodplain. Sampling efforts include use of beach seines, fyke nets, directional weir traps in combination with marking and tagging fish to determine extent of residence, fitness and distribution in relation to seasonal shifts in habitat characteristics Results indicate that some juvenile coho leave natal areas and re-distribute within the mainstem river corridor with movements closely associated with seasonal changes in water quality and flow patterns. The use of non-natal habitats within the mainstem corridor, including small tributaries and off-channel features, appears to be an important survival mechanism for some juvenile coho in the Mid Klamath region during summer when water temperatures exceed lethal levels, and during winter when high flows occur. The relative importance of an overwintering re-distribution, however, appears to differ between the upper reach of the Mid Klamath region, where winter flows are more stable due to less precipitation compared to the lower part of the region. Flow patterns are much more dynamic downstream of Happy Camp in winter. Findings indicate that recovery actions could be tailored to benefit juvenile

coho that utilize the mainstem corridor, thereby improving overall population viability. Strategic habitat restoration within the corridor could benefit all spawning aggregates located upstream.

#139

Factors Affecting Coho Smolt Survival in the Lower Klamath River

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Coho salmon (Oncorhynchus kisutch) populations in the lower Klamath River were listed as threatened under the Federal Endangered Species Act, and the Biological Opinion that followed in 2002 spurred several management actions. One action included implementation of minimum discharges at the lowermost of six dams on the Klamath River. The premise behind this action was that increased discharge during spring would increase survival of coho salmon smolts, thereby aiding recovery. This hypothesis appeared logical, but had not been studied in the Klamath River. A study of the relation between coho smolt survival and environmental factors including river discharge was conducted between 2006 and 2009. Discharge at the dam was not experimentally controlled, however survival rates were evaluated under a wide range of observed flow conditions during the four year study. In each year, apparent survival of radio-tagged fish released near Iron Gate Dam was estimated in seven different river reaches downstream using Cormack-Jolly-Seber mark-recapture models. Estimates of apparent survival through 276 km downstream from the dam ranged from 0.406 (SE = 0.032) to 0.659 (SE = 0.049) among years. The lowest estimates and greatest differences in apparent survival among years were in areas upstream from the Scott River, the first 75 km downstream from the dam. The effects of river discharge, water temperature and several other variables on survival were also evaluated.

#016

Monitoring Adult Spawning Populations of Lost River and Shortnose Suckers to Support Recovery Planning

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Lost River and shortnose suckers are federally endangered, long-lived catostomids endemic to the Upper Klamath River Basin of southern Oregon and northern California. Since 1995, the U.S. Geological Survey has been monitoring the adult spawning populations of both species in support of recovery planning efforts. The two locations of primary concern for management are Upper Klamath Lake in Oregon and Clear Lake Reservoir in California. A monitoring and research program based on modern capture-recapture methods has produced precise estimates of annual survival for populations of both species in Upper Klamath Lake and shows promise for populations in Clear Lake Reservoir. Results show that survival is typically high, in accordance with life history expectations, but that populations experience substantial mortality in some years. Implementation of remote detection systems for passive integrated transponder (PIT) tags has dramatically increased the amount of information collected. This wealth of data has made it possible to explore more realistic models and hypotheses about factors affecting the conservation and recovery of these species. Of particular interest to recovery planning, the capture-recapture program now produces estimates of recruitment and annual rates of change for the adult spawning populations in Upper Klamath Lake. In this system, both Lost River and shortnose sucker populations are dominated by fish that were spawned in the early 1990s, with little evidence of recruitment in the past decade. Populations have declined by 25-50% over the last 6-7 years because mortality has not been counterbalanced by recruitment. The capture-recapture program is complemented by efforts to develop reliable methods for aging these species, as age data can provide a second source of information about recruitment to the adult spawning populations. Our monitoring and research program has provided a solid science foundation that informs managers tasked with recovering these imperiled species.

Fish Health and Disease 1

#105

Mercury Contamination in Lampreys of the Lower Klamath Basin.

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Mercury has been linked to a host of lethal and non-lethal impacts to biological organisms. Impacts from mercury include immunosuppression, teratogenic effects and endocrine disruption. Mercury, referred to as Quicksilver by goldminers, was widely used in Northern California during the gold rush. High levels of mercury in the Trinity River led to health advisories for the consumption of fish in Trinity Lake. We investigate presence of mercury in long lived filter feeders in the Klamath Basin, lamprey ammocoetes (*Entosphenus spp.*). In 2007, we sampled freshwater mussels (*Margaritifera falcata*) and lamprey ammocoetes from three paired locations in the Trinity River. In 2008 we sampled lamprey ammocoetes and sediment samples from 31 locations in the Klamath River and its tributaries. In 24 of the 31 (77%) batch sample sites collected had Total Mercury (THg) levels above 0.3 ppm, a level of concern set by the EPA for human consumption. At a single site where 31 individual ammocoetes were sampled and tested for THg, 28 of 31 (90%) were above 0.3 ppm. Adult lampreys were collected at the mouth of the Klamath with a partnership with the Yurok Tribe and had muscle fillets examined for total mercury, as well as a subset of adult females examined for biodistribution of mercury in muscle fillets, liver, ovaries and muscle biopsies. Adults were tested for muscle fillets had 23% (5 of 21) of the samples above 0.3ppm. For the smaller portion of adult females tested for several organs, the individual with the highest levels of THg for muscle fillet also had correspondingly high levels in the liver, ovaries and the muscle biopsy. Considerations of future work with mercury levels in these unique species are discussed.

#099

Ceratomyxosis and *Parvicapula minibicornis* Infection of Klamath River Juvenile Salmon.

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Two myxosporean parasites, *Ceratomyxa shasta* and *Parvicapsula minibicornis*, are quite prevalent in juvenile Chinook salmon that rear or migrate through the Klamath River. Both parasites have a freshwater polychaete alternative host, *Manayunkia speciosa,* that is found at high densities in some reaches of the Klamath River. *Ceratomyxa shasta* infection can result in lethal enteritis while *P minibicornis* infects the kidney. Prevalence of infection for *C. shasta* has ranged from 21 – 49% in samples collected above the confluence of the Trinity R. with *P. minibicornis* infection > 90%. Data on disease progression, species susceptibility, infection characteristics, and potential control measure studies will be discussed. A concerted research effort to understand the ecological factors influencing fish disease in the Klamath River is being conducted by collaboration of Klamath R. tribes, federal and state agencies, and university researchers.

#067

Effects of *Ceratomyxa Shasta* Infections on Klamath River Salmon: What do we Know and Where do we go Next?

Jerri L. Bartholomew

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Severe infection by the myxozoan parasite *Ceratomyxa shasta* has contributed to the declining numbers of juvenile Klamath River fall Chinook and coho salmon and subsequent impacts on later adult returns. Over the past 7 years, efforts in our laboratory have been directed at understanding the ecology of the parasite in the Klamath River with a goal of reducing disease effects. A monitoring program that utilizes real-time PCR assessment of water samples has provided insights on the temporal and spatial occurrence of the parasite. This monitoring has identified an area of the river below Iron Gate Dam where parasite abundance reaches >10-100 parasites/L. Sentinel studies conducted in this area provide evidence that an exposure dose of 10 parasites/L represents a threshold for mortality in native Chinook and coho salmon. Results of sentinel fish exposures in 2009 show that disease effects this year were severe and also suggest that the infectious zone was expanded in 2009. In contrast to the high mortality in salmon in the lower river as a result of *C. shasta*, exposure of salmon at a location with similar parasite densities in the Williamson River did not result in mortality. Investigation of this anomaly resulted in identification of four parasite genotypes that appear to have specificity for different salmonid species. All of this data is being incorporated into a disease model that will inform efforts directed at reducing parasite numbers and enable us to make predictions on disease effects as either dam removal or fish passage plans progress over the next decade.

#075

Ceratomyxa Shasta Infection in Sentinel Fish Exposed in the Klamath River, 2007-2009

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Sentinel juvenile fish exposures to detect infections of *C. shasta* were conducted for 72 hr at various sites in the Klamath River system during May, June and September 2007-2009. These studies were done to identify those areas of the river where "hot spots" of infection occur, to allow comparisons of infection levels with previous years, and to examine susceptibility of the Klamath fall Chinook and coho juveniles. At most sites, a known susceptible rainbow trout stock, and Iron Gate Hatchery Chinook and coho were exposed, then reared at the Salmon Disease Laboratory, Corvallis, OR and observed for infections of *C. shasta*. The rainbow trout suffered 90-100% loss at all sites except at Keno Eddy above J.C. Boyle Dam and above the Klamathon Bridge below Iron Gate Dam. Severe losses of fall Chinook occurred near Beaver Creek and Seiad Valley in May and June. In June 2007, 30-40% of the Chinook died but in June 2008 and 2009, losses reached 60-90%. Coho were affected at all sites below Iron Gate Dam, but most severely near Beaver Creek and Seiad Valley. Post-exposure holding at a water temperature of 18°C resulted in higher loss of coho when compared to those held at 13°C. Very low loss was observed in Chinook and coho exposed in the lower Williamson River. No mortality occurred in Chinook salmon exposed at Keno Eddy. The sentinel exposures demonstrate that only a 3-day exposure of Chinook and coho in the river reach encompassing Beaver Creek and Seiad Valley resulted in serious mortality. Also, there appears to be a shift downstream of greater infection severity seasonally from spring to summer within this hot zone.

#002

Evaluation of *Ceratomyxa shasta* and *Parvicapsula minibicornis* Infection in Returning Adult Chinook Salmon (*Oncorhynchus tshawytscha)* Throughout the Klamath River Basin

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I examined incidence and density of *Ceratomyxa shasta* and *Parvicapsula minibicornis* infection in adult Chinook salmon (*Oncorhynchus tshawytscha*) returning to spawn in the Klamath River Basin. From August 2007 through December 2007, 506 adult salmon were sampled at various locations throughout the basin. Trophozoite and myxospore life stages of the myxozoan parasites *C. shasta* and *P. minibicornis* were identified and quantified using wet mount, histology, and polymerase chain reaction. Chi-square tests were used to correlate any temporal or geographical patterns with incidence and density. Incidence and density for both pathogens peaked on October 25 in samples collected from Iron Gate Hatchery. No clear trends were seen in samples collected from Trinity River Hatchery. Chinook salmon carcasses collected from Bogus Creek, Shasta River, and the mainstem Klamath River were found to have significantly more *C. shasta* myxospores than Chinook salmon artificially spawned at Iron Gate and Trinity River Hatcheries. Further research should focus exclusively on naturally-spawned salmon carcasses to gain a better understanding of the timing and frequency of the myxospore load in the Klamath River Basin.

Fish Health and Disease 2

#019

Modeling the *Ceratomyxa shasta* Cycle in the Klamath River System

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In the Klamath River (KR) the disease ceratomyxosis is one of the factors impacting the survival of out-migrating juvenile salmon. This disease is caused by the myxozoan parasite *Ceratomyxa shasta*. *Ceratomyxa shasta*, endemic to the Pacific Northwest, requires a salmonid host and a freshwater polychaete host (*Manyunkia speciosa*) to complete its life cycle. Over the past ten years, research in our laboratory has been conducted to determine the distribution and densities of both the parasite and the polychaete host within the Klamath system and also to monitor the severity of disease in juvenile salmon. We have developed a mathematical model that identifies the basic interaction parameters of *C. shasta* and its two hosts. From the parameters in this model a series of equations were developed to describe each stage in the parasites life cycle. These equations were then solved to define the basic reproduction number (R_0) of *C. shasta*. To estimate the value of the basic reproduction number we conducted field experiments to quantify a range of values for select parameters in the model. In the Klamath River, we exposed caged sentinel fish for various lengths of time and measured water velocity to estimate the transmission rate of *C. shasta* and the infectious dose juvenile salmon are exposed to in the river. From these field exposures we identified a non-linear threshold to mortality from *C. shasta* in Chinook salmon. As the number of parasite per fish surpassed $5.5 – 9.9 \times 10^5$, the mortality greatly increased. From the basic reproduction number equation we will be able to identify the key parameters that may act as bottlenecks in the transmission cycle. This model also provides a platform to perform computer simulations to determine the relative effectiveness of different management strategies on reducing the in-river parasite burden.

#018

Ceratomyxa Shasta in the Williamson River: Implications for Salmonid Reintroduction and Management in the Upper Klamath Basin

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Ceratomyxa shasta is a myxozoan parasite endemic to the Klamath River basin and is dependent upon both a polychaete worm (*Manayunkia speciosa*) and a salmonid to complete its life cycle. *Ceratomyxa shasta* is established throughout the main-stem Klamath River, with levels highest below Iron Gate Dam and in the lower Williamson River. Questions about how dam removal and the reintroduction of anadromous salmonids into the upper basin will affect disease have necessitated research on parasite density, distribution, host overlap and the parasite genotypes present in the Williamson River. Parasite density was assessed using a *C. shasta* specific quantitative PCR assay from water samples collected throughout the Williamson River and its tributaries. Parasite DNA was sequenced to determine parasite genotype. Polychaete surveys were focused in areas of highest parasite densities to compare polychaete habitat and qualitative polychaete densities between sampling locations. We determined two areas where the highest (>10 parasites/L) parasite densities occur, from the mouth of the Williamson River to below the confluence of Sprague River and above the confluence of Spring Creek. Polychaetes were present in both locations surveyed and were mostly found in slow-flowing, depositional areas. Genetic analysis of parasites from water samples and infected fish in the Williamson River demonstrate parasite genotypes found in the native redband trout differ from those that cause mortality in the stocked susceptible rainbow trout and that the parasite genotype found in Chinook salmon is not present. However, reintroducing anadromous fish could potentially introduce novel genotypes into the upper Klamath basin.

#125

Effects of Elevated Water Temperature on Early Life Stage Development and Survival of Spring-run Chinook Salmon in the Klamath-Trinity Basin

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Key uncertainties regarding the adequacy of temperature management criteria for protecting spring-run Chinook salmon, a racial component of the Upper Klamath-Trinity rivers Chinook salmon ESU, were identified in the Trinity River Flow Evaluation because of a paucity of data on stock-specific responses to water temperature regimes. Temperature-specific developmental characteristics and mortality of incubating eggs and pre-emergent larvae between 10 °C and 16.6°C were evaluated in a blocked experimental design using eggs from 10 one male to one female matings (to control for interfamilial variation) over two study years. Temperature-specific mortality rate exhibited a threshold response as opposed to a continuous function reported for a number of other salmon species. A statistically significant ($P<0.001$) critical water temperature threshold was identified at 14.5°C above which the mortality of incubating embryos and pre-emergent larvae rapidly increases. Temperature-specific embryo development followed a typical van't Hoff rate function. Fry surviving incubation at temperatures above 14.5°C were significantly ($P<0.001$) smaller at emergence than fry incubated at cooler temperatures. Furthermore, latent mortality of post-emergent fry generally increased for eggs incubated at and above 13.3°C compared with eggs incubated at lower temperatures. This latter result suggests that the temperature conditions during egg incubation and its effects on embryonic development persist after fish begin to exogenously feed.

#136

Monitoring the Salmon Parasite *Ceratomyxa shasta* in the Klamath River Through Water Sample Analysis

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Severe intestinal infection by the myxozoan parasite *Ceratomyxa shasta* has contributed to declining numbers of juvenile Klamath River (KR) fall Chinook and coho salmon and subsequent impacts on later adult returns. The small, spore-forming parasite is found throughout the Pacific Northwest but is most prevalent in the KR. The high prevalence and severity of *C. shasta* infections in KR fish indicates this parasite is a key factor limiting salmon recovery in this system. *Ceratomyxa shasta* has a complex life cycle, involving a polychaete worm host as well as salmon and trout. KR salmon have evolved with *C. shasta* and are relatively resistant to infection compared to salmon from rivers where the parasite is absent, thus the current severity of ceratomyxosis in these fish suggests a shift in the host:parasite balance. In addition to sentinel fish exposures and polychaete sampling, we have been directly sampling KR water to assess the abundance of *C. shasta*. We filter replicate 1L samples and test the concentrated material for parasite DNA using a specific and sensitive molecular assay (quantitative PCR). This approach enables us to readily follow the spatial and temporal abundance of waterborne stages of the parasite. This monitoring began in 2006 and in 2008 we tested over 1000 water samples from five mainstem index sites and four tributaries from March through September. Samples were also taken during sentinel fish exposures to relate parasite dose with fish mortality. We found the geographical and seasonal pattern of abundance of *C. shasta* largely consistent during our monitoring program, although parasite levels fluctuate between years. The parasite increases in abundance in the spring from less than 1 spore/L to peak in June at over 100 spores/L (at Beaver Creek, Rkm 259; 45 Rkm below Iron Gate Dam). Above Beaver Creek, levels are low (around 1 spore/L), and below Beaver Creek abundance decreases westward, likely a combination of dilution from the tributaries and disintegration of the fragile actinospore stage. Only small quantities of parasite (less than 1 spore/L) are detected in the tributaries. Generally, mortalities in sentinel Chinook attributable to *C. shasta* occur once parasite abundance exceeds 10 spores/L. Inconsistencies in dose and mortality (i.e. lower and upper Klamath River) appear to be explained by the presence of two different strains of parasite that differ in host preference. We have now accumulated sufficient data to begin looking for patterns in parasite abundance associated with variables including water flow and temperature.

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#141

Effects of Myxozoa Disease on Population Dynamics of Klamath Fall Chinook Salmon

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Animal populations are frequently infected by pathogens, but it is not always easy to determine their significance on overall population dynamics. One of the difficulties in detecting disease effects in population time-series data originates from the fact that the hosts are also affected by many other environmental factors. In this study, we investigated the effect of Ceratomyxa shasta (a myxozoa) disease on the population dynamics of fall-run Chinook salmon spawning within the Klamath River basin (California, USA). We analyzed existing spatially structured abundance data for naturally spawning salmon and survival data on hatchery-released salmon, and examined the

effect of C. shasta disease. The results from this analysis were supplemented with previous results from a field experimental study monitoring fish survival and a field sampling of C. shasta infection rates among migrating juvenile salmon. Based on this synthesis of the results, we conclude that C. shasta disease significantly affects the survival of fish that migrate through the location where the pathogen is concentrated, and that this effect is detectable in both survival and spawning-abundance estimates.

Environmental Influences on Endangered Sucker Ecology 1

#052

Lack of Recruitment to Spawning Sucker Populations and Timing of Juvenile Sucker Mortality in Upper Klamath Lake, Oregon

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Lack of substantial recruitment into adult Lost River and shortnose sucker populations in Upper Klamath Lake, Oregon was one of the major factors leading to the listing of these species under the Endangered Species Act in 1988. There is strong evidence for a lack of substantial recruitment, but less information is available on the timing and causes of juvenile sucker mortality. Length frequency and age data show that the spawning populations of Lost River and shortnose suckers are relatively homogeneous groups spawned in the early 1990s. Estimates of recruitment based on capture-recapture data indicate that few individuals have been added to the spawning populations over the last decade. Regardless of the gear used for capture, catches of age-0 juvenile suckers decline each year in August and age-1 and older suckers are always low. Potential causes of declining catches include emigration from a sampling region and reduced catchability as fish grow. Occupancy models that account for imperfect and changing detection probabilities and sampling across a wide geographic range, however, suggest that mortality is a more likely cause of diminishing catches. The timing of decreasing catches suggests high mortality may occur in July or August in most years. One hypothesis is that a lack of suitable in-lake rearing habitat and periodic poor water quality events reduce survival. Another hypothesis is that toxic cyanobacteria are linked to age-0 sucker mortality through the food chain.

#114

Ecological Strategies Utilized by Cyanobacteria

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Cyanobacteria, also known as blue-green algae, are the most primitive group of algae. They are simple but remarkably successful organisms. They are most closely related to other bacteria because they are prokaryotic, however, like other algae and higher plants, they have chlorophyll *a*, the primary pigment for photosynthesis. They also have two other important light-harvesting pigments, phycocyanin and phycoerythrin.

Individually, cells are microscopic; however, large clusters of cells are easily visible as surface a scum (a type of algal bloom) on any stable body of water. Distinct colony morphologies include large gelatinous matrices with numerous embedded cells, as found in the genus *Microcystis* and bundles of filaments as found in the genus *Aphanizomenon*. These morphologies reduce the ability of invertebrates to graze on these organisms and also enhance floatation and water column positioning.

Nutrient enrichment often increases the amount of cyanobacteria and they are able to store excess nutrients, termed luxury uptake, and utilize these stored nutrients when environmental supplies become limiting. Polyphosphate bodies are one of the common structures that exemplify this trait.

Several cyanobacteria are capable of producing a heterocyst. This structure is the site of nitrogen fixation; using atmospheric N_2 and converting it into organic compounds. When nitrogen is limiting in an aquatic system, this group of cyanobacteria often dominate because of their ability to perform this metabolic function.

Some kinds of cyanobacteria produce natural toxins. Ingestion of these toxins has caused the poisoning of animals, including domesticated animals, wildlife and fish. Human exposure and toxicity has only recently been documented and awareness at water treatment facilities has increased. The US EPA has added blue-green algal toxins to its Candidate Contaminate List, which might result in new regulatory measures for surface waters. The toxins are generally of two types: neurotoxins and hepatotoxins. The neurotoxins are normally fast-acting, and animals that ingest a large dose experience paralysis of skeletal and respiratory muscles which results in death. Hepatotoxins affect the liver, disrupting the important proteins that keep the liver functioning. Hepatotoxins generally act slower and a higher dose is needed before death occurs, however, they also may be tumor promoters at low doses.

#097

Seasonal and Spatial Dynamics of Cyanobacteria and Associated Water Quality Variables in Upper Klamath Lake, Oregon

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Massive blooms of phytoplankton, dominated by cyanobacteria, occur annually from June through October in hypereutrophic Upper Klamath Lake, Oregon, due, in part, to hydrologic and land use changes made to the lake and its watershed during the past century. High rates of photosynthesis during bloom growth elevate lake water pH (9.5 and higher), and decomposition during episodes of severe bloom decline increases the concentration of un-ionized ammonia (> 0.5 mg L^{-1}) and dissolved nutrients. This seasonal cycle of phytoplankton growth and decline also causes oxygen concentrations to fluctuate from supersaturation to near anoxia. Preliminary work by the U.S. Geological Survey and others has shown that, in addition to degrading water quality, cyanobacteria in Upper Klamath Lake produce microcystins (hepatotoxins) at concentrations that may be detrimental to the endangered Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers. Data collected in 2009 from samples collected for the analysis of water quality parameters and cyanotoxin concentrations help to relate the spatial and temporal occurrence of microcystins, produced primarily by *Microcystis aeruginosa*, to the seasonal bloom dynamics of the most abundant (in terms of biovolume) cyanobacterium in the lake, *Aphanizomenon flos-aquae*. Peak concentrations of dissolved microcystins observed in lake water samples collected on August 3, 2009 coincided with low levels of chlorophyll *a* (a surrogate measurement of phytoplankton biomass) and elevated concentrations of dissolved nutrients. Given that *A. flos-aquae* composes the majority of chlorophyll *a* measured in lake water samples and that *M. aeruginosa* has been directly linked to microcystin production in Upper Klamath Lake, these observations suggest that microcystins are released during the rapid decline of the *A. flos-aquae* bloom. Whether populations of *M. aeruginosa*, and therefore, microcystin concentrations, increase as conditions in the lake become less favorable for the *A. flos-aquae* bloom is currently under investigation.

#059

Cyanobacterial Toxins Found in Upper Klamath Lake, Oregon: Implications for Endangered Fish

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Upper Klamath Lake is a large hyper-eutrophic lake, found on the east side of the Cascade Mountains in Southern Oregon. Conditions in the lake include high levels of nitrogen and phosphorus nutrients that facilitate large, continuous cycles of cyanobacterial blooms from late spring through the fall. These cyanobacterial blooms include species of algae that are known to produce toxins that adversely affect other aquatic organisms. This study was designed to evaluate the presence of these toxins over three summer seasons (2007 - 2009) and to determine if there is any risk to the two endangered fish in the system: the Lost River sucker (*Deltistes luxatus*) and the shortnose sucker (*Chasmistes brevirostris*). Juvenile fish of these species are rare and appear to have poor survival in this ecosystem. Water and algae samples were collected monthly in 2007; bi-weekly in 2008 and weekly in 2009 from late June through September. Collected water/algal samples were filtered, extracted and analyzed using an enzyme-linked immunoassay (ELISA) method for quantitation of microcystin toxins, in water and algae. In 2007, high levels of microcystin toxins (up to 17.4 ug/L) were found in algae late in the summer and evidence from fish pathology showed exposure and adverse effects from these toxins. In 2008, lower levels of total microcystin were found in water/algal samples; from a low of 0.17 ug/L to a high concentration of 6.1 ug/L. The high dissolved water concentrations of microcystin in 2009 showed a high of 4.9 ug/L. Published LD50s for fish are around 550 ug/kg for one microcystin toxin variant; so assuming that juvenile fish are consuming 1% of their body mass in toxic algae, the average exposure to fish from microcystin was assessed to be approximately 5-fold greater than the published effects levels of microcystins to fish in 2007 and 3-fold greater in 2008. Thus, cyanobacterial toxins may be limiting survival of juvenile endangered Lost River sucker and shortnose sucker in Upper Klamath Lake.

#046

Algal Toxins in Upper Klamath Lake, Oregon: Histopathology of Age-0 Lost River and Shortnose Suckers in 2007 and 2008

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Recruitment into the adult populations of Upper Klamath Lake Lost River and shortnose suckers has been identified as a limiting factor in the recovery of these endangered species. One hypothesis for this lack of recruitment is based on poor survival of age-0 fish. In 2007 we began a multidisciplinary integrated assessment of factors with potential influence on age-0 sucker survival. This assessment, guided largely by existing data, included a fish health component. In this presentation we will focus on the histopathology data obtained in the assessment. In August 2007 (n = 47) and July – September 2008 (n = 103), age-0 Lost River and shortnose suckers obtained from Upper

Klamath Lake were evaluated for histopatholgy. Fish were fixed and processed using standard histologic methods and viewed as whole–fish serial cross-sections. Histopathology data were compared based on capture locality. Age-0 suckers obtained in 2007 exhibited high frequency (45-55%) locality-specific occurrence of liver necrosis. Percent occurrence of intestinal (79-80%) and kidney (40-42%) necrosis was also high in these age-0 suckers. In 2008, age-0 suckers exhibited liver necrosis at locality-specific occurrence frequencies (0-20%) that were substantially lower than observed in 2007. The intestinal and kidney lesions observed in 2007 were absent or occurred at a very low frequency in these 2008 age-0 fish. Gill pathology and parasitic infections were also observed in both 2007 and 2008 and will be described.

Environmental Influences on Endangered Sucker Ecology 2

#045

Skin Bacterial Flora of Age-0 Lost River and Shortnose Suckers in 2008: Nature Conservancy Delta Restoration Project and Upper Klamath Lake

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In 2007 we began a multidisciplinary integrated assessment of factors with potential influence on age-0 Lost River and shortnose survival in Upper Klamath Lake (UKL). This assessment included a fish health component. In this presentation we will focus on bacterial data obtained in the assessment. In July – September 2008, age-0 Lost River and shortnose suckers obtained from Upper Klamath Lake (n = 52) or the newly flooded region of the Nature Conservancy Delta Restoration Project (Tulana Farm; n = 76) were evaluated for skin bacterial flora. Fish mucous samples were examined for bacterial community composition by targeting 16s ribosome DNA using terminal restriction fragment length polymorphism analysis for genus-level identification. Data were compared based on fish capture locality. The bacterial flora on the age-0 suckers exhibited significant changes along a north to south gradient in Upper Klamath Lake. Fish sampled from the Tulana Farm region exhibited skin bacterial floras with similarities to those fish obtained from near shore areas in either the northern or central regions of UKL. Although there were similarities, fish from localities in both Tulana Farm and UKL did exhibit unique characteristic in their bacterial flora that permitted accurate assignment of individual fish to a specific locality using discriminate analysis. In addition to data on locality-specific age-0 sucker skin bacterial community composition, we will discuss the impacts these bacteria may have on juvenile sucker health and on delta restoration.

#113

Direct and Indirect Consumption of Cyanobacteria by Juvenile Suckers in Klamath Lake, Oregon

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Cyanobacteria and the associated toxin microcystin, have the potential to harm Lost River and shortnose sucker populations in Upper Klamath Lake, Oregon. To understand the potential exposure to cyanobacteria through consumption, the digestive tracts of several young of the year suckers collected in 2008 and 2009 were examined microscopically. Digestive tracts were extracted in the field, preserved in 1% glutaraldehyde, and kept cold during transportation and storage prior to examination. The contents from a 2-4 mm section of the intestine were extruded onto a microscope slide, examined, and photographed at 400x. The majority of intestinal contents were dominated by invertebrate larvae in the chironomid family. Only limited amounts of cyanobacteria were found directly in intestines of the suckers; *Microcystis aeruginosa* colonies were the most commonly found organism. Optical dissection of the chironomid larvae showed that cyanobacteria were being consumed by these invertebrates, which were then consumed by the suckers. This leads to the strong possibility that invertebrate larvae represent an important cyanotoxin exposure route for the young of the year suckers.

#005

Within-year and Among-year Distributions of Benthic Invertebrates in Upper Klamath Lake and the Newly Restored Delta Wetlands

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Invertebrates represent an integral part of lake and wetland ecosystem function. Benthic invertebrates have been sampled from the Upper Klamath Lake ecosystem since spring 2006. Four research questions have been addressed: 1) are densities sufficiently high to contribute to solute benthic flux via bioturbation, 2) what is the per-invertebrate metabolic contribution to nutrient flux, 3) what is the seasonality of mid-lake and wetland invertebrate densities during the ice-free period, and 4) how does the benthic assemblage change inter-annually in response to wetland restoration? High densities of invertebrates were detected in the benthos. Tubificid worms (63%), chironomid midges (21 %), and leeches (14%) dominated the benthos at lake sites, representing almost 98% of the individuals present. Weekly collections during summer 2008 at four lake sites revealed mean total invertebrate densities exceeding 10,000 individuals per square meter, strong location and temporal signals among species, and a potential to significantly influence nutrient flux. A sequence of changes in the assemblage structure also has occurred in the newly restored wetland. Given their densities, trophic importance, and potential to influence many lake and wetland processes, considerably more research is necessary on this important component of the Upper Klamath Lake ecosystem.

#050

Larval Lost River Sucker *Deltistes luxatus* and Shortnose Sucker *Chasmistes brevirostris* Response to Wetland Restoration at the Williamson River Delta, Upper Klamath Lake, Oregon

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The Williamson River Delta restoration project is a large wetland restoration project located at the interface of the Williamson River and Upper Klamath Lake with a primary goal of providing rearing habitat for larval suckers at the mouth of the river. Historically a fully functioning wetland ecosystem, the delta was drained and converted to farmland beginning in the 1940s, thus eliminating access to the deltaic wetlands for passively drifting larvae. Emergent macrophytes typical of wetland systems have been shown to benefit larval suckers by providing protection from non-native species, better feeding and growing opportunities, and shelter from a clockwise, wind-driven gyre in Upper Klamath Lake. In 2007, The Nature Conservancy began the hydrologic reconnection of 5,500 acres of historic deltaic wetlands to Upper Klamath and Agency lakes and the Williamson River by breaching and lowering more than 22 miles of levees. We examined larval sucker habitat use and fish condition (size and gut fullness) at shallow water sites (<1m deep) in both restored and existing lakeshore wetlands to assess the response of larvae to the restoration. Preliminary results from 2009 show that larvae captured in restored areas with emergent vegetation had a size and gut-fullness advantage over fish captured at open water sites. Data collected for several years prior to restoration showed that higher catches of sucker larvae occurred in existing lakeshore wetlands compared to restored wetlands, a trend that was reversed in 2009 when larval suckers were caught more frequently in the newly restored deltaic wetlands. Our results from the initial year of monitoring the fully restored delta suggest that larval suckers are rearing in the shallow water habitat available now for the first time in over 50 years. Increasing larval habitat and high levels of larval survival in restored wetland habitat may help in the long term recovery of both species.

#036

Migrational Movements and Distribution of Spawning Klamath Largescale, Lost River, and Shortnose Suckers in the Sprague River Before and After the Removal of Chiloquin Dam

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The migratory movements of Klamath largescale suckers (*Catostomus snyderi*), Lost River suckers (*Deltistes luxatus*), and shortnose suckers (*Chasmistes brevirostris*) entering the Sprague River to spawn were restricted by an irrigation dam located near Chiloquin, Oregon. Chiloquin Dam was removed in August 2008 to improve access to upstream spawning habitat and to reduce crowding of spawning fish immediately below the structure. The migratory behaviors and location of spawning areas were determined by tracking radio-tagged individuals before and after the removal of the dam. The spawning distributions of these populations were collected from individuals detected on a series of remote passive integrated transponder (PIT)-tag detection arrays constructed in several reaches above and below the dam. Results suggest adult migrants congregate in discrete reaches of the Williamson River and the Sprague River above and below the former dam site with each species showing some level of temporal and spatial separation in their spawning behavior. Fish passage at the Chiloquin Dam fish ladder prior to dam removal was apparently low. Post-dam removal monitoring has shown an increase in the number of tagged fish migrating past the dam site. Spawning was also observed in the first 2.2 river kilometers above the former dam site the year after removal on what was previously identified as underutilized spawning habitat. Most tagged fish, however, still migrated to spawning areas within a few river kilometers of the former dam site the year after removal. This indicates that although dam removal apparently allowed fish to disperse into underutilized spawning habitat in the lower Sprague River, substantial shifts in migration patterns and spawning distributions at a population level were not observed in the first year after removal.

Riparian Dependent Species 1

#017

Oregon Spotted Frogs (*Rana Pretiosa*) in the Klamath Basin: Status, Threats, and Local Restoration

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The Oregon spotted frog (*Rana pretiosa*) is a highly aquatic species that is estimated lost from 70% of its historic range in the Pacific Northwest. It is a candidate for Federal Listing and information on the status and threats to the species is needed. The species is presumed extirpated from the Willamette Valley and most of its extant populations are located in the Deschutes and Klamath basins. Genetic data suggest Klamath populations constitute a clade that differs from other parts of the species' range. We present an overview of the status and threats to the species in the Klamath basin and compare this with information from other parts of the species' range. Our recent preliminary results identify factors that suggest that Klamath populations are more at risk than those in the upper Deschutes basin. We discuss information gaps and ongoing work to address these threats.

#064

Comparative Ecology of the Western Pond Turtle (*Actinemys marmorata*) on Two Forks of the Trinity River, Trinity County, California

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The western pond turtle (*Actinemys marmorata*) is a habitat generalist, occurring in numerous habitats where surface water is available for a significant portion of the year. Despite its ability to survive in a variety of habitat types, this species is declining across much of its range, primarily due to habitat conversion and water resource management. Northern California harbors the majority of remaining robust populations, but even in remote areas, populations can be threatened by land and water use practices. To assess population impacts from damming, flow management, and subsequent river restoration efforts, we studied turtles on two forks of the Trinity River, one dammed and one free-flowing. Here we provide an overview of research conducted from 2005 to 2007, with reference to similar research from the same areas from 1991 to 1994. Where data were comparable across decades, we describe trends. We compare various population parameters between the two forks including demographics, thermoregulatory behaviors, body size and condition, growth rates, and riverine spatial dynamics. While population sizes appear to be relatively stable, several differences are attributable to management of the Mainstem. Most notably, turtles on the dammed Mainstem are considerably smaller than those of the same cohort on the free-flowing South Fork. Implications of smaller body size on population viability are discussed, providing direction for further research.

#104

Thermoregulatory behavior and growth characteristics of western pond turtles (Actinemys marmorata) on regulated and unregulated forks of the Trinity River

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The western pond turtle (*Actinemys marmorata*) is a California State Species of Special Concern and a Sensitive Species in Oregon. Understanding population specific life-history traits is necessary to make proper management decisions to preserve local populations. We have monitored western pond turtles on the mainstem Trinity River near the Lewiston Dam and on the South Fork Trinity River near Willow Creek, California since 2003. Our objectives were to better assist managers in restoration design and flow management. From 2005 to 2007, we combined the use of radio-telemetry and digital recording thermometers on the external carapace of turtles to study their thermoregulatory behavior in relations to river temperatures. We also conducted mark-recapture studies on both forks to obtain population estimates and estimate demographic parameters such as age structure, sex ratios and growth trajectories. The mainstem Trinity River has a cold thermal regime in the summer due to hypolimnetic releases from the dam, whereas the south Fork has a warm water regime due to solar input. These differences result in both a change in thermoregulatory behaviors and slower growth in the colder aquatic environment of the mainstem Trinity River.

#094

Freshwater Mussel Abundance, Distribution, and Habitat Preference in Two Northern California Rivers Within Karuk Ancestral Territory

Aaron David and Emily Davis

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Freshwater mussels (Bivalvia: Unionoida) are an integral component of freshwater ecosystems. Historically, they formed an important part of the diets and material culture of indigenous peoples in North America, including the Karuk Tribe and other Klamath Basin indigenous groups. West of the Rockies, mussels are not well-understood, but because of their sensitivity to anthropogenic changes, legacy as an indigenous cultural resource, and importance as bioindicators of water quality and freshwater ecosystem health, it is imperative to advance our understanding of this taxon. This study, a collaborative effort between the Karuk Tribe and Whitman College, is the first systematic survey to examine freshwater mussel abundance, diversity, distribution, and habitat preference in the Klamath and Salmon rivers of Northern California. In 2007 and 2009, eighty sites on the mid-Klamath between the Klamath-Trinity confluence and Irongate Dam, and 15 sites on the lower Salmon were snorkel-surveyed to assess abundance, diversity, distribution, and habitat preference of mussels. In 2009, 15 sites on the mid-Klamath were surveyed for mussel population age structure to determine mussel recruitment success and population health. Historical and contemporary use of mussels by local Karuk tribal members were assessed via interviews. Three mussel genera (*Margaritifera*, *Gonidea*, and *Anodonta*) were recorded, with *Gonidea* abundant and well-distributed within the Klamath, *Margaritifera* present in low numbers, and *Anodonta* present at 2 upriver sites. In the Salmon, only *Margaritifera* were found. Mussels were situated in microhabitats that minimized shear stress and provided protection from bed scour during high flows. Mussels were located on sand, gravel, and bedrock substrates significantly more often than on other substrates. Preliminary interviews indicated that mussels remained a significant portion of Karuk traditional diet until the mid-20th century and continue to function as a ceremonial food today. Preliminary data from population age structure surveys indicate that *Gonidea* populations are successfully recruiting. Continued study of Klamath mussel habitat and ecology will be essential to their conservation. Funding for the 2009 research was provided through the US Fish and Wildlife Service Tribal Wildlife Grant Program.

Riparian Dependent Species 2

#123

Ecology and Conservation of Western Pond Turtles in the Klamath Basin: What are the Challenges Ahead?

R. Bruce Bury

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The Western Pond Turtle is a species of concern in OR and CA, and was earlier proposed for federal listing. Yet, we have scant information on the species in the Klamath Lake basin or along the Klamath River. Fortunately, there are on-going studies at a few sites in the Trinity River basin: (1) BOR/USFS efforts along the river since mid-1990s and (2) Hayfork Creek, a tributary, where I have studied the turtle since 1968. These data sets provide unprecedented opportunities to design effective studies that compare trends in numbers, growth rates, and habits of turtles throughout the Klamath Basin, including responses to proposed dam removal on the Klamath River. My preliminary data reveal recaptures of turtles marked 40-41 yrs ago. Although few reach such age, some are 55+ yrs or older. Our preliminary work indicates marked differences in population features within the Klamath system: Hayfork turtles are the slowest-growing anywhere whereas recent preliminary surveys indicate that turtles in the Klamath Lake basin are among the fastest growing (2nd only to turtles in the Central Valley). Now, we could establish an effective network of permanent sampling sites to track changes in turtle numbers over time, including an effort to locate and archive all existing data sets. We need more work on understanding their population features, particularly their fecundity and survivorship. The ecology of small-sized or juvenile turtles remains almost unknown. Because habitat loss and alteration remain the principal threats to the long-term survival of turtles, management agencies may find these data useful for determining if specific areas should be considered for protection. Turtles receive widespread public support and are charismatic, which assists in efforts to protect them.

#107

Breeding Distribution and Phenology of the Foothill Yellow-legged Frog (*Rana boylii*) in Regulated and Unregulated Tributaries of the Trinity River Basin

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The foothill yellow-legged frog (*Rana boylii*) is adapted for life in dynamic river systems and is the only western ranid that is an obligate breeder in lotic habitats. Stabilized flows resulting from damming of the Mainstem Trinity River have resulted in a suite of structural habitat changes that have degraded oviposition and rearing conditions for this species. These changes combined with unnatural timing of flows have led to severe population declines of this frog below the dam. Annual float surveys of twenty miles of the mainstem river below the dam have been conducted since 2004 to determine numbers of egg masses and the distribution of breeding sites. Comparable surveys have been conducted on the undammed South Fork and North Fork rivers. Over the past five years the mainstem breeding population has been two to three orders of magnitude lower than the undammed South Fork and one to three orders of magnitude lower than the North Fork. In 2008 and 2009 surveys were conducted to monitor the fate of egg masses in relation to managed changes in flow on the mainstem river. The desiccation rate of the annual egg mass cohort was 68% in 2008 and 30% in 2009. Beginning in 2006 we examined the timing of oviposition and larval development rates at sites in several tributaries to better elucidate the impacts of flow regimes and temperature impacts on key aspects of larval ecology. We compared timing of oviposition, rates of

development, and time and size at metamorphosis between the Mainstem and six tributaries of the Trinity River. Differences are described relative to thermal regime and flow characteristics.

#124

What are the Challenges for Amphibians and Reptiles in the Klamath River Watershed: Biogeographic Barriers, Endemism, and Conservation Status

R. Bruce Bury

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Assessing and monitoring populations of amphibians and reptiles throughout the Klamath River watershed will assist management agencies entrusted with their protection. This basin and adjacent areas in the Klamath-Siskiyou Ecoregion (KSE) is an ancient landscape with markedly rugged topography and abrupt climate breaks. The KSE has the highest species richness of herpetofauna (amphibians and reptiles) in the Pacific Northwest due, in large part, to the overlap of two Biotas: Arcto-Tertiary (Northern, forest-dependent amphibians) and Madro-Tertiary (Southern, hot-adapted reptiles). Mountain slopes along the Klamath River are home to 3 endemic species of woodland salamanders plus up to least 3 more undescribed species. Field surveys now indicate that several species terminate their geographic ranges at the Siskiyou Mountains along the OR-CA border. These features run east-to-west, creating the "Great Wall of the Siskiyous" blocking N-S movements of the herpetofaunas along the Coast Range and Cascade Mountains. Also, species of concern such as Western Pond Turtles and Foothill Yellow-legged Frogs frequent the region's flowing waters. We know little how these species will respond to conversion of reservoirs to free-flowing rivers. Invasive species (e.g., bullfrogs) are invading standing waters and slow sections of rivers. These increasingly complex relationships merit greater study. We barely understand the local distribution of the herpetofauna let alone possible causative factors for occurrence. Biologists and managers could work together and incorporate educational efforts to create a regional "task force" to study and manage populations of amphibians and reptiles in the Klamath River watershed.

Environmental Assessment and Monitoring 1

#133

Vegetation and Fluvial Geomorphology of the Riparian Greenline in the Sprague River Basin

Michael L. Hughes and Christopher A. Leeseberg, Klamath Tribes Research Station, Chiloquin, OR

Like many regions in the western U.S., valley-floor environments of the semi-arid Sprague River basin of southern Oregon are heavily irrigated and widely grazed by cattle. These and other land uses have diminished water quality in channel systems throughout much of the basin. To better understand these impacts and to set a baseline for ongoing and future restoration efforts, the Klamath Tribes have begun a long-term, basin-wide biogeomorphic riparian monitoring program. Because if its widespread application, determining the composition of the lowest line of perennial vegetation above baseflow, or the "greenline," has been included. The goal of this paper is to summarize results of 38 greenline surveys conducted at 19 sites in 2008-9 and to explore geomorphic hypotheses that may explain vegetation patterns evident in the surveys. Spikerush (Eleocharis ssp.) and reed-canary grass (Phalaris arudinacea) were the most commonly occurring vegetation in the greenline across all sites. Because these species are aggressive colonizers, they indicate widespread availability of fresh alluvium in greenline zone. This availability may be associated with chronic channel-bank disturbance. Sedges dominated portions of the greenline at most of the sites, but occurred in less abundance. Because many of these sedges are late successional or early-to-late transitional species, their relative scarcity further supports the hypothesis that geomorphic environments remains

chronically disturbed and dynamic. Grazing is common, but variable in intensity, at nearly all of the study sites, likely contributing to the persistence of channel-bank disturbance at some sites. Among meandering channels, the richness of dominant species (i.e., "intracommunity diversity") was higher on the outer bends than on the inner bends of meanders at 10 of 12 sites. The variability of geomorphic surfaces (abandoned or incised floodplain, incipient floodplain, failed bank, bar, accreted toe material, etc.) incorporated into the greenline by the spatially discontinuous processes of channel-bank failure appears to increase the types of habitats surveyed on the outer bends of meanders, and therefore their combined floral biodiversity. In contrast, the spatial continuity of bar accretion on the inner meander bends appears to result in a more uniform geomorphic setting with fewer dominant species in the greenline. Despite widespread recognition that geomorphic processes influence riparian vegetation, factors such as the type and severity of bank erosion, the location of the survey with respect to meander geometry, and the type of geomorphic surface underlying greenline observations are not explicitly included in published guidance for biogeomorphic monitoring of the riparian greenline. Inclusion of such factors the greenline methodology improve the design, communication, and application of interdisciplinary research aimed at developing a better understanding of interactions between fluvial processes and riparian vegetation.

#112

Long-term Ecological Effects of Debris Flows and Debris Floods on Tributary Streams in the Klamath Mountains

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Debris flows and debris floods are catastrophic disturbances in steep, mountainous landscapes, but little is known about their long-term effects on stream ecosystems. In 10 basins (10 - 20 km2) in the Klamath Mountains that are tributaries to the Klamath River and Scott River, we used a space-for-time substitution to infer the long-term (10 – 100 y) ecological effects of debris flows on the structure of stream ecosystems. Debris flows mobilized sediment and wood and removed riparian vegetation in large portions (often >50%) of the channel networks of many study basins. Streams that had recent (1997) debris flows had riparian zones dominated by young, even-aged stands of white alder (Alnus rhombifolia). Although these young forests provided substantial canopy cover, canopy cover was reduced following the flood of December 31, 2005, resulting in increased stream temperatures and primary productivity. Debris flows resulted in reduced levels of large woody debris and benthic organic matter that persisted for at least 40 years. The composition of benthic macroinvertebrate assemblages reflected these ecological changes. For example, detritivorous stoneflies were virtually absent in recent debris flow streams. Although rainbow trout (Oncorhynchus mykiss) were abundant in most of the streams that had recent debris flows, populations of other vertebrates, such as Coastal giant salamander (Dicamptodon tenebrosus) and coastal tailed frog (Ascaphus truei), were virtually absent. Stream temperatures at the mouths of streams that had recent debris flows were substantially higher than temperatures in other streams, indicating that debris flows can have long-term impacts on the quality of cold-water refugia in the mainstem of the Klamath River. Our findings suggest that debris flows have substantial long-term effects on the structure of stream ecosystems and cause local extirpations of aquatic species. Environmental management of aquatic habitats in major tributaries, as well as in the Klamath River, needs to reflect the history and long-term impacts of debris flows and debris floods.

#054

Applications of environmental monitoring in the Scott Valley

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Abstract: The Siskiyou RCD and cooperators have been performing biological and stream condition monitoring and water quality and quantity monitoring in the Scott River for over a decade. This monitoring data has been used to develop watershed plans, prioritize and implement restoration and protection projects, develop a better understanding of watershed process and assess the effectiveness of resource protection and conservation programs. Three examples of monitoring programs will be discussed and connected to the applications in watershed management and planning: coho salmon adult and juvenile direct observation surveys, water temperature monitoring and water quantity monitoring. Direct observation of juvenile and adult coho salmon over all brood years has identified stream reaches, meso habitat types and micro habitat types that are utilized by higher densities of coho salmon. This information is important for the prioritization of locations for stream and riparian protection and enhancement. Additionally, these surveys document existing structures utilized by coho salmon allowing for the replication of natural designs in reaches needed enhanced carrying capacity. Stream temperature has been collected for over a decade throughout the Scott River's tributaries and main stem. In 2008, U. C. Davis, University of Nevada – Reno and the Siskiyou RCD performed a distributed temperature (DTS) survey on a valley reach of the Scott River. This effort combined biological monitoring with water quality and quantity monitoring to increase our understanding of stream processes and groundwater-surface water interactions. The USGS, Cal. Dept. of Water Resources and the Siskiyou RCD have been collecting stream discharge data in the Scott River. The existing stream discharge data has been used to help develop the Scott River Water Balance and monitor the water supply and effectiveness of the Scott River Water Trust activities in the summer and fall. In October 2009, continuous stream discharge monitoring in the main stem Scott River discharge was utilized to monitor the forbearance of water by the Scott Valley Irrigation District to increase the flows and allow for the migration of adult Chinook salmon to the Scott Valley.

#034

Feasibility Assessment of Constructed Treatment Wetlands in the Vicinity of the Klamath Hydroelectric Project

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In 2008, we conducted a feasibility assessment on behalf of PacifiCorp to determine the potential for constructed treatment wetlands to provide improved water quality in the vicinity of the Klamath Hydroelectric Project. The Project's reservoirs receive large inflowing loads of nutrients and organic matter from upstream sources (notably Upper Klamath Lake), which fuel summertime blooms of cyanobacteria in the reservoirs. Treatment wetlands can act as filters removing particulate material, as sinks accumulating nutrients, or as transformers converting nutrients to different forms. As a team of scientists and engineers with expertise in constructed wetlands and water quality, we conducted a joint field survey to identify candidate treatment sites in the Klamath River upstream of Copco reservoir. Conceptual layouts for constructed treatment wetlands were developed for these sites, along with calculated estimates of potential treatment effectiveness (e.g., nutrient reductions). The sites are generally low-lying and directly adjacent to the river, and would be amenable to wetland construction. However, a major constraint identified in this assessment is that the potential sites for constructed wetlands on PacifiCorp-owned lands in the Project area could receive and treat only a minor fraction of the total flow of the Klamath River, and would be unlikely to provide a demonstrable river nutrient and organic matter load reduction. Instead, to achieve such a reduction, it would be necessary to develop more and larger wetland sites that would collectively or in the aggregate treat a substantial portion of the river flow. This would by necessity involve constructed treatment wetlands on

lands elsewhere above the Project area in proximity to the river system. The need to "scale-up" the overall size of constructed wetlands to achieve demonstrable and meaningful water quality benefits points to the need for a basin-wide effort that would require multiple stakeholder participation.

#122

Using Spatial Techniques to Aid Ecological Inventory and Monitoring at Regional Scales

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The Klamath Inventory & Monitoring Network is one of 32 networks set up by the National Park Service to conduct natural resource inventories and to monitor key ecological indicators (vital signs) across the nation. The Klamath Network is composed of six park units in northern California and southern Oregon: Crater Lake National Park, Lassen Volcanic National Park, Lava Beds National Monument, Oregon Caves National Monument, Redwood National and State Parks, and Whiskeytown National Recreation Area. Doing inventory and monitoring projects at this large scale requires careful planning and innovative strategies that may help inform similar efforts in the Klamath Basin. Use of a variety of spatial (GIS) techniques helps delineate sampling frames and target populations and generates probabilistic sampling designs. The appropriate spatial sampling design depends upon our goals and objectives, resource limitations, statistical power considerations, spatial characteristics of the population being sampled, and practical concerns related to ease of access and safety.

GIS is heavily used in all aspects of planning, implementation and data analysis associated with each inventory or monitoring project. Models to estimate travel times to survey locations help crews avoid obstacles and steep slopes and take into account the frequent need to locate sites at least 100m off of a road or trail to avoid anthropogenic disturbance signals. Map atlases have been developed so field crews can quickly create maps specific to their needs. Additionally, extensive use of GPS units with ArcPad allows for quick data entry, better quality data collection, and faster accessibility to data for reports and presentations. These "raw data" are then processed and analyzed, often within the GIS environment, to create maps, run analyses and write reports. Additionally, new GIS technologies such as a program called eCognition are applied to assist in object-oriented image analysis, which facilitates habitat classification and sampling frame delineation. This talk will discuss completed and ongoing natural resource inventories and monitoring research and what methodologies the Network applies to adequately survey such a large region.

Environmental Assessment and Monitoring 2

#100

Where in Upper Klamath Lake are the Largest Concentrations of Phosphorus, Organic Carbon and Metals Found in Bottom Sediment?

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The largest source of phosphorus to the water column in Upper Klamath Lake (UKL) is phosphorus from bottom sediments. There have been less than a half-dozen studies of UKL sediment in which cores were analyzed for phosphorus concentrations. Sampling locations selected for previous studies have been in southern, western and northwestern areas of the lake. For this study, sediment cores were collected in October, 2006, at 21 sites distributed throughout the lake that conform to a circulation pattern proposed by USGS scientists.

Cores were sectioned at 1-cm intervals to a depth of 5-cm. Sediment was separated into < 63µ and > 63µ particle-size fractions and chemical analyses were carried out on both fractions. Percent organic carbon was larger in the > 63µ particle-size fraction than in the < 63µ particle-size fraction. Concentrations of analytes in whole samples were calculated using the proportional contribution of each particle size fraction. Data from these cores were used to produce contour maps for total concentrations of Al, Ca, Fe, Ti, organic N, and organic C in UKL surface sediments. Concentration data for metals indicate that inflowing waters in the northern portion of the lake are the primary sources of metals to the lake. Phosphorus analyses provided data for the construction of contour maps which indicate the distribution of total P determined by dissolution of sediment samples, and geochemical forms of P determined by sequential extraction. Total phosphorus concentrations were found to be largest along the northern portion of the lake and at sites also near marshes on the southeastern lake shore. There was no significant correlation between total phosphorus and total iron concentrations in these sediment samples. Acid-soluble phosphorus concentrations were related to the distribution of metals in the lake. The largest fraction of phosphorus in these sediments was residual phosphorus. The concentration of residual phosphorus is calculated as the difference between the concentration of total phosphorus and the sum of the concentrations of inorganic phosphorus (determined by sequential extraction). Residual phosphorus can contain organic phosphorus, phosphate bound to clays, and/or refractory phosphorus minerals. Preliminary data indicate that a portion of the residual phosphorus is sorbed onto clays (smectite) in the sediments. ^{31}P NMR analyses indicate that most of the phosphorus in the clays is present as orthophosphate with a smaller fraction present as organic phosphorus. It is unclear whether the phosphorus adsorbed by these clays is refractory or bioavailable.

#080

Building a Foundation for Coordinated Water Quality Monitoring in the Klamath River Basin

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The 303(d) listing and the subsequent Total Maximum Daily Load (TMDL) development and implementation for improving water quality in the Klamath Basin has been a challenge due to the lack of coordinated water quality monitoring within the Basin. Although a multitude of state, federal, tribal, and non-profit organizations collect water quality data within the Basin, progress toward obtaining a Basin-wide picture of water quality has been hampered by duplication of effort, sampling gaps, and lack of data sharing. In 2006, the California Water Resources Control Board, with funding from the U.S. EPA and the California Nonpoint Source Pollution Control Program, engaged the Klamath Watershed Institute (KWI) at Humboldt State University to facilitate the development of a coordinated monitoring plan with the participation of the Klamath Basin Monitoring Program (KBMP), formerly the Klamath Basin Water Quality Monitoring Coordination Group, an existing network of monitoring organizations. Other project goals were to build a data sharing web portal to inform monitoring and management decisions, and to establish a communications plan to promote dissemination of information. KWI also worked with the KBMP on their group's organizational development, including drafting a mission and vision, and developing mechanisms for long-term sustainability of the organization and the monitoring plan. Presenters share products of this collaborative effort, including the KBMP Draft Klamath Basin Water Quality Monitoring Plan, technical and political challenges to developing collaborative data sharing agreements.

#149

Benthic Sources of Dissolved Nutrients and Trace Metals in Upper Klamath Lake and Associated Wetlands after Designed Levy Breaches

By James S. Kuwabara and Brent R. Topping, U.S. Geological Survey, Menlo Park, CA.

In October 2007, a series of planned explosions hydrologically reconnected levied agricultural lands to adjacent Upper Klamath and Agency Lakes. Because the intended wetland restoration involved areas used for agriculture for decades, there was interest in the chemical and biological effects of this hydrologic reconfiguration. With support from the Bureau of Reclamation, benthic-flux studies of Upper Klamath Lake were extended to include these newly

restored wetlands, as well as established wetlands that had not been levied. Previous studies have established that benthic flux of biologically reactive solutes represent important solute-transport processes for Upper Klamath Lake. Porewater profilers were deployed in triplicate, immediately after the levy breach then in subsequent years prior to and at the latter stages of the annual *Aphanizomenon flos-aquae* bloom to quantify the benthic flux of dissolved (0.2-micron filtered) macronutrients (soluble reactive phosphorus, nitrogen species and silica) and trace elements (iron, manganese, copper and others) at three sites within Upper Klamath Lake and four sites in the proximal wetlands. Through these flux measurements, we describe time scales of chemical transition associated with this major change in land-use.

#033

Well Designed Performance Measures are Essential for Planning, Operation and Validation of Landscape Scale Restoration Programs

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The Klamath River Restoration Program is one of an ever increasing number of ecosystem scale restoration programs. These projects are likely to be a central organizing feature in determining how the United States re-engineers its infrastructure in the coming decades. Quantitative determinations of how a landscape scale watershed can be expected to perform following engineered modifications are essential for planning, actual operation, and subsequent validation of the effects of an engineered solution. The term "Performance Measures" has been used by scientists working with the Comprehensive Everglades Restoration Program (CERP) to describe topic-specific, information filters that quantitatively describe the simulated ecological effects of engineered projects and altered water management on the ecosystem. The process of development, use, and refinement of performance measures in the Everglades restoration program has been complex and has resulted in multi-agency agreement that ideal performance measures are based on objective facts determined through scientific experiment and which can be validated with rigorous monitoring. When performance measures have been developed in this way, they are also useful for guiding operation of the system, since they can be developed to capture the key causes that lead to negative environmental impacts, and they provide the necessary context for systematic uncertainty reduction. This presentation will provide a brief analysis of the key uncertainties associated with the Klamath Restoration program compared to a similar analysis of uncertainties facing the Everglades Restoration program, followed by a brief description of an Active Adaptive Management approach formulated to address a few of the key uncertainties in the Everglades Restoration program. While developing and utilizing performance measures is intellectually challenging, these tools are essential for crafting credible restoration programs which will affect the lives of millions of people.

#071

Seasonal Water Quality Patterns Downstream of a Hypereutrophic Lake: Summary of 2007 – 2009 Multi-probe Monitoring in the Lake Ewauna Reach of the Klamath River

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The 21-mile reach of the Klamath River from Link River to Keno Dam exhibits poor water quality on a seasonal basis, manifested as high concentrations of algae and ammonia, elevated pH, and hypoxic to anoxic dissolved-oxygen conditions. The hypoxic to anoxic conditions are caused by an extremely high organic load from Upper

Klamath Lake. The heavy organic load imposes a high biochemical oxygen demand (BOD) on the Lake Ewauna reach of the Klamath River. The high BOD in combination with sediment oxygen demand can deplete nearly all oxygen in the water column for several river miles, which typically lead to annual fish die-off events. Recent monitoring efforts with multi-probe instrumentation in the Lake Ewauna reach of the Klamath River for temperature, pH, specific conductance and dissolved-oxygen show that for the three years of the study, all twelve monitoring locations during the winter and spring had dissolved-oxygen concentrations near saturation, but during the summer and fall, all of the monitoring locations except Link River, had dissolved-oxygen concentrations less than 4 mg/L. The monitoring efforts also show that for the three years of the study, all monitoring locations during the summer and fall had temperatures that exceeded 22 ºC.

Trinity River

#151

Hatchery Impacts on the Genetic Structure of Native Stocks in the Klamath Trinity Basin

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Understanding the impact of hatchery origin fish on wild stock is of critical importance for salmonid restoration because recent research suggests hatchery fish may depress the fitness of wild fish. We evaluated the genetic contribution of hatchery fish to native stocks by constructing a genetic baseline data set for Chinook salmon from the Klamath Trinity basin composed of 12 populations and 29 microsatellite loci. We found that Klamath Trinity Chinook salmon exhibit substantial levels of genetic structuring despite the large amount of out of basin transplantation that has historically occurred in the basin. It appears that both Trinity River Hatchery and Iron Gate Hatchery serve has source of migrants that genetically homogenize wild and hatchery populations. The degree of homogenization appears to be related to geographic distance, with geographically proximate populations more likely become homogenized than distance populations. The Salmon River, which is geographically sandwiched between Iron Gate and Trinity River hatcheries, appears to be genetic mixture of these hatchery populations but does contain a small degree of genetic uniqueness.

#152

Using Integrated Hatchery Practices to Improve Genetic Fitness of Naturally and Hatchery Produced Coho Salmon in the Trinity River, California

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In recent years there have been large adult returns of hatchery fish to the Trinity River. The average hatchery coho salmon adult and jack return from 1997 to 2008 was 16,469, roughly three times the Trinity River Hatchery coho salmon mitigation goal. The average percentage of hatchery coho salmon in the total return during the same period was 89%. The substantial numbers of adult hatchery fish, the majority of which were not harvested by tribes and could not legally be harvested by recreational or commercial anglers, prompted concern from several stakeholders on the effects of hatchery stocks on naturally produced stocks. The Trinity River Hatchery Technical Action Group was formed to make technical recommendations to a policy group. We used information from historical run sizes, spawner-recruit relationships, smolt-to-adult returns, and "All H Analyzer" modeling to examine current production

relative to mitigation goals and objectives. Spawner-recruit relationships indicated that in years of large hatchery returns, carrying capacity of the river may have been exceeded, possibly triggering density dependent mechanisms leading to reduced productivity. Using the smolt-to-adult returns rates from 1997 to 2008, we calculated hypothetical adult returns based on three different theoretical juvenile release levels. We also modeled likely outcomes of changes such as decreased juvenile production and increased natural origin broodstock. Based on the information, we formulated a variety of recommendations to the policy group such as a reduction in juvenile coho salmon production and trapping of surplus hatchery adults.

#153

Legacy Effects of Trinity River Gold Mining

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This presentation explores the history and legacy effects of hydraulic and dredger gold mining on the Trinity River. Gold was discovered in 1848 at Reading Bar near Douglas City, the second find of the California Gold Rush. From 1849 through 1862, large placer mining works were erected at major bars along the river. These works included wing dams, water wheels, and several dams that fully spanned and diverted the Trinity River. Intensive hydraulic placer mining of the valley walls and surrounding mountains started in the early 1860's and lasted until 1950. Ninety years of intensive hydraulic mining literally washed away mountains, contributing vast amounts of sediment to the mainstem. This is three times as long as the well known hydraulic mining in the Sierra Nevada mountains that was effectively banned by the 1884 Sawyer Decision (which did not apply to the Trinity River). Topographic surveys of the Trinity River from the 1930's and 40's show evidence of several sediment waves resulting from the hydraulic mining.

Dredger mining of the mainstem channel and floodplains began in the early 1900's and lasted through the 1950's. The dredges worked their way back and forth from valley wall to valley wall, digging down to bedrock looking for gold. The larger dredges could chew through 6 acres of floodplain a week, processing over 50,000 cubic yards of material. The result was a straightened river inside a floodplain with an inverted sediment profile and full of large tailings piles. The combination of dredger mining, the large floods of 1955 and 1964, and reduced flows due to water diversions to the Central Valley has created terraces.

#025

A New Model for Introducing Environmental Challenges into the Public School Curriculum: Learning and Applying Core Science to Save Salmon

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Educational Solutions is a Klamath Falls-based non-profit that has successfully completed a 2008-2009 project Klamath Watershed project involving 315 students from nine Oregon and California high schools. Students learned about stakeholders' perspectives, causes of water shortage, evaluation of water quality, and factors influencing fish mortality. The focus was finding solutions to watershed problems. Average student improvement, based upon pre- and post-test evaluations, was 91%. In addition, 57% of the students qualified for one unit of biology credit for OIT. Participating teachers requested that additional projects directly address state standards mandated by the No Child Left Behind Act. To this end, ES is developing a new educational model, reverse-engineered from state standards, to help students understand and solve important environmental problems. This project focuses on salmon because of the range of habitat and the problems that returning salmon will face in the Klamath Basin when mid-basin dams are removed.

ES has been encouraged by the Oregon Department of Education to submit a proposal for a Title IIB grant to test the model. We have also been encouraged by the willingness of scientists from the Hatfield Marine Science Center,

Oregon State University's Salmon Disease Laboratory, and the United States Geological Survey to work with us to facilitate our model. This presentation will demonstrate how to relate state standards to important research related to salmon restoration.

#150

Adaptive Environmental Assessment and Management in the TRRP: Progress, Challenges and Opportunities

David R. Marmorek, Darcy Pickard, Marc Porter, Katherine Wieckowski

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Adaptive Environmental Assessment and Management (AEAM) is a rigorous approach to environmental management designed to explicitly address and reduce uncertainty regarding the most effective on-the ground actions for achieving management goals and objectives. But it isn't easy, particularly at watershed scales. This presentation reflects some insights we've gained over the last 30 years of tackling AEAM challenges, including the last five years of working intensively with TRRP and external scientists on the Integrated Assessment Plan and other work products. We briefly describe 'ideal AEAM', and provide examples of rigorous adaptive management designs for ecosystem rehabilitation and species recovery in Western North America. We emphasize the need for strong contrasts, replication and randomization of actions, coupled with rigorous monitoring and evaluation (M&E) that provides clear signals for revising hypotheses and management actions. We then examine various spatial and time scales of AEAM in the TRRP, from annual decisions on flow and sediment augmentation, to periodic adjustments in rehab site designs, to multi-decadal evaluations of the effectiveness of habitat restoration in meeting Program goals. At each scale, we highlight progress made over the last few years (e.g. improved sampling designs and monitoring protocols) and outline remaining challenges (e.g. tightening up domain-specific management targets, formulating if…then decision rules, resolving tradeoffs among competing ecosystem objectives). We conclude by highlighting various opportunities for improving the implementation of AEAM in the TRRP.

Physical Hydrology and Climate

#063

Simulation of Regional Groundwater Flow to Inform Resource Management in the Upper Klamath Basin, Oregon and California

Marshall W. Gannett[1] and Brian J. Wagner[2]

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[2]US Geological Survey, National Research Program, Menlo Park, CA

The upper Klamath Basin encompasses approximately 21,000 km^2, spanning the Oregon California border east of the Cascade Range. Average precipitation ranges from 166 cm/yr in the Cascade Range to 28 cm/yr in interior lowlands. Because of the semiarid conditions in the interior parts of the basin, cultivated lands (approximately 200,000 ha) are irrigated, primarily from surface water. During the past decade, however, there has been increasing competition for limited surface water due to the habitat requirements of threatened and endangered fishes. As a result, there has been considerable interest in using groundwater to supplement surface-water sources. While groundwater use has the potential to augment water supplies, it also has the potential to negatively affect streamflow. The importance of groundwater to the flow and temperature of streams is generally recognized, but without the ability to quantitatively evaluate the connection, clear management strategies have remained elusive.

A regional groundwater flow model has been developed to fill this need. The model encompasses the entire upper Klamath Basin and simulates groundwater interaction with major streams, lakes, and wetlands. Groundwater discharge to agricultural drains in the 77,000 ha Bureau of Reclamation Klamath Project area is also simulated. The model was calibrated using 5,562 head observations at 662 wells and 643 groundwater discharge observations for 10 spring complexes, stream reaches, or drainages. Preliminary results show that the distribution of the effects of pumping primarily depends on well location and depth. In some areas, much of the water pumped from wells is reflected as diminished discharge to streams. In agricultural areas with shallow groundwater, in contrast, much of the pumping is reflected as diminished discharge to agricultural drains. The regional groundwater model will provide useful insights into the spatial and temporal distribution of the effects of groundwater pumping, but the model alone can not identify the best management strategy. Groundwater management in the upper Klamath Basin will require controlling the timing and location of effects of pumping on streams and exploiting aquifer storage properties to balance the pumping and recharge at a variety of time scales. This presents a complex problem with many interdependent variables. Optimization techniques are being employed to identify the best management strategy given certain objectives, constraints, and decision variables, and to help identify ways in which the strategy must adapt to varying climate conditions.

#010

Use of a Simulation-optimization Model to Evaluate Alternative Groundwater Management Strategies for the Upper Klamath Basin, Oregon and California

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Demand for groundwater in the upper Klamath Basin has increased in recent years due to drought and changes in surface-water management aimed at improving habitat for fish listed under the Endangered Species Act. Water and environmental managers in the basin need methods to determine groundwater withdrawal strategies that provide additional water supply while avoiding detrimental impacts of pumping on stream flows and groundwater levels. Here we present a decision model for the upper Klamath Basin that combines groundwater simulation with optimization. The simulation–optimization management model evaluates a complex array of water management options to identify strategies that best meet the resource allocation objectives of the basin.
The upper Klamath Basin has a groundwater flow system that discharges to streams throughout the basin and provides the majority of late-summer stream flows needed to support critical wildlife habitat. The effects of groundwater pumping on stream discharge have not been directly measured, and there is uncertainty regarding the timing, distribution, and magnitude of the effects of sustained groundwater development on surface water resources. A numerical groundwater simulation model for the upper Klamath Basin has been developed to provide insight into these questions. The model can be used to explore the response of the groundwater/surface water system to pumping. When linked with techniques of optimization, the simulation model can identify groundwater management practices that support the complex set of goals and constraints associated with groundwater use in the basin. These include (1) determining groundwater withdrawal patterns that support the spatially and temporally varying water demands for irrigation and wildlife habitat, (2) ensuring that impacts on stream flow resulting from managed pumping are within acceptable limits, (3) ensuring that drawdown due to managed pumping does not exceed that allowed by Oregon water law, and (4) identifying the impact of spatially and temporally varying recharge on groundwater availability, including the necessity, timing, and extent of pumping restrictions during extended drought cycles. Groundwater management alternatives for the basin will be described in terms of trade-offs among groundwater pumping decisions, water demand constraints, stream-flow impact constraints, drawdown constraints, and recharge variability.

#128

Streamflow Response to Climate in the Klamath Basin Region

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This study is the second part of our analysis of Klamath Basin hydroclimatology. Here, we examine the response of streamflow in the region to reduced snowpack, as documented in our previous study. We examine streamflow characteristics and trends at 21 predominately unregulated basins in the region with long measurement records (>40 years). The objective of this work is to investigate how elevation and geology interact to control streamflow response to climate.

Precipitation varies across the region from 50 to 200 cm on the west side of the Cascades to 10 to 50 cm on the east side. Consequently, river basins on the wetter, west side are typically more productive (mean annual runoff, normalized to basin area) than streams on the drier east side. The strong precipitation gradient masks the relationship of mean annual runoff and elevation. However, elevation is a strong control of streamflow timing, with higher elevation basins having a later runoff date.

The region transitions from the high relief, impermeable bedrock geology of the west side to the low relief, permeable volcanic geology on the east side. These geologic differences result in a shift from rain-snow stream types on the west side to groundwater-dominated streams on the east side. Rain-snow stream hydrographs are characterized by rapidly rising discharge in the fall, broad peaks throughout the winter, a recession beginning between April and June, and low baseflows in summer and early fall. Groundwater stream hydrographs are characterized by slowly increasing discharge in winter, more muted snowmelt peaks, and high baseflows in summer and fall.

The response of groundwater streams to winter recharge is smoothed and delayed, on a seasonal and annual scale. Groundwater streams tend to be more responsive to dry or wet multi-year cycles rather than a single dry or wet year. Summer and fall flows in these systems, measured in absolute terms or as a percentage of total flow, are about 8 times greater than in rain-snow streams. Groundwater streams sustain a large fraction of the late season flows in many of the major river systems in the region, including the Klamath, the Rogue, and the Umpqua.

While both stream types show declines in total annual flow over the last 4-6 decades, corresponding to reductions in snowpack, groundwater streams show much higher relative and absolute declines in summer and fall. Absolute flow declines in August are about 20 times greater in groundwater streams than in rain-snow streams. The significance of these declines suggests summer and fall flows in these systems are more responsive to snowpack reductions than rain-snow streams. The declines have serious implications for the region because of their importance to water supply, aquatic ecosystems, and mainstem flows.

#001

Watershed Scale Response to Climate Change: Sprague River Basin, Oregon

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The U.S. Geological Survey Global Change study, "An integrated watershed scale response to climate change in selected basins across the United States," began in 2008. The long term goal of this study is to provide the foundation for hydrologically based climate-change studies across the nation. Fourteen basins for which the Precipitation Runoff Modeling System (PRMS) had been calibrated and evaluated were selected as study sites.

PRMS is a deterministic, distributed-parameter, watershed model developed to evaluate the effects of various combinations of precipitation, temperature, and land use on streamflow and general basin hydrology. PRMS results for the Sprague River basin in Oregon are summarized below.

Six General Circulation Models (GCMs) incorporating three climate change scenarios were used to develop an ensemble of climate change inputs to PRMS. Although, the climate change projections for 2001–2099 showed a wide range of variability between the GCMs, which would indicate a large amount of uncertainty, the central tendency lines showed an overall increase in temperature (2 to 3 degrees Fahrenheit) and a slight increase in precipitation over the 21st century. Using these data as model input, simulated streamflow output from PRMS for the Sprague River indicate increased flooding earlier in the spring and decreased summer baseflow as a consequence of increased and decreased proportions of rainfall and snowfall, respectively. Supplying approximately 25 percent of inflow to the Upper Klamath Lake, the Sprague River basin is vital to environmental and human water needs within the Klamath River basin. As water demands increase, the reliability and timing of flow from the Sprague River becomes increasingly critical in water-management decisions. Potential alterations in flows to the Upper Klamath Lake as a result of climate change could necessitate (1) modifications to the operation of the lake as a storage reservoir and (2) creation of additional storage capacity to meet water demand during the summer.

#087

Bathymetric Mapping with Airborne LiDAR in the Klamath-Trinity Basin

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The Trinity River Restoration Program (TRRP) collected airborne bathymetric LiDAR over 40 miles of the Trinity River in April of 2009. The airborne survey was performed by USGS personnel based in Florida using the EAARL (Experimental Advanced Airborne Research LiDAR) system, whereas supporting ground surveys based on both wading and sonar measurements were performed by TRRP and a separate USGS group from Colorado. Immediately after completion of the Trinity mission, both the airborne and ground USGS groups collected similar data from a short reach of the Klamath River. The EAARL system utilizes a green laser to penetrate water, and records full waveform returns that can be used to identify the stream bed with a nominal vertical precision of about ± 20 cm. Waveform data from the Trinity mission were initially processed to xzy coordinates by USGS personnel and delivered to TRRP in September 2009. This initial attempt to process the raw waveform data was largely unsuccessful. Although errors in shallow areas were only slightly larger than expected (RMS ~ 26 cm compared with wading ground-truth measurement), errors in deep water were typically on the order of m. Closer inspection revealed that initial processing had identified false bottoms, commonly at a depth of about 1 m, such that the magnitude of errors in deep water were often approximately H-1 m, where H is the actual water depth. Fortunately, subsequent inspection of the raw waveforms suggests that the raw data do contain sufficient information to correctly identify the stream bed to depths of approximately 3 m. At the time of abstract submission, TRRP is attempting to reprocess the waveform data to extract correct bottom elevations in areas where depths are between about 1 and 3 m, and is acquiring additional sonar surveys to patch in areas with greater depths. Techniques employed by TRRP in this re-processing effort and results will be presented.

Ecohydrology

#031

Klamath River Stream Temperature Modeling and Use of Thermal Refugia by Salmonids

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Late summer and early fall water temperature regimes are critical to the persistence of endangered and threatened salmon on the Klamath River. Water temperatures critically influence fish physiology in numerous ways and understanding water temperature dynamics is a prerequisite to assessing acute and chronic thermal impacts on salmonids. Currently, the temperature dynamics of the Klamath River mainstem are not well understood at the appropriate scales necessary for fisheries management decisions. The presence and duration of cold water refugia may be a key factor for salmonid survival, yet little is known about the spatiotemporal dynamics of these refugia – particularly in relative to the mainstem temperature dynamics. We are addressing these issues through a combination of high-resolution stream temperature and fish mortality models of the Klamath River mainstem, and fish tracking studies to evaluate the associated spatial response of salmonid fishes in and around selected thermal refugia. This model is driven by recently developed NASA satellite derived climate data and will provide hindcasts and forecasts (including various climate change scenarios) of the mainstem at sub-hourly intervals for every 1km of stream reach. These data will be used as inputs to spatially explicit fish mortality models to evaluate the temperature impacts on salmonids at sub-adult life stages. Finally, we will measure fine-scale spatiotemporal use of the thermal refugia and mainstem by salmonids through radio tracking of individual fish.

#081

Potential Impacts of Climate Change on Aquatic Fauna: Finding a New Paradigm for Wetland and Riparian Systems in the Upper Klamath Basin, OR

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Resiliencies of the Klamath Basin's physical and ecological systems to precipitation and temperatures have provided the framework of our understanding of biotic response to abiotic patterns and processes. Climate change is poised to greatly alter the timing and magnitude of abiotic processes. Understanding which species and which ecological systems will be most vulnerable to climate change and how they will be vulnerable will be critical for setting conservation and management priorities and for developing successful adaptation strategies. One approach is to model climate change projections that have been downscaled from Global Circulation Models for a given watershed, link relevant climate parameters (e.g., temperature and precipitation) to a hydrologic model, and develop future projections for the hydrologic parameters of interest (e.g., streamflow, groundwater recharge, water table elevation). This information was used to design and implement management strategies which took into account how climate change may affect aspects of the freshwater ecosystem and species' responses and the complex socio-political landscapes in which they were implemented. We found the complicated systems of agrarian economics, water use and related infrastructure a constraint in prioritizing freshwater conservation strategies within any particular river basin.

#048

Application of Hydrological and Ecological Models to Access Effects of Changing Climate and Adaptation Strategies on Pastures and Water Resources in the Wood River Basin

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It is important to design climate change adaptation strategies after accounting for the effects on water resource availability of various ecosystems in the Klamath Basin. Flood irrigated pasture is the dominant agricultural land uses in the major tributary subbasins (e.g. the Wood River, Williamson River, and Sprague River Subbasins) of the Klamath River. Therefore, understanding potential effects of changing climate and adaptation strategies on productivity and water use efficiency is a key factor for decision makers to predict water resource availability in the Klamath Basin. Our study used the MIKE-SHE hydrologic and the DAISY ecological models to model pasture systems in the Wood River Basin. These models were calibrated with observed vegetation and hydrologic data obtained from fully- and non-irrigated pastures. The models were run with moderately increased temperatures (annual average +1.3 °C, summer +1.4 °C and winter +1.2 °C) and precipitation (+2%) projected for the 2020s under the A2 (differentiated world) scenario. In addition, we ran the models with increased legume composition and with sprinkler irrigation systems to access the effects of these practices as potential farm-level adaptation strategies. Calibration results indicated that nitrogen deficiency and heat stress suppressed productivity of the cool-season grass-dominated pasture systems after July. The results also indicated that converting to non-irrigated pasture could make approximately 500 mm of water during the growing season available for instream flow by suppressing evapotranspiration and by the drainage of water from surface and subsurface layers. (Under irrigation, this drainage of water would only occur at the end of the growing season.) As a result, the non-irrigated pasture would reduce productivity by 15%.

Simulation results indicated that the changing climate by 2020s is expected to 1) increase the growing season length by 22 days, 2) increase crop water demand (crop evapotranspiration) by 9.8 %, and 3) increase total seasonal forage production by 0.3 %. These changes result in reduction of average daily productivity by 10.4 % and water use efficiency by 8.7 %.

As a farm-scale adaptation strategy, introducing 30% legume composition would improve pasture productivity by 26 % mainly by increasing nitrogen availability. Upgrading flood irrigation systems to sprinkler irrigation systems would save approximately 160 mm water during the growing season by the drainage of water from subsurface layers. In conclusion, our study demonstrated usefulness of the combined use of two models by providing key information for decision makers in the Klamath River Basin.

#068

Protecting Groundwater-dependent Ecosystems in the Klamath Basin

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In many states within the US and countries around the world, the value of groundwater for drinking water, irrigation, and industry is reflected in laws and policies that control groundwater availability and quality. However, few or no policies currently exist to protect groundwater for ecosystems. Groundwater-dependent ecosystems (GDEs) include wetlands, lakes, rivers, springs, and species that are supported partially or entirely by groundwater. Effective protection and management of GDEs are hindered by inadequate information on their locations and the condition of their associated groundwater supplies. To address this data gap, we developed a methodology to map GDEs and their threats by 6th-field Hydrologic Unit Code (HUC6), and applied it across Oregon, Washington, and Northern California. Our results demonstrate the importance of groundwater to aquatic ecosystems in the Klamath Basin,

where springs and/or groundwater-dependent rivers occur in more than 50% of HUC6s, and groundwater-dependent wetlands are found in more than 40% of HUC6s in the Basin. Moreover, a number of large spring complexes are known in the Klamath Basin for their important role in sustaining aquatic ecosystems throughout the year. In addition to ecosystems, there are more than 50 obligately groundwater-dependent species that are of conservation concern, including 36 molluscs.

A number of activities pose a threat to GDEs by affecting groundwater quantity and quality. While there are very few data available to understand how these activities are currently affecting GDEs, our mapping work shows where we can expect impacts to occur based on the extent of these activities and their proximity to HUC6s with high densities of GDEs. In our assessment, we identified HUC6s most likely affected by changes in groundwater availability due to groundwater pumping from both irrigation and domestic wells. We also evaluated potential impacts to groundwater quality from industrial contaminants, pesticides, and nutrients.

This initial assessment of GDEs and threats to their groundwater supply highlights the ecological importance of groundwater and the need to incorporate protection of GDEs in water management policy. To address the threats to groundwater quantity, The Nature Conservancy has begun to work with the US Forest Service on a pilot study to develop a method for quantifying environmental water requirements for GDEs. These requirements will describe the amount of water that must remain within the ecosystem for the species and ecosystems to remain viable, and how much can be sustainably abstracted for other uses.

#069

How Much Water Does a Wetland Need? Developing Environmental Water Requirements for Groundwater-dependent Ecosystems in the Upper Klamath Basin

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Groundwater-dependent ecosystems (GDEs) include lakes, wetlands, rivers, and springs that are found at points of groundwater discharge, as well as subterranean and aquifer ecosystems. A recent Oregon state-wide assessment demonstrated a high density of GDEs in the Klamath Basin. They are strongly adapted to relatively stable groundwater supply. Similar to groundwater sources for human consumption, GDEs are threatened by groundwater depletion and contamination. Yet unlike municipal and agricultural groundwater supply systems, little is known about groundwater quality and quantity, and even less is known about thresholds below which a GDE is irreversibly altered.

To address this data gap, we are developing quantitative thresholds for groundwater discharge, termed environmental water requirements, for groundwater-dependent wetlands called fens. This pilot project is being conducted in three fens in the Fremont-Winema National Forest, in the Jack Creek drainage. The fens are in a grazing allotment where water is withdrawn for cattle, thus understanding thresholds for groundwater discharge and withdrawal is critical to manage these ecosystems.

We are using two complementary approaches to set upper limits on water withdrawals. In a “top-down” approach, we are developing numerical hydrologic models to test the sensitivity of water budget parameters to change and to evaluate their effect on groundwater availability. In a “bottom-up” approach, we are developing quantitative relationships between indicator plant species, peat properties, and the timing and depth of water table fluctuations.

For the latter, bottom-up approach, we are monitoring depth to water table, piezometric head at several depths within the peat profile, and total peat depth across the sites. Peat depth ranges from 0.5-2 m, and is closely related to consistent groundwater discharge. We identified a suite of potential indicator species, and we are monitoring their

distribution with respect to seasonal depth to water table. We are supplementing our field data collection with data from the published literature on depth to water table requirements of these plants. A combination of botanical, hydrologic, and edaphic data will be used to define the ideal and minimum depths to water table. We will use this information to inform the parameters in the numerical hydrologic model.

Dams, Sediment and Fish

#111

Effects of Dams on the Klamath: Historical Changes, Distinct Sediment Impacts by Reach, and Implications for Restoring Native Fish

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The six dams on the Klamath River included in the Pacificorp hydroelectric project have affected sediment transport, and in some cases, flow regime, interacting with natural physiographic differences to create seven flowing river reaches with distinct sediment transport regimes. Based on the most extensive field studies of channel form, bed material, and sediment transport on the river to date, we developed a conceptual model for the Klamath River downstream of Upper Klamath Lake. In upstream to downstream order, these are 1. Link River (steep, sediment starved, fed by outflow from Upper Klamath Lake), 2. Lake Euwana (flat gradient reach above Keno Dam, formerly overflowed into Lower Klamath Lake during floods), 3. Keno-Boyle (steep, bedrock, sediment-starved), 4. Boyle Bypass Reach (steep, sediment starved, dewatered by diversion but still subject to high flows spilled, large sediment source from canal washout), 5.Boyle Full-Flow Reach (steep, low sediment supply, some key tribs, flows vary with generation), 6.Copco2–Iron Gate (short, steep, sediment-starved bypassed reach, heavily encroached by riparian vegetation), 7.Iron Gate downstream to Cottonwood Ck confluence (sediment-starved, regulated by Iron Gate, moderate gradient reach still accessible to anadromous fish) , 8.Downstream of Cottonwood Creek confluence (geologic change to Klamath Mountains terrane, with flow and sediment supply increasing with each tributary)
The seven reaches vary with respect to sediment availability and transport regimes. In addition, some key historical changes include modifications to the channel to facilitate log transport and elimination of flood overflows into Lower Klamath Lake in the early 20th century, which resulted in higher peak flows through the reaches downstream.

#060

Sediment Transport Dynamics in Dam-influenced Reaches of the Klamath River: Lessons from 10 Years of Study

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The draft Klamath Hydroelectric Settlement Agreement of September 30, 2009 notes that additional studies will be required to support a decision by the Secretary of the Interior as to whether removal of the lower four dams on the Klamath River will advance restoration of the salmonids fisheries of the Klamath Basin. Sediment transport is identified in the draft settlement agreement as one of the key discipline areas requiring study and analysis for the secretarial determination. Significant study and analysis of sediment transport in the dam-influenced reaches has been conducted over the past ten years. However, most of this effort over the past five years has focused on reservoir sediment composition and modeling studies of sediment transport. We conducted studies of reservoir sedimentation, bed material size, bed mobility, sediment transport, and channel form between Klamath Falls, Oregon and Seiad Valley, California between 2001 and 2005. These studies resulted in the collection of empirical data on channel form, bed material composition, thresholds of bed mobility, and sediment transport downstream of

dams. Based on our results from these studies, we identified geomorphically distinct reaches and quantified sediment transport as a basis to evaluate dam effects on downstream channel morphology. Our studies characterized important characteristics of the Klamath River that should be considered in future studies and planning for dam removal. The upper reaches of the Klamath are low-gradient, lake and bedrock-sill-controlled, with small sediment yields but large influxes of natural and anthropogenic nutrients. In addition, the river's gradient and sediment load increase downstream as it passes through the steep Klamath Mountains and Coast Range. Therefore, the impact of the four dams proposed for removal on downstream geomorphic conditions will vary with location in the watershed. Thus, some expectations of downstream dam effects based on observations on other rivers may not be directly applicable to the Klamath dams. Our findings could be used to inform future dam removal approaches for the Klamath River.

#022

Effects of Sediment Release Following Dam Removal on the Aquatic Biota of the Klamath River: Application of Results from a Fine Sediment Transport Model.

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Four dams on the Klamath River are under consideration for removal: Iron Gate, Copco 1 and 2, and J.C. Boyle. Current dam removal scenarios would result in the transport of 1.3–2.9 million metric tons of fine sediment (sand, silt, and finer) to downstream reaches of the Klamath River. We applied the results of the DREAM 1 sediment transport model to analyze the duration and concentrations of total suspended sediment (TSS) likely to occur downstream during dam removal. To investigate the potential effects of the sediment releases on downstream biota, we evaluated the downstream TSS levels for their potential impacts on selected focal species. Sediment model results indicated that increases in daily average TSS concentrations will fluctuate during dam removal, ranging from approximately 50 ppm (parts per million by mass) to 38,000 ppm, with the duration of peak concentrations ranging from days to weeks depending on location and hydrological conditions in the basin. The worst-case scenario for potential focal species' population responses was analyzed using TSS concentration and duration predictions in conjunction with Newcombe and Jensen's (1996) "severity of ill effects" indices. The focal species, including Chinook salmon (fall and spring) and coho salmon, steelhead (summer and fall/winter), coastal cutthroat trout, Pacific lamprey, and green sturgeon, possess numerous life stages that rely on mainstem habitat on a seasonal basis (winter, spring and/or summer). Effects of predicted exposure to high TSS concentrations range from sublethal avoidance behavior and physiological stress to direct mortality rates of up to 100% of fish exposed to TSS, depending on species, exposure duration, and concentration. However, complete mortality is not expected for any species or life stage. The primary mitigating factor is that all species analyzed possess extensive temporal and spatial distribution within the Klamath River basin, a distribution expected to facilitate survival during dam removal, and contribute towards a strong recovery subsequent to dam removal. The combination of tributary use during spawning and rearing, off-channel habitat use for over-wintering, rearing in the lower mainstem or the estuary, and life histories that include mature adults in the ocean, is predicted to buffer short-term (1–2 years) impacts of elevated TSS in the mainstem river. Although focal species' populations are expected to recover in the long term (>2 years), mitigation measures are recommended to support the survival of individuals during dam removal, and to facilitate a stronger population recovery in the short term.

#023

DREAM-1 and Its Application to Klamath River Dam Removal Sediment Transport Simulation.

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DREAM-1 is one of the Dam Removal Express Assessment Models originated from a sediment transport model developed for simulation of sediment pulses in rivers. DREAM-1 and other closely related models have been applied in many sediment transport related projects, and have proven to be successful where data is available to examine model performance. The successful application of these models include: landslide evolution in the Navarro River, California; mining waste disposal in the Ok Tedi and Fly River in Papua New Guinea; Marmot Dam removal in the Sandy River, Oregon; Lake Mills drawdown experiment, Elwha River, Washington; land management in the Waipaoa River, New Zealand; and at least three different sets of flume experiments conducted at different institutions. We have applied DREAM-1 in the Klamath River to predict sediment transport dynamics associated with the proposed removal of Iron Gate, Copco 1, Copco 2, and J.C. Boyle dams under the concurrent drawdown scenario. Using reasonable assumptions with regard to channel geometry to be formed in the former reservoirs following dam removal, DREAM-1 predicted that 1.3–2.9 million metric tons of sediment will be released downstream, resulting in a suspended sediment concentration in excess of 30,000 ppm just downstream of Iron Gate Dam. Predicted suspended sediment concentration peaks in early winter before the arrival of high flow events following the commencement of reservoir drawdown in mid November, disappears with the arrival of high flow events that refills the reservoirs and effectively stops sediment erosion with the rising pool levels in the reservoirs, and reappears in the spring when the incoming flow becomes small enough to allow for a second drawdown of the reservoirs. The predicted suspended sediment concentration in spring is significantly smaller than winter peaks, on the order of a couple thousand ppm just downstream of Iron Gate Dam. Predicted suspended sediment concentration decreases in the downstream direction due to the contribution of flow from tributaries. Downstream of the Trinity River confluence, for example, predicted winter peak TSS is on the order of several thousand ppm compared to over 30,000 ppm just downstream of Iron Gate Dam. Because of the small fraction of sand-sized and coarser particles contained in the reservoir deposits, the model predicts no discernable aggradation over the 190 miles of river downstream of Iron Gate Dam following reservoir drawdown and dam removal. The predicted suspended sediment concentration provided the basis for biological and water quality evaluations.

#148

Evaluating Model Accuracy: Predicted and Observed Sediment Dynamics Following the Chiloquin Dam Removal

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Hydrodynamic models are often used to reduce uncertainty regarding the outcomes of dam removal, though the accuracy of these models is not regularly evaluated post-removal. With the goal of improving understanding on the accuracy and limitations of making predictions of sediment dynamics following dam removal, we will compare predicted and observed sediment deposition at three sites downstream of the Chiloquin Dam removal. Results from a 1D hydraulic (HEC-RAS) model, developed to estimate sediment transport rates at the sites, will be compared to cross-sectional and longitudinal profile surveys collected approximately one year following the dam removal. Pre-removal and post-removal bathymetry and grain size distributions document the changes in depth, size, and mass of sand downstream. Modeled estimates of mass and dominant size of sediment remaining and the thickness of sediment in the channel will be reported. Results of field surveys indicate that bathymetric changes over the past year have been minimal in both the reservoir and the downstream reaches, due in part to the low water year and the

low volume of sediment stored in the reservoir. Model results generally match observed erosional patterns but predicted greater deposition in pools downstream than was observed. The relationships between the model predictions and observations are reported and potential sources of error and improvement in modeling and field observations will be discussed. Findings will be placed in the context of dam removal in general, and suggestions are made about data needs and potential modeling approaches in future dam removal studies.