RECLAMATION
Managing Water in the West

Long-Term Plan to Protect Adult Salmon in the Lower Klamath River

Independent Scientific Peer Review
Northern California Area Office, Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation

October 2016

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Abbreviations and Acronyms

°C	degrees Celsius
CA-NV	California Nevada
cfs	cubic feet per second
Columnaris	*Flavobacter columnare*
CVP	Central Valley Project
Draft LTP	Draft Long-Term Plan for Protecting Late Summer Adult Salmon in the Lower Klamath River
Ich	*Ichthyophthirius multifiliis*
KFHAT	Klamath Fish Health Assessment Team
LTP EIS	Long-Term Plan to Protect Adult Salmon in the Lower Klamath River Environmental Impact Statement
NMFS	National Marine Fisheries Service
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
TRD	Trinity River Division
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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Chapter 1 Introduction

In September 2002, an unforeseen and unprecedented fish die-off occurred during a two-week period in the lower Klamath River. A subsequent U.S. Fish and Wildlife Service (USFWS) report indicated that of the approximately 34,000 anadromous salmonids estimated to have perished during this event, nearly all (98.4 percent) were adult salmonids. Of this total, 97 percent were fall-run Chinook Salmon, 1.8 percent were steelhead, and 1 percent were Coho Salmon. The two fish disease pathogens leading to the die-off were identified as *Ichthyophthirius multifiliis* (Ich) and *Flavobacter columnare* (Columnaris). High fish densities, due to the relatively large run size (approximately 170,000 adult Chinook Salmon), low flows, and relatively high water temperatures were identified as causative factors for the rapid spread of disease. Although a larger number of Klamath River fall-run Chinook Salmon died, a greater proportion of the Trinity River run was lost because the die-off occurred during the peak migration of Trinity River fish. Since 2002, Reclamation has been working with stakeholders to protect fall-run Chinook Salmon returning to the Klamath and Trinity Rivers.

Since the large-scale die-off of 2002, the U.S. Department of Interior, Bureau of Reclamation (Reclamation) provided augmentation flows in 2003, 2004, 2012, 2013, 2014, 2015, and 2016 to improve fishery conditions in the lower Klamath River. Augmentation flow volumes have ranged from 17,500 acre-feet in 2013 to 64,000 acre-feet in 2014, with an average volume of approximately 40,000 acre-feet. During these years, Reclamation collaborated with basin partners, and consulted with water and power users, to develop and refine monitoring and flow augmentation criteria.

In response to the need for augmentation flows in the past several years, the indication that such flows may be needed in future years, and competing environmental and water supply demands, Reclamation developed the *Draft Long-Term Plan for Protecting Late-Summer Adult Salmon in the Lower Klamath River* (Draft LTP) in 2013. An initial Draft LTP was provided to stakeholders on December 31, 2014. Reclamation received comments on the Draft LTP from tribes, fisheries agencies, water users, power users, and other stakeholders. In response to these comments, Reclamation revised the Draft LTP and provided it to the public on April 17, 2015. The Draft LTP provides a framework for protective measures, including criteria for determining when flow augmentation is required (both preventive flow augmentation and emergency flow augmentation), long-term volumetric requirements, and annual implementation processes (including schedule of annual actions). An Independent Scientific Peer Review is being used to review identified flow augmentation criteria and determine their scientific merit.

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Chapter 2
Peer Review Process and Reviewers

The purpose of the peer-review process is to have experts evaluate the scientific basis and appropriateness of the documents relied upon to create flow augmentation criteria. The peer reviewers chosen for this peer review are recognized technical experts with expertise and experience in fish ecology and habitat, water resource planning, and fish pathogens. The peer reviewers were:

- Dr. Leo Bodensteiner, Western Washington University
- Dr. Christopher Caudill, University of Idaho
- Dr. Christine Moffitt, U.S. Geological Survey (USGS) Cooperative Fish and Wildlife Research Unit, University of Idaho
- Dr. Raymond Morgan II, Appalachian Laboratory, University of Maryland
- Dr. James Petersen, USGS Cooperative Fish and Wildlife Research Unit, Oregon State University

Curriculum vitae for each reviewer is provided in Appendix A.

Reclamation, tribes, regulatory agencies, and other basin partners spent considerable time developing and refining criteria for considering whether and when to implement flow augmentation. This review is focused solely on the criteria for augmentation flows to prevent an epizootic disease outbreak in the lower Klamath River. Each peer reviewer was provided with the peer review process charge (Appendix B), which provided the list of documents and questions to be answered. In addition, six supporting documents were provided to the experts for review. These documents (Appendix C) are:

1. Trinity River Restoration Program Fall Flow Subgroup. 2012. *2012 Fall Flow Release Recommendation*. May 31, 2012.
2. USFWS. 2012. *Summary of Klamath River Chinook Salmon In-River Run Size Data and Lower Klamath River Flows to Support TRRP Fall Flow Planning Efforts in 2012*. May 28, 2012.
3. National Marine Fisheries Service (NMFS) and USFWS. 2013. *2013 Fall Flow Release Recommendation*.
4. USFWS. 2015. *Response to Request for Technical Assistance Regarding 2015 Fall Flow Releases*.

5. Reclamation. 2015. *2015 Lower Klamath River Late-Summer Flow Augmentation from Lewiston Dam. Environmental Assessment*.

6. Reclamation. 2016. *Frequency of Action Analysis: Preventive Pulse and Emergency Flows*.

Each reviewer prepared a report providing the answers to two specific questions (Appendix D). These questions are:

Question 1: Are the implementation criteria supported by the science?

Question 2: Have the assumptions and uncertainties associated with utilizing the flow criteria been appropriately characterized?

The reviewed criteria, which vary slightly from the Draft LTP, were:

Preventive Base Flow Augmentation (primary response):

Initiate preventive base flow augmentation from Lewiston Dam when:

- Flow in the lower Klamath River is projected to be less than 2,800 cfs [cubic feet per second] at the Klamath, California gage (gage # 11530500) in August and September (USFWS 2015).

- Ich infection of adult salmon or steelhead is identified in July and early August suggesting a low level infection is present that could worsen with poor environmental conditions.

- Thermal regime of the lower Klamath River is inhibitory to the upstream migration of infected adult salmon.

- Adult salmon are showing abnormal signs of behavior, crowding at tributary mouths, or are not migrating out of the lower Klamath River on a volitional basis.

- The cumulative harvest of Chinook Salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish (see NMFS and USFWS 2013).

- Initiate preventive base flow augmentation releases by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in NMFS and USFWS 2013).

- Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the Klamath, California gage through September 21. Continue to implement fish pathology monitoring to determine the potential need for the secondary flow augmentation action (preventive pulse flow).

- The need for preventive base flow augmentation is expected to occur during years with limited or low precipitation levels in the Klamath River basin (e.g., dry conditions). Since the fish die-off in 2002, Reclamation has made preventive base flow augmentation releases in six years over a 13 year period. However, criteria for preventive flow augmentation have changed over this period. Based on the above criteria, it is estimated that preventive base flow augmentation would have occurred in approximately three of the 13 years, or about 20 to 25 percent of the years.

Preventive Pulse Flow Augmentation (secondary response):

During the preventive base flow period, a preventive pulse flow targeting a flow of 5,000 cfs for one 24 -hour period at the Klamath, California gage would occur when the peak of fall-run migration (typically the first or second week of September) is identified in the lower Klamath River as indicated by tribal harvest. This flow level is based upon the experience of 2015, which was intended to use a small volume of water to provide a change to the environmental conditions of the lower Klamath River to further reduce the risk of an Ich infection that could result in a disease outbreak (see Reclamation 2015). Specifically, the anticipated benefit of the pulse is to enhance flushing and dilution of the river of parasites when the bulk of fall run Chinook Salmon adults are likely to be in the lower river while also facilitating movement of adult salmon to reduce the potential for crowding. Conditional release of this pulse flow requires low level Ich infections (less than 30 Ich per gill arch) that are confirmed on three fall-run adult salmon (of a maximum sample size of 60) captured in the lower Klamath River in one day during this time of typical peak migration. Disease sampling and confirmation of disease findings would follow the methods as described in NMFS and USFWS (2013).

Emergency Flow Augmentation (tertiary response):

Initiate emergency flow release to target a flow of 5,000 cfs in the lower Klamath River for up to five days in August or September if emergency conditions exist as identified by USFWS and NMFS (2013b):

- Diagnosis of severe Ich (30 or more parasites on a gill arch) infection of gills in 5 percent or greater of a desired sample of 60 adult salmonids confirmed by the USFWS California Nevada (CA-NV) Fish Health Center, or

- Observed mortality of greater than 50 dead adult salmonids in a 20 kilometer reach in 24 hours coupled with the confirmed presence of Ich by the USFWS CA-NV Fish Health Center.

- Use the protocol for sharing and confirming information on a real-time basis to determine if and when the emergency flows would be implemented.

- Key staff members would be on high alert during the flow augmentation action and would be getting timely monitoring results. The USFWS CA-NV Fish Health Center would provide a pathology report documenting the findings of diagnostics survey to State, Federal, and Tribal fish biologists and pathologists (LTP Technical Team), and the

Klamath Fish Health Assessment Team (KFHAT). An emergency release would be considered by Reclamation on receipt of a positive pathology report.

- The need for emergency flow augmentation is expected to be low considering the infrequent use in the past (only once in 6 years of implementing an action since 2002) and the knowledge gained from these previous years regarding the dynamics of Ich infection and environmental variables that include flow."

Chapter 3
Summary of Peer Reviewer Responses

This section provides a summary of each reviewer's response to each question.

Question 1

Are the Implementation Criteria Supported by the Science?

Reviewer 1: Yes, all preventive flow augmentations (including the pulse flow and emergency flow augmentations) are supported by science. This includes those criteria that were developed based on historical conditions or reactions to previous augmentations.

Reviewer 2: No, the six documents provided did not provide adequate information to determine whether or not the implementation criteria are supported by the science because too few studies of fish diseases have been conducted and there are too few data points for each flow augmentation criteria. The criteria were based on some limited correlations and basic principles of physiology and fish health, but lack peer reviewed publications and studies for support. Additional studies or information are needed to scientifically validate the criteria. Reviewer 2 did, however, feel that several criteria were valid or reasonable, even if there was no strong evidence to validate them. The emergency flow augmentation criteria appear to have the least scientific support of all the criteria.

Reviewer 3: Overall, because the analysis was based primarily on studies and analyses from grey (unpublished) literature, the scientific support for the criteria was weakened, or not possible to evaluate. For example, the scientific evidence that the specific 2,800 cfs threshold chosen is adequate for protecting adult salmon is relatively weak. Additionally, there is insufficient information on the effectiveness of providing additional flow in reducing Ich infection and mass mortality events. Reviewer 3 did feel that the criterion based on thermal regimes creating a barrier to upstream migration, and that adult salmon show abnormal signs of behavior, crowding, or not migrating on a volitional basis, had strong scientific support.

Reviewer 4: Yes, the primary response is well supported in an adaptive management context, and the five triggers are acceptable for the protection of the salmonids in the lower Klamath River.

Reviewer 5: Yes, the implementation criteria are supported by available science on the disease ecology of adult salmon in freshwater, including known or well-supported relationships between temperature and disease transmission and pathogenesis.

Question 2

Have the assumptions and uncertainties associated with utilizing the flow criteria been appropriately characterized?

Reviewer 1: Yes and no. Reviewer 1 felt most of the assumptions and uncertainties were appropriately characterized. However, Reviewer 1 felt that use of the Yurok Tribal harvest present some challenges, and using the harvest data should include confidence intervals to provide context for the criterion. Additionally, the use of a fixed harvest number may not provide small runs with the appropriate timing to implement the preventive actions. Reviewer 1 recommended instead using the proportion of harvest based on catch divided by pre-run estimates of run size. Reviewer 1 also felt that flow augmentation triggers based on the number of fish is better than a trigger based on a calendar date. Reviewer 1 stated that field sampling protocols need to be designed to ensure that dead and dying fish are detected. Reviewer 1 recommends the expression of confidence intervals or some other standard reflection of variability of estimates would help with prediction of numbers of fish.

Reviewer 2: No. Reviewer 2 stated that infections do not always show mortality, nor do they subside following flow augmentations. Additional studies are needed to validate the assumptions for the criteria. For example, the association of parasite loads from *Parvicapsula* and *Ceratonova* with fish susceptibility to Ich was not well addressed, nor was the potential for fish immune response to Ich. Reviewer 2 recommends that each of these criteria should be considered a hypothesis, and thusly followed up with monitoring and controlled studies to improve understanding. While past augmentations have improved fish migration, the lack of mortality and other possible factors need additional evaluations.

Reviewer 3: Mostly no, as results of future studies should be published in peer-reviewed scientific outlets, and that confidence intervals need to be provided to measure the uncertainty around the chosen trigger. Reviewer 3 felt the authors of the documentation did not explicitly identify the assumptions regarding the mechanisms behind many of the criteria, nor do they provide estimates of uncertainty in the response of fish (e.g., estimates of change in Ich prevalence). Reviewer 3 did feel that the assumptions for the criteria in which the thermal regime can inhibit upstream migration, were suitable and scientifically supported. Reviewer 3 felt that the assumptions regarding the ability to detect pathogens were poorly documented. The preventive pulse and emergency flow augmentations assume the occurrence of pathogens can be detected with certainty, which is not typically the case, and the assumption that pulsed flow treatment would successfully treat an outbreak is based on a single observation and a hypothesis based on a single year of data.

Reviewer 4: Mostly yes, overall the assumptions on employing the flow criteria are more than adequately addressed. There is an excellent body of work developed over time that supports using managed flow regimes to mitigate the potential disease problems for Chinook Salmon. However Reviewer 4 identified uncertainty with respect to the presence of *ceratomyxosis* and how it may affect the juvenile population, and indicated that the genetic structure of the salmonid stocks should be discussed. Reviewer 4 suggested calculating confidence intervals because of the relatively short time period for the data available to support the criteria. Reviewer 4 also identified uncertainty caused by climate change and how water temperatures will be impacted in future years, and uncertainty surrounding available water for future instream flows based on the competing water demands.

Reviewer 5: Yes for most of the criteria, but stated that assumptions for some of the criteria are broadly plausible—and likely true—but the details of relationships are uncertain and challenging to directly evaluate. For example, the assumption that reduced salmon/volume decreases transmission rate may not be valid for non-proliferative pathogens is plausible, but uncertain. Reviewer 5 also felt that the effects of flow and water temperature should be separated. Reducing holding time may be more important than inducing upstream migrations. Reviewer 5 also identified uncertainty caused by climate change. Reviewer 5, however, did feel that the assumptions regarding thermal regimes creating migration barriers are appropriate and well supported.

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Chapter 4
Conclusions and Recommendations

Overall, reviewers felt that the flow augmentation program was reasonable given the local circumstances in the lower Klamath River, even if not fully supported by science. All reviewers agreed that the Preventive Flow Augmentation criterion regarding thermal conditions inhibiting upstream migration and the criterion to initiate preventive flow augmentation releases by August 22) were supported by science or were reasonable, even if they questioned the exact mechanism of effect. All agreed that temperature was probably the most important environmental variable in Ich epizootic outbreaks, and lowering temperatures could have multiple benefits. However, there was disagreement on scientific support for all other augmentation flow criteria. In most cases, the reviewers that felt the criteria were not supported by science felt that additional information was needed to strengthen the validity of the criteria. For example, several reviewers felt that augmenting the flows to 2,800 cfs was not sufficiently supported with enough data to justify this specific flow, even if they felt it was likely sufficient based on past experience with preventive flows. For the rest of the criteria, some reviewers felt that most of the criteria had unsubstantiated assumptions or were too uncertain to validate. For example, with regards to the Preventive Flow Augmentation criterion based on initiating flow augmentation to target a flow of 2,800 cfs through September 21, one reviewer stated that the assumptions for setting a hard date were unclear. Additionally with regards to the Preventive Flow Augmentation criterion based on the Ich infection of adult salmon or steelhead being identified in July and early August, three reviewers stated the assumptions were uncertain or they were not provided.

All reviewers recommended continued monitoring and application of an adaptive management approach, especially in light of the small number of years since 2002 where flow augmentation has been used, noting that additional data collection would allow for refinement of criteria. Two reviewers recommended using predictive models to help determine when and how to implement augmentation flow releases. Two reviewers recommended that climate change conditions should be factored into the flow augmentation implementation process. One reviewer recommended establishing a conceptual model to assist in the flow augmentations. Two reviewers recommended additional studies on other disease or pathogen (such as *C. shasta*) effects to determine potential interactions with Ich that may lead to an epizootic. All reviewers, however, felt that pathogen monitoring and studies on flows and release dates was necessary for a successful flow augmentation program to prevent an Ich epizootic or fish die-off.

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Appendix A – Curricula Vitae of Independent Science Peer Reviewers

Independent Scientific Peer Review
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Education

Ph.D., Zoology with minor in Physiology, Southern Illinois University at Carbondale, 1991

M.A., Zoology, Southern Illinois University, 1986

B.A., Biology with minor in Chemistry, Minnesota State University at Moorhead, 1979.

Academic History at Western Washington University

Professor, Dept. of Environmental Sciences, 2012-present

Chair, Dept. of Environmental Sciences, 2008-2012 (one term)

Graduate Program Advisor, Dept. of Environmental Sciences, 2003- 2007

Associate Professor, Dept. of Environmental Sciences, 2000- 2012

Assistant Professor, Center for Environmental Sciences, 1995- 2000

Visiting Assistant Professor, Center for Environmental Sciences, 1994-1995

Teaching

(1994-2016) Limnology (23 qtrs); Limnology Laboratory (24 qtrs); Stream Ecology (2 qtrs and lab 3 qtrs); Environmental Impact Assessment (11 qtrs); Wetlands Ecology (3 qtrs); Water Quality (3 qtrs); Water Quality Laboratory (3 qtrs); Environmental Biology of Fishes (16 qtrs); Forest and Fish Assessment (previously Investigations in Fish Ecology Lab) (11 qtrs); Fisheries Management Laboratory (9 qtrs); Environmental Disturbances (Pollution) (9 qtrs); Environmental Systems (3 qtrs); Fundamentals of Ecology (8 qtrs); Explorations in Environmental Studies (2 qtrs); Topics in Environmental Studies (3 qtrs); Art, Science and Ethics of Flyfishing (13 qtrs – summer); Advanced flyfishing: river stewardship, reflection, and native trout (6 qtrs – summer)

Teaching Awards

2007 – Excellence in Teaching award (lifetime award)

2006 – My new summer course in 2004, Environmental Science 315: Art, Science, and Ethics of Flyfishing, was selected by the North American Association of Summer Sessions as one of three finalists in the innovative and creative programs category based on creativity; uniqueness; benefit to students; university, and/or community; and adaptability to other institutions.

Research

(1995-2016) Conducted research in aquatic ecology in the Midwest and Pacific Northwest with an emphasis on fish ecology; Supervised 30 M.S. graduate students (list attached) with topic areas including heterogenous distribution of fishes in eelgrass meadows; age determination in six-gill sharks; decompression syndrome in copper rockfish; trophic competition among redside shiners and native trout; environmental factors affecting freshwater mussel populations; assessment of stream habitat based on autopsy based assessment of fishes; role of habitat diversity in rivers in fish community structure; impacts of natural sources of metals on fish populations; relation of stream restoration to fish communities; barriers to fish distribution in streams; hydrological management to facilitate fish restoration; hyporheic chemistry as a cue to site selection by spawning coho salmon; factors associated with landslide hazards in small stream basins; development of age determination techniques for six-gill sharks; relation of buffer widths to fish communities in agricultural waterways; and population dynamics of an invasive freshwater mussel

Publications and Reports

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LeMoine, M. T., and L. R. Bodensteiner. 2014. Barriers to upstream passage by two migratory sculpins, prickly sculpin *Cottus asper* and coastrange sculpin *Cottus aleuticus*, in northern Puget Sound lowland streams. Canadian Journal of Fisheries and Aquatic Sciences 71:1758-1765 [http://dx.doi.org/10.1139/cjfas-2014-0029].

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Gabriel, A. O., and L. R. Bodensteiner. 2012. Impacts of riprap on wetland shorelines, Upper Winnebago Pool Lakes, Wisconsin. Wetlands 32:105-117.

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Watkins, J., and L. Bodensteiner. 2010. Chromium in rainbow trout from an exposed dunite formation, Twin Sisters Mountain, Washington. Journal of Freshwater Ecology 25:495-498.

Kallis, J., L. Bodensteiner, and A. Gabriel. 2010. Hydrological controls and freshening in meromictic Soap Lake, Washington, 1939-2002. Journal of the American Water Resources Association 46:744-756.

Gabriel, A.O., and L.R. Bodensteiner. 2009. Cumulative effects of gravel mining and barging operations, Jackson/Lafarge Beach, Washington, 1960-2003. Shore & Beach 77:9-18.

Mueller, K.W. (MS student) and L.R. Bodensteiner. 2009. Shelter occupancy by mixed-species pairs of native signal crayfish and non-native red swamp crayfish held in enclosures. Journal of Freshwater Ecology 24:66-76.

Bodensteiner, L.R., and A. Gabriel. 2003. Response of mid-water common reed stands to water level variations and winter conditions in Lake Poygan, Wisconsin, USA. Aquatic Botany 76:49-64.

Hu, Shunfu, A.O. Gabriel, and L.R. Bodensteiner. 2003. Inventory and characterization of wetland habitat on the Winnebago Upper Pool Lakes, Wisconsin, USA: an integrated multimedia-GIS approach. Wetlands 23:82-94.

Gabriel, A., and L.R. Bodensteiner. 2002. Historical changes in mid-water stands of common reeds in the Winnebago Pool Lakes, Wisconsin. Journal of Freshwater Ecology 17:563-573

Thomas, J.F., L.R. Bodensteiner, T.J. Hall, A.M. Obery, and W.G. Landis. In review. Confirmation of a relative risk model ecological risk assessment of multiple stressors using multivariate statistics. Environmental Toxicology and Chemistry.

Bodensteiner, L.R., R.J. Sheehan, W.M. Lewis, A.M. Brandenburg, and P.S. Wills. 2000. Flowing water: an effective treatment for ichthyophthiriasis. Journal of Aquatic Animal Health 12:209-219.

Landis, W.G., M. Luxon, and L.R. Bodensteiner. 1999. Design of a relative risk model regional-scale risk assessment with confirmational sampling for the Willamette and McKenzie Rivers, Oregon. Ninth Symposium on Environmental Toxicology and Risk Assessment: Recent Achievements in Environmental Fate Transport, ASTM STP1381 F.T. Price, K.V. Brix, and N.K. Lane, editors, American Society for Testing and Materials, West Conshohocken, Pennsylvania, 2000.

Bodensteiner, L.R., W.G. Landis, and A.J. Markiewicz. 1998. A regional comparative multiple-stressor ecological risk assessment. Proceedings of the Annual Meeting of the Society for Environmental Toxicology and Chemistry, Denver, Colorado.

Landis, W.G., L.R. Bodensteiner, and J.F. McLaughlin. 1998. The relative rank risk model for regional-scale risk assessment and potential applications in freshwater and terrestrial systems. Proceedings of the Risk Assessment of Environmental End Points Workshop, Auckland, New Zealand.

Bodensteiner, L.R., and W.M. Lewis. 1994. Downstream drift of fishes in the upper Mississippi River during winter. Journal of Freshwater Ecology 9:45-56.

Bodensteiner, L.R., R.J. Sheehan, W.M. Lewis, P.S. Wills, and R.W. Herman. 1993. Effects of repetitive formalin treatments on channel catfish juveniles. Journal of Aquatic Animal Health 5:59-63.

Bodensteiner, L.R., and W.M. Lewis. 1992. Role of temperature, dissolved oxygen, and backwaters in the winter survival of freshwater drum (*Aplodinotus grunniens*) in the Mississippi River. Canadian Journal of Fisheries and Aquatic Sciences 49:59-70.

Bodensteiner, L.R., R.J. Sheehan, and W.M. Lewis. 1990. Differences in the physical environment of the Upper Mississippi River as a factor in overwinter survival of fish. Restoration of Midwestern Stream Habitat, a symposium held at the 52nd Midwest Fish and Wildlife Conference, December, 1990, Minneapolis, Minnesota.

Sheehan, R.J., L.R. Bodensteiner, W.M. Lewis, D. E. Logsdon, and S.D. Scherck. 1990. Long-term survival and swimming performance of young-of-the-year river fishes at low temperatures: links between physiological capacity and winter habitat requirements. Restoration of Midwestern Stream Habitat, a symposium held at the 52nd Midwest Fish and Wildlife Conference, December, 1990, Minneapolis, Minnesota.

Bodensteiner, L.R., and R.J. Sheehan. 1988. Implications of backwater habitat management strategies to fish populations. Invited Paper. Proceedings of the Upper Mississippi River Conservation Committee 44:60-65.

Publication Work in Progress

Bodensteiner, L.R., and A.O. Gabriel. Nearshore effects of offshore protection structures on aquatic habitat, Winnebago Pool Lakes, Wisconsin. Submitted to Journal of Great Lakes Research.

Professional Presentations and Posters as Author or Co-author

The impacts of legacy metal mining on streams in the North Cascades. Washington-British Columbia Chapter of the American Fisheries Society, Chelan, Washington, March 28-31, 2016. Best presentation award to master’s student Brooke Bannerman.

Relation of Antimycin A exposure to mortality in Rainbow Trout, 141st American Fisheries Society Annual Meeting, Seattle, Washington, September 3-9, 2011.

Assimilated life history and diet investigation of the redside shiner (*Richardsonius balteatus*) in Ross Lake, Washington. 141st American Fisheries Society Annual Meeting, Seattle, Washington, September 3-9, 2011.

Relations of Antimycin exposure and recovery by rainbow trout (*Onchyrynkis mykiss*) 2010 Sigmi Xi-CST Poster Fair Award Recipient, May, 2010, Bellingham, Washington.

Age Determination of the sixgill shark from hard parts, using a series of traditional and novel approaches. Cowshark Conservation Workshop III, Seattle Aquarium, Seattle, Washington.

Barriers to upstream migration of prickly sculpin *Cottus asper* and coastrange sculpin *Cottus aleuticus* Annual Meeting of the American Fisheries Society North Pacific International Chapter March 4-6, 2008, Bellingham, Washington

Groundwater presence influences coho salmon spawning site selection at the reach level Annual Meeting of the American Fisheries Society North Pacific International Chapter March 4-6, 2008, Bellingham, Washington

An elemental approach to age estimation in the sixgill shark (Hexanchus griseus) Annual Meeting of the American Fisheries Society North Pacific International Chapter March 4-6, 2008, Bellingham, Washington

Current and Historical Limnological Conditions of Soap Lake, Washington. Washington Lake Protection Association, Annual Conference, August, 2004.

Current and Historical Limnological Conditions of Soap Lake, Washington. Northwest Science, Annual Conference, March 2004.

Sensitive shoreline assessment for the Winnebago Pool Lakes, Wisconsin: a multimedia database. Canadian Association of Geographers 53rd Annual Meeting, May 27- 31, 2003, University of Victoria, Victoria, B.C.

Nearshore effects of shore protection on aquatic habitat in the Winnebago Pool Lakes, Wisconsin. Washington Lake Protection Association 16th Annual Conference on Lakes, Reservoirs and Watersheds, Chelan, Washington, April 2-4, 2003.

Sensitive shoreline assessment: a multimedia decision support tool. Georgia Basin/Puget Sound Research Conference, March 31- April 3, 2003, Westin Bayshore, Vancouver, B.C.

Dilution and concentration of saline lakes: limnology of Soap Lake. Saline Lakes Science Conference 2002, Soap Lake, Washington, August 26-27, 2002.

Management effects on Soap Lake limnology. Washington Lake Protection Association 15th Annual Conference on Lakes, Reservoirs and Watersheds, Olympia, Washington, April 4-7, 2002.

The effects of wetland restoration breakwaters on water quality and fish communities in two Wisconsin lakes. Washington Lake Protection Association 15th Annual Conference on Lakes, Reservoirs and Watersheds, Olympia, Washington, April 4-7, 2002.

Resource management issues in a hyper-eutrophic midwestern lake system. Washington Lake Protection Association 14th Annual Conference on Lakes, Reservoirs and Watersheds, Spokane, Washington, April 4-7, 2001.

Design of a relative risk model regional-scale risk assessment with confirmational sampling for the Willamette and McKenzie Rivers, Oregon, Ninth Symposium on Environmental Toxicology and Risk Assessment: Recent Achievements in Environmental Fate Transport, 1999, West Conshohocken, Pennsylvania.

Assessment of Stress-Response to Water Level Fluctuations in Common Reed Stands, Lake Poygan, Wisconsin. Poster presented at the Annual Meeting of the Canadian Association of Geographers, June 2-6, 1998, University of Ottawa, Ottawa, Ontario.

A regional comparative multiple-stressor ecological risk assessment, Society for Environmental Toxicology and Chemistry Annual Meeting, 1998, Denver, Colorado.

The relative rank risk model for regional-scale risk assessment and potential applications in freshwater and terrestrial systems Risk Assessment of Environmental End Points workshop, October 28-30, 1998, Auckland, New Zealand.

A Conceptual Framework for Ecosystem Management of Rural-Urban Watersheds, Annual Meeting of the Canadian Association of Geographers, August 18-22, 1997, St. John's, Newfoundland.

Assessment of biocriteria as a regulatory standard, Illinois Association of Wastewater Agencies Conference, March, 1994, Springfield, Illinois.

The potential for coordination for fisheries and wildlife uses in moist-soil waterfowl management units, 32nd Illinois American Fisheries Society Meeting, March, 1994, Marion, Illinois.

Winter fish composition and structure in backwaters of the Upper Mississippi River, 53rd Midwest Fish and Wildlife Conference, December, 1991, Des Moines, Iowa.

Sampling for determining fish habitat guilds in large rivers during the winter, 27th Illinois Chapter American Fisheries Society Meeting, March, 1989, LaSalle, Illinois.

Implications of backwater habitat management strategies to fish populations, Invited Paper, 44th Annual Meeting of the Upper Mississippi River Conservation Committee, March, 1988, Peoria, Illinois.

Importance of riverine backwaters to winter survival of fishes,48th Midwest Fish and Wildlife Conference, December, Omaha, Nebraska.

Winter survival strategy of small freshwater drum (*Aplodinotus grunniens* R.) in the Mississippi River, Joint Meeting of the Illinois, Indiana, and Michigan American Fisheries Society Chapters, March, 1986, Chicago, Illinois.

Other Presentations

Ecosystem function and restoration of common reed stands in Lake Poygan, Wisconsin, July, 2000, public presentation to Wisconsin Department of Natural Resources and Lake Poygan Sportsman's Club, Butte des Morts, Wisconsin.

A proposed sampling protocol for fish in small and large rivers for long-term biological assessment, presentation to NCASI National Science Advisory Panel, November, 1999, Hattiesburg, Mississippi.

Responses of midlake common reed stands to cumulative stresses, Lake Poygan, Wisconsin, University of Wisconsin-Oshkosh Sigma Xi Lecture Series, March, 1999, University of Wisconsin-Oshkosh, Wisconsin.

Wetland, sensitive shoreline, and hazard research on the Winnebago Pool lakes, Fox-Wolf Basin Surface Water and Shoreland Habitat Monitoring and Research Workshop, April, 1999, Lawrence University, Appleton, Wisconsin.

Cane bed research progress report: findings and potential for restoration, Key presentation at public meeting hosted by the Lake Poygan Sportsman's Club and Wisconsin Department of Natural Resources, May, 1998, Duck Inn, Lake Poygan, Wisconsin.

Research on the Winnebago Pool Lakes. Included a poster presentation entitled: Cane bed research, Winnebago Lakes' Fair '98. Sponsored by Fox Wolf Basin 2000 and Wisconsin Department of Natural Resources, June, 1998, Oshkosh Convention Center, Oshkosh, Wisconsin.

Reports

Bodensteiner, L.R., R. Glesne, and A. Rawhouser. 2012. Mountain lake non-native fish eradication pretreatment planning reconnaissance surveys of Kettling, Skymo, and Sourdough Lakes at North Cascades National Park Service Complex, WA: 2010 data summary; 77 pp.

Bodensteiner, L.R., and A.O. Gabriel. 2005. Limnology of Soap Lake, Washington. National Science Foundation Grant Report.

Bodensteiner, L. R., and B. Bingham. 2004. Macroinvertebrate population abundance and distribution in the Nooksack River estuary, Whatcom County, Washington.

Gabriel, A. O., and L. R. Bodensteiner. 2000. Restoration and ecosystem functions of common reed stands in Lake Poygan, Wisconsin. Wisconsin Department of Natural Resources Lake Protection Grant Final Report.

Bodensteiner, L.R., and W.G. Landis. 2000. NCASI Year 2 report: June 15, 1999-June 14, 2000. Prepared for National Council for Air and Stream Improvement, Anacortes, Washington.

Bodensteiner, L.R., and W.G. Landis. 1999. NCASI Year 1 report: June 15, 1998-June 14, 1999. Prepared for National Council for Air and Stream Improvement, Anacortes, Washington.

Bodensteiner et al. for EVS Consultants. 1999. Cherry Point screening level risk assessment. Prepared for Washington Department of Natural Resources.

Gabriel, A.O., and L. Bodensteiner. 1998. Assessment of Stress-Response to Water Level Fluctuations in Common Reed Stands, Lake Poygan, Wisconsin. Wisconsin Department of Natural Resources Lake Planning Grant Report.

Bodensteiner, L., and B. Webber. 1997. Terrestrial and aquatic resources at Squires Lake. Report to Squires Lake Advisory Committee.

Sheehan, R.J., and L.R. Bodensteiner. 1995. Evaluation of proposed modification of Illinois water quality regulations: biological criteria, criteria for compounds that accumulate, bioaccumulative chemicals of concern, and requirements for whole-effluent toxicity testing. Metropolitan Water Reclamation District of Greater Chicago Research and Development Report No. 95-16.

Current and Recently Funded Research Projects

Bodensteiner. North Cascades National Park. 2016-17. Aquatic Resource Management. Support to assess fish populations in alpine lake aquatic ecosytems and analyse temporal trends in water quality; $27,000.

Gilman, Bodensteiner, Helfield, and Rawhouser. 2014-16. U.S. Forest Service. Salish sucker distribution gaps, habitat characterization, and genetic analysis; three years $60, 000

Bodensteiner. North Cascades National Park. 2010. Aquatic Resource Management. Support to conduct monitoring of alpine lake aquatic ecosytems; $75,000 ($43K to WWU & $32K in kind).

Bodensteiner and Nooksack Salmon Enhancement Association. Liam Wood Flyfishing and River Guardian School. Continued funding and in-kind support received from Patagonia, 4th Corner Fly Fishers, Sage, SAROC, and Bracken for stream ecology/flyfishing courses; ongoing; $20,000

Bodensteiner. Ecology of BP-Cherry Point. Funding provided for student research activities associated with British Petroleum Cherry Point Refinery; 1/06-12/08; $30,000

Bodensteiner. Limnology of Soap Lake. Senior Investigator on National Science Foundation project Microbial Observatory at Soap Lake: Biochemistry, Microbial Diversity, and Productivity of Anaerobic Haloalkaliphilic Communities (submitted with Pinkart, H.C., M.R. Mormille, B.M. Peyton, A.O. Gabriel, M.C. Storrie-Lombardi, and D.R. Hosford), 07/02-07/05; $825,000 (Western sub-contract for $100,000)

Bodensteiner and Gabriel. Evaluation of a large-scale shoreline protection and restoration project, Lake Poygan, Wisconsin. U.S. Corps of Engineers; 6/01-12/01; $43,000.

Bodensteiner and Landis. Application of a multiple stressor framework to discriminating between anthropogenic impacts to aquatic biological communities. National Council for Air and Stream Improvement of the Paper and Pulp Mill Industry; 1998-2001; $240,000

Gabriel, Bodensteiner, and Hu. The Application of the ABC Resource Survey Method, GIS, and and Integrated Multimedia Approach to Sensitive Shoreline Designation on the Winnebago Pool Lakes, Wisconsin. DNR Shallow Lakes Funding Program Grant; 7/99-7/01; $58,000

Gabriel and Bodensteiner. Effects of Offshore Protection on Aquatic Habitat in the Winnebago Pool Lakes. DNR Shallow Lakes Funding Program Grant; 7/99 - 9/01; $30,000

Gabriel and Bodensteiner. Nearshore Effects of Shoreline Protection on Aquatic Habitat in the Winnebago Pool Lakes. DNR Shallow Lakes Funding Program Grant; 7/99 - 9/01; $15,000

Bodensteiner and Gabriel. Restoration and Ecosystem Function of Common Reed Stands in Lake Poygan, Wisconsin. DNR Lake Protection Grant (co-authored for Lake Poygan Sportsman's Club); 5/99-9/00; $22,000

Gabriel and Bodensteiner. Assessment of Stress-Response to Water Level Fluctuations in Common Reed Stands, Lake Poygan, Wisconsin. DNR Lake Planning Grant (co-authored for Lake Poygan Sportsman's Club); 5/97-3/98; $13,000

Summers and Bodensteiner. Large Fishes of Whatcom Waterway, Bellingham Bay. Georgia Pacific, Inc., 7/96-6/97, $3,500.

Memberships and Certifications

Commissioner, Skagit Environmental Endowment Commission (established by treaty with Canada concerning construction of Skagit River dam)

Certified for Rotenone and Antimycin Application for Fisheries (1 wk. course, Logan, Utah, 2011 and six field applications)

American Fisheries Society, Life member

Sigma Xi Scientific Research Society, past president of local chapter

Washington State Lake Protection Association, past board member

Liam Wood Flyfishing and River Guardian School, board member

Soap Lake Science Advisory Board

Phi Kappa Phi National Honor Society

PADI and NAUI Certified Open Water Diver

Master of Science Students Supervised and their Current Employment

1. Rapin, Nancy Gibble. 1999. The effects of shallow-rapid mass wasting on macroinvertebrates in three tributaries to the South Fork Nooksack River. Environmental specialist, Muckleshoot Indian Tribe

2. Downen, Mark. 1999. Relation of salmonid survival, growth and outmigration to environmental conditions in a disturbed, urban stream, Squalicum Creek, Washington. Fisheries biologist, Washington Dept. of Fish and Wildlife

3. Koenig, Sue. 2000. Relation of physical factors to the behavior and distribution of the freshwater mussel, *Margaritifera falcata* (Gould). Instructor, Skagit Valley Community College and WWU

4. LaCroix, Renee L. 2001. Macroinvertebrate re-colonization of Whatcom Creek after a fuel spill, fire and restoration. Environmental Specialist, City of Bellingham

5. Brown, Melissa. 2001. Reproductive ecology of hatchery and wild steelhead (*Oncorhynchus mykiss*) in natural environments. Fisheries biologist, City of Portland, Oregon

6. Reeves, Kerry S. 2001. Use of shoreline wetlands by young-of-the-year fishes. PhD, University of Missouri; Environmental officer, US Agency for International Development

7. Switzer, Robin W. 2002. Effects of mowing *Spartina alterniflora* to enhance overwintering success of biocontrol agent *Prokelisia marginata* in Willapa Bay, Washington.

8. Klacan, Julie. 2003. An assessment of fish health in the upper Willamette River and the lower McKenzie River, Oregon. Fisheries biologist, Washington Dept. of Fish and Wildlife

9. Dielman, Todd. 2003. Fish use of backwaters in the Willamette River, Oregon. Owner, private recreation-based company and habitat specialist, Columbia River Recovery Team

10. Kallis, Jahn L. 2005. A water budget and changes in salinity for Soap Lake, Washington. PhD at Ohio State University, research faculty at OSU

11. Gilman, Jeremy M. 2005. Sub-surface chemistry as an indicator of preferred spawning habitat for coho salmon. Fisheries biologist, US Forest Service

12. Meyer, Donald S. 2006. Depressurization stress in copper rockfish, <u>Sebastes</u> _. Instructor, WWU

13. Penaluna, Brooke E. 2006. Fish community characterization at the edge and interior of eelgrass beds in Padilla Bay, Puget Sound, WA. PhD at Oregon State University; Research fisheries biologist, US Forest Service PNW Research Station, Corvallis

14. Gardner, Courtney. 2006. Predicting landslide hazard in the Racehorse Creek watershed, Washington using Geographic Information Systems.

15. Allred, Ryan E. 2007. A comparison of snorkeling and redd counts to detect trends in adult bull trout (*Salvelinus confluentus*) populations. High school science and math instructor, Medford, OR

16. LeMoine, Michael. 2007. Barriers to upstream migration of prickly sculpin *Cottus asper* and coastrange sculpin *Cottus aleuticus*. PhD at University of Montana, fish ecologist with Upper Skagit Tribe

17. Valz, J. Henry. 2007. Variability of groundfish populations in the proposed marine reserves of Skagit County, Washington. High school science instructor, Olympia, WA

18. Mueller, Karl W. 2007. Shelter competition between native signal crayfish and non-native red swamp crayfish in Pine Lake, Sammamish, Washington: the role of size and sex. Instructor and marine technician, WWU

19. Roberts, Melissa S. 2008. Pre-spawn mortality of coho salmon *Oncorhynchus kisutch* in Whatcom County, Washington. Marine biologist, Whatcom County Marine Resources Committee

20. Anderson, Jason B. 2008. Winter juvenile salmonid abundance in select restoration project streams in the Stillaguamish, Snohomish, and Skagit River basins. Riparian ecologist, Stillaguamish Tribe

21. Smith, Ian F. 2009. The effects of introduced warm water fishes to the native kokanee population of Lake Whatcom, WA. Fisheries biologist, Federal Bureau of Land Management, Sacramento

22. Vasak, Ryan S. 2010. Viability of coho salmon *Oncorhynchus kisutch* in relation to streamflow regulation in Terrell Creek, Washington. Instructor in aquatic sciences, Bellingham Technical College

23. Campbell, S. Jeffrey. 2010. Age determination of the sixgill shark from hard parts using a series of traditional and novel approaches. Instructor, Northwest Indian College

24. Bailes, Clay. 2012. Non-lethal determination of heavy metals in spiny dogfish (Squalus suckleyi) spines using LA-ICP-MS. PhD candidate at University of South Dakota

25. Welch, Carmen. 2013. Seasonal and age-based aspects of diet of the introduced redside shiner (Richardsonius balteatus) in Ross Lake, Washington. Fisheries biologist, North Cascades National Park

26. Derenne, Emily. 2014. How juvenile trout and char use Ross Lake's perennial tributaries during winter drawdown. Habitat specialist, Skagit County Public Works

27. Leigh, Deanna. 2015. Bird-damage to sweet cherries in the Pacific Northwest and the effect of American kestrels on deterrence. Biologist, Minnesota Dept. of Natural Resources

28. Buehler, Jason. 2016. Population and habitat characteristics of the introduced Asiatic clam Corbicula fluminea in Lake Whatcom, WA. Habitat biologist, Skagit Systems Fisheries Cooperative

29. Shaw, Jessica. 2016. Effect of riparian buffer width on temperature and fish communities in agricultural waterways in Whatcom County, WA. Agricultural specialist, Washington State University Cooperative Extension Service

30. Bannerman, Brooke. 2016. Relation of metal mining on water chemistry and aquatic macroinvertebrates in the upper Skagit River watershed. Aquatic ecologist, North Cascades National Park

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Education

Ph.D., 2002, Department of Entomology, Cornell University, Ithaca, N.Y. Dissertation: *Metapopulation biology of the mayfly* Callibaetis ferrugineus hageni *in high-elevation beaver ponds.* Advisor: Barbara Peckarsky.

M.S., 1995, Department of Zoology, University of New Hampshire, Durham, N.H. Thesis: *Molecular evidence of population genetic differentiation and sibling species in* Acartia tonsa *(Copepoda: Calanoida).* Advisor: Ann Bucklin.

B.S., 1991, General Biological Sciences, with Honors in Biology, University of Maryland, College Park. Advisor: Roger Newell.

Professional Experience

<u>Assistant Professor</u> (2013-present) and Director/Lead Scientist, Fish Ecology Research Laboratory (FERL; 2008-present). Department of Fish and Wildlife Sciences, University of Idaho.

<u>Research Assistant Professor</u>, Sept 2009-Aug2013.

<u>Research Scientist</u>, 2006-2009. Department of Fish and Wildlife Sciences, University of Idaho & FERL.

<u>Research Associate</u>, 2004-2006. Department of Fish and Wildlife Sciences, University of Idaho & FERL.

<u>Postdoctoral Fellow</u>, 2003-2004. Department of Fish and Wildlife Sciences, University of Idaho & FERL.

NSF-IGERT Postdoctoral Fellow and Instructor, 2002-2003. School of Biology, Georgia Institute of Technology, Project title: Susceptibility of chemically-defended aquatic insects to fish predators: determining the relative importance of predator versus prey traits in the outcome of predator-prey interactions. Advisor: Mark Hay.

Instructor, 2002. Rocky Mountain Biological Laboratory (RMBL), Gothic Colorado.

Teaching Experience

Assistant Professor, University of Idaho, 2013-present

Fish Ecology (300-level undergraduate; 4 credit, Fall 2013);
Animal Movement, Dispersal, and Migration (Graduate; 2 credit, Fall 2014);
Statistical Analysis of Ecological Data (Graduate; 1 credit co-taught with M. Wiest, Spring 2015).
Fish and Wildlife in a Changing World (200-level undergratue for non-majors, 3 credit co-taught with J. Rachlow, Fall 2015)
Climate Change and the Conservation and Management of Populations (Graduate, 1 credit with on-line option, Fall 2015)
Ichthyology (400-level undergraduate; 4 credit with lab, Spring 2016).

Instructor, University of Idaho, 2006-7.

Fish and Wildlife Population Ecology (upper-level undergraduate course co-taught with O. Garton and C. Peery, Fall 2007)
Cumulative Watershed Processes (graduate seminar co-taught with T. Link, Spring 2007).
Limnology (upper-level undergraduate/graduate course with lab co-taught with C. Peery Fall 2006).
Models of Cause and Correlation in Biology: Structural Equation Modeling for Non-experimental Systems (graduate seminar co-taught with O. Garton, Spring 2006).

Instructor, Georgia Institute of Technology, 2002-2003.

Aquatic Chemical Ecology Laboratory (graduate course co-taught with Mark Hay and Julia Kubanek, School of Biology, Fall 2002).
Biological Applications of Fluid Dynamics (graduate course co-taught with Phil Roberts, School of Civil Engineering, Spring 2003).

Instructor, Rocky Mountain Biological Laboratory, 2002.

Ecology and Conservation of Freshwater Invertebrates (upper-level undergraduate course).

Teaching Assistant, Cornell University, 1995-2001.

Stream Ecology, Freshwater Invertebrate Biology, Evolution, Insect Ecology, Insect Biology, Introductory Biology.

Teaching Assistant, University of New Hampshire, 1993-1995.

General Ecology, Marine Biology, Anatomy and Physiology.

Mentoring Activities

Post-doctoral advisor:

Geoff Moret, 2009-2014. Project title: Developing long term monitoring protocols for aquatic resources in the Mojave Network of the NPS Inventory and Monitoring Program.
Tracy Bowerman, 2013-present. Project title: Prespawn mortality in Chinook salmon of the Columbia Basin.

Graduate committee chair, current:

Charles Erdman, M.S., Fish and Wildlife Sciences
Matthew Dunkle, M.S., Fish and Wildlife Sciences
Nathan Fuchs, M.S., Fish and Wildlife Sciences
Adam Wicks-Arshack, Ph.D., Water Resources
Sammy Matsaw, Ph.D., Water Resources

Graduated:

James “Channing” Syms (M.S., 2016; Civil Engineering, co-advised w/ Daniele Tonina)
Mark Kirk (M.S. Fisheries Resources 2015)
Samuel Bourret (M.S. 2013; co-advised with B.P. Kennedy)
Christopher Noyes (M.S. 2013)
Hattie Zobott (M.S. Civil Engineering 2013, co-advised with R. Budwig)
Adrienne Roumasset (M.S., 2012; Water Resources)
Brian McIlraith (M.S., 2011; co-advised with B.P. Kennedy)

Graduate committee member:

Current: Laura Jenkins (Ph.D., U.I. Biology), Francine Mejia (Ph.D., U.I. Fish & Wildlife Sciences), Zachary Beard (M.S., U.I. Fish & Wildlife Sciences), Zach Klein (Ph.D., U.I. Fish & Wildlife Sciences). Past: Adrianne Zuckerman (M.S. 2015, U.I. Fish & Wildlife Sciences), Anthony Prisciandaro (M.S. 2015, U.I. Fish & Wildlife Sciences), K. Marius Myrvold (Ph.D. 2014, U.I. Fish & Wildlife Sciences), Karen Laitala (M.S. 2007, U. I. Plant Science)

Undergraduate research advisees:

Keala Bush, supported by UI Office of Undergraduate Research, spring 2016, Robert Hogg, U.I. Environmental Sciences/NSF REU mentor, summer 2007
U.I. McNair Scholar Program mentor (with Ed Galindo and Aaron Haines) for Eva Sebesta, summer 2007. Project title: Habitat components associated with beaver site selection in central and southern Idaho.

Publications

Peer-Reviewed Publications

(*indicates student publication)

55. Keefer, M. L, C.C. Caudill, E.L. Johnson, T.S. Clabough, C.T. Boggs, P.N. Johnson, and W.T. Nagy. *In press.* Inter-observer bias in fish classification and enumeration using dual-frequency identification sonar (DIDSON): a Pacific lamprey case study. Northwest Science.

54. Bowerman, T.E., M.L. Keefer, and C.C. Caudill. Pacific salmon prespawn mortality: patterns, methods, and study design considerations. *In press*, Fisheries.

53. Bourret, S.L, C.C. Caudill, and M.L. Keefer. Diversity of juvenile Chinook salmon life history pathways. Reviews in Fish Biology and Fisheries. DOI 10.1007/s11160-016-9432-3

52. Kirk, M.A.*, C.C. Caudill, D. Tonina, and J. Syms. 2016. Effects of water velocity, turbulence, and obstacle length on the swimming capabilities of adult Pacific lampreys. Fisheries Management and Ecology. DOI 10.1111/fme.12179

51. Benda, S.E.*, M.L. Kent, C.C. Caudill, C.B. Schreck, and G.P. Naughton. 2015. Cool, pathogen free refuge lowers pathogen associated prespawn mortality of Willamette River Chinook Salmon *Oncorhynchus tshawytscha*. **144(6):**1159-1172 Transactions of the American Fisheries Society.

50. Keefer, M.L., C.C. Caudill. 2015. Estimating thermal exposure of adult summer steelhead and fall Chinook salmon migrating in a warm impounded river. Ecology of Freshwater Fish. DOI 10.1111/eff.12238.

49. Kirk, M.A.*, C.C. Caudill, E.L. Johnson, M.L. Keefer, and T.S. Clabough. 2015. Characterization of adult Pacific Lamprey swimming behavior in relation to environmental conditions within large dam fishways. Transactions of the American Fisheries Society **144**:998–1012. DOI 10.1080/00028487.2015.1059368.

48. Keefer, M.L., T.S. Clabough, M.A. Jepson, G.P. Naughton, T.J. Blubaugh, D.C. Joosten, and C.C. Caudill. 2015. Thermal exposure of adult Chinook salmon in the Willamette River basin. Journal of Thermal Biology **48**: 11-20. DOI 10.1016/j.jtherbio.2014.12.002

47. McIlraith*, B.J., C.C. Caudill, B.P. Kennedy, C.A. Peery, and M.L. Keefer. 2015. Seasonal migration behaviors and distribution of adult Pacific Lamprey in unimpounded reaches of the Snake River basin. North American Journal of Fisheries Management **35:** 123-134. DOI 10.1080/02755947.2014.986344

46. Hess, J.E., C.C. Caudill, D.A. Close, M.L. Keefer, B.J. McIlraith, M.L. Moser, and S.R. Narum. 2014. Genes predict long distance migration and large body size in a migratory fish, Pacific lamprey. Evolutionary Applications **7**: 1192-1208. DOI 10.1111/eva.12203

45. Bourret, S.L.*, B.P. Kennedy, C.C. Caudill, and P.M. Chittaro. 2014. Assessing the Feasibility of Geochemical Signatures to Distinguish Early Freshwater Movement, Habitat Use, and Life History of Chinook Salmon (*Oncorhynchus tshawytscha*). Journal of Fish Biology **85**: 1507-1525. DOI 10.1111/jfb.12505

44. Keefer, M.L., C.C. Caudill, and M.L. Moser. 2014. Bottleneck relief models: prioritizing fishway passage improvements for Pacific lamprey. Transactions of the American Fisheries Society **143(4):** 1049-1060. DOI 10.1080/00028487.2014.911210

43. Caudill, C.C., M.A. Jepson, S.R. Lee, T.L. Dick, G.P. Naughton, and M.L. Keefer. 2014. A field test of eugenol-based anesthesia versus fish restraint in migrating adult Chinook salmon and steelhead. Transactions of the American Fisheries Society **143(4):** 856-863. DOI 10.1080/00028487.2014.892533

42. Zabel, R.W., B.J. Burke, M.L. Moser, and C.C. Caudill. 2014. Modeling temporal phenomena in variable environments with parametric models: an application to migrating salmon. Ecological Modeling **273**: 23-30. DOI 10.1016/j.ecolmodel.2013.10.020

41. Keefer, M.L., C.C. Caudill. Homing and straying by anadromous salmonids: a review of mechanisms and rates. 2104. Reviews in Fish Biology and Fisheries. **24(1):** 333-368. DOI 10.1007/s11160-013-9334-6

40. Caudill, C. C., M. L. Keefer, T. S. Clabough, G. P. Naughton, B. J. Burke and C.A. Peery. 2013. Indirect Effects of Impoundment on Migrating Fish: Temperature Gradients in Fish Ladders Slow Dam Passage by Adult Chinook Salmon and Steelhead. PLOS One **8(12)**: 1-13; e85586. DOI 10.1371/journal.pone.0085586

39. Moser, M. L., M. L. Keefer, C. C. Caudill, and B. J. Burke. 2013. Migratory behavior of adult Pacific lamprey and evidence for effects of individual temperament on migration rate. Pages 132-151 *in* H. Ueda and K. Tsukamoto, editors. *Physiology and Ecology of Fish Migration*. CRC Press, Boca Raton.

38. Keefer, M.L., C.C. Caudill, T.S. Clabough, M.A. Jepson, E.L. Johnson, M. Higgs, and M. Moser. 2013. Fishway passage bottleneck identification and prioritization: a case study of Pacific lamprey at Bonneville Dam. Canadian Journal of Fisheries and Aquatic Sciences **70(10):** 1551-1565. DOI 10.1139/cjfas-2013-0164

37. Keefer, M.L., C.C. Caudill, C.A. Peery, and M.L. Moser. 2013. Context-dependent diel behavior of upstream-migrating anadromous fishes. Environmental Biology of Fishes **96:** 691-700. DOI 10.1007/s10641-012-0059-5

36. Keefer, M. L., G. A. Taylor, D. F. Garletts, C. Helms, G. A. Gauthier, T. M. Pierce, and C. C. Caudill. 2013. High-head dams affect downstream fish passage timing and survival in the Middle Fork Willamette River. River Research and Applications **29:** 483-492. DOI 10.1002/rra.1613

35. Keefer, M.L., C.T. Boggs, C.A. Peery, and C.C. Caudill. 2013. Factors affecting dam passage and upstream distribution of adult Pacific lamprey in the interior Columbia River basin. Ecology of Freshwater Fish **22**: 1-10. DOI 10.1111/j.1600-0633.2012.00586.x

34. Laitala, K. L., T. S. Prather, D. Thill, B. Kennedy and C. Caudill. 2012. Efficacy of Benthic Barriers as a Control Measure for Eurasian Watermilfoil (*Myriophyllum spicatum*). Invasive Plant Science and Management **5(2)**: 170-177. DOI 10.1614/IPSM-D-09-00006.1

33. Clabough, T.S., M.L. Keefer, C.C. Caudill, E.L. Johnson, and C.A. Peery. 2012. Use of night video to enumerate adult Pacific lamprey passage at hydroelectric dams: challenges and opportunities to improve escapement estimate. North American Journal of Fisheries Management **32(4)**: 687-695. DOI 10.1080/02755947.2012.690820

32. Keefer, M. L., G. A. Taylor, D. F. Garletts, C. K. Helms, G. A. Gauthier, T. M. Pierce and C. C. Caudill. 2012. Reservoir entrapment and dam passage mortality of juvenile Chinook salmon in the Middle Fork Willamette River. Ecology of Freshwater Fish **21(2)**: 222-234. DOI 10.1111/j.1600-0633.2011.00540.x

31. Keefer, M.L., R.J. Stansell, S.C. Tackley, W.T. Nagy, K.M. Gibbons, C.A. Peery, and C.C. Caudill. 2012. Use of radiotelemetry and direct observation to evaluate sea lion predation on adult Pacific salmonids at Bonneville Dam. Transactions of the American Fisheries Society **141(5)**: 1236-1251. DOI 10.1080/00028487.2012.688918

30. Hyun, S-Y, M.L. Keefer, M.A. Jepson, C.C. Caudill, J.K. Fryer, R. Sharma, J.M. Whiteaker, and G.P. Naughton. 2012. Population-specific escapement of Columbia River fall Chinook salmon: tradeoffs among estimation techniques. Fisheries Research 129-130: 82-93. DOI 10.1016/j.fishres.2012.06.013 (30)

29. Johnson, E.L., C.C Caudill, M.L. Keefer, T.S. Clabough, C.A. Peery, M.A. Jepson, and M.L. Moser. 2012. Movement of radio-tagged adult Pacific lampreys during a large-scale fishway velocity experiment. Transactions of the American Fisheries Society **141(3):**571-579 DOI 10.1080/00028487.2012.683468

28. Naughton, G. P., M. L. Keefer, T. S. Clabough, M. A. Jepson, S. R. Lee, C.A. Peery and C. C. Caudill. 2011. Influence of marine mammal injuries on the survival of Chinook salmon and steelhead in the Columbia River basin. Canadian Journal of Fisheries and Aquatic Sciences **68(9)**: 1615-1624. DOI 10.1139/F2011-064

27. Johnson, E.L., T.S. Clabough, C.A. Peery, C.C. Caudill, M.L. Keefer, and M.C. Richmond. 2010. Migration depths of adult steelhead (*Oncorhynchus mykiss*) in relation to dissolved gas supersaturation in a regulated river system. Journal of Fish Biology **76(6)**: 1520-1528. DOI 10.1111/j.1095-8649.2010.02578.x

26. Keefer, M.L., G.A. Taylor, D.F. Garletts, G.A. Gauthier, T.M. Pierce, and C.C. Caudill. 2010. Prespawn mortality in adult spring Chinook salmon outplanted above barriers dams. Ecology of Freshwater Fish **19**: 361-372. DOI 10.1111/j.1600-0633.2010.00418.x

25. Keefer, M.L., C.C. Caudill, C.A. Peery, and S.R. Lee. 2008. Transporting juvenile salmonids around dams impairs adult migration. Ecological Applications **18**(8): 1888-1900. DOI 10.1890/07-0710.1

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Caudill, C.C, C.A. Peery and S.R. Lee. 2008. Up and down and back again, adult biology of American shad in the Columbia basin. American Fisheries Society Western Division Annual Meeting, Portland Oregon.

R. Hogg*, and C.C. Caudill. Relationships between recent ocean growth, condition, spawning history, and adult migration behavior in American shad. 2008. American Fisheries Society Western Division Annual Meeting, Portland Oregon. *Undergraduate researcher.

M.J. Parsley & C.C. Caudill. What's that small shad doing here? 2008. Evidence of multiyear freshwater residence by juvenile American shad. American Fisheries Society Western Division Annual Meeting, Portland Oregon.

Caudill, C.C., L. Garrett, E. Starkey, T. Rodhouse, R. K. Steinhorst, and K.M. Irvine. 2008. Integrated water quality monitoring plan for the Upper Columbia Basin Network (poster). 2008 National Park Service Aquatic Professionals Meeting, Fort Collins, Colorado.

Caudill, C.C., A. Chung-MacCoubrey, and D. Hughson. 2008. Establishing a long term monitoring plan for aquatic resources of the National Park Service Mojave Desert Network (poster). 2008 National Park Service Aquatic Professionals Meeting, Fort Collins, Colorado and the 56th Annual Meeting of the North American Benthological Society, Salt Lake City, Utah.

Funding & Awards

(amounts are direct award to CCC)

Current

Caudill, C.C. 2015. The role of Pacific lamprey marine-derived nutrients in freshwater food webs, Year 1. $34,334 awarded from Columbia River Intertribal Fisheries Commission.

Loge, F. and C.C. Caudill. 2015. Evaluation of adult fish ladder modifications to improve Pacific lamprey passage at McNary Dam, 2015. $78,203 awarded from USACE Walla Walla District.

Courter, I. et al. 2015. Evaluation of adult Pacific lamprey passage at lower Snake River dams, 2015. $105,966 awarded from USACE Walla Walla District.

Caudill, C.C. 2015. USACE-U. Idaho CESU Columbia River Fish Mitigation 2015 Steelhead closeout. $33,601 awarded from USACE Portland District.

Caudill, C.C. and C. Sharpe (ODFW). 2015. Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, 2015. $475,931 awarded from USACE Portland District.

Caudill, C.C. 2015. Evaluation of upper Columbia River steelhead adult migration and overwintering behavior. $144,884 awarded from Washington Division of Fish and Wildlife.

Courter, I. et al. 2014. Evaluation of adult Pacific lamprey passage at lower Snake River dams, 2014. Walla Walla District USACE: $56,576.

Caudill, C.C (Lead PI), K. Frick (NOAA-Fisheries), B. Burke (NOAA-Fisheries), R. Budwig, D. Tonina, T. Friesen (ODFW), and C. Sharpe (ODFW). 2014. USACE-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation, 2014. Multi-component research grant investigating fish migration passage and survival in the Columbia and Willamette rivers with seven major tasks currently awarded and one anticipated: Task 1: Evaluation of Adult Lamprey Passage Behavior in Relation to Lower Columbia River Dam Modifications – 2014; Task 2: Evaluation of adult Pacific lamprey behavior and fate in the lower Columbia River using acoustic telemetry, 2014; Task 3: Development of Adult Lamprey Passage Structures at Lower Columbia and Snake River Dams – 2014; Task 4: Evaluation of Adult Salmon and Steelhead Passage Behavior and Success in the lower Federal Columbia River Hydrosystem – 2014; Task 5: Migration and Passage Behavior of Overwintering Summer Steelhead in the Lower Columbia and Snake Rivers – 2014; Task 6: Evaluation of adult UWR winter steelhead and summer steelhead upstream migration, distribution, survival, and life history, 2014; Task 7: Characterization and return rates of different juvenile UWR Chinook life history types; Task 8: Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, 2014 total: $1,995,743.

Caudill, C.C., M.L. Moser (NOAA-Fisheries), B. Burke (NOAA-Fisheries), R. Budwig, D. Tonina, C. Schreck (OSU), M. Kent (OSU), T. Friesen (ODFW), and C. Sharpe (ODFW). 2013. USACE-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation, 2013. Multi-component research grant investigating fish migration passage and survival in the Columbia and Willamette rivers with six major tasks: Task 1: Improving Adult Pacific Lamprey Passage and Survival at Lower Columbia River Dams – 2013; Task 2: Evaluation of adult Pacific lamprey behavior and fate in Columbia River reservoirs using acoustic telemetry, 2013; Task 3: Synthetic evaluation of adult Pacific lamprey passage, 2013; Task 4: Design and Fabrication of a Lamprey Passage Structure Modifications at Bonneville Washington Shore and John Day North fishways; Task 5: Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, Middle fork Basin of the Willamette River; Task 6: Monitoring upstream migration, distribution, and pre- and post-spawn survival of adult UWR winter steelhead and summer steelhead. 2013 Total: $2,630,074

Caudill, C.C. and R. Qualls. 2012-2016. Development of water quality and climate monitoring plan and protocols for the Mojave Desert Network. $160,332 (2012) & $120,522 (2013) awarded for continuing development of sample design, statistical analysis, and initial implementation of a long term monitoring plan for groundwater, spring, lake, and stream resources for seven national park units covering 3,292,732 hectares (8,136,518 acres) as part of the NPS Vital Signs program (http://science.nature.nps.gov/im/units/mojn/).

Evans, A., C.C. Caudill, and M.L. Keefer. 2015. Summary of adult Steelhead passage and conversion in the Federal Columbia River Power System. $69,886 awarded from the U.S. Army Corps of Engineers, Walla Walla District.

Awarded 2010-2014

Loge, F. and C.C. Caudill. 2014. Evaluation of Adult Fish Ladder Modifications to Improve Pacific Lamprey Passage at McNary and Ice Harbor Dams, 2014. $200,606 awarded from the U.S. Army Corps of Engineers, Walla Walla District.

Caudill, C.C., F. Loge, and M. Timko. 2013. Adult Steelhead and Chinook Salmon Passage, Survival, and Conversion through the Lower Snake River. $395,670 awarded from the U.S. Army Corps of Engineers, Walla Walla District.

Loge, F. and C.C. Caudill. 2013. Underwater video monitoring of adult fish ladder modifications to improve Pacific lamprey passage at McNary, Ice Harbor and Lower Monumental dams, 2013. $194,869 awarded from the U.S. Army Corps of Engineers, Walla Walla District.

Caudill, C.C., M.L. Moser (NOAA-Fisheries), R. Budwig, D. Tonina, C. Schreck (OSU), M. Kent (OSU), T. Friesen (ODFW), and C. Sharpe (ODFW). 2012. USACE-Univ. of Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation, 2012. Multi-component research grant investigating fish migration passage and survival in the Columbia and Willamette rivers with six major tasks: Task 1: Improving Adult Pacific Lamprey Passage and Survival at Lower Columbia River Dams – 2012; Task 2: Evaluation of adult Pacific lamprey behavior and fate in Columbia River reservoirs using acoustic telemetry, 2012; Task 3: Synthetic evaluation of adult Pacific lamprey passage, 2012; Task 4: Design and Fabrication of a Lamprey Passage Structure Modifications at Bonneville Washington Shore and John Day North fishways; Task 5: Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, Middle fork Basin of the Willamette River; Task 6: Monitoring upstream migration, distribution, and pre- and post-spawn survival of adult UWR winter steelhead and summer steelhead. Total: $1,568,570.

Loge, F. and C.C. Caudill. 2012. Underwater video monitoring of adult fish ladder modifications to improve Pacific lamprey passage at McNary, Ice Harbor and Lower Monumental dams, 2012. $300,325 awarded from the U.S. Army Corps of Engineers, Walla Walla District.

Caudill, C.C. and M.L. Keefer. 2011. Review of Pacific Salmon and Steelhead Straying in the Columbia River Basin. $52,883 awarded to UI. U.S. Army Corps of Engineers, Walla Walla District.

Loge, F. and C.C. Caudill. 2011. Underwater video monitoring of adult fish ladder modifications to improve Pacific lamprey passage at McNary and Ice Harbor dams, 2011. $304,941 awarded to UI. U.S. Army Corps of Engineers, Walla Walla District.

Caudill, C.C. and M.L. Moser. 2011. Improving adult Pacific lamprey passage and survival at Lower Columbia River Dams, 2011. $613,693.

Caudill, C.C., C. Schreck, and M. Kent. 2011. Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, Middle fork Basin of the Willamette River, 2011. $355,0491. U.S. Army Corps of Engineers, Portland District.

Fremier, A.F., B.P. Kennedy, and C.C. Caudill. 2011. Integrated data-driven spatial analysis to support life cycle modeling for effectiveness monitoring in the Columbia Basin 2011. $499,808 awarded from Bureau of Reclamation to A. Fremier.

Caudill, C.C. Development of a long-term water quality monitoring plan and protocol for the Mojave Network. National Park Service. $380,414 (2007-2012). Development of sample design, statistical analysis, and initial implementation of a long term monitoring plan for groundwater, spring, lake, and stream resources for seven national park units covering 3,292,732 hectares (8,136,518 acres) as part of the NPS Vital Signs program (http://science.nature.nps.gov/im/units/mojn/).

Caudill, C.C., B.P. Kennedy, and L. Borgerson. 2011. Comparing the Effectiveness of Head-of-Reservoir Collection and Transport with Direct Reservoir and Dam Passage: Estimating relative abundance and production of Chinook salmon life history types in select Willamette River tributaries, 2011. $150,015. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Caudill, C.C., and B.J. Burke. 2010. Evaluation of adult salmon and steelhead delay and fallback at Snake and Columbia river dams, 2010. $518,301 awarded to U.I. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Caudill, C.C. and M.L. Moser. 2010. Evaluation of adult Pacific lamprey passage success at McNary and Ice Harbor dams, 2010. $187,595 awarded to UI. U.S. Army Corps of Engineers Walla Walla District.

Caudill, C.C., C.B. Schreck, and M. Kent. 2010. Condition and spawning success of adult spring Chinook salmon in the Willamette River, 2010. $119,748 awarded to UI. U.S. Army Corps of Engineers Portland District.

Caudill, C.C. and F. Loge. 2010. Video monitoring of adult fish ladder modifications to improve Pacific lamprey passage at the McNary Dam Oregon shore fishway, 2010. $56,405 awarded to UI. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Walla Walla District.

Caudill, C.C. 2010. Evaluation of adult Pacific lamprey behavior and fate in Columbia River reservoirs using acoustic telemetry, 2010. $89,088 awarded to UI. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Caudill, C.C., and M.L. Moser. 2010. Improving adult Pacific lamprey passage and survival at lower Columbia River dams, 2010. $315,908 awarded to UI. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

2008 and Earlier

Comparative survival of reservoir reared and reservoir bypassed spring Chinook salmon in the Willamette River basin: Phase 1: Use of otolith and scale analyses to characterize life history variation in spring Chinook salmon in three Willamette Valley Project reservoirs and tributaries. 2009. Caudill, C.C. and B.P. Kennedy. $146,680 awarded to UI. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Migration of adult Chinook salmon and Steelhead in Hood River, Oregon, 2009. C.C. Caudill. $41,631. Confederated Tribes of the Warm Springs Reservation of Oregon.

Juvenile fall Chinook telemetry monitoring (continuation of Telemetry evaluation of habitat use by juvenile Snake River Fall Chinook salmon in reservoirs). 2009. Caudill, C.C. $177,530. U.S. Army Corps of Engineers, Walla Walla District.

Condition and spawning success of adult spring Chinook salmon in the Willamette River-2009. 2008. Caudill, C.C., C.B. Schreck, and M. Kent. $156,501 awarded to U.I. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Evaluation of adult salmon and steelhead delay and fallback at Snake and Columbia river dams, 2009. 2008. Caudill, C.C., and B.J. Burke; $306,260 awarded to U.I. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Improving adult Pacific lamprey passage and survival at lower Columbia River dams, 2009. 2008. Caudill, C.C., and M.L. Moser. $314,943. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland District.

Evaluation of adult Pacific lamprey passage success at McNary and Ice Harbor dams, 2009. 2008. Caudill, C.C. and M.L. Moser. $221,608. U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Walla Walla District.

Telemetry evaluation of habitat use by juvenile Snake River Fall Chinook salmon in reservoirs as part of Aquatic Monitoring of Navigation Channel Maintenance Sites, Snake River, WA. (FY 2008-2009). Caudill, C.C. & D. Bennett. $292,034. U.S. Army Corps of Engineers, Walla Walla District.

Improvement in estimates of Columbia River fall Chinook salmon (*Oncorhynchus tshawytscha*) escapements. $70,218 (FY2009-2010). Collaborative with Columbia River Inter-tribal Fisheries Commission (S.-Y. Hyun, lead CRITFC P.I.), funded by Pacific Salmon Commission.

Development and implementation of water quality monitoring protocols for the National Park Service I&M program: Upper Columbia Basin Network (UCBN). Caudill, C.C., $109,100 (FY 2005- 2007).

Ecology and distribution of migratory fishes in the Mekong River. Hogan, Z, G.P. Naughton, C.A. Peery, and C.C. Caudill. 2005. $70,000, IUCN World Conservation Union Mekong Wetlands Biodiversity Program.

Habitat use and migration behavior of adult salmon in the Columbia River Estuary as a test of the National Marine and Estuary Classification. C. Peery, N. Wright, and C.C. Caudill. 2004-2006. $196,000, NOAA Coastal Services Program.

National Science Foundation Dissertation Improvement Grant. 1998-2000. $9,000.

Research and travel grants during Ph.D. training, 1996-2000. Fifteen awards totaling $6,856. Sources: Sigma Xi Grants-in-Aid of Research (National and Cornell Chapters), North American Benthological Society Student Travel Award, Cornell University Rawlins Endowment, Cornell University Griswold Endowment, Cornell Graduate School, RMBL Lee R.G. Synder Fund.

Research and travel grants during M.S. training, 1993-1995. Four awards totaling $2,400. Sources: University of New Hampshire Center for Marine Biology and UNH Graduate School.

Awards

2013 American Fisheries Society Fisheries Engineering Committee Distinguished Project in Fisheries Engineering and Ecohydrology, Honorable Mention for *Lamprey passage at migration barriers on the Columbia River* (multiagency award shared with 32 other federal and tribal biologists and engineers including 2 graduate advisees, H. Zobbot and C. Symms).

2005 Zayed International Prize for the Environment, co-recipient as participant in the Millennium Ecosystem Assessment.

Professional Service, Development and Outreach

University Service

2016-present – University of Idaho Common Read selection committee.

2015 – Faculty search committee (Wildlife Ecology Management), Department of Fish and Wildlife Sciences.

2015 – Search committee, CNR Director Graduate Studies

2014 – Faculty search committee, Department of Fish and Wildlife Sciences.

2014 – Faculty search committee, Department of Fish and Wildlife Sciences.

2014 – College of Natural Resources ad hoc committee reviewing service performance of CNR Fiscal Services.

2014 – Promotion and Tenure review committee, Department of Forestry, Rangeland, and Fire Sciences.

2013-present – University of Idaho Research Council, Faculty Representative for College of Natural Resources.

2013-2014 – University-wide committee to review compensation time policy, Faculty Representative for College of Natural Resources.

2013 – College of Natural Resources ad hoc committee faculty representative on CNR internal accounting policy

Scientific Outreach

Caudill, C.C. 2015. Pink fish for blackfish: A short history of Pacific Northwest Salmon. American Society for Literature and the Environment Biennial Meeting, University of Idaho, Moscow, Idaho (Invited speaker and panel member).

Organizer of screening of *Blackfish* at the Kenworthy Theater, Moscow, ID and host/moderator for panel discussions with three cast members of the movie. October 16-17 2014, Moscow, ID. Co-sponsored by UI Fish and Wildlife Sciences and the Moscow Food Co-op.

Caudill, C.C. 2014. Snake River Steelhead: Trials and tribulations of migration in the modern world. Clearwater Flycasters, Moscow, ID.

Caudill, C.C. 2014. Pink fish for blackfish: A short history of Pacific Northwest Salmon. Super Pod Three, The Whale Museum, Friday Harbor, WA (Invited).

Caudill, C.C. and M.L. Keefer. 2014. Conversion of radio-tagged adult salmon and steelhead through the Federal Columbia River Power System. Bilateral Okanagan Technical Work Group, 27 March 2014.

Conference Advisory Board Member (invited), National Conference on Engineering and Ecohydrology for Fish Passage, June 27-29, 2011, Amherst, MA.

Participant, Lamprey Technical Work Group and Lamprey Passage Metrics Standards Subcommittee, both subcommittees of the Columbia Basin Fish and Wildlife Authority's Anadromous Fish Advisory Committee, 2009-2010.

Co-organized and moderated "Overview of shad in the Columbia Basin: history and current status". 2008 American Fisheries Society Western Division Annual Meeting, Portland Oregon.

Organized and moderated "Migration in a Changing World" Evening Session at 2005 Ecological Society Meetings, Montreal, Quebec.

Manuscript reviewer for *2015: River Research and Applications; Journal of Applied Ecology; Fisheries; Hydrobiologia; Springer (Edited Volume Book Proposal); Book chapter for* Jawless Fishes of the World*; Ecological Engineering; Environmental Biology of Fishes; 2014: Freshwater Science (review recognized as Excellent by Editor); Environmental Science and Policy; Ecological Engineering; 2013: PLOS One, Fisheries, River Research and Applications, Transactions of the American Fisheries Society (2), Canadian Journal of Fisheries and Aquatic Sciences; 2012: Conservation Letters, North American Journal of Fisheries Management (2); 2011: Animal Behaviour, Physiological and Biochemical Zoology, North American Journal of Fisheries Management, American Fisheries Society Books. 2008-2010: Ecology, Ecological Applications, Hydrobiologia, Journal of Animal Ecology, Journal of Applied Ecology, Journal of the North American Benthological Society, North American Journal of Fisheries Management, Oikos, Transactions of the American Fisheries Society, USFWS, and USGS.*

Proposal reviews for the National Science Foundation, Canadian Natural Sciences and Engineering Research Council (NSERC), Great Lakes Fishery Commission.

Attended Leading and Sustaining Your Research Program, weeklong workshop on “business for scientists” jointly presented by University of Idaho Institute of Bioinfomatics and Evolutionary Studies and the College of Business and Economics. June 2-6, 2014, Moscow Idaho.

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Christine M. Moffitt

Research Fishery Biologist GS 14
Updated June 2016
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Education

High School Diploma, 1965, Earl Warren Senior High School, Downey, California

B.A., Biology, 1969, University of California, Santa Cruz, California

M.A., Biological Sciences, 1973, Smith College, Northampton, Massachusetts

Ph.D., Fisheries Biology, 1979, University of Massachusetts, Amherst

Additional Formal Training & Short Courses (recent 6 yrs)

Making the Connection Between Human Rights and Ecology, November 25, 2014 Webinar training AAAS and ESA. 1 hr. Jessica Wyndham Associate Director of the Scientific Responsibility, Human Rights and Law Program of AAAS

Adaptive Management of Natural Resources. 7-11 June 2010. USGS Webinar. James Nichols and Julien Martin, instructors. 10 h.

Aquatic Invasive Species-Hazard Analysis and Critical Control Point Workshop. Sea Grant and FWS. 10 September 2006 Lake Placid, NY. 8 h.

Decision Analysis Seminar, June 19-23, 2006, NCTC/ Shepherdstown, WV.24 h

Fish Nutrition Workshop. AFS Meeting. Twin Falls, Idaho. 16 February 2006. 8 h

Applying Risk Assessment Principles to Fish Health Situations. 27 June 2005. Boise Idaho.8 h

Emerging Animal Health Issues Identification and Analysis, Training Course, US Department of Agriculture. September 14 – 17, 2004, Fort Collins, CO 20 h.

Work Experience

See also supporting information in Courses Taught; Graduate Students

2002-present. Professor and Assistant Unit Leader, Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho 83844-1141.

2011 (June- August) Professor and Acting Unit Leader, Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife Resources, University of Idaho. I served, as unit leader while the position was vacant.

2000-2003, Research Professor, Department of Fish and Wildlife Resources, University of Idaho. Moscow, Idaho 83844-1136.

1999-2000, President, American Fisheries Society. 5410 Grosvenor Lane, Bethesda, MD 20814.

1989-99, Adjunct Associate Professor, Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho 83844-1136.

1983-89, Adjunct Assistant Professor Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho 83844-1136

1981-83, Visiting Research Assistant Professor, Fishery Resources, University of Idaho

1980-81, Postdoctoral Associate for Anadromous Fish Research, Connecticut River Fishways, Massachusetts Cooperative Fishery Research Unit, University of Massachusetts, Amherst, MA 01003

1978-80, Instructor, Department of Biological Sciences, Smith College, Northampton, MA 01060.

1977, Teaching Assistant, Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, Massachusetts. 01003.

1975-78, Graduate Research Assistant, Department of Forestry and Wildlife Management, University of Massachusetts

1971-75, Research Associate, Amherst College

1969-71, Teaching Fellow in the Biological Sciences, Smith College, Northampton, Massachusetts.

Courses Taught

University of Idaho
Fish 499 – Directed study in Tribal Fisheries Management. 1 credit, Spring 2016.

Fish 504. Fish and Wildlife Sciences' Invited Scientist Seminar series, 1 credit. Spring 2016.

Fish499 – Directed study Management issues in aquaculture and fish health, 3 credits, Fall 2015.

Env Sci 599 – Research Aquatic Invasive Species, 1 credit, Spring 2015

Fish 499 - Directed Study Aquatic Invasive Species, 1 credit

Env Sci 598 - Aquatic Invasive Species Internship, 3 credits, Spring 2015

Fish 599 - Contemporary Issues in Fisheries Management 1 credit, Spring 2014, Spring 2015

Fish 511. Fish Physiology, 2 credits, Fall 2008; Fall 2010, Fall 2012, Fall 2014

Fish/Wildlife 501, 1 credit, each Fall semester, 1990 - 2010.

Fish 510. Advanced Fisheries Management, 3 credits, Spring 2003; Spring 2005, Spring 2007, Spring 2009; Spring 2011. Spring 2013.

Environmental Science 599, varying credits 2004- present.

Special Topics Fish 499 1 credit, spring 2007

ECB Honors Project 2007 Fish 483 fall and spring, 1 credit

Fish 504. Sustainable Aquaculture. 1 credit, Fall 2004

Practicum in Environmental Science, 2 credits 2002

Fish 500 Masters Research, varying credits, 1983 - present

Fish & Env Sci 600, Dissertation Research, varying credits, 1993 – present.

Geography 500 Masters Research, 3 credits, 2008

Aquaculture and Fish Health, 4 credits with lab, 1999

Fish Diseases, with lab 3 credits, 1995

Fish 501 - Graduate Seminar, 1 credit, fall semester, 1989-2013

Principles of Fish and Wildlife Biology, 3 credits, 1981-83

Directed Study – Fish Pathology; Fish Pharmacology, 1 credit, 1992, 1994

Smith College

Vertebrate Zoology, with lab 4 credits, 1978-79

Animal Behavior, with lab 3 credits, 1980

Introductory Biology, with lab 3 credits, 1979

University of Massachusetts

Techniques of Fisheries Management, with lab 1 credit, 1977

Extension and Service including Workshops and Research Interns

2016. Meeting with Wood River Land Trust regarding studies at Rock Creek restoration site. Explore potential for internship program. Advising regarding temperature profiles, fish species, and invertebrate sampling.6 June 2016.

2016. Understanding factors affecting the efficacy of KCl as a toxicant for adult and veliger quagga mussels. Webinar for Rapid Response Working Group, Columbia Basin Team. 18 February.

2015-16- Member of tribal natural resources team for outreach activities with tribes, outreach with visiting tribes, travel to meet with tribal educators.

2015 - Member of organizing and planning team for Natural Resources Tribal Engagement Educational Summit September-October 2015. Panel moderator.

2015. Co-organizer for two day workshop and presentations on multi-cultural inclusion with Dr. Carolyn Finney author of Black faces and White Spaces. 27-30 September. Panel moderator.

2015. Organizer for special session “Actions and dialog to change perceptions and increase engagement of underrepresented minorities in fisheries and aquatic sciences”. American Fisheries Society, Portland OR August 2015.

2015. Doris Duke Conservation Scholars. Co-PI and Mentor. Five interns for summer experience. Fieldtrip and interactions regarding anadromous fish and invasive species.

2015. Planning team for Western Region New Zealand mudsnail workshop. Seattle WA, June 16-17.

2015. Climate change and the potential effects on salmonid rearing in the future- Dr. Christine Moffitt, University of Idaho “Inflow-Outflow, Responsible and Efficient Aquaculture” Idaho Chapter American Fisheries Society. 3 March.

2014. Interactive workshop with Universidad Católica de Temuco, Presentation of program, tours of facilities and collaborative opportunities. August 2014.

2014-2015. Doris Duke Conservation Scholars. Co- PI and Mentor for Emily Rankin and Bethany Guzman. Field investigations of Asian clams in Lake Pend Oreille, ID. June – August. School year interactions, and placement for internships with tribal and agencies for summer 2015.

2014. Mentor for REU CRISSP student Jordan Rutland. Investigation of reproductive potential and genetics of Asian clams in the Snake/Columbia Rivers. June – August.

2014. Moffitt, C.M. Asian clam infestation in Lake Pend Oreille and Lake Tahoe. Special citizens meeting, Panida Theater, Sandpoint, ID. June.

2014.100th Meridian Initiative – Columbia River Basin Team Participant 13-14 May 2013.

2014. Aquatic Invasive Invertebrates Workshop. Attended by WDFW, Colville Tribe, Osoyoos Lake Managers, and Okanagon Nations. Oroville, WA, 4 March.

2013. 100th Meridian Initiative - Columbia River Basin Team Participants 3-4 October 2013.

2013. Mentor for REU CRISSP student Mary Frances Babrowicz. Ballast treatment studies of invasive mollusks, and zooplankton.

2013. HOIST (Helping Orient Indian Students and Teachers into STEM) workshop on stream invertebrates of Paradise Creek. Led four day workshop with 16 participants to introduce them to the function of freshwater streams.

2012. HOIST (Helping Orient Indian Students and Teachers into STEM). Mentor for Marilena Gartiez June - July.

2012. Mentor for REU CRISSP student Mindy Torres. Summer student research.

2012. Mentor for REU EPSCoR student Justin Shearer. Summer, and will extend into fall of 2012 as he completes senior thesis.

2011-12. Mentor, Scholarships for Education and Economic Development (SEED) Program, USAID. Angel Tiburcio Suriel, Domican Republic.

2011-12. Mentor. Environmental Science thesis students: Rhett Madsen (Monitoring dissolved gasses at Dworshak National Fish Hatchery) and Laura Hughes (Studies of control measures for invasive mollusks).

2011. Review of oral and injectable applications of erythromycin to control bacterial kidney disease. Presented in “Practical tools for managing bacterial kidney disease.” Continuing education workshop AFS Fish Health Section 52nd workshop. 14 June Nanaimo, BC.

2011. HOIST (Helping Orient Indian Students and Teachers into STEM).mentor for Janae Crispin. June – July.

2011. Mentor, REU, EPSCoR student, Heath Hewett. Summer and Fall 2011.

2011. Mentor, CRISSP-REU student. Veatasha Dorsey. Summer 2011. Physiology of steelhead kelts.

2011. 6th National New Zealand mudsnail conference. Moscow, Idaho. March 15-16.

2011. New Zealand mudsnails and invasive mollusks. Workshop for Idaho Department of Fish and Game and others. Nampa Research. January 2011.

2010- Mentor, CRISSP-REU students. Kousi Martin Perales, and Brittany Whitney

2010. Mentor, Water of West REU students. Tim Allan and Jessica Kohls

2010-2011. Mentor, REU student EPSCoR Will Schrader

2010. Webinar. Management of BKD and Erythromycin Drug Therapy for Alaska Hatchery Managers, Anchorage, AK. 16 January 2010.

2009-2010.Mentor environmental science theses students: Amber Barenberg, Kristy Marks, Chelsea Merrill, Josh Peterson.

2010. Workshop on invasive mollusks for Idaho Department of Fish and Game. 2 day workshop on identification of invasive mollusks, HACCP process, and quality assurance. With graduate student Kelly Stockton.

2010. Minority Recruitment in the Cooperative Research Units. Breakout session. National Meeting Hotel Monteleone, New Orleans, Louisiana, March 1 – 5.

2009. HOIST (Helping Orient Indian Students and Teachers into STEM). Mentor for Effie Hernandez.

2009. Mentor. Water of the West REU student interns: Jonathan Megli and Amanda Eckhart.

2009. Mentor. CRISSP REU student, Liz Marchio. Studies of invasive New Zealand mudsnails.

2009. USFWS, USGS & USFWS Webinar Participants across USA "Ecology and Management of New Zealand Mud Snails:" June 18 http://training.fws.gov/branchsites/CSP/WebSeminarSeries/june_09/information_page.html.

2008. Mentor, Water footprints and sustainability. Water of the West REU student intern, Anthony Lopez.

2008 HOIST (Helping Orient Indian Students and Teachers into STEM). Mentor research on invasive species. June – July. Kristine Atto

2008- Co- organizer. Control of New Zealand Mudsnails in Hatcheries. 1.5 d workshop, Hagerman Fish Culture Experiment Station, and Hagerman National Fish Hatchery, 13-14 May 2008.

2008. Workshop leader. Determining future location for AFS offices, Governing Board Retreat, Annapolis, MD. March.

2007. Summer Intern mentor. Research Experience for Undergraduates, National Science Foundation. One undergraduate intern, Kala Hamilton.

2006. Control of NZMS in Hatcheries. Workshop for Interested Partners. Sponsored by USFWS, and U of Idaho Coop Research Unit. 4-5 May 2006.

2006. AFS Enhancement of Value Retreat, 8 September, Lake Placid. American Fisheries Society Governing Board Retreat Leader.

2006. Summer Intern mentor. Research Experience for Undergraduates, National Science Foundation. One undergraduate intern.

2006. Summer Intern mentor. Center for Research on Invasive Species and Small Populations. One undergraduate intern.

2004. Universidad de Concepcion – University of Idaho Academic Collaboration. October 31-November 5. Delegation visits Idaho. Patagonia ecosystems research center with University of Montana. Claudio Meier, Dr. Pedro Real, Hugo Romeo, Evelyn Habit, Oscar Parra.

1995-2005, University of Idaho Hoist Program, Helping Orient Indian Student to Sciences-Mentor for 6-week summer interns every year.

1996-99, Girls with Natural Resources Workshop for junior high school girls – Aquatic Ecology Field Day.

1994, University of Idaho Hoist Program - 6-week program with Nez Perce Tribal Young Women.

1993, Development of Regional INADs for erythromycin. New Orleans, Louisiana. January 26-28. Short Course for U.S. Fish and Wildlife Service to assist in development of regional INADs for aquaculture drugs.

1991, 4-H Teen Conference: Aquatic Biology Fisheries and Aquaculture. June.

1991, Moscow High School Environmental Symposium. October.

1990, Expanding Your Horizons: Workshop for young women. March. Careers in Science.

1990, 4-H Teen Conference Science and Technology Workshop. June 11-15. Aquatic Biology, Fisheries and Aquaculture.

1990, FFA Conference. July. Fisheries and Aquaculture.

1990, Science by Mail - pen pal with 6 young children from New Hampshire to California. Program run by the Boston Museum of Science.

1989-90, Moscow High School Gifted and Talented Program, Mentor Program

1982, Short course presentation “Environmental effects of small scale hydro,” in small scale hydro shortcourse, University of Idaho, June

1979 and 1980, Workshop Leader, “Fishes of the Pond,” Massachusetts Audubon Society, Focus Outdoors, Mt. Holyoke College

1974 Instructor, University of California Extension Service, Davis, California, "Floods and Rivers"

Research Review Panels, and Advisory Boards

2015- present. Scientist Expert Panel for Delta Science Program- Review of feasibility of use of shore-based ballast water reception and treatment facilities in California. Delta Stewardship Council, and the California State Lands Commission. http://deltacouncil.ca.gov/feasibility-study-shore-based-ballast-water-reception-and-treatment-facilities-california-0

2015. Invited participant to share information, and discuss Dreissenid mussel research priorities. Portland State University. Organized by Pacific States, USGS, and USFWS. 4-5 November.

2015. Chair, Research Grade Evaluation Aquatic Scientists, 7 panel members, 19 scientist in review, USGS. January – May.

2015. Outside reviewer for tenure and promotion, University of Michigan-Flint. August.

2015. Reviewer, Great Lakes Fisheries Commission Science Board. Peer reviewer for 2 research proposals.

2015. Peer Review of Asian Clam Risk Assessment, BC Ministry of Environment. May.

2015- present, Member, USGS Emerging Wildlife Diseases work group

2013 –present. Proposal reviewer for North Pacific Research Board (NPRB). (1-2 proposals per year).

2014- present. Member at large, Western Regional Panel Aquatic Nuisance Species. Quarterly Conference calls, Panel committee participation. Annual in Person Meetings. http://www.fws.gov/answest/

2012- present. Member and participant. Idaho Invasive Species Council. Meetings twice yearly.

2012- present. Columbia River Basin Team of the 100th Meridian Initiative. Meetings twice yearly. http://www.100thmeridian.org/Columbia_RBT.asp

2014-15. Primary Reviewer and Panel Member US. Department of Agriculture, Agricultural Research Service NP 106 Aquaculture Panel. August – October- January 2015. Office of Scientific Quality Review

2014 External Reviewer for promotion package for Environmental Sciences faculty member, University of California, Davis. July.

2013. Great Lakes Fisheries Commission Science Board. Reviewer for research proposals. May-July.

2013. Reviewer for Department of Agriculture CREES, Small Business Investment in Research (SBIR) Phase I and Phase II grants – Aquaculture.

2012-2013. Member, Fisheries Strategic Plan Steering Committee for USFWS, Sport Fishing and Boating Partnership. 5 meetings and final report.

2012. Outside reviewer for Promotion, Department of Biology, Michigan Technology University.

2012. Reviewer for Department of Agriculture CREES, Small Business Investment in Research (SBIR) Phase II grants- Aquaculture.

2012. Reviewer for Alaska Marine Ecosystem Grant Program.

2011-2012. Reviewer for Israel Bi-national Agricultural Research and Development Fund proposals.

2011. Reviewer: Ohio Agriculture Research and Development Center (OARDC) Research Enhancement Competitive Grants Program for fiscal year 2012C

2011. Outside reviewer for tenure decision. Oregon State University, Hatfield Marine Science Center and Department of Fish and Wildlife Conservation. August and September 201l

2011. Outside Reviewer for tenure decision, University of California @ Davis (August- Sept 2011)

2010-13. Reviewer Lake Tahoe Tahoe Science Consortium Research Program. 5-6 proposals each year.

2010. Reviewer for Israel Bi-national Agricultural Research and Development BARD Fund Proposals.

2010. Reviewer. Montana Water Resources Seed Grants. December

2010. Reviewer. New York Sea Grant Proposals, June

2009 – 2011. Reviewer of Alaska Marine Ecosystem Grant Program, January - March.

2009. Reviewer Oregon Sea Grant Proposals, April-May.

2008. Reviewer of Animal Health and Disease proposals: Oregon Agricultural Experiment Station Sun Grants. May 2008

2007-present. Associate Editor, *Transactions* of the American Fisheries Society.

2008. Member, Aquatic Nuisance Species, Task Force. Meetings Quarterly with Invasive Species Council, State of Idaho. 15 January, 16 April, 15 July;

2008. SBIR ad hoc grant reviewer. Department of Agriculture, Aquaculture Program. January

2007- 2009. Member of the Board of Governors, The Council for Frontiers of Knowledge, Uganda, Africa.

2006-07. Task Force Member Reviewer "An Aquatic Nuisance Species Plan For Idaho: A Supplement to Idaho's Strategic Action Plan For Invasive Species," DRAFT April 2007.

2007. NSF International Research Fellowship Program Reviewer

2007. CREES Department of Agriculture Ad hoc reviewer

2007. Reviewer for Western Division AFS. Whirling disease risk assessment.

2003-2007. Working Group on Quality Assurance, of the Joint Subcommittee on Aquaculture. Participant in group meetings, 2 X annually.

2005-2006. Review Panel Lead CREES Department of Agriculture Small Business Innovative Research Program Aquaculture Phase I and Phase II Proposals. Assembled panel of 9 members, and ad hock review team of over 60 additional scientists across the world to review 58 research proposals. Organized and facilitated discussions and final reviews for all proposals.

2005-7. North Pacific Research Board (NPRB), the Exxon Valdez Oil Spill Trustee Council (EVOS), and the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (AYK SSI) Proposal Reviewer.

2005. Participant in panel SBIR Phase II 2005.

2004-2007. Journal Outreach Co-Editor, Journal of Aquatic Animal Health.

2004 - 2007. Reviewer for US- Israel Binational Agricultural Research and Development Fund Proposals. BARD

2005. CREES Department of Agriculture SBIR Aquaculture Program Panel Member. One of 6 panelists. Primary Reviewer for 6 proposals, secondary for 6 proposals.

2004-2007. Chair, Technical Advisory Board for Silver Creek Watershed, The Nature Conservancy, Hailey, Idaho.

2003-2008. Potlatch Corporation Community Advisory Board. Acting Chair 2004-5.

2003 – 2005. SeaGrant of New York proposal Reviewer.

2004. United States- Israel Bi-national Agricultural Research and Development Fund Review Board. Proposal reviewer.

2004. CREES Department of Agriculture, Animal Protection Program Review Panel. Reviewed 16 proposals, primary reviewer on 6, secondary 5 and reader of 5.

2004-2005: FWS Strategic Plan Evaluation Committee, appointed by Sport Fishing and Boating Partnership to Evaluate the USFWS Fisheries Program Progress toward their draft Strategic Plan.

2003. Reviewer, California Sea Grant program proposals.

2003. Research Grade Evaluation Panel, USGS. November.

2001-2003, Member, Fisheries Strategic Plan Steering Committee for USFWS, of the Sport Fishing and Boating Partnership.

1991-2005– Research Proposal Reviewer, Department of Agriculture, CSREES program, one to two proposals each year as a reader.

1995-2003- Sea Grant Program, Reviewer, 1 – 2 proposals per year.

2003- present - Research Proposal Reviewer, National Science Foundation, Environmental Biology Program, intermittent.

2002-2008- Member of working group on quality assurance in aquaculture production. CVM,FDA, USDA/APHIS/NRSP-7, EPA

1999-2001- WRAC Board- Research Technical Review Team

1994-97. Associate Editors, Journal of Aquatic Animal Health

1991-94. Associate Editor, North American Journal Fisheries Management

1985-95. Idaho Water Resources Research Institute. Technical Review Team.

Paper Reviews for Journals

2016. Canadian Journal of Fisheries and Aquatic Sciences, Fisheries Magazine, Ecology; Diseases of Aquatic Organisms; Aquaculture; Journal of Fish Biology.

2015. Ecological Engineering; Water, Air and Soil Pollution; North American Journal of Fisheries Management, Freshwater Science, Ecology.

2014. Aquaculture, Aquatic Invasions, Aquatic Ecology, Journal of Fish Biology, River Research and Applications; Aquatic Ecology; Environmental Engineering; Hydrobiology

2013. Aquaculture; Aquatic Toxicology, Aquatic Invasions, Ecological Engineering, Hydrobiology

2012. Environmental Toxicology and Chemistry, Northwest Science; Aquatic Invasions; North American Journal of Aquaculture; Environmental Management. Fisheries, Aquaculture, Environmental Science and Pollution Research.

2011. Freshwater Biology, Aquaculture Research; Environmental Toxicology; Chinese Journal of Oceanography and Limnology, Bulletin of Environmental Contamination and Toxicology; Environmental Management

2010. Freshwater Biology; North American Journal of Aquaculture

2009. Functional Ecology, North American Journal of Aquaculture

2008. North American Journal of Aquaculture; Aquaculture Research; Veterinary Microbiology; Freshwater Biology.

2007. North American Journal of Aquaculture, Journal of Aquatic Animal Health. Aquaculture Research, Journal of Fish Diseases.

2006. Transactions of the American Fisheries Society, North American Journal of Fisheries Management, North American Journal of Aquaculture, Journal of Fish Diseases, Journal of Aquatic Animal Health.

2005. International Journal of Environment and Pollution (IJEP). Paper reviewer. Contact Ann Hudson.

2004. Reviewer for Environmental Assessment of Oxytetracycline for control of Cold Water Disease in trout and salmon. USGS Upper Mississippi Science Center.

University of Idaho Committee Assignments

2016 - present. Member of climate committee Fish and Wildlife Sciences.

2015**.** Member search committee, Administrative specialist. Fish and Wildlife Sciences.

2014-15**.** Search Committee, Fish Physiology. July - March

2014 - Laboratory Support Committee.

2013. CNR Promotion Committee. September – December

2012. Member departmental promotion committee Sept - October

2012. Evaluation team for Morris K. Udall Scholarship applications February – March 2012.

2012 Lead for additional wet laboratory safety and repairs projects April - June

2011. Member search committee for Environmental Science Program Director (May – August 2011).

2011 – 2012. Safety committee, College of Natural Resources.

2011. Member search committee for Unit Leader (May-June)

2009-2010. Member Search Committee for Assistant Unit Leader, Fisheries (October – January).

2006-08. Lead representative for College of Natural Resources, Fisheries Wetlab renovations. Worked with University facilities and Idaho Department of Public Works to provide information, oversight and coordination for project to renovate chiller systems in CNR fisheries wetlab. Project completed summer 2008. Estimated cost $420,000. Provided Tour for Permanent Building Fund Advisory Council Sept 3-4.

2007. Member search committee, Riparian Ecologist. College of Natural Resources.

2006-2007. Chair, Search Committee for Limnologist, College of Natural Resources.

2004-2006. Member at large, Athena Board.

2003-2004. Fish Ecology Search Committee, College of Natural Resources.

2003- present, Coordinator CNR Fisheries Wet Lab operations.

1999-2003. CNR Fisheries Wet Lab Committee.

2000-2001. Fund for Idaho Faculty/Staff Committee

1988-96, FWR Safety Officer

1990-93, Affirmative Action Committee

1989-93, Chair, Air Quality Committee

1989, Fish Ecologist Search Committee

1987-88, Aquaculture Search Committee

1982-85, Fine Arts Committee

Other Professional

Membership and Service in Professional and Scholarly Organizations

American Association for the Advancement of Science since 1976

American Fisheries Society, life member

Lead for special session: Actions to increase the engagement of underrepresented minorities in fisheries and aquatic science. Special session for American Fisheries Society Annual Meeting, Kansas City, MO. August 2016.

Lead organizer special session "Actions and dialog to change perceptions and increase engagement of underrepresented minorities in fisheries and aquatic sciences". American Fisheries Society, Portland OR August 2015.

Co-chair, Awards Committee. 2014-2016.

Member, Hutton Jr. Fisheries Biologist Oversight Committee, 2013-present, evaluate applicants from Canada and US for placement in summer.

Member, Steering Committee for Symposium on the Role of Propagated Fishes in Fisheries Resource Management 2011 - 2014

Member, Executive Director Search Committee. 2012-2013

Chair, AFS Award of Excellence Committee. 2010-2014

Policy/Position Development Fish Health Section AFS 2011-2013.

Chair, J. Frances Allen Scholarship Committee. 2007-08.

Chair, AFS Transition Committee to Prioritize Choices for Moving AFS Headquarters from Grosvenor Lane, Bethesda.2007-2009

Member Steering Committee for Second Anadromous Catadromous Fish Symposium for 2007. Leader of session on climate change and anthropogenic influences.

President, Fisheries History Section. 2006- 2008.

President Elect, Fisheries History Section, 2004-2006

Outreach Editor for Journal of Aquatic Animal Health 2004-2007

Chair, Task Force on Enhancement of AFS Value 2005-2006

Chair, Award of Excellence Committee, 2002-2005.

Committee on the Visibility and Stature of North American Journal of Aquaculture 2002-2003.

Page Charge Analysis Committee for Journals 2001-2002

Member Development Committee 1998 - 2003

Past President, 2000-01

President 1999-2000

President Elect 1998-99

First Vice President 1997-98

Second Vice President 1996-97

Chair, Standards of Professional Conduct Committee, 1995-96

Member, Western Division Scholarship Committee, 1994-2000

Member, Equal Opportunities Section Mentor Award Committee, 1994-95

Member-at-Large, Long-Range Planning Committee, 1994-95

Secretary-Treasurer, Western Division AFS, 1992-95

Chair, Education Section, Video Review Committee, 1994-96

Chair, Skinner Awards Committee, 1991-92

Chair, Membership Committee, Equal Opportunities Section, 1992-93

University Liaison, Education Section, 1989-present

Symposium/special sessions coordinator, 119th annual meeting, Anchorage, Alaska, September 1989

Contributed papers session Moderator, 118th annual meeting, Toronto, Ontario, Canada, 1988

Convenor-organizer-editor, “Common Strategies of Anadromous and Catadromous Fish” an international conference, Boston, Massachusetts, 1986

Coordinator, Poster Session 115th annual meeting, Sun Valley, Idaho, September 1985

Palouse Unit
Faculty Advisor or Co-advisor 1984- Present

Genetics Workshop Advisory Panel, 1983

Nominations Committee, 1981-83

Equal Opportunity in Fisheries Committee, 1980-82, 1985-90

Membership Concerns Committee
Member, 1982-83, 1993-95

Chair, 1983-88

Editorial Overview Committee, 1982-83

Northeastern Division Program Committee, 1980-81

Southern New England Chapter
Secretary-Treasurer, 1978-79

President Elect, 1979-80

President, 1980-81

American Institute of Biological Sciences, member since 1978

Association for Women in Science
Ecology Society of America, member since 1978

Society for Environmental Toxicology and Chemistry, since 2009

Society for Sigma Xi., member since 1972

American Institute for Fisheries Research Biologists, Fellow

Publications

Manuscripts in Final Preparation or Review

Yankee, J., C.M. Moffitt, W. Connor, J. Congleton, and K Steinhorst. Growth, survival, and physiology of subyearling fall Chinook salmon PIT-tagged and then reared at elevated water temperatures. North American Journal of Fisheries Management.

Published or in Press in Refereed Journals and Peer Reviewed Symposia

Moffitt, C.M. K. A. Stockton-Fiti, and R. Caudi.2016. Toxicity of potassium chloride to veliger and byssal stage dreissenid mussels related to water quality. Management of Biological Invasions 7 http://www.reabic.net/journals/mbi/2016/Accepted/MBI_2016_Moffitt_etal_correctedproof.pdf

Stockton, K.A., C.M. Moffitt, B. J. Watten, and B. Vinci. 2016. Hydraulics and particle removal efficiency of mixed cell raceway and Burrow's pond rearing systems. Aquacultural Engineering 74:52-61. doi:10.1016/j.aquaeng.2016.04.005

Penney, Z. L., C.M. Moffitt, B. Jones, and B. Marston. 2016. Physiological comparisons of plasma and tissue metrics of selected inland and coastal steelhead kelts. Environmental Biology of Fishes 99:487-498. Doi:10.1007/s10641-016-0493-x

Moffitt, C.M., B. J. Watten, A. Barenberg, and J. Henquinet. 2015. Hydroxide stabilization as a new tool for ballast disinfection: efficacy of treatment on zooplankton. Management of Biological Invasions 6:263-275.

Trushenski, J.T., H. L. Blankenship, J. D. Bowker, T. A. Flagg, J. A. Hesse, K. M. Leber, D. D. MacKinlay, D. J. Maynard, C.M. Moffitt, V. A. Mudrak, K.T. Scribner, S. F. Stuewe, J. A. Sweka, G. E. Whelan, and C. Young-Dubovsky 2015. Introduction to a special section: Hatcheries and management of aquatic resources (HaMAR)—Considerations for use of hatcheries and hatchery-origin fish. North American Journal of Aquaculture 77:327-342.

Plumb, J. M., and C.M. Moffitt 2015. Re-estimating temperature-dependent consumption parameters in bioenergetics models for juvenile Chinook salmon. Transactions of the American Fisheries Society 144:323–330.

Buelow, J., and C.M. Moffitt. 2015. Physiological indices of seawater readiness in postspawning steelhead kelts. Ecology of Freshwater Fish. 24: 112-122.

Penney, Z. L, and C.M. Moffitt. 2014. Fatty acid consumption in white muscle and liver tissue of stream maturing steelhead during early migration and kelt emigration. Journal of Fish Biology 86: 105-120

Penney, Z. L. and C.M. Moffitt. 2014. Proximate composition and energy density of stream maturing adult steelhead during upstream migration, sexual maturity, and kelt emigration. Transactions of the American Fisheries Society 143:399-413

Penney, Z. L., and C.M. Moffitt. 2014. Histological assessment of organs in sexually mature and post-spawning steelhead trout and insights into iteroparity. Reviews in Fish Biology and Fisheries 24:781–801.

Connor, W. P., K. F. Tiffan, J. M Plumb, and C.M. Moffitt. 2013. Evidence for density-dependent growth opportunity as a factor for changes in downstream movement timing and body size of subyearling Chinook salmon. Transactions of the American Fisheries Society 142:1453-1468.

White, G., J. Claussen, C. Moffitt, B. Norcross, and D. Parrish. 2013. Dr. J. Frances Allen: pioneer of women in fisheries. Fisheries 38:103-111.

Stockton, K. and C.M. Moffitt. 2013. Disinfection of three wading boot surfaces infested with New Zealand mudsnails. North American Journal of Fisheries Management 33:529-538.

Plumb, J. M., W. P. Connor, K. F. Tiffan, C.M. Moffitt, R. W. Perry, and N.S. Adams. 2012. Estimating and predicting collection probability of fish at dams using multistate modeling. Transactions of the American Fisheries Society 141:1364-1373.

Moffitt, C.M., and C.A. James. 2012. Response of New Zealand mudsnails *Potamopyrgus antipodarum* to freezing and near freezing fluctuating water temperatures. Freshwater Science 31:1035-1041. 2012

Nielson, R.J., C.M. Moffitt and B. J. Watten. 2012.Toxicity of elevated partial pressures of carbon dioxide to invasive New Zealand mudsnails. Environmental Toxicology and Chemistry, 31:1838–1842.

Stockton, K.A., C.M. Moffitt, D. L. Blew, and C. N. Farmer. 2012. Acute toxicity of sodium fluorescein to ashy pebblesnails *Fluminicola fuscus*. Northwest Science 86:190-197.

Nielson, J., C.M. Moffitt, and B. J. Watten. 2012. Hydrocyclonic separation of invasive New Zealand mudsnails from an aquaculture water source. Aquaculture.326–329:156–162

Moffitt, C.M. and C.A. James. 2012. Seasonal dynamics of *Potamopyrgus antipodarum* infestations in a heavily used recreational watershed in intermountain North America. Aquatic Invasions 7:193–202.

Williams, C. J., and C.M. Moffitt. 2010. Estimation of fish and wildlife disease prevalence from imperfect diagnostic tests on pooled samples with varying pool sizes. Ecological Informatics 5: 273-280.

Anlauf, K. A., and C.M. Moffitt. 2010. Modelling of landscape variables at multiple extents to predict fine sediments and suitable habitat for *Tubifex tubifex* in a stream system. Freshwater Biology 55: 794–805.

Cassinelli, J. and C.M. Moffitt. 2010. Growth and physiology of selected desert and montane adapted populations of redband trout (*Oncorhynchus mykiss gairdneri*). Transactions of the American Fisheries Society 139:339–352.

Bruce, R. L., and C.M. Moffitt. 2010. Quantifying risks of volitional consumption of New Zealand mudsnails by steelhead and rainbow trout. Aquaculture Research. Aquaculture Research 41:552-558.

Moffitt, C.M. 2009. Climate change and anthropogenic Influences – Pages 151–153 in A. J. Haro, K. L. Smith, R.A. Rulifson, C.M. Moffitt, R.J. Klauda, M. J. Dadswell, R.A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for diadromous fishes in a dynamic global environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Bruce, R.L., C.M. Moffitt, and B. Dennis. 2009. Survival and passage of ingested New Zealand mudsnails through the intestinal tract of rainbow trout. North American Journal of Aquaculture 71:287–301.

Lindstrom, N.M., D.R. Call, M.L. House, C.M. Moffitt, and K.D. Cain. 2009. A quantitative enzyme-linked immunosorbent assay (ELISA) and filtration-based fluorescent antibody test (FAT) as potential tools to screen broodstock for *Flavobacterium psychrophilum* infection. Journal of Aquatic Animal Health.21:43-56.

Colvin, M.E., and C.M. Moffitt. 2009. Evaluation of irrigation canal networks to assess stream connectivity in a watershed. River Research and Applications.25: 486-496.

Cajas Cano, L., and C.M. Moffitt. 2008. Comparing footprints of trout and beef production. World Aquaculture 39(3): 10-13; 70-72.

Anlauf, K. and C. Moffitt. 2008. Models of stream habitat characteristics associated with tubificid populations in an intermountain watershed. Hydrobiologia. 603:147–158.

Jones, D.T., C.M. Moffitt, and K. Kenneth Peters. 2007. Temperature-mediated differences in bacterial kidney disease expression and survival in *Renibacterium salmoninarum* challenged bull trout and other salmonids. North American Journal of Fisheries Management, 27:695–706.

Moffitt, C.M., and S.M.A. Mobin. 2006. Profile of microflora of the posterior intestine of Chinook salmon before, during and following administration of rations with and without erythromycin. North American Journal of Aquaculture. 68:176-185.

Williams, C. J., and C.M. Moffitt. 2006. *Erratum* Estimation of pathogen prevalence in pooled samples using maximum likelihood methods and open source software. Journal of Aquatic Animal Health 18:149-155.

Moffitt, C.M. 2005. Environmental, economic and social aspects of animal protein production and opportunities for aquaculture. Fisheries 30(9):36-38.

Williams, C.J., and C.M. Moffitt. 2005. Estimation of prevalence of pathogens in pooled samples using maximum likelihood methods and open source software. Journal of Aquatic Animal Health. 17:386-391.

Moffitt, C.M., A.H. Haukenes, and C.J. Williams. 2004. Evaluating and understanding fish health risks and their consequences in propagated and free-ranging fish populations. American Fisheries Society Symposium 44:529-537.

Moffitt, C.M. 2004. The implications of aquaculture production and development on sustainable fisheries. American Fisheries Society Symposium 43.91-108

Moffitt, C.M. 2004. The implications of aquaculture production and development on sustainable fisheries. Pp.91-108 in Fish in our future: perspectives on fisheries sustainability. American Fisheries Society Symposium 43.

Jones, D. and C.M. Moffitt. 2004. Swimming endurance of bull trout, lake trout, arctic char, and rainbow trout following challenge with *Renibacterium salmoninarum.* Journal of Aquatic Animal Health 16: 10-22.

Williams, C. J., and C.M. Moffitt 2003. Bayesian estimation of fish disease prevalence from pooled samples incorporating sensitivity and specificity. pp 39-51 in C. J. Williams, editor, Bayesian Inference and Maximum Entropy Methods in Science and Engineering: 22nd International Workshop. American Institute of Physics.

Kiryu, Y. and C.M. Moffitt.2002. Models of comparative toxicity of injectable erythromycin in four salmonid species. *Aquaculture* 211:29-41.

Haukenes, A. and C.M. Moffitt. 2002. Hatchery evaluation of erythromycin phosphate injections in pre-spawning spring chinook salmon. *North American Journal of Aquaculture*.64:167-174.

Hiner, M. and C.M. Moffitt. 2002. Modeling *Myxobolus cerebralis* infections in trout: associations with habitat variables. Whirling Disease: Reviews and Current Topics. American Fisheries Society Symposium 29:167-179.

Williams, C.J. and C.M. Moffitt. 2002. A brief critique of the methods of sampling and reporting of pathogens in populations of fish (brief review of status) Whirling Disease: Reviews and Current Topics. American Fisheries Society Symposium 29:213-214.

Williams, C.J. and C.M. Moffitt. 2001. A critique of methods of sampling and reporting of pathogens in populations of fish. *Journal of Aquatic Animal Health* 13:300-309.

Kiryu,Y. and C.M. Moffitt. 2001. Acute LD50 and kidney histopathology following injection of erythromycin (Erythro-200) and its carrier in spring chinook salmon *Journal of Fish Diseases*. 24: 409-416.

Moffitt, C.M. and Y. Kiryu. 2001. Acute and chronic toxicity following parenteral application of erythromycin (Erythro-200) to maturing spring chinook salmon held at two water temperatures. *Journal of Aquatic Animal Health.* 13:8-19.

Hiner, M. and C.M. Moffitt. 2001. Variation in *Myxobolus cerebralis* infections in field exposed cutthroat and rainbow trout in Idaho. *Journal of Aquatic Animal Health.* 13:124-132.

Haukenes, A.H. and C.M. Moffitt. 1999. Concentrations of erythromycin in maturing chinook salmon following intraperitoneal injection of one of two drug formulations. *Journal of Aquatic Animal Health* 11:61-67.

Moffitt, C.M. and Y. Kiryu. 1999. Toxicity, teratogenesis, and efficacy of injectable erythromycin (Erythro-200) administered repeatedly to adult spring chinook salmon. *Journal of Aquatic Animal Health* 11:1-9.

Assaf, N.A., J.V. Pothuluri, R-F. Wang, C.E. Cerniglia, and C.M. Moffitt. 1999. Bioassay procedure for the evaluation of erythromycin activity in aquaculture environments. *Journal of World Aquaculture Society* 30:137-146.

Moffitt, C.M. 1998. Field trials of investigational new animal drugs. *Veterinary and Human Toxicology* 40 (supplement 2):48-52.

Moffitt, C.M. and seven coauthors. 1998. Pathogens and diseases of fish in aquatic ecosystems: implications in fisheries management. *Journal of Aquatic Animal Health* 10:95-100.

Peters, K.K., and C.M. Moffitt. 1996. Optimal dosage of erythromycin in a new feed additive to control bacterial kidney disease. *Journal of Aquatic Animal Health* 8:229-240.

Moffitt, C.M., and A.H. Haukenes. 1995. Regional investigational new animal drug permits for erythromycin feed additive and injectable. *Progressive Fish-Culturist* 57:97-101.

Moffitt, C.M. 1992. Survival of juvenile chinook salmon challenged with *Renibacterium salmoninarum* and administered oral doses of erythromycin thiocyanate for different durations. *Journal of Aquatic Animal Health* 4:119-125.

Moffitt, C.M. 1991. Oral and injectable applications of erythromycin in salmonid fish culture. *Human and Veterinary Toxicology* 33:49-53.

Moffitt, C.M., and T.C. Bjornn. 1989. Protection of chinook salmon smolts with oral doses of erythromycin against acute challenges of *Renibacterium salmoninarum*. *Journal of Aquatic Animal Health* 1:227-232.

Moffitt, C.M., and J.A. Schreck. 1988. Accumulation and depletion of orally administered erythromycin thiocyanate in tissues of chinook salmon. *Transactions of the American Fisheries Society* 117:394-400.

Moffitt, C.M. 1988. A profile of AFS membership and their opinion about society organization and policies. *Fisheries* 13(2):24-30.

Schreck, J.A., and C.M. Moffitt. 1987. Palatability to chinook salmon of feed containing different concentrations of erythromycin thiocyanate. *Progressive Fish-Culturist* 49(4):241-247.

Moffitt, C.M. 1985. Membership concerns are your concerns. *Fisheries* 10(4):13-15.

Brower, L.P., B.E. Horner, M.A. Marty, C.M. Moffitt, and B. Villa. 1985. Mice as predators on overwintering monarch butterflies (*Danaus plexippus* L.) in Mexico. *Biotropica* 17(2):89-99.

Moffitt, C.M. 1983. A survey of women members of AFS. *Fisheries* 8(3):12-13.

Moffitt, C.M., B.E. Kynard, and S.G. Rideout. 1983. Fish passage facilities and anadromous fish restoration in the Connecticut River basin. *Fisheries* 7(6):1-11.

Brower, L.P., D.O. Gibson, C.M. Moffitt, and A.L. Panchen. 1978. Cardenolide content of *Danaus chrysippus* butterflies from three regions of East Africa. *Biological Journal of the Linnean Society* 10:251-273.

Roeske, C.N., J.S. Seiber, L.P. Brower, and C.M. Moffitt. 1976. Milkweed cardenolides and their comparative processing by monarch butterflies (*Danaus plexippus* L.). *Recent Advances in Phytochemistry* 10:93-167.

Brower, L.P., M. Edmunds, and C.M. Moffitt. 1975. Cardenolide content and palatability of a population of *Danaus chrysippus* butterflies from West Africa. *J. of Entomology* (A)49:183-196.

Brower, L.P., and C.M. Moffitt. 1974. Palatability dynamics of cardenolides in the monarch butterfly. *Nature* 240:260-283.

Books and Book Chapters

Moffitt, C.M., A. Barenberg, K. A. Stockton, and B. J. Watten. 2015. Efficacy of two approaches for disinfecting surfaces and water infested with quagga mussel veligers. Pp 467-477, Chapter 30 *in* W. H. Wong and S. Gerstenberger, editors. Biology and management of invasive quagga and zebra mussels in the Western United States. CRC Press.

Moffitt, C.M., Z.L. Penney, and L. Cajas Cano 2014. Reconnecting people to their natural environment. Pp.185-192 *in* W. Taylor, A. Lynch, and N. Neonard, editors. The future of fisheries: perspectives for the next generation of professionals. American Fisheries Society. Bethesda, MD.

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Haro, A.J., K.L. Smith, R.A. Rulifson, C.M. Moffitt, R.J. Klauda, M. J. Dadswell, R.A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. 2009 Challenges for diadromous fishes in a dynamic environment. Symposium 66. American Fisheries Society, Bethesda. MD.

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Major Submittals for FDA Drug Approval

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Moffitt, C.M. 2005. Evaluating the safety of administration of erythromycin feed additive for salmonids on bacteria of human health concern, qualitative risk assessment:Hazard identification and characterization release assessment; exposure assessment; consequence assessment;and overall risk estimate. 4 Books.

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Moffitt, C.M. 1996. Data on target animal safety of erythromycin as a feed additive to juvenile and age zero salmon; INADs 6013, 4333. Submittal to U.S. Food and Drug Administration. Center for Veterinary Medicine. December 1996. 11 Books, follow up October 1979 with 1 book and all electronic data.

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Hiner, M. and C. Moffitt. 1998. Epidemiological modeling of *Myxobolus cerebralis* infections: identifying environmental variables in Idaho. Pp. 77-80. In Whirling Disease Symposium, Research in progress. 1998. Whirling Disease Foundation, Bozeman, Montana.

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Moffitt, C.M., A.H. Haukenes, T.L. Burnham, and J.K. Erickson.1994. Bacteria isolated from eggs and developing progeny of adult chinook salmon injected with erythromycin. International Symposium on Aquatic Animal Health. Seattle, Washington. University of California, Davis.

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Moffitt, C.M. 1992. Diseases and other factors affecting survival of wild and hatchery smolts, p. 203 in Passage and survival of juvenile chinook salmon migrating from the Snake River Basin. *Proceedings* of a technical workshop, University of Idaho, Moscow.

Moffitt, C.M. 1991. Antibiotic therapy for salmon. *Women in Natural Resources* 12(4):17.

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Moffitt, C.M. 1987. Female roles in evolution. Review of *Females of the Species* by Bettyann Kevles. *Women in Forestry* 8(4):49.

Moffitt, C.M. 1987. *Earth*, review of the book by Anne and Paul Ehrlich. *Women in Natural Resources* 9(1):5.

Moffitt, C.M. 1986. Is the women's movement improving conditions for women in America? A review of two books: *A Lesser Life* by Sylvia Ann Hewlett and *How Men Feel* by Anthony Astrachen. *Women in Forestry* 8(3):35.

Moffitt, C.M. 1986. Neptune's revenge: common resource produces problems for the future. Book review of *Neptune's Revenge, the Ocean of Tomorrow* by Anne W. Simon. *Women in Forestry* 8(2):47.

Moffitt, C.M. 1985. Where are we headed in fisheries. *Idaho Forester* 30-31.

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Moffitt, C.M. 1983. Equal rights for fish and wildlife. *Idaho Forester* 32-33.

1982. Directory of respondents, survey of women members, American Fisheries Society.

Unpublished Reports

Moffitt, C.M. 2011. Developing strategies to improve survival and return recruitment of steelhead kelts from Snake River stocks. Contract No C08-22Purchase Order No C0802240Annual Report- 2010 – 2011. Submitted to Columbia River Inter-tribal Fish Commission. Portland. Oregon.

Moffitt, C.M. 2010. Developing strategies to improve survival and return recruitment of steelhead kelts from Snake River stocks. Contract No C08-22Purchase Order No C0802240Annual Report- 2009 – 2010. Submitted to Columbia River Inter-tribal Fish Commission. Portland. Oregon.

Moffitt, C.M. 2007. Continuation of testing of control strategies to reduce New Zealand mudsnail infestation at fish propagation faculties. Annual Report to FWS. Requisition Number 11332-4-2006, Amendment Modification 3. Idaho Cooperative Fish and Wildlife Research Unit. September 2007.

Nielson, R.J., C.M. Moffitt, B.J. Watten. October 2007. Testing the Feasibility of Using a Hydrocyclone to Remove New Zealand Mudsnails from a Hatchery Water Source. Preliminary Draft Summary of Field Trials Conducted at Hagerman National Fish Hatchery, July 2007

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Cassinelli, J., C. Moffitt, and K. Meyer. 2007. Laboratory studies of growth and physiology of redband trout from desert and montane streams. FY 2006 Progress ReportMarch. Idaho Fish and Game Report 07-18. March.

Moffitt, C.M. 2006. Report to Governing Board, American Fisheries Society. Enhancement of AFS Value Committee. 21 August 2006. 8 pages.

Moffitt, C.M. 1999-2004. Completing FDA approved registration of erythromycin for treatment of bacterial kidney disease in salmon. Annual Reports for Bonneville Power Administration, Oregon.

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Bjornn, T.C., C.M. Moffitt, R.E. Myers, R.W. Tressler Jr., K.P. Reese, C.J. Cleveland, C.M. Falter, and J.H. Milligan. 1987. An evaluation of sediment and nutrient loading in Bear Lake National Wildlife Refuge on fish and wildlife production (draft). Technical Report 87-3. Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho.

Bjornn, T.C., J.L. Congleton, R.R. Ringe, and C.M. Moffitt. 1985. Survival of chinook salmon smolts as related to stress at dams and smolt quality, 1984. Idaho Cooperative Fish and Wildlife Research Unit Technical Report 85-1. 25 pp.

Moffitt, C.M., and T.C. Bjornn. 1984. Fish abundance upstream from Dworshak Dam following exclusion of steelhead trout. Final Technical Completion Report. Project WRIP/371404. Idaho Water and Energy Resources Research Institute. 54 pp.

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1982. The status of women members of the American Fisheries Society--results of a survey of members. Report to the president of the American Fisheries Society. August 1982.

1981. Connecticut River Basin Anadromous fish studies. Performance Report AFS-4-R-20, Jobs 101, 102, 303, 304, 305, and 403.

1979. Recolonization by three species of *Alosa* in water above Rainbow Dam, Farmington River, Connecticut. Final Report AFS-4-C, Job No. II-l.

Invited and Contributed Presentations at Meetings and Symposia

Multimedia Presentations

2015. Plenary and Business Award Ceremonies for 145th Annual Meeting of the American Fisheries Society. Portland, OR, August

2014. Plenary and Business Award Ceremonies for Annual Meeting of the American Fisheries Society. Quebec City, August.

2013. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Little Rock, AR, September 2013.

2012. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, St. Paul, MN, August 2012.

2011. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Seattle, WA. Sept 2011.

2010. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Pittsburgh, PA. Sept 2010.

2009. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Nashville, TN. August – Sept 2009.

2008. Plenary and Business meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Ottawa, Canada. 17-22 August.

2007. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, San Francisco, CA. 2-6 September 2007.

2006. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Lake Placid, New York.

2005.Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Anchorage Alaska.

2004. World Fisheries Congress History of World Fisheries. A photographic essay for the Plenary Presentations at the 4th World Fisheries Congress, British Columbia.

2004. Plenary and Business Meeting Awards Ceremonies for Annual Meeting of the American Fisheries Society, Madison, Wisconsin.

2003. Plenary and Business Meeting Awards Ceremony for Annual Meeting of the American Fisheries Society, Quebec City, Quebec.

2002. Plenary and Business Meeting Awards Ceremony for the Annual Meeting of the American Fisheries Society, Baltimore, Maryland.

2001. Plenary and Business Meeting Awards Ceremony for the Annual Meeting of the American Fisheries Society, Phoenix, Arizona.

2000. Plenary and Business Meeting Awards Ceremony for the Annual Meeting of the American Fisheries Society, St. Louis, Missouri.

2000. Plenary Presentation: Reflections – A History of the Fisheries and the American Fisheries Society in North America. St. Louis, Missouri.

Invited Oral Papers and Presentations

2016. Moffitt, C.M. Aquamycin update and progress toward PMF. 22nd Annual Aquaculture Drug Approval Coordination Workshop. Jackson, WY. 9-10 June.

2016. Moffitt, C.M. K. Stockton-Fiti, and R. Claudi. Factors affecting the efficacy for potash treatment for dreissenids control Columbia Basin, Columbia River Basin Team Meeting, Spokane WA, 24-25 May 2016

2015. Moffitt, C.M., Water and Energy, Dams, Ships, Fish, CO2 and other things. Guest lecture and discussion leader for Chemistry 400, Honor's Seminar. October 28. Instructor Tom Bitterwolf.

2015. Moffitt, C.M. Summary of considerations regarding KCl treatments for quagga mussels. Dreissenid mussel research priorities workshop. Portland State University. 4-5 November.

2015. Moffitt, C.M. and K. Stockton. Potential Chemical Control Tools for Dreissenids and other Invasive Mollusks. Columbia Basin, Columbia River Basin Team Meeting, Portland, 7-9 October 2015.

2015. Moffitt, C.M. Risks and management of diseases to avoid unwanted outcomes in aquaculture. Ethics in Aquaculture and Fisheries Management, 145th Annual Meeting American Fisheries Society. Portland OR. 19 August.

2015. Moffitt, C.M., and B. Kibler. *Corbicula* response in Lake Pend Oreille LPO, Idaho. Columbia River Basin Team Meeting, 12-13 May, Boise. ID.

2015. Moffitt, C.M., and F. Wilhelm. Use of elevated pH under barriers at Lake Pend Oreille, ID. Idaho Invasive Species Council, 6 March. Boise, ID

2014. Moffitt, C.M., B Watten, A. Barenberg, J. Henquinet. Hydroxide stabilization as a new tool for ballast disinfection: efficacy of treatment on zooplankton. Columbia River Basin Team, 100th Meridian. 1-2 October, 2014. Heathman Lodge, Vancouver, Washington.

2014. Moffitt, C.M. Reconnecting People to Their Natural Environment. American Fisheries Society Annual Meeting, Quebec City, August.

2013. Moffitt, C.M. Dynamics of social values and fish culture. Hatcheries and management of aquatic resources special session at American Fisheries Society annual meeting, Little Rock, AR. 8-12 September.

2013. Moffitt, C. Invasive mollusks: what are the risks and what can we do?(paper presented by K. Stockton due to sequester). Western Division, AFS, Boise, ID 15 -18 April 2013.

2013. Moffitt, C., and A. Barenberg. Asian clams infestations and Lake Pend Oreille. Invasive Aquatic Species Treatment Prevention and Education in the Northern Interior Columbia Basin. Dover City Hall, ID.28 March 2013. (presented by Barenberg due to travel restrictions)

2012. Moffitt. Asian Clams in Lake Pend Oreille. Presentation to Clark Fork Management Committee Meeting, September 19, Noxon, Montana.

2012. Moffitt, C., and L. Cajas Cano. Conflicts for global aquatic resources: the need for tools to assess tradeoffs. 143nd Annual meeting of American Fisheries Society. St. Paul, MN, 19 – 23 August.

2012. Moffitt, C.M. Diversity and equality. Workshop and presentation to SEEDS group, 1 February and 15 February. University of Idaho.

2012. Moffitt, C.M., Invasive species. Guest lecture for Wildlife 314 class. 27 January.

2011. Penney*, Z. L. and C. Moffitt. Modeling starvation in Snake River steelhead trout. University of Arkansas Pine Bluff Fish Physiology Class via video (Moscow, ID), November. Presented by Z. Penney.

2011. Penney*, Z. L. and C. Moffitt. Energy expenditure in Snake River steelhead trout. To National Russian Science Academy delegates at the University of Idaho (Moscow, ID), November. Presented by Z. Penney

2011. Moffitt, C.M., Dams and fish. Guest lecture and discussion leader for Chemistry 400, Honor’s Seminar. 26 and 28 September. Instructor Tom Bitterwolf.

2011. Moffitt, C.M. Ethical conduct in science and society. Presentation and workshop to SEEDS group. June 24.

2011. Moffitt, C.M. Aquatic invasive species invertebrates, parasites and pathogens. Lecture and discussion. 9 February. Environmental Science Capstone Class, University of Idaho.

2010. Moffitt, C.M. History of fisheries science in North America. 140th annual meeting of the American Fisheries Society, Special Student Colloquium. 16 September.

2010. Moffitt, C.M. Snake River steelhead trout: increasing their capacity for successful return. University of Idaho Physics Department Annual Banquet. April 30. Moscow ID.

2010. Moffitt, C.M. Minority Recruitment in the Cooperative Research Units. Breakout session. National Meeting Hotel Monteleone, New Orleans, Louisiana, March 1 – 5,

2009. Moffitt, C.M. Good laboratory practices, introduction to requirements, examples, and rationale. 2 h session with Advance Limnology Workshop .Department of Fish and Wildlife Resources, Moscow.

2008. Moffitt, C.M. Factors affecting establishment and control of New Zealand mudsnails. Annual meeting, Oregon Lakes Association, 13 September, Wallowa Lake, Oregon.

2008. Moffitt, C.M. Review of research on New Zealand mudsnails with emphasis on control strategies for hatcheries. Western Regional Panel on Invasive Species. Annual meeting, September 9 – 11, Fort Collins, Colorado.

2008. Moffitt, C.M. Keynote Luncheon Speaker, Equal Opportunity Section, AFS Annual Meeting, Ottawa, Canada. 18 August 2008.Subject: Highlights of successful women in the history of the American Fisheries Society.

2008. Moffitt, C.M. Update and Progress on AQUAMYCIN 100® Claim. 14th Annual Aquaculture Drug Approval Coordination Workshop July 28- 31, 2008, Bozeman, Montana.

2008. Moffitt, C.M. Invited speaker for NSF Pan American Advanced Study Institute, Human, Physical, and Natural Capital Investment in Patagonia: A Predictive Approach under the Sustainability Criterion. 11 – 23 August 2008. Conception Chile. www.ciep.cl. Both presentations presented by Lubia Cajas Cano.

2008. Moffitt, C.M. Summary of research on control of New Zealand mudsnails at fish hatcheries. Idaho Invasive Species Taskforce, Hagerman, ID. 15 July 2008.

2008. Moffitt, C.M. Environmental Assessments for Therapeutants for Aquaculture Models, Process and Variables. Idaho Chapter, American Fisheries Society.6-8 February, 2008. Post Falls, ID.

2008. Moffitt, C.M. Idaho Chapter of the American Fisheries Society, Post Falls, ID. “Palouse Unit: 1978-2008. 30 Years of Excellence.” Invited panel presentation moderator.

2007. Moffitt, C.M. Drug approval of erythromycin to treat bacterial kidney disease. 13th 13th Annual Aquaculture Drug Approval Coordination Workshop. July 31- August 1, 2007. Bozeman, MT.

2007. Moffitt, C.M. Vectors, Vehicles and Invasive Species in Stream Watersheds. Landscapes to riverscapes: bridging the gaps between research and management of stream taxa and their ecosystems. University of Idaho. Moscow 15-16 May 2007.

2007. Moffitt, C. M, Fish Health Management of cultured fish: parasites, pathogens, and physiology. Presentation to University of Arkansas, Pine Bluff, and University of Maryland, Easter Shore 19 April 2007 for graduate class in use of cultured fish in supplementing marine and inland fisheries. Organized by Paul Port and Alf Haukenes.

2007. Moffitt, C.M. Definition of environmental footprints and applications to animal protein production and aquaculture. Sustainable aquaculture. World Aquaculture San Antonio, TX 26-29 February 2007.

2007. Moffitt, C.M. Use of Antibiotics in Production: myths, reality and comparisons. Sustainable aquaculture. World Aquaculture San Antonio, TX 26-29 February 2007.

2007. Moffitt, C.M. Erythromycin to Control Bacterial Kidney Disease in Salmonids. Producers Session, World Aquaculture, San Antonio, TX. 26-28 February 2007.

2006. Moffitt, C.M., R. L. Bruce, and C.A. James. Understanding the risks of invasive New Zealand mudsnails to free ranging fish communities and to aquaculture. Invasive species session, 5th International symposium on Aquatic Animal Health. 2-6 September. San Francisco, CA.

2006. Moffitt, C.M. A model framework for evaluating risks of invasive species and diseases in hatchery and wild fish - examples from salmonids 136th Annual Meeting, American Fisheries Society, Lake Placid, New York. September 10-14 2006.

2006. Moffitt, C.M. Progress toward drug approval for oral erythromycin. Annual Drug Approval Workshop. La Crosse, Wisconsin, 1-2 August, 2006.

2006. Moffitt, C.M. Assessment of risks to the environment and humans from aquaculture drugs. Presentation to Idaho Aquaculture Association, Twin Falls, June 2006.

2006. Cajas Cano*, L. and C.M. Moffitt. Environmental and Social Costs of Beef and Fish Production for Human Consumption: Can we Export Information from Idaho to Guatemala?. Idaho Aquaculture Association, 17th Annual Meeting, Twin Falls, Idaho. June 2006.

2006. Bruce, L., and C.M. Moffitt. Summary of laboratory trials to model survival and passage of New Zealand mudsnails in the gastrointestinal tract of rainbow trout. New Zealand Mudsnails Control workshop. Hagerman, May 2006.

2006. Moffitt, C.M. and L. Bruce. Control of New Zealand mudsnails in hatcheries: conceptual model of components to consider and options for potential collaborations. New Zealand mudsnail control workshop, Hagerman, Idaho. May 2006.

2006. James, C. and C. Moffitt. New Zealand mudsnails in Silver Creek, Idaho. Presentation to the Idaho Nature Conservancy's Citizen's Advisory Group, Hailey, Idaho, March, 2006.

2005. Moffitt, C.M. Idaho Research initiatives. New Zealand and Aquatic Nuisance Species Biologist Workshop, 20 April. Denver, Colorado.

2005. Moffitt, C.M. Environmental assessment of erythromycin to control bacterial kidney disease in salmon hatcheries. Northwest Fish Culture Conference, 6-8 December Boise, Idaho.

2004. Moffitt, C.M. Economic and environmental aspects of animal protein production. 134th Annual American Fisheries Society, Madison, Wisconsin. August

2004. Moffitt, C.M. Getting to the finish line with erythromycin approvals. INAD Workshop, August Bozeman, Montana.

2004. Moffitt, C.M. Modeling the effects of antibiotic treatments in cultured fish. 134th Annual American Fisheries Society, August. Madison, Wisconsin.

2003. Moffitt, C.M. Progress in Approval of Erythromycin for Salmonid Bacterial Kidney Disease. INAD Workshop, 30-31 July, Bozeman Montana.

2003. Moffitt, C.M. New Approaches to Evaluate and Understand Risks of Pathogens to Cultured and Free-Ranging Fish Populations. Uses and Effects of Propagated Fishes in Fisheries Management. June 03, Boise, ID. 2003.

2003. Moffitt, C.M. Gerald D. Schmidt Memorial Lecture "The puzzle of whirling disease: can we use landscape level approaches to understand and model risk?" Rocky Mountain Conference of Parasitologists, 34rd Annual Meeting May 1-3rd Colorado Springs, CO.

2003. Moffitt, C.M. Models for whirling disease. 9th Annual Whirling Disease Symposium, February 03, Seattle WA.

2003. Moffitt, C.M. Aquaculture America Special Session on Drug Approval Studies, February. Louisville, Kentucky.

2002. Moffitt, C.M. Student Leadership retreat leader: "Ethics in Daily and Professional Life". 20-21 September

2001. Moffitt, C.M. Influence of disease interactions of natural and cultured fishes, WRAC Research Board Meeting, Scottsdale, Arizona. October 15-16, 2001.

2001. Implications of Aquaculture Production and Development on Sustainable Fisheries 131st Annual Meeting, American Fisheries Society, Phoenix, Arizona, August 20-24, 2001.

2001. Moffitt, C.M. Spent Carcasses and Fish Pathogens: A workshop to assess the state of knowledge, define research and monitoring needs, and potential funding sources, Annual Meeting of the American Fisheries Society Fish Health Section, Victoria, British Columbia, Canada, June 28-30, 2001.

2000. Moffitt, C.M. Reflections on our AFS roots. Annual Meeting, Montana Chapter American Fisheries Society. 7-11 February. Great Falls, MT

1999. Moffitt, C.M. Historical View of Attitudes Toward Fishery Resources in North America. Western Association of Science Writers. University of Idaho. Moscow.

1999. Moffitt, C.M. Institutional Constraints and Impediments of Management Institutions. Panel participant. The Value of Native Coldwater Fish. February 9 – 11, Coeur d Alene. ID. Forest Service.

1994. Moffitt, C.M. NRSP-7 FDA Workshop. Bethesda, Maryland. Title: Establishing field trials for investigational new animal drugs.

1993. Moffitt, C.M. Review of the INAD process – a case study. INAD Development workshop, New Orleans, Louisiana. January 27-28.

1990. Moffitt, C.M. Fifth IR-4/FDA Workshop for Minor Use Drugs: Focus on Aquaculture. Bethesda, Maryland, October 15-16, 1990. Title: Erythromycin in salmonids.

Contributed Oral and Poster Papers Presented by Moffitt, Students and Colleagues
*indicates presenter other than CM

2016. Moffitt, C.M. Factors affecting the use of erythromycin therapy to control bacterial kidney disease in juvenile salmonids. 57th Western Fish Disease Workshop and American Fisheries Society Fish Health Section Meeting. 7-10 June. Jackson, WY.

2016. Moffitt, C.M. and K. A. Stockton*. 2016. Mortality responses of quagga mussels to KCl solutions prepared in different source waters. 19th International Conference on Aquatic Invasive Species April 10-14, 2016, Winnipeg, MB Canada

2016. Moffitt, Christine M., K. A. Stockton-Fiti*and R. Claudi. Mortality responses of quagga mussels to KCl solutions prepared in different source waters. Western Division AFS March 2016, Reno NV.

2016. Stockton-Fiti, K. A.*, and C.M. Moffitt. 2016. Assessing the risk of an invasion of New Zealand mudsnails and a review of the tools to prevent and manage an infestation. Western Division of AFS. Reno, NV.

2015. Wilhelm*, F. C. Moffitt, E. Braker, B. Kibler, J. Noonan, and T. Woolf. 2015. Efforts to use elevated pH and benthic barriers to eradicate Asian clams (Corbicula) from Idaho's Great Lake, Lake Pend Oreille. North American Lake management Society symposium. November 17 – 20, Sarasota Springs, N.Y.

2015. Moffitt, C.M. Factors affecting the outcome of potential chemical control tools for dreissenids and other invasive mollusks. Annual Meeting of the Western Regional Panel on ANS, September 2-4, Lake Tahoe, CA.

2015. Guzman*, B., E. Rankin, E. Braker, C.M. Moffitt, and F. M. Wilhelm. (poster) Benthic survey of Ellisport Bay, Lake Pend Oreille, Idaho, for invasive Asian clams. Ecological Society of America, August. Baltimore, MD.

2015. Moffitt, C.M., B Watten*, A. Barenberg, J. Henquinet. (poster) Hydroxide stabilization as a new tool for ballast disinfection: efficacy of treatment on zooplankton. International Association for Great Lakes Research, 58th Annual Conference. 25-29 May. Burlington VT.

2015. Vierling, K., C. J. Conway, C. Moffitt, and E. Braker. Internship programs in the Fish and Wildlife Sciences Department at the University of Idaho: opportunities for expanding wildlife education. Idaho Chapter of The Wildlife Society Annual Meeting, 10 March 2015. Pocatello, ID

2015. Braker, E., C.M. Moffitt*, K, Vierling, C. Conway, and M. Quist. Investment in mentoring: training to promote diversity in conservation professions. Idaho Chapter American Fisheries Society, March. Boise ID.

2015. Moffitt, C.M. Socio-economic and environmental factors influence the relevance of natural resources. Idaho Chapter American Fisheries Society, March. Boise ID.

2015. Moffitt, C.M., F. Wilhelm, E. Braker, B. Kibler, J. Noonan, and T. Woolf. Asian clams can pose a significant threat to aquatic resources: updates on the Lake Pend Oreille infestation and management. Idaho Chapter American Fisheries Society, March. Boise ID.

2014. Moffitt, C.M., B Watten*, A. Barenberg, J. Henquinet*. (poster) Hydroxide stabilization as a new tool for ballast disinfection: efficacy of treatment on zooplankton. Upper Midwest Invasive Species conference, 20-22 October, Duluth MN.

2014. Moffitt, C.M. Elevated pH: An Effective, Economical and Safe Tool to Control Release of Invasive Species. American Fisheries Society Annual Meeting Quebec City August.

2014. Rankin*, E., B. Guzman*, A. Barenberg, E. Braker, and C.M. Moffitt. Population density and management of invasive Asian clams in Lake Pend Oreille. Upward bound workshop.McCall Outdoor Science Center, July.

2014. Moffitt, C.M. Z. L. Penney, J. Buelow, B. Jones and B.Marston. Energetics and physiology of Columbia/Snake Steelhead. Pacific Coast Steelhead Management Meeting at Skamania Lodge. March 18-20,

2013. Barenberg*, A., C.M. Moffitt, and B. J. Watten (oral). Toxicity studies to control invasive mollusks. Washington State Lake Protection Association (WALPA) and Oregon Lake Management Association. Vancouver, WA. 16-18 October.

2013. Barenberg*, A., C.M. Moffitt and B. J. Watten (oral).Elevated pH as a disinfection tool against three invasive mollusks of concern. Annual Meeting, American Fisheries Society. Little Rock AR. 8-12. September.

2013. Penney*, Z. L., and C.M. Moffitt. (oral).Finding death: the relationship between energy and iteroparity in steelhead trout. AFS/Sea Grant best student presentations. Annual Meeting, American Fisheries Society. Little Rock AR. 9 September.

2013. Penney*, Z. and C.M. Moffitt. (oral). Histological assessment of selected tissues in maturing and post spawning Snake River steelhead. Western Division American Fisheries Society, Boise, ID 17 April.

2013. Cajas Cano*, L. and C.M. Moffitt. (oral).Life cycle assessment (LCA) of marine mussels production in Washington, US. Western Division American Fisheries Society, Boise, ID 17 April.

2012. Barenberg*, A., C.M. Moffitt, and B. J. Watten (oral).Elevated pH as a management tool to control invasive mollusks. Washington State Lake Protection Association (WALPA). Wenatchee, WA, 24-26 October.

2012. Shearer*, J., C.M. Moffitt, and A. Barenberg. (poster) NaOH toxicity to invasive quagga mussels and Asian clams: estimating lethal time of exposure to NaOH pH 12. Idaho NSF EPSCoR and Idaho NASA EPSCoR annual meeting, Boise, ID. 2-3 October.

2012. Barenberg*, A., C.M. Moffitt, and B. J. Watten. (poster) Use of hydrated lime and sodium hydroxide to reducing the risks of release of invasive species from ballast systems.143rd Annual Meeting, American Fisheries Society, St. Paul, MN. 19 – 13 August.

2012. Penney*, Z., and C.M. Moffitt. (oral) No guts no glory: using histology to assess the capacity for post-reproductive recovery in Snake River steelhead kelts. 143rd Annual Meeting, American Fisheries Society, St. Paul, MN. 19 – 13 August.

2012. Penney*, Z., C.M. Moffitt, B. Marston, C. Woods, B. Jones, and J. Buelow. Nutritional and energetic status of inland Snake River and coastal Situk River kelts using blood plasma chemistry (poster). 13th Steelhead Management Meeting Pacific States Management Council, Fort Worden, WA, March.13-14

2012. Hughes*, L., A. Barenberg*, T Britton*, C. Withers-Haley*, C.M. Moffitt, B. J. Watten, and J. Davis*. Use of hydrated lime to reducing the risks of release of invasive species from boats and ballast systems (Poster). Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March.

2012. Jones*, B., C.M. Moffitt, T. Copeland, B. Bowersox, D. Hatch, Z. Penney, and J. Buelow (oral). Migration and physiology of Clearwater River steelhead kelts. Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March.

2012. Madsen*, R., C.M. Moffitt, J. Christiansen, and J. Olson. Monitoring and mitigation of saturated gasses at Dworshak National Fish Hatchery (poster). Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March.

2012. Penney, Z. L., C.M. Moffitt, B. Marston. J. Buelow, B. Jones.(oral) A comparison of the nutritional and energetic status of kelts from the Snake River and coastal Situk River, AK using blood plasma metrics. Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March.

2012. Plumb*, J. M., C.M. Moffitt, J. A. Yanke, W. P. Connor and K. F. Tiffan. (oral) Thermal shift in maximum consumption helps explain bioenergetics and growth by subyearling fall Chinook salmon. Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March.

2012.Cajas Cano*, L. and C.M. Moffitt.(oral) Life cycle assessment integrating two or more species to improve sustainability in marine aquaculture.Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March

2012. Hewett*, H., C.M. Moffitt and Z. L. Penney. (poster) Prevalence of otolith aberrancy in hatchery-reared juvenile steelhead trout from the Snake River basin. Idaho Chapter American Fisheries Society Annual Meeting. Coeur d Alene. 6-9 March

2011. Jones*, B. C.M. Moffitt, (oral) Physiological and migratory characteristics of Clearwater River steelhead kelts. 142nd Annual Meeting, American Fisheries Society, Seattle, WA. 4 – 8 September.

2011.Buelow*, J., C.M. Moffitt, Z. Penney, K. Hamilton, A. Pape, and B. Jones. (oral) Physiological characteristics of migrating steelhead trout kelts from the Snake River system. 142nd Annual Meeting, American Fisheries Society, Seattle, WA. 4 – 8 September.

2011. Penney*, Z. C.M. Moffitt. J. Buelow, B. Jones. (oral) Understanding energy expenditure of upstream migration, sexual maturation, and kelt emigration of Snake River steelhead trout with bioenergetic models and empirical data from tissues. 142nd Annual Meeting, American Fisheries Society, Seattle, WA. 4 – 8 September.

2011. Penney*. Z., C.M. Moffitt, V. Dorsey, B. Jones, J. Buelow. Taking a look inside: histological changes within the liver during freshwater spawning cycles of Snake River steelhead trout. (poster). 142nd Annual Meeting. American Fisheries Society, Seattle WA 4-8 September.

2011. Plumb*, J. M., K. Tiffan , C. Moffitt, and B. Connor. (oral) Bioenergetics and migration of Snake River fall chinook salmon. 142nd Annual Meeting, American Fisheries Society, Seattle, WA. 4 – 8 September.

2011. Stockton*, K. and C. Moffitt. (oral) Evaluation of Virkon Aquatic as a potential tool to disinfect mollusk infested field and hatchery gear . Idaho Chapter AFS Annual Meeting, Boise, ID. March.

2011. Penney, Z.*, C.M. Moffitt, J. Buelow, J. Plumb and W. Schrader. (oral) Evaluating energy expenditure in adult Snake River steelhead trout (*Oncorhynchus mykiss*).48th Idaho Chapter of the American Fisheries Society Annual Meeting (Boise, ID).March.

2011. Jones*, B., C. Moffitt, T. Copeland, B. Bowersox, J. Buelow, and W. Schrader. Migration timing, run characteristics and selected plasma metrics of steelhead trout kelts from three Clearwater River tributaries, Idaho. Idaho Chapter AFS Annual Meeting, Boise, ID. March.

2011. Buelow*, J. C. Moffitt, Z. Penney, K. Hamilton, A. Pape, B. Jones.(oral) Physiological characteristics of steelhead kelts in the Snake River, Idaho Idaho Chapter AFS Annual Meeting, Boise, ID. March.

2011. Stockton, K*. T. Allan, C.M. Moffitt, B. Watten, B.Vinci. (poster) Modeling water and small particle residence times in two rearing units used for intensive culture of steelhead trout in Idaho. Idaho Chapter AFS Annual Meeting, Boise, ID. March.

2011. Schrader*, W., Z. Penney, C. Moffitt. (poster) Energy and proximate content of selected tissues from Snake River steelhead trout kelts sampled at Lower Granite Dam. Idaho Chapter AFS Annual Meeting, Boise, ID. March.

2011. Plumb*, J. M. K F. Tiffan, C M. Moffitt, W. P. Connor.(oral) Factors affecting early life history and growth of naturally-produced fall chinook salmon in the Lower Snake River, Idaho. Idaho Chapter AFS Annual Meeting, Boise, ID. March.

2010. Cajas-Cano*, L., and C.M. Moffitt.(poster) Life cycle assessment to simulate the benefits of integration of mussels in aquaculture. Life Cycle Assessment X, Portland, Oregon. Nov. 2-4, 2010.

2010. Reyes, P. C.M. Moffitt* and J.Brostrom. (poster) Using GIS to assess the risks and benefits of culvert removal to native bull trout (*Salvelinus confluentus*) in the upper Boise River basin. American Fisheries Society Annual Meeting, Pittsburgh, PA. September.

2010. Penney, Z. L.*, C.M. Moffitt (oral). Tissue composition, condition and energy storage of sexually mature steelhead trout from the Snake River. American Fisheries Society Annual Meeting, Pittsburgh, PA. September.

2010. Buelow, J.*, C.M. Moffitt, Z. Penney, K. Hamilton and A. Pape.(poster) Physiological and migrational characteristics of steelhead kelts in the Snake River, Idaho. American Fisheries Society Annual Meeting, Pittsburgh, PA. September.

2010. Stockton, K.*, C.M. Moffitt. (oral).Development of biosecurity measures for aquaculture facilities. American Fisheries Society Annual Meeting, Pittsburgh, PA. September.

2010. Plumb*,J. C.M. Moffitt, K. Tiffan, and W. P. Connoer. (oral). Estimating and predicting the probability of bypassing subyearling Chinook salmon at Lower Granite Dam. Snake River fall Chinook salmon workshop.Hood River, Oregon. May 26-27.

2010. Stockton*. K., C.M. Moffitt. (oral). Development of Biosecurity Measures for Hatcheries to Protect Against Invasive Mollusks Western Division, Salt Lake City, Utah, April

2010. Reyes*, P., C.M. Moffitt, and J. Brostrom. (oral). Barrier removals: Tools to Assess the Risks of Invasive Species. Salt Lake City, Utah, April

2010.Plumb*, J. M., C. M. Moffitt, and W.P. Connor. (oral) Quantifying the effects of Snake River dam operations on the collection and detection of subyearling fall Chinook salmon. Idaho Chapter, American Fisheries Society. Pocatello, ID. March.

2010. Plumb*, J. M., C. M. Moffitt, and W.P. Connor.(poster). A non-parametric assessment of Snake River fall Chinook salmon (*Onchorynchus tshawytscha*) out-migration timing. Idaho Chapter, American Fisheries Society. Pocatello, ID. March.

2010.Penney*, Z., C.M. Moffitt, J. Buelow, K. Hamilton, and A. Pape.(oral). Tissue composition and condition of sexually mature hatchery origin steelhead. Idaho Chapter, American Fisheries Society. Pocatello, ID. March.

2010. Reyes*, P., C.M. Moffitt, and J. Brostrom. (oral).GIS tools to assess the risks and benefits of barrier removal to native fish populations in Idaho trout Idaho Chapter, American Fisheries Society. Pocatello, ID. March.

2010. Buelow*, J., C. Moffitt, Z. Penney, K. Hamilton, A. Pape.(oral). Characteristics of steelhead kelts in the Snake River. Idaho Chapter, American Fisheries Society. Pocatello, ID. March.

2010. Stockton*, K. and C. Moffitt.(oral). Development of biosecurity measures for hatcheries to protect against invasive mollusks. Idaho Chapter, American Fisheries Society. Pocatello, ID. March.

2010. Barenberg*, A., K. Stockton, and C.M. Moffitt..(poster).Efficacy of Virkon Aquatic ® to disinfect wading gear infested with New Zealand mudsnails. American Fisheries Society. Pocatello, ID. March.

2009. Fritz*, R., L. Cajas-Cano*, and C.M. Moffitt (oral).An Assessment of the Potential Use of for Mollusks to Improve Water Quality in Aquaculture Systems Filtration. 4-6 March. Idaho Chapter AFS. Boise.

2009. Teater, K., C.M. Moffitt*, and B. Watten. (oral) Evaluation of Mixed Cell Raceways at Dworshak National Fish Hatchery. Idaho Chapter AFS, 4-6 March. Boise.

2009. Reyes, P.*, C. Moffitt, and J. Brostrom. (oral).Using GIS to estimate the risks and benefits of barrier removal to native fish populations in Idaho. Idaho Chapter AFS.4-6 March. Boise.

2009. Stockton, K.* 2009. (oral).Colorado’s zebra/quagga mussel monitoring program. Idaho Chapter AFS.4-6 March. Boise.

2008. Cajas Cano, L. and C.M. Moffitt*(poster) Life cycle analysis approach to understanding sustainable aquaculture production. American Fisheries Society Annual Meeting, Ottawa, ON. CANADA. 17-21 August.

2008. Cajas Cano, L*. and C.M. Moffitt.(invited oral presentations and workshop leader) Environmental considerations in considering sustainable development for Chile. and Aquaculture development and social and economic measures of sustainability. NSF Pan American Advanced Study Institute, Human, Physical, and Natural Capital Investment in Patagonia: A Predictive Approach under the Sustainability Criterion. 11 – 23 August 2008. Conception Chile.

2008. Cajas Cano, L*. and C. Moffitt. (invited oral) "Putting aquaculture production into reality: recognizing environmental and other factors affecting sustainability. "Jornada de Piscicultura Marina AECI-Guatemala". June 2008.

2008. Nielson, J.*, C. Moffitt, and B. Watten. (oral) Feasibility of two step system for removing New Zealand mudsnails from infested hatchery inflow waters. Idaho Chapter, American Fisheries Society.6-8 February, 2008. Post Falls, ID.

2008. Cassinelli, J.* and C. Moffitt.(oral) Effects of water temperature on growth and physiology of different populationsof redband trout (O*ncorhynchus mykiss gairdneri*). Idaho Chapter, American Fisheries Society.6-8 February, 2008. Post Falls, ID.

2008. Cajas Cano, L.*, and C.M. Moffitt (oral). Estimating water, land, and other resources used to produce beef and trout for human consumption in Idaho. Idaho Chapter, American Fisheries Society.6-8 February, 2008. Post Falls, ID.

2007. Cajas Cano, L. and C.M. Moffitt*. (poster). Estimating water, land, and other resources used to produce beef and trout for human consumption in Idaho. Idaho Water Resources Research Symposia, Idaho Environmental Summit, December 12 and 13, 2007 – Boise, Idaho.

2007. Nielson, R.J*.,Moffitt, C.M., and Watten, B.J. (oral) Feasibility of two step system for removing New Zealand mudsnails from infested hatchery inflow waters. Northwest Fish Culture Conference 2007, Portland, OR.

2007. Nielson, R.J., Moffitt, C.M., and B. J. Watten*, 2007. (poster) Toxicity of CO2 to New Zealand Mudsnails (*Potamopyrgus antipodarum*): Implications for Control. 15th International Conference on Aquatic Invasive Species, September. Nijmegen, The Netherlands. 24 September 07.

2007. Nielson, R.J*., Moffitt, C.M., and B. J. Watten, 2007.(Oral) Feasibility of two step system for removing New Zealand mudsnails from infested hatchery inflow waters. 137th Annual Meeting American Fisheries Society, San Francisco, CA. 3-7 September, 2007.

2007. Hamilton, K. 2007. (poster) Using Hydrocyclone Filtration to remove the invasive New Zealand mudsnail from fish hatchery inflow REU2 Inter Program Poster Presentation. August 2007.

2007. Nielson, R.J.* C.M. Moffitt, and B. J. Watten (oral) A two-step approach for controlling New Zealand mudsnails (*Potamopyrgus antipodarum*) in fish hatcheries. 5th New Zealand Mudsnail in the Western USA Conference, Putah Creek Lodge, 27-28 June 27, 2007.

2007. Moffitt, C.M.* Dealing with changing environments: xenobiotics and emerging diseases. (poster) Challenges for Diadromous Fishes in a Dynamic Global Environment. Halifax, NS. June 18-21 2007.

2007. Nielson, J.* Moffitt, C.M., and B. J. Watten, 2007. (oral) Toxicity of New Zealand Mudsnails (*Potamopyrgus antipodarum*) to CO2: Implications for Control. Idaho Chapter of American Fisheries Society, Boise, ID. 21-24 February, 2007.

2007. Cassinelli, J.*, and C.M. Moffitt 2007. (oral) Effects of water temperature on growth and physiology of different populations of redband trout (*Oncorhynchus mykiss gairdneri*). Idaho Chapter of American Fisheries Society, Boise, ID. 21-24 February, 2007.

2006. Nielson, J. , C.M. Moffitt, and B. J. Watten. 2006. (oral) Progress on Methods of Controlling New Zealand Mudsnails (*Potamopyrgus antipodarum*) in Fish Hatcheries. December 4 – 6, 2006, Portland OR.

2006. Moffitt, C.M. C. James, L. Bruce, J. Nielson, and B. Watten.(poster).Invasive New Zealand Mudsnails (*Potamopyrgus antipodarum*) in Idaho: assessment of risks and opportunity for control. Poster for USGS headquarters highlights of research on invasive species. November 2006.

2006 Moffitt. C.M. (oral). Presentation of studies of small populations and invasive species. New Zealand mudsnails in Idaho. Presentation to CRISSP advisory board 13 October 2006.

2006. C.M. Moffitt (oral).A model framework for evaluating risks of invasive species and diseases in hatchery and wild fish - examples from salmonids 136th Annual Meeting, American Fisheries Society, Lake Placid, New York. September 10-14 2006.

2006. Howard, S., J. Nielson, and C. Moffitt. 2006. (oral). Control of New Zealand mudsnails using CO2 toxicity. CRISSP summer interns group presentations. August 2006.

2006. Bruce, L. R. and C.M. Moffitt. (oral) Survival and passage of New Zealand mudsnails in the gastrointestinal tract of rainbow trout. Idaho Chapter American Fisheries Society Twin Falls, Feburary 2006.

2006. James, C. and C.M. Moffitt. (oral) Seasonal population dynamics of New Zealand mudsnails in Silver Creek and Riley Creek Drainage, Idaho. Idaho Chapter American Fisheries Society, Twin Falls February.

2006. Moffitt, C.M., Do Aquaculture Drug Treatments Pose a Serious Risk to Humans and the Environment – a case study. (oral) Idaho Chapter of the American Fisheries Society. Idaho Falls, 15-17 February, 2006.

2005. Bruce, R. L, and C.M. Moffitt. (oral) Passage of New Zealand mudsnails in the GI tract of rainbow trout. Northwest Fish Culture Conference, 6-8 December 2006. Boise, Idaho.

2005.Cajas Cano, L. and C.M. Moffitt. 2005. (oral) Environmental and Social Footprints of Beef and Fish Production for Animal Protein. Northwest Fish Culture Conference. 6-8 December 2005, Boise, Idaho.

2005. Bruce, L., and C.M. Moffitt*. (oral) Survival of New Zealand mudsnails in the gastrointestinal tract of rainbow trout. New Zealand Mudsnails Conference, 16-17 August. Montana State University. Bozeman. MT.

2005. James, C.*, and C.M. Moffitt. (oral) Assessing winter populations of New Zealand mudsnails (*Potamopyrgus antipodarum*) in Silver Creek drainage, Blain County, Idaho, and Riley Creek drainage, Gooding County, Idaho. New Zealand Mudsnails Conference, 16-17 August. Montana State University. Bozeman. MT.

2005. Moffitt, C.M., K. A. Anlauf, and A. H. Haukenes. (oral) Risk characterization of erythromycin effluents from salmon hatcheries. Western Fish Disease Workshop, June. Boise.

2005. Moffitt, C.M. and S. M. A. Mobin. (oral) Profile of the microflora in the hatchery water, the trout and New Zealand mudsnails at Hagerman State Fish Hatchery. Western Fish Disease Workshop, June. Boise.

2005. Bruce, L., and C.M. Moffitt. (oral) Survival of New Zealand mudsnails in the gastrointestinal tract of rainbow trout. Western Fish Disease Workshop. June. Boise.

2005. Cajas, L., and C. Moffitt. (oral)Comparison of the environmental, social, and economic factors in trout and beef production in Idaho. Presentation for Forestry 510. May.

2005. James, C. and C.M. Moffitt.(oral) New Zealand Mudsnails in Silver Creek Drainage. Idaho Chapter American Fisheries Society, Boise February.

2005. Yanke, J., C. Moffitt, J. Congleton, and W. Connor. (oral) Survival growth and physiology of Snake River fall Chinook salmon following chronic temperature stress and application of passive integrated transponder (PIT) tags. Idaho Chapter American Fisheries Society, Boise, ID.

2005. Colvin, M., K. Anlauf, C. Moffitt, and K. Johnson. (oral) The ecology of *Myxobolus cerebralis* in the Pahsimeroi River drainage, Idaho. Idaho Chapter American Fisheries Society, Boise, ID.

2005. Anlauf, K., C. Moffitt, M. Colvin.(oral) The influence of landscape, stream, and microhabitat parameters on tubificid habitat and population abundances. Idaho Chapter American Fisheries Society. Boise.

2005. Anlauf, K. A., C.M. Moffitt, M. E. Colvin, and B. Rieman. (poster). Ecology of whirling disease through aquatic habitat modeling using geospatial attributes. Whirling disease symposium. February. Denver, Colorado.

2004. Moffitt, C.M. What about resistant microorganisms? (Poster) in Reconciling fisheries with conservation and the ecological footprint of aquaculture. World Fisheries Congress. Vancouver, British Columbia, Canada. 3-6 May 2004.

2003. Moffitt, C.M., J. Yanke. (oral) Effects of PIT Tags on Growth, Survival and Blood Chemistry of Fall Chinook Salmon in Different Temperatures. 133rd annual American Fisheries Society, Quebec City, Quebec. August 2003

2003. Moffitt, C.M., S. M. A. Mobin. (oral) Profile of bacteria in the gastrointestinal tract of Chinook salmon (*Oncorhynchus tshawytsha*) before, during, and following administration of erythromycin rations. Northwest Fish Culture Conference. December 3-5, Portland Oregon

2002. Moffitt, C.M., M. Colvin, and K. Anlauf. (oral) Distribution of *Myxobolus cerebralis* in free-ranging fish populations in Idaho: associations with landscape variables. Proceedings International Symposium on Aquatic Animal Health, September 1-5 2002. New Orleans, Louisiana.

2001. Moffitt, C.M. (oral) Epidemiological modeling of *Myxobolus cerebralis* infections in trout: Associations with habitat variables. 6th Annual Whirling Disease Workshop. Salt Lake City, Utah, February 6-8, 2001.

2001.Moffitt, C.M., and C. Williams. (oral) A Critique of methods of sampling and reporting pathogens in populations of fish. 6th Annual Whirling Disease Workshop. Salt Lake City, Utah, February 6-8, 2001.

2000. Moffitt, C., M., (oral) Dealing with risk assessments for resistant microorganisms to achieve drug approval for erythromycin to treat bacterial kidney disease. Western Fish Disease Workshop, June 27-29, Gig Harbor, Washington.

2000. Moffitt, C.M., and S. Intelmann (oral).Spatial distribution of pathogens in free ranging populations of salmonids and their relationships with anthropogenic influences in the intermountain west 130th Annual Meeting American Fisheries Society, August 20-24, 2000, St. Louis, Missouri.

1999. Risk Assessments for Aquaculture Drugs: What we know and do not know? AFS/Fish Health Section 1999 Annual Meeting and Western Fish Disease Workshop, June 9-11, 1999, Twin Falls, Idaho.

1999. Redefining models of epidemiology of *Myxobolus cerebralis* in Idaho. 5th Annual Whirling Disease Symposium, Research and Management Perspectives, February 1999, Missoula, Montana.

1998. Disease interactions of natural and cultured fishes, WRAC Board Research Board Meeting. October 1998. San Diego, California.

1998. Understanding epidemiology of whirling disease in Idaho. February 1998. Idaho Chapter AFS, Idaho Falls.

1998. Visions for the American Fisheries Society in 2000. February 1998. Missouri Chapter American Fisheries Society.

1996. Northwest Fish Culture Conference, Victoria, British Columbia. December 1996. Registration of aquaculture chemicals – Will we ever get to the finish line?

1995. Western Fish Disease Workshop. Twin Falls, Idaho. Title: Residues of erythromycin in filets of muscle and skin tissue from salmonids following oral and parenteral administration.

1994. International Symposium on Aquatic Animal Health. Seattle, Washington. September. C.M. Moffitt, A.H. Haukenes, T.L. Burnham, and J.K. Erickson. Title: Bacteria isolated from eggs and developing progeny of adult chinook salmon injected with erythromycin.

1994. American Fisheries Society, Annual Meeting. Halifax, Nova Scotia. August. Title: Field trials of erythromycin feed additive and eythromycin injectable with INAD permits.

1994. Western Fish Health Workshop. Bozeman, Montana. June. A.H. Haukenes and C.M. Moffitt. Title: Assessing the environmental effects of applications of erythromycin in fish culture.

1994. Western Fish Health Workshop. Bozeman, Montana. June. C.M. Moffitt and A.H. Haukenes. Title: Comparisons of techniques for evaluating *Renibacterium salmoninarum* in chinook salmon at spawning.

1993. Pacific Northwest Fish Health Protection Committee. Twin Falls, Idaho. September. Title: Use of erythromycin in critical stocks.

1993. Western Fish Disease Workshop. Wenachee, Washington. June. Title: Pharmacokinetics of administrations of erythromycin to adult salmon.

1992. Western Fish Disease Conference. Parkville, British Columbia. July. H. Kaiser and C.M. Moffitt. Title: Feeding strategies to improve palatability and absorption of erythromycin thiocyanate rations administered to chinook salmon.

1992. Western Fish Disease Conference. Parkville, British Columbia. July. A.H. Haukenes and C.M. Moffitt. Title: Field trials of two formulations and two routes of injection of erythromycin administered to maturing chinook salmon.

1992. Western Fish Disease Conference. Parkville, British Columbia. July. K.K. Peters and C.M. Moffitt. Title: Dose titration tests of erythromycin thiocyanate to control acute infections of bacterial kidney disease in juvenile chinook salmon.

1992. Western Fish Disease Conference. Parkville, British Columbia. July. Poster Paper: A.H. Haukenes, K.B. Hills, J.C. Faler, C.M. Moffitt, and S.L. Leek. Title: Toxic responses of erythromycin administered to juvenile and adult salmon.

1992. American Fisheries Society Fish Health Section. Auburn, Alabama. July. C.M. Moffitt, A. Haukenes, and W.R. Hayton. Title: Determination of an optimal window for injection of erythromycin to maturing chinook salmon.

1992. Idaho Chapter, American Fisheries, Society. McCall, Idaho. March. A.H. Haukenes and C.M. Moffitt. Title: Retention of erythromycin in adult chinook salmon related to maturity, drug formulation and sex of fish. Application of erythromycin to control bacterial kidney disease in salmon.

1992. U.S. Trout Farmers Meeting. Colorado. January. Title: Steps to development of INAD field trials.

1991. Idaho Chapter American Fisheries Society. Boise, Idaho, March 7-9, 1991. Title: Application of erythromycin to control bacterial kidney disease in salmon.

1991. Idaho Chapter American Fisheries Society. Boise, Idaho, March 7-9, 1991. Title: Role of Idaho Chapter in Advocacy vs. Professionalism.

1990. Forty-First Annual Northwest Fish Culture Conference. Boise, Idaho, December 4-6, 1990. Title: Progress on the registration of erythromycin for use in fish culture.

1989. Fortieth Annual Northwest Fish Culture Conference. Gleneden Beach, Oregon, December 5-7, 1989. Moderator panel discussion, “Administration of erythromycin to adult and juvenile salmonids - what are we doing and what do we know?”

1988. American Fisheries Society 119th Annual Meeting. Toronto, Ontario, Canada, September 10-15, 1988. Title: Differential mortality in disease-challenged chinook salmon.

1988. 1st International Fish Health Conference. Vancouver, B.C., Canada, July 19-21, 1988. Title: Protection of chinook salmon against bacterial kidney disease by feeding erythromycin thiocyanate.

1988. Idaho Chapter American Fisheries Society. Boise, Idaho, March 3-5, 1988. Title: Challenging chinook salmon with bacterial kidney disease.

1987. Idaho Chapter American Fisheries Society. Boise, Idaho. March 12-14, 1987. Two papers--titles: Palatability of erythromycin thiocyanate to chinook salmon; Retention of erythromycin thiocynate in tissues of chinook salmon.

1986. American Fisheries Society 116th Annual Meeting. Providence, Rhode Island. September 14-18, 1986. Title: Interactions of sediments, nutrients, fish, and wildlife in Bear Lake National Wildlife Refuge, Idaho.

1985. Idaho Chapter, American Fisheries Society. Boise, Idaho. March 7-9, 1985. Title: Chinook workshop--Effects of feeding drugs to juveniles.

1984. American Fisheries Society 114th Annual Meeting. Cornell University, Ithaca, New York. August 12-16, 1984. Title: Behavioral and physiological assessment of smoltification in hatchery-reared steelhead trout and chinook salmon.

1983. Idaho Chapter, American Fisheries Society. Boise, Idaho. March 4-5, 1983. Title: Behavioral assessment of smoltification in Snake River steelhead trout and chinook salmon in 1982.

1982. Biology Department Seminar, University of Idaho. November 3, 1982. Title: Voluntary migration in hatchery-reared chinook salmon and steelhead trout smolts.

1982. Idaho Chapter, American Fisheries Society. Boise, Idaho. February 25-27, 1982. Panel Title: The dilemmas of mixed stocks (wild and hatchery) steelhead management.

1981. American Fisheries Society 111th Annual Meeting. Albuquerque, New Mexico. September 16-18, 1981. Title: Upstream movements of subadult striped bass at fish passage facilities in the Connecticut River watershed.

1980. Third Annual Research Conference on the Connecticut River Flood Plain. Enfield, Connecticut. March 7, 1980. Title: A review of fish studies in the Connecticut River.

1978. American Fisheries Society 108th Annual Meeting. University of Rhode Island, Kingston, R.I. August 20-25, 1978. Title: Dynamics of natural recolonization by American shad, *Alosa sapidissima*, at a fish ladder facility.

1977. Southern New England Chapter, American Fisheries Society. Shrewsbury, Massachusetts. June 1977. Title: Sexual selectivity at Rainbow Dam fishway, Farmington River, Connecticut.

1977. Northeast Division of American Fisheries Society and the Wildlife Society Meetings. Boston, Massachusetts. March 1977. Title: Progress in recolonization of American shad above Rainbow Dam.

Grants Funded

2016. Co-Investigator with F. Wilhelm Survey of Asian clam distribution at Hope in Lake Pend Oreille, Idaho. Idaho Department of Agriculture.8,000

2013-2018. Co-Investigator. Effects of changes in disturbance regimes on animal communities. USGS. 81,666. August 30, 2013 - June 30, 2018

2013-2016. Principal Investigator. Guidance Documents to Improve Operations at Fish Hatcheries USFWS. $16,500.July 1, 2013 - June 30, 2016

2013-2016. Principal Investigator. Aquatic Invasive Species Investigations to assist UDWR. $26,000. May 1, 2013 – June 30, 2016

2013 – 2016. Principal Investigator. Risks and effectiveness of benthic barriers as tools to eradicate infestation of Asian clams in the Ellisport Bay treatment area of Lake Pend Oreille, Idaho. U S Geological Survey SSP project. 46,018. December 2013 to 30 June 2016.

2012 -2013. Principal Investigator. Native American student capacity. US. Geological Survey. $16,500.

2011-2013. Co-Investigator. High Risk Ballast Water – Refinement and Application of a Promising New Treatment Method for the NPS Ranger III and Other Ships Plying the Great Lakes. $50,000. National Park Service. Collaboration with Leetown Science Center and Western Fisheries Research Center.U of Idaho portion to date, total project $250,000.

2011-2012. Principal investigator. Research, monitoring and evaluation of emerging issues and measures to recover the Snake River fall Chinook ESU. Bonneville Power Administration. $40,000

2008 – 2013. Principal Investigator. Developing strategies to improve survival and return recruitment of steelhead kelts from Snake River stocks. Columbia River Inter-Tribal Fish Commission. $ 440,000 for year one; 200,000 for year two; 200,000 for year three, $66,000 for year 4; 42,000 for year 5..

2008-2012. Principal Investigator. Development of decision analysis tools for controlling New Zealand mudsnails in fish hatcheries. USFWS. $76,700

2008- 2009 – Principal Investigator. Assessing the Risks and Benefits of Barrier Removal to Native Fish Populations in Idaho. USFWS. $35,000.

2008-2011. Principal Investigator. Research, monitoring and evaluation of emerging issues and measures to recover the Snake River fall Chinook ESU. $162,300.

2005-2008- Principal Investigator. Physiology of Redband trout. Idaho Department of Fish and Game. $80,000.

2005-2008. Continuation of development of control strategies for New Zealand mudsnails. U.S. Fish and Wildlife Service. $67,6000.

2005-2007. Principal Investigator. Exploring feasibility of proposed control strategies for New Zealand Mud Snails at Fish Hatcheries**.** Science Support Project $21,800 for the first year; $12.500 for second installment.

2004-2005. Principal Investigator. Startup studies for control of New Zealand mudsnails in FWS hatchery waters. USFWS. $11,00.

2004-2005. Principal Investigator. Studies of New Zealand Mudsnail in Silver Creek Idaho. Idaho Department of Fish and Game. $43,000, 1.2 years.

2004-05. Principal Investigator. Collaborations to measure risk of whirling disease. Trout Unlimited. $10,000; and Montana State Partnership. $5,000.

2004-2005. Principal Investigator. Spatially based monitoring and modeling of resistant microorganisms at freshwater aquaculture facilities UI/WSU Aquaculture Initiative, The Northwest Center for Aquaculture Research and Education. $12,000

2003-2005. Principal Investigator. Effects of water and PIT-tagging on the survival, growth, physiology and health status of subyearling fall Chinook salmon. FWS $105,000.

2003-2005. Principal Investigator. Completing models to predict risks of infection of *Myxobolus cerebralis* within river drainages. U. S. Geological Survey. $13,000.

2003-2006. Principal Investigator . Infrastructure to complete FDA registration of erythromycin for salmonids. Bonneville Power Administration. $156,000 year 1; $140,000 year 2; $100,000 year 3

2003-2004. Principal Investigator . Whirling Disease Studies. Idaho Department of Fish and Game. $7,000.

2001-2003: Principal Investigator. Development of Empirical Models of *Myxobolus cerebralis* to Predict Risks for Populations of Fish Across River Drainages. Montana State University. Whirling Disease Partnership Projects. $27,587 year one: 34,000 year two.

2000-02, Principal Investigator. Susceptibility of bull trout to infection by Renibacterium salmoninarum. U.S. Fish and Wildlife Service and USGS. $44,000.

1999-2002, Principal Investigator. Infrastructure to complete FDA registration of erythromycin Bonneville Power Administration, $142,000.

1998-2002. Principal Investigator. Disease interactions between wild and cultured salmonids. Western Regional Aquaculture Center. University of Washington. $76,000.

1997-99, Principal investigator: Understanding factors affecting the epidemiology of Whirling Disease. Idaho Department of Fish and Game. $38,000.

1995-97, Principal investigator: Registration of erythromycin for salmonids. $165,000. USFWS.

1995-97, Principal investigator: FDA approved registration of erythromycin for treatment of bacterial kidney disease (BKD) in juvenile and adult salmon. $170,000. Bonneville Power Administration.

1992-95, Principal investigator: FDA approved registration of erythromycin for treatment of bacterial kidney disease (BKD) in juvenile and adult chinook salmon. $400,000 per year for 4 years. Bonneville Power Administration.

1989-91, Principal investigator: FDA approved registration of erythromycin for treatment of bacterial kidney disease (BKD) in juvenile and adult Chinook salmon. $300,000 per year for 2 years. Bonneville Power Administration.

1997, Co-principal investigator: Equipment to enhance university research capabilities in fish research. USDA 1433 Formula Funds. $8,000.

1996, Principal Investigator: FDA approved registration of erythromycin for treatment of bacterial kidney disease (BKD) in juvenile and adult salmon. $152,000. Bonneville Power Administration.

1992-95, Principal Investigator: FDA approved registration of erythromycin for treatment of bacterial kidney disease (BKD) in juvenile and adult chinook salmon. $400,000 per year for 4 years. Bonneville Power Administration.

1989-91, Principal Investigator: FDA approved registration of erythromycin for treatment of bacterial kidney disease (BKD) in juvenile and adult chinook salmon. Bonneville Power Administration. $300,000 per year for 2 years.

1988, Co-Principal Investigator: Equipment to enhance university research capabilities in fish research. USDA 1433 Formula Funds. $8,000.

1987, Principal Investigator: Determination of dosage and duration of oral administration of erythromycin thiocyanate to treat bacterial kidney disease in chinook salmon. IR-4 Program, Department of Agriculture. $14,000.

1987, Co-Principal Investigator: Natural immunity to IHN and BKD in salmon and trout. University of Idaho Aquaculture Program. State Board of Education. $19,000.

1986, Co-Investigator: International symposium on common strategies of anadromous and catadromous fishes. National Science Foundation (Grant to East Carolina University). $20,000.

1984-87, Co-Investigator: Evaluation of proposed use of Bear Lake NWR as a sediment and nutrient trap for inflows into Bear Lake. U.S. Fish and Wildlife Service. $240,000.

1983, Co-Principal Investigator: Fish production in drainages where anadromous fish have been excluded by construction of dams. Phase I. Idaho Water and Energy Resources Research Institute. $15,000.

1982-87, Co-Investigator: Evaluation of hatchery practices and methods to control bacterial kidney disease in hatchery stocks of Snake River chinook salmon. U.S. Fish and Wildlife Service. $70,000.

1981-83, Evaluation of wild stock status and development of plans for use of hatchery salmon in the Snake River. U.S. Fish and Wildlife Service. $60,000.

1975-77, Principal Investigator: Restoration of anadromous fish at Rainbow Fishway U.S. Fish and Wildlife Service anadromous fish research. Agencies involved: Stanley Works, Inc., of New Britain, Connecticut, and Connecticut River Anadromous Fish Programs, Hadley, Massachusetts. $35,000.

1971, Sloan Foundation Grant for summer research on the Mill River, Massachusetts. $5,000.

Honors and Awards

Elected as Fellow of the American Fisheries Society. Recognition in Portland, Oregon. 2015. AFS members who are recognized by their peers as distinguished for their outstanding and/or sustained contributions to the discipline and Society.

Idaho Chapter American Fisheries Society Excellence in Aquaculture. Boise, ID. March 2015.Continued leadership in aquaculture and fish health.

American Fisheries Society Equal Opportunity Section and Student Subsection. Honored for Influential Career Contributions 2013. "Ladies Night," AFS annual meeting, Little Rock, AR. September

American Fisheries Society Distinguished Service Award, 2013. For team leadership to select a new Society Executive Director. May 2013.

University of Idaho Alumni Award for Excellence as a Mentor –2012 for Zachary L. Penney, December

USGS Performance Award. 2012. For maintaining active research, teaching and outreach.

Lifetime Achievement Award, Idaho Chapter of the American Fisheries Society. March 2012.

Columbia River Intertribal Fish Commission. 2012. Recognition of outstanding partnership and collaboration with tribal entities. Presented to the University of Idaho in recognition of the Moffitt laboratory collaborations.

USGS Performance Award. 2011. For maintaining active research, teaching and outreach programs. November 2012

USGS Star Award for Outstanding Mentoring and Unit Support. September 2011

Outstanding Faculty Member in Environmental Science. University of Idaho. May 2011.

Outstanding Advisor 2010-2011. College of Natural Resources, April 2011

University of Idaho, Virginia Wolf Distinguished Service Award – Faculty. For continuous dedication to activism for gender justice.

USGS, Performance Award. 2010. For maintaining active research and outreach programs. November 2010.

American Fisheries Society Emmeline Moore Prize for Lifetime Contributions to Diversity. 13 September. 2010. Pittsburgh, PA.

AFS Palouse Unit Distinguished Service Award. April 2010.

U of Idaho Alumni Award for Excellence as Mentor – 2009 for Lubia Cajas Cano Outstanding Graduate Student.

USGS Headquarters Diversity Award. 2009.

Idaho Chapter American Fisheries Society, Outstanding Mentor Award, 2008-09.

USGS Star Award. 2009. Maintaining active research and mentoring.

College of Natural Resources, Outstanding Advisor. 2008.

University of Idaho, Candidate for U of Idaho Supervisor of the Year – Human Resources.

University of Idaho Alumni Award for Excellence as Mentor –2007 for Outstanding Graduate Student John Cassinelli

USGS, Star Award, 2006. For maintaining active research and outreach programs.

USGS, Star Award. 2004. For mentoring student that achieved awards and recognition for his studies and contributions.

University of Idaho Alumni Award for Excellence Mentor - for Outstanding Graduate student, Michael Colvin. 2004.

American Fisheries Society, Water Quality Section, Best Student Poster Award for Jeffrey Yanke (co-advised with Dr. Jim Congleton). 2004

Who's Who in Medicine and Healthcare, 2003 – present.

Who's Who in America 2003 –present.

Who's Who of American Women 2002-present.

University of Idaho Alumni Award for Excellence Mentor - for Outstanding Graduate Student, Darin Jones, 2001.

University of Massachusetts, Department of Natural Resource Conservation Distinguished Alumna Award, 1999

University of Idaho Alumni Award for Excellence - Mentor for Outstanding Graduate Student, Monica Hiner, 1999.

Certificate of Appreciation for Visionary Leadershi and Commitment to Advance Fisheries Science and Communications. AFS 2000 Strategic Planning Committee.

American Fisheries Society, Western Division, Special Recognition, 1999

American Fisheries Society, Meritorious Service Award, 1995

American Fisheries Society, Award of Merit, Western Division, 1995

Post Doctoral, Masters and PhD Students Supported

Post Doctoral Students
Horst Kaiser, 1989-1991
Anita Koehn, 1994—1996
S. M. A. Mobin, 2003-2005
Shawn P. Young 2009

Major Professor for

Name	Program	Enter Date	Status
Giambra, Trisha	M.S.	Spring 2012	in progress
Cajas, Lubia	Ph. D.	Fall 2006	in progress
Braker, Elizabeth	M.S.	Fall 2013	Completed Fall 2015
Barenberg, Amber	M.S.	Spring 2011	completed May 2015
Penney, Zachary	PhD.	Spring 2009	Completed Dec 2013
Jones, Bryan	M.S.	Spring 2010	completed Dec 2012
Plumb, John	Ph. D.	Spring 2009	completed December 2012
Maggie Picard	M.S.	Fall 2010	completed May 2012
Buelow, Jessica	M.S.	Spring 2009	completed Dec 2011
Stockton, Kelly	M.S.	Spring 2009	completed May 2011
Reyes, Paul	M.S.	Summer 2008	completed June 2010
Kautza, Adam	M.S.	Summer 2007	Completed May 2008
Nielson, Jordan	MS	Summer 2006	Completed June 2008
Cassinelli, John D	MS	Fall 2005	completed December 2007
James, Christopher Anthony	M.S.	Summer 2004	completed, Jan 2007

Bruce, Rolita Louise	M.S.	Fall 2004	completed fall 2006
Cajas, Lubia	M.S.	Fall 2004	completed August 2006
Yanke, Jeffrey Alan	M.S.	Summer 2003	Completed, Jan 2006
Amberg, Jon	Ph.D.	Spring 2003	transferred in 2004
Anlauf, Kara Janaye	M.S.	Fall 2002	completed 2005
Colvin, Michael Eric	M.S.	Fall 2002	completed 2005
Santora, Maura Kathleen	M.S.	Fall 2000	completed 2003
Jones, Darin Thomas	M.S.	Fall 1999	completed, 2002
Intelmann, Steven Stanley	M.S.	Spring 1998	completed 2001
Hiner, Monica D.	M.S.	Fall 1997	completed 2000
Faler, Joyce C.	M.S.	Fall 1994	completed (Dr. Powell)
Kiryu, Yasunari	Ph.D.	Summer 1993	completed
Hills, Kent	M.S.	Spring 1992	dropped
Haukenes, Alf	MA	Summer 1991	completed
Peters, Kenneth	M.S.	Summer 1990	completed
Fagan, Colleen	M.S.	Fall 1990	completed
Schreck, Julie	M.A.	Summer 1985	completed
Lam, Devona	M.A.	Summer 1982	completed

Member of Graduate Committee or Examination Committee

(List is not complete)

Coyle, Mary	Ph.D.	spring 2014	in progress
Smith, Clinton	M.S.	Fall 2012	in progress
Howard, Michelle	Ph.D.	Spring 2012	in progress
Bellinger, Kristy (WSU)	PhD.	Spring 2010	completed, fall 2015
Hill, Matthew	M.S.	Fall 2012	completed 2015
Liu, Boya	M.S.	Spring 2012	completed 2014

Hemingway, R.J.	M.S.	Spring 2012	completed 2014
Fehringer, Tyson	M.S.	Fall 2010	completed 2014
Wiedeback, Benjamin David	M.S.	Fall 2010	completed 2013
Long, Amy	Ph.D.	Fall 2008	completed 2013
Nduwayo-Ntore, Jean-Paul	M.S.	Summer 2011	completed 2012
Johnson, Zachary	M.N.R	Spring 2012	completed 2012
Turner, Tony	M.S.	Spring 2007	completed 2008
Lindstrom, Nicole	M.S.	Fall 2004	completed 2007
Pinson, Amy Marie	M.S.	Fall 2002	completed 2005
Kraemer, Mary Kathleen	M.S.	Fall 1997	completed
Welker, Thomas Lee	Ph.D.	Fall 1994	completed
Seigel, Debbie	M.S.	Fall 1993	complete
Saffel, Patrick	M.S.	Fall 1994	completed
Monk, Patrick A.	M.S.	Fall 1993	completed
Hunt, Joel	M.S.	Spring 1989	completed
Dresser, Tom	M.S.	Fall 1989	completed
Porter, Pamela Elizabeth	Ph.D.	Fall 1988	completed
Chandler, Gwen	MS	Fall 1986	completed
Tressler, Ron	M.S.	Spring 1984	completed

Research Experience for Undergraduates: NSF Funded Interns

2014. mentor. CRISSP, REU student. Jordan Rutland, Paine College, Augusta, GA.

2013. mentor. CRISSP, REU student Mary Frances Babrowicz, College of Charleston Honors College.

2012. mentor. CRISSP, REU student, Mindy Torres, Northern Arizona University, Yuma.

2012. mentor EPSCoR REU student Justin Shearer.

2011-13. mentor. EPSCoR student Heath Hewett.

2011. mentor. CRISSP, REU student. Veatasha Henri Dorsey, North Carolina Central University.

2011. mentor HOIST intern, Janae Crispin. janaecrispin@yahoo.com

2010. mentor. Water of the West Environmental Science REU. Interns.Jessica Kohls Timothy Allan

2010. Mentor, CRISSP. REU students, Kausei Perales, Brittany Winston

2010. Mentor EPSCoR REU student, Will Schrader

2010. Mentor HOIST. Effie Hernandez

2009. Mentor. Water of the West REU student interns: Jonathan Megli and Amanda Eckhart.

2009. Mentor. CRISSP REU student, Liz Marchio. Studies of invasive New Zealand mudsnails.

2008. Mentor, Water footprints and sustainability. Water of the West REU student intern, Anthony Lopez.

2008. Hoist Student mentor research on invasive species. June – July. Kristine Atto

2007. Kala Hamilton

2006. Sean Howard

2006. Katherine Teater

Environmental Science Senior Thesis Students

Daniel Olsen. 2013-2014. Survey of Asian clam infestations in Lake Pend Oreille, ID.

Colin Heath. 2013-2014. Measures to control aquatic invasive mollusks.

Justin Shearer. 2012. Control strategies for invasive Asian clams. Completed December 2012

Rhett Madsen. 2011 – 2012. Monitoring and mitigation of supersaturation of dissolved gasses in the release waters from Dworshak dam.

Laura Hughes. 2011-2012. Use of calcium hydroxide as an agent to kill invasive species in boat ballast.

William Schrader. 2010 – 2011. Analysis of proximate constituents of steelhead kelts at Lower Granite Dam.

Amber Barenberg, 2009-2010.Efficacy of Virkon Aquatic® To Disinfect Wading Gear Infested with New Zealand Mudsnails

Chelsea Merrill 2009-2010. Otolith Aberrancy in A run and B run Hatchery Steelhead and Associated Problems with Aging

Josh Peterson2009-2010. Ecosystem service valuation of phosphorus and nitrogen removal by freshwater mussels

Kristy Marks 2009 – 2010. Enhancing the Potential for Marine Mussels in Aquaculture

Fritz, Rebecca. 2009. Potential Use of Mollusks to Improve Water Quality in Aquaculture.

Teater, Katherine. 2009 completed. Evaluation of Mixed Cell Raceways at Dworshak National Fish Hatchery.

Thesis and Dissertation Titles (incomplete)

Barenberg, Amber. 2015. The Use of elevated pH to reduce the risk of release of select invasive mollusk species from vessel ballast and bilge water. Master's Thesis, Fisheries. College of Natural Resources.

Penney, Zachary. 2013. Physiological and energetic constraints of iteroparity in Steelhead Trout (*Oncorhynchus mykiss*). PhD Dissertation, College of Natural Resources, University of Idaho. December.

Jones, Bryan. 2013. Migratory and physiological characteristics of steelhead kelts from the Clearwater River, Idaho, and Lower Granite Dam, Washington. Master's Thesis. College of Natural Resources.

Plumb, John. 2012. Evaluation of models and the factors affecting the migration and growth of naturally produced subyearling fall Chinook salmon (*Oncorhynchus tshawytscha*) in the Lower Snake River. PhD.Dissertation. College of Natural Resources. University of Idaho.

Buelow, Jessica. 2011. Physiological and physical characteristics of steelhead kelts (*Oncorhynchus mykiss*) from the Snake River, captured at Lower Granite Dam. Master's Thesis. December.

Stockton, Kelly. 2011. Methods to assess, control, and manage risks for two invasive mollusks in fish hatcheries. Master's Thesis. May.

Reyes Paredes, Paul Eugenio. 2010.GIS Tools to assess the risks and benefits of barrier removal to native fish populations in Idaho. Master's Thesis

Nielson, R. Jordan. 2008. Control of New Zealand Mudsnails in Fish Hatcheries. Master's Thesis. Department of Fish and Wildlife Resources, University of Idaho. May 2008.

Kautza, Adam. 2008. Growth, Age Distribution, and Population Dynamics of Black Crappies From Idaho. Report Prepared for Idaho Department of Fish and Game. Non thesis project for Master's Degree.

Cassinelli, J. D. 2007. Effects of Water Temperature on Growth and Physiology of Different Populations of Redband Trout (*Oncorhynchus mykiss gairdneri*). Master's Thesis, Department of Fish and Wildlife Resources. University of Idaho. December 2007.

James, C.A. 2007. Investigations of the invasive New Zealand mudsnail *Potamopyrgus antipodarum* in Idaho: implications for temperature limitations. Master's Thesis, University of Idaho.

Cajas, Cano, L. 2006. Environmental and social footprints of beef and trout production for human consumption: using Idaho as an example. Master's Thesis. University of Idaho.

Bruce, R. L. 2006. Methods of Fish Depuration to Control New Zealand Mudsnails at Fish Hatcheries. Master's Thesis, Fishery Resources. University of Idaho. September 2006.

Anlauf, K. 2005. Understanding the ecology of whirling disease through modeling of the tubificid host. Masters thesis, University of Idaho.

Colvin, M. 2005. Ecology of *Myxobolus cerebralis* in the Pahsimeroi River drainage, Idaho. Masters Thesis, University of Idaho.

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Dr. Raymond P. Morgan II

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Education

BS Frostburg State College, 1966
Major: Biology
Minors: Chemistry, Secondary Education

PhD University of Maryland, College Park 1971 (Department of Zoology)
Major: Ecology
Minor: Physiology

Honors

Honors in Biology, Frostburg State College

Sigma Zeta

Fellow, American Institute of Fishery Research Biologists

UMCES President’s Award for Excellence in Application of Science (2003)

Good Neighbor Award, Nemacolin Chapter of Trout Unlimited (2006)

Current Societies and Professional Organizations

American Fisheries Society

American Association for the Advancement of Science

American Institute of Fishery Research Biologists

American Society of Ichthyologists and Herpetologists

Atlantic Estuarine Research Society

Estuarine Research Federation

Society for Freshwater Science (old North American Benthological Society)

Past Societies and Professional Organizations

American Society of Limnology and Oceanography

Conservation Biology Society

Society of Environmental Toxicology and Chemistry

Professional Appointments

1966-1968 – Teaching Assistant (Animal Ecology, Comparative Vertebrate Morphology, Hydrobiology), Department of Zoology, University of Maryland

1966 – Research Assistant, Department of Zoology, University of Maryland (Summer)

1967 – Instructor, Field Biology, Prince George's County, Maryland (Summer)

1967 – Research Assistant, Hallowing Point Field Station, Natural Resources Institute, University of Maryland (Summer)

1968-1970 – Graduate Research Assistantship, Natural Resources Institute, University of Maryland

1970-1971 – Faculty Research Assistant, Natural Resources Institute, University of Maryland

1971-1974 – Research Associate, Natural Resources Institute, University of Maryland

1974-1977 – Research Assistant Professor, Center for Environmental and Estuarine Studies, University of Maryland

1977-1979 – Principal Research Scientist, William F. Clapp Laboratories, Inc. of Battelle Columbus Laboratories

1979-1985 – Assistant Professor, Appalachian Environmental Laboratory, Center for Environmental and Estuarine Studies, University of Maryland

1979-2015 – Adjunct Professor, Department of Biology, Frostburg State University

1980-1985 – Member, Graduate Faculty, University of Maryland

1982-2015 – Associate Member, Graduate Faculty, Frostburg State University

1983-1985 – Research Analyst (State Department of Legislative Reference, Research Division) to Committee on Environmental Matters, House of Delegates, General Assembly of the State of Maryland. 1983, 1984, and 1985 Sessions.

1985-1990 – Assistant to the Head of the Laboratory for Research, Education and Development

1989-2002 – Coastal and Environmental Policy Program (CEPP) Faculty

1990-2015 – UMCES Graduate Faculty

1990-1999 – Associate Professor (Tenured)

1992-2002 – Fellow, Maryland Institute for Ecological Economics

1992-2015 – Regular Member, Graduate Faculty, University of Maryland

May-July 1993 – Acting Director, Appalachian Environmental Laboratory

July-August 1996 – Acting Director, Appalachian Environmental Laboratory

1998–2015 – Member, USM Inter-Institutional Graduate Council

2012-2015 – Interim Director 1 July 2012 – 31 December 2015

1999-2015 – Full Professor (Tenured)

2016 – Professor Emeritus

Projects Directed or Assisted

1970 - 1977 (Chesapeake Biological Laboratory)
Investigator - Laboratory experiments, Chesapeake and Delaware Canal study. (USACE)

Investigator - Fish bioassay studies, Baltimore Harbor bioassay project. (MDDES)

Principal Investigator - Muscle chemistry of the genus *Morone*.

Principal Investigator - Biochemical characteristics of Chesapeake Bay fishes.

Principal Investigator - Polymorphic albumins of the white perch, *M. americana*.

Collaborator - Post-operative assessment of effects of estuarine power plants. (MDDNR)

Collaborator - Effects of sediments on estuarine organisms. (ACE)

Collaborator - Biology and management of the striped bass.

Collaborator - Population dynamics and ecology of Maryland cottontail rabbits.

Investigator - Effects of Morgantown steam electric station operations on entrained organisms. (MDDNR)

Principal Investigator - Potomac River fisheries study - Striped bass spawning stock assessment. (1974-1977, MDDNR)

Principal Investigator - Upper Bay striped bass spawning stock assessment. (MDDNR)

Principal Investigator - Biochemical identification of the mallard and the black duck. (USFWS)

Principal Investigator - Biochemical identification of populations of the striped bass, *Morone saxatilis*.

Principal Investigator - Environment alterations and species introduction effects on genetic systems. (USFWS, NSF)

Collaborator - Shellfish research hatchery.

Principal Investigator - Ecological effects of nuclear steam electric station operations on estuarine systems. (MDDNR, AEC)

Collaborator - Development of temperature and pressure sensitive ultrasonic transmitters and receiving systems. (ACE)

Collaborator - Ecology of the nutria, *Myocastor coypus*, in Maryland marshes. (MDDNR)

Collaborator - Bioecology of Maryland raccoons.

Co-Principal Investigator - Biotoxicity of chlorine species to estuarine organisms. (MDDNR, USFWS)

Principal Investigator - Advisory service on the Chesapeake Bay and related environmental matters.

Collaborator - Epizootiology and mortality factors in estuarine animals.

1977 – 1979 (Battelle Columbus Laboratories)

Project Task Leader - Millstone Ecology Program directing shore-zone fish, gill net, otter trawl work, winter flounder juvenile and adult population estimation, and plankton tasks. (NUSCO)

Project Leader - Bioassay of sediments from the Mystic River. (Union Oil)

Project Leader - Bioassay of sediments from New Haven harbor. (ACE-NED)

Project Leader - Bioassay of sewage effluents from Boston harbor. (MDC)

Project Leader - Inter-laboratory comparison of bioassay techniques for *Mysidopsis bahia*. (EPA)

Project Leader - Toxicity of organic effluents. (EPA)

Principal Investigator - Review of chemistry and toxicity of copper. (Copper Development Association)

Principal Investigator - Bioassays of sediment - No. 13 slip. (General Dynamics)

Principal Investigator - A review and critique of fisheries studies performed at the Ludington pumped storage power plant. (Consumers Power Co. - Detroit Edison)

Principal Investigator - Evaluation of bioassay protocols. (EPA)

1979 – Present (Appalachian Laboratory – UMCES)
Collaborator - Bioecology of rabbits.

Co-Investigator - Taxonomic status of *Rhinichthys bowersi*. (USDA, Forest Service)

Principal Investigator - Biochemical systematics and population analyses of the genus *Morone*.

Principal Investigator - Aquatic Integration Team, Site Evaluation Aquatic Group. (MDDNR)

Co-Principal Investigator - Water quality sampling of Youghiogheny-Little Youghiogheny Rivers. (MDDHMH)

Co-Investigator - Lake Louise studies.

Principal Investigator - Effect of mining activities on black-nosed dace populations.

Principal Investigator - Biological integration: Coal leachate and cooling tower pollutant issues. (MDDNR)

Principal Investigator - Effects of Treflan on embryonic development of bobwhite quail. (International Quail Foundation)

Principal Investigator - Conowingo benthic and fish studies. (MDDNR)

Principal Investigator - Brighton Dam small-scale hydroelectric evaluation. (MDDNR)

Principal Investigator - Hybridization in Delmarva fox squirrel. (MDDNR)

Principal Investigator - Brighton and Union Dams. (MDDNR)

Co-Principal Investigator - Georges Creek and Braddock Run baseline studies. (MDDNR and MDHMH)

Co-Principal Investigator - *In situ* striped bass bioassays in the Choptank River. (MDDNR)

Principal Investigator - Final Cut Pond. (MDDNR)

Principal Investigator - Environmental review. (MDDNR)

Principal Investigator - Bureau of Mines contract. (MDDNR)

Co-Principal Investigator - Sublethal effects of electromagnetic pulses on fish. (US Navy)

Co-Principal Investigator - Sublethal effects of EMP on sea turtles. (US Navy)

Principal Investigator - 1986 Choptank striped bass work. (MDDNR)

Principal Investigator - Coldwater: Phase I. (MDDNR)

Project Leader - Striped bass swim bladder project. (BG&E)

Principal Investigator - 1987 Choptank water chemistry. (MDDNR)

IPA (Interagency Personnel Agreement) - Army Corps of Engineers, Waterways Experiment Station (1986 - 1990).

Principal Investigator - Stream neutralization projects. (MDDNR, IS&T)

Principal Investigator - Cave invertebrate project. (MDDNR)

Principal Investigator - Coldwater: Phase II. (1988-1990, MDDNR)

Co-Principal Investigator - Bay anchovy genetics (1989-1990, MDDNR)

Principal Investigator - Stream blockage study. (1989-1990, MDDOT)

Principal Investigator - Baseflow ANC study. (MDDNR)

Principal Investigator - Stream doser feasibility. (MDDNR)

Principal Investigator - As/Se project. (APS)

Principal Investigator - Episodic storm events in Western Maryland streams. (1989-1992, MDDNR)

Principal Investigator - Critical loads (1989-1991, MDDNR)

Co-Principal Investigator - Identification and conservation of indigenous Tilapiine genetic resources. (USAID)

Co-Principal Investigator - Identification of commercially important fishes of Lake Malawi. (USAID)

Principal Investigator - Development of genetic inventories for Maryland game fishes: Brook trout. (MDDNR)

Principal Investigator - Acid rain and stream chemistry monitoring program. (MDOE)

Principal Investigator - Watershed liming program (1990-1994, ERM-DNR)

Principal Investigator - North Branch restoration project (1990-1996, MDDNR)

Principal Investigator - Coldwater project: Phase III and IV (1990-1993, MDDNR)

Member, Research Coordinating Committee - Multiscale Experimental Ecosystem Research Center (1992-1994, USEPA)

Principal Investigator - Comparative analysis of scales of contaminant inputs (1992-1993, USEPA-MEERC)

Principal Investigator - Development of an IBI for Piney and Alloway Creeks. (1995, MDDNR)

Principal Investigator - Florida largemouth bass project. (1994-1996, MDDNR)

Principal Investigator - IFIM - North Branch of the Potomac River. (1995-1996, MDDNR)

Principal Investigator - Fluidized bed ash disposal analysis. (1990-1995, MDDNR)

Cooperator - Episodic acidification of streams in western Maryland. (1995-1998, MDDNR)

Principal Investigator - Biological, geochemical, and hydrogeological services. (1997-1999, MDE).

Principal Investigator - Cherry Creek Basin Project. (1997 to 1999, MDE).

Principal Investigator - Quantitative and qualitative assessment of sediment. (1997 to 1999, MDE).

Principal Investigator - Analysis of Lake Jennings Randolph fisheries potential. (1997 to 1997, MDDNR).

Principal Investigator - Development of a physical habitat index for Maryland streams. (1997 to 1999, MDDNR).

Principal Investigator - Remediation and restoration of Lake Louise. (1997 to 2006, MDOT-SHA).

Principal Investigator - Biological monitoring consultant: Albright and Fort Martin power stations. (1987-2004, APS)

Principal Investigator - Maryland Biological Stream Survey (1993-2007, MDDNR – water quality and field work)

Principal Investigator - Assessment of fish movement at Dam #4 (2002-2004, DOI-NPS)

Principal Investigator - Casselman River Biotic Survey (2002-2003, MDE-BOM)

Principal Investigator - Water Quality and Hydrological Support for the LaVale Sanitary Commission (2002-2004, La Vale SC)

Principal Investigator - Water quality analyses for MDE (2000-present, MDE)

Principal Investigator - Kempton Bioremediation Project (2002-2004. MDE-BOM)

Principal Investigator - Stream restoration studies (1998 -present, MDDOT - SHA)

Principal Investigator – Sediment TMDL development for Maryland (2002-2005, MDE)

Principal Investigator – Stressor identification for Maryland (2004-2007)

Principal Investigator – Biological and chemical services. (2000-2006, MDE).

Principal Investigator – Biological and chemical services for the MBOM. (2003-2006, MDE).

Co-Principal Investigator – Investigation of effects of salt on nitrogen transport (USGS, 2006-2007)

Co-Principal Investigator – Reinventory of Maryland brook trout populations (MDDNR, 2007-2009)

Co-Principal Investigator – Estimating space requirements and extinction risk for Maryland brook trout (MDDNR, 2006-2008)

Co-Principal Investigator - Western Maryland TMDL Chemistry and Benthic Analyses. (2008-2009, MDE).

Co-Principal Investigator - Field and laboratory support for Potomac River monitoring. (MDDNR, Fisheries Service, 2008-2009).

Co-Principal Investigator - Field and laboratory support for upper North Branch Potomac River metals survey. (MDE 2008-09).

Co-Principal Investigator - Maryland Biological Stream Survey Water Quality (2008-present), MDDNR

Co-Principal Investigator - Casselman River Literature Review. (2009-2010, MDE).

Co-Principal Investigator - Casselman River Mining Assessment. (2010-2012, MDE).

Co-Principal Investigator - Analyses of coal combustion byproducts (CCB) at ash disposal sites. (2009-2010, MDE)

Principal Investigator - McDonald Mine (and Butcher Run) Project Support. (2010-2015, MDE).

Co-Principal Investigator - Stressor Identification: Methodology development for assessing biological impairments related to urbanization and flow modification in Maryland. (MDE-TARSA, 2010-2011)

Co-Principal Investigator - Casselman River pH TMDL Monitoring Program. (2010-2015, MDE).

Co-Principal Investigator – Phase II - Analyses of coal combustion byproducts (CCB) at ash disposal sites. (2012-2013, MDE).

Co-Principal Investigator - Establishing Baseline Water Quality Conditions in Surface Waters in Western MD in Advance of Marcellus Shale Natural Gas Development (2011-2015, MDE).

Co-Principal Investigator – Bioswales Project (2014-2015, MDOT-SHA)

Research Interests

Pollution and Aquatic Restoration Ecology

I was an ecotoxicologist long before the term was considered within the scientific community as a true discipline. In the field of pollution ecology, the major focus of my work centers on organismal response to stresses, particularly anthropogenic stressors, at a number of different strata including molecular/cellular, population, community, and ecosystem levels. To this end, I have often used the overall environmental impact of electric production on aquatic organisms, communities, and ecosystems as a research area to test hypothesis concerning organism response to stresses. Over the years, my research efforts in this field have evolved from the eras of calefaction effects on aquatic systems, to analyses of impingement and entrainment impacts on aquatic biota, to the mysteries of biocide chemistry and its associated toxic effects on populations and communities, to the current vogue of acidic precipitation with its ecological and economic ramifications, and now to land-use (urbanization and agriculture) effects.

Besides many contemporary studies in Maryland on the effects of acidic precipitation, my other research interests center on the environmental impacts of small-scale hydroelectric production, ash disposal from coal-fired steam electric stations, and restoration of AMD-affected aquatic systems -- now a major emphasis within the Chesapeake Bay watershed. Of particular interest has always been the effect of stressors on the early life stages of fishes as well as the physiological, biochemical, histological, and behavioral responses of fishes to pollution, essentially attempting to assay ecological integrity in aquatic ecosystems. Recently, my work is evolving into analyses of impacts on watersheds at the landscape level, especially urbanizing watersheds, and the restoration ecology of lotic systems.

Conservation Biology and Fishery Genetics

Overall, I am interested in the varied effects of the Pleistocene, with its four major glaciations, on the population structure of fishes in the mid-Atlantic region since the Pliocene. My primary focus is directed towards moronids and salmonids, although I have worked with many freshwater, estuarine, and marine fishes. I completed a major study on the population genetics of the bay anchovy, the most abundant fish within Chesapeake Bay, as well as continuing work on the genetic structure of brook trout populations and other Appalachian fishes. In addition to my inquisitiveness in identifying fish populations, I am interested in solving problems associated with the field of conservation biology such as the effect of bottlenecks and founder effects on the genetic structure of populations as well as species and subspecies identification, generic relationships, and hybridization effects.

Publications

Journals (Peer-reviewed)

Morgan II, RP and RG Stross. 1969. Destruction of phytoplankton in the cooling water supply of a steam electric station. Chesapeake Sci. 10:165-171.

Morgan II, RP, TSY Koo and GE Krantz. 1972. Albumin polymorphism in the white perch, *Morone americana*. Chesapeake Sci. 13:66-68.

Morgan II, RP, TSY Koo and GE Krantz. 1973. Electrophoretic determination of populations of the striped bass, *Morone saxatilis*, in the Upper Chesapeake Bay. Trans. Amer. Fish. Soc. 102(1):21-32.

Morgan II, RP, RF Fleming, VJ Rasin, Jr. and DR Heinle. 1973. Sublethal effects of Baltimore Harbor water on the white perch, *Morone americana*, and the hogchoker, *Trinectes maculatus*. Chesapeake Sci. 14(1):17-27.

Laird, M and **RP Morgan II**. 1973. *Haemogregarina platessae* Lebailly (*H. achisis* Saunders) from the hogchoker in Maryland. J. Parasitol. 59(4):736-738.

Morgan II, RP. 1973. Marking fish eggs with biological stains. Chesapeake Sci. 14:303-305.

Chapman, JA and **RP Morgan II**. 1974. Onset of the breeding season and size of first litters in two species of the cottontail from southwestern Texas. Southwestern Natur. 19(3):277-280.

Morgan II, RP. 1975. Identification of larval white perch and striped bass by electrophoresis. Chesapeake Sci. 16(1):68-70.

Frank, JR, SD Sulkin and **RP Morgan II.** 1975. Biochemical changes during the larval development of the Xanthid crab, *Rhithropanopeus harrisii* (Gould) I. Protein, total lipid, alkaline phosphatase, and glutamic oxaloacetic transaminase. Mar. Biol. 32(2):105-111.

Sulkin, SD, **RP Morgan II** and LL Minasian, Jr. 1975. Biochemical changes during the larval development of the Xanthid crab, *Rhithropanopeus harrisii* (Gould) II. Nucleic acids. Mar. Biol. 32(2):113-117.

Morgan II, RP and NI Ulanowicz. 1976. The frequency of muscle protein polymorphism in *Menidia menidia* (Atherinidae) along the Atlantic Coast. Copeia: 356-360.

Wickes, MA and **RP Morgan II**. 1976. Effects of salinity on three enzymes involved in amino acid metabolism from the American oyster, *Crassostrea virginica*. Comp. Biochem. Physiol. 53(B): 339-343.

Morgan II, RP, RE Ulanowicz, VJ Rasin, Jr., LA Noe and GB Gray. 1976. Effects of shear on eggs and larvae of striped bass, *Morone saxatilis*, and white perch, *M. americana*. Trans. Amer. Fish. Soc. 105(1): 149-154.

Morgan II, RP, LA Noe and CJ Henny. 1976. Biochemical identification of the mallard and black duck. Comp. Biochem. Physiol. 53(B): 499-503.

Kim, HR, R D'Antonio, J Buchanan, SM Larson, **RP Morgan II**, JI Thorell and HH Wagner, Jr. 1976. Toadfish serum as a binder for *in vitro* assay of Vitamin B. J. Nucl. Med. 17: 737-739.

Morgan II, RP, ST Sulkin and SB Block. 1977. Serum proteins and esterases of sandhill cranes and bald eagles. Comp. Biochem. Physiol. 57(B): 197-293.

Morgan II, RP, ST Sulkin and CJ Henny. 1977. Serum proteins of Canada goose (*Branta canadensis*) subspecies. The Condor 79(2): 275-278.

Morgan II, RP and RD Prince. 1977. Chlorine toxicity to eggs and larvae of five Chesapeake Bay fishes. Trans. Amer. Fish. Soc. 106(4): 380-385.

Cole, MA and **RP Morgan II**. 1978. Muscle, eye and serum proteins of the blue crab, *Callinectes sapidus* Rathbun. Comp. Biochem. Physiol. 59(B): 25-26.

Cole, MA and **RP Morgan II.** 1978. Genetic variation in two populations of blue crabs, *Callinectes sapidus*. Estuaries 1(3): 203-205.

Morgan II, RP and RD Prince. 1978. Chlorine effects on larval development of striped bass (*Morone saxatilis*), white perch (*M. americana*) and blueback herring (*Alosa aestivalis*). Trans. Amer. Fish. Soc. 107(4): 636-641.

Morgan II, RP, SB Block, NI Ulanowicz and C Buys. 1978. Genetic variation in the soft-shelled clam (*Mya arenaria*). Estuaries 1(4): 255-258.

Morgan II, RP, E Kramarsky and SD Sulkin. 1978. Biochemical changes during larval development of the Xanthid crab, *Rhithropanopeus harrisii*. III. Isozyme changes during ontogeny. Mar. Biol. 48(3): 233-226.

Morgan II, RP and SE Sommer. 1979. Polychlorinated biphenyls in Baltimore Harbor sediments. Bull. Environ. Contam. Toxicol. 22(405): 413-419.

Morgan II, RP, VJ Rasin, Jr. and RL Copp. 1981. Temperature and salinity effects on development of striped bass eggs and larvae. Trans. Amer. Fish. Soc. 110: 95-99.

Morgan II, RP and VJ Rasin, Jr. 1982. Influence of temperature and salinity on development of white perch eggs. Trans. Amer. Fish. Soc. 111: 396-398.

Feldhamer, GA, **RP Morgan II**, PE McKeown and JA Chapman. 1982. Lack of polymorphism in liver and muscle enzymes from sika deer (*Cervus nippon*). J. Mammal. 63(3): 512-514.

Goodfellow Jr., WL, **RP Morgan II**, CH Hocutt and JR Stauffer, Jr. 1982. Electrophoretic analysis of *Campostoma anomalum* and *Rhinichthys cataractae* and their F_1 offspring. Biochem. Syst. Ecol. 10: 95-98.

Mosher, JA, **RP Morgan II**, EA Haug and WL Goodfellow, Jr. 1982. Serum proteins of selected Falconiformes and Strigiformes. Biochem. Syst. Ecol. 10: 373-376.

Morgan II, RP, VJ Rasin, Jr. and LA Noe. 1983. Sediment effects on eggs and larvae of striped bass and white perch. Trans. Amer. Fish. Soc. 112(2): 220-224.

Morgan II, RP, RE Smith, Jr. and JR Stauffer, Jr. 1983. Electrophoretic identification of larval silver redhorse (*Moxostoma anisurum*) and golden redhorse (*Moxostoma erythrurum*). Comp. Biochem. Physiol. 76B: 721-722.

Swift, MC and **RP Morgan II**. 1983. Acute toxicity of nitric acid to fingerling rainbow trout. Comp. Biochem. Physiol. 76C(2): 227-229.

Morgan II, RP, WL Goodfellow, Jr., CH Hocutt and JR Stauffer, Jr. 1984. Karyotype of *Nocomis micropogon, Rhinichthys cataractae* and their supposed hybrid, *Rhinichthys bowersi* (Pisces: Cyprinidae). Copeia 1984(4): 990-992.

Goodfellow, Jr., WL, CH Hocutt, **RP Morgan II** and JR Stauffer, Jr. 1984. Biochemical assessment of the taxonomic status of "*Rhinichthys bowersi*" (Pisces: Cyprinidae). Copeia 1984(3): 652-659.

McKeown, PE, CH Hocutt, **RP Morgan II** and JH Howard. 1984. An electrophoretic analysis of the *Etheostoma variatum* complex, with zoogeographic implications. Envir. Biol. Fishes 11: 85-95.

Morgan II, RP, DW Meritt, SB Block, MA Cole, ST Sulkin, FB Lee and CJ Henny. 1984. Biochemical analysis of mallard-black duck hybrids. I. Inheritance patterns of enzymes and serum proteins. Biochem. Syst. Ecol. 12: 119-123.

Morgan II, RP, DW Meritt, SB Block and ST Sulkin. 1984. Biochemical analysis of mallard-black duck hybrids. II. Frequency of hybrids along the Atlantic Coast. Biochem. Syst. Ecol. 12: 125-128.

Davin, T., **RP Morgan II** and GA Feldhamer. 1984. Variation of individual electromorphs in *Microtus pennsylvanicus* and *Peromyscus leucopus*. Biochem. Syst. Ecol. 12(4): 435-440.

Sheffield, SB, **RP Morgan II**, GA Feldhamer and DM Harman. 1985. Genetic variation in white-tailed deer (*Odocoileus virginianus*) populations in western Maryland. J. Mammal. 66(2): 243-255.

Goodfellow, Jr., WL, **RP Morgan II**, JR Stauffer, Jr. and CH Hocutt. 1986. An intergeneric cyprinid hybrid, *Campostoma anomalum* x *Rhinichthys atratulus*, from the Youghiogheny River drainage, West Virginia. Biochem. Syst. Ecol. 14(2): 233-238.

Chiotha, SS and **RP Morgan II**. 1987. Molluscicides used to control schistosomiasis. LUSO: J. Sci. Tech. (Malawi) 8(12): 11-22.

Morgan II, RP, KJ Killgore and NH Douglas. 1988. Modified popnet design for collecting fishes in varying depths of submersed vegetation. J. Freshwat. Ecol. 4(4): 533-539.

Killgore, KJ, **RP Morgan II** and NB Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North Amer. J. Fish. Manag. 9: 101-111.

Clearwater, DH, GA Feldhamer, **RP Morgan II** and JA Chapman. 1989. Taxonomic analysis of the coastal marsh raccoon (*Procyon lotor maritimus*) in Maryland. Brimleyana 15: 31-36.

Welch, TJ, JR Stauffer, Jr. and **RP Morgan II**. 1989. Temperature preference as an indicator of the chronic toxicity of cupric ions to Mozambique tilapia (*Oreochromis mossambicus*) Bull. Environ. Contam. Toxicol. 43: 761-768.

Morgan II, RP, SB Weisberg, RE Jacobsen, LA McDowell and HT Wilson. 1991. Effects of flow alterations on benthic macroinvertebrate communities below the Brighton hydroelectric dam. J. Freshwat. Ecol. 6(4): 419-429.

Sverdrup, H, P Warfvinge, M Rabenhorst, A Janicki, **R. Morgan** and M Bowman. 1992. Critical loads and steady state chemistry for streams in the State of Maryland. Environmental Pollution 77: 195-203.

McKaye, KM, JH Howard, JR Stauffer, Jr., **RP Morgan II** and F Shonhiwa. 1993. Sexual selection and genetic relationships of a sibling species complex of bower building cichlids in Lake Malawi, Africa. Japan. J. Ichthyol. 40(1): 15-21.

Howard, JH and **RP Morgan II**. 1993. Allozyme variation in the mottled sculpin (*Cottus bairdi*): A test of stream capture hypothesis. Copeia 1993(3): 870-875.

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Eshleman, KE, **RP Morgan II**, JR Webb, FA. Deviney and JN Galloway. 1998. Temporal patterns of nitrogen leakage from mid-Appalachian forested watersheds: Role of forest disturbance. Water Resources Research 34(8): 2005-2116.

Roth, NE, MT Southerland, SB Weisberg, JC Chaillou, PF Kazyak, SA Stranko, RJ Klauda, LW Hall and **RP Morgan II**. 1998. Development and evaluation of a fish index of biotic integrity for Maryland streams. Envir. Monitor. Assess. 51: 89-106.

Danzmann, RG, **RP Morgan II**, MW Jones, L Bernatchez and PE Ihssen. 1998. A major sextet of mitochondrial DNA phylogenetic assemblages extant in eastern North American brook charr (*Salvelinus fontinalis*): Distribution and post-glacial dispersal patterns. Can. J. Zool. 76: 1300-1318.

Castro, MS and **RP Morgan II**. 2000. Input-output budgets of major ions for a forested watershed in western Maryland. Water, Air and Soil Pollution 119:121-137.

Killgore, KJ, ST Maynord, MD Chan and **RP Morgan II**. 2001. Evaluation of propeller-induced mortality on early life stages of selected fish species. North America Journal of Fisheries Management 21:947-955.

Hall, MR**, RP Morgan II**, and RG Danzmann. 2002. Mitochondrial DNA analyses of mid-Atlantic USA populations of brook trout (*Salvelinus fontinalis*): the zone of contact for major historical lineages. Transactions of the American Fisheries Society 131:1140-1151.

Castro, MS, EN McLaughlin, SL Davis and RP Morgan II. 2002. Total mercury concentrations in lakes and fish of Western Maryland. Archives of Environmental Contamination and Toxicology 42:454-462.

Hall, Jr., LW, **RP Morgan II**, ES Perry and A Waltz. 2002. Development of a physical habitat index for Maryland freshwater streams. Environmental Monitoring and Assessment 77:265-291.

Wiley, DJ, **RP Morgan II**, RH Hilderbrand, RL Raesly and DL Shumway. 2004. Relations of physical habitat and American eel abundance in five river basins in Maryland. Transactions of the American Fisheries Society 133:515-526.

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Southerland, MT, GM Rogers, MJ Kline, **RP Morgan**, DM Boward, PF Kazyak, RJ Klauda and SA Stranko. 2007. Improving biological indicators to better assess the condition of streams. Ecological Indicators 7:751-767. [Erratum to above paper published in Ecological Indicators 2008. 8:778-779]

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Stranko, SA, RH Hilderbrand, **RP Morgan II**, MW Staley, AJ Becker, A Roseberry-Lincoln, ES Perry and PT Jacobsen. 2008. Brook trout declines with land cover and temperature changes in Maryland. North American Journal of Fisheries Management 28:1223-1232.

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1981 - Evidence in support of species status for the Cheat Minnow (*Rhinichthys bowersi*). American Society of Ichthyologists and Herpetologists, Corvallis, OR. (W Goodfellow, C Hocutt, R Morgan and J Stauffer - presented by C Hocutt).

1981 - Taxonomic status of two sibling cyprinid species, *Nocomis micropogon* and *N. platyrhynchus*. American Society of Ichthyologists and Herpetologists, Corvallis, OR. (E Esmond, C Hocutt, R Morgan and J Stauffer - presented by C Hocutt).

1982 - An electrophoretic analysis of the *Etheostoma variatum* complex, with zoogeographical implications. American Society of Ichthyologists and Herpetologists, DeKalb, IL. (P McKeown, C Hocutt, J Howard and R Morgan - presented by C Hocutt).

1983 - Sublethal effects of Treflan on bobwhite quail. Society of Environmental Toxicology and Chemistry, Arlington, VA. (J Beskid and R Morgan - poster presented by J Beskid).

1984 - Protecting genetic integrity. Emergency Striped Bass Planning and Coordination Group (NMFS-USFWS), Norfolk, VA.

1984 - The history of limited entry. Maryland Department of Natural Resources, Annapolis, MD.

1985 - Genetics of striped bass. Maryland Department of Natural Resources, Annapolis, MD.

1985 - Black duck-mallard hybrids and their genetics. Atlantic Waterfowl Council, Cherry Hill, NJ.

1985 - Acid mine drainage-monitoring in Western Maryland. State Water Quality Advisory Committee, Riverdale, MD.

1985 - *In situ* striped bass larval bioassays: Choptank 1985. Atlantic States Marine Fisheries Commission, Windsor Locks, CT. (With J Serafy, C Hocutt, J Quattro and J Bureau).

1986 - Restoration of Georges Creek. Potomac Chapter, American Fisheries Society, St. Michaels, MD.

1987 - Temperature preference as an indicator of the chronic toxicity of cupric ions to Mozambique tilapia. American Fisheries Society, Winston-Salem, NC. (T Welch, J Stauffer and R Morgan - presented by T Welch).

1987 - Potential hazards to the water. Symposia: Toxic Health Risks: New Solutions for You, Frostburg, MD.

1988 - Water quality: Choptank 1988. Atlantic States Marine Fisheries Commission, Norfolk, VA. (With C Ogden, C Butler, C. Murray).

1988 - Habitat value of Hydrilla to fishes in the Potomac. Submerged Aquatic Vegetation in the Potomac, MWCOG/WRRC. UDC Technical Symposium, Washington, DC. (With J Killgore).

1988 - Effects of water quality on the survival of striped bass - Choptank 1987, Power Plant Research Program, Effects of acidification on Chesapeake Bay Fishes. Annapolis, MD.

1988 - Genetic evidence for stream capture in the central Appalachians. 49th Annual Meeting of the Association of Southeastern Biologists, Biloxi, MS. (J Howard and R Morgan - presented by J Howard).

1988 - Mitochondrial variability in brook trout *Salvelinus fontinalis* from the Eastern United States. International Symposium and Educational Workshop on Fish-Marking Techniques, Seattle, WA. (With J Quattro and R Chapman).

1989 - Genetic evidence for runaway sexual selection and cichlid speciation. Society for the Study of Evolution, State College, PA. (J Howard, K McKaye, J Stauffer and R Morgan - presented by J Howard).

1989 - Genetic evolution in Atlantic slope populations of *Etheostoma blennioides*. Society for the Study of Evolution, State College, PA. (J Howard, R Raesly and R Morgan - presented by J Howard).

1990 - Genic and morphological evolution in Atlantic Slope populations of the greenside darter, *Etheostoma blennioides* (Teleostei: Percidae). American Society of Ichthyologists and Herpetologists, Charleston, SC. (R Raesly, J Howard, J Stauffer and R Morgan - presented by R Raesly).

1990 - Genic and morphological evolution in Atlantic Slope populations of the greenside darter, *Etheostoma blennioides* (Teleostei: Percidae). Inter. Cong. Syst. Evol. Biol. IV, College Park, MD. (R Raesly, J Howard, J Stauffer and R Morgan - presented by R Raesly).

1990 - Critical loads and steady state chemistry for streams in the State of Maryland. International Conference on Acidic Deposition: Its nature and impacts, Glasgow, Scotland (H Sverdrup, P Warfvinge, M Rabenhorst, A Janicki, R Morgan and M Bowman - presented by H Sverdrup).

1990 - Mapping critical loads and steady state stream alkalinity in Maryland. International Conference on Acidic Deposition: Its nature and impacts, Glasgow, Scotland. (H Sverdrup, P Warfvinge, M Rabenhorst, A Janicki, R Morgan and M Bowman - presented by H Sverdrup).

1990 - Pollution effects on aquatic communities. Symposium: A Fly Fisherman's Entomology. Eastern Branch, Entomological Society of America, 62nd Annual Meeting, Baltimore, MD. (Invited paper).

1990 - Coal ash pile effluents: Effects on freshwater communities. Symposium: The effects of water quality on insect communities. Eastern Branch, Entomological Society of America, 62nd Annual Meeting, Baltimore, MD. (Invited paper, with R Herd and R Jacobsen).

1990 - Trout stream carrying capacity and resiliency. Watershed urbanization and Maryland trout streams: A workshop. Metropolitan Washington Council of Governments, Washington, D. C. (Invited paper).

1991 - Trout density as a function of habitat quality. Trout and Timber Workshop: Forestry Practices and Trout Management. Trout Committee, Southern Division, American Fishery Society, Deep Creek Lake, MD.

1991 - Brook trout: A genetic examination of Maryland populations. WASHPEG 91. Washington Area Population and Evolutionary Geneticists, Smithsonian Institution, Suitland, MD.

1991 - Future anthropogenic impacts and genetic conservation of brook trout in Maryland. NATO Advanced Study Institute: Genetic Conservation of Salmonid Fishes, University of Idaho (Moscow, ID) and Washington State University (Pullman, WA).

1991 - Degradation of fish habitat quality from acidification in Maryland streams. American Fisheries Society 1991 Annual Meeting, San Antonio, TX. (R Klauda, M Bowman, R Morgan and A Janicki - presented by R Klauda).

1991 - Toxicity of fly ash leachate in a first-order Appalachian stream. Society for Environmental Toxicology and Chemistry, Twelfth Annual Meeting, Seattle, WA. (R Morgan and R Herd - presented by R Herd).

1992 - Degradation of fish habitat quality from acidification in Maryland streams. Tidewater Chapter, American Fisheries Society, 6th Annual Meeting, Easton, MD. (R Klauda, M Bowman, R Morgan and A Janicki - presented by R Klauda).

1992 - Current water quality and bioassessment programs in western Maryland. Environmental Protection Agency, Region III Biology Workshop, Cacapon State Park Lodge, Berkeley Springs, WV.

1992 - Description of a light trap to sample larval fishes in complex habitats. American Society of Ichthyologists and Herpetologists, 72nd Annual Meeting, Urbana-Champaign, IL. (With J Killgore).

1992 - Fish abundance and distribution in Potomac River submersed aquatic vegetation. Army Corps of Engineers Workshop on Relationships between Fish and Aquatic Plants, New Orleans, LA.

1992 - Effects of stocking on the genetic structure of Maryland brook trout. East Coast Trout Culture and Management Workshop, University Park, PA. (With B Baker).

1993 - Development of genetic inventories for Maryland brook trout. 1st Annual Southern Division Technical Session, American Fisheries Society, Chattanooga, TN. (With B Baker).

1993 - Impact of episodic events on stream water chemistry in the Allegheny Plateau. Acid Rain Symposium, West Virginia Academy of Sciences, Davis and Elkins College, Davis, WV. (Invited paper).

1993 - Acid rain. Eighth Annual Symposium, Maryland Association for Environmental and Outdoor Education, Rockville, MD. (Invited paper).

1993 - Western Maryland stream survey: Relationships between fish distributions, acidification, and water characteristics. 123rd Annual Meeting, American Fisheries Society, Portland, OR. (With A Janicki, C Murray, M Pawlowski and M Pinder).

1994 - Episodic effects on water chemistry in a western Maryland watershed. Mid-Atlantic Highlands Area Environmental Monitoring and Assessment Conference, United States Environmental Protection Agency, Region 3, Office of Research and Development, Hershey, PA. (With C Murray and K Eshleman).

1994 - Interactions of pH and habitat on cyprinid distribution in acid-sensitive Appalachian streams of Maryland. Mid-Atlantic Highlands Area Environmental Monitoring and Assessment Conference, United States Environmental Protection Agency, Region 3, Office of Research and Development, Hershey, PA. (M Pinder and R Morgan II - presented by M Pinder).

1994 - Maryland biological stream survey: an examination of methods and results of the 1993 summer index period. Mid-Atlantic Highlands Area Environmental Monitoring and Assessment Conference, United States Environmental Protection Agency, Region 3, Office of Research and Development, Hershey, PA. (Poster session, with M Pinder).

1994 - Maryland biological stream survey: an examination of methods and results of the 1993 summer index period. Mid-year Technical Meeting, Southern Division, American Fisheries Society, Little Rock, AK. (With M Pinder).

1994 - Watershed liming of an acidic stream in western Maryland. 1994 Northeast Fish and Wildlife Conference, Burlington, VT. (R Price, R Klauda, R Morgan and M Bowman - presented by R Price).

1994 - Brook trout along the Appalachians. Appalachian Rivers and Watershed Symposium, West Virginia University, Morgantown, WV.

1994 - Acidification of the Appalachians. Appalachian Rivers and Watershed Symposium, West Virginia University, Morgantown, WV.

1994 - Watershed liming and hydrologic event monitoring of an acidic stream in western Maryland. Annual Meeting, American Fisheries Society, Halifax, Nova Scotia, Canada. (D Terry, R Price, R Klauda, R Morgan and M Bowman - presented by D. Terry).

1994 - Maryland's biological stream survey. Annual Meeting, American Fisheries Society, Halifax, Nova Scotia, Canada. (P Jacobson, P Kazyak, R Morgan, L Hall and R Klauda - presented by P Jacobson).

1995 - MBSS: Preliminary results from 1993 and 1994. Mid-Atlantic Water Pollution Biology Workshop, Berkeley Springs, WV.

1995 - Chemical and biological restoration of the North Branch of the Potomac River. 51st Annual Northeast Fish and Wildlife Conference, Ocean City, MD. (With J Mills, A Abar and D Britt).

1995 - Brook trout genetics in the Appalachians. East Coast Trout Culture and Management Workshop II, Pennsylvania State University, University Park, PA. (With R Danzmann).

1995 - Environmental disturbance and within basin population dynamics of brook trout under different land use conditions. East Coast Trout Culture and Management Workshop II, Pennsylvania State University, University Park, PA. (R Hilderbrand and R Morgan - presented by R Hilderbrand).

1995 - Chemical assessment of fluidized bed ash. 1995 International Ash Utilization Symposium, Lexington, KY. (With W Holtsmaster, K Meagher, M Pegg and J O'Connor).

1996 - A major sextet of mtDNA clades in southern brook trout (Invited paper). American Fisheries Society Southern Division Trout Committee, Brook Trout Genetics Workshop, Clemson, SC. (With R Danzmann and B Baker).

1996 - Comparison of allozyme versus mtDNA analysis in discerning southern populations of brook trout *(Salvelinus fontinalis)*. 76th Annual Meeting, American Society of Ichthyologists and Herpetologists, New Orleans, LA. (With R Danzmann and B Baker).

1996 - "A Twist of Lime -- Restoring Western Maryland Streams." History in Bloom (3rd Symposium), Council of the Alleghenies, Frostburg State University, Frostburg, MD.

1996 - Temporal patterns of dissolved nitrogen leakage from mid-Appalachian forested watersheds. Chapman Conference on Nitrogen Cycling in Forested Catchments, Sunriver, OR. (K Eshleman, J Galloway, J Webb, F Deviney, R Morgan, M Meagher and N Castro - presented by K Eshleman).

1997 - The evolutionary significance of southern brook trout populations. Wild Trout VI, Montana, State University, Bozeman, MT (With R Danzmann).

1997 - Effect of flooding on brook trout populations in Maryland Appalachian streams. American Fisheries Society Annual Meeting, Monterey, CA. (K Surgent and R Morgan - presented by R. P. Morgan)

1997 - A major sextet of mitochondrial DNA phylogenetic assemblages extant in eastern North American brook charr (*Salvelinus fontinalis*): distribution and post-glacial dispersal patterns. American Fisheries Society Annual Meeting, Monterey, CA. (R Danzmann, R Morgan, M Jones, L Bernatchez and P Ihssen - presented by R Danzmann)

1997 - Predicting amphibian species presence from landscape patterns. 59th Midwest Fish and Wildlife Conference, Milwaukee, WI. (A Walz, R Morgan and M Ottinger - presented by A Walz).

1997 - Influence of stream stability on brook trout abundance and species diversity in Maryland Appalachian streams. Third EMAP Research Symposium, Albany NY. (K Surgent and R Morgan - presented by K Surgent).

1997 - A twist of lime. Mid-Atlantic Water Pollution Biology Workshop, Cacapon State Park, WV.

1997 - Distribution and ecological assessment of brook trout in small streams located in Garrett and Allegany Counties, Maryland. Society of Environmental Toxicology and Chemistry, Seattle, WA (M Hawkins, R Morgan and R Lee - presented by K Surgent).

1998 - Flooding effects on brook trout populations in Maryland Appalachian streams. Eleventh International Trout Stream Habitat Improvement Workshop, Fayetteville, AR. (with K Surgent).

1998 - Effects of highway culverts on fish and benthic macroinvertebrate colonization and fish passage in two first-order coldwater streams in Northcentral Pennsylvania. 54th Annual Northeast Fish and Wildlife Conference, Camp Hill, PA. (T Shervinskie and R Morgan - presented by T Shervinskie).

1998 - The evolutionary significance of Maryland brook trout populations. Conservation of Biological Ddiversity Conference. Annapolis, MD. (With R Danzmann).

1998 - Effects of highway culverts on fish and benthic macroinvertebrate colonization and fish passage in two first-order coldwater streams in North Central Pennsylvania. Connections 98: Transportation, wetlands, and the natural environment, New Bern, NC. (T Shervinskie and R Morgan - presented by T Shervinskie).

1999 - The return of the river's living resources. North Branch of the Potomac River Symposium, Frostburg, MD.

1999 - FIBI, BIBI, and PHI: An acronymic assault to assess aquatic assemblages. Appalachian Rivers II Conference, Morgantown, WV.

1999 - Physical habitat index. Maryland Biological Stream Survey Symposium, St. Mary's City, MD.

1999 - Acid rain – what goes up must come down. Maryland Biological Stream Survey Symposium, St. Mary's City, MD.

1999 - Fishability – The undiscovered fishing hotspots of Maryland. Maryland Biological Stream Survey Symposium, St. Mary's City, MD. (Given twice.)

1999 - Environmental Impact of Coal Mining. Coal in Western Maryland Conference, Frostburg, MD.

1999 - Sharpless, M, A Faber, J Ammon, C Moore and R Morgan. Appalachian Laboratory: Building for learning and research. Mid-Atlantic Regional Conference, Society for College and University Planning, Princeton, NJ.

1999 - Ammon, J, A Faber, M Sharpless, C Moore and R Morgan. Appalachian Laboratory: Building for learning and research. National Conference, Society for College and University Planning, Atlanta, GA.

2000 - Castro, M, R Morgan, S Davis and E McLaughlin. 2000. Assessment of the Piney Creek reservoir in Western Maryland. Maryland Water Monitoring Council Annual Meeting, Baltimore, MD.

2000 - Wiley, D and R Morgan. Effects of dams, habitat and water quality on the distribution and abundance of American eel in Maryland from 1994-1997. American Fisheries Society Annual Meeting (130th), St. Louis, MO.

2000 - Morgan, R, M Kline, K Kline, D Gates, W Branch and A Brookens. Using SAPS to remediate a lake ecosystem. 12th International Trout Stream Habitat Improvement Workshop. Waterville Valley, NH.

2001 - Morgan, R, M Kline K Kline and D Gates. Biological community recovery in the North Branch of the Potomac River after AMD treatment with limestone dosers. 57th Annual Northeast Fish and Wildlife Conference. Saratoga Springs, NY.

2001 - Hall, M, R Morgan and R Danzmann. Mitochondrial DNA analyses of mid-Atlantic USA populations of brook trout *Salvelinus fontinalis*: the zone of contact for major historical lineages. 81st Annual Meeting of the American Society of Ichthyologists and Herpetologists, State College, PA

2001 - Fish composition methods. Methods for measuring and evaluating the effects of mining on streams: Implications for coal development assessment. West Virginia Water Research Institute, Morgantown, WV.

2002 – Biological effects of sediment loading. Sediment and the Chesapeake Bay Watershed – From Top to Bottom. Sponsored by USFWS, MDNR, MDE, USEPA, and USGS. Linthicum Heights, MD.

2002 – Ramsey, M, W Currie, K Eshleman and R Morgan. Wetland occurrence at a rehabilitated ecosystem: The role of microtopography. 23rd International Meeting of the Society of Wetland Scientists, Lake Placid, NY.

2002 - Wiley, D and R Morgan. Effects of artificial structures on distribution and abundance of American eels (*Anguilla rostrata*) in five river basins in Maryland. American Fisheries Society Annual Meeting (132nd), Baltimore, MD.

2003 – Morgan, R, M Kline, K Kline, D Gates, W Branch and A Brookens. Using SAPS to restore a lake ecosystem. Southern Division, American Fisheries Society, Wilmington, NC.

2003- Morgan, R and S Stranko. Where have all the (Maryland) brook trout gone? 133rd Annual Meeting, American Fisheries Society, Quebec City, Quebec, Canada.

2003 – Where has all the landscape gone? Regional Planning Conference, Maryland and Delaware Chapters, American Planning Association, Rocky Gap Lodge, Cumberland, MD.

2003 - Morgan, R and S Cushman. Urbanization effects on Maryland stream communities. Symposium on Urbanization and Stream Ecology, Melbourne, Australia.

2004 – Morgan, R, D Wiley, M Kline, J Holt, S Stranko and P Kazyak. Managing brook trout populations in an urbanizing environment. Wild Trout VIII, Old Faithful Lodge, Yellowstone National Park, WY.

2004 – D Currey, M Southerland, J Volstad, G Rogers, R Morgan and E Nizeyimana. Using the Maryland Biological Stream Survey data to identify sediment impairments. 60th Annual Northeast Fish and Wildlife Conference, Ocean City, MD.

2005 - Morgan, R 2005. Are we failing at stream restoration? First International Conference on Environmental Science and Technology, American Academy of Sciences, New Orleans, LA.

2005 - Kline, K and R Morgan. *In situ* accumulation of metals in stocked rainbow trout. First International Conference on Environmental Science and Technology, American Academy of Sciences, New Orleans, LA.

2005 - Morgan, R, D Wiley, M Kline, J Holt, S Stranko and P Kazyak. Managing brook trout populations in an urbanizing environment. 2005 Spring Meeting, Southern Division, American Fisheries Society, Virginia Beach, VA.

2005 - Cushman, S and R Morgan. Differential movement of stream cyprinids in urban and rural watersheds. 2005 Spring Meeting, Southern Division, American Fisheries Society, Virginia Beach, VA.

2005 - King, T, S Julian, C Callahan, R Morgan, J Atkinson, B Connery and S Moore. Conservation genetics of brook trout (*Salvelinus fontinalis*): Phylogeography, population structure, captive breeding management, and the adaptive significance of observed differentiation. East Coast Trout Management and Culture Workshop IV, Loch Haven State University, PA.

2005 - Emerging treats to Maryland's Biota. Second Maryland Streams Symposium, Carroll Community College, Westminster, MD.

2005 - The brook trout: Maryland's native. Second Maryland Streams Symposium, Carroll Community College, Westminster, MD.

2005 - Southerland, M, L Erb, G Rogers, R Morgan, K Eshleman, M Kline, K Kline, S Stranko, P Kazyak, J Kilian, J Ladell and J Thompson. Stressors affecting Maryland streams. Second Maryland Streams Symposium, Carroll Community College, Westminster, MD.

2005 - Staley, M, S Stranko, A Roseberry-Lincoln, J Ladell, R Morgan and A Becker. A case study documenting brook trout decline as urbanization increased in the Baltimore metropolitan area of Maryland. Second Maryland Streams Symposium, Carroll Community College, Westminster, MD.

2005 - Rule, T, L Currey, M Southerland, J Volstad, G Rogers and R Morgan. Maryland sediment impairments – stressor identification and TMDLs. Second Maryland Streams Symposium, Carroll Community College, Westminster, MD.

2005 - Southerland, MT, G Rogers, M Kline, R Morgan, D Boward, P Kazyak and S Stranko. New biological indicators to better assess the condition of Maryland streams. Second Maryland Streams Symposium, Carroll Community College, Westminster, MD.

2005 - Morgan, R, M Kline, D Wiley and R Hilderbrand. Fragmentation, compression and extinction of Maryland brook trout populations. 135th Annual Meeting of the American Fisheries Society, Anchorage, AK.

2005 - Cushman, S and R Morgan. Differential movement of stream cyprinids in urban and rural watersheds. 135th Annual Meeting of the American Fisheries Society, Anchorage, AK.

2005 - The North Branch: Perils, Progress and Projections. Human influences on the biology of the Potomac River. Interstate Commission on the Potomac River Basin, Arlington, VA.

2006 - Walz A., R Morgan and M Ottinger. Resolution and age effects of landuse/land cover data on association strength between amphibian species and landscape patterns in the Piedmont region of Maryland. Presented at the 91st Annual Meeting of the Ecological Society of America, Memphis, TN.

2006 - Kline, K, K Eshleman, R Morgan and N Castro. Long-term changes in the acid-base status of western Maryland streams. Taking the Pulse of Maryland's Waters: Back to Basics, Maryland Water Monitoring Council, 12th Annual Conference, Linthicum, MD.

2006 - Kline, K, K Eshleman, R Morgan and N Castro. Long-term changes in the acid-base status of western Maryland streams. American Geophysical Union, Fall Meeting, San Francisco, CA.

2006 - Water quality in the Upper Potomac: State of our local streams (presented twice). Upper Potomac Roundtable Conference, “Chesapeake Bay Tributary Strategies in the Upper Potomac: One Watershed, Many Solutions”, National Conservation Training Center, Shepherdstown, WV.

2006 - Morgan, R, M Castro and J Thompson. 2006. Comparison of mercury concentrations in western Maryland streams. Eighth International Conference on Mercury as a Global Pollutant, Madison, WI.

2006 - Overview of the status of brook trout in Maryland. Eastern Brook Trout Joint Venture Meeting, ThorpeWood, Thurmont, MD.

2007 - Morgan II RP and SF Cushman. Urbanization effects on stream fishes in Maryland’s Piedmont. Emerging issues along urban-rural interfaces II: Linking land-use science and society, Atlanta GA.

2007 - Morgan II RP and SF Cushman. Urbanization effects on fish assemblages in Maryland’s Piedmont. 137th Annual Meeting of the American Fisheries Society, San Francisco, CA.

2007 - Cushman, SF, RP Morgan and RH Hilderbrand. Habitat selection by stream cyprinids across the urban-rural gradient: Implications for stream restoration. 92nd Annual Meeting of the Ecological Society of America. San Jose, CA.

2008 – Effects of road salt on urban fish assemblages. 138th Annual Meeting of the American Fisheries Society, Ottawa, Ontario, Canada.

2008 – King, T, B Lubinski, R Morgan and D Pavek. Conservation genetics of brook trout (*Salvelinus fontinalis*): phylogeography, population structure, and assessing the adaptive significance of observed differentiation. 138th Annual Meeting of the American Fisheries Society, Ottawa, Ontario, Canada.

2008 - Eshleman, KN, KM Kline, RP Morgan II, and AJ Elmore. A watershed and water quality threat surveillance system to support EPA’s anti-degradation policy and its implementation in Maryland. 14th Annual Conference, Maryland Water Monitoring Council, Linthicum, MD.

2009 – Morgan, R. Effects of road salt on urban fish assemblages. 2009 Spring Meeting, Southern Division, American Fisheries Society, New Orleans, LA.

2009 – Morgan, R. Effects of road salt on fish assemblages in Maryland. 2009 Joint Meeting of Ichthyologist and Herpetologists, Portland, OR.

2010 - Morgan, R., T. King and B. Lubinski. A revisitation of Maryland brook trout genetics. 2010 Southern Division AFS Spring meeting, Asheville, NC.

2010 - Hilderbrand, R., R. Morgan, A. Heft and M. Sell. Brook trout population trends in Western Maryland 1988-2007. 2010 Southern Division AFS Spring meeting, Asheville, NC.

2010 - King, T., S. Moore, J. Wofford, M. Kulp, T. Petty and R. Morgan. Islands in the stream: Fine-scale analysis of brook trout population structure reveals the need for research and management paradigm shifts. 2010 Southern Division AFS Spring meeting, Asheville, NC.

2010 - Morgan, R. Effects of road salt on fish assemblages in Maryland. AFS 140th Annual Meeting, Pittsburgh, PA.

2010 - King, T., S. Moore, J. Wofford, M. Kulp, T. Petty and R. Morgan. Islands in the stream: Genetic analysis of brook trout population structure and demographics reveals a high degree of population fragmentation and prodigious differentiation within and among streams. AFS 140th Annual Meeting, Pittsburgh, PA.

2011- Morgan, R. 2011. Stream nutrients and biotic assemblages. AFS 141st Annual Meeting, Seattle, WA.

2011 - Morgan, R. 2011. A Revisitation of Maryland Brook Trout Genetics. Maryland Streams Symposium and Mid-Atlantic Volunteer Monitoring Conference, Westminster, MD.

2011 - King, T., B. Lubinski, J. Wofford, R. Morgan and J. Stauffer. 2011. Conservation Genetics and Genomics of Brook Trout (*Salvelinus fontinalis*) Populations: Identification of the Functional Unit of Management in the Chesapeake Bay System. Maryland Streams Symposium and Mid-Atlantic Volunteer Monitoring Conference, Westminster, MD.

2012- Southerland, M., S. Schreiner, L. Methratta, B. Franks, R. Morgan. L. Currey and A. Kasko. 2011. Conceptual framework for urban TMDL's. 17th Maryland Water Quality Monitoring Conference, Linthicum, MD.

2013- King, T., S. Moore, J. Wofford, T. Petty, R. Morgan and J. Stauffer. Conservation genetics and genomics of Brook Trout: Identification of the functional unit of management. AFS 143th Annual Meeting, Little Rock, AR.

2013 - Morgan, R. White roads, white trees and white stripes: Stream conductivity and road salt relationships to land use and fish assemblages in Maryland streams. 34th SETAC North America Annual Meeting, Nashville, TN.

2014 - Morgan, R. Stream conductivity and road salt relationships to land use and fish assemblages in Maryland streams. AFS 144th Annual Meeting, Quebec City, Quebec, Canada.

2014 - Sell, MT, AA Heft, DC Kazyak, RH Hilderbrand and RP Morgan II. Short-term and seasonal movements of brook trout in the upper Savage river watershed. Wild Trout XI symposium, Old Faithful Lodge, YNP, Montana (conference canceled due to government sequestration).

2014 – Morgan, R. Perspectives on assessment of SHA stream restoration projects. 20th Maryland Water Quality Monitoring Conference, Linthicum, MD.

2015 – Morgan, R., K. Kline and J. Garlitz. Coal combustion byproduct utilization in Western Maryland strip mines. 2015 World of Coal Ash, Nashville, TN.

2015 – Ashton, M., A. Pinkney, K. Kline and R. Morgan. Preliminary characterization of surface and pore water quality as a potential stressor to dwarf wedgemussel (*Alasmidonta heterodon*). 2015 Joint Meeting of the Freshwater Mollusk Conservation Society and the Upper Mississippi River Conservation Committee, St. Charles, MO.

2015 – Morgan, R. Perspectives on Assessing Stream Restoration Projects in Maryland. American Fisheries Society, Portland, OR.

External and Internal Lectures, Seminars, Workshop Presentations, and Environmental Science Education Activities

These are far too numerous to detail over the span of my professional career.

Administrative/Professional Responsibilities

USM Service

Member, Graduate Advisory Council, Department of Zoology, University of Maryland, 1969-1970.

Seminar Chairman, Chesapeake Biological Laboratory, Solomons, Maryland, 1971-1972.

Acting Seminar Chairman, CBL, Summer, 1973.

Chairperson, Controlled Environment Laboratory Planning Committee, 1972-1974.

Editor, Hydrographic and Ecological Effects of Enlargement of the C and O Canal (Final Report and 15 Appendices), 1974.

Program Planner, Center for Environmental and Estuarine Studies, 1973-1974.

Member, Seminar Committee, 1975.

Radiochemical Safety Officer (CBL), 1974-1976.

Acting Head, Department of Environmental Research (CBL), 1975.

Member, Search Committee, Biostatistician, 1975.

Member, Limnologist Search Committee, AEL, 1979.

Chairperson, Invertebrate Physiologist Search Committee (HPEL) 1979-1980.

Member, Contract and Grant Task Force, 1979-1990.

Member, Aquatic Ecologist Search Committee, 1980-1981.

Co-Chairman, Registration Committee, Worldwide Furbearer Conference, 1980.

Senator - AEL, UMCEES Faculty Senate, 1983-1985.

Secretary and Member, Executive Committee, UMCEES Faculty Senate, 1984-1985.

Member, Aquatic Ecologist Search Committee, 1984.

Member, Senior Scientist Search Committee, 1984.

Member, Mammalogist Search Committee, 1985.

Member, AEL Research Review Committee, 1985-1990.

Chairman, Aquatic Ecologist Search Committee, 1987-1988.

Graduate Program Coordinator, 1988-1991.

Member, Search Committee for Landscape Ecologist, Hydrologist, and Atmospheric Scientist, 1993-1994.

Member (AEL Representative), UMCEES Affirmative Action Advisory Committee, 1984-2015.

Substance Abuse and Sexual Harassment Officer for AEL, 1984-2015.

Member, CEES Graduate Faculty Council, 1990-2001.

Member, CEES Hazardous Materials Committee, 1993-1997. Chair, 1996-1997.

Chair, Promotion and Tenure Review Committees [1995(2): 1999(1)].

Member, Promotion and Tenure Review Committees [1998(1): 1999(1)]

Member, CEES-DNR Cooperative Fisheries Agreement Committee (1996).

Member, Professor Emeritus Review Committee (1996).

Senator - AEL, UMCEES Faculty Senate, 1994-1996. (Elected Vice-Chairman 1995).

Member, Selection Committee for Truitt Environmental Award, 1997.

Member, Search Committee (CBL) for Faculty Research Position in Fisheries Science, 1997.

Member, Search Committee (CBL) for Faculty Position in Toxicology, 1998.

Co-chair, Fisheries AOS, MEES Program (1996-1999).

Member, Program Committee for MEES (1996-1999).

Member, AEL Building Committee, 1996-1999.

Member, AEL Education Committee, 1996-1999.

Member, Aquatic Ecologist Search Committee, 1999.

University of Maryland System Representative to the National Association of State Universities and Land-Grant Colleges (NASULGC) -- Section on Fish and Wildlife Resources, 1996-2015.

Chair, UMCES Faculty Senate, 1999-2002.

Member, Council of University Faculty, 1999-2005.

Member, USM Senate Faculty, 1999-2002.

Member, Regent's Faculty Awards Committee (2000-02, 2004)

Member, Faculty Promotion and Tenure Appeals Committee (2000-2012)

Chair, AL Graduate Education Committee (2003-2006)

Member, Richard Johnson Award Committee (2004-2007)

Member, Promotion Committee (2004-2005)

Member, Search Committee (CBL 2005)

Member, Tenure Review Committee (AL 2005-2006)

Chair, Promotion Committee (AL 2005-2006)

Co-Chair, Ecology AOS, MEES (2005-2007)

Member, Promotion Committee (2006-2007)

Chair, Promotion and Tenure Committee (AL 2007-2008)

Member, PE Committee (CBL 2008)

Chair, PE Committee (AL 2008)

Chair, Search Committee (AL 2008)

Member, Promotion Committee (HPL 2008-2009)

Co-Chair, Environmental Science AOS, MEES (2009-2012)

Member, PE Committee (HPL 2013)

Member, Graduate Faculty Council (2015)

Chair, AL Education Committee (2015)

Member, UMCES Self-Study Steering Committee for MSCHE Accreditation (2014 – 2015).

Member, MSCHE Working Group 2 – Leadership, Governance, Administration and Integrity (2014-2015).

Member, Search Committee for AL Coordinator of External Affairs (2015).

Chairman, "Blood from a Turnip" Al seminar series (Fall 2015).

State and Public Service

Member, Advisory Committee, Chesapeake Bay Cooling Waters Study Group, 1972-1977.

Member, *Ad Hoc* Committee for Additions and Emissions Program, CRC Inc., 1973.

Research Analyst (State Department of Legislative Reference, Research Division) to Committee on Environmental Matters, House of Delegates, General Assembly of the State of Maryland. 1983, 1984, 1985 Sessions.

Commissioner, Water Resources Advisory Commission (MDDNR), 1986-1994.

Reviewer, Targeted Watersheds Program (MDDNR), 1990.

Advisor, Savage River State Forest Management Plan (MDDNR), 1990-1992.

Member, Governor's Interdepartmental Task Force on the Preservation of State Streams, 1990-1991.

Member, Piney Creek Watershed Management Group (City of Frostburg), 1990-1991.

Member, Landfill Liaison Committee (Allegany County), 1991-1994.

Reviewer, Targeted Watersheds Program (MDDNR), 1995.

Member, Allegany County Solid Waste Management Plan Committee, 1995-1996.

Member, ME 2000 Technical Advisory Committee/Ecological Team (MDE), 1995-1996.

Member, Savage River State Forest Advisory Committee (Ecologist), 1993-2006

Member, Upper Potomac Tributary Team, 1995-2010.

Interim Chair, Upper Potomac Tributary Team, 1995-1996.

Chair, Upper Potomac Tributary Team, 1996-1997.

Member, Board of Directors, Maryland Water Monitoring Council, 1995-2000.

Member, Fly Fishing Advisory Committee, Adventuresports Institute, Garrett Community College, 1997-2002.

Member, Coal Ash Utilization Committee, MDOE -- MDBOM, 1998-1999.

Member, Maryland Acid Mine Drainage Committee, 1999-2010.

Member, Board of Evitts Creek Environmental Learning Center, 1997-2003.

Chair, Biocriteria Committee, Maryland Department of the Environment, 1999-2000.

Member, Program Committee, Mid-Atlantic Water Pollution Biology Workshop (1997-2006).

Moderator - Fishery Resources in Streams - Second Maryland Streams Symposium, Carroll Community College, Westminster, MD (2005).

Member, Governor Martin O'Malley Transition Work Group – Environment and Natural Resources, Living Resources Subcommittee (2006 – 2007).

Peer Advisory Committee, DNR Task Force on Fisheries Management (2007-2008)

Member, Technical Review Committee, Anne Arundel County Biological Program (2014-present)

Member, Power Plant Research Advisory Committee, 1994-present.

Commissioner, Sport Fisheries Advisory Commission (2011-present)

Professional Society Service

Secretary-Treasurer, Atlantic Estuarine Research Society, 1975-1976.

President-elect, Atlantic Estuarine Research Society, 1976.

Member, AERS Nominating Committee, 1979-1980.

Member, Environmental Concerns Committee, American Fisheries Society, 1989-1990.

Member, Pollution Committee, American Fisheries Society (Southern Division), 1992-2006.

Member, Trout Committee, American Fisheries Society (Southern Division), 1997-present.

Associate Editor, North American Journal of Fisheries Management, 1997-2000.

Member Editorial Board, American Fisheries Society, 1997-2000.

Symposium Chairman, 1999 Annual Meeting of the American Society of Ichthyologists and Herpetologists, 1997-1999.

Symposium Chairman, 2001 Annual Meeting of the Society of Ichthyologists and Herpetologists, 1999-2001.

Program Committee Member, local arrangements chair, Third East Coast Trout Culture and Management Workshop, 2000.

Symposium Moderator, Northeast Division, American Fisheries Society, "New Directions in the use of multimetric indicators to assess biological and habitat conditions in streams and rivers." 60th Annual Northeast Fish and Wildlife Conference (with R. Klauda and P. Ferreri).

Symposium Moderator, American Fisheries Society, 140th Annual Meeting - 2010, Pittsburgh, PA.

Program Committee Member, local arrangements chair, Fifth East Coast Trout Culture and Management Workshop, 2011- 2012.

Moderator, World of Coal Ash, 2015. Nashville, TN.

External Academic Service

Promotion review, Frostburg State University (T&P - 2)

Promotion review, The Pennsylvania State University (Full Professor Rank)

Promotion review, (Full Professor Rank) for the Department of Fisheries and Wildlife, Oregon State University

Promotion review, (Full Professor Rank) for the Davis College of Agriculture, Forestry and Consumer Sciences, Division of Forestry and Natural Resources, West Virginia University (2)

Grants or Contracts Awarded

(Asterisk indicates peer-reviewed.)

Chesapeake Biological Laboratory

Hydrographic and ecological effects of enlargement of the Chesapeake and Delaware Canal. Ecology program. Part II. Effects of environmental variation on fish eggs and larvae. US Army Corps of Engineers, Philadelphia District. October 1970 to October 1973. $151,000.

Bioassay for chronic effects of water from Baltimore Harbor. Maryland Environmental Service. March 1972 to September 1972. $27,000.

CEES Program Planning. University of Maryland. November 1973 to May 1974. $15,150.

Biochemical identification of the mallard and black duck and other migratory species. US Fish and Wildlife Service (USFWS), Migratory Bird and Habit Research Laboratory. October 1973. $795.

Striped bass spawning stock assessment program. MDNR, Power Plant Siting Program. 1974. $49,927.

Biochemical identification of the mallard and black duck and other migratory species. USFWS, Migratory Bird and Habitat Research Laboratory. July 1974 to June 1975. $8,000.

Macroplankton investigation in relation to the siting and operations of stream electric stations in Chesapeake Bay. MDNR, Power Plant Siting Program. July 1975 to December 1975. $8,414.

Potomac River striped bass work and Calvert Cliffs monitoring program. MDNR, Power Plant Siting Program. 1975. $95,906.

Biochemical identification of the mallard and black duck and other migratory species. USFWS, Migratory Bird and Habitat Research Laboratory. July 1975 to September 1976. $9,000.

Bioassay of effluents. FMC Corporation. August 1975. $4,000.

Potomac River striped bass work and Calvert Cliffs monitoring program. MDNR, Power Plant Siting Program. 1976. $96,935.

Biochemical identification of the mallard and black duck and other migratory species. USFWS, Migratory Bird and Habitat Research Laboratory. September 1976 to June 1977. $6,500.

Biotoxicity of chlorine to estuarine organisms. MDNR, Power Plant Siting Program. 1976 to 1978. $257,000.*

Estuarine community dynamics in relation to power plant operations. MDNR, Power Plant Siting Program. January 1976 to June 1977. $96,993.

Upper Bay gill net survey. MDNR, Power Plant Siting Program. February 1976 to August 1976. $56,920.

Biotoxicity of chlorine to estuarine fish eggs and larvae. USFWS, National Power Plant Siting Team. March 1976 to July 1976. $29,014.*

Potomac River striped bass work and Calvert Cliffs monitoring program. MDNR, Power Plant Siting Program. 1977. $116,004.

Battelle Columbus Laboratories

(Also had responsibility for fisheries work at Millstone under large annual contract)

Bioassay of Mystic River sediments. Union Oil Corp. March 1978 to April 1978. $13,000.

Bioassay of New Haven Harbor sediments. USACE (NED). May 1978 to July 1978. $9,000.

Bioassay of sewage effluents from Nut Island and Deer Island sewage treatment plants, Boston Harbor. MDC - Metcalf & Eddy, Inc. 1978. $6,665.

Bioassays of sediment - Slip No. 13. General Dynamics. 1979. $5,250.

Interlaboratory comparison of bioassay techniques for *Mysidopsis bahia*. US Environmental Protection Agency (USEPA). 1979-1980. $47,950.*

Toxicity of organic pollutants. USEPA. 1979-1981. $100,000.*

Evaluation of test protocols. USEPA. 1978-1981. $123,000.*

Appalachian Laboratory

Aquatic site evaluation. MDNR, Power Plant Siting Program. July 1981 to June 1982. $19,783.

General water quality sampling program of the Youghiogheny - Little Youghiogheny Rivers. MDHMH. 1982. $19,582.

Biological integration: Coal leachate and cooling tower pollutant issues. MDNR, Power Plant Siting Program. July 1982 to June 1983. $5,600.

Chemical analysis of effluent from clay mining. Kaiser Refractories. 1982. $528.

Effects of Treflan on embryonic development of bobwhite quail. International Quail Foundation. April 1983 to February 1984. $11,308.*

Benthic, drift and weight studies for Conowingo. MDNR, Power Plant Siting Program. August 1983 to June 1984. $25,747.

Brighton Dam small-scale hydroelectric evaluation. MDNR, Power Plant Siting Program. August 1983 to June 1984. $15,500.

Hybridization in Delmarva Fox Squirrels. MDNR, Wildlife Administration. January 1984 to December 1984. $9,906.

Brighton - Union Dam small-scale hydroelectric evaluation. MDNR, Power Plant Siting Program. July 1984 to June 1985. $23,635.

Georges Creek and Braddock Run baseline study. MDNR, BOM, and MDHMH. July 1984 to June 1985. $18,752.

Field assessment of striped bass larval survival in the Choptank River. MDNR, Tidewater Administration. April 1985 to December 1985. $79,840.

Biological survey of Final Cut Pond. MDNR, BOM. May 1985 to April 1986. $4,226.

Brighton-Union Dam small-scale hydroelectric evaluation. MDNR, Power Plant Siting Program. July 1985 to June 1986. $24,600.

Biological services. MDNR, BOM. July 1985 to December 1982. $25,000.

Environmental review. MDNR, Tidewater Administration. June 1985 to June 1986. $35,000.

Interagency Personnel Agreement. USACE. January 1986 to December 1986. $23,148.

Coordinating, developing quality assurance and quality control, and integral reporting for 1986 projects in striped bass spawning areas. MDNR. March 1986 to December 1986. $35,160.

Sublethal effects of electromagnetic pulses on fish. Department of the Navy, Theater of Nuclear Warfare. April 1986 to April 1987. $219,422.

Sublethal effects of electromagnetic pulses on sea turtles. Department of the Navy, Theater of Nuclear Warfare. April 1986 to April 1987. $157,178.

Brighton Dam small-scale hydroelectric evaluation. MDNR, Power Plant Siting Program. July 1986 to June 1987. $25,932.

Development of a coldwater data base for Allegany and Garrett Counties - Phase I. MDNR. January 1987 to June 1987. $19,350.

A preliminary evaluation of the effect of water hardness, magnesium and calcium levels, salinity and larval access to environmental air on swim bladder development. Baltimore Gas and Electric. January 1987 to December 1987. $4,054.

Choptank water chemistry and support for *in situ* bioassays. MDNR. January 1987 to December 1987. $27,500.

Brighton Dam small-scale hydroelectric evaluation. MDNR, Power Plant Research Program. July 1987 to June 1989. $43,361.

Investigating, analyzing data, and compiling a report on the natural significance and conservation needs of the state's cave systems with an emphasis on cave invertebrates. MDNR. September 1987 to September 1987. $6,500.

Biological monitoring consultant: Albright and Fort Martin power stations. Allegheny Power Service Corporation (APSC). March 1987 to December 1988. $31,874.

Stream neutralization: Liming. MDNR and International Science and Technology, Inc. January 1987 to December 1987. $8,125.

Biological monitoring consultant: Albright and Fort Martin power stations. APSC. December 1988 to December 1989. $28,994.

Development of a coldwater data base for Allegany and Garrett Counties - Phase II. MDNR. March 1988 to December 1988. $85,693.

Microgeographical differentiation in the bay anchovy (*Anchoa mitchilli*). MDNR. January 1989 to October 1990. $79,126.*

Blockages to fish passage caused by highway culverts. MDT, SHA. October 1988 to January 1991. $195,530.*

Development of a coldwater data base for Allegany and Garrett counties--Phase II. MDNR. January 1989 to December 1989. $81,680.

Chemical and biological sampling and analysis necessary to support a variance from the state water quality standard for selenium at the Ft. Martin ash area. APSC. May 1989 to December 1989. $12,856.

Evaluation of relationships between sensitivity to acidification, watershed characteristics, and fish distributions in western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. May 1989 to December 1989. $30,774.*

To develop a preliminary design for an acid mine drainage mitigation demonstration program. WRA, BOM, MDNR. March 1989 to June 1989. $35,200.

Modeling of steady-state alkalinity and estimation of critical loads of sulfur and nitrogen for Maryland streams. MDNR. Chesapeake Bay Research and Monitoring Division. October 1989 to January 1990. $182,674.*

Fish data compilation. Martin-Marietta Energy Systems, Inc. July 1989 to September 1989. $2,757.

Development of a coldwater data base for Allegany and Garrett counties. MDNR, Tidewater Administration. January 1990 to December 1990. $80,220.

Biological monitoring consultant: Albright and Fort Martin power stations. APSC. January 1990 to December 1990. $25,400.

Episodic storm events in western Maryland streams. MDNR, Chesapeake Bay Research and Monitoring Division. July 1989 to November 1990. $84,266.*

Identification and conservation of indigenous tilapiine genetic resources. United States Agency for International Development. March 1991 to March 1993. $150,000. (J. H. Howard, J. Gopo, R. P. Morgan, F. Feresu).*

Identification of commercially important fishes of Lake Malawi. United States Agency for International Development. August 1990 to July 1992. $149,235. (K. R. McKaye, S. S. Chiotha, J. R. Stauffer, R.P. Morgan).*

Fort Martin power station ash area variance request for selenium. APSC. March 1990 to August 1990. $66,455.

Acid rain/stream chemistry monitoring program. MDE. May 1990 to April 1992. $5,000.

Development of genetic inventories for Maryland game fish: Brook trout. MDNR, Tidewater Administration. July 1990 to June 1991. $49,513.*

Episodic storm events in western Maryland streams. MDNR, Chesapeake Bay Research and Monitoring Division. August 1990 to March 1992. $117,850.*

Water chemistry and biological sampling program in support of a watershed liming project in western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. August 1990 to July 1990. $32,379.*

Development of a coldwater data base for Allegany and Garrett Counties - Phase III. MDNR, Tidewater Administration. December 1990 to December 1991. $47,469.

Feasibility study of restoring the North Branch of the Potomac River. MDNR, WRA, BOM. November 1990 to April 1991. $30,062.

Biological monitoring consultant: Albright and Fort Martin power stations. APSC. January 1991 to December 1991. $28,771.

1991 Maryland doser study in coastal plain. MDNR, Tidewater Administration (thru Agriculture Experiment Station). February 1991 to December 1991. $12,168.

Assessing potential biological impacts of proposed coal mining operations on selected streams in western Maryland. MDNR, WRA, BOM. December 1990 to December 1991. $20,000.

Design of stream-specific monitoring program. MDNR, WRA, BOM. June 1991 to November 1991. $2,500.

Abandoned surface mine ponds: Time dependent changes in water quality. Water Resources Research Center. May 1991 to April 1992. $32,579. (S. Seagle and R. P. Morgan II).*

Water chemistry and biological sampling program in support of a watershed liming project in western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. September 1991 to July 1992. $56,763.*

Episodic storm events in western Maryland streams. MDNR, Chesapeake Bay Research and Monitoring Division. October 1992 to January 1993. $106,800.*

Biological monitoring consultant: Albright and Fort Martin power stations. APSC. January 1992 to December 1992. $30,881.

Development of a coldwater data base for Allegany and Garrett Counties - Phase IV. MDNR, Forest, Park, and Wildlife Service. March 1992 to December 1992. $74,395.

Water chemistry and biological sampling program in support of a watershed liming project in western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. August 1992 to July 1993. $59,594.*

Multiscale Experimental Ecosystem Research Center (MEERC). USEPA - Exploratory Environmental Research Centers Program. May 1992 to May 1994 (Member, Research Coordinating Committee). Approximately $12,000/year.*

Comparative analysis of scales of contaminant inputs. Multiscale Experimental Ecosystem Research Center (MEERC). USEPA - Exploratory Environmental Research Centers Program. July 1992 to March 1991. $14,318.*

Assessing potential biological impacts of proposed coal mining operations on selected streams in western Maryland. MDNR, WRA, BOM. March 1993 to June 1995. $20,000.

Determine potential for toxic effects from the disposal of fluidized bed ash in coal mines of western Maryland. MDNR, WRA, BOM. April 1993 to December 1995. $70,000.

Analyzing stream water samples in support of the Maryland Biological Stream Survey Pilot Survey. MDNR, Chesapeake Bay Research and Monitoring Division. April 1993 to July 1993. $17,490.

Biological monitoring consultant: Albright power station. APSC. December 1992 to December 1993. $11,288.

Maryland Biological Stream Survey - Western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. July 1993 to December 1993. $65,743.

Water chemistry and biological sampling program in support of a watershed liming project in western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. August 1993 to July 1994. $50,268.

Hydrologic event monitoring at Alexander Run. MDNR (through Environmental Resources Management, Inc.) Chesapeake Bay Research and Monitoring Division. August 1993 to July 1994. $44,000.*

Biological monitoring consultant: Albright power station. APSC. January 1993 to December 1994. $25,989.

Benthic macroinvertebrate stream monitoring at Hatsfield's Ferry and Mitchell disposal sites. APSC. April 1994 to December 1994. $12,151.

Maryland Biological Stream Survey (AEL). MDNR, Chesapeake Bay Research and Monitoring Division. March 1994 to March 1995. $100,000.

Maryland Biological Stream Survey - Water chemistry work for 1994. MDNR, Chesapeake Bay Research and Monitoring Division. March 1994 to August 1994. $25,573.

Analytical services. Tetra Tech. June 1994 to July 1994. $4,875.

Preparation of benthic report on Albright benthic macroinvertebrate work. Great Lakes Environmental Center (EPRI Contract). December 1994 to March 1995. $2,000.*

Water chemistry and biological sampling program in support of a watershed liming project in western Maryland. MDNR, Chesapeake Bay Research and Monitoring Division. August 1993 to July 1994. $50,268.

Florida largemouth bass project. MDNR, Fish, Heritage and Wildlife Division. September 1994 to August 1995. $9,600.

1995 - Maryland Biological Stream Survey (AEL). MDNR, Chesapeake Bay Research and Monitoring Division. February 1995 to June 1996. $106,250.

Maryland Biological Stream Survey - Water chemistry work for 1995. MDNR, Chesapeake Bay Research and Monitoring Division. February 1995 to January 1995. $45,581.

Biological monitoring consultant: Albright power station - 1995. APSC. January 1995 to December 1995. $31,112.

Development of a fish community index for Piney and Alloway Creeks. MDNR, Tidewater Administration - CWRD. May 1995 to September 1995. $9,500.

IFIM - North Branch of the Potomac River. MDNR, Freshwater Fisheries Division. September 1995 to August 1996. $9,841.

Laboratory analytical services for the Winding Ridge Project. MDNR, Power Plant Research Program (Subcontract through ERM). October 1995 to September 1995. $5,000.

Episodic acidification of streams in western Maryland: A field/modeling study for quantifying and predicting regional acid deposition impacts. MDNR, Chesapeake Bay Research and Monitoring Division. September 1995 to December 1998. $272,563. * (Principal Investigator - Dr. Keith Eshleman, Cooperator - R. P. Morgan II)

Biological and chemical evaluation of the North Branch of the Potomac River restoration. MDNR, WRA, BOM. May 1991 to June 1999. $201,314.

1996 - Maryland Biological Stream Survey (AEL). MDNR, Chesapeake Bay Research and Monitoring Division. February 1995 to June 1996. $105,000.

Maryland Biological Stream Survey - Water chemistry work for 1996. MDNR, Chesapeake Bay Research and Monitoring Division. February 1995 to January 1995. $40,320.

Biological monitoring consultant: Albright power station - 1996. APSC. January 1996 to December 1996. $31,019.

Biological, geochemical, and hydrogeological services support for the Maryland Bureau of Mines. MDE, BOM. September 1997 to August 1999. $125,000.

Biological, geochemical, and hydrogeological services support for the Maryland Bureau of Mines. MDE, BOM. Additional funds award – 1999-2000. $125,000.

Biological, geochemical, and hydrogeological services support for the Maryland Bureau of Mines. MDE, BOM. Additional funds award – 2001-2002. $125,000

Cherry Creek Basin Project. MDE, BOM. October 1997 to October 1999. $15,386.

The quantitative and qualitative assessment of sediment associated with the installation and operations of AMD-neutralizing dosers on the North Branch of the Potomac River. MDE, BOM. September 1997 to February 1999. $52,602.

Analysis of Lake Jennings Randolph fisheries potential. MDNR, Fisheries Service. January 1997 to December 1997. $10,000.

1997 - Maryland Biological Stream Survey (AEL). MDNR, Resource Assessment Service. March 1997 to December 1998. $105,000.

Maryland Biological Stream Survey - Water chemistry work for 1997. MDNR, Resource Assessment Service. March 1997 to January 1998. $40,320.

Development of a physical habitat index for non-coastal Maryland freshwater streams and development of an ecological assessment of Maryland streams using a probability-based monitoring program. MDNR, Resource Assessment Service. November 1997 to October 1999. $125,000.

Remediation and restoration of Lake Louise: 1997 Physical, Chemical and Biological Characterization. MDT, SHA. March 1997 to January 1998. $64,531.

Biological monitoring consultant: Albright power station - 1997. APSC. January 1997 to December 1997. $30,824.

Analysis of mitochondrial DNA phylogenetic assemblages in Maryland brook trout. MDNR, Fisheries Service. September 1997 to June 1999. $10,000.

Biological monitoring consultant: Albright power station - 1998. APSC. January 1998 to December 1998. $27,519.

Remediation and restoration of Lake Louise: 1998-2005. MDT, SHA. March 1998 to December 2005. $467,435.

1998 Pilot project for ecological assessment of fourth order and larger non-tidal streams and a comparison of EMAP/EPA versus MBSS sampling methods. MDNR. March 1998 to October 1999. $114,942.

Stream restoration assessment of SHA. MDT, SHA. $49,695.

Biological monitoring consultant: Albright power station - 1999. APSC. 1999. $27,519.

Stream restoration assessment for SHA: 1999-2000. MDT, SHA. 1999-2000. $54,209.

Support for East Coast Trout Management and Culture Workshop III. MDNR, Fisheries Service. 1999-2000. $7,360.

Scope of Work for MDE Water Quality Analyses. MDE, TARSA. 1999-2000. $38,400.

Aaron and Jennings Run Biotic Survey. MDE, BOM. 1999-2001. $25,000.

North Branch of the Potomac River Biotic Survey for 1999. MDE, BOM. 1999. $10,000.

1999 MBSS Sampling. MDNR, RAS. 1999-2000. $99,895.

Scope of work for the 1999 MBSS water quality sampling. MDNR, RAS. 1999-2000. $18,812.

North Branch of the Potomac River Final Report. MDE, BOM. 1999-200. $25,000.

MBSS 2000: Maryland Biological Stream Survey for CY2000 (AL). MDNR. 2000-2001. $113,948.

Scope of work for 2000 MBSS water quality sampling. MDNR. 2000. $30,996.

Albright Biological Sampling: 2000. APSC. 2000. $39,005.

Water quality assessment of the Piney Creek Reservoir – Watershed System. MDE, WMA, WSP. 2000 – 2002. $309,187 (M. Castro, lead PI)

MBSS 2000: Maryland Biological Stream Survey for CY2000 (AL). MDNR. 2000-2001. $113,948.

Water Quality Analyses for Potomac River Basinwide Monitoring Plan. MDE, TARSA. 2000-2001. $164,792.

Albright Biological Sampling: 2001. Allegheny Energy. 2001-2002. $47,645.

Stream restoration assessment for SHA: 2001-2002. MDT, SHA. 2001-2002. $63,864.

Trail design and usage: Avoiding and minimizing environmental impacts. MDNR, Waterways and Green ways Division. 2001. $27,904.

MBSS 2000: Maryland Biological Stream Survey for CY2001 (AL). MDNR. 2000-2001. $113,948.

Scope of work for 2001 MBSS water quality sampling. MDNR. $30,884.

Water Quality Analyses for Potomac River Basinwide Monitoring Plan. MDE, TARSA. 2001-2002. $164,792.

Gunpowder River: Assessment of minimum flows using the Montana Wetted Perimeter Technique. MDNR, Fisheries Service. $19,825.

Albright Biological Sampling: 2002. Allegheny Energy. 2002-2003. $47,645.

Assessment of fish movement at Dam #4. USDI, National Park Service. 2002-2004. $85,000.

Casselman River Biotic Survey. MDE, BOM. 2002-2003. $30,000.

Conceptual approach for using MBSS data to support sediment TMDL development for Maryland. MDE. 2002-2005. $175,631.

Hellbender water quality survey. MDE, BOM. 2002-2003. $13,750.

Hellbender water quality parameters and annotated bibliography for the hellbender. MDE, BOM. 2002. $5,235 (Gates and Morgan, Co-PIs).

Kempton Bioremediation Project. MDE, BOM. 2002-2004. $230,870. (Co-Pi with K. Kline)

Water quality and Hydrological Support for the LaVale Sanitary Commission. La Vale Sanitary Commission. 2002-2004 $24,973. (Morgan and Eshleman: Co-PIs)

Scope of work for 2002 MBSS water quality sampling. MDNR. 2002. $26,374.

MBSS 2002: Maryland Biological Stream Survey for CY2002 (AL). MDNR. 2002-2003. $116,123.

Water Quality Analyses for Potomac River Basinwide Monitoring Plan. 2002-2003. MDE, TARSA. 2002-2003. $133,533.

Albright Biological Sampling: 2003 Selenium Work. Allegheny Energy. 2003-2005. $19,858.

Biological and Chemical Services Support for the Maryland Bureau of Mines. MDE, BOM. 2003 – 2006. $50,000.

Contract Modification Number One to Kempton Bioremediation Project. MDE-BOM. 2002-2004. $61,201 (Co-PI with K. Kline).

Contract Modification Number Two to Kempton Bioremediation Project. MDE-BOM. 2002-2004. $103,000 (Co-PI with K. Kline).

Additional Funds Award to Casselman River Biotic Survey, MDE, BOM. $8,580, 2003.

Scope of work for 2003 MBSS water quality sampling. MDNR. 2003. $26,374.

MBSS 2003: Maryland Biological Stream Survey for CY2003 (AL). MDNR. 2003-2004. $116,123.

Stream restoration assessment for SHA: 2003-2004. MDT, SHA. 2003-2004. $41,895.

Water Quality Analyses for Potomac River Basinwide Monitoring Plan. 2003-2004. MDE, TARSA. 2002-2003. $136,898.

Contract Modification Number Three to Kempton Bioremediation Project. MDE, BOM. 2002-2004. $7,809 (Co-PI with K. Kline).

Contract Modification Number Four to Kempton Bioremediation Project. MDE, BOM. 2002-2004. $24,000 (Co-PI with K. Kline).

Contract Modification Number Five to Kempton Bioremediation Project. MDE, BOM. 2002-2004. $3,973 (Co-PI with K. Kline).

Supplemental funds for "Assessment of Fish Movement at Dam #4." MDNR, Fisheries Service. 2004. $9,975.

Additional Funds Award Number One to Biological and Chemical Services Support for the Maryland Bureau of Mines. MDE, BOM. 2004 - $20,000.

Additional Funds Award Number Two to Biological and Chemical Services Support for the Maryland Bureau of Mines. MDE, BOM. 2004 - $78,656.

Scope of work for 2004 MBSS water quality sampling. MDNR. 2004. $28,619.

MBSS 2004: Maryland Biological Stream Survey for CY2004 (AL). MDNR. 2004-2005. $153,635.

Stream restoration assessment for SHA: 2004-2005. MDT, SHA. 2004-2005. $38,033.

Georges Creek Survey and Field Support. MDE, BOM. 2004 - $75,169.

2004 North Branch Potomac River Chemical Contaminant Survey. MDE. 2004 - $124,957.

Water quality sampling and analytical support for the City of Frostburg. $20,747. City of Frostburg, 2005-2006. (Co-PI with K. M Kline).

Using MBSS Data to Identify Stressors for Streams that Fail Biocriteria in Maryland. 2004-2006. $152,266. MDE-TARSA.

MBSS 2005: Maryland Biological Stream Survey. MDNR $137,908 (Co-PI with R. Hilderbrand)

Scope of Work for 2005 MBSS Water Quality Sampling. MDNR ($15,414, with K. Kline).

Round Three Maryland Biological Stream Survey. 2005-2007 MDNR ($137,908, Co-PI with R. Hilderbrand)

Investigation of the impacts of the Poplar Lick ORV trail on water quality and invertebrate and brook trout populations in Poplar Lick in comparison to other upper Savage River tributaries without ORV trails. 2005-2006. $35,279 MDNR.

Investigation of the effects of increased salinization from deicer use on increased transport of nitrogen in streams of the Chesapeake Bay watershed. Maryland Water Resources Research Center 2006-2007 (S. Kaushal – PI, K. Eshleman – Co-PI, and R. Morgan – Co-PI). $~25,000.

Western Maryland Low pH Contaminant Study. MDE. 2005-2006, $149,368 (Co-PI with K. Kline).

Western Maryland Low pH Contaminant Study: Additional Funds Award. MDE. 2005-2006, $43,359 (Co-PI with K. Kline).

Additional subsampling of archived MBSS benthic samples. 2006. MDNR $24,900.

Stream restoration assessment for SHA: 2005-2006. Maryland Department of Transportation, State Highway Administration. 2005-2006. $39,409.

MBSS Benthic Sample Analyses (2006-2007). MDNR, 2006-2007, $42,251.

Scope of Work for 2006 MBSS Water Quality Sampling. MDNR ($19,413, Co-PI with K. Kline).

Estimating space requirements and extinction risk for Maryland brook trout. 2006-2008. MDDNR, $44,999 (Co-PI with R. Hilderbrand).

Field and laboratory support for Potomac River monitoring. MDDNR, Fisheries Service. 2007-2008. $9,204.00 (Co-PI with K. Kline).

Re-inventory of targeted brook trout (GCN species) populations in western Maryland. MDDNR, Fisheries Service. 2007-2009. $35,000 (Co-PI with R. Hilderbrand).

Scope of Work for 2007 MBSS Water Quality Sampling. 2007. MDNR $29,844 (Co-PI with K. Kline).

MBSS 2008: Maryland Biological Stream Survey. 2008-2009. MDNR, $159,776 (Co-PI with R. Hilderbrand).

Stream restoration assessment for SHA: 2006-2007. Maryland Department of Transportation, State Highway Administration. 2006-2007. $47,197.

Scope of Work for 2008 MBSS Water Quality Sampling. 2008. MDNR $37,935 (Co-PI with K. Kline).

Western Maryland TMDL Chemistry and Benthic Analyses. 2008-2009. MDE $149,894 (Co-PI with K. Kline).

Field and laboratory support for Potomac River monitoring. MDDNR, Fisheries Service. 2008-2009, $9,204. (Co-PI with K. Kline). <u>Renewal</u>

Field and laboratory support for upper North Branch Potomac River metals survey. MDE 2008-2009, $38,450. (Co-PI with K. Kline).

Stream restoration assessment for SHA: 2007-2008. MDOT, SHA. 2007-2008, $74,323.

Tier 2 Sampling Support. MDNR. 2008-2009, $30,233. (Co-PI with R. Hilderbrand).

Western Maryland TMDL Chemistry and Benthic Analyses. MDE 2008-2009, $149,894. (Co-PI with K. Kline).

Western Maryland TMDL Chemistry and Benthic Analyses. MDE 2009-2010, $85,620. (Co-PI with K. Kline). Renewal

Stream restoration assessment for SHA: 2008-2009. MDOT, SHA. 2008-2009, $76,665.

Scope of Work for 2009 MBSS Water Quality Sampling. 2009. MDNR $38,840 (Co-PI with K. Kline).

Modification to 2009 MBSS Water Quality Sampling. 2009. MDNR $10,253 (Co-PI with K. Kline).

Casselman River Literature Review. 2009-2010. MDE $17,396.

Casselman River Mining Assessment. 2010-2011. MDE $10,272.

Analyses of coal combustion byproducts (CCB) at ash disposal sites. 2009-2010. MDE $49,762. (NCE to 12.31.11)

Scope of Work for 2010 MBSS Water Quality Sampling. 2010. MDNR $33,652 (Co-PI with K. Kline).

McDonald Mine Project Support. 2010-2011. MDE $19,967.

Stream restoration assessment - additional funding. 2009-2010. MDOT, SHA. $42,785.

Stressor Identification: Methodology development for assessing biological impairments related to urbanization and flow modification in Maryland. MDE-TARSA. 2010-2011, $152,967. (NCE to 12/31/11)

Scope of Work for 2011 MBSS Water Quality Sampling. 2011. MDNR $35,954 (Co-PI with K. Kline).

McDonald Mine Project Support- Phase II. 2010-2011. MDE $22,879. (NCE to 6.30.12).

Casselman River pH TMDL Monitoring Program. 2010-2011. MDE $17,167. (Co-PI with K. Kline).

Casselman River Mining Assessment. 2011-2012. MDE $10,272.

Casselman River pH TMDL Monitoring Program. 2011-2012. MDE $34,472 (Co-PI with K. Kline).

McDonald Mine Project Support- Phase III. 2012-2013. MDE $29,532.

2012 MBSS Water Quality Sampling. MDNR $47,956 (Co-PI with K. Kline).

SHA Stream Restoration Assessment Projects: FY 2012. MDOT, SHA. 2011-2012, $61,577.

Establishing Baseline Water Quality Conditions in Surface Waters in Western MD in Advance of Marcellus Shale Natural Gas Development (Year 1) - DNR - $88,857

Casselman River pH TMDL Monitoring Project. MDE/BOM, 2013-2014. $40,477

Assessment of Bioswale Performance. MDOT/SHA, 2013-2015 (1.5 years), $248,136.

Casselman River pH TMDL Monitoring Project. MDE/BOM, 2014-2015. $40,032

Scope of Work for Jennings Run Project. MDE/BOM, 2014-2015. $98,450

Establishing Baseline Water Quality Conditions in Surface Waters in Western MD in Advance of Marcellus Shale Natural Gas Development (Year 2). DNR, 2013-2015. $88,857.

2013 MBSS Water Quality Sampling. MDNR $17,667 (Co-PI with K. Kline).

SHA Stream Restoration Assessment Projects: FY 2014. MDOT, SHA. 2013-2014, $68,434.

2014 MBSS Water Quality Sampling.MDNR $25,915 (Co-PI with K. Kline).

Establishing Baseline Water Quality Conditions in Surface Waters in Western MD in Advance of Marcellus Shale Natural Gas Development – II. DNR, 2013-2015. $20,433. (Co-PI with K. Kline).

Scope of Work for 2015 MBSS Water Quality Sampling. MDNR. $38,086 (Co-PI with K. Kline).

McDonald Mine and Butcher Run Project. MDE/BOM. $16,291.

SHA Stream Restoration Assessment Projects: FY 2015. MDOT/SHA. $67,749.

Establishing Baseline Water Quality Conditions in Surface Waters in Western MD in Advance of Marcellus Shale Natural Gas Development – III. DNR, 2015-2017. $18,313. (Co-PI with K. Kline).

SHA Stream Restoration Assessment Projects: FY 2016. MDOT/SHA. $67,276.

Assessment of Bioswale Performance – Phase II. MDOT/SHA, 2013-2015 (1.5 years), $289,764.

Temporal Analysis of Georges Creek Water Quality. MDE-BOM 2015-16. $49,484.

McDonald Mine and Butcher Run Project – Phase III. MDE/BOM. $20,653.

Hoffman Tunnel Project, MDE-BOM. $16,036.

Student Projects Directed (CBL)

1972 - N. Ulanowicz (NSF) - The frequency of muscle protein polymorphism in *Menidia menidia* (Atherinidae) along the Atlantic Coast.

1973 - N. Ulanowicz (NSF) - Acute effects of selenium on the hogchoker (*Trinectes maculatus*).

1973 - P. Benner (CBL) - The development of a method of electrophoresis for *Chrysaora quinquecirrha* and comparison of proteins between red and white phases.

1974 - R. Lunsford (St. Mary's Intern Program) - Oversized striped bass.

1974 - Six NSF students - Utilization of white perch and hogchoker.

1974 - M. A. Wickes (CBL) - Salinity effects on enzymes of American oyster.

1975 - S. Murphy (St. Mary's Intern) - Otoliths and scales of striped bass.

1975 - R. Baker (St. Mary's Intern) - Anchovy distributions at Calvert Cliffs.

1975 - P. Mooar (CBL Intern) - Physiology of thermal acclimation in *Mya arenaria*.

1975 - J. Frank (NSF) - Biochemical changes in mud crabs.

1975 - C. Buys (NSF) - Genetic variability in *Mya arenaria*.

1976 - M. Cole (NSF) - Genetic variation in *Callinectes sapidus*.

1976 - N. Ulanowicz (CBL) - Genetic variation in striped bass.

1976 - E. Kramarsky (CBL) - Isozyme changes in mud crabs.

Graduate Student Committee Member (1970-1978)

John Hitron, MS - Long Island Univ.

William Baun, MS - Long Island Univ.

Eddy Forman, MS - Dept. of Animal Science, UMCP.

Lester Hatton, Jr., PhD - Dept. of Animal Science, UMCP.

Robert Knight, MS - Dept. of Biology, Southern Connecticut State College.

Graduate Students (1979-Present) as Major Professor

Graduated

P.E. McKeown (Fisheries, co-advisee with C.H. Hocutt) - An electrophoretic analysis of the *Etheostoma variatum* complex with zoogeographic implications. MS 1982.

J.R. Lebo (Fisheries) - The distribution and zoogeography of the fishes of the Potomac River. MS 1983.

J. Quattro (Fisheries) - Microgeographic DNA sequence dynamics within and among populations of the eastern brook trout *Salvelinus fontinalis*. MS 1986.

T. Brush (Wildlife) - Analysis of geographic variation in gastrointestinal helminth parasites of *Sylvilagus floridanus* and *Lepus americanus*. MS 1987.

R. Stouffer (Fisheries) - The larval development of the black acara *Cichlasoma bimaculatum* with emphasis on temperature effects on juvenile growth rates. MS 1987.

J. Beskid (Wildlife) - Effects of Treflan on embryonic development of bobwhite quail. MS 1988.

M. Pinder (Fisheries) - Effects of water chemistry, physical habitat, and watershed characteristics on cyprinid presence and distribution in Western Maryland streams. MS 1991.

R. Gregg (Biology, co-advisee with J. H. Howard) - Heterozygosity and fitness components in mottled sculpin (*Cottus bairdi*). MS 1992.

D. Kenney (Fisheries) - An evaluation of factors influencing salmonid habitation in Idaho mid-elevation headwater streams. MS 1994.

M. K. Meagher Kline (Fisheries) - Use of a geology-based method to predict sensitivity of higher elevation streams in western Maryland to acid deposition. MS 1995.

K. Surgent Lippenholz (Applied Ecology and Conservation Biology) - Use of the riffle stability index and stream morphology to predict fish abundance and diversity in western Maryland. MS 1997.

R. Burke Hott (Applied Ecology and Conservation Biology) - Effects of acid mine drainage on riffle stability. MS 1997.

M. Pacella Hawkins (Applied Ecology and Conservation Biology) - Elevational distribution of brook trout in western Maryland. MS 1998.

T. Prochaska (Wildlife/Fisheries Biology) - Determination of ecological requirements for twenty freshwater fishes of Maryland. MS 1999.

M. Hall (UMCES/MEES) - Genetic relationships among Maryland brook trout populations. MS 2000.

D. Wiley (Wildlife/Fisheries Biology). Effects of artificial structures and physical habitat on distribution and abundance of American eels (*Anguilla rostrata*) in five river basins in Maryland. MS 2002

A. Walz (UMCES/MEES, co-advisee with M. Ottinger - UMCP) - The study of associations between Maryland's amphibian species and habitat parameters at local and landscape scales. PhD 2002.

J. Holt (Wildlife/Fisheries Biology) – Predicting stream biological integrity using landscape characteristics. MS 2003

J. Kilian (Wildlife/Fisheries Biology) - Fish assemblages in non-tidal streams of Maryland: The influences of assemblage spatial variability on the index of biotic integrity. MS 2004

S. Cushman (UMCES/MEES) - Habitat complexity, patch selection, and movement of fish in small urban streams. PhD 2006.

Current

K. Ashcraft Pearce (MEES, PHD – Co-advisor with Dr. Thomas Serfass, FSU)

D. Feller (FSU, MS).

Graduate Students (1979-Present) as Committee Member

D. Bruch (Wildlife, MS 1982)
W. Goodfellow (Fisheries, MS 1983)
J. Zibel (Fisheries, deceased)
D. Oswald (Fisheries)
T. Davin (Wildlife, MS 1983)
T. Welch (Fisheries, MS 1985)
K. Titus (UMCEES/MEES, PhD 1984)
E. Price (Fisheries, MS 1984)
C. Twigg (Biology, MS 1984)
J. Pizza (NYU, PhD 1983)
D. Clearwater (Wildlife, MS 1984)
D. Vann (Fisheries)
P. Tirrell (Wildlife)
M. Breslin (Physical Education)
R. Spencer (Wildlife, MS 1985)
F. Arnold (MEES, MS 1986)
D. Shuharte (Biology, MS 1986)
L. Vukovich (Fisheries, MS 1988)
J. Siemien (Fisheries, MS 1987)
H. Severyn (UMCEES/MEES, PhD 1993)
S. Curd (Wildlife, MS 1996)
P. Farr (Wildlife, MS 1995)

M. Barbour (UMCEES/MEES, PhD 1994)
J. Evans (UMAB/MEES, PhD 1998)
J. Roberts (Wildlife, MS 1995)
E. Strobel-Douglas (AE&CB, MS 1997)
C. Sewalk (Wildlife, MS 1997)
J. White (Agronomy, UMCP, MS 1997)
D. Neely (AE&CB, MS 1999)
B. Marsh (AE&CB, MS 1998)
L. Farley (AE&CB)
B. Melvin (AE&CB)
H. Berndt (UMCES/MEES, MS 1999)
S. Julian (AE&CB, MS 1999)
B. Shrader (UMBC/MEES, Ph.D. 2001)
E. Sheninger (AE&CB)
M. George (AE&CB)
M. Stanley (WVU, deceased)
D. Swartz (UMCEES/MEES, PhD 1989)
T. Wharton (Wildlife, MS 1994)
S. Chiotha (UMCEES/MEES, PhD 1990)
D. Walbeck (Wildlife, MS 1989)
M. Mazambani (Fisheries, deceased)
L. DeWald (Fisheries, MS 1990)
R. Waid (Fisheries, MS 1990)
R. Kawula (Wildlife, MS, 1992)
S. Smith (Wildlife, MS 1994)
N. Stewart (Wildlife, MS 1994)
R. Thomas (Biology)
J. Norman (Biology)
R. Keller (Biology)
F. Shonhiwa (Biology, MS 1993)
R. Kwaramba (Fisheries, MS 1992)
K. Spyker (Fisheries, MS 1992)
A. Caschetta (AE&CB, MS 1993)
J. Yacabucci (AE&CB)
T. Goodwill (AE&CB MS 2001)
J. Hakala (WVU, MS 2000)
J. Sweka (PhD, WVU 2003)
J. Barker (MEES, MS 2002)
C. Giffen (MEES, MS 2005)
M. Ramsey (MEES, MS 2001)
A. Burke (Wildlife)
M. O’Connor (MEES, MS 1999)
J. Jacobs (MEES, PhD 2007)
H. Y. Kim (MEES, MS 2007)
C. Klocker (MEES, MS 2007)
T. Manyin (MEES, PhD, 2008)

S. Pollock (MEES, PhD, 2008)
D. Hanks (WVU, PhD)
D. Kazyak (MEES, PhD, 2015)
L. Tempinson (MEES, MS)

Technical/Classified Staff Directed

1971 – 5
1972 – 5
1973 – 10
1974 – 8
1975 – 10
1976 – 10
1977 – 10
1978 – 10
1979 – 6
1980 – 0
1981 – 0
1982 – 0
1983 – 2
1984 – 5
1985 – 2
1986 – 2
1987 – 3
1988 – 3
1989 – 14
1990 – 15
1991 – 8
1992 – 6
1993 – 3
1994 – 4
1995 – 9
1996 – 5
1997 – 5
1998 – 3
1999 – 4
2000 – 5
2001 – 6
2002 – 9
2003 – 10
2004 – 8
2005 – 9
2006 – 7
2007 – 8
2008 – 10
2009 – 2

2010 – 3
2011 – 3
2012 – 3
2013 – 3
2014 – 4
2015 – 5

Teaching Interests

Aquatic Ecology/Stream Ecology

Environmental Toxicology

Aquatic Toxicology

Animal Ecology

Fish Physiology

Fisheries Science

Fisheries Genetics

Conservation Biology

Teaching Experience – Academic Year

(Excludes student thesis credits.)

1979-1980

Fish Management and Culture (4 cr., 0401.420)

Wildlife/Fisheries Seminar - Habitat Management (1 cr., 0401.493)

Independent Study in Fisheries - Aquatic Toxicology (2 cr., 0401.692)

Wildlife/Fisheries Seminar - Animal Communication (1 cr., 0401.691)

1980-1981

Fish Management and Culture (4 cr., 0401.420)

Independent Study in Fisheries - Biochemical Systematics of Fishes (3 cr., 0401.692)

Physiology and Biochemistry of Pollution (Biol/AEL 1680, 3 cr.)

Independent Study in Fisheries - Fish Disease (2 cr., 0401.692)

Environmental Toxicology (3 cr., 0401.691)

Independent Study in Fisheries/Wildlife - Biochemical Systematics (2 cr., 0401.692)

1981-1982
Fish Management and Culture (4 cr., 0401.420)

Independent Study in Fisheries - Aquatic Toxicology (2-3 cr., 0401.692)

Independent Study in Fisheries - Advanced Electrophoresis Techniques (3 cr., 0401.692)

1982-1983
Wildlife/Fisheries Seminar (1 cr., 0401.493)

Environmental Toxicology (3 cr., 0401.615)

1983-1984
Fish Management and Culture (4 cr., 0401.420)

Physiology and Biochemistry of Pollution (Biol/AEL 1680, 3 cr.; 0401.692, 3 cr.)

Summer 1984
Independent Study in Fisheries - Readings in Biochemical Toxicology (3 cr., 0401.692)

Independent Study in Fisheries - Readings in Molecular-Biochemical Systematics (3 cr., 0401.692)

1984-1985
Environmental Toxicology (3 cr., 0401.615)

Special Topics in Fisheries and Wildlife - Aquatic Toxicology (2 cr., 0401.650)

1985-1986
Wildlife Management and Ecology (4 cr., 0401.624)

Independent Study in Fisheries - Population Genetics (2 cr., 0401.692)

Special Topics in Wildlife and Fisheries - Advanced Electrophoretic Techniques in Wildlife and Fisheries (2-3 cr., 0401.650)

Special Topics in Wildlife and Fisheries - Advanced Fisheries Management (2-3 cr., 0401.650)

Independent Study in Fisheries - Genetic Consequences of Stream Capture in Fishes (3 cr., 0401.692)

Special Topics in Wildlife and Fisheries - Biometry (3 cr., 0401.650)

1986-1987
Environmental Toxicology (3 cr., 0401.615)

Wildlife Management and Ecology (4 cr., 0401.624)

Special Topics in Wildlife and Fisheries - Aquatic Toxicology (3 cr., 0401.650)

Special Topics in Wildlife and Fisheries - Biometry (3 cr., 0401.650)

Advanced Limnology (4 cr., 0401.608)

1988-89

Environmental Toxicology (3 cr., 0401.615)

Special Topics in Wildlife and Fisheries - Aquatic Toxicology (3 cr., 0401.650)

Advanced Limnology (4 cr., 0401.608)

Special Topics in Wildlife and Fisheries - Readings in Ichthyology (4 cr., 0401.650)

1989-1990

Fisheries Science (3 cr., 0401.611)

1990-1991

Individual Research in Biology - Air Quality in Western Maryland (4 cr., 0401.699)

Environmental Toxicology (3 cr., 0401.615)

Individual Research in Biology - Design of a Water Chemistry Monitoring Program (2 cr., 0401.699)

Fisheries Science (3 cr., 0401.611)

Special Topics in Fisheries - Aquatic Toxicology (3 cr., 0401.650)

Advanced Limnology (4 cr., 0401.608)

1991-1992

Environmental Toxicology (3 cr., 0401.615)

Graduate Seminar (1 cr., 0401.694)

1992-1993

Special Topics in Fisheries - Aquatic Toxicology (3 cr., 0401.650)

Advanced Limnology (4 cr., 0401.608)

1993-1994

Island Biogeography and Reserve Design (2 cr., 0401.641)

Special Topics in Fisheries (3 cr., 0401.650)

Environmental Toxicology (3 cr., 0401.615)

1994-1995
Environmental Toxicology (3 cr., 0401.615)

Ecological Toxicology (3 cr., 0401.650)

Design of Nature Reserves (3 cr., 0401.650)

Freshwater Ecology (3 cr., 0401.650)

1995-1996
Environmental Toxicology (3 cr., 0401.615)

Ecological Toxicology (3 cr., MEES 698P)

1996-1997
Aquatic Ecology (3 cr., 0401.615, MEES 698Q)

Special Topics - Readings in Conservation and Population Genetics (3 cr., 0401.650)

1997-1998
Individual Research in Fisheries - Special Readings in Environmental Monitoring Research (3 cr., 0401.699)

Environmental Toxicology (3 cr., 0401.615; MEES 698P)

1998-1999
Aquatic Ecology (3 cr., 0401.615, MEES 698Q)

1999-2000
Special Topics - Readings in Stream Restoration (3 cr., 0401.650)

2000-2001
Stream Ecology (3 cr., 0401.615, MEES 698Q)

Seminar in Principles of Aquatic Restoration Ecology (1 cr., MEES 608X, 0401.694)

2002-2003
Stream Ecology (3 cr., 0401.615, MEES 698Q)

Seminar – Advanced Topics in Aquatic Ecology: Stream Processes (1 cr., MEES 608X, 0401.694)

2003-2004
Stream Ecology (3 cr., 0401.615, MEES 698Q) – Fall 2003

Readings in Aquatic Chemistry (MEES 699) – Spring 2004

2004-2005
Stream Ecology (3 cr., 0401.615, MEES 698Q) – Fall 2004

Seminar – Advanced Topics in Aquatic Ecology: Riparian Ecology (1 cr., MEES 608X, 0401.694)

2005-2006
Applied Environmental Chemistry (3 cr., MEES 698Q)

2006-2007
Stream Ecology (3 cr., 0401.615, MEES 698Q) – Fall 2006

Seminar – Advanced Topics in Aquatic Ecology: Stream Restoration: Fact and Science Fiction (1 cr., MEES 608X, 0401.694)

2008-2009
Stream Ecology (3 cr., 0401.615, MEES 698Q) – Fall 2008

Seminar – Neoclassical Papers in Aquatic Ecology – Spring 2009 (1 cr., MEES 608X, 0401.694)

2011-2015
Seminar (2011) – Ecological Risk Assessment in Aquatic Ecosystems – Spring 2011 (1 cr., MEES 608X, 0401.694)

Seminar (2013) - Theoretical Stream Ecology – Spring 2013 (2 cr., MEES 608X, 0401.694)

Seminar (2015) – Conservation Biology of Appalachian Fauna – Spring 2015 (1 cr., MEES 608X, 0401.694)

Reviewer (Publication, Report, or Proposal)

Journal Articles and Book Chapters
35th Ann. Conf. SE Assoc. Fish & Wildlife Agencies

37th Ann. Conf. SE Assoc. Fish and Wildlife Agencies

38th Ann. Conf. SE Assoc. Fish and Wildlife Agencies (2)

44th Southeastern Association of Fish and Wildlife Agencies

American Fisheries Society - Genetic Principles and Practices for Fisheries Scientists (review of book chapter)

Archives of Environmental Contamination and Toxicology (2) by George Cox

Canaan Valley and Its Environs, Proc. WV Academy of Science (2)

Canadian Journal of Fisheries and Aquatic Sciences

Chesapeake Science (3)

Copeia (2)

Ecology and Management of High-Elevation Forests of the Central and Southern Appalachian Mountains

Environmental Biology of Fishes

Environmental Management (5)

Environmental Monitoring and Assessment (2)

Environmental Science and Technology (12)

ERDA Symposium Series

Estuaries (2)

Fisheries Management and Ecology

Fisheries Research

Freshwater Science

Hudson River Environmental Society - Hudson River Symposium

Hydrobiologia

Journal of Aquatic Ecosystem Stress and Recovery

Journal of Mammalogy (2)

Journal of Physical Geography

Journal of the Pennsylvania Academy of Science

Kuwait Journal of Science and Engineering (2)

Landscape Ecology

Marine Biology (2)

Marine Ecology--Progress Series

North American Journal of Fisheries Management (8)

Northeastern Naturalist

Pennsylvania Academy of Sciences (2)

Proceedings of the Southeastern Association of Fish and Wildlife Agencies

Restoration Ecology (2)

Reviews in Aquatic Science

Risk Assessment: Logic and Measurement - review of "Landscape perspective on ecological risk assessment" chapter by Carl Richards and L.B. Johnson.

Sixth Annual Larval Fish Conference

South African Journal of Zoology

Transactions of the American Fisheries Society (16)

W. C. Brown Publishers - review of "Aquatic Ecology" chapter for Conservation Biology: Concepts and Applications

Water (2)

Water Resources Bulletin (3)

West Virginia Academy of Science

West Virginia University Press

Wetlands (2)

Technical Reports

Maryland Department of the Environment

MDNR - Chesapeake Bay Research and Monitoring Division (2)

MDNR - WRA, Bureau of Mines

MDNR -Tidewater Administration (2)

Proposal and Panels

Hudson River Foundation (4)

Illinois Indiana - Sea Grant College Program

Louisiana State University Sea Grant (2)

MAES (2)

Maryland Department of Natural Resources RAS – MANTA

Maryland Department of the Environment

Maryland Institute for Agriculture and Natural Resources

Maryland Power Plant Siting Program (2)

MDNR - TA, Chesapeake Bay Research and Monitoring Program (3)

National Biological Survey (USDI)

National Institutes of Health

National Science Foundation (13)

NOAA-NMFS

Northeastern Forest Experiment Station (USDA-FS)

Pennsylvania Academy of Science Research Grant Committee

Scientific and Technical Advisory Committee -- Chesapeake Bay Program

The Pennsylvania State University Sea Grant

The Universities Council on Water Resources, Inc. (9)

U.S. EPA -- Environmental Education Fellowships (3)

United States Department of the Interior, US Geological Survey, Species at Risk Program (2)

University of Maryland Sea Grant (4)

University of Michigan Sea Grant (2)

USAID (Forestry Panel 1992 - Three primary, six secondary reviews)

USAID (UNIARCL - 26 preproposals, 16 full proposals)

USEPA (Office of Research and Development – Endocrine Disrupters Panel, four primary reviews)

USEPA (Office of Research and Development – Graduate Environmental Study Fellowships, three primary reviews)

USEPA STAR Program – Futures Research in Natural Science (Nine proposals)

West Virginia University, Water Research Institute

Wild Resource Conservation Fund (3 proposals)

Consultant Activities

3-M Corporation

Akin, Gump, Strauss, Hauer and Feld (multiple projects)

Battelle Columbus Laboratories

Becton Dickinson Immunodiagnostics

City of Frostburg (Whitman, Requardt and Associates)

Copper Development Association

Corning Glass Works

Dames and Moore

Department of Justice

Federal Power Commission (Federal Energy Regulatory Commission)

Free Flow Power

Jackson Kelly

Lewis, Wilson, Lewis and Jones, Ltd.

Maryland Power Plant Siting Program

Mettiki Coal

Micromedia Systems

MMA & SP

National Renewable Resources (Arlington Associates)

Pharmacia, Inc.

Soap and Detergent Association

Southern Environmental Law Center

Trident Engineering Associates, Inc.

Upper Mississippi River Basin Commission

Westinghouse Electric Corporation

XA Fishing Inc.

Continuing Professional Education

Atomic Absorption Spectrometry Lecture Series. Society for Applied Spectroscopy, 1973.

Workshop in Acoustic Stock Estimation. College of Fisheries, University of Washington, 1974.

Workshop on Electrophoresis. LKB, Inc., 1983.

Recombinant DNA Methodology and Polymerase Chain Reaction Methodology. Exon-Intron, Inc., 1991.

James T. Peterson

Oregon Cooperative Fish and Wildlife Research Unit
104 Nash Hall, Oregon State University
Corvallis, Oregon 97331-3803
Phone: 541.737.1963, FAX: 541.737.3590
jt.peterson@oregonstate.edu
http://people.oregonstate.edu/~peterjam/

Education

Doctor of Philosophy, Fisheries, University of Missouri at Columbia, December 1996

Master of Science, Biology, University of Illinois at Urbana- Champaign, May 1990

Bachelor of Science, Ecology, Ethology, and Evolution, University of Illinois at Urbana-Champaign, May 1986

Professional Experience

2011 – present Assistant Unit Leader, USGS Oregon Cooperative Fish and Wildlife Research Unit

2011 – present Associate Professor, Department of Fisheries and Wildlife, Oregon State University

1999 – 2011 Assistant Unit Leader, USGS Georgia Cooperative Fish and Wildlife Research Unit

2006 – present Adjunct Associate Professor, Warnell School of Forestry and Natural Resources, University of Georgia

1999 – 2006 Adjunct Assistant Professor, Warnell School of Forest Resources, University of Georgia

1997 – 1999 Research Biologist, USDA Forest Service, Rocky Mountain Research Station

Research Summary

Research-related Awards

Honorable Mention for Best Paper in 1993. Awarded by the American Fisheries Society for *Colonization rates of fishes in experimentally defaunated warmwater streams*, with P.B. Bayley, Transactions of the American Fisheries Society Volume122.

Award for Best Paper in 1995. Awarded by the American Fisheries Society for *Optimizing sampling effort for sampling warmwater stream fish communities*, with C.F. Rabeni, North American Journal of Fisheries Management volume 15.

Award for Best Presentation in 2000. Awarded by the North Carolina Chapter of the American Fisheries Society for *Modeling the Effects of Land Use and Climate Change on Riverine Smallmouth Bass*, with Thomas Kwak, North Carolina Chapter of the American Fisheries Society Annual Meeting.

Honorable Mention for Best Paper in 2001. Awarded by the American Fisheries for *Species presence for zero observations: an approach and an application to estimate probability of occurrence of fish species and species richness*, with P.B. Bayley, Transactions of the American Fisheries Society volume 130.

Best Scientific Presentation 2005 Annual Meeting, Idaho Chapter American Fisheries Society, 02/27/2005.

Best Scientific Presentation, Illinois Chapter of the American Fisheries Society, 02/24/2009.

Excellence in Science Award, USGS Cooperative Research Units Program, 02/02/2010.

Career Contribution Award awarded by Georgia Chapter of the American Fisheries Society 2/11/2011

Service Excellence Award, USGS Cooperative Research Units Program, 02/02/2013.

Honorable mention for the American Publishers Awards for Professional and Scholarly Excellence (The PROSE Awards, 2013) for *Decision Making in Natural Resource Management: A Structured, Adaptive Approach*

Excellence in Science Award, USGS Cooperative Research Units Program, 02/02/2014.

Publications

Peer-reviewed, 70 journal articles, 2 proceedings, 6 book chapters, 1 Book

* Publication of student or post-doctoral fellow

1. Peterson, J.T., and P.B. Bayley. 1993. Colonization rates of fishes in experimentally defaunated warmwater streams. Transactions of the American Fisheries Society 122:199-207.

2. Peterson, J.T., and C.F. Rabeni. 1995. Optimizing sampling effort for sampling warmwater stream fish communities. North American Journal of Fisheries Management 15:528-541.

3. Peterson, J.T., and C.F. Rabeni. 1996. Natural thermal refugia for temperate warmwater stream fishes. North American Journal of Fisheries Management 16:738-746.

4. Peterson, J.T. and T.J. Kwak. 1999. Modeling the effects of land use and climate change on riverine smallmouth bass. Ecological Applications 9:1391-1404.

5. Peterson J.T. and C.F. Rabeni. 2001. Evaluating the efficiency of a one-square-meter quadrat sampler for riffle-dwelling fish. North American Journal of Fisheries Management 21:76-85.

6. Bayley, P.B. and J.T. Peterson. 2001. Species presence for zero observations: an approach and an application to estimate probability of occurrence of fish species and species richness. Transactions of the American Fisheries Society 130:620-633.

7. Rieman, B.E., J.T. Peterson, J. Clayton, P. Howell, R.F. Thurow, W. Thompson, and D.C. Lee. 2001. Evaluation of the potential effects of federal land management alternatives on the trends of salmonids and their habitats in the Interior Columbia River Basin. Journal of Forest Ecology and Management. Journal of Forest Ecology and Management 153:43-62.

8. Peterson, J.T. and C. F. Rabeni. 2001. The relation of fish assemblages to channel units in an Ozark stream Transactions of the American Fisheries Society 130:911-92.

9. Peterson, J.T. and C.F. Rabeni. 2001. Evaluating the physical characteristics of channel units in an Ozark stream. Transactions of the American Fisheries Society 130:898-910.

10. Dunham, J.B., B. E. Rieman, and J.T. Peterson. 2002. Patch-based models of species occurrence: lessons from salmonid fishes in streams. *Pages* 327-334 *in* J.M. Scott and P. J. Heglund, *editors*. Predicting Species Occurrences: Issues of Accuracy and Scale. Island Press, Covelo, California.

11. Peterson, J.T., J. Dunham, P. Howell, S. Bonar, R. Thurow. 2002. Protocol for determining bull trout presence. Western Division of the American Fisheries Society. American Fisheries Society, Bethesda, Maryland. (This is a peer-refereed special publication of the Western Division of the American Fisheries Society).

12. Weigel, D.E., J.T. Peterson, and P. Spruell. 2002. A probabilistic model to detect introgression between westslope cutthroat trout and rainbow trout based on phenotypic characteristics. Transactions of the American Fisheries Society 131:389-403.

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47. Peterson, J.T., K. McDonnell, M.C. Colvin. 2014. Coarse Resolution Planning Tools for Prioritizing Central Valley Project Improvement Act Fisheries Activities. Final Report to Central Valley Project Improvement Act Fisheries Program, Sacramento, CA.

48. Romito, A., J.T. Peterson, and M.J. Conroy. 2014. Structured Decision Making for Brown Bears on National Park Service Lands in Alaska - Integration of Monitoring to Inform Management. Final Report to the U.S. Geological Survey. Warnell School of Forestry and Natural Resources, University of Georgia, Athens.

49. Kauffman, J.B., I. Basuki, V. Arifanti, G. Anshari, D. Hadriyanto, J. Peterson and D. Murdiyarso. 2014. The Kalimantan Wetlands and Climate Change Project (KWACs), Progress Report. Prepared for: U.S. Agency for International, Development American Embassy – Jakarta, Jl. Medan Merdeka Selatan No. 3-5, Jakarta 10110, Indonesia.

50. Scheerer, P.D., J.T. Peterson, and S. Clements. 2015. 2014 Warner Sucker Investigations (Lower Twentymile Creek). Annual Progress Report, Fish Research Project Oregon. Oregon Department of Fisheries and Wildlife, Corvallis, Oregon.

51. Scheerer, P.D., J.T. Peterson, and S. Clements. 2015. 2014 Foskett Spring Speckled Dace Investigations. Annual Progress Report, Fish Research Project Oregon. Oregon Department of Fisheries and Wildlife, Corvallis, Oregon.

52. Peterson, J.T. and J. Saenz. 2015. The Development of An Adaptive, Decision-Support Tool For The Conservation And Recovery Of Least Chub, Iotichthys Phlegethontis Report to Bureau of Land Management. May 2015. Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, Oregon.

53. Kauffman, J.B., I. Basuki, V. Arifanti, G. Anshari, D. Hadriyanto, J. Peterson and D. Murdiyarso. 2015. The Kalimantan Wetlands and Climate Change Project (KWACs), Progress Report. Prepared for: U.S. Agency for International, Development American Embassy – Jakarta, Jl. Medan Merdeka Selatan No. 3-5, Jakarta 10110, Indonesia.

54. Peterson, J.T. 2015. The Development of an Adaptive, Decision-Support Tool for the Conservation and Recovery of Columbia Spotted Frog (Rana Luteiventris). Interim Final Report. June 2015. Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, Oregon.

55. Kauffman, J.B., I. Basuki, V. Arifanti, G. Anshari, D. Hadriyanto, J. Peterson and D. Murdiyarso. 2016. The Kalimantan Wetlands and Climate Change Project (KWACs), Progress Report. Prepared for: U.S. Agency for International, Development American Embassy – Jakarta, Jl. Medan Merdeka Selatan No. 3-5, Jakarta 10110, Indonesia.

Software Developed

1. Haas, T.C, J.T. Peterson, and D.C. Lee. 2000. CATDAT categorical data analysis software, available online at: <http://coopunit.forestry.uga.edu/unit_homepage/Peterson/Software/software>

2. Peterson J.T. and J. Zhu. 2004. CapPost: software for estimating stream-dwelling salmonid capture, detection, and posterior presence probabilities, available online at: <http://coopunit.forestry.uga.edu/unit_homepage/Peterson/Software/software>

3. Peterson, J.T, and M. Key. 2010. SMPOP: software for simulating stream-fish metapopulation dynamics, available online at: http://coopunit.forestry.uga.edu/unit_homepage/Peterson/Software/software

Technical Presentations **(last 6 years)**

Prior to 2010, 133 presentations with 29 of those as invited presentations.

*Presentation by a student or post-doctoral fellow.

1. *Dycus, J.C., J.T. Peterson, and R. Bringolf. 2010. An evaluation of the influence of stream flows on freshwater mussel growth. Annual Meeting of the Georgia Chapter of the American Fisheries Society, Perry, GA.

2. *Kirsch, J.E. and J.T. Peterson. 2010. A multi-scaled approach to evaluating the fish community structure in southern Appalachian stream fishes. Annual Meeting of the Georgia Chapter of the American Fisheries Society, Perry, GA.

3. *Shea, C.P. and J.T. Peterson 2010. Misidentification of Freshwater Mussels: Contributing Factors, Management Implications, and Potential Solutions. Annual Meeting of the Georgia Chapter of the American Fisheries Society, Perry, GA.

4. *Trushel, B.E., J.T. Peterson, and C.A. Jennings. 2010. Influence of landscape- and lake-level characteristics on sportfish production in southeastern U.S. impoundments. Annual Meeting of the Georgia Chapter of the American Fisheries Society, Perry, GA.

5. Crownhart, A.K., R.B. Bringolf, J.T. Peterson, and J. Wisniewski. 2010. Development of a non-lethal approach for assessing stress in freshwater mussels. Annual Meeting of the Georgia Chapter of the American Fisheries Society, Perry, GA.

6. *Dycus, J.C., J.T. Peterson, and R. Bringolf. 2010. An evaluation of the influence of stream flows on freshwater mussel growth. Annual Meeting of the Southern Division of the American Fisheries Society, Asheville, NC.

7. *Kirsch, J.E. and J.T. Peterson. 2010. A multi-scaled approach to evaluating the fish community structure in southern Appalachian stream fishes. Annual Meeting of the Southern Division of the American Fisheries Society, Asheville, NC.

8. *Shea, C.P. and J.T. Peterson 2010. Misidentification of Freshwater Mussels: Contributing Factors, Management Implications, and Potential Solutions. Annual Meeting of the Southern Division of the American Fisheries Society, Asheville, NC.

9. *Trushel, B.E., J.T. Peterson, and C.A. Jennings. 2010. Influence of landscape- and lake-level characteristics on sportfish production in southeastern U.S. impoundments. Annual Meeting of the Southern Division of the American Fisheries Society, Asheville, NC.

10. Peterson, J.T., M.C. Freeman, W.B. Hughes, G.R. Buell, L.E. Hay, K.R. Odom, J.W. Jones, R.B. Jacobson, J.S. Schindler, and S.A. Jones. 2010. The Southeast Resource Assessment Project. Meeting of the Southeastern Natural Resource Management Agencies. August 3 - 4, Mansfield, GA.

11. Peterson, J.T., M.C. Freeman, W.B. Hughes, G.R. Buell, L.E. Hay, K. R. Odom, J.W. Jones, R.B. Jacobson, J.S. Schindler, and S.A. Jones. 2010. An integrated, multiscale approach to predicting the response of lotic biota to climate change in the Southeast Resource Assessment Project. The third USGS modeling Conference. June 8 - 10, Denver CO.

12. Peterson, J.T. 2010. The effects of dams and impoundments on stream fish communities. The ACF Water Conference. June 2-3, Bainbridge GA.

13. Freeman, M. C., R. B. Jacobson, J. W. Jones, C. P. Shea, and J.T. Peterson. 2010 Stream classification for modeling ecological responses to hydrologic alteration. Annual Meeting of the International Association of Landscape Ecology, Athens, GA.

14. Peterson, J.T., M.C. Freeman, W.B. Hughes, G.R. Buell, L.E. Hay, K. R. Odom, J.W. Jones, R.B. Jacobson, J.S. Schindler, and S.A. Jones. 2010. Predicting the response of Flint River biota to water use, land cover, and climate change with spatially explicit metapopulation models. Annual Meeting of the International Association of Landscape Ecology, Athens, GA.

15. Peterson, J.T. 2010. Occupancy estimation for monitoring stream fishes. APO Fish Passage Workshop. March 16-18, Portland OR.

16. *Dycus, J.C. and J.T. Peterson. 2011. Annuli verification and comparison of growth-measurement techniques for Villosa vibex and Villosa lienosa, in the lower Flint River Basin, Georgia. Annual Meeting of the Georgia Chapter of the American Fisheries Society. February 2-3, Perry GA.

17. *Kirsch, J.E. and J.T. Peterson. 2011. An assessment of the effects of scale on the perceived importance of environmental influences on fish distribution in southern Appalachian streams. Annual Meeting of the Georgia Chapter of the American Fisheries Society. February 2-3, Perry GA.

18. *Shea, C.P., J.T. Peterson, and J.M. Wisniewski. 2011. Estimation of mussel population response to hydrologic alteration in the Apalachicola, Chattahoochee, and Flint River Basin. Annual meeting of the Southern Division of the American Fisheries Society, January 13-16, Tampa, FL (Invited)

19. Wisniewski, J.M., J.T. Peterson, S. Abbott, C. Shea, and C. Stringfellow. 2011. Lessons learned from a long-term mussel tagging study. Annual meeting of the Southern Division of the American Fisheries Society, January 13-16, Tampa, FL (Invited)

20. Fritts, A.K., J.T. Peterson, and R.B. Bringolf. 2011. Development of a non-lethal approach for assessing stress in freshwater mussels. Annual meeting of the Southern Division of the American Fisheries Society, January 13-16, Tampa, FL

21. *Dycus, J.C. and J.T. Peterson. 2011. Annuli verification and comparison of growth-measurement techniques for Villosa vibex and Villosa lienosa, in the lower Flint River Basin, Georgia. Annual Meeting of the North Carolina Chapter of the American Fisheries Society. February 22-23, Charlotte, NC.

22. Wisniewski, J.M., J.T. Peterson, S. Abbott, C.P. Shea, and C. Stringfellow. 2011. Known knowns and known unknowns: what do we really know? Freshwater Mollusk Conservation Society 7th Biennial Symposium, April 11-15, Louisville, KY.

23. *Shea, C.P., J.T. Peterson, J.M. Wisniewski, and N.A. Johnson. 2011. Misidentification of freshwater mussel species (Bivalvia: Unionidae): contributing factors, management implications, and potential solutions. Freshwater Mollusk Conservation Society 7th Biennial Symposium, April 11–15, Louisville, KY.

24. Freeman, M.C., J.T. Peterson, C.M. Elliott, C.P. Shea, and M.M. Hagler. 2011. Using species traits and geomorphic characteristics to condition coarse-resolution assessment of climate change effects on aquatic species. 96th Annual Meeting of the Ecological Society of America, August 7-12, Austin, TX. (Invited)

25. Peterson, J.T., M.C. Freeman, J. LaFontaine, R.B. Jacobson, C. Elliott, L.E. Hay, and J.W. Jones. 2011. Using Structured Decision Making and Adaptive Management to Reduce Critical Uncertainties in Water Resource Decisions: Examples from ACF Basin. 141st Annual Meeting of the American Fisheries Society, September 4-8, Seattle, WA. (Invited)

26. Peterson, J.T., M.C. Freeman, J. LaFontaine, L.E. Hay, J.W. Jones, R.B. Jacobson, C. Elliott, and W.B. Hughes 2011. An Evaluation of the Influence of Fragmentation on Stream Fish Communities Using Spatially-Explicit Metapopulation Models. 141st Annual Meeting of the American Fisheries Society, September 4-8, Seattle, WA. (Invited)

27. *Trushel, B., C.A. Jennings, and J.T. Peterson. 2012. Influence of Multi-Scale Factors on Fish Structural Indices in Freshwater Impoundments: Implications for Successful Fisheries Management. Annual Meeting of the Southern Division of the American Fisheries Society, January 28-29, Biloxi, MS.

28. *Trushel, B., C.A. Jennings, and J.T. Peterson. 2012. Influence of Multi-Scale Factors on Fish Structural Indices in Freshwater Impoundments: Implications for Successful Fisheries Management. 20th Annual Meeting of the Georgia Chapter of the American Fisheries Society, February 7-9, Perry, GA.

29. Peterson, J.T. and C.P. Shea. 2012. An Integrated Decision Modeling Approach for Estimating the Response of Mussel Populations to Hydrologic Alteration in the Southeastern U.S. Annual Meeting of the Society for Northwestern Vertebrate Biology, March 20-22, Hood River, OR. (Invited)

30. *Romito, A.M., J.T. Peterson, M.J. Conroy and N. Nibbelink. 2012. Adaptive resource management for linking interagency monitoring and management: A case study using NPS Inventory and monitoring of Southwest Alaska sea otter populations. Annual meeting of the Alaska Chapter of the Wildlife Society, Anchorage, AK. (Invited)

31. Bringolf, R.B., A. Fritts, and J. Peterson. 2012. Non-Lethal Assessment of Drought-Related Stress in Mussels. Freshwater Mollusk Conservation Society 2012 Symposium, April 18-20, Athens GA. (Invited)

32. *Shea, C.P., J.T. Peterson, and J.M. Wisniewski. 2012. Estimation of Mussel Population Response to Hydrologic Alteration in the Apalachicola, Chattahoochee, and Flint River Basin. Freshwater Mollusk Conservation Society 2012 Symposium, April 18-20, Athens GA. (Invited)

33. *Romito, A.M., M.J. Conroy, and J.T. Peterson. 2012. Interagency and cross-jurisdictional management challenges in formal decision analysis: 2 case studies involving the management of sea otters and brown bears in Alaska. The Adaptive Management Conference Series, Ithaca, NY.

34. *Trushel, B., J.T. Peterson, and C.A. Jennings. 2012. Influence of Multi-Scale Factors on Fish Structural Indices in Freshwater Impoundments: Implications for Successful Fisheries Management. 142nd Annual Meeting of the American Fisheries Society, August 19-23, St Paul, MN.

35. Peterson, J.T. 2012. An Evaluation of Fish Electrofishing Capture Efficiency and Sample Designs for Wadeable Warmwater Streams. 142nd Annual Meeting of the American Fisheries Society, August 19-23, St. Paul, MN. (Invited)

36. *Romito, A.M., J.T. Peterson, M.J. Conroy, and N. Nibbelink. 2012. Structured decision making for linking inter-agency monitoring to management: A case study using National Park Service inventory and monitoring of sea otters in Southwest Alaska Network Park Units. The Annual meeting of the Wildlife Society, Portland, OR. (Poster)

37. Peterson, J.T. 2013. System-wide: Estimating juvenile habitat with stream channel characteristics. Trinity River Restoration Program Science Symposium, Weaverville, CA. (Invited)

38. Peterson, J.T. 2013. Decision Support System framework for adaptive management. Trinity River Restoration Program Science Symposium, Weaverville, CA. (Invited)

39. *Saenz, J. and J. Peterson 2013. The Use of Dynamic Multi Season Occupancy Models in the Conservation of Desert Fishes. Annual meeting of the American Fisheries Society Oregon Chapter, February 18-21, Bend, OR.

40. *McDonnell, K. and J. Peterson. 2013. An example of quantitatively identifying the optimal spatial arrangement of freshwater salmon habitat restoration/improvement projects in a California Stream. Annual meeting of the American Fisheries Society Oregon Chapter, February 18-21, Bend, OR.

41. *Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, C. Schreck, M. Kent, B. Dolan, and C. Caudill. 2013. Upper Willamette River spring Chinook prespawn mortality synthesis and modeling. Annual Meeting of the American Fisheries Society Oregon Chapter, February 18-21, Bend, OR.

42. Peterson, J.T. 2013. Integrating Monitoring, Research, and Management: Leveling the 3 legged stool. Annual meeting of the *Salvelinus confluentus* Curiosity Society, Aug 13-15, Anthony Lakes, OR. (Invited)

43. *Saenz, J. and J.T. Peterson. 2013. An Adaptive Framework for Managing Least Chub in Aridland Wetlands. EPA Region 8 Wetland Capacity Building Workshop, September 24 - 27, Salt Lake City, Utah. (Invited)

44. Peterson, J.T. and M.C Freeman. 2013. Integrating Modeling, Monitoring, and Management to Reduce Critical Uncertainties in Water Resource Decision Making. 143nd Annual Meeting of the American Fisheries Society, September 8-12, Little Rock, AR. (Invited)

45. *Saenz, J. and J.T. Peterson. 2014. An adaptive framework for managing least chub in aridland wetlands. Annual Meeting of the Oregon Chapter of the American Fisheries Society, February 25-28, Eugene, OR.

46. *Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda1, M. Kent, B. Dolan, and C. Schreck. 2014. Upper Willamette River spring Chinook prespawn mortality synthesis and modeling. Annual Meeting of the American Fisheries Society Oregon Chapter, February 25-28, Eugene, OR.

47. *Saenz, J. and J.T. Peterson. 2014. An adaptive framework for managing least chub in aridland wetlands. Annual Meeting of the Western Division of the American Fisheries Society, April 7-11, Mazatlan, MX.

48. Fritts, A., J. Peterson, P. Hazelton, and R. Bringolf. 2014. Laboratory evaluation of physiological biomarkers of stress in freshwater mussels. Mississippi River Research Consortium, April 23-25, La Crosse, WI.

49. Peterson, J.T., A.M. Romito, and M.J. Conroy. 2014. Structured Decision Making for Brown Bear Management on National Park Service Lands in Alaska. International Association for Landscape Ecology 2014 Annual Symposium, May 18-21, Anchorage, AK. (Invited)

50. Peterson, J.T. 2014.Influence of incomplete capture on fish monitoring and management: problems and solutions. Annual California Delta Science Conference, October 29-31, Sacramento, California. (INVITED)

51. Hall, J.D., J.T. Peterson, and K.M. Dugger. 2015. Estimating trout mortality caused by feeding of the chestnut lamprey in the Manistee River, Michigan. 145th Annual Meeting of the American Fisheries Society, August 16-20, Portland, OR.

52. Peterson, J.T., C.P Paukert, A.E. Rosenberger, S.K. Brewer. 2015. Standardized sampling: a call for gear calibration. 145th Annual Meeting of the American Fisheries Society, August 16-20, Portland OR. (INVITED)

53. *McDonnell, K. and J.T. Peterson. 2015. A state-space approach to the estimation of juvenile out-migrant survival of Chinook salmon (Oncorhynchus tshawytscha) in the Lower American River, California. 145th Annual Meeting of the American Fisheries Society, August 16-20, Portland OR.

54. *Barajas, M. and J.T. Peterson. 2015. The development of a structured adaptive approach to Klamath Basin sucker recovery planning. 145th Annual Meeting of the American Fisheries Society, August 16-20, Portland OR.

55. Scheerer, P., S. Clements, and J. Peterson. 2015. Oregon's Native Nongame Fishes: A Tale of Diverse Habitats, Endemics, Recovery Success, and Prioritization of Future Research 145th Annual Meeting of the American Fisheries Society, August 16-20, Portland OR.

56. Peterson, J.T. 2015. Bayesian probability modeling. Third International Workshop on Instream Flows. April 28-30, Portland, Oregon. (INVITED)

57. *Saenz, J. and J.T. Peterson. 2015. The use of dynamic multi season occupancy models in the conservation of desert fishes. 7th Annual meeting of the Desert Fishes Council Annual Meeting, Death Valley National Park, CA. (Contributed Oral)

58. Peterson, J.T. and K. Boomer. 2015. Integrating multiple models, monitoring, and management to reduce uncertainties and improve wetland restoration decision making in Chesapeake Bay watersheds. 23rd Biennial Conference of the Coastal and Estuarine Research Federation, Portland OR. (Invited)

59. Boomer, K. and J.T. Peterson. 2015. Downscaling watershed model predictions and characterizing structural uncertainty to support decision-making and develop monitoring priorities. 23rd Biennial Conference of the Coastal and Estuarine Research Federation, Portland OR. (Invited)

60. Peterson, J.T., and M.C. Freeman. 2016. Integrating Modeling, Monitoring, and Management to Reduce Critical Uncertainties in Water Resource Decision Making. 52nd Annual Meeting of American Fisheries Society Oregon Chapter. March 1-4, Seaside, Oregon (Invited)

61. Kent, M.L., C.B. Schreck, C. Herron, and J.T. Peterson. 2016. Salmon life histories and environment effect modes of transmission of pathogens. 52nd Annual Meeting of American Fisheries Society Oregon Chapter. March 1-4, Seaside, Oregon.

62. *Barajas, M. and J.T. Peterson. 2016. Modeling alternative conservation strategies for Klamath Basin sucker recovery. 52nd Annual Meeting of American Fisheries Society Oregon Chapter. March 1-4, Seaside, Oregon (Invited)

63. *Saenz, J. and J.T. Peterson. 2016. An adaptive decision-support tool for the conservation of least chub. 2016 Annual Meeting of the Western Division of the American Fisheries Society, Reno.

64. Peterson, J.T. 2016. Background on Adaptive Management and Decision Support Systems. Trinity River Science Symposium, March 29-30. Weaverville, CA.

65. *Millers, K. and J.T Peterson. 2016. Evaluating the uncertainty in long-term fish monitoring data in the San Francisco Estuary. The International Society for Ecological Modelling Global Conference 2016. 8-12 May, Towson University, MD.

66. *Millers, K.A and J.T Peterson. 2016. Are the fishes imperiled? Evaluating uncertainty from long-term fish monitoring in the San Francisco Delta. International Statistical Ecology Conference 2016, Seattle. (Contributed Oral)

67. *Duarte, A., C.A. Pearl, M.J. Adams, and J.T. Peterson. 2016. The use of integrated population models to document amphibian reintroduction efforts within restored habitat. North American Congress for Conservation Biology. Madison, WI.

68. *Kurnianto, S., J.T. Peterson, J. Selker, J.B. Kauffman, D. Murdiyarso. 2016. The impact of land cover change on the hydraulic conductivity in tropical peatlands. 15th International Peat Congress. August 15-19 Kuching, Sarawak, Malaysia.

Grants Awarded

1998 Life-cycle model development and application to system planning
Funding: Bonneville Power Administration ($70,000)
Role: Co-Principal Investigator (20%)
Co-Principal Investigators: D. Lee, USFS (60%) and B. Thompson, USFS (20%)
Development of a database to support a multi-scale analysis of the distribution of westslope cutthroat trout (*Oncorhynchus clarki lewisi*).
Funding: U.S. Fish and Wildlife Service ($28,800)
Role: Co-Principal Investigator (30%)
Co-Principal Investigators: B. Rieman, USFS (40%) and J. Dunham, USFS (30%)
Development of Bull Trout Sampling Protocols
Funding: U.S. Fish and Wildlife Service ($38,600)
Role: Co-Principal Investigator (50%)
Co-Principal Investigator: R. Thurow, USFS (50%)

2000 Development of interim tools for predicting bull trout detection probabilities.
Funding: State of Washington Department of Natural Resources ($14,084)
Role: Principal Investigator (100%)
Development of a common framework for assessing the distribution and potential threats to bull trout.
Funding: U.S. Fish and Wildlife Service ($54,730)
Role: Principal Investigator (100%)

2001 An evaluation of drought impacts on fish communities in the lower Flint River Basin, Georgia
Funding: U.S. Fish and Wildlife Service ($32,027)
Role: Principal Investigator (100%)
The development of decision analysis tools for Federal land management in the Inland Northwest
Funding: USDA Forest Service ($101,000)
Role: Co-Principal Investigator (70%)
Co-Principal Investigator: M. Conroy, GA Coop Unit (30%)
An evaluation of the needs and feasibility of decision analysis tools for evaluating impacts to aquatic ecosystems in the Southeastern U.S.
Funding: U.S. Geological Survey ($10,350)
Role: Principal Investigator (100%)
Distribution and status of Tallapoosa River system fauna
Funding: U.S. Fish and Wildlife Service ($51,492)
Role: Co-Principal Investigator (33%)
Co-Principal Investigators: E. Irwin, AL Coop Unit (33%), M. Freeman, USGS (34%)

2002 Regional analysis of biodiversity in the ACT/ACF basins (aquatic GAP)
Funding: U.S. Geological Survey ($247,891)
Role: Co-Principal Investigator (33%)
Co-Principal Investigators: E. Irwin, AL Coop Unit (33%), B. Freeman, UGA (33%)
The evaluation of flow requirements for stream fishes in the Lower Flint River Basin, Georgia
Role: Co-Principal Investigator (70%)
Funding: Georgia Department of Natural Resources ($470,460)
Co-Principal Investigator: C. R. Jackson, UGA (30%)
Development of juvenile bull trout sampling protocols
Funding: U.S. Fish and Wildlife Service ($108,032)
Role: Principal Investigator (100%)
Collaborator: R. Thurow, USFS

2003 Software package to estimate capture efficiency and detectability for fish population monitoring
Funding: USDA Forest Service ($5,000)
Role: Principal Investigator (100%)
Development of a decision support tool and procedures for evaluating dam operation in the Southeastern US
Funding: U.S. Geological Survey ($221,497)
Role: Co-Principal Investigator (50%)
Co-Principal Investigator: E. Irwin, AL Coop Unit (50%)
The effects of hydrologic stressors on wading bird foraging distributions and nesting patterns in the Everglades from 1985-2001
Funding: South Florida Water Management District ($339,976)
Role: Co-Principal Investigator (33%)
Co-Principal Investigators: M. Conroy, GA Coop Unit (34%) and C. Moore, USGS (33%)

2004 The development and evaluation of a channel classification system for low-order Georgia streams
Funding: GA Department of Natural Resources ($30,000)
Role: Principal Investigator (100%)

2005 The development of models for evaluating the effects of river regulation and water use on native fishes in the Chattahoochee River National Recreation Area
Funding: National Park Service- Park Oriented Support Program ($59,929)
Role: Principal Investigator (100%)
Validation of snorkeling and electrofishing in small streams
Funding: USDA Forest Service ($22,000)
Role: Principal Investigator (100%)
Design of a Long Term Monitoring Program for Freshwater Mussels in the Lower Altamaha River Basin
Funding: GA Department of Natural Resources ($61,600)
Role: Principal Investigator (100%)

2006 An adaptive sample survey design for the ivory-billed woodpecker
Funding: U.S. Fish and Wildlife Service ($15,000)
Role: Co-Principal Investigator (20%)
Co-Principal Investigators: M. Conroy, GA Coop Unit (40%) and R. Cooper, UGA (40%)
Influence of land-based activities on riverine delivery of contaminants to estuaries
Funding: Georgia Sea Grant ($121,196)
Role: Co-Principal Investigator (60%)
Co-Principal Investigators: A. Fisk, University of Windsor (20%), G. Tomy, Environment Canada (20%)
Science Support for the Upper Coosa Basin Phase I
Funding: U.S. Fish and Wildlife Service ($255,150)
Role: Co-Principal Investigator (60%)
Co-Principal Investigators: B. Freeman, UGA (40%)
Water availability for ecological needs: a pilot study on the upper Flint River system, Georgia
Funding: U.S. Geological Survey ($265,600)
Role: Principal Investigator (100%)

2007 Evaluation of the distribution and ecology of mussels in the Lower Flint River Basin
Funding: Georgia Department of Natural Resources ($117,152)
Role: Co-Principal Investigator (70%)
Co-Principal Investigator: C.R. Jackson, UGA (30%)
Long-Term Plan to Protect Adult Salmon in the Lower Klamath River Independent Scientific Peer Review
A proposed approach for implementing a region-wide search for the ivory billed woodpecker with the objectives of estimating occupancy and related parameters
Funding: U.S. Geological Survey ($106,393)
Role: Co-Principal Investigator (20%)
Co-Principal Investigators: M. Conroy, GA Coop Unit (40%) and R. Cooper, UGA (40%)

2008 Using Decision Models to Assist Vital Signs Monitoring in National Parks, A Prototype Using Sea Otters (*Enhydra lutris*) in Coastal Alaska
Funding: National Park Service-Park Oriented Support Program ($71,720)
Role: Co-Principal Investigator (50%)
Co-Principal Investigators: M. Conroy, GA Coop Unit (25%) and N. Nibblink, UGA (25%)

2009 Decision support models for the conservation and recovery of imperiled mussels
Funding: U.S. Fish and Wildlife Service ($239,775)
Role: Co-Principal Investigator (70%)
Co-Principal Investigators: R. Bringolf, UGA (30%)
Influence of limnological characteristics on sportfish production in lakes on Georgia's public fishing areas
Funding: Georgia Department of Natural Resources ($138,495)
Role: Co-Principal Investigator (50%)
Co-Principal Investigators: C. Jennings, GACFWRU (50%)

2010 Multi-resolution Assessment of Potential Climate Change Effects on Aquatic and Hydrologic Dynamics Part I: Estimating Ecological Change
Funding: U.S. Geological Survey ($85,000)
Role: Principal Investigator

2011 Development of a Standardized Sampling Protocol for Endangered and Threatened Fishes--How do We Assess Population Status when Electrofishing May Harm the Species?
Funding: US Fish and Wildlife Service ($20,000)
Role: Co-Principal Investigator (50%)
Structured Decision Making for Brown Bears on National Park Service Lands in Alaska: Integration of Monitoring to Inform Management
Funding: National Park Service ($163,723)
Role: Co-Principal Investigator (50%)
The Development of an Adaptive, Decision-Support Tool for the Conservation and Recovery of Least Chub, *Iotichthys phlegethontis*
Funding: Bureau of Land Management ($87,580)
Role: Principal Investigator
The Development of an Adaptive, Decision-Support Tool for the Conservation and Columbia Spotted Frog (*Rana Luteiventris*)
Funding: U.S. Geological Survey ($75,000)
Role: Principal Investigator

2012 Development of a Model for Adaption Management of the Lower American River Channel and Floodplain Restoration
Funding: US Fish and Wildlife Service ($92,350)
Role: Principal Investigator
Condition and Spawning Success of Adult Spring Chinook Salmon in the Willamette River
Funding: US Army Corps of Engineers ($317,407)
Role: Co-Principal Investigator (33%)

2013 Coarse Resolution Planning Tools for Prioritizing Central Valley Project Improvement Act Fisheries Activities
US Fish and Wildlife Service ($47,906)
Role: Principal Investigator
The Kalimantan Wetlands and Climate Change Study
United States Agency for International Development ($999,997)
Role: Co-Principal Investigator (33%)

2014 The Development of Structured Adaptive Approach to Klamath Lake Sucker Recovery Planning
U.S. Fish and Wildlife Service ($66,982)
Role: Principal Investigator
Developing a Structured, Adaptive Approach for Cruise Ship Management in Glacier Bay National Park, Phase I-II
USGS Natural Resources Preservation Project ($187,350)
Role: Principal Investigator
A Structured, Adaptive Approach to Bull Trout Recovery Planning Phase I: Sycan Core Area
U.S. Fish and Wildlife Service ($51,240)
Role: Co-Principal Investigator
Development of an adaptive decision support system for management of the Trinity River restoration
Bureau of Reclamation ($79,735)
Role: Principal Investigator

2015 Incorporating Amphibians in Decision Support Systems
U.S. Geological Survey ($121,018)
Role: Principal Investigator
Structured Framework for Managing Cackling Goose
Pacific Flyway Council ($10,294)
Role: Co-principal Investigator (50%)
An Evaluation of Bay-Delta Fish Monitoring with Recommendation for Future Protocols
Southern Metropolitan Water District ($321,938)
Role: Principal Investigator
Describing the potential predator field of young suckers in Upper Klamath Lake
Bureau of Reclamation ($100,000)
Role: Co-principal Investigator (50%)

2016 Adaptive Management of Central Valley Project Fisheries Phase II: Multiscale Integration and Refinement
U.S. Fish and Wildlife Service ($96,031)
Role: Principal Investigator
Willamette River Instream Ecological Flow Science Review and Analyses Prioritization
U.S. Army Corps of Engineers ($145,465)
Role: Co-principal Investigator (50%)

Lectureships and Other Academic Service

Invited Seminars

The Elephant in the Living Room: the Effect of Sampling Bias on Ecological Inference, University of Georgia Institute of Ecology, Athens, Georgia, 2005.

MCMC Methods for Modeling Meta-Demographic Parameters of Stream-Dwelling Fishes for Water Resources Decision-Making U.S. Environmental Protection Agency, Athens, Georgia, 2007.

The Elephant in the Living Room: Ambiguity, Natural Resource Decision-Making, and the Scientific Method, University of Missouri School of Natural Resources, 2007.

Trends- Schmends, why drive the fish management machine using the rearview mirror? Department of Fisheries and Wildlife, Oregon State University, 2012.

Introduction to structured decision making and adaptive management. US. Bureau of Reclamation Research and Development Office, 2013

Introduction to structured decision making and adaptive management. Oregon Department of Environmental Quality, 2013.

Peterson, J.T. 2015. Incorporating Dynamics in Evaluations of Climate Change Effects on Aquatic Ecosystems. Center for International Forestry Research (CIFOR), August 5, Bogor, Indonesia.

Guest Lectures

Fish population dynamics, invited lectures for *Fisheries Management* at the University of Georgia, Athens, Fall 2000- 2003.

The effect of dams on salmonids in the Northwest US, invited lecture for *Watershed Conservation* at the University of Georgia, Athens, Spring 2000.

Large-scale land management in the Intermountain West, invited lecture for *Perspectives on Conservation Ecology and Sustainable Development* at the University of Georgia, Athens, Spring 2000.

Field techniques for stream fish research and management, invited lectures and laboratory for *Fisheries Management* at the University of Georgia, Athens, Fall 2000-2009.

Empirical Bayesian approach to estimating species presence and richness, invited lectures for *Estimation of Fish and Wildlife Population Parameters* at the University of Georgia, Athens, Fall 2001.

Ecology of stream fishes in the Missouri Ozarks, invited lectures for *Fish Ecology* at the University of Georgia, Athens, Spring 2002.

Population Viability Analysis, invited lectures for *Applied Population Modeling* at the University of Georgia, Athens, Fall 2003.

Hierarchical and mixed effects modeling, invited lectures for *Advanced Quantitative Techniques in Ecology* at the University of Georgia, Athens, Spring 2006-2007

International issues in Fisheries Conservation, invited lecture for *International Studies* at the University of Georgia, Fall 2008, Spring 2009-2010.

Manuscript submission and oral presentation, four invited lectures for *Scientific Communication* at the University of Georgia, Fall 2008.

Decision Making in Fish and Wildlife Management, two lectures each in Fall and Winter terms, *Problem Solving In Fisheries And Wildlife Science,* 2012-2016

Courses Developed and Taught

Decision analysis under uncertainty. FORS 8300, Fall 2001.

Quantitative Approaches to Conservation Biology. FORS/WILD8360, Fall 2001 - 2010.

SAS for biologists. FORS8300, Spring 2001-2003.

Multivariate techniques for community/ecosystem-level studies. FORS8300, Spring 2003.

Open source computing for fisheries and wildlife studies. FORS8300, Spring 2005

Biology and ecology of freshwater mussels. FORS8300, Spring 2008.

Estimation of parameters of fish and wildlife populations. FW505, Spring 2013

Structured Decision Making in Natural Resource Management (e-course lecture + lab) FW537-538, Fall 2012-2015.

Quantitative Decision Analysis for Fish and Wildlife Management. FW544, Winter 2012-2016.

An introduction to data management and R for Fisheries and Wildlife applications. FW599, Fall 2013-2105.

Courses Developed and Taught

Decision analysis under uncertainty. FORS 8300, Fall 2001.

Quantitative Approaches to Conservation Biology. FORS/WILD8360, Fall 2001 - 2010.

SAS for biologists. FORS8300, Spring 2001-2003.

Multivariate techniques for community/ecosystem-level studies. FORS8300, Spring 2003.

Open source computing for fisheries and wildlife studies. FORS8300, Spring 2005

Biology and ecology of freshwater mussels. FORS8300, Spring 2008.

Estimation of parameters of fish and wildlife populations. FW505, Spring 2013

Structured Decision Making in Natural Resource Management (e-course lecture + lab) FW537-538, Fall 2012-2015.

Quantitative Decision Analysis for Fish and Wildlife Management. FW544, Winter 2012-2016.

An introduction to data management and R for Fisheries and Wildlife applications. FW599, Fall 2013-2105.

Students – Theses and Dissertations of Former Students

1. Banish, N. 2003. Diel summer habitat use by bull trout, *Salvelinus confluentus*, in Eastern Cascade streams. Master's Thesis, University of Georgia, Athens.

2. McCargo, J. W. 2004. Influence of drought on seasonal fish assemblages and habitat in the Lower Flint River Basin, Georgia. Master's Thesis, University of Georgia, Athens.

3. Whitehead, A. 2004. Optimal harvest of shovelnose sturgeon (*Scaphirhynchus platorynchus* Rafinesque) in the Wabash River, Illinois. Master's Thesis, University of Georgia, Athens.

4. McPherson, R. D. 2005. An assessment of fish community structure and seasonal habitat use of headwater confined channels and headwater wetlands in the lower Flint River Basin, southwest Georgia. Master's Thesis, University of Georgia, Athens.

5. Ruiz, J.C. 2005. An evaluation of the relative influence of spatial, statistical, and biological factors on the accuracy of stream fish species presence models Master's Thesis, University of Georgia, Athens.

6. Shea, C. P. 2005. Fish habitat use and assemblage structure in regulated and unregulated reaches of a large southeastern warmwater stream. Master's Thesis, University of Georgia, Athens.

7. Craven, S.W. 2007. Evaluation of the influence of thermal and hydrologic regime on native fish communities in the upper Chattahoochee River. Master's Thesis, University of Georgia, Athens.

8. Dennard, S. 2007. The life history of *Cambarus halli*, an endemic crayfish of the Tallapoosa River. Senior Thesis, University of Georgia, Athens.

9. Meador, J.M. 2008. The development and evaluation of a freshwater mussel sampling protocol for a large lowland river. Master's Thesis, University of Georgia, Athens.

10. Price, A.L. 2008.Development and evaluation of sampling protocols for at-risk fishes in wadeable warmwater streams. MS Thesis, University of Georgia, Athens.

11. Fauver, R.J. 2008. The Influence of Land-Based Activities on Contaminants in Riverine Systems. Master's Thesis, University of Georgia, Athens.

12. Bickerstaff, W.J. 2008. Passive sampling model of warm water species in north Georgia streams. Senior Thesis, University of Georgia, Athens

13. Dycus, J.C. 2011. Demography of freshwater mussels within the Lower Flint River Basin, southwest Georgia. Master's Thesis, University of Georgia, Athens.

14. Kirsch, J.E. 2011. A multi-scaled approach to evaluating the fish community structure within southern Appalachian streams. Master's Thesis, University of Georgia, Athens.

15. Shea, C.P. 2011. Water resource management under uncertainty: approaches for the management and conservation of freshwater mussel species in the lower Flint River Basin, Georgia. PhD Dissertation, University of Georgia, Athens.

16. Trushel, B.E. 2013. Influence of multi-scale factors on sportfish structural indices in small- to medium-sized impoundments in Georgia, U.S.: Implications for successful fisheries management. Master's Thesis, University of Georgia, Athens. (Co-advised with Cecil Jennings)

17. Romito, A.M. 2014. A structured approach to interagency and cross-jurisdictional monitoring and management of Sea Otters (*Enhydra Lutris Kenyoni*) and Brown Bears (*Ursus Arctos*) in Alaska PhD Dissertation, University of Georgia, Athens. (Co-advised with Michael Conroy)

18. Saenz, J. 2014. Patch dynamics of desert fishes in the arid wetlands of western Utah, Master's Thesis, Oregon State University, Corvallis.

Other Graduate Advisees

Kevin McDonnell, Ph.D. Fisheries and Wildlife, 2011- present

Sofyan Kurnianto, Ph.D., Fisheries and Wildlife, 2013 - present

Miguel Barajas, MS Fisheries and Wildlife, 2014- present

Steven Whitlock, PhD., Fisheries and Wildlife, 2015 - present

Membership on Graduate Student Advisory Committees

University of Georgia: PhD, 22 completed, MS, 17 completed

Oregon State University: PhD, 3 current, 1 completed, MS, 4 current

Oklahoma State University: PhD, 1 current

University of Montana: PhD, 1 current

Postdoctoral Research Fellows (current position)

Christopher J. Fonnesbeck (Vanderbilt)	June 2003 - December 2004
Maureen G. Walsh (USGS)	June 2003 - May 2005
Jonathan P. Runge (CO Div. Wildlife)	November 2005 - May 2007
Zy F. Biesinger (USFWS)	July 2012 - May 2013
Michael E. Colvin (MS State U)	June 2012 - August 2014
J. Tyrell Deweber	September 2014 - Present
Kimberly Millers	March 2014 – Present

Adam Duarte July 2015- Present

University Committees and Workgroups

UGA WSFNR Graduate Affairs Committee 2006 – 2011

OSU Fisheries and Wildlife Graduate Committee 2011 – present

OSU Fisheries and Wildlife Voting Procedures Committee 2011 – present

OSU Search committees: Administrative staff, 2012, Wildlife faculty, 2013

Technical Training Provided

Instructor at *An Introduction to Bayesian Belief Networks* to researchers and biologists as part of a program for the Interior Columbia River Basin Ecosystem Management Program, November 1998.

Instructor at *Categorical Data Analysis* as part of a professional development program for USDA Forest Service biologists, May 1999.

Organizer and co-instructor of *An Introduction to Decision Analysis for Natural Resource Management* a continuing education workshop for the American Fisheries Society, August 2000.

Instructor at *Decision Modeling and Bayesian Belief Networks* at White River Ecosystem Management Workshop. Stuttgart, Arkansas, July 2002.

Organizer and co-instructor of *Native Fish Species Reintroductions: Risks and Rewards* a workshop for the Georgia Department of Natural Resources Fisheries Section. Bainbridge, September 2004.

Co-organizer and instructor at *Using MCMC in Winbugs and Python to fit random effects and hierarchical models* a continuing education workshop for the Wildlife Society, Calgary, Alberta, September 2004.

Co-organizer and instructor of *Workshop on Statistical Sampling and Estimation for Fisheries and Wildlife* a continuing education workshop for Georgia Department of Natural Resources (GADNR) and U.S. Fish and Wildlife Service biologists (GA Unit Cooperators), May 2006.

Co-organizer and instructor of *Integrating management, monitoring, and research: adaptive resource management and gamebirds* continuing education workshop for the joint national meeting of Quail VI and Perdix XII, June 2006.

Co-organizer and instructor of *Workshop on occupancy and detection for monitoring wildlife* and continuing education workshop at the 2008 Southeast Partners in Amphibian and Reptile Conservation Annual Meeting, Athens GA. February 2008.

Instructor of *Adaptive management of temporary wetlands,* U.S. Fish and Wildlife Service adaptive management workshop, Windom, MN, March 2008.

Co-organizer and instructor of *Adaptive Management* a workshop for students and cooperators of the Missouri Unit, Columbia MO, April 2008.

Organizer and instructor of *Chattahoochee National Recreation Area Bayesian Belief Network (BBN) Workshop* a one day workshop with National Park Service biologists, May 2008.

Co-organizer and instructor of *Workshop on Monitoring for Natural Resource Conservation Decision-making* a continuing education workshop for GADNR biologists on monitoring animal populations, May 2008.

Co-organizer and instructor of *Workshop on Monitoring for Natural Resource Conservation Decision-making* a continuing education workshop for FWS biologists on monitoring animal populations, December 2008. Instructor at *Climate Change and its Effects on Fisheries and Aquatic Resources* a Continuing Education Short Course at North Carolina Chapter of the American Fisheries Society, February 2009.

Co-organizer and instructor of *Workshop on Structured Decision Making for Wild Turkey Management in Pennsylvania* a continuing education workshop for Pennsylvania Game Commission biologists, May 2009.

Co-organizer and instructor of *Structured Decision Making for Allegheny Woodrat Conservation and Management* a continuing workshop for woodrat biologists on monitoring and modeling woodrat populations, May 2009.

Organizer and instructor of *Structured Decision Making for Mussel Conservation and Management* a continuing education workshop for mussel biologists, Atlanta, GA, September 2009.

Co-organizer and instructor of *Structured Decision Making and Modeling for Sea Otter Conservation and Management* a continuing workshop for sea-otter biologists on monitoring and modeling, October 2009.

Organizer and instructor of An Introduction to Structured Decision-making for Natural Resource Management a continuing education workshop for the American Fisheries Society, Seattle WA September 2011.

Organizer and instructor of Structured decision-making and management of Aridland wetlands a workshop for BLM, FWS, USFS and UDW, Salt Lake City Utah, April 2011

Organizer and instructor of Occupancy estimation and Modeling, a continuing education workshop for ODFW fisheries biologists, Corvallis OR April 2011.

Instructor of Structured decision making and management of the lower American River. NCTC continuing education workshop, Sacramento California, October 2011

Organizer and instructor of Capture-Recapture Estimation Methods workshop for Oregon Department of Fisheries and Wildlife biologists. February 7-8 & May 8-9, 2012.

Instructor at Structured Decision Making Approaches to Brown Bear Management on NPS Lands in Alaska. March 13-14, 2012.

Organizer and instructor of An Introduction to Structured Decision Making for Natural Resources Management, The Wildlife Society Continuing Education Course, October 13, 2012.

Organizer and instructor of Workshop on the Conservation of Klamath Lake Suckers- a Structured Decision Making Approach, December 27-29, 2012.

Instructor at Ecological modeling and decision support with probabilistic networks for the DOI Natural Resources Biometrics series, May 23, 2013.

Estimation of Population Parameters with Capture-Recapture Methods taught to Oregon Department of Fisheries and Wildlife biologists, June 17-18, 2013.

Organizer and instructor of Occupancy estimation workshop taught to Oregon Department of Fisheries and Wildlife biologists. July 1-2, 2013.

Co-organizer and instructor of Structured decision making and adaptive management short course taught to Oregon Department of Fisheries and Wildlife biologists, September 18, 2013.

Organizer and instructor of An Introduction to Structured Decision Making for Natural Resources Management, Oregon Chapter of the American Fisheries Society Continuing Education Course, February 25-26, 2014.

Organizer and instructor of Structured Decision Making for Conservation of Long Creek Bull Trout workshop March 31-April 2, 2014.

Organizer and instructor of Introduction to R for Biologists, taught to Oregon Department of Fisheries and Wildlife biologists, June 17-18 & July 29-30, 2014.

Organizer and instructor of A Brief and Gentle Introduction to Program MARK. American Fisheries Society Continuing Education Course, Aug. 17, 2015.

Organizer and instructor of An introduction to R for fish biologists for Oregon Department of Fisheries and Wildlife biologists. July 6-7, 2016.

Organizer and instructor of Capture-Recapture Estimation Methods workshop for Oregon Department of Fisheries and Wildlife biologists. Aug. 17-18, 2016.

Professional Organizations and Activities

American Fisheries Society

Fisheries Management, Computer Users, and Education Sections

Coeditor Missouri Chapter Newsletter, 1992-1993

Publications Awards Committee, 1998-1999

Western Division- Bull Trout Sampling Protocol Development Committee, 1999- 2005

Co-chair Publication Awards Committee, 2000-2001, 2002-2003

Chair Publication Awards Committee, 2002

Chair Annual Meeting Symposia Review Committee, 2004

Chair Best Student Paper Award Committee, 2008-2011

Organizer of Structured Decision-making and Adaptive Management Symposium, 2009

Society for Freshwater Science

American Statistical Association

Editor, Southeastern Naturalist Special Edition, 2010-2011

Trinity River Restoration Project, Science Advisory Board Member 2011-present

Glen Canyon Dam Adaptive Management Program, Evaluation Panel Member, 2016

Outreach Activities

Bottom Feeders. Aired for the first time January 18, 2003. I was featured on the Georgia Public Television Georgia Outdoors documentary about stream-dwelling organisms. My research on the aquatic communities in the Flint River Basin was used to highlight the streamflow needs. (January 18, 2003).

Presentations about local fauna to students at Oglethorpe County (GA) Elementary School. (May 2007 - 2010).

RECLAMATION
Managing Water in the West

Long-Term Plan to Protect Adult Salmon in the Lower Klamath River

Appendix B – Independent Scientific Review Charge

Independent Scientific Peer Review
Northern California Area Office, Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation **October 2016**

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Independent Scientific Review Charge for the Long-Term Plan to Protect Late Summer Adult Salmon in the Lower Klamath River

Background

The Draft Long-Term Plan for Protecting Late Summer Adult Salmon in the Lower Klamath River (LTP) is intended to provide the fundamental long-term elements for protecting adult salmonids entering the lower Klamath River in late summer. Reclamation developed trigger criteria to aide in determining when to make flows available to the lower Klamath River. As such, the trigger criteria are foundational to analyses being prepared for the LTP, which will be presented in an Environmental Impact Statement (EIS) prior to implementing these associated flows. This LTP is a result of the 2002 fish die-off in the lower Klamath River. An Independent Scientific Peer Review process is being used to review these criteria and determine their scientific validity.

Review Charge

Reclamation and Klamath River partners spent considerable time developing and refining scientifically-based criteria for considering flow augmentation, culminating in the Trinity River Restoration Program (TRRP) Fall Flow Subgroup recommendations developed May 31, 2012, the May 28, 2012 TRRP Fall Flow Workgroup Summary, the 2013 Joint Memorandum, the 2015 U.S. Fish and Wildlife Service (USFWS) Memo, criteria associated with the 2015 Environmental Assessment for Flow Augmentation, and the 2016 Frequency Technical Memo. This review is focused solely on the use of flow criteria in its application to prevent an epizootic disease outbreak in the lower Klamath River as presented below, and supported by these documents.

Implementation Criteria to be Reviewed

Preventive Base Flow Augmentation (primary response):

Initiate preventive base flow augmentation from Lewiston Dam when:

- Flow in the lower Klamath River is projected to be less than 2,800 cfs at the Klamath, California gage (gage # 11530500) in August and September (USFWS 2015).

- Ich infection of adult salmon or steelhead is identified in July and early August suggesting a low level infection is present that could worsen with poor environmental conditions.

- Thermal regime of the lower Klamath River is inhibitory to the upstream migration of infected adult salmon.
- Adult salmon are showing abnormal signs of behavior, crowding at tributary mouths, or are not migrating out of the lower Klamath River on a volitional basis.
- The cumulative harvest of Chinook Salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish (see National Marine Fisheries Service [NMFS] and USFWS 2013).
- Initiate preventive base flow augmentation releases by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in NMFS and USFWS 2013).
- Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the Klamath, California gage through September 21. Continue to implement fish pathology monitoring to determine the potential need for the secondary flow augmentation action (preventive Pulse Flow).
- The need for preventive base flow augmentation is expected to occur during years with limited or low precipitation levels in the Klamath River basin (e.g, dry conditions). Since the fish die-off in 2002, Reclamation has made preventive base flow augmentation releases in six years over a 13 year period. However, criteria for preventive flow augmentation have changed over this period. Based on the above criteria, it is estimated that preventive base flow augmentation would have occurred in approximately three of the 13 years, or about 20 to 25 percent of the years.

Preventive Pulse Flow Augmentation (secondary response):

During the preventive base flow period, a preventive pulse flow targeting a flow of 5,000 cfs for one 24 -hour period at the Klamath, California gage would occur when the peak of fall run migration (typically the first or second week of September) is identified in the lower Klamath River as indicated by tribal harvest. This flow level is based upon the experience of 2015, which was intended to use a small volume of water to provide a change to the environmental conditions of the lower Klamath River to further reduce the risk of an Ich infection that could result in a disease outbreak (see Reclamation 2015). Specifically, the anticipated benefit of the pulse is to enhance flushing and dilution of the river of parasites when the bulk of fall run Chinook Salmon adults are likely to be in the lower river while also facilitating movement of adult salmon to reduce the potential for crowding. Conditional release of this pulse flow requires low level Ich infections (less than 30 Ich per gill arch) that are confirmed on three fall-run adult salmon (of a maximum sample size of 60) captured in the lower Klamath River in one day during this time of typical peak migration. Disease sampling and confirmation of disease findings would follow the methods as described in NMFS and USFWS (2013).

Emergency Flow Augmentation (tertiary response):

Initiate emergency flow release to target a flow of 5,000 cfs in the lower Klamath River for up to five days in August or September if emergency conditions exist as identified by USFWS and NMFS (2013b):

- Diagnosis of severe Ich (30 or more parasites on a gill arch) infection of gills in 5 percent or greater of a desired sample of 60 adult salmonids confirmed by the USFWS California Nevada (CA-NV) Fish Health Center, or

- Observed mortality of greater than 50 dead adult salmonids in a 20 kilometer reach in 24 hours coupled with the confirmed presence of Ich by the USFWS CA-NV Fish Health Center.

Use the protocol for sharing and confirming information on a real-time basis to determine if and when the emergency flows would be implemented.

- Key staff members would be on high alert during the flow augmentation action and would be getting timely monitoring results. The USFWS CA-NV Fish Health Center would provide a pathology report documenting the findings of diagnostics survey to State, federal, and Tribal fish biologists and pathologists (LTP Technical Team), and the Klamath Fish Health Assessment Team (KFHAT). An emergency release would be considered by Reclamation on receipt of a positive pathology report.

The need for emergency flow augmentation is expected to be low considering the infrequent use in the past (only once in 6 years of implementing an action since 2002) and the knowledge gained from these previous years regarding the dynamics of Ich infection and environmental variables that include flow.

Questions

As a peer reviewer, please provide a response to the following two questions:

Question 1. Are the implementation criteria supported by the science?

Question 2. Have the assumptions and uncertainties associated with utilizing the flow criteria been appropriately characterized?

The six documents to review are as follows:

1. Trinity River Restoration Program Fall Flow Subgroup. 2012. 2012 Fall Flow Release Recommendation. 20 pages. (Referred to above as the Trinity River Restoration Program (TRRP) Fall Flow Subgroup recommendations developed May 31, 2012.)

2. USFWS. 2012. Summary of Klamath River Chinook salmon in-river run size data and lower Klamath River flows to support TRRP Fall Flow planning efforts in 2012. 39 pages. (Referred to above as the May 28, 2012 TRRP Fall Flow Workgroup Summary.)

3. NMFS and USFWS. 2013. 2013 Fall Flow Release Recommendation. 46 pages. (Referred to above as the 2013 Joint Memorandum).

4. USFWS. 2015. Response to Request for Technical Assistance Regarding 2015 Fall Flow Releases. 11 pages. (Referred to above as the 2015 U.S. Fish and Wildlife Service Memo.)

5. USBR. 2015. 2015 Lower Klamath River Late-Summer Flow Augmentation from Lewiston Dam. Environmental Assessment. 46 pages. (Referred to above as the 2015 Environmental Assessment for Flow Augmentation.)

6. USBR. 2016. Frequency of Action Analysis: Preventive Pulse and Emergency Flows. 5 pages. (Referred to above as the 2016 Frequency Technical Memo.)

Please provide a technical memorandum with your responses to the two questions by email to:

Barbara McDonnell, Principal Environmental Scientist
MWH, Inc.
Barbara.J.McDonnell@mwhglobal.com

The review will begin upon execution of a subcontractor agreement with MWH. Your technical memorandum will be due no later than close of business on September 30, 2016. Response to comments by Reclamation will be due 10 days after receipt.

RECLAMATION
Managing Water in the West

Long-Term Plan to Protect Adult Salmon in the Lower Klamath River

Appendix C – Materials Provided to Independent Science Peer Reviewers

Independent Scientific Peer Review
Northern California Area Office, Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation

October 2016

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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Table of Contents

Trinity River Restoration Program Fall Flow Subgroup. 2012. *2012 Fall Flow Release Recommendation*. May 31, 2012

USFWS. 2012. Summary of Klamath River Chinook Salmon In-River Run Size Data and Lower Klamath River Flows to Support TRRP Fall Flow Planning Efforts in 2012. May 28, 2012

NMFS and USFWS. 2013. 2013 Fall Flow Release Recommendation

USFWS. 2015. Response to Request for Technical Assistance Regarding 2015 Fall Flow Releases

Reclamation. 2015. 2015 Lower Klamath River Late-Summer Flow Augmentation from Lewiston Dam. Environmental Assessment

Reclamation. 2016. Frequency of Action Analysis: Preventive Pulse and Emergency Flows

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2012 Fall Flow Release Recommendation

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MEMORANDUM

TO:	BRIAN PERSON, RECLAMATION NORTHERN CALIFORNIA AREA MANAGER
FROM:	FALL FLOW SUBGROUP
SUBJECT:	2012 FALL FLOW RELEASE RECCOMENDATION
CC:	TRRP FLOW WORKGROUP MEMBERS
	ERNEST CLARKE, TRRP SCIENCE COORDINATOR
	ROBIN SCHROCK, TRRP EXECUTIVE DIRECTOR
DATE:	MAY 31, 2012

Background

In September 2002, a significant fish kill occurred in the lower Klamath River. Though estimates vary, the US Fish and Wildlife Service reported that over 34,000 adult fish died, comprised primarily of fall-run Chinook Salmon. Carcasses were observed between September 18 and October 1, 2002 within the lower 36 river miles, extending from the estuary upstream to Coon Creek Falls. Several efforts and evaluations have occurred in the past to reduce the likelihood of another fish kill, including releases of water from Lewiston Dam on the Trinity River in 2003 and 2004, as well as development of criteria for releasing supplemental flows during the fall-run Chinook salmon migration season (Clarke 2010; Hayden 2012).

The 2012 Klamath Basin fall-run Chinook escapement is projected to be significantly larger than any other year on record. The Pacific Fishery Management Council's Salmon Technical Team indicates that over 380,000 adult fall-run Chinook salmon will return to the Klamath River; nearly 2.4 times the run size associated with the 2002 fish kill and over 50% greater than the highest recorded run size in 1995 (Table 2; Appendix D). The record breaking prediction does not include two year old fall-run Chinook salmon, spring-run Chinook salmon, coho salmon, or steelhead that will return to the Klamath Basin in 2012. Given the prediction of a record breaking run size, the fall flow subgroup (subgroup) was faced with considerable uncertainty in the decision making process because there were no prior years with a similar run size that could be used to estimate the probability of fish kill occurring in 2012.

While there were substantial improvements in hydrologic conditions in the Klamath Basin during the spring of 2012, advanced hydrologic predictions by the California Nevada River Forecast Center indicate that below average discharge in the lower Klamath River can be expected during the Chinook salmon migration season. Importantly, large run size combined with low river discharge were thought to be contributing factors in the 2002 fish kill (Guillen 2003; Belchik et al. 2004; Turek et al. 2004). Below average stream discharge has been associated with ich outbreaks in other fish populations (John 1964; Maceda-Veiga et al. 2009).

Over the course of several meetings during the spring of 2012, the subgroup, comprised of TRRP staff, TRRP partners and Reclamation's Klamath Basin Area Office jointly developed 1) preventative flow release criteria designed to minimize the risk of a fish disease outbreak and subsequent fish kill, and 2) emergency flow release criteria designed to reduce the severity of a fish kill. The subgroup evaluated the 2012 hydrologic conditions, predicted fall-run Chinook salmon run size, relevant scientific literature, and previous fall flow release recommendations and assessments to develop criteria for both preventative and emergency flow releases in 2012. The subgroup reached consensus on the recommendations described in more detail below.

Recommendation for preventative fall flow releases

Utilizing the best available information, the subgroup developed preventative flow release criteria designed to reduce the risk of an outbreak of *Ichthyophthirius multifiliis* (ich) in order to reduce the probability a fall-run Chinook salmon fish kill in the lower Klamath River (Table 1).

Table 1. Summary of 2012 preventative fall flow release criteria and management actions.

Preventative fall flow release criteria	Management action
Flows projected to be above 3,200 cfs in the Klamath River (RKM 13) during the primary adult fall-run Chinook salmon migration season (August 15-Sept 21)	No preventative fall flow release
Flows projected to be below 3,200 cfs at Klamath River (RKM 13) during the migration season	Increase base flows to at least 3,200 cfs during primary fall Chinook salmon migration season (August 15-Sept 21). If water temperature exceeds 23°C after September 21, maintain at least 3,200 cfs until (1) September 30 or (2) water temperature recedes below 23°C.

We recommend maintaining flows in the lower Klamath River (U.S. Geological Survey Site #11530500; Klamath near Klamath gauge) of at least 3,200 cfs from August 15, 2012 to September 21, 2012 with ramping of flows occurring before and after these dates (Figure 1; Appendix A). Reduction of flows below 3,200 cfs after September 21, 2012 would commence based on water temperatures remaining below the adult Chinook salmon migration threshold of 23°C for the last week in September (Strange 2010a). We also recommend timing a pulse flow (to achieve at least 4,400 cfs at the KNK gage) to arrive concurrently to the lower Klamath River with the already scheduled cultural flow releases from Iron Gate Dam (to achieve 2,800 cfs at Orleans gage on September 2, 2012). At a later date when there is more certainty regarding water availability, policy guidance, and likely accretion flows, additional release schedules could be developed specifically for Lewiston and Iron Gate dams. Due to our conceptual model of how an ich outbreak would occur in the lower Klamath River, the source of water is unimportant for maintaining the effectiveness of these preventive flows. However, there is the potential for unintended negative consequences due to unseasonably high flow releases from basin dams (Iron Gate and Lewiston; see Additional Considerations below). Such potential consequences would be reduced if the magnitude of flow releases from a given dam in one sub-basin were reduced by concurrent flow releases from the dam in the other sub-basin. The volume of water required to supplement flows in the lower Klamath River to achieve the hydrograph in Figure 1 given the advanced hydrologic predictions currently available is approximately 48,000 acre feet in addition to the base flows and ceremonial releases currently planned at Lewiston and Iron Gate dams (Appendix A).

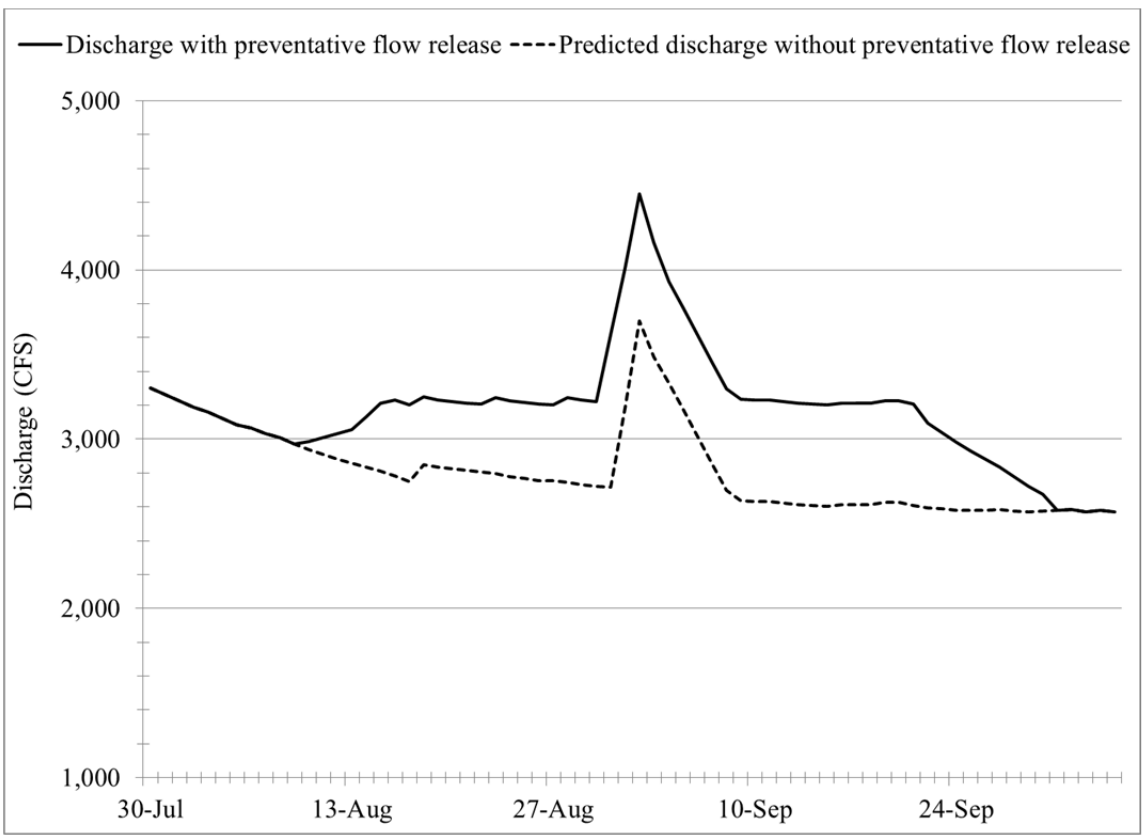

Figure 1. Recommended hydrograph (solid line) for the U.S. Geological Survey Site #11530500 (Klamath River near Klamath, California) during the 2012 fall-run Chinook salmon migration period. Predicted flows (dashed line) for the same location based on advanced hydrologic predictions by the California Nevada River Forecast Center.

The subgroup reviewed the information in previous assessments of fall flow releases provided in Strange (2010b) and Hayden (2012). While Strange (2010b) and Hayden (2012) recommended flows of at least 2,800 cfs during years of run sizes greater than 170,000 adult fall-run Chinook salmon, the recommendations were made in the context of what was then the maximum number of fall-run Chinook salmon which occurred in 1995 (Table 2). The record breaking run size predicted for 2012 was never contemplated by Strange (2010b) or Hayden (2012). Accordingly, the subgroup decided it was appropriate to reexamine the previous recommendations and develop new recommendations as needed to reduce the probability of a fish kill occurring in 2012.

Gaging records for the lower Klamath River indicate that the long term average discharge for both August and September is approximately 3,200 cfs, with the 50% exceedance during those months of approximately 3,000 cfs (Appendix B). The subgroup compared other large fall-run Chinook salmon run sizes to discharge in the lower Klamath River to gain an understanding of the hydrologic conditions in years with large runs (Table 2). The information indicated that average discharge during years with large fall-run Chinook salmon run sizes (≥170,000) was over 3,000 cfs in the lower Klamath River and under these conditions no significant pre-spawn mortality was recorded for fall-run Chinook salmon.

Table 2. Average discharge in cfs for July, August, and September in the lower Klamath River for various above average fall-run Chinook salmon run size levels.

Adult Run Size Category	July	August	September	Adult Chinook salmon run size or mean run size
Fish Kill - 2002	3,187	2,327	1,993	160,800
Largest Run – 1995	7,352	4,156	3,604	222,800
Mean of runs greater than the 2002 run	4,589	3,184	3,236	199,000
Mean of runs above the estuary greater than the 2002 run	4,495	3,098	3,175	174,000

The subgroup chose a discharge of at least 3,200 cfs for lower Klamath River during the fall-run Chinook salmon migration period because long term gaging records indicated this is approximately the average discharge, a higher level of discharge is thought to lead to lower a probability of an ich outbreak as described in more detail by Strange (2010b), and due to the precautionary approach taken by the subgroup given the considerable uncertainty of a fish kill occurring with the unprecedented fall-run Chinook salmon run size predicted for 2012.

The purpose of higher base flows is not necessarily to reduce water temperatures or to provide migration cues but to achieve the associated increased water velocities and higher turnover rates of water in holding areas, which should reduce the ability of ich to find and attach to a host fish during its free swimming infectious stage (known as a "theront"). Sufficiently high water velocities and turnover rates should be maintained throughout the primary fall Chinook salmon migration season in order to reduce the probability of an ich outbreak (Strange 2010b). In addition, the higher base flows would help to reduce the overall density of adult fall-run Chinook salmon, and thereby reduce the probability that the theronts would be successful in finding a host. The peak flow recommended by the subgroup to coincide with the cultural releases scheduled to occur in the lower Klamath River is intended to further disrupt the ability of ich theronts to find a host and flush any ich theronts that may be present in the lower Klamath River at the peak of the fall-run Chinook salmon migration season into the estuary and ocean where higher salinities would kill the organisms. For example, Jessop (1995) suggested that high discharge may flush the infective stages of ich downstream.

Recommendation for emergency fall flow releases

Utilizing the best available information, the subgroup developed new criteria and management actions for emergency flow releases for 2012 designed to reduce the number of fish killed in the unlikely event of an imminent, unexpected fish disease outbreak. We adopted the response outlined by Clarke (2010) to double preexisting flows, regardless of whether or not a preventative flow release was carried out, for seven days in the event that the criteria for an emergency fall flow release were met or exceeded (Table 3).

Table 3. Summary of 2012 emergency fall flow release criteria and management actions.

Emergency fall flow release criteria	**Management action**
1. 15% of adult salmonids with 30 or more ich parasites per gill as confirmed by Fish Health Center Or 2. Observed mortality of > 50 dead adult salmonids in a 20 km index reach in 24 hr coupled with confirmed presence of ich by USFWS Fish Health Center.	Recommend immediate Emergency Fall Flow release with a 7 day duration pulsed spike to double pre-existing flows in the Lower Klamath River up to 6400 cfs.

The duration of the 7 day (total duration with ramping) peaked flow release was determined by the life cycle of ich, which takes 7 days to complete at 20°C (Strange 2010b). The subgroup decided to limit the magnitude of the emergency flow release to 6,400 cfs because flows of this magnitude in August are rare (<5% exceedance probability, Appendix B), and because the group felt that this flow level should be sufficient to interrupt an imminent fish kill and significantly reduce total mortality rates. Discharge of 6,400 cfs during the adult fall-run Chinook salmon migration period is not without precedent in the gaging records: discharge in five years (1913, 1952, 1953, 1958, 1983) during August has been greater than 6,400 cfs as measured at the KNK gage. A variety of monitoring efforts are planned that will be integral to determining the need for an emergency fall flow release in 2012 and provide valuable data with which to assess the effectiveness of the recommended preventative release strategy (Appendix C).

Additional Considerations

While modest increases from river discharge in the Klamath Basin from summer rainstorms are not uncommon during the adult fall-run Chinook salmon migration period, these rain events are typically short in duration and occur with limited frequency. The sustained release of a substantial volume of water from one or both Klamath Basin dams, as recommended above, would mark a departure from the natural flow regime (Poff et al. 1997; Lytle and Poff 2004) of the Klamath and Trinity rivers because the duration of the elevated flows is unnatural. Modification of flow can be expected to have cascading effects on the ecological integrity of rivers and the organisms that depend on them (Poff et al. 1997). Below, we outline a list of potential negative ecological and operational consequences, some less likely than others, from the release water during the late summer and fall months in order to inform decision makers. These considerations are largely informed by specialists working on the Trinity River. In addition, there are likely other negative ecological effects that are currently unknown, as well as beneficial effects that are unknown. Importantly, the subgroup expects that the potential negative consequences of the unseasonably elevated flows would be reduced if the magnitude of flow releases from a dam in one river were reduced by concurrent flow releases from the dam in the other river. Despite these potential consequences, we still recommend implementing the preventative flow release described above, recognizing that efforts have been made to reduce these consequences (e.g. restricting the duration of the preventative flow prescription and capping emergency flow rates to 6,400 cfs at KNK gauge). The subgroup also recommends that monitoring efforts be structured to gain knowledge regarding the ecological response to these "unnatural" flows to evaluate the potential consequences.

Potential negative ecological consequences of releasing water from Lewiston Dam:

- Unseasonably high flows could trigger premature migration of juvenile lamprey (Stutsman 2005).
- Maintaining high flows after the second week in September, followed by reductions in flows to 450 cfs could cause up to 20% of Chinook salmon redds in the upper Trinity River to be dewatered.
- High flows in September could cause increased hybridization of spring-run and fall-run Chinook salmon if early migration of fall-run Chinook salmon occurred.
- Negative effects to amphibians and reptiles.

Potential negative operational consequences of releasing water from Lewiston Dam:

- Any flows over 1,800 cfs at the USGS Hoopa gage (approximately 1,400 cfs at Lewiston) would make the operation of the Willow Creek adult salmon weir impossible; loss of Chinook salmon, coho salmon, and steelhead monitoring data would occur. Loss of fall-run Chinook salmon monitoring data would have wide ranging consequences and 2012 run size may not be able to be estimated. Fishery allocations, minimum escapement requirements, and analyses of management rely on this estimate.
- Any flows over 600 cfs at Lewiston Dam will put mechanical channel rehabilitation site implementation in jeopardy of proceeding during 2012 and will cost the TRRP time and money. Over two years of work in designs, environmental compliance, realty actions, stakeholder negotiations, etc. have been invested to allow implementation this year.

- Any flows over 700-900 cfs at Lewiston Dam would impact the ability to operate the Junction City adult salmon weir.
- Any flows over 900 cfs at Lewiston Dam would make the operation of the Junction City adult salmon weir impossible, causing a loss of spring-run Chinook salmon monitoring data.
- Any flows over 1,500 cfs at the Hoopa gage (approximately 1,100 cfs at Lewiston) will make the operation of the Willow Creek adult salmon weir challenging, fall-run Chinook salmon, coho salmon, and steelhead monitoring data could be compromised.
- Flows of 1,200 cfs or greater would cause loss of redd/carcass survey data.
- Flows greater than 450 cfs for a prolonged period will potentially compromise systemic juvenile habitat assessment.

Klamath experts have been asked to provide comparable information to decision makers on the negative ecological and operational consequences of releasing water from Iron Gate Dam to reduce the likelihood of a fish kill in the lower Klamath River.

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Appendices

A. Reccomended flow schedule for the lower Klamath River (U.S. Geological Survey Site #11530500).

B. Exceedance table for the lower Klamath River.

C. Planned monitoring components for Klamath Basin adult fall-run chinook salmon migration 2012

D. Additional 2012 chinook salmon run size information: memo from Joe Polos to Robin Schrock, February 24, 2011

E. List of participants

Appendix A: Reccomended flow schedule for the lower Klamath River (U.S. Geological Survey Site #11530500)

Appendix Table A1. Reccomended flow schedule for the lower Klamath River (U.S. Geological Survey Site #11530500).

Date	50% flow forecast river flow without dam releases (from CNRFC)	IGD Flows	Lewiston Flows	Flow estimate at KNK with no supplemental flows	Supplemental Flows	Flow estimate at KNK with supplemental flows
7/30/2012	1972	880	450	3302	0	3302
7/31/2012	1932	880	450	3262	0	3262
8/1/2012	1894	880	450	3224	0	3224
8/2/2012	1859	880	450	3189	0	3189
8/3/2012	1830	880	450	3160	0	3160
8/4/2012	1792	880	450	3122	0	3122
8/5/2012	1756	880	450	3086	0	3086
8/6/2012	1735	880	450	3065	0	3065
8/7/2012	1701	880	450	3031	0	3031
8/8/2012	1677	880	450	3007	0	3007
8/9/2012	1642	880	450	2972	0	2972
8/10/2012	1608	880	450	2938	50	2988
8/11/2012	1581	880	450	2911	100	3011
8/12/2012	1553	880	450	2883	150	3033
8/13/2012	1527	880	450	2857	200	3057
8/14/2012	1503	880	450	2833	300	3133
8/15/2012	1483	880	450	2813	400	3213
8/16/2012	1451	1000	450	2781	450	3231
8/17/2012	1422	1000	450	2752	450	3202
8/18/2012	1398	1000	450	2848	400	3248
8/19/2012	1383	1000	450	2833	400	3233
8/20/2012	1373	1000	450	2823	400	3223
8/21/2012	1364	1000	450	2814	400	3214
8/22/2012	1358	1000	450	2808	400	3208
8/23/2012	1345	1000	450	2795	450	3245
8/24/2012	1327	1000	450	2777	450	3227
8/25/2012	1317	1000	450	2767	450	3217
8/26/2012	1306	1000	450	2756	450	3206
8/27/2012	1302	1000	450	2752	450	3202
8/28/2012	1296	1000	450	2746	500	3246
8/29/2012	1282	1000	450	2732	500	3232
8/30/2012	1272	1475	450	2722	500	3222

Date	50% flow forecast river flow without dam releases (from CNRFC)	IGD Flows	Lewiston Flows	Flow estimate at KNK with no supplemental flows	Supple mental Flows	Flow estimate at KNK with supplemental flows
8/31/2012	1268	2000	450	2718	900	3618
9/1/2012	1260	1800	450	3185	825	4010
9/2/2012	1249	1650	450	3699	750	4449
9/3/2012	1237	1500	450	3487	675	4162
9/4/2012	1230	1350	450	3330	600	3930
9/5/2012	1224	1200	450	3174	600	3774
9/6/2012	1212	1050	450	3012	600	3612
9/7/2012	1204	1000	450	2854	600	3454
9/8/2012	1196	1000	450	2696	600	3296
9/9/2012	1188	1000	450	2638	600	3238
9/10/2012	1183	1000	450	2633	600	3233
9/11/2012	1179	1000	450	2629	600	3229
9/12/2012	1172	1000	450	2622	600	3222
9/13/2012	1164	1000	450	2614	600	3214
9/14/2012	1160	1000	450	2610	600	3210
9/15/2012	1155	1000	450	2605	600	3205
9/16/2012	1161	1000	450	2611	600	3211
9/17/2012	1163	1000	450	2613	600	3213
9/18/2012	1162	1000	450	2612	600	3212
9/19/2012	1176	1000	450	2626	600	3226
9/20/2012	1179	1000	450	2629	600	3229
9/21/2012	1156	1000	450	2606	600	3206
9/22/2012	1144	1000	450	2594	500	3094
9/23/2012	1139	1000	450	2589	450	3039
9/24/2012	1131	1000	450	2581	400	2981
9/25/2012	1128	1000	450	2578	350	2928
9/26/2012	1130	1000	450	2580	300	2880
9/27/2012	1133	1000	450	2583	250	2833
9/28/2012	1127	1000	450	2577	200	2777
9/29/2012	1119	1000	450	2569	150	2719
9/30/2012	1124	1000	450	2574	100	2674
10/1/2012	1129	1000	450	2579	0	2579
10/2/2012	1134	1000	450	2584	0	2584
10/3/2012	1121	1000	450	2571	0	2571
10/4/2012	1129	1000	450	2579	0	2579
10/5/2012	1122	1000	450	2572	0	2572
Acre feet:					48,510	

Appendix B: Exceedance table for the lower Klamath River

Appendix Table B2. Exceedance table based on monthly average flows, not daily flows, for the Lower Klamath River (U.S. Geological Survey Site #11530500) using years 1911-2011.

Exceedence	July	August	September
0.05	9,664	4,872	4,890
0.10	8,959	4,399	4,258
0.15	7,795	4,326	4,120
0.20	7,369	4,136	3,943
0.25	6,701	3,703	3,788
0.30	6,423	3,550	3,605
0.35	5,497	3,458	3,430
0.40	5,120	3,271	3,355
0.45	4,755	3,158	3,169
0.50	4,408	2,972	3,030
0.55	4,261	2,944	2,923
0.60	4,080	2,896	2,846
0.65	3,907	2,854	2,750
0.70	3,775	2,783	2,685
0.75	3,564	2,658	2,594
0.80	3,306	2,559	2,535
0.85	3,226	2,368	2,500
0.90	2,949	2,193	2,446
0.95	2,501	1,873	2,003

Appendix C: Planned monitoring components for Klamath Basin Adult Fall Chinook Salmon Migration 2012

1. Adult Chinook Salmon Pathology Monitoring (Yurok Tribe)
    - Mid-August through Mid-October 2012
    - Fish will be captured with gill nets from Techtah Creek rkm 38 to Blue Creek rkm 26
    - Goal of 30 adult fish sampled per week
    - External examination of skin and gills for indication of columnaris and ich infections along with digital imaging and video recordings of ich inside gill arches.
    - Conducted every year since 2003
    - USFWS Pathologist Scott Foott on call
    - Further training for field crews in 2012 with CANFHC

2. Harvest Monitoring/Adult Salmon Abundance
    - Yurok Tribal harvest as weekly summaries by area for catch-per-unit-effort
    - CDFG weekly summaries of creel surveys of sport catches
    - Summer snorkel surveys of thermal refugia associated with the mouth of Blue Creek (YTFP)
    - DIDSONS could be added to aid in monitoring abundance of fish
    - Weir summaries from CDFG

3. Water Temperature and Flow
    - USGS site 11530500 Klamath River near Klamath, CA: http://waterdata.usgs.gov/ca/nwis/uv/?site_no=11530500&PARAmeter_cd=00065,00060
    - Yurok Tribal Environmental Program real time monitoring: http://exchange.yuroktribe.nsn.us/lrgsclient/stations/stations.html
    - California Nevada River Forecast Center advanced hydrologic prediction for USGS site 11530500 Klamath River near Klamath, CA http://www.cnrfc.noaa.gov/espTrace.php?id=KLMC1

4. Coordination and Response
    - Klamath Fish Health Assessment Team (KFHAT) Web Portal: http://www.kbmp.net/collaboration/kfhat

Appendix D: Memo from Joe Polos to Robin Schrock, February 24, 2011

February 24, 2011

To: Robin Schrock (TRRP ED), Ernie Clarke (TRRP SC), and Tim Hayden (TRRP Flow WG coordinator)
From: Joe Polos, TRRP Fish Work Subgroup Coordinator
Subject: Projected Klamath River Fall Chinook Salmon Inriver Run Size for 2012

During the February 8, 2012, TRRP Fish Work Subgroup meeting there was an update on the 2011 Klamath River fall Chinook salmon run (KRFC), particularly the large jack (age 2) return (Table 1). The numbers of age 2, age 3 and age 4 fish returning in one year are used to predict the population size in the ocean the following year. Additionally, during the discussion of water year 2012 planning, the efforts of the fall flow subgroup were discussed. The TRRP Flow WG has developed criteria for implementing fall flow measures and is currently updating this information.

The Fish Work Subgroup wanted to alert the TMC and the TRRP Flow Work Subgroup of the potential large KRFC inriver run in 2012, in addition to concerns with the dry conditions occurring in the Klamath Basin. In northern California, the current snow water equivalent is 35% of average for mid-February, just slightly greater than the lowest year on record (1976-1977; Figure 1). The KFRC inriver run (hatchery and natural fish combined) may be as large as approximately 350,000 adults in 2012 (Table 2). In addition to this, there will be a jack component (age 2 fish) to the inriver run in 2012 of which there is no preseason estimate. In 2002, the year of the fish kill, the adult KRFC inriver run was 161,000 fish (Figure 2) and the total inriver run (jacks and adults) was 170,000 fish..

This information pertaining to the estimated inriver KRFC run this fall is **very preliminary** and there may be large changes as data continue to be analyzed. Additionally, there is large variability in the accuracy of these projections, especially for the age 3 component, but it should be expected that there will be a large return in 2012. Any updated information developed as the Pacific Fishery Management Council (PFMC) proceeds with its fishery management planning in the coming months will be provided. These estimates were derived by applying seasonal mortality and harvest impact factors (Attachment A) which will not produce the same values that will be modeled in the PFMC stock assessment process.

Additionally, a cursory look at the relationship between Klamath Basin spring Chinook inriver run size and fall Chinook inriver run size was conducted (Attachment B). This analysis will be updated when the recent spring Chinook salmon "megatable" is available. While this is a strong relationship, there is greater variability at larger populations sizes and the fall Chinook inriver run is beyond the range of the dataset used to develop the relationship. With these caveats in mind, the projected inriver size of adult spring Chinook salmon in 2012 is 84,500 fish.
The Fish Work Subgroup will also provide other pertinent information that may be developed over the next several months.

Summary:

A large Klamath River fall Chinook salmon inriver run is expected in 2012, approximately 350,000 adults, and the dry hydrologic conditions occurring in the Klamath Basin raise concerns over the potential for a fish-kill. Additionally, there may also be a large spring Chinook salmon inriver run. The TRRP Flow WG has been developing documents to assist in implementing a fall flow effort, if needed, in addition to their efforts in in evaluating conditions pertaining to the need for a fall flow. While the data on Klamath fall Chinook salmon inriver run size are **very preliminary**, we feel that they are suitable to inform the TRRP that a very large inriver run in 2012 should be anticipated. Additionally, while there is still time in the water year for more precipitation, it is likely than below average hydrologic conditions will occur this water year and TRRP should plan accordingly.

Table 1. Klamath Basin fall Chinook salmon age specific estimates of the 2011 inriver return (estimates include both hatchery and natural fish). [1]

Age	2011 return
2	85,840
3	59,776
4	41,243
5	1,986
Total Adults	103,005

1. Age specific population estimates for the 2011 return from KRTT 2011 Klamath Basin Age Composition Report, Feb 2012.

Table 2. **Preliminary** Klamath Basin fall Chinook salmon age specific adult inriver run prediction for 2012 assuming full fishing in ocean fisheries (harvest rate = 0.16 on age 4 Klamath River fall Chinook salmon). No estimates are made for jacks (age 2 fish). See Attachment A for explanation of how estimates were derived.

Age	Inriver run (1000s)
3	302.7
4	47.0
5	2.5
Total	**352.2**

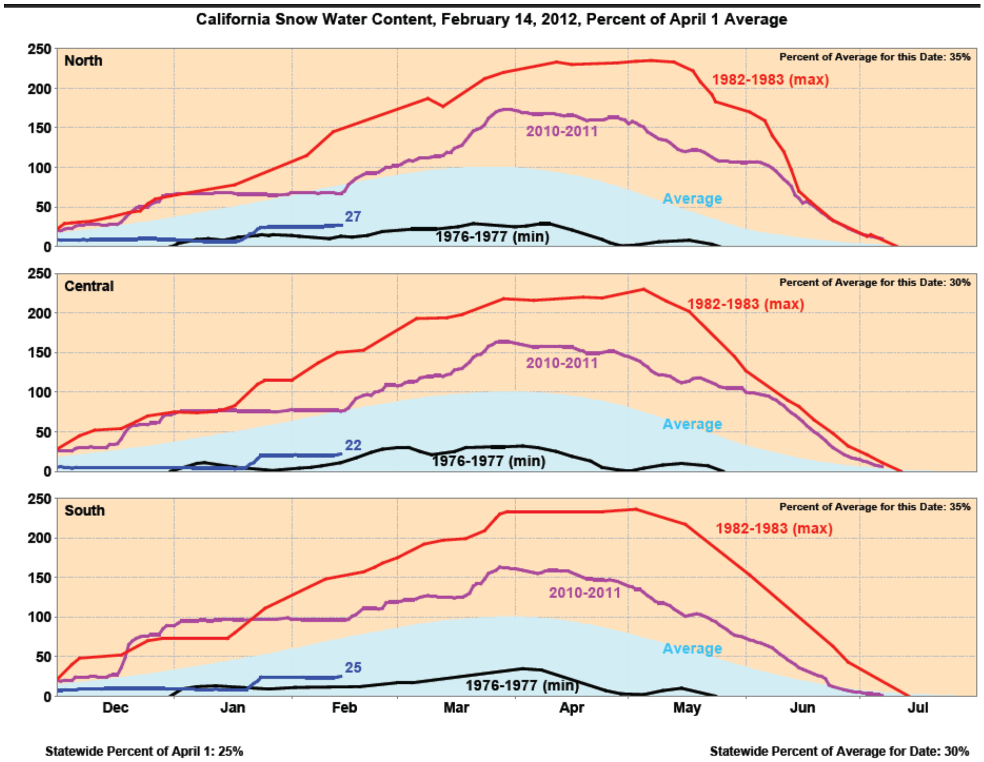

Figure 1. Current state wide California snow water content (blue line) along with extremes and average for the period of record.

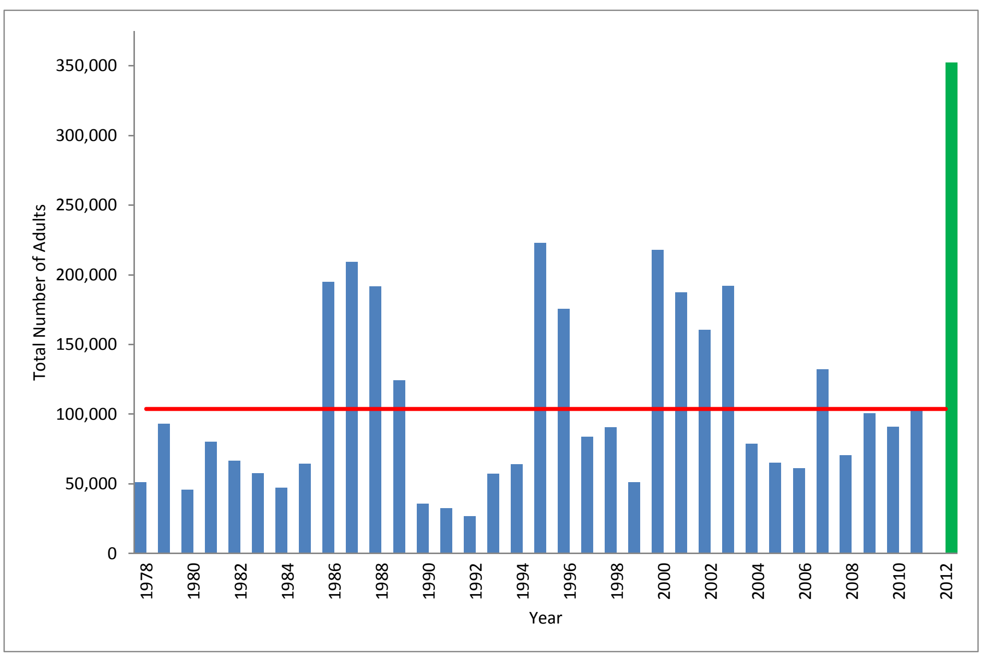

Figure 2. Klamath River adult fall Chinook salmon inriver run, 1978-2011, and projected 2012 inriver run. Horizontal red line is 1978-2011 mean.

Attachment A. Derivation of Klamath Basin fall Chinook salmon inriver run for 2012.
The 2012 adult Klamath River fall Chinook salmon (KRFC) inriver run was estimated using the sibling regression models (zero-intercept) to estimate the ocean population (Table A1, KRTT 2011). Overwinter survival, ocean impact parameters and age-specific maturity rates (PFMC and NMFS 2007) were used to estimate the 2012 inriver run (Table A2). The harvest rate of 0.16 for age 4 KRFC was used in this analysis which is the maximum allowed under the Endangered Species Act to protect Coastal California fall Chinook salmon populations. All population estimates are for hatchery and natural fish combined. The following equations were used to generate age-specific populations estimates:

1. Number of age (*i*) KRFC in the ocean in the fall (Sept 1) of year (*t-1*)=

   $N(O_{Sept1})_{i,t-1} = N(R)_{i-1,t-1} * B_{i.}$, where B_i slope parameter of the zero intercept regression model for age(i-1) to age *i* fish between inriver return, $N(R)_{i-1,t}$, and siblings remaining in the ocean.

2. Number of age *i* KRFC in the ocean the following spring (May 1) of year *t* =

   $N(O_{May\ 1})_{i,t} = N(O_{Sept\ 1})_{i,t-1} * S_{i.}$, where S_i is the age specific overwinter survival.

3. Number of age *i* KRFC contacted by ocean fisheries in year *t*:

   $N(C)_{i,t} = N(O_{May\ 1})_{i,t} * V_i * HR_{(t)}$, where V_i is the age specific vulnerability and $HR_{(t)}$ is the ocean harvest rate of age 4 KRFC in year *t*.

4. Number of age *i* KRFC landings in year *t* =

   $N(L)_{i,t} = N(C)_{i,t} * \%L_i$, where $\%L_i$ is the percentage of legal sized fish of age *i*.

5. Number of age *i* KRFC shaker mortalities of undersized fish in year *t* =

   $N(S)_{i,t} = N(C)_{i,t} * (1-\%L_i) * SM$, where SM is the shaker mortality rate.

6. Number of age *i* KRFC suffering mortality due to contact with fishing gear in year *t* =

   $N(D)_{i,t} = N(C)_{i,t} * DO$, where DO is the drop-off mortality rate.

7. Number of age *i* KRFC ocean fishery impacts in year *t* =

   $N(OI)_{i,t} = N(L)_{i,t} + N(S)_{i,t} + N(D)_{i,t}$.

8. Number of age *i* KRFC in the ocean on August 31 following ocean fishery impacts =

   $N(O_{Aug31})_{i,t} = N(O_{May\ 1})_{i,t} - N(OI)_{i,t}$

9. Number of age *i* KRFC fish returning to the river in the fall (Sept 1) of year *t* =

   $N(R_{Sept1})_{i,t} = N(O_{Aug31})_{i,t} * MR_i$,where MR_i is the age specific maturity rate.

References

KRTT. 2011. Ocean Abundance Projections and Prospective Harvest Levels for Klamath River Fall Chinook, 2011 Season

PFMC and NMFS. 2007. Final environmental assessment for Pacific Coast salmon plan amendment 15: An initiative to provide de minimis ocean fishing opportunity for Klamath River fall Chinook. Pacific Fishery Management Council, Portland, Oregon.

Table A1. Klamath River fall Chinook salmon age specific estimates of the 2011 inriver return and corresponding estimates of fish remaining in the ocean in the fall (August 31) of 2011 from each respective brood year.

Age	Regression Slope Parameter (zero intercept model) [1]	2011 inriver return (1000s) [2]	Ocean 2011 estimate (Sept 1) (1000s) [3]
$2_{inriver}$ to 3_{ocean}	18.2920	85.84	1570.2
$3_{inriver}$ to 4_{ocean}	1.3330	59.776	79.7
$4_{inriver}$ to 5_{ocean}	0.1120	41.243	4.6
$5_{inriver}$	N/A	1.986	N/A

1. Source of slope parameters: KRTT. 2011 and do not reflect any refinement that may occur through analyses that will occur in developing the 2012 stock projection.
2. Source: KRTT. 2012.
3. Ocean population estimated by multiplying the number of fish retuning to the river by the age specific regression slope parameter.

Table A2. Klamath fall Chinook salmon ocean and inriver population estimates for 2012. All calculation based on assumed age 4 harvest rate of 0.16 which is the maximum rate allowed in ocean fisheries due to ESA constraints for Coastal California fall Chinook salmon populations.

Max Ocean HR = 0.16															
Age	2011 Ocean estimate (Sept 1) (1000s)	Survival[1]	2012 Ocean Population in May (1000s)[2]	Vulnerability[1]	%legal[1]	Contacts (1000s)	Landings (1,000)	Shaker mortality[1]	Shaker impacts (1000s)	Drop-off Rate[1]	Drop-off impacts (1000s)	Ocean Impact (1000s)	Ocean popn after fishing impact (1000s)	Maturity Rate[3]	Inriver run (1000s)
3	1570.2	0.5	785.1	0.25	0.8	31.4	25.1	0.26	1.6	0.05	1.6	28.3	756.8	0.4	302.7
4	79.7	0.8	63.7	1	0.95	10.2	9.7	0.26	0.1	0.05	0.5	10.3	53.4	0.88	47.0
5	4.6	0.8	3.7	2	1	1.2	1.2	0.26	0.0	0.05	0.1	1.2	2.5	1	2.5
Total	1,654.5		852.5				36.0		1.8		2.1	39.9	812.6		**352.2**

1. Source: PFMC and NMFS (2007). Final environmental assessment for Pacific Coast salmon plan amendment 15: An initiative to provide de minimis ocean fishing opportunity for Klamath River fall Chinook. Pacific Fishery Management Council, Portland, Oregon.
2. Age specific ocean populations in May were estimated by multiplying the 2011 ocean population by the annual age-specific survival .
3. Personal Communication: Michael O’Farrell. NOAA-Fisheries Santa Cruz.

Attachment B. Relationship between Klamath Basin Spring Chinook salmon inriver run based on Klamath Basin fall Chinook salmon inriver run for 2012.

A cursory analysis of the relationship between the adult Klamath Basin spring and fall Chinook salmon inriver runsize was conducted to provide additional information concerning the potential inriver run in 2012. Total inriver run data from the spring Chinook salmon "megatable" and the fall Chinook salmon "megatable" were used for this analysis. Although data are not complete for all harvest and escapement components of the run for the spring Chinook salmon data, these data are probably sufficient to provide a general indicator of the potential magnitude of the adult spring Chinook salmon inriver run. Data from 1981-2005 were used in this analysis, except for 1983 and 1995 when the Junction City weir was not operated. The data from these two years were excluded because the natural escapement above Junction City is a major portion of the run in most years.

The relationship between the adult spring Chinook and adult fall Chinook run is strong ($r^2 = 0.71$) but the relationship indicates there is greater variability at larger run sizes (Figure B1). An additional complicating factor in using this relationship to predict the 2012 adult spring Chinook salmon inriver run is that the 2012 fall Chinook inriver run prediction (352,200) is beyond the range of the dataset used to develop the regression equation. With these caveats in mind, the projected inriver size of adult spring Chinook salmon in 2012 is 84,500 fish.

The primary utility of this information is that, in addition to a larger fall Chinook salmon run, it should be expected that there will also be a large spring Chinook salmon run entering the Klamath Basin in 2012. This information will be updated when additional information becomes available.

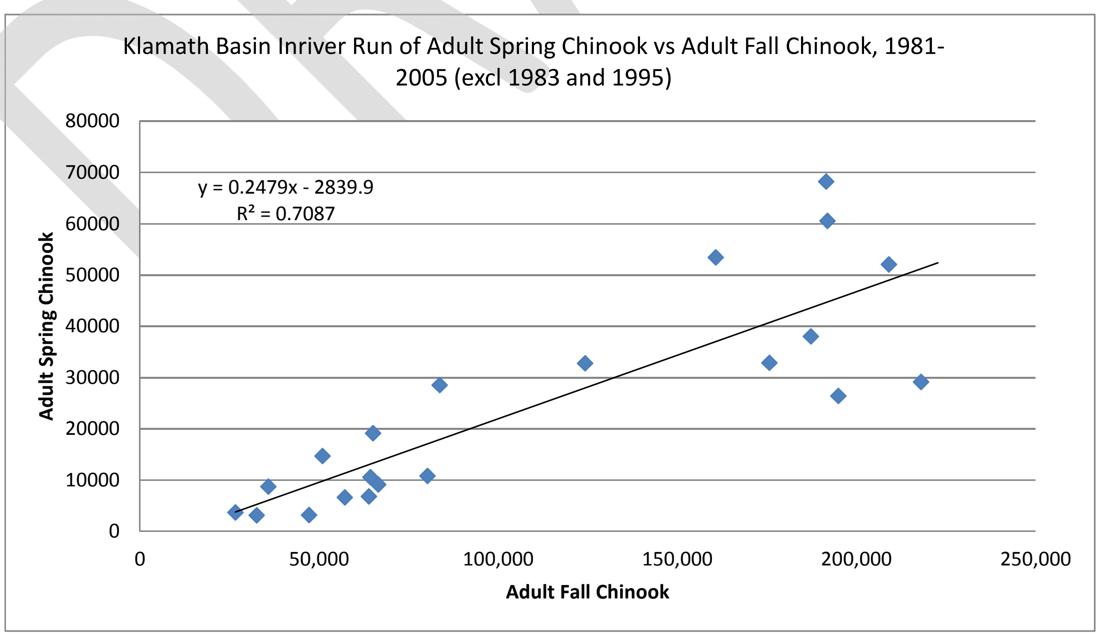

Figure B1. Relationship between the inriver run of adult spring Chinook salmon and adult fall Chinook salmon in the Klamath Basin.

Appendix E. List of Participants

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Summary of Klamath River Chinook Salmon In-River Run Size Data and Lower Klamath River Flows to Support TRRP Fall Flow Planning Efforts in 2012

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May 28, 2012

To: TRRP Fall Flow Workgroup

From: Joe Polos, USFWS – Arcata

Subject: Summary of Klamath River Chinook salmon in-river run size data and lower Klamath River flows to support TRRP Fall Flow planning efforts in 2012.

The large projected run size of Klamath River fall Chinook salmon in 2012 has raised concern of the potential for a fish kill this summer/fall. Until recently, the dry hydrologic conditions experienced in the Klamath/Trinity Basin heightened this concern. While the hydrologic conditions have greatly improved since mid-March, the unprecedented large projected in-river run and the characteristic late summer and early fall low flows necessitate the development of an effective and efficient plan to guide the implementation of flow augmentation during this critical low flow period.

The purpose of this document is to assist the Trinity River Restoration Program's Fall Flow workgroup in developing recommendations for 2012. This information was last presented to the Fall Flow workgroup in 2010 and has been updated with contemporary information.

Klamath River Fall Chinook Salmon

Projected 2012 In-river Run and Historical In-river Runs

The projected in-river run of Klamath River fall Chinook salmon, after accounting for projected ocean harvest impacts, is **381,000** adult fish (PFMC 2012a). The 2012 in-river run is projected to be the largest since comprehensive monitoring and harvest management activities were initiated in 1978 (Figure 1). The adult fall Chinook salmon run has ranged from 26,700 to 222,800, with a mean of 103,750; while the total fall Chinook salmon run has ranged from 34,400 to 245,500, with a mean of 122,500 (CDFG 2012a).

While the projected run size data are used for fishery management purposes, comparing post-season estimates to the preseason forecast shows there is substantial error in the projections, especially at projections greater than approximately 85,000 adults (Figure 2). Data available to compare preseason forecasts to post-season in-river run estimates were from 1984 to 2011, excluding 1995 and 1997 (data for these two years could not be located). While the preseason forecasts and post-season in-river estimates are significantly correlated ($r=0.653$, $n=26$, $p< 0.001$), the relationship is highly variable. The post-season estimated in-river adult run has ranged from 37% to 257% of the preseason forecast.

Variability in ocean survival rates, age-specific maturity rates, and anticipated harvest impact rates, as well as sampling errors associated with fishery and spawning escapement estimates contribute to the variability observed in the relationship between the preseason forecasts and the post-season estimates.

Another factor that will affect the accuracy of the 2012 in-river run size is the dominance of the age 3 component of the ocean population. The 2012 ocean abundance forecast of Klamath River in fall Chinook salmon is composed of 94.9% age 3 fish (FMC 2012b). The accuracy of the forecast is highly variable with substantial underestimates at population forecasts greater than approximately 200,000 fish (Figure 3). The postseason estimate of the age 3 Klamath fall Chinook salmon ocean population has ranged from 37% to 306% of the preseason forecast. Additionally, the data used for estimating the age 3 component of the ocean stock size is beyond the range of the data used to develop the stock-projection relationship, increasing the uncertainty of the estimate.

Estimation of Total Fall Chinook In-river Run – Accounting for Jacks

In addition to the adults, an unknown number of jacks (age 2 mature fish) will also contribute to the in-river fall Chinook salmon run in 2012. No forecast for the number of jacks is made as this age class is not part of the annual stock assessment/harvest management process.

The proportion of jacks in the total in-river run is highly variable, especially at the lower and moderate adult run sizes, ranging from 0.01 to 0.52, with a mean of 0.17 for the 1978 to 2011 return years (Figure 4). While a curvilinear function could be fit through the data, an alternative approach was used to estimate the proportion of jacks since the projected in-river adult run is beyond the range of the data. An estimate of the proportion of jacks was derived by calculating the mean proportion of jacks for years with higher adult run sizes, when the in-river run was estimated to be greater than 110,000 adults (demarcated by vertical dashed red line in Figure 4, n=11). The proportion of jacks in these years ranged from 0.013 to 0.186, with a mean of 0.071.

The total in-river run for 2012 was estimated by dividing the forecast in-river adult run by [1-(proportion of jacks)], using the mean proportion of jacks from the larger return years.

Using this method the estimated total Klamath River fall Chinook salmon in-river run for 2012 is:

381,000/(1-0.071) = **410,100**

Klamath River Spring Chinook Salmon

Klamath River Spring Chinook Salmon Run

While monitoring of spring Chinook salmon in the Klamath River is not as comprehensive as for fall Chinook salmon, data from 1981 through 2011 are comparable. Data from 1983 and 1995 were excluded because the Junction City Weir was not operated during these years and the run above this site is a substantial contributor to the total in-river run. The adult spring Chinook salmon run has ranged from 3,100 to 68,200, with a mean of 22,200 (Figure 5); while the total spring Chinook salmon run has ranged from 3,300 to 69,000 with a mean of 24,200 (CDFG 2012b).

Projected 2012 In-river Spring Chinook Salmon Run

No preseason forecasts are made for Klamath River spring Chinook salmon, primarily due to the lack of a comprehensive harvest/escapement management plan for this run. Since there is no forecast, the relationship between the magnitude of Klamath River adult spring and fall Chinook salmon runs was used to forecast the 2012 adult spring Chinook salmon in-river run.

Data from 1981 to 2011, excluding 1983 and 1995, were used to develop a regression relationship to predict the adult spring Chinook salmon in-river run based on the in-river forecast of adult fall Chinook salmon (Figure 6).

$$\text{Adult Spring Chinook Salmon Run} = 0.2481 * \text{Adult Fall Chinook Salmon Inriver Forecast} - 3723$$

Using this relationship, based on the adult fall Chinook salmon in-river forecast of 381,000 adults, an estimated **90,800** adult spring Chinook salmon are forecast to return to the Klamath River. The 2012 in-river spring Chinook salmon run is projected to be the largest since comprehensive monitoring was initiated in 1981 (Figure 5).

Although the projected fall Chinook salmon run is beyond the range of the data used to develop this relationship and the accuracy of the resulting spring Chinook salmon estimate uncertain, it should be expected that there will be a large spring Chinook salmon run in addition to the large fall Chinook salmon run in the Klamath River in 2012.

Estimation of Total Spring Chinook Salmon In-river Run – Accounting for Jacks

Similar to fall Chinook salmon data, the proportion of jacks in the spring Chinook salmon run compared to the adult run is highly variable, ranging from 0.007 to 0.50 with a mean of 0.10 (Figure 7). As was done with the fall Chinook salmon data, an estimate of the proportion of jacks was derived by calculating the mean proportion of jacks (ranging from 0.012 to 0.085, mean of 0.040) for the years with adult run sizes greater than 27,000 cfs (demarcated by vertical dashed red line in Figure 7, n=9).

The total projected in-river run of spring Chinook salmon for 2012 was estimated by dividing the forecast in-river adult run by the [1-(proportion of jacks)], using the mean proportion of jacks from the larger return years.

Using this method the estimated total Klamath River spring Chinook salmon in-river run for 2012 is:

90,800/(1-0.040) = **94,600**

Run Timing of Trinity River Hatchery Spring Chinook Salmon

The potential for a large spring Chinook salmon run is of interest because, although they typically enter the river in April through June, at times there are significant numbers of Trinity River Hatchery (TRH) origin spring Chinook salmon harvested by the Yurok fishery in the estuary in July and August (USFWS 1988, USFWS 1989). In 1987, 90% of the TRH origin spring Chinook salmon harvested by the Yurok fishery occurred in estuary during the fall fishery which occurred from mid-July through September (USFWS 1988). In 1988, this was also observed as well as a large number of TRH origin fall Chinook salmon harvested in the estuary in July which is unusual because this component of the fall run typically enters the river in late August and September (USFWS 1989, Polos and Craig 1994). It should be anticipated that if the spring Chinook salmon run is as large as projected, a large number of spring Chinook salmon will likely contribute to the run in the lower Klamath River in July and August since the spring Chinook run is dominated by Trinity and TRH fish. This will further increase the density of fish utilizing the lower Klamath River this summer/fall.

2002 Klamath Basin Run size and Flow Conditions

At least 33,000 fall Chinook salmon died during the 2002 fish kill (Guillen 2003) with the potential of an additional 45,000 fish due to the conservative nature of the fish kill assessment methodology (CDFG 2004). The mortality event occurred during the second half of September. In 2002, the adult fall Chinook salmon run was 160,800 fish (9th largest observed in the period from 1978 to 2011) and the total run (jacks and adults) was 170,000 fish (10th largest). The spring Chinook salmon run was 53,400 adults (3rd largest observed in the period from 1981 to 2011) and the total run was 56,200 fish (4th largest).

In 2002, mean monthly flows in the lower Klamath River (rkm 13) near Klamath, CA (KNK) from July through September were 3187 cfs, 2327 cfs, and 1993 cfs, respectively. These rank as the 4th lowest flow for July, 4th lowest for August, and 3rd lowest for September for the period 1978 to 2011.

2003 and 2004 Fall Flows and In-river Run Size

Following the 2002 fish kill, additional flows were released into the Trinity River in 2003 (34,000 acre-feet) and in 2004 (36,200 acre-feet) to improve conditions in the lower Klamath River to avert a fish kill. The additional flows were released in late August/ early September (Figure 8). In 2003, mean monthly flows at KNK for July through September were 5201 cfs, 3463 cfs, and 3383 cfs, respectively. In 2004, mean monthly flows at KNK for July through September were 4258 cfs , 3003 cfs, and 3004 cfs, respectively. The total fall Chinook salmon run size in 2003 and 2004 was 195,800 and 88,600, respectively. The total spring Chinook salmon run was 61,700 in 2003 and 20,100 in 2004. No salmonid fish kills occurred in the lower Klamath River during the fall in either of these years.

TRRP Fall Flow Triggers for 2010 and 2011

Two minimum flow targets to prevent a fish kill were recommended following the 2002 fish-kill: (1) 2300 cfs measured as the sum of flow at the Orleans gage (Klamath River) and Hoopa gage (Trinity River) (CDFG 2004) and (2) 2500 cfs at the KNK gage (Belchik et al. 2004) (Figure 9). Both of these targets are similar in flow magnitude due to the flow accretion between the upper gages (Orleans and Hoopa) and the lower gage (KNK). The lower river gage at KNK has generally been adopted as the appropriate location because of its proximity to the area of the 2002 fish kill. The Trinity River Restoration Program had adopted two flow criteria that would trigger a proactive flow release based on the projected in-river run of fall Chinook salmon (Attachment 1). Proactive flow releases would be implemented if flows at KNK went below 2500 cfs and the in-river run was projected to be less than 170,000 fish or if flows at KNK went below 2800 cfs and the in-river run was projected to be greater than or equal to 170,000 fish. Additionally, Zedonis et al. (2003) recommended 3000 cfs flow at KNK as a trigger for flow augmentation (Attachment 2). It should be noted that these flow targets were developed without considering the potential flow needs for a very large run. When these flow criteria were developed, the largest fall Chinook salmon run was 222,800 adults and the total run was 245,500 fish, occurring in 1995.

For the period from 1978-2011 when comprehensive fall Chinook salmon monitoring data are available, mean monthly flows in the lower Klamath River below the 2500, 2800 or 3000 cfs flow thresholds were uncommon in July (Table 1). Flows below the 2500 cfs threshold occurred five times (14.7%) in August and six times (17.6%) in September and coincided with large runs in 1987, 1988, and 2002. Flows below the 2800 cfs threshold occurred 8 times (23.5%) in August and 12 times (35.3%) in September and coincided with large in-river runs in 1987, 1988, 2001, and 2002. Flows below the 3000 cfs threshold occurred 14 times (41.2%) in August and 13 times (38.2%) in September and coincided with large in-river runs in 1986, 1987, 1988, 2001, and 2002. The frequency and percentage of times when flow thresholds ranging from 2500 cfs to 4000 cfs were not met are presented to show the range of hydrology that has occurred in the lower Klamath River from 1978 to 2011.

Adult Fall Chinook Salmon In-river Run and Lower Klamath Flows – 1978-2011

Annual fall Chinook salmon adult (Figures 10-12) and total (Figures 13-15) in-river runs and mean monthly lower Klamath River flows were plotted to investigate the patterns of run size and flow. In-river adult runs greater than the 2002 run and without a fish kill have occurred eight years since 1978 (Figure 10). During these high run years, July mean monthly flow in the lower Klamath was 4589 cfs, ranging from 3165 cfs to 7352 cfs (Figure 10). In August, the mean monthly flow was 3184 cfs, ranging from 2395 cfs to 4156 cfs (Figure 11) and in September it was 3236 cfs, ranging 2103 cfs to 4304 cfs (Figure 12).

During the large return years, mean flow in the lower Klamath River in July has always been greater than 3000 cfs, and sometimes substantially greater (1995, 1996, 2000, 2003). Mean monthly flow during August was less than 2500 cfs in one year (1987), below 2800 cfs in three years (1987, 1988, 2001) and below 3000 cfs in four years (1986, 1987, 1988, 2001) (Figure 11). Mean monthly flow in September was less than 2500 cfs in one year (1988), less than 2800 cfs in three years (1987, 1988, 2001), and less than 3000 cfs in three years (1987, 1988, 2001) (Figure 12). There have also been years with lower Klamath flows in August and September (1991, 1992 and 1994), but these low flow conditions coincided with some of the lowest in-river runs. These general patterns are similar for the total run data (Figures 13-15).

While monthly flow data provide useful information for this exercise, they do mask the variability and trends in flows that actually occur throughout the late summer and early fall and across years. Plots of daily flows during 2002 and years when the in-river adult fall Chinook salmon run was greater than the 2002 run show the variability and trends in flows during these years (Figure 16)

In 1987 and 1988 no fish kill occurred when the in-river adult fall Chinook salmon runs were greater than the 2002 run with similar flows in August (1987) and September (1988) (Table 2). One factor that may have helped prevent a fish kill in these years was the reduction of fish abundance due to the Yurok fishery in the estuary. A total of 35,700 fall Chinook salmon were harvested by this fishery in August 1987 (USFWS 1988) and 35,400 in August 1988 (USFWS 1989). While the 1986 run was also large, fall rains, particularly after mid-September, greatly increased the mean monthly flow.

Adult Fall Chinook Salmon In-river Run above the Estuary and Lower Klamath Flows – 1978-2011

As noted in the previous section, the estuary fishery of the Yurok Tribe can significantly decrease the number of fish moving upstream since it is often the area of highest harvest for this fishery. In addition to the tribal fishery, a recreational fishery in the estuary harvests substantial numbers of fall Chinook salmon in some years. To evaluate the run size above the estuary and coincident flows, the adult harvest impacts of the estuary fisheries (tribal and recreational) were subtracted from the in-river adult run estimates (Figures 17-19).

Adult in-river runs above the estuary greater than the 2002 run occurred seven times since 1978 (Figure 17). During these years, mean flow for July was 4495 cfs, ranging from 3165 cfs to 7352 cfs (Figure 17). In August the mean flow was3098 cfs, ranging from 2395 cfs to 4156 cfs (Figure 18). In September the mean flow was 3175 cfs, ranging 2103 cfs to 4304 cfs (Figure 19). The frequency and years which thresholds of 2500 cfs, 2800 cfs or 3000 cfs were not met were the same as presented for the total adult in-river run in the previous section.

It has been speculated that the harvest of fish in the estuary fisheries (tribal and recreational) may have sufficiently reduced the populations size and density of fish moving upriver which could have contributed to preventing an epizootic. Data on the adult runs do not support this as runs above the estuary in 1987 and 1988 were still greater than that observed in 2002 (Table 2). While the total numbers of adult fall Chinook salmon moving above the estuary were not reduced to levels lower than that observed in 2002, the timing of the fisheries, especially the tribal fishery which may have had higher impacts on the earlier part of the run (Polos and Craig 1994), may have contributed to limiting fish density/abundance earlier in the season.

Flow Conditions During the Largest Fall Chinook Salmon Run

Since contemporary monitoring activities were initiated in 1978, the largest in-river run of Klamath River fall Chinook salmon occurred in 1995 with an adult run of 222,800 fish and a total run of 245,500 fish. Mean monthly flows in the lower Klamath River from July through September were 7352 cfs, 4156 cfs, and 3604 cfs, respectively (Figure 20, upper graph). During this year, flows in the lower Klamath River were substantially greater than flows observed in 2002, and somewhat greater than flows observed in 2003 and 2004 when flow augmentation occurred (Figure 20, lower graph).

The largest in-river adult fall Chinook salmon in-river run above the estuary also occurred in 1995. The estimated adult run above the estuary in that year was 216,200 fish while in 2002 it was 135,500 fish.

Summary

The large projected in-river run size of Klamath River fall Chinook salmon in 2012 has raised concern of the potential for a fish kill this summer/fall. The forecast of 381,000 adult fall Chinook salmon, and a total run of 410,100 fish, will be the largest run since comprehensive monitoring and harvest management activities were initiated in 1978. The projection for the adult in-river run is 71% greater than the largest fall Chinook salmon run within the monitoring period of record which occurred in 1995. The projection for the total (jacks and adults) in-river run is 67% greater than the largest observed run which also occurred in 1995. While there is substantial variability in the accuracy of the forecasts, it should be expected that there will be a very large fall Chinook salmon run in 2012.

In addition to the large fall Chinook salmon run, a large spring Chinook salmon run should be anticipated. Based on the forecast of fall Chinook salmon and the correlation between spring and fall Chinook salmon runs, 90,800 adult spring Chinook salmon are forecast to return to the Klamath River in 2012; and a total run of 94,600 fish. The projection for the adult in-river run is 33% greater than the largest observed spring Chinook salmon run which occurred in 1988 and the total in-river run projection is 37% greater than the largest total spring Chinook salmon run, also in 1988. The potential for a large spring Chinook salmon run is of particular interest when addressing the potential need for fall flow augmentation because some of this run, primarily from Trinity River Hatchery, enters the river in August and overlaps with the beginning of the fall Chinook salmon run.

While large Chinook salmon runs and low late summer to early fall flows have occurred on several occasions in the lower Klamath River, only in 2002 did these conditions result in a fish kill (Table 2). In 1987 and 1988, large fall Chinook salmon runs coincided with flow conditions similar to those experienced in 2002 without a fish-kill. While the runs above the estuary where the fish-kill occurred were also greater than in 2002, it is possible that the estuary harvest by the Yurok fishery in these years removed sufficient numbers of fish early in the run to prevent the build-up of fish that appear to have contributed to the epizootic. Anecdotal information during the 2002 fish kill noted large numbers of lethargic and moribund adult Chinook salmon observed in the lower Klamath River, especially in the Blue Creek area, and these fish may have initiated the development of the Ich epizootic.

For years when the in-river adult run was greater than in 2002, the mean monthly flows during the months of August, and September were substantially greater than the flows during 2002 (Table 3). In 1995, the year with the largest adult run, the flow during these months was even higher.

When looking at the occurrence of flows in the lower Klamath River in August and September in relation to various thresholds that have been proposed, flows below 2500 cfs (14.7% and 17.6% occurrence, respectively) and 2800 cfs (23.5% and 35.3% occurrence, respectively) are not uncommon (Table 1). Flows below the 3000 cfs threshold were more common in August (41.2%) and September (38.2%). These percentages are based on the short period of record from 1978 to 2011when comprehensive in-river run size estimates are available.

The Trinity River Restoration Program had adopted flow thresholds (2500 cfs and 2800 cfs) for 2010 and 2011to trigger flow augmentation that was anticipated to provide improved conditions in the lower Klamath River with the expectation that these flow levels would prevent conditions that led to the 2002 fish kill. When these flow thresholds were developed, the largest fall Chinook salmon run was 245,500 fish (1995). These flow thresholds did not consider the potential flow needs for a very large run and should be revisited in light of the large anticipated fall Chinook salmon run in 2012.

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Table 1. Frequency of occurrence (percentage in parentheses) of lower Klamath River flows rkm 13) being lower than flow thresholds ranging from 2500 cfs to 4000 cfs for the period 1978-2011 (n=34).

Month	Flow Threshold (cfs)							
	2,500	2,800	3,000	3,200	3,400	3,600	3,800	4,000
July	1 (2.9%)	2 (5.9%)	2 (5.9%)	4 (11.8%)	7 (20.6%)	9 (26.5%)	10 (29.4%)	13 (38.2%)
August	5 (14.7%)	8 (23.5%)	14 (41.2%)	17 (50.0%)	17 (50.0%)	21 (61.8%)	26 (76.5%)	27 (79.4%)
September	6 (17.6%)	12 (35.3%)	13 (38.2%)	16 (47.1%)	18 (52.9%)	20 (58.8%)	25 (73.5 %)	28 (82.4%)

Table 2. Mean monthly flows in August and September in the lower Klamath River (rkm 13) and adult fall Chinook salmon run size (total in-river and run size above the estuary) for years with runs greater than observed in 2002. Yellow highlighted cells indicate years when flows were similar to 2002.

	2002	1986	1987	1988	1995	1996	2000	2001	2003
August Flow (cfs)	2,327	2,869	2,395	2,630	4,156	3,792	3,457	2,713	3,463
September Flow (cfs)	1,993	4,304	2,625	2,103	3,604	3,664	3,605	2,601	3,383
Total In-river Adult Run	160,788	195,019	209,134	191,642	222,768	175,773	218,077	187,333	191,948
Adult Run Size above the Estuary	135,534	175,897	163,173	148,081	216,228	N/A [1]	198,082	151,132	165,665

1. The adult run above the estuary in 1996 was 119,214 fish.

Table 3. Mean monthly flows (cfs) of the lower Klamath River (KNK, rkm 13) for a variety of adult fall Chinook salmon run sizes and grouping of high run sizes.

Run Size Category	July	August	September	Adult Run Size or Mean Adult Run Size
Fish Kill - 2002	3187	2327	1993	160,800
Largest Run – 1995	7352	4156	3604	222,800
Mean of runs greater than 2002	4589	3184	3236	199,000
Mean of adult runs above the estuary greater than 2002	4495	3098	3175	174,000

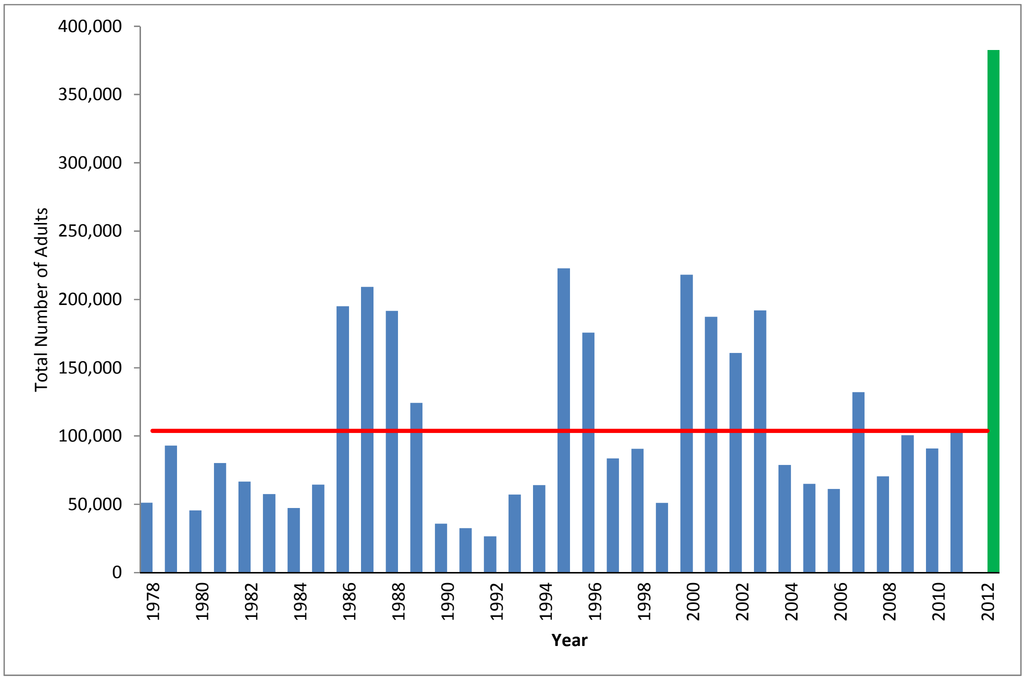


Figure 1. Klamath River adult fall Chinook salmon in-river run, 1978-2011, and 2012 projection. Horizontal red line is the 1978-2011 mean of 103,750 adult fall Chinook salmon.

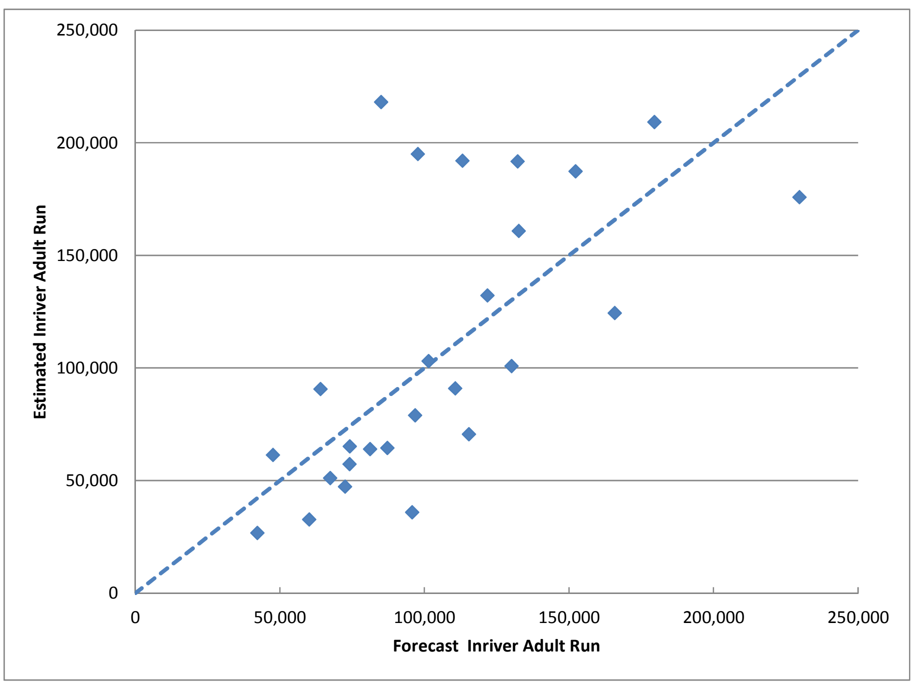


Figure 2. Post-season in-river run estimate vs. preseason forecast for Klamath River adult fall Chinook salmon, 1984-2011. Dashed blue line indicates one-to-one relationship. (Preseason projections for 1984-2011, 1995 and 1997 not available).

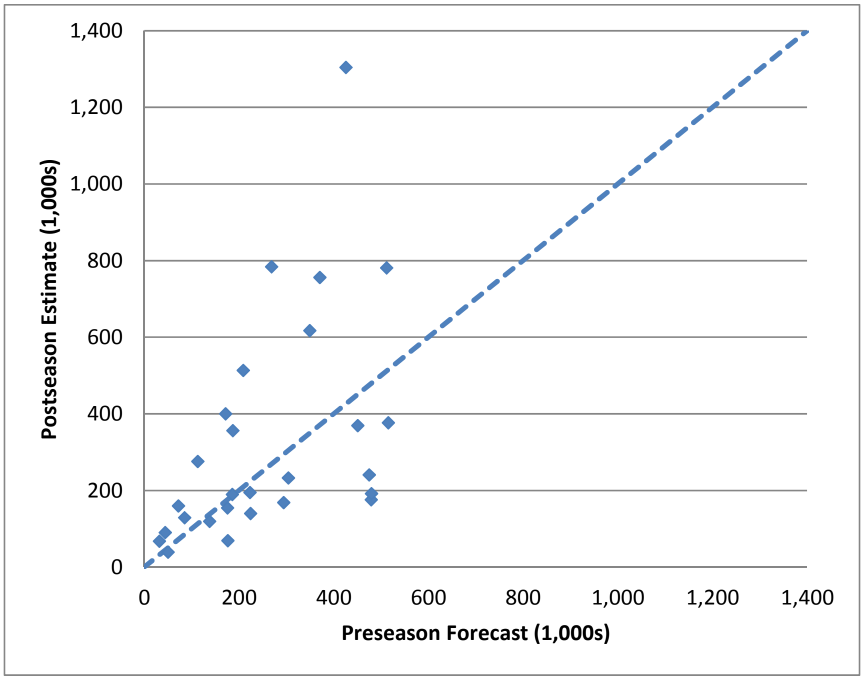


Figure 3. Post-season estimate vs. preseason forecast of age 3 ocean population of Klamath River fall Chinook salmon, 1985-2011. Dashed blue line indicates one-to-one relationship.

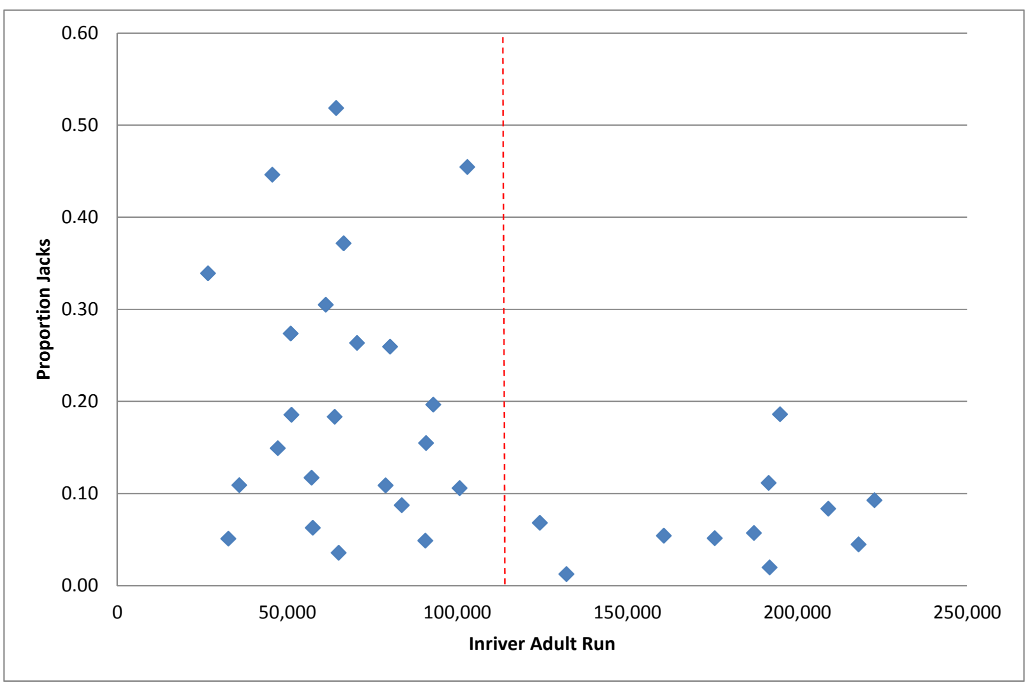


Figure 4. Proportion of jacks vs. in-river adult run for Klamath River fall Chinook salmon, 1978-2011. Vertical red dashed line depicts cutoff used to segregate dataset to estimate jack proportion for the 2012 run.

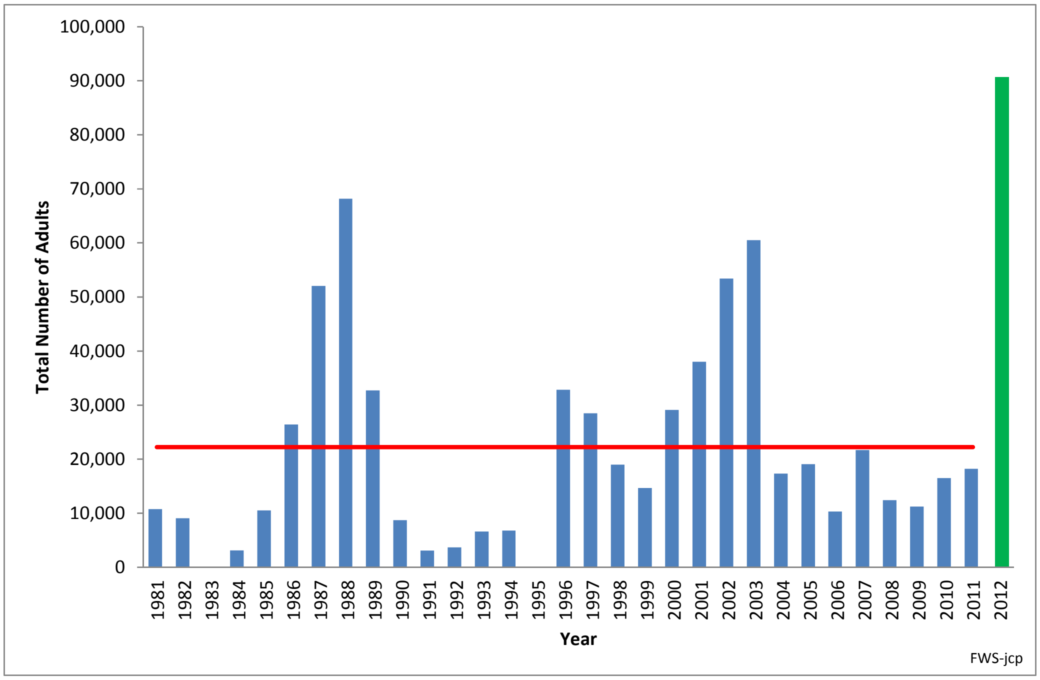


Figure 5. Klamath River adult spring Chinook salmon in-river run, 1981-2011, and 2012 projection. Horizontal red line is the 1981-2011 mean.. Data from1983 and 1995 were excluded due to incomplete monitoring of the spring Chinook salmon run in these years.

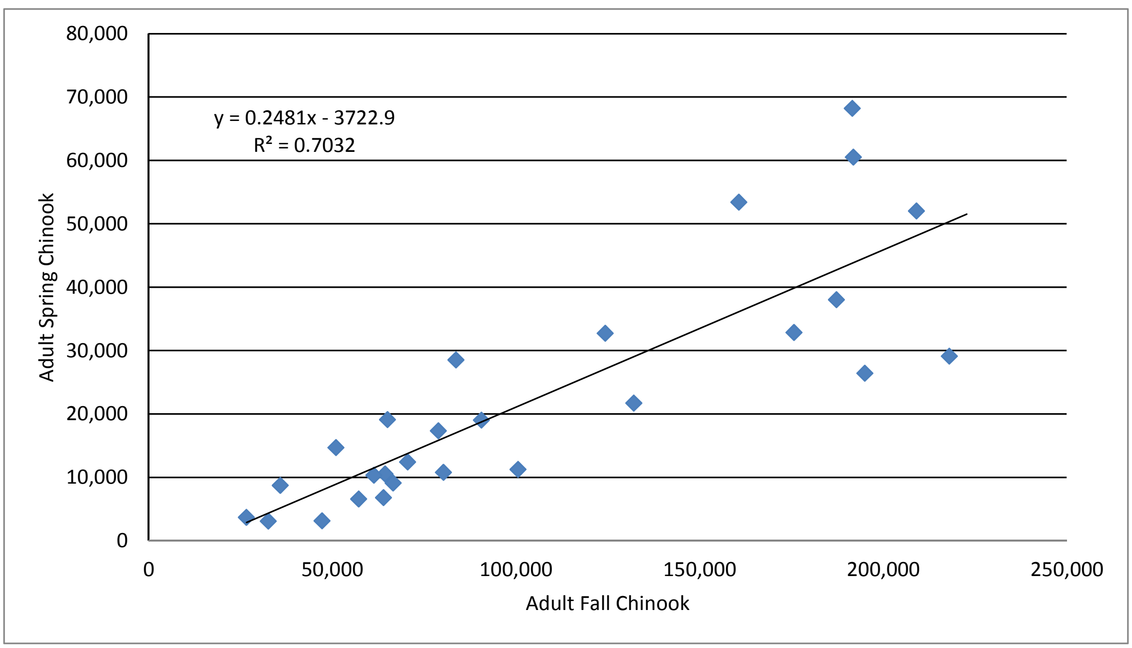


Figure 6. Relationship between Klamath River adult spring Chinook salmon and adult fall Chinook salmon in-river run size, 1981-2011. Data from 1983 and 1995 were excluded due to incomplete monitoring of spring Chinook salmon run in these years.

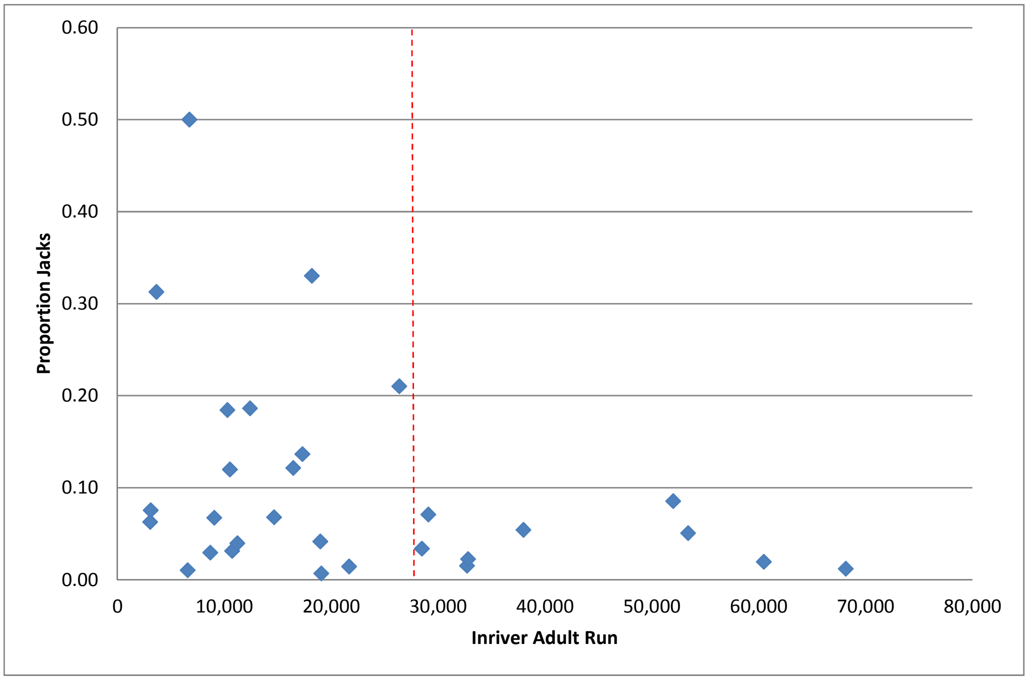


Figure 7. Proportion of jacks vs. in-river adult run for Klamath Basin spring Chinook salmon, 1981-2011. Vertical red dashed line depicts cutoff used to segregate dataset to estimate jack proportion for the 2012 run. Data from 1983 and 1995 were excluded due to incomplete monitoring of spring Chinook salmon run in these years.

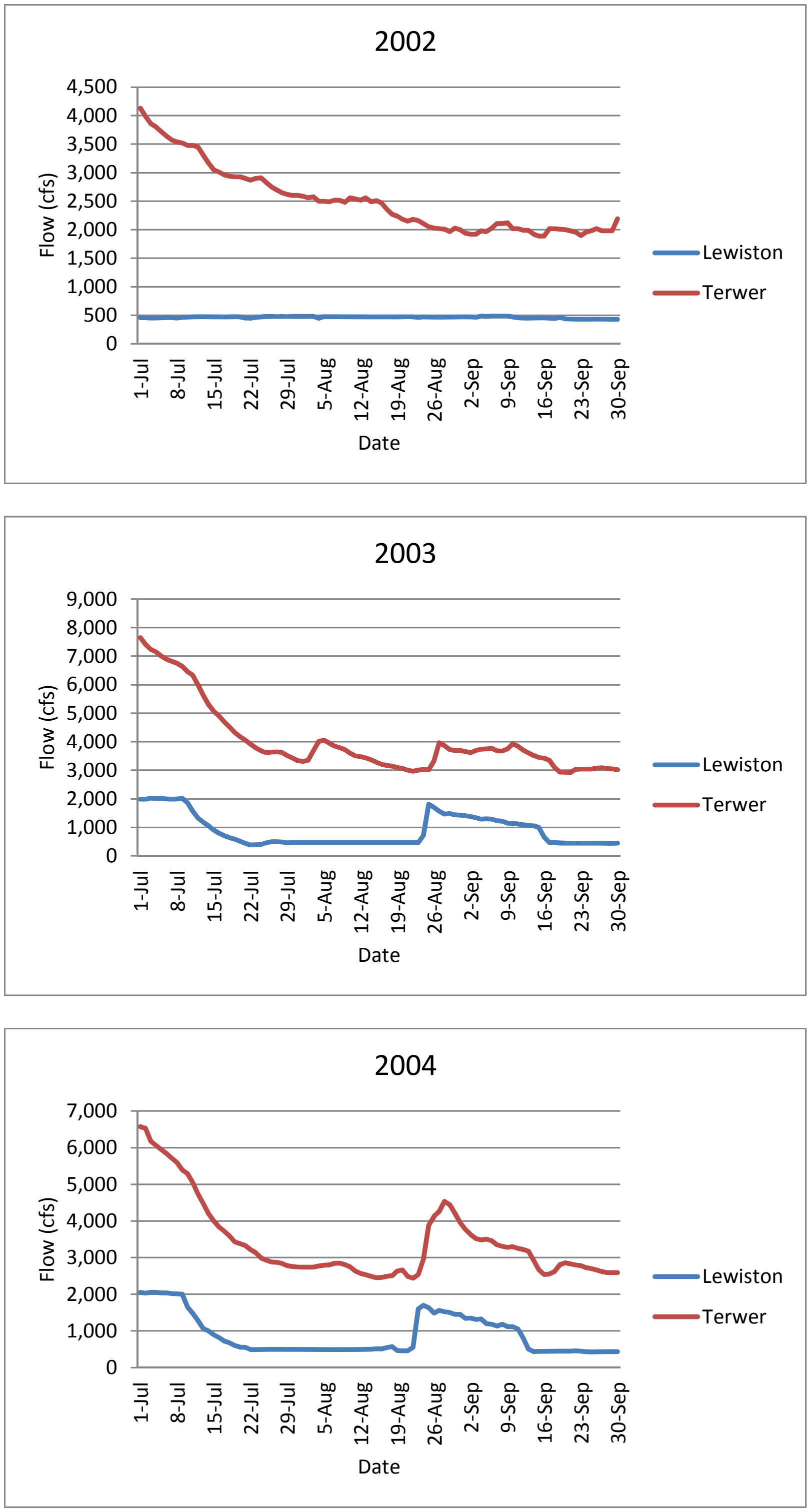


Figure 8. Daily flow levels in the Trinity River at Lewiston (rkm 178) and the lower Klamath River (rkm 13) from July through September during the year the fish-kill occurred (2002) and the years when fall flows were augmented with releases from the Trinity River (2003 and 2004).

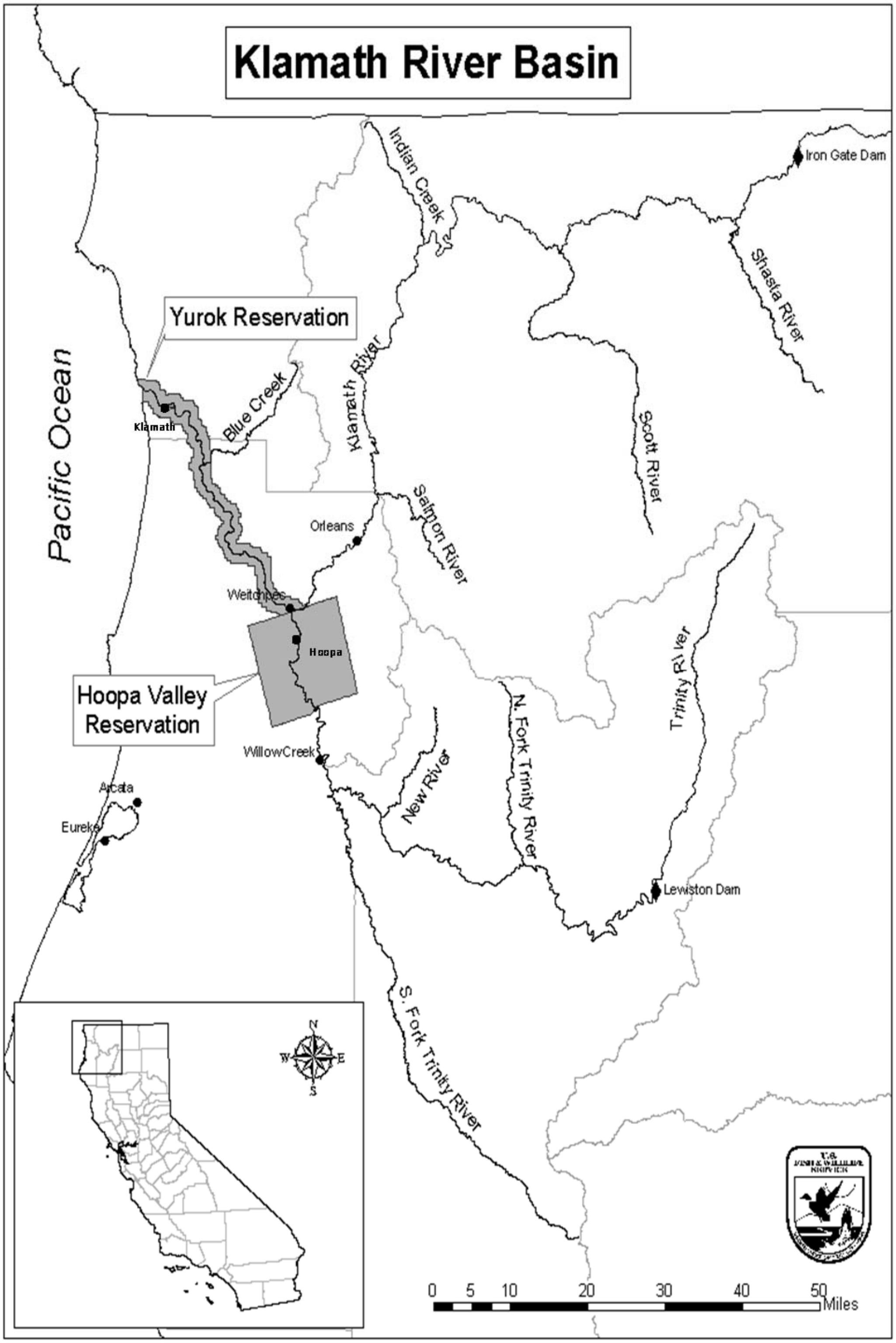


Figure 9. Klamath River Basin.

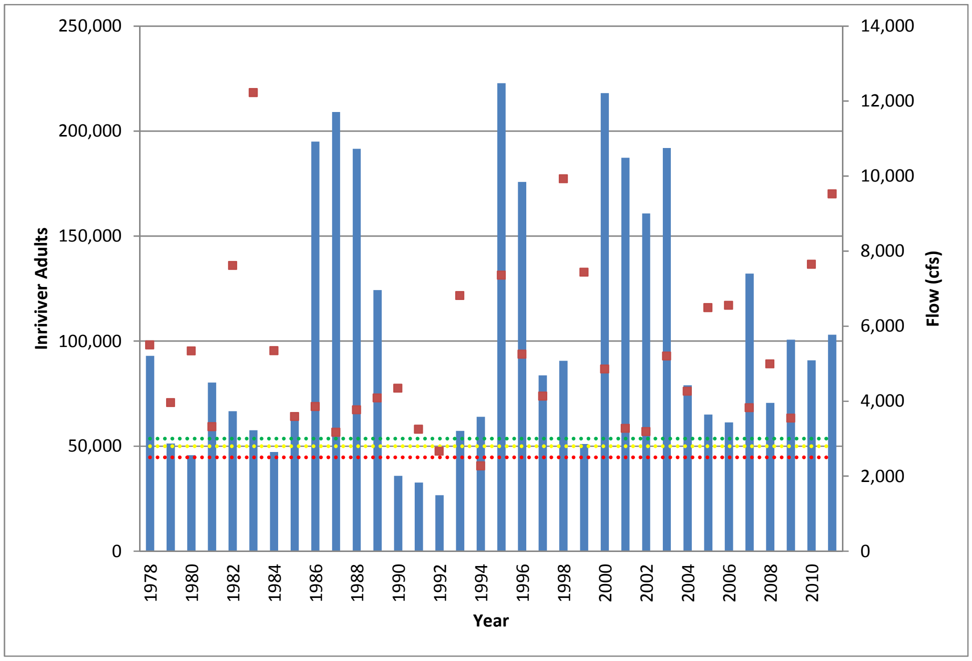


Figure 10. Klamath River fall Chinook salmon adult in-river run and mean monthly July flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

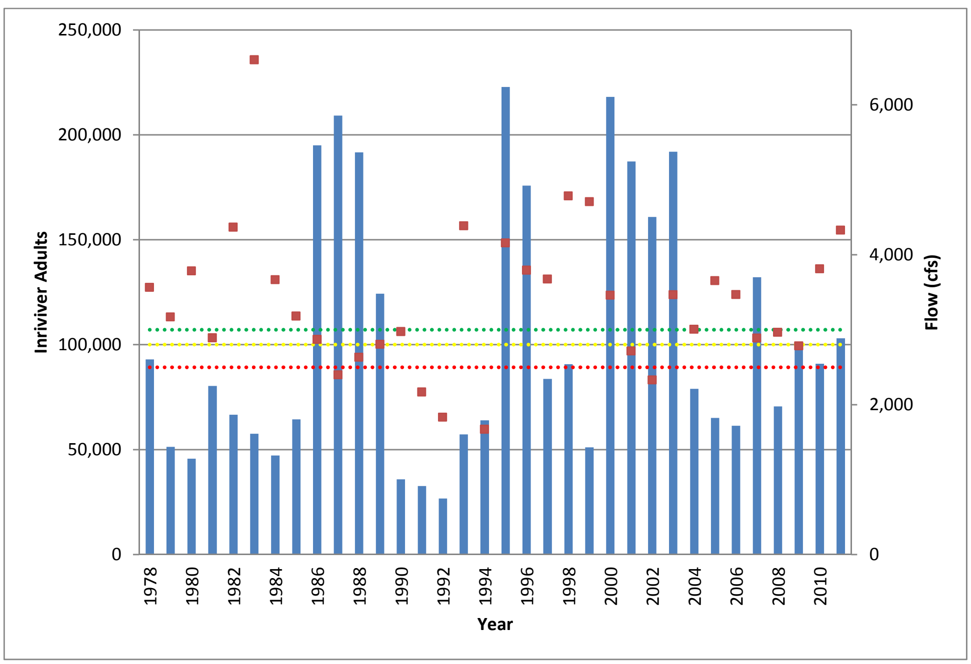


Figure 11. Klamath River fall Chinook salmon adult in-river run and mean monthly August flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

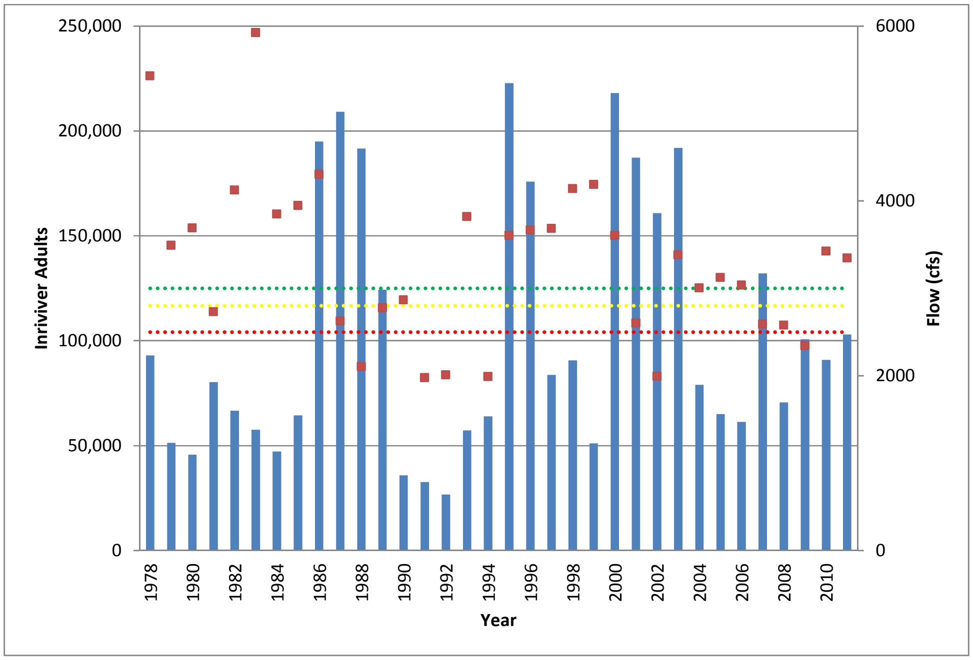


Figure 12. Klamath River fall Chinook salmon adult in-river run and mean monthly September flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

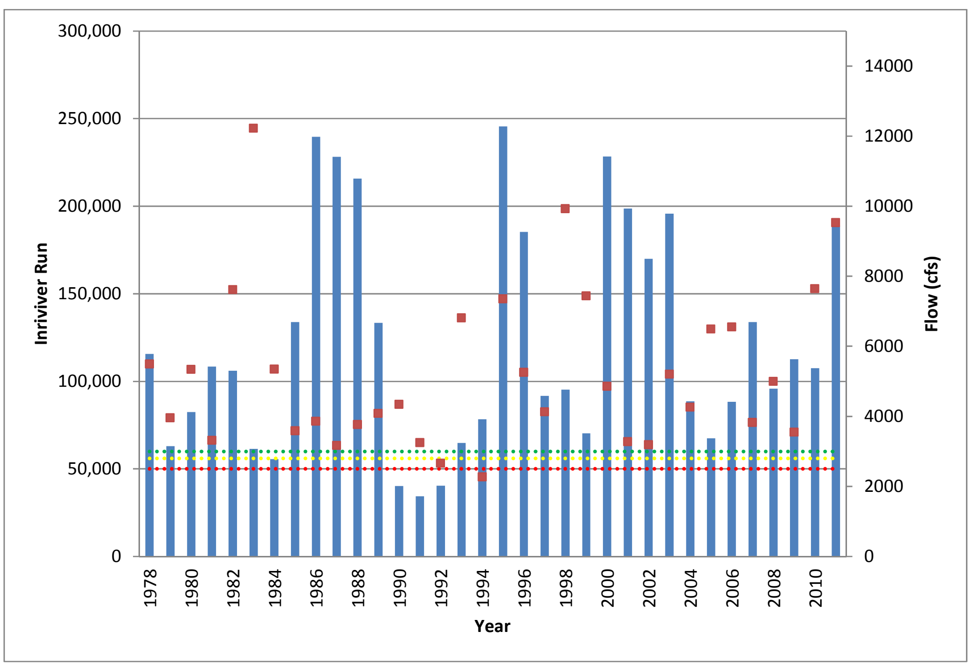


Figure 13. Klamath River fall Chinook salmon total in-river run and mean monthly July flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

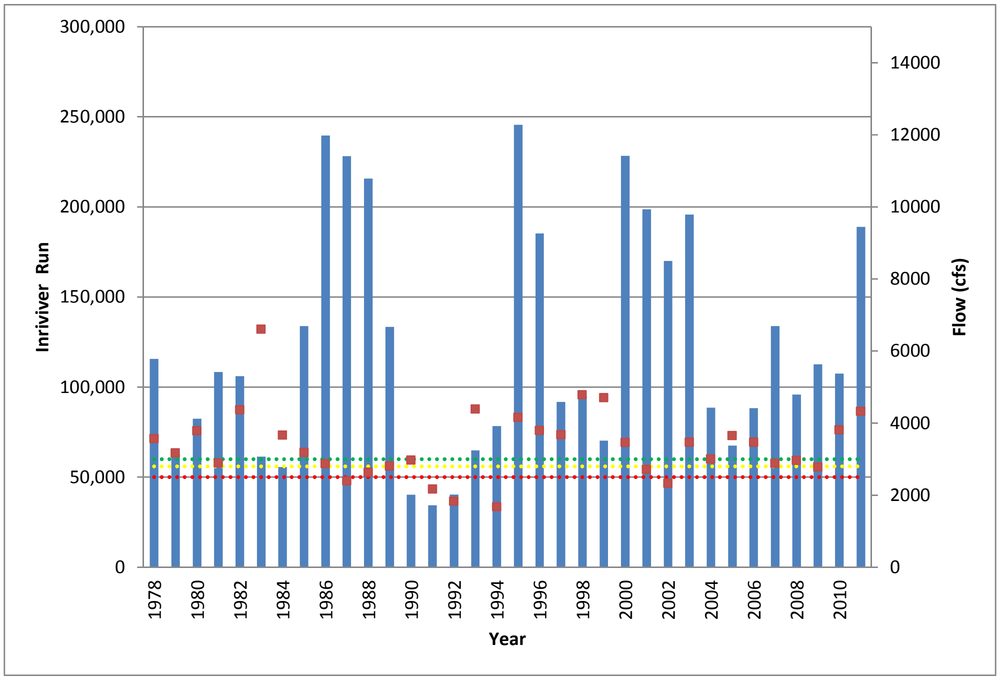


Figure 14. Klamath River fall Chinook salmon total in-river run and mean monthly August flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

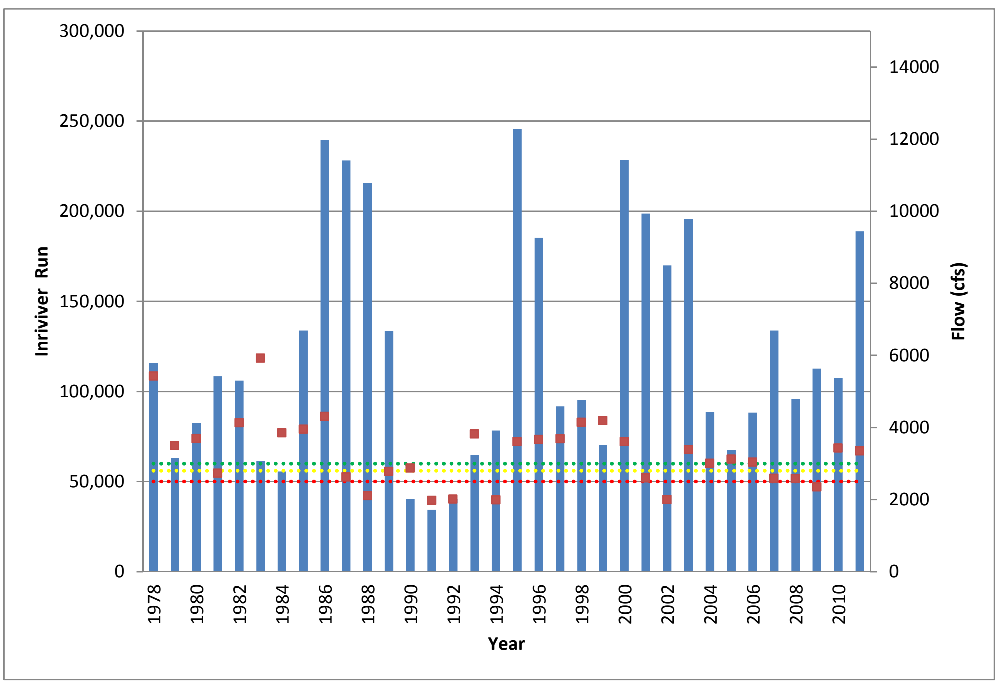
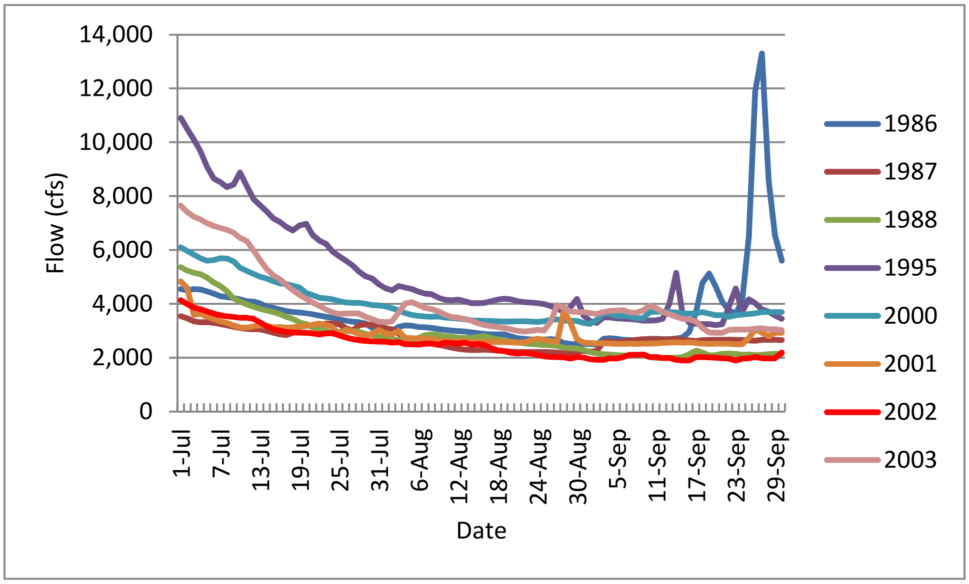


Figure 15. Klamath River fall Chinook salmon total in-river run and mean monthly September flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.



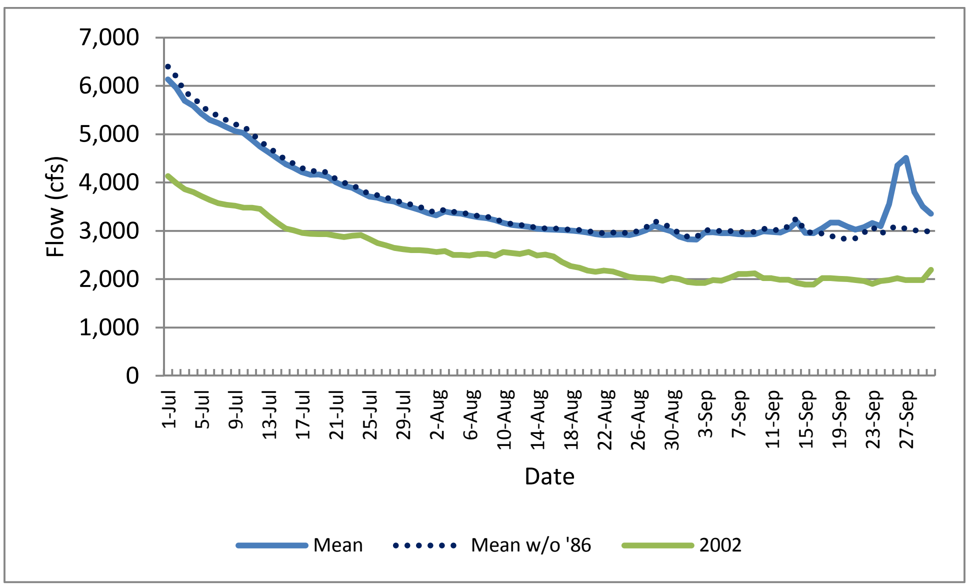


Figure 16. Daily flows in the lower Klamath River (rkm13) in 2002 and years when the in-river adult fall Chinook salmon run was greater than the 2002 run (upper graph) and mean daily flow of years with larger runs compared to 2002 (lower graph). Mean graph for years with larger runs excluding 1986 flow data is presented because in September 1986 there was an unusually high flow event. (Flow data for the lower Klamath River not available for 1996.)

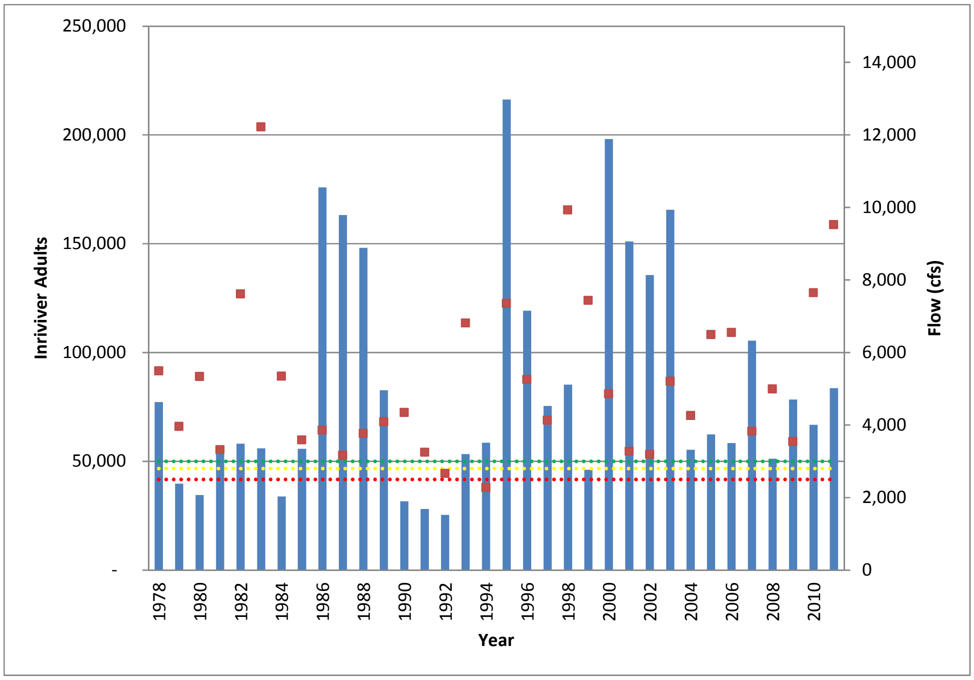


Figure 17. Klamath River fall Chinook salmon adult in-river run above the estuary and mean monthly July flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

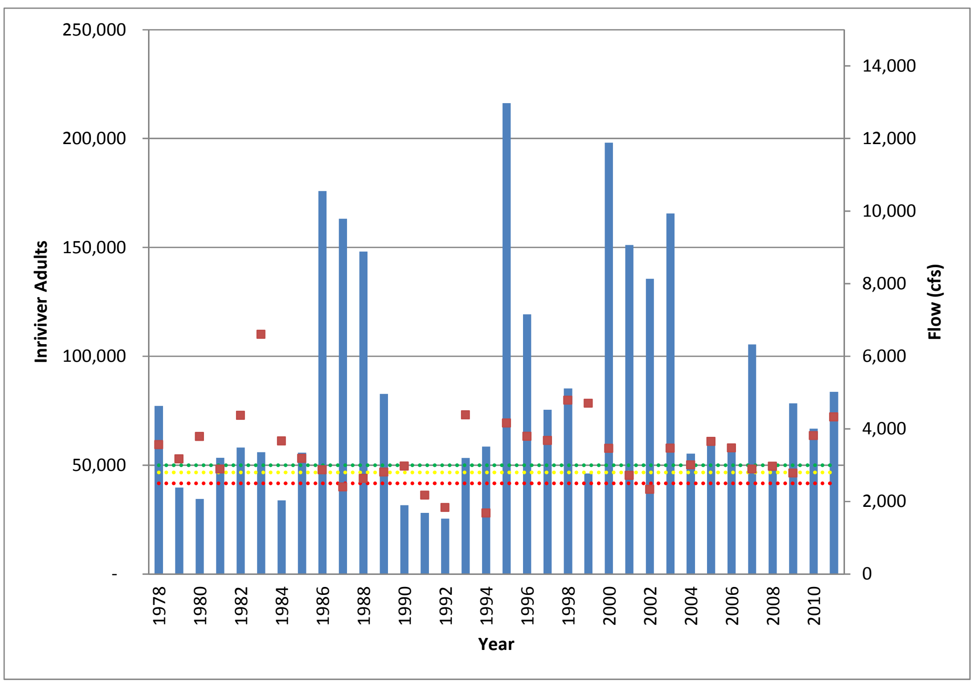


Figure 18. Klamath River fall Chinook salmon adult in-river run above the estuary and mean monthly August flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

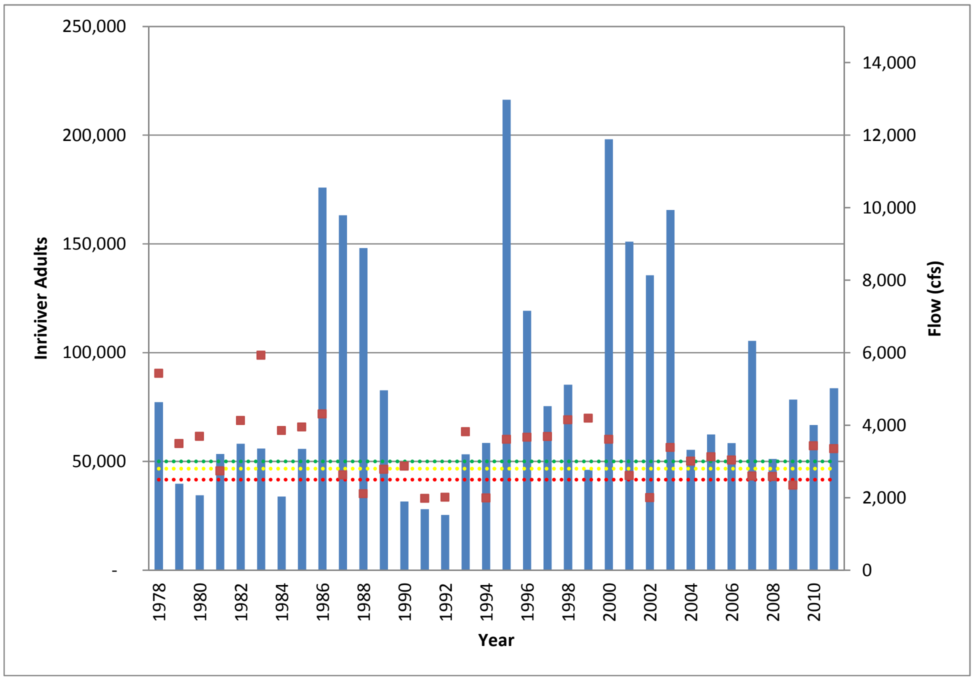


Figure 19. Klamath River fall Chinook salmon adult in-river run above the estuary and mean monthly September flow in the lower Klamath River (at rkm13), 1978-2011. Blue bars are number of fish, red squares are flow, horizontal red line is the 2,500 cfs threshold, yellow horizontal line is the 2,800 cfs threshold, and green line is the 3,000 cfs threshold.

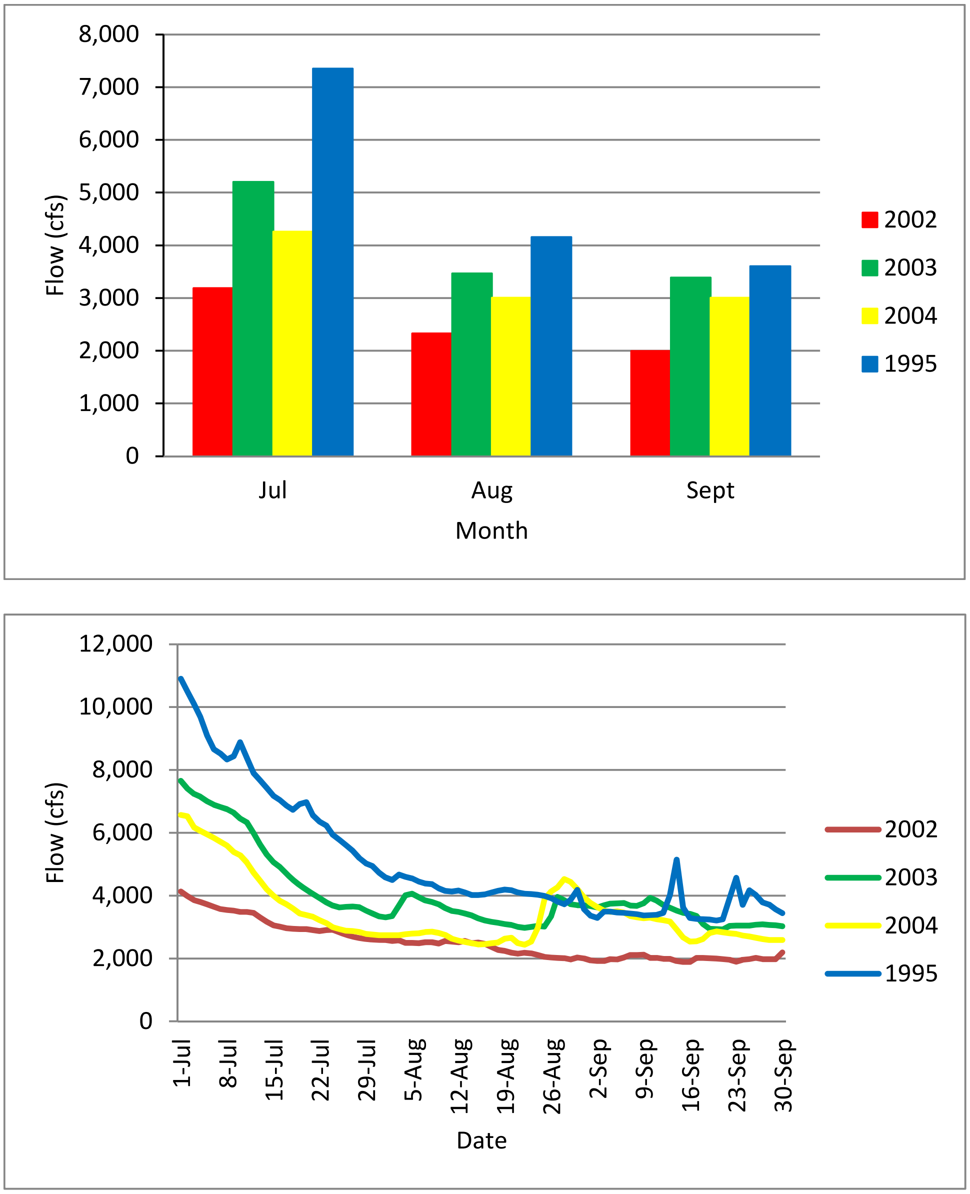


Figure 20. Mean monthly (upper graph) and daily (lower graph) flow levels in the lower Klamath River (rkm 13) from July through September during the fish kill year (2002), augmented fall flow years (2003 and 2004), and the year with the largest fall Chinook salmon run (1995).

Attachment 1. 2010 and 2011 Fall Flow Release Criteria and Evaluation Process Memorandum to TRRP Fall Flows Subgroup. March 20, 2012.

MEMORANDUM

TO: TRRP FALL FLOWS SUBGROUP

FROM: TIM HAYDEN, FLOW SCHEDULE WORKGROUP COORDINATOR

SUBJECT: 2010 AND 2011 FALL FLOW RELEASE CRITERIA AND EVALUATION PROCESS

CC: TRRP FLOW WORKGROUP MEMBERS
ERNEST CLARKE, TRRP SCIENCE COORDINATOR
ROBIN SCHROCK, TRRP EXECUTIVE DIRECTOR

DATE: MARCH 20, 2012

In 2010 the TRRP staff, TRRP partners and KBAO jointly developed Proactive and Emergency fall flow release criteria which were designed to avert a fish disease outbreak and subsequent fish kill, such as the kill that occurred in 2002.

During WY 2011/2012, the Fall Flows Technical Subgroup evaluated conditions utilizing the 2010 fall flow release criteria/triggers to determine the need for a proactive fall flow release.

Based on river forecast models and run-size projections during the late-summer/fall of 2011, the Fall Flows Technical Subgroup recommended that neither a Proactive or Emergency Fall Flows release were warranted to prevent the outbreak of *Ichthyophthirius multifiliis* (Ich) and/or *Flavobacterium columnare* (Columnaris) to avert a Klamath/Trinity fall-run Chinook salmon disease outbreak (TMC Memo 2010). The 2010/2011 physical and biological criteria and recommended management actions are summarized below:

<u>Proactive Fall Flow Release Criteria (Table 1):</u>

1. Flows projected above 2,800 cfs at Klamath River RKM 13 during the adult fall-run Chinook salmon migration season = no recommendation for a Proactive fall flow release (Strange 2010) ;
2. Flows projected below 2,800 cfs at Klamath River RKM 13 during the migration season and projected fall Chinook salmon run-size at or above 170,000 adult and jacks (estimated run size during the 2002 fish kill year) = recommend implement Proactive fall flow release to increase base flows to 2,800 cfs during primary fall Chinook salmon migration season (3^{rd} week August-Sept 30) (Strange 2010);

3. Flows projected below 2,500 cfs at RKM 13 during the migration season = recommend implement Proactive fall flow release to increase base flows to at least 2,500 cfs during migration season regardless of projected fall Chinook salmon run-size (Turek et al. 2004) .

Table 1. Summary of Proactive Fall Flows release criteria and Linked Recommended Management Actions.

Proactive Criteria	**Management Action**
Flows projected above 2,800 cfs at Klamath River (RKM 13) during the adult fall-run Chinook salmon migration season (3rd week August-Sept 30)	Recommend No Proactive Fall Flow release
Flows projected below 2,800 cfs at Klamath River (RKM 13) during the migration season and projected fall Chinook salmon run-size at or above 170,000 fish	Recommend Implement Proactive Fall Flow release to increase base flows to 2,800 cfs during primary fall Chinook salmon migration season (3rd week August-Sept 30)
Flows projected below 2,500 cfs at Klamath River (RKM 13) during the migration season	Recommend Implement Proactive Fall Flow release to increase base flows to at least 2,500 cfs at Klamath River RKM 13 during the migration season regardless of projected fall Chinook salmon run-size.

<u>Emergency Fall Flow Release Criteria (Table 2.)</u>

An emergency release is designed to decrease the severity of a disease outbreak if real-time monitoring indicates an increase in the incidence of Ich infections of fall-run Chinook salmon. The recommendation for an Emergency Fall Flow release is conditional upon two-stage criteria, including:

1. No Proactive Fall Flow release is planned, and;
2. Multiple severe confirmed Ich infections are observed and confirmed = recommendation to implement immediate Emergency Fall Flow release with a 7 day duration pulsed spike to ***double pre-existing base flows*** in the lower Klamath River (RKM 13) at the time of Ich infections, followed by a bench release to increase base flows to the minimum recommended level of 2,500 or 2,800 cfs, depending on run-size for the remainder of the migration season (Strange 2010).

   A single observed incidence of Ich would lead to greater monitoring and evaluation effort, including confirmation by fish disease experts. If multiple severe infections are documented and confirmed, an emergency release would be recommended. The duration of the 7 day (total duration with ramping) peaked flow release is determined by the life cycle of Ich, which takes 7 days to complete at 20°C (Dickerson and Dawe 1995). No Ich infections have been documented in annual monitoring since the 2002 fish kill, with the exception of a few infected fall-run Chinook salmon in 2003, thus any documented Ich infections are very significant and may indicate an impending disease outbreak (Strange 2010).

Table 2. Summary of Emergency Fall Flow Release Criteria and Linked Management Action.

Emergency Criteria	**Management Action**
1. No Proactive Fall Flow release is planned	
AND	
2. A single incidence of Ich is observed	Increase amount and intensity of Ich disease monitoring
3. Multiple severe confirmed Ich infections are observed	Recommend implement immediate Emergency Fall Flow release with a 7 day duration pulsed spike to ***double pre-existing base flows*** at the time of Ich infections, followed by a bench release to increase base flows to the minimum recommended level of 2,500 or 2,800 cfs for the remainder of the migration season.

<u>TRRP Fall Flows Subgroup Criteria Evaluations: 2011 River Flow and Run-size Projections</u>

In 2011, the Fall Flows Subgroup Coordinator, Tim Hayden worked with members of the subgroup to conduct bi-weekly evaluations of both the Proactive and Emergency Fall Flow release criteria to determine if recommendation of a Proactive and/or Emergency fall flow release was warranted. The Fall Flows Subgroup utilized the following river flow forecasting and fall-run Chinook salmon run size estimation methods to evaluate the previously described Proactive and Emergency Criteria;

Lower Klamath River Flows Forecast

The TRRP Fall Flows Subgroup conducted bi-weekly estimates of lower Klamath River flows at RKM 13 for the period from August 1 through September 30 by summing:

1. The National Weather Service Advanced Hydrologic Prediction Services prediction for lower Klamath River flows excluding reservoir releases
2. Estimated Iron Gate flow releases using the Variable Flow Release Procedure as described in the 2011 Klamath River Operations Plan
3. 2011 TRRP summer base-flow releases from Lewiston Dam.

2011 Fall Chinook Salmon Run-size Projections

The ocean escapement of Klamath Basin fall Chinook salmon in 2011 was projected at 102,000 adult fish (Klamath Ocean Harvest Model, 12 April 2011, STT-PFMC). In addition to the adult escapement, the expected age-2 (jack) return is estimated by assuming the inter-annual proportion of jacks relative to the total run from 1978 through 2010. In 2010, Bureau staff and TRRP partners concluded that variability in the jack proportion was high when considering all years of record. However, in years of moderate to high adult run sizes (≥ 100,000), the post-season estimated jack proportion was much less variable and somewhat stable at larger run sizes (Polos, Memorandum to Fall Flow Augmentation Ad Hoc Group, 29 June 2010).

Given the moderately high projected adult ocean escapement in 2011, an expected proportion of jacks based on the average historic observations during moderate to high run size years is 0.076.

Hence, Total 2010 Klamath Basin Fall Chinook Salmon Run Size was estimated as:

(Adult Forecast)/(1-jack proportion),

Or

$(102,000)/(1-0.076) =$ **110,390**

Additional 2011 Fall Flows Subgroup Recommendations

The Fall Flows Subgroup also developed several recommendations regarding the role of the subgroup, future evaluation of criteria and the need and purpose for Fall Flow Implementation Plan to support technical evaluations and management recommendations. These recommendations include:

1. The Fall Flows Subgroup is technical and advisory; and does not make policy recommendations. Implementation would be dependent upon source of water, release schedules from IGD and/or Lewiston Dam, and environmental permitting issues. The sub-group recommends to the TRRP Flow Workgroup that a broader interagency group address comprehensive monitoring strategies and data gaps.

2. Future evaluation of criteria should be conducted regularly (bi-weekly) by the Fall Flows Subgroup with broad-based participation by technical representatives from all TRRP Partner agencies.

3. Evaluations of flow and temperature each summer and fall should commence in July and continue bi-weekly through the end of September. All Fall sub Work group members should be given the results of the evaluations and be ready to meet as the season progresses. If the flow predictions appear to indicate declining flows in the lower Klamath, or evidence of ich, a larger meeting should be called to make recommendations.

4. The Fall Flows Sub-group attempted to develop a draft purpose statement for the Fall Flows Implementation Plan. Core to the Fall Flows subgroup is to understand the evolution of fall flow release criteria and recognizing that the realities and impacts of the 2002 fish die off to the fishery resources of the Klamath and Trinity rivers and the dependent fisheries, which is the impetus for fall flow releases.

   The purpose of the annual Fall Flows Implementation Plan is to define the technical evaluations needed, data gaps, identification of the proposed total water volume recommended, potential water sources, release schedules from Iron Gate Dam and/or Lewiston Dam, and the timing and duration of the releases (considering travel time from the dams to the Lower Klamath River) required to implement a Proactive/Preventative and/or Emergency fall reservoir release(s) from the Iron Gate or Lewiston Dams for the purposes of minimizing or averting chronic and acute effects of disease pathogens on adult Klamath/Trinity fall run Chinook salmon in the Lower Klamath River. The Fall Flows Subgroup provides technical evaluation into this process, including; river flow forecasts/modeling, run-size forecasts, and evaluation of the need to recommend Proactive and Emergency flow using the release criteria. The Fall Flows Subgroup will also recommend biological and physical assessments for the purposes of refining our ability to predict the need for a fall flow. Knowledge gaps will be identified and prioritized.

References

Dickerson, H. W., and D. I. Dawe. 1995. *Icthyophthirius multifiliis* and *Cryptocaryon irritans* (Phylum Ciliophora). Pages 181-227 *in* P. T. K. Woo, editor. Fish Diseases and Disorders: Protozoan and Metazoan Infections, volume 1. CABI, New York, New York.

Strange, J.S., 2010. Summary of scientific evidence to guide special flow releases to reduce the risk of adult fall Chinook salmon mass disease mortality in the lower Klamath River. TRRP. 17 pp.

Turek, S., Rode, M., Cox, B., Heise, G., Sinnen, W., Reese, C., Borok, S., Hampton, M., and Chun, C. 2004. September 2002 Klamath River Fish-Kill: Final Analysis of Contributing Factors and Impacts. California Department of Fish and Game. 183pp.

Attachment 2. Recommendations for Averting Another Adult Salmonid Die-off. March 18, 2003.

Recommendations for Averting Another Adult Salmonid Die-off

March 18, 2003

Prepared By:

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Averting another adult salmonid die-off - A case for using an emergency allocation of Trinity River water, and possible scenarios to induce migration of Trinity River Fish through the lower Klamath River

BACKGROUND

Causative factors for the epizootics last fall of *Icthyopthiris multifilis* (ICH) and *Flavobacter columnare* (columnaris) and the resulting unprecedented large scale fish die-off in the lower Klamath River may have included a relatively large return of adult fish compared to recent years, and potential behavioral or physical migration barriers that resulted in high densities of adult fish in the lower river. These pathogens are transmitted to fish through the water column. Crowded conditions have been implicated in epizootic outbreaks of these pathogens in hatcheries, aquaria, fish culture operations, and in river systems. Water temperatures near 20-21º C like those measured last year are typical in the Klamath River in late summer. These temperatures may behaviorally inhibit migration (EPA 2002), are conducive for ICH and columnaris, and can induce physiological stress that reduces a fish's immunological defenses.

Conditions similar to those that existed in the lower Klamath prior to and during the die-off are likely to occur again this summer. Recent water supply forecasts for the Klamath Basin predict dry conditions similar to those experienced last year. In addition, the preliminary fall chinook run-size projections for the Klamath Basin are expected to be close to last year's run size (D. Hillemeier , Yurok Tribe, pers. comm..). These conditions, in combination, may cause high densities of physiologically stressed fish to be exposed to conditions favorable for an ICH or columnaris outbreak.

Many of the fish that will return to spawn this year are cohorts of the same broods affected by last year's fish die-off. Chinook that spawn in the Klamath Basin are mainly comprised of three year old fish and progressively smaller fractions of four and five year old fish. Maximizing survival of all age classes of returning salmon for this year's run is especially important to avoid two consecutive years of significant loss of the population and will help stabilize Klamath and Trinity basin salmonid populations. Successful spawning of the four and five year old components of this year's run is important for the longer term success of the brood years most affected by last year's die-off.

A pro-active approach is required to avoid conditions that could result in another fish die-off. The diseases implicated in last years die-off can be rapidly transmitted and are ubiquitous in the system necessitating a management plan that is orchestrated well in advance of conditions that result in fish die-offs. Some triggering mechanisms selected to activate a response to relieve hazardous conditions are proposed

RECOMMENDATION

Two of the potential causative factors for last year's fish kill, run-size and migration inhibition, lead to high densities of adult fish that increased physiological stress, reduced immunological-defense, and increased the likelihood of successful transmission of the disease vectors. This year, under potentially similar circumstances, providing additional Trinity River water above normal water year flows may reduce fish densities in the lower Klamath and draw Trinity fish out of the Klamath and into the Trinity River. This would be done by eliciting a movement response through the “migration cue” offered by increased flow, and may relieve the physical and/or behavioral migration barriers that contributed to the high densities of fish observed last year. In sufficient quantity, the cooler Trinity River water will also slightly reduce water temperatures of the lower Klamath, thereby decreasing physiological stress on the fish and reducing their susceptibility to ICH and columnaris. The additional water volume will also serve to dilute the infectious forms of these pathogens and reduce their likelihood of encountering fish to infect.

The primary approach recommended focuses on the goal of preventing high densities of adult salmon from occurring in the lower Klamath River. Mid-August to mid September was chosen as the target period to consider management options for density reduction. These target dates are based on historical run timing of fall-run Chinook salmon as determined by the Yurok Tribal harvest monitoring, CDFG estuary beach seining activities, Trinity River weir operations, and the period when fish densities of last year contributed to rapid infection and spread of ICH and columnaris. Mid September was chosen as the end date to avoid dewatering of spring chinook redds at Lewiston that may be constructed at higher flows only to become dewatered when flow is reduced to base levels. Flows of the magnitude being considered in these options take about one and a half to two days to travel from Lewiston Dam to the lower Klamath. Pulse flow timing of all the scenarios developed coincides with the timing of the Hoopa Valley Tribal dance flow tentatively scheduled for September 2.

Scenario One - Sustained Flow:

Summary points:

- Ramps Lewiston discharge up to a sustained 1,500 cfs for the entire critical period August 15 to September 15
- This scenario will have the largest effect on lower Klamath River temperatures, perhaps as much as 1.0-1.5ºC or more depending on volume and temperature of Klamath River contribution
- Increases river stage about 0.6 ft at Terwer gage near the estuary
- May have some negative impact on early spring chinook redds in the Trinity River due to potential dewatering
- Largest volume scenario at 69,206 acre-feet

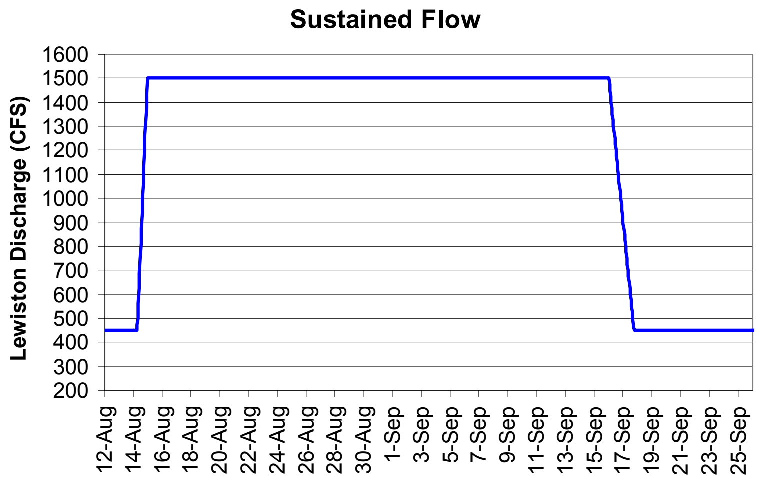

Figure 1. Scenario One - Sustained Flow. Flows would be increased at Lewiston Dam from 450 cfs summer baseflow to 1,500 cfs August 15 and maintained until September 15. Total additional volume over baseflow is 69,206 acre-feet.

This approach is intended to provide a sustained flow of cold Trinity water of sufficient quantity to significantly increase the stage and discharge of the lower Klamath, relieve potential migration barriers and encourage Trinity River fish to migrate out of the lower Klamath and into the Trinity (Figure 1). The sheer volume of a sustained high flow release of cold Trinity River water from Trinity Dam will have a significant thermal mass and will reduce water temperatures in the lower Klamath. In late August 2001, a one-day pulse release of 1,600 cubic feet per second (cfs) from Lewiston Dam reduced temperatures about 1.5º C in the lower Trinity at its confluence to the Klamath. Temperature reduction would be expected to be even greater over a multi-day pulse release and could influence temperatures in the lower Klamath River a degree C or more under circumstances similar to last year. The effectiveness of temperature control in the lower Klamath River is largely dependent on the volume and temperature of the Klamath River at the point of mixing – the smaller the proportion the greater the effect.

Under this scenario, flows would begin ramping up August 14 from 450 cfs summer base flows to reach 1,500 cfs August 15. Flows would be held at 1,500 cfs through September 15 and ramp back down to 450 cfs by September 17. The descending limb should discourage early spawning spring chinook from constructing redds in zones at risk of dewatering. The 1,050 cfs net increase in Trinity River discharge would increase the stage in the lower Klamath roughly 0.6 feet at the Terwer Gage near the estuary. The total additional volume of water over baseflow required to implement this scenario is 69,206 acre-feet.

Scenario Two - Pulsed Flow

- Uses a number of significant pulses intended to periodically induce migration
- First pulses have two-day duration peaks to maximize the influence Trinity Water will have on the Klamath when temperatures conditions in the lower Klamath are highest
- Later one-day pulses to continue to induce migration as more fish enter the River over the critical period
- Lowest volume scenario at 39,857 acre-feet
- Pulse timing designed to coincide with pulse for tentatively scheduled Hoopa Valley Tribal dance

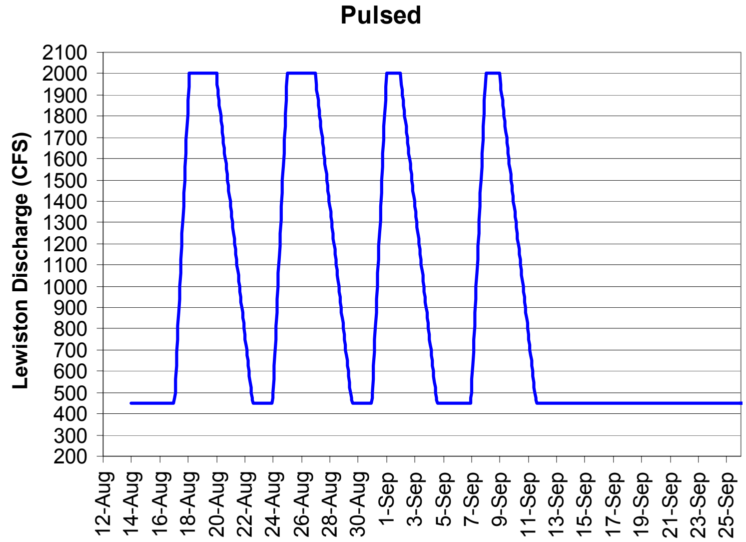

Figure 2. Scenario Two - Pulsed Flow. Flows would be periodically pulsed to 2,000 cfs at Lewiston Dam. The first two peaks would be of two-day duration each to maximize thermal benefits to the lower Klamath. The second two peaks would be of one-day duration each to minimize spring chinook risk. Total additional volume over baseflow is 39,857 acre-feet.

This approach is intended to periodically cue migration of Trinity River fish from potentially high density areas of the lower Klamath River over the immigration period with four significant pulses of Trinity River water (Figure 2.). These pulses would involve ramping up weekly from 450 cfs baseflow to 2,000 cfs at Lewiston Dam. The duration of peak flows would be two-days for the initial two peaks, and one day each for the latter two peaks. The two day pulses will provide greater temperature benefits to the lower Klamath early in the target period when temperature conditions are expected to be the most challenging. The shorter duration one-day pulses later in the period are an extra measure to minimize risk to early spawning spring chinook redds in the Trinity River.

Target dates for the 2,000 cfs peaks of the Pulsed scenario would be August 18-19, August 25-26, September 1, and September 8. The total additional volume of water over baseflow required to implement this scenario is 39,857 acre-feet.

Scenario Three - Hybrid Pulsed/Sustained (Recommended)

- This option is the recommendation of the biologists that developed these scenarios
- Adaptable combination of scenarios one and two
- First attempts to elicit migration response with two pulse flows of 2,000 cfs
- If the desired responses in fish movement are observed with pulse flows, continue to pulse through the critical period or until fish densities are relieved
- If pulses fail to elicit the desired response in fish migration, fall back to a longer sustained Lewiston discharge of 1,500 cfs from September 1 to September 17 to deliver a high volume of cooler Trinity water and effect greater temperature change on the lower Klamath
- Fall-back option may have some impact on early spring chinook redds in the Trinity River
- Requires real-time monitoring to determine effectiveness of first two pulses in order to determine the appropriate operation for the remainder of the critical period
- Pulse timing designed to coincide with pulse for tentatively scheduled Hoopa Valley Tribal dance

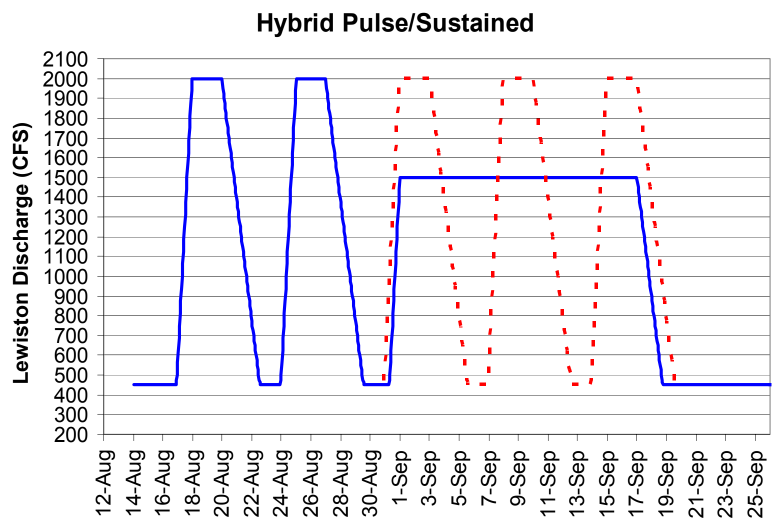

Figure 3. Scenario Three - Hybrid Pulse/Sustained. The first two pulses of 2,000 cfs would be similar under any option of this scenario. Additional pulses (red dashed line) could be used to continue to disperse adult fish that immigrate over the target period, or dropped in favor of a sustained release of 1,500 cfs if the pulses are ineffective and hazardous conditions persist in the lower Klamath River. The solid blue line represents the worst case scenario and would require the highest volume of water over baseflow at 59,096 acre-feet. If pulses are shown adequate to significantly move fish, pulses would continue throughout the target period or until conditions are no longer hazardous for disease epidemic.

This scenario is an adaptable combination of the two previous and is the preferred of the group that conceptualized these scenarios. It provides for two 2,000 cfs peaks early in the critical period, then an option to continue with similar pulses for the remainder of the period or to release a sustained block of water similar to Scenario 1 (Figure 3.). The option to continue similar pulses of flow for the remainder of the period would be selected *only* if the first two pulses are shown to be effective at dispersing fish and reducing densities. If the desired fish response to pulse flows is not observed, flows would be increased from base 450 cfs to 1,500 cfs for the remainder of the target period to attempt to alleviate challenging environmental conditions in the lower Klamath River.

The adaptability of this alternative is "water-conservative" in that it first tries two significant pulses to test their effectiveness to move fish, and commits to a larger volume of water through sustained release of 1,500 only if monitoring indicates that fish are not significantly dispersed by the first pulses. This scenario likewise provides a measure of safety for the fish because the strategy can change from pulsed to sustained releases in the event that pulses do not work. Effective implementation of this scenario will require more intensive monitoring than the other scenarios, but will also provide more insight into fish response to potential migration cues and future management options to avoid fish die-offs.

Under the Hybrid Pulsed scenario, target dates for the 2,000 cfs pulse flows (minimum of the first two) would be August 18-19, August 25-26, September 1-3, September 8-9, and September 15-16. If the sustained flow option was implemented, it would reach 1,500 cfs on September 1 and continue through September 17. This scenario would require a maximum of 59,096 acre feet over baseflow volume. If the pulse flows were shown to be effective, 34,805 to 57,976 acre feet would be required over baseflow volume, depending on how many additional peaks were necessary to alleviate densities of fish immigrating over the target period.

IMPLEMENTATION STRATEGY

A strategy is proposed to minimize the risk of another significant loss of Trinity stocks to a fish die-off. This approach focuses on density as a primary causative factor and takes proactive action to encourage migration of Trinity fish if marginal conditions suggest that another large run or migration bottleneck may result in high fish densities. We selected targets to trigger implementation of the preferred scenario based on the critical need to protect this year's returning fish in a year expected to be similar to last.

We propose the following or similar process occur for implementation of potential relief scenarios:

1. A Technical Group formed of biologists representing the U.S. Fish and Wildlife Service, Bureau of Reclamation, Trinity Restoration Program Office, NOAA Fisheries, the Yurok and Hoopa Valley Tribes, and California Department of Fish and Game meets in late August to assess the impending risk of the immigrating salmonid population to a fish die-off. Three triggering criteria will be evaluated. Any one of the following criteria will trigger implementation of the relief action:
    - Run size – a fall chinook run-size greater than or equal to the long term average
        - Prediction of an average or larger run size through stock projections or other appropriate measure would indicate that high fish densities are potential and should be considered a triggering element
    - River discharge – projected discharge for August less than 3,000 cfs at Terwer Gage (long term average low summer baseflow at Terwer is approximately 3,200)
        - Water conditions from Terwer and Klamath Basin tributary gages combined with August release schedules for Klamath and Trinity Rivers will be evaluated
    - Water temperature – 19ºC or greater average daily temperature in the lower Klamath in early August
        - Water temperature as monitored at an appropriate site in the lower Klamath River will be evaluated

- In future years, an evaluation of meteorological projections for August to September may also provide insight to expected conditions for the lower Klamath. Development of meteorological criteria as a triggering mechanism may be warranted for future use

2. If implementation of the relief action is triggered, the Group provides final review of the relief strategy scenarios and coordinates to monitor the response of the fish and environmental conditions of the Klamath and Trinity Rivers. Implement an adaptive management strategy that evaluates pulse flow(s) effectiveness at averting a large scale salmon die-off.

MONITORING COMPONENT

Fish migration and environmental conditions should be monitored closely to determine the effectiveness of any Scenario eventually implemented in reducing die-off risk to Trinity River fish in the lower Klamath. For example, under Scenario Three there is a decision point after the second pulse flow on how to proceed for the remainder of the critical period. This will require relatively intensive monitoring to determine the effects of first Trinity pulse flows, but may provide the most insight into the effectiveness of pulse flows and fish migration response, and help determine appropriate future management actions to avoid large scale fish die-offs.

Tagging of fall chinook in the estuary and lower Klamath River with radio or sonic tags should occur. Tracking efforts are already planned this year for spring chinook and green sturgeon which should reduce costs associated with monitoring for this event. To detect response of fall chinook to pulse flows, changes in stage, water temperature, etc., data collection activities would be significantly intensified to include diurnal periods immediately before, during, and after pulses of water transit through the lower Klamath River. In addition, other monitoring methods including hydro-acoustic counting stations, weir counts, and direct observation will be evaluated and utilized as appropriate. While these pulses are intended to protect Trinity River stocks that were especially impacted by last year's fish die off, they will likely collaterally benefit Klamath stocks as well. Removal of Trinity fish from the affected area will reduce densities for Klamath fish. Klamath fish should be monitored closely however to detect any potential negative impacts to those stocks.

2013 Fall Flow Release Recommendation

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MEMORANDUM

TO:	BRIAN PERSON, RECLAMATION NORTHERN CALIFORNIA AREA MANAGER
FROM:	IRMA LAGOMARSINO (NOAA) AND NICHOLAS HETRICK (USFWS)
SUBJECT:	2013 FALL FLOW RELEASE RECOMMENDATION
CC:	ROBIN SCHROCK (TRRP)
DATE:	AUGUST 12, 2013

Irma Lagomarsino

Nicholas A. Hetrick

Background

A significant fish kill occurred in the lower Klamath River in September 2002. Though estimates vary, the US Fish and Wildlife Service (Service) reported that a minimum of 34,000 adult fish, primarily fall-run Chinook salmon, died during the event, (Guillen 2003a). Carcasses were observed between September 18 and October 1, 2002 within the lower 36 miles of the Klamath River, extending from the estuary upstream to Coon Creek Falls. The Service (Guillen 2003b) reported that:

> *"Low river discharges apparently did not provide suitable attraction flows for migrating adult salmon, resulting in large numbers of fish congregating in the warm waters of the lower River. The high density of fish, low discharges, warm water temperatures, and possible extended residence time of salmon created optimal conditions for parasite proliferation and precipitated an epizootic of Ich and columnaris."*

The Yurok Tribe (Belchik et al. 2004) concluded that:

> *"the clinical cause of mortality was massive infections of ich and columnaris. This fact was confirmed by direct observations, as well as pathology reports by USFWS and CDFG."*

California Department of Fish and Game (Turek et al. 2004) concurred with the findings of the Service's and Yurok Tribe's causative factors reports, adding that:

> *"flow is the only controllable factor and tool available in the Klamath Basin... to manage risks against future epizootics and major adult fish kills."*

Several flow-related evaluations and management actions have been implemented in the past to reduce the likelihood of occurrence of an adult fish kill, including the development of criteria for triggering the release of supplemental flows during the fall-run Chinook salmon migration season (Clarke 2010; Hayden 2012; TRRP 2012a) as well as supplemental flow releases from Lewiston Dam on the Trinity River in 2003, 2004, and 2012.

Snowpack and precipitation were below average during the fall/winter 2012-2013 throughout southern Oregon and northern California, resulting in below average river flows in the region. Hydrologic forecasts released by the California Nevada River Forecast Center (CNRFC) predict below average discharge in the lower Klamath River during the 2013 adult fall-run Chinook salmon migration season (Appendix A). Mean monthly discharge for the lower Klamath River is predicted to be 2,168 cfs in August and 2,076 cfs in September, based on inflow predictions and current operation plans that guide managed flow releases from Iron Gate and Lewiston dams. These predicted mean monthly flows are similar to mean monthly flows experienced in the lower Klamath River during the 2002 fish kill (Table 1; Figure 1; Appendix A). Anticipated flow accretions to the lower Klamath River are about 50% of those observed in 2012. Discharges in the lower Klamath River during the 2013 adult fall-run Chinook salmon migration season are predicted to be equivalent to about 90-95% exceedances (Appendix B).

Escapement of fall-run Chinook salmon to the Klamath Basin in 2013 is projected to be the second largest on record. The Pacific Fishery Management Council's Salmon Technical Team estimated that 272,400 adult fall-run Chinook salmon will return to the Klamath River (PFMC 2013); which is about 110,000 fish greater than the adult run size associated with the 2002 fish kill (CDFW 2013). This is important as a large run size combined with low river discharge were reported as the primary contributing factors in the 2002 fish kill (Guillen 2003b; Belchik et al. 2004; Turek et al. 2004). Similarly, below average stream discharge has been associated with Ich outbreaks in fish populations in other rivers (Maceda-Veiga et al. 2009).

Given the concerns described above, the Bureau of Reclamation (Reclamation) requested that the US Fish and Wildlife Service and the National Marine Fisheries Service provide technical assistance in assessing the current and predicted hydrologic conditions for the time period overlapping with the 2013 adult fall-run Chinook salmon migration season in the lower Klamath River, and in developing preventative and emergency measures that would reduce the risk of the occurrence of an adult fish kill, while being conservative of limited water resources given the dry hydrologic conditions. This memorandum contains only technical analyses and recommendations regarding adult fall-run Chinook salmon in the Klamath-Trinity Basin. It does not contain any analyses regarding the potential effects of the fall flow releases on any species listed under the Endangered Species Act (ESA) and does not address, nor is it intended to address, compliance with the ESA or any biological opinions issued under the ESA.

Review of 2012 preventative fall flow releases

During spring 2012, Trinity River Restoration Program (TRRP) staff, TRRP partners and Reclamation's Klamath Basin Area Office jointly developed 1) preventative flow release criteria designed to minimize the risk of a fish disease outbreak and subsequent fish kill (TRRP 2012a), and 2) emergency flow release criteria designed to reduce the severity of a fish kill (TRRP 2012b). The preventative flow release measures identified by the TRRP Fall Flow Subgroup in 2012 were implemented by Reclamation, with supplemental flows originating primarily from Lewiston Dam with a lesser amount of water released from Iron Gate Dam for ceremonial purposes at the request of the Yurok Tribe (Figure 2). Following the recommendations of the Subgroup, BOR targeted a discharge of 3,200 cfs in the lower Klamath River from August 15-September 21 (Figure 2). A fish kill did not occur during the 2012 adult salmon migration season in the lower Klamath River, despite dry hydrologic conditions and an unprecedented return of 302,100 fall-run Chinook salmon to the Klamath Basin (CDFW 2013). While it is not known to what extent the preventative flow releases contributed to averting a fish kill, measures taken in 2012 did contribute to reducing water temperatures by up to 1.4°C in the lower Klamath River (Magneson 2013; Figure 2) and a fish kill did not occur. Similar decreases in water temperatures of about 2.1 °C and 1.6 °C were observed in the lower Klamath River during the 2003 and 2004 fall flow releases (Zedonis 2004, 2005).

Table 1. Discharge (cfs) in the Klamath River near Klamath gage (U.S. Geological Survey Site #11530500) in August and September 2002 and predicted discharge in 2013.

Year	August	September
2002	2,327	1,993
2013 (predicted)	2,168	2,076
Long term average	3,170	3,170

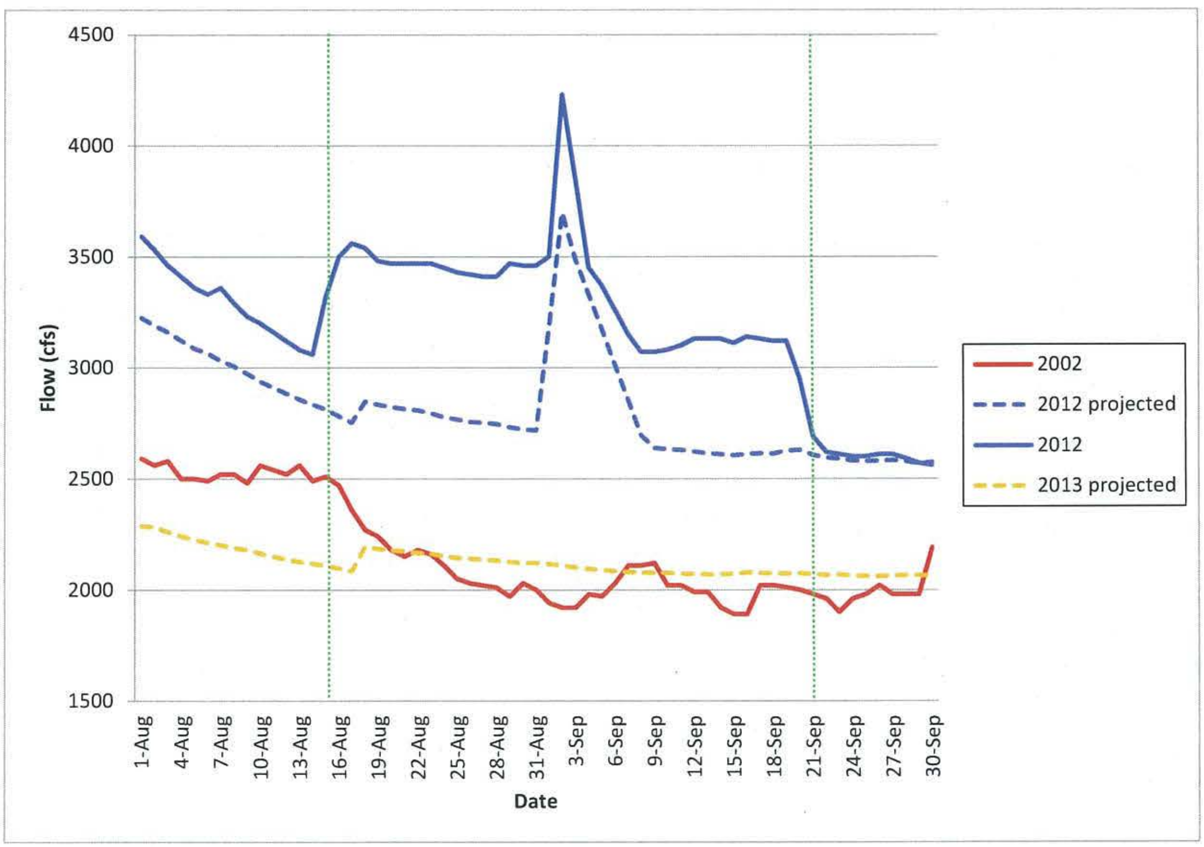


Figure 1. Observed flows in the lower Klamath River (RKM 13) in 2002 and 2012 (includes preventative fall flow augmentation) and preseason flow forecasts for 2012 (includes ceremonial pulse event for the Yurok Tribe released from Iron Gate Dam) and 2013 (without preventative or emergency fall flow augmentation or ceremonial release flow recently requested by the Hoopa Valley Tribe). Vertical green lines depict the primary period of the fall-run Chinook salmon migration season in the lower Klamath, August 15 through September 21.

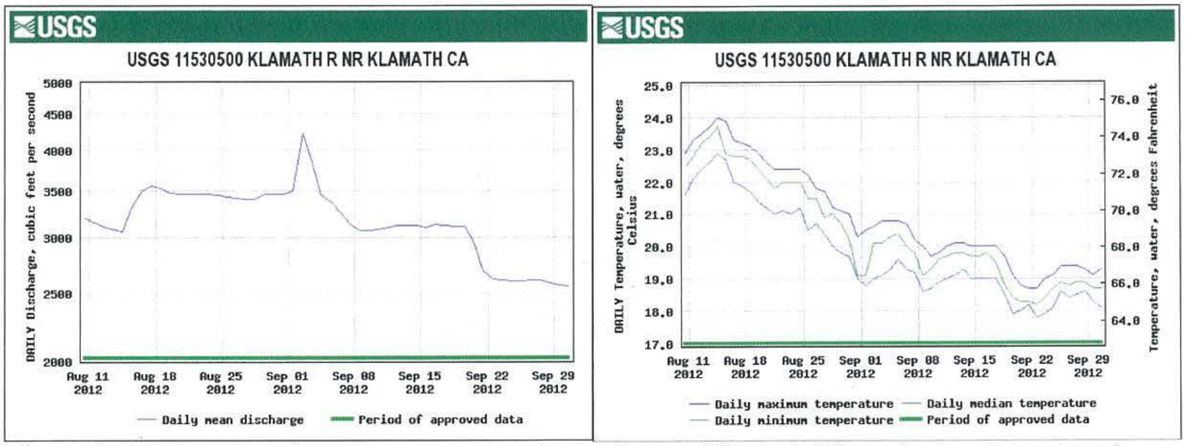


Figure 2. Discharge and water temperature in the Lower Klamath River during August and September of 2012.

Review of past recommendations for preventative fall flow releases

Several minimum flow recommendations for the lower Klamath River have been reported in the literature for the fall time period, ranging from 2,500 cfs to 3,200 cfs (Table 2). Recommendations of Turek et al. (2004) and Strange (2010a), however, were made without consideration of recent run sizes that exceeded previous maximum adult returns observed since comprehensive fall-run Chinook salmon monitoring was initiated in 1978.

While not independent of flow, water temperature can also be a critical parameter in affecting adult salmon behavior (Goniea et al. 2006). Strange (2010b) identified an adult Chinook salmon migration threshold of 23°C in the Klamath River, which is important because thermal migration barriers can lead to crowding of adult migrant fish and therefore, conditions conducive to fish-to-fish disease transmission and fish kills.

Recommendation for 2013 preventative fall flow releases

Given the large forecasted run size for 2013 and that preventative flow measures were taken in 2012 and a fish kill did not occur, implementing the 2012 fall flow plan (TRRP 2012a, 2012b) is likely to pose a lower risk for the occurrence of a fish kill in 2013 than the risk associated with other flow recommendations presented in Table 2. It is not possible, however, to assess if a fish kill would have occurred had discharge in the lower Klamath River been lower than 3,200 cfs experienced in fall 2012. While we do know that a fish kill did not occur in 2012, there is considerable uncertainty with regard to the specific discharge that flow augmentation should target in the lower Klamath River to prevent a fish kill.

We acknowledge that Reclamation has multiple obligations to consider in managing water resources in the Klamath-Trinity Basin. In addition, hydrologic conditions in 2013 are drier than those measured in 2012. For example, the 90% forecasted end of September storage for Trinity Reservoir in 2013 is 1.3 million acre feet (MAF), which is about 28% lower than the 1.8 MAF experienced in 2012. In addition, the 2013 projected end of September carryover storage is similar to that observed in 2009, which contributed to water temperature concerns in the Trinity River and resulted in the use of the auxiliary outlet of Trinity Reservoir. Similarly, the hydrologic conditions in the Upper Klamath Basin are also drier in 2013 than 2012.

Table 2. Review of previous for minimum discharge recommendations for the lower Klamath River during the fall-run Chinook salmon migration season.

Author	Minimum Flow Recommendation	Projected Adult Fall Chinook Salmon Run Size
Turek et al. (2004)	2,200 cfs (Klamath near Orleans +Trinity at Hoopa) ~ 2,500 cfs in Lower Klamath	None specified.
Strange (2010a)	2,500 cfs in Lower Klamath	Less than 170,000
Strange (2010a)	2,800 cfs in Lower Klamath	Greater than 170,000
TRRP (2012a)	3,200 cfs in Lower Klamath	380,000

Given the large fall-run Chinook salmon run size predicted for 2013 and the dry hydrologic conditions being experienced throughout the Klamath Basin, we recognize the need to provide supplemental flows in the Lower Klamath River to prevent a fish kill using a strategy that minimizes risk while conserving limited water resources. We also recommend that an adaptive management approach be taken that incorporates real-time environmental and biological conditions. In general, our joint recommendations are as follows, with more detail following and in the emergency fall flow recommendation section.

- Initiate preventative flow augmentation in the lower Klamath River (RKM 13) to a minimum of 2,800 cfs when the cumulative harvest of Chinook salmon in the Yurok Tribal fishery in the Estuary area meets or exceeds a cumulative total of 7,000 fish (Appendix C). The accounting of harvest should commence starting July 4 and we recommend all Chinook salmon, regardless of race, count toward the cumulative total.
- Fall flow augmentation should be initiated by August 22 if the fish metric is not triggered.
- Fall flow augmentation should continue until September 21 unless mean daily water temperature at rkm 13 is projected to be ≥23°C, in which case flow augmentation to maintain a minimum of 2,800 cfs should continue until daily water temperature at rkm 13 is projected to be < 23°C or until the end of September when seasonal air temperatures typically cool and contribute to water temperatures suitable for upstream migration (Figure 4).
- Implement real-time flow-temperature management using the RBM10 and SN Temp water temperature models developed for the Klamath and Trinity rivers and NOAA Weather Service weather projections to manage flows in assessing the 23°C water temperature migration threshold emergency flow release.
- Implement fish pathology monitoring to determine the need for a fish pathology/mortality emergency release, and
- Monitoring should occur during the fall-run Chinook salmon migration period in the lower Klamath River to inform the need and timing of preventative and emergency flow releases based on real-time environmental conditions (Figure 3; Appendix D).

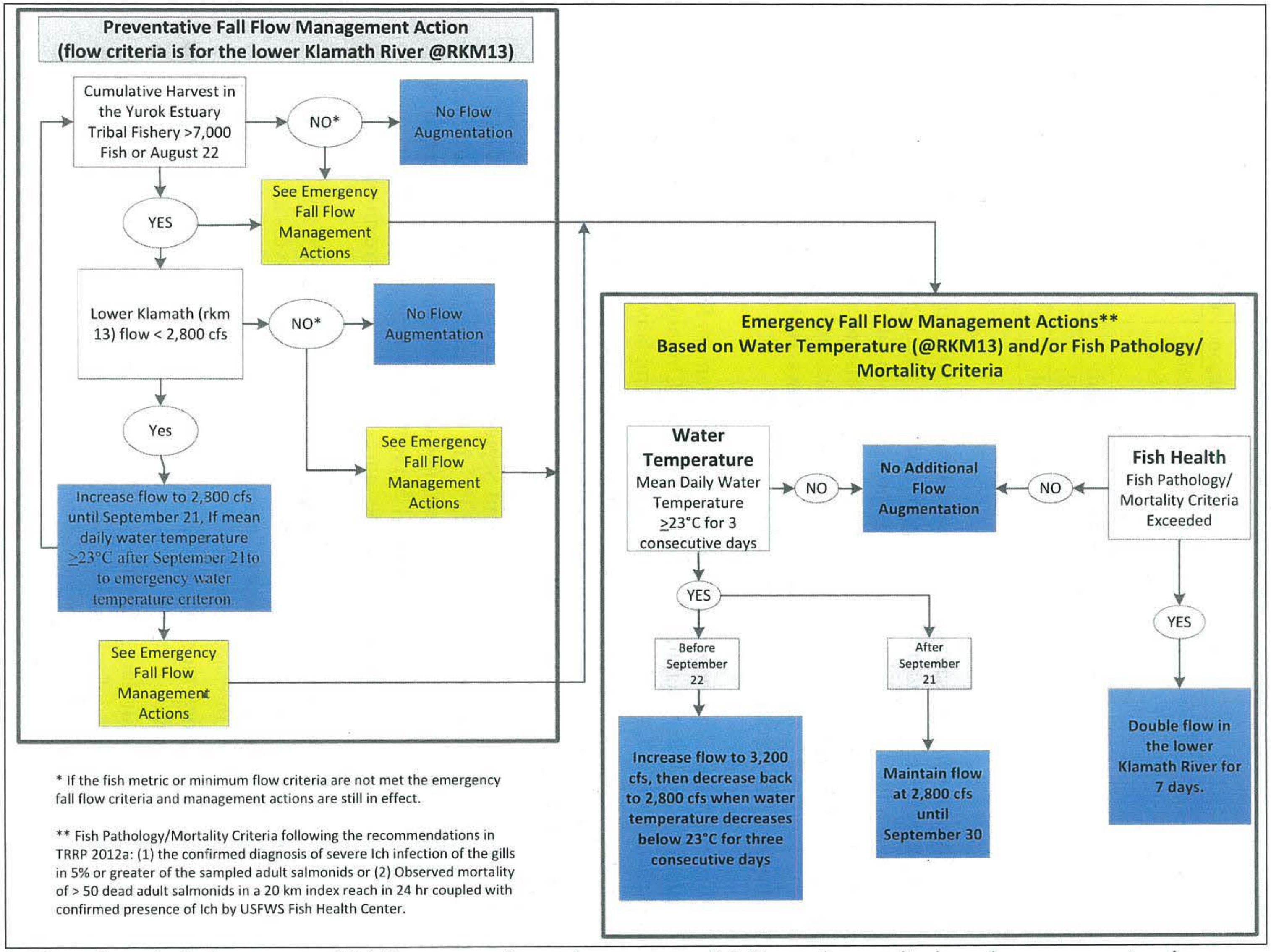
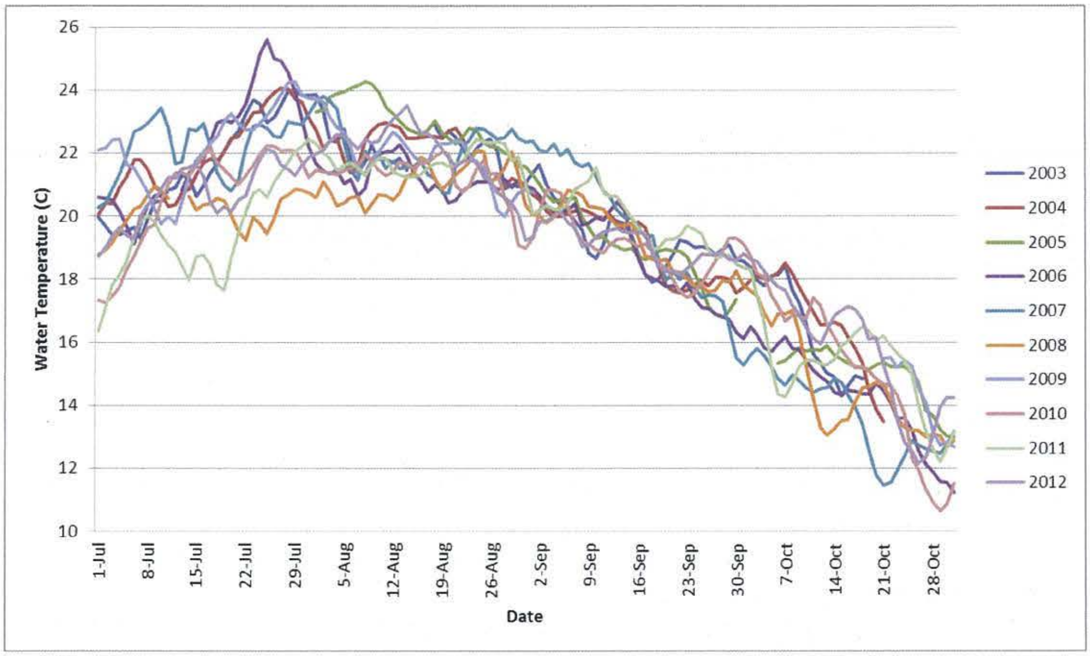


Figure 3. Flow chart depicting proposed 2013 preventative and emergency fall flow release criteria and management actions.



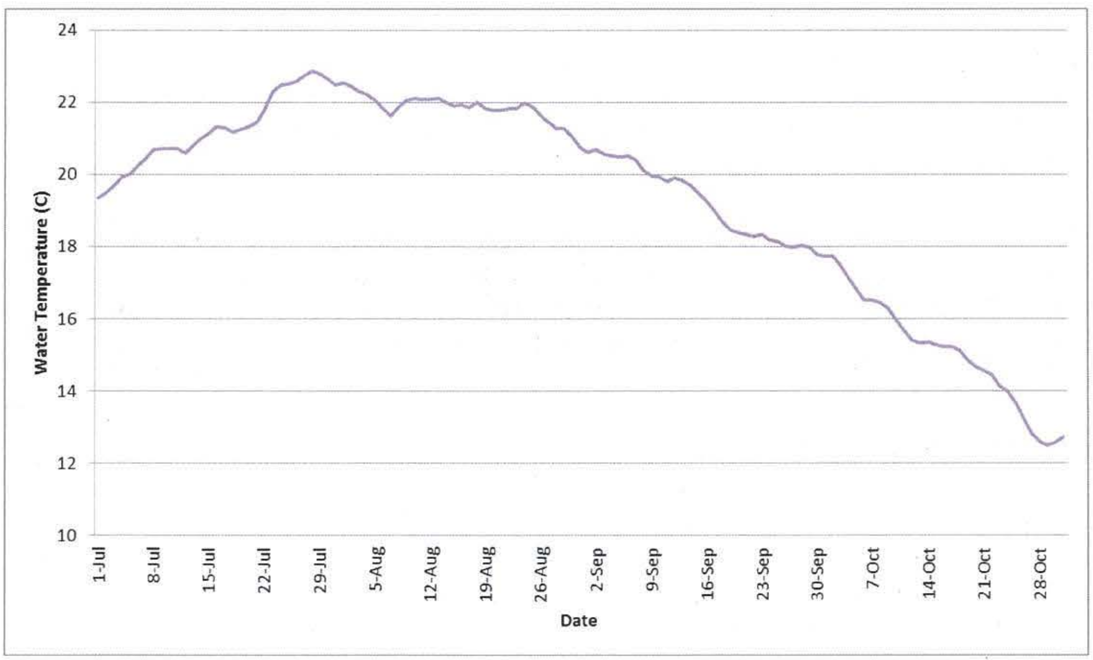


Figure 4. Mean daily water temperature (C) from July through October in the lower Klamath River (rkm 13), 2003-2012 (upper) and mean for all years (lower).

Fish Metric

We recommend that fall flow augmentation should be initiated once the cumulative harvest of Chinook salmon in the Estuary Area by the Yurok Tribal fishery exceeds 7,000 adults. The tallying of the cumulative harvest of Chinook salmon in the Estuary Area to commence on July 4 and the 2013 Yurok Tribal commercial fishery in the estuary will open on August 10. The use of a fish metric as a real-time indicator of the initiation of upriver migration of fall-run Chinook salmon will entail significant coordination among the Yurok Tribe who collect the fishery data and federal managers that will be implementing the fall flow augmentation.

Initiation of Fall Flow Augmentation if Fish Metric Is Not Met

Fall flow augmentation should be initiated by August 22 if the fish metric is not triggered. The reasoning behind this date is as follows:

- The short time period provided to develop the fish-based metric precluded an in-depth evaluation of temperature and flow data, which may have a significant influence on harvest and effort data in the Estuary and Middle Klamath areas. As a result, the metric may not be conservative enough to ensure that flow augmentation will occur.
- It is anticipated that there will be large numbers of fall Chinook salmon in the Estuary Area due to the large projected inriver run. In addition, the 2013 forecast is expected to be more accurate than the 2012 projection and is comprised of a higher proportion of Klamath fall Chinook salmon stocks (Shasta River, Iron Gate Hatchery, Bogus Creek, and mainstem Klamath River) which tend to enter the estuary and river earlier than Trinity River stocks.
- In four of the five years (80%) included in the break point analyses we conducted to define the fish metric, large numbers of fish were harvested in the Estuary Area by August 22 and harvest in the Middle Klamath Area starts to increase in the following weeks, suggesting that the upriver migration of the run had commenced by this date.

Ending of Fall Flow Augmentation

Fall flow augmentation should be continued through September 21 and can end after this date if mean daily water temperature in the lower Klamath River at rkm 13 remains below 23°C (TRRP 2012). See "Recommendation for emergency fall flow releases for 2013 – Water Temperature Criterion" if the mean water temperature in the lower Klamath River exceeds 23°C after September 21.

Recommendation for emergency fall flow releases for 2013

The recommended triggers for emergency flow releases in 2013 are two-tiered, both of which are intended to minimize the potential for the occurrence of an epizootic disease outbreak and resulting fish-kill. The first phase recommends that flow in the lower Klamath River be increased to 3,200 cfs at rkm 13 when the fish metric criterion is met or exceeded and mean daily water temperature (actual and/or predicted) at rkm 13 is $\geq 23^{\circ}$ C for three consecutive days. The second phase of the emergency release is based on the fish pathology/mortality criteria adopted by the Trinity River Restoration Program - Fall Flow Subgroup's recommendation for 2012 (TRRP 2012a; TRRP 2012b).

Water Temperature Criterion

Water temperature is widely known as a critical factor for influencing the upstream migration of adult salmonids (Goniea et al. 2006, Strange 2010b), with Strange (2010b) identifying mean daily water temperature threshold of 23°C for the migration of adult Chinook salmon in the Klamath River.

We recommend the use of a water temperature criterion when the fish metric is met or exceeded and mean daily water temperature (actual and/or predicted) is ≥ 23° C for three consecutive days to trigger the increase of flow in the lower Klamath River (rkm 13) to 3,200 cfs. While it can be expected that water temperatures will occasionally exceed this temperature threshold, prolonged periods of water temperatures above this threshold can lead to large densities of fish in the lower river as they migrate from the estuary. Therefore, we recommend a three consecutive day period for this water temperature trigger to avoid reacting to short (one or two day) temperature increases above the water temperature criterion. Maintaining mean water temperature below this temperature threshold for the following three days will allow adult to migrate upstream and reduce fish density in the lower river. This emergency action is intended to eliminate thermal migration barriers and reinitiate upstream migration of adult fish, thereby reducing the extended residence time of adult fish in thermal refugia and as a result, conditions conducive to fish-to-fish disease transmission and associated fish kills.

We also expect that adult Chinook salmon will resume upstream migration on the onset of periods of declining river temperatures that would result from increasing flows from 2,800 cfs to 3,200 cfs in the lower Klamath River. This real-time management concept is supported by the findings of Strange (2010b) who reported that adult Chinook salmon key into periods of declining river temperature during their upriver migration to take advantage of brief windows of thermal opportunity.

Fall flow augmentation should continue until September 21 unless mean daily water temperature at rkm 13 is projected to be ≥23°C, in which case flow augmentation to maintain a minimum of 2,800 cfs should continue until daily water temperature at rkm 13 is projected to be < 23°C or until the end of September. In early October, mean water temperatures in the lower Klamath River are generally decreasing (Figure 4) due to seasonal decreases in air temperatures and most of the fall-run Chinook salmon have commenced their upstream migration based on harvest data from the Middle Klamath Area (Appendix C, Figure 12)

Fish Pathology/Mortality Criterion

Two primary fish health monitoring efforts will be relied upon to determine the need for a diagnostic Ich survey which could trigger an emergency fall flow release.

1. Adult fish health monitoring will be conducted by the Yurok Tribal Fisheries Program (YTFP) in the lower reach of the Klamath River to determine the presence and severity of Ich and columnaris infection throughout the fall Chinook salmon run. Additionally,

Tribal Fisheries crews will count and examine all pre-spawn mortalities to determine possible cause of death. Pre-spawn mortality due to columnaris, wounds (hook, net, or seal bites), and other causes will be documented but will not be used as diagnostic criteria for identifying an imminent Ich epizootic. Results of these sampling efforts will be used to determine if a more intensive diagnostic Ich survey is needed.

2. In addition to the directed fish health monitoring conducted by the YTFP, the Klamath Fish Health Assessment Team (KFHAT) will implement its response plan if moribund or dead fish are observed in any areas of the Klamath or Trinity rivers. KFHAT response plan documents can be found at the following link: http://www.kbmp.net/images/stories/pdf/KFHAT/FinalResPlan_AppendicesUpdatedMarch2011.pdf

These efforts will provide information on the disease incidence observed in adult salmonids in the lower Klamath River or the numbers/condition of dead or moribund fish throughout the Klamath-Trinity Basin. We recommend that the criteria used to institute a diagnostic Ich survey should be:

1. Prevalence of severe Ich infection in 5% or greater of the weekly adult fish health monitoring samples collected by resource agencies, with Ich infection to be confirmed by the Service's California-Nevada Fish Health Center (CNFHC) from fixed samples, or

2. Observed mortality of > 50 adult salmonids (Chinook and/or coho salmon and steelhead), regardless of cause, in a 20-km reach within a 24-h time period. Recently deceased fish (<24 hours post death) will be differentiated from older mortalities (>24 hours post death) by the presence of at least one clear eye. Data on the presence of hook scars, gill net marks, predator wounds (seal/sea lion, lamprey, otter), and condition of gills (i.e. columnaris) will also be collected to determine other possible causes of mortality.

<u>Diagnostic Ich Survey</u>

If either of the criteria established for the adult fish health monitoring effort are met, an intensive sampling of adult salmonids will be initiated to collect live or recently deceased fish. Ich diagnostic surveys will be performed by the CNFHC that will provide a pathology report documenting the findings of these surveys. These efforts will focus on determining the level and severity of Ich infection or the possible cause of death in the event of large numbers of dead fish are observed. We recommend the level and severity of an Ich infection that would trigger an emergency release be defined as a confirmed observation of a minimum of 5% of the sampled fish having 30 or more parasites on one gill arch. The recommended action is to augment flows in the lower Klamath River to double the preexisting flow for 7 consecutive days.

If possible, a minimum of 60 adult salmonids should be sampled within a consecutive 2-day period. While a sample of 60 fish is desired, it may not always be achievable and the minimum acceptable sample size is set at 30 fish. These fish should be live or recent mortalities (< 3 hours).

Criteria for triggering an emergency flow release and recommended management action based on the level and severity of an Ich infection are as follows.

Fish Pathology/Mortality Emergency Criteria	Management action
1. The confirmed diagnosis of severe Ich infection of the gills in 5% or greater of a desired sample of 60 adult salmonids (3 infected out of a 60-fish sample). Following the 5% threshold criteria, a confirmed diagnosis of 2 or more individuals having a severe Ich infection would meet the criteria for a sample size of less than 60 but greater than the minimum of 30 fish. Or 2. Observed mortality of > 50 dead adult salmonids in a 20 km index reach in 24 hr coupled with confirmed presence of Ich by USFWS Fish Health Center.	Recommend immediate Emergency Fall Flow release with a 7 day duration pulsed spike to double pre-existing flows in the Lower Klamath River.

The Service's CNFHC will provide a pathology report documenting the findings of the diagnostic survey to Brian Person of Reclamation, to other federal, state and tribal co-managers, and to the KFHAT group. It is recommended that an emergency release be implemented immediately upon BOR's receipt of a positive pathology report to limit fish mortalities associated with a potential Ich epizootic.

Additional Considerations

While modest increases of river discharge in the Klamath Basin from summer rainstorms are not uncommon during the adult fall-run Chinook salmon migration period, these rain events are typically short in duration and occur with limited frequency. The sustained release of a substantial volume of water from one or both Klamath Basin dams, as recommended above, would mark a departure from the natural flow regime (Poff et al. 1997, Lytle and Poff 2004) of the Klamath and Trinity rivers because the duration of the elevated flows is unnatural. Modification of flow can be expected to have cascading effects on the ecological integrity of rivers and the organisms that depend on them (Poff et al. 1997). However, both the Klamath and Trinity rivers are extensively managed systems and given existing water withdrawals and conveyances, their hydrology already deviate significantly from the natural conditions.

References

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Appendices

Appendix A. Predicted discharge for the lower Klamath River (U.S. Geological Survey Site #11530500) with no preventative flow release. (Data from CNFRC downloaded on June 30, 2013).

Date	50% flow forecast river flow without dam releases (from CNRFC)	IGD Flows	Lewiston Flows	Flow estimate at KNK with no supplemental flows
7/30/2013	990	880	450	2,320
7/31/2013	972	880	450	2,302
8/1/2013	957	880	450	2,287
8/2/2013	952	880	450	2,282
8/3/2013	931	880	450	2,261
8/4/2013	913	880	450	2,243
8/5/2013	896	880	450	2,226
8/6/2013	882	880	450	2,212
8/7/2013	871	880	450	2,201
8/8/2013	859	880	450	2,189
8/9/2013	850	880	450	2,180
8/10/2013	834	880	450	2,164
8/11/2013	821	880	450	2,151
8/12/2013	806	880	450	2,136
8/13/2013	796	880	450	2,126
8/14/2013	788	880	450	2,118
8/15/2013	780	880	450	2,110
8/16/2013	766	1,000	450	2,096
8/17/2013	754	1,000	450	2,084
8/18/2013	743	1,000	450	2,193
8/19/2013	734	1,000	450	2,184
8/20/2013	728	1,000	450	2,178
8/21/2013	724	1,000	450	2,174
8/22/2013	716	1,000	450	2,166
8/23/2013	713	1,000	450	2,163
8/24/2013	702	1,000	450	2,152
8/25/2013	694	1,000	450	2,144
8/26/2013	691	1,000	450	2,141
8/27/2013	686	1,000	450	2,136
8/28/2013	682	1,000	450	2,132
8/29/2013	676	1,000	450	2,126
8/30/2013	671	1,000	450	2,121
8/31/2013	671	1,000	450	2,121

Date	50% flow forecast river flow without dam releases (from CNRFC)	IGD Flows	Lewiston Flows	Flow estimate at KNK with no supplemental flows
9/1/2013	667	1,000	450	2,117
9/2/2013	660	1,000	450	2,110
9/3/2013	651	1,000	450	2,101
9/4/2013	644	1,000	450	2,094
9/5/2013	639	1,000	450	2,089
9/6/2013	634	1,000	450	2,084
9/7/2013	630	1,000	450	2,080
9/8/2013	628	1,000	450	2,078
9/9/2013	626	1,000	450	2,076
9/10/2013	627	1,000	450	2,077
9/11/2013	623	1,000	450	2,073
9/12/2013	621	1,000	450	2,071
9/13/2013	619	1,000	450	2,069
9/14/2013	619	1,000	450	2,069
9/15/2013	622	1,000	450	2,072
9/16/2013	628	1,000	450	2,078
9/17/2013	626	1,000	450	2,076
9/18/2013	624	1,000	450	2,074
9/19/2013	623	1,000	450	2,073
9/20/2013	624	1,000	450	2,074
9/21/2013	621	1,000	450	2,071
9/22/2013	616	1,000	450	2,066
9/23/2013	618	1,000	450	2,068
9/24/2013	614	1,000	450	2,064
9/25/2013	611	1,000	450	2,061
9/26/2013	611	1,000	450	2,061
9/27/2013	613	1,000	450	2,063
9/28/2013	615	1,000	450	2,065
9/29/2013	616	1,000	450	2,066
9/30/2013	611	1,000	450	2,061
10/1/2013	608	1,000	450	2,058
10/2/2013	614	1,000	450	2,064
10/3/2013	620	1,000	450	2,070
10/4/2013	609	1,000	450	2,059
10/5/2013	618	1,000	450	2,068

Appendix B. Exceedance table based on monthly average flows, not daily flows, for the Lower Klamath River (U.S. Geological Survey Site #11530500) using years 1911-2012.

Exceedance	July	August	September
0.05	9,646	4,869	4,875
0.10	8,894	4,397	4,247
0.15	7,770	4,326	4,113
0.20	7,352	4,131	3,943
0.25	6,650	3,683	3,773
0.30	6,397	3,532	3,605
0.35	5,455	3,447	3,415
0.40	5,177	3,279	3,346
0.45	4,793	3,170	3,139
0.50	4,477	2,982	3,032
0.55	4,265	2,956	2,968
0.60	4,083	2,901	2,857
0.65	3,924	2,861	2,758
0.70	3,789	2,787	2,691
0.75	3,574	2,672	2,598
0.80	3,313	2,574	2,538
0.85	3,230	2,372	2,501
0.90	2,960	2,200	2,447
0.95	2,518	1,876	2,003

Appendix C. Development of a Fish Metric to Inform the Timing of Fall Flow Augmentation for the Lower Klamath River in 2013.

Introduction

In 2012 the Trinity River Restoration Program Fall-Flow subgroup developed flow recommendations to protect the forecasted large inriver run of fall-run Chinook salmon expected to enter the Klamath/Trinity Basin and prevent a fish-kill (TRRP 2012). Recommendations made by the group included a temporal component (August 15-September 21) based on Yurok Tribal net harvest data collected in the Klamath River estuary, which was used as a proxy for inriver run timing.. With a large fall-run Chinook salmon inriver run forecast for 2013 (PFMC 2013a, Figure 1) and the expected low flows in the lower Klamath River in August and September, the Bureau of Reclamation sought technical assistance from the US Fish and Wildlife Service and National Marine Fisheries Service to develop recommendations for augmenting fall flows, while being conservative of the limited water resources given the dry hydrologic conditions.

One component of the recommendation developed by the Fall-Flow subgroup in 2012 that needed refinement was to better define and support the period when flow augmentation would be implemented. A fish abundance-based metric and associated real-time monitoring was deemed desirable to inform the timing of flow augmentation rather than relying on fixed dates as specified in the 2012 plan.

The projected 2013 inriver run of adult fall-run Chinook salmon is 282,400 fish, approximately 110,000 greater than the 2002 inriver run (Figure 1), of which the majority are predicted to be age-4 fish (PFMC 2013a). The projected age composition of the run is pertinent in that the age-4 predictions are generally more accurate than the age-3 predictions (PFMC 2013b). The 2012 inriver run was 79% of the preseason projection with this error partially attributed to the relatively low precision and accuracy in the preseason forecast for the age-3 component of the run at large stock sizes which comprised 82% of the 2012 run (KRTT 2012). In addition to the age composition of the 2013 run being skewed towards age-4 fish (69%; O'Farrell, pers. com.), the run is expected to be dominated by Klamath stocks (Iron Gate Hatchery, Klamath River mainstem, Bogus Creek, Shasta River, Scott River and Salmon River) based on the distribution of spawners observed in 2012 (CDFW 2013, Figure 2) and these stocks tend to enter the river earlier than Trinity stocks (Polos and Craig 1994, Strange 2007). Therefore, we expect the number of fall-run Chinook salmon that return to the Klamath Basin will be closer to the forecast as compared to 2012 and that many of the fish will return earlier than average.

The goal of this analysis was to develop a fish metric that can be used as an indicator of the first substantial increase of fall-run Chinook salmon in the lower Klamath River, indicating that the inriver run and subsequent upstream migration has commenced. This fish metric is intended to be used as a trigger to initiate fall flow augmentation. The benefit of this real-time management approach is its potential to more efficiently use limited water resources as needed to protect the large predicted return of Klamath Basin fall-run Chinook salmon, rather than relying on fixed dates to start and end flow augmentation.. However, it is critical that an abundance-based metric be conservative so that augmented flows are released in time to protect the run, with the need amplified by the low flows projected for August and September (similar to those in 2002). A metric that is not conservative enough may result in large numbers of adult fall-run Chinook salmon entering the river and commencing their upstream migration under flow conditions that are similar to those that occurred during the 2002 fish-kill.

An ideal metric for guiding the management decision of when additional water should be released would be based on the density of fish holding above the estuary in the mainstem Klamath River in the reach where the 2002 fish-kill occurred. This is an area where adult and juvenile salmonids often congregate in high densities in thermal refugia when warm mainstem Klamath River water temperatures inhibit migration. Another potential metric would be the abundance of Ich theronts in this reach of the mainstem Klamath River. This information, in combination with the fish density data, could be used to determine the potential for an Ich epizootic. While the development of this fish metric has focused on the abundance of adult fall-run Chinook salmon, the abundance of juvenile salmonids as well as other fish species that may be holding in thermal refugia should be considered because they can also be infected by Ich and can possibly be the source of the initiation of an Ich epizootic. At this time, however, fish and Ich theront density information are not available. As an alternative we chose to use the harvest data from the Yurok Tribal fishery as a proxy for fish density in the mower mainstem river because the historic information were readily available and implementation and tracking of the metric in real-time is feasible.

Methods.

We evaluated the Yurok Tribal net harvest and effort data from the Estuary and Middle Klamath monitoring areas provided by the Yurok Tribal Fisheries Program (Figure 3). These data were selected for exploratory analyses because they: (1) are assumed to provide an indirect measure of fish abundance and run timing, (2) were collected in the area (Middle Klamath) where the 2002 fish-kill occurred, (3) were quickly accessible given the limited time provided to us to develop a fish metric, and (4) the data are updated every 24 hours during the fishery to facilitate a real-time use of the metric to inform flow augmentation decisions. Utilizing harvest data for this task requires two assumptions:

- The number of fall-run Chinook salmon that have escaped estuary harvest is positively associated with the number of estuary harvested fish.
- Fish that escape estuary harvest will soon-after arrive at, and potentially hold in, the section of the Klamath River considered most susceptible to fostering a disease outbreak in returning adult salmon.

The data consisted of weekly estimates of Chinook salmon harvest and fishing effort from July 4 through November 30 for years 2001 through 2012 (Williams, pers. com.). The Estuary Area is an area of intense fishing effort and harvest and rigorous monitoring, especially during years when a commercial fishery is conducted, and can indicate when large numbers of fall–run Chinook salmon have migrated into the estuary. The Middle Klamath Area is the area where the 2002 fish-kill occurred (Guillen 2003), where fall-run Chinook salmon initiate their upstream migration and where they are susceptible to temperature induced migration delays (Strange 2010), potentially leading to high fish densities. These conditions, in combination, can contribute to the initiation of an Ich epizootic (Guillen 2003, Turek et al. 2004, Belchik et al. 2004).

Following discussions with the Yurok Tribal biologists concerning the harvest data, it was decided that the data from five years (2001, 2002, 2003, 2007 and 2009) were most appropriate for analyses for the following reasons:

- the Klamath Basin fall-run Chinook salmon inriver runs during these years were large (Figure 1),
- commercial fisheries occurred in the Estuary Area during these years, and
- the commercial fisheries began between July 29 and August 1.

Data from 2011 and 2012 were not considered because the commercial fisheries started on August 21 and August 19, respectively, which significantly shifts the timing of effort and harvest in the Estuary Area (Figure 4). While weekly data were provided for each year from July 4 through December 4, our analyses focused on the time period from July 4 through November 6 as it encompasses the initiation and the end of the fall-run Chinook salmon migration through the Estuary and Middle Klamath areas. In evaluating catch-effort data, the period was limited from August 1 through October 2 when significant fishery effort and harvest occur and comparable effort data (net-hours) were available. Graphic display of the data used the last day of the week rather than the first day of the week so cumulative data were representative of the sum of weekly data up to that date. While the data are not continuous, line graphs were used for display purposes to facilitate comparative display of the data.

Weekly harvest, effort and catch-effort (CE) data for the Estuary Area and Middle Klamath Area were plotted to evaluate any obvious patterns that could be further evaluated as fish abundance metrics. Weekly values of harvest, effort or CE data were graphed as well as cumulative values of harvest and effort throughout the period. Additionally, proportions and cumulative proportions of each year's harvest and effort were plotted.

Differences in the timing of harvest between the Estuary Area and the Middle Klamath Area were examined to determine potential patterns that could be used to infer run timing into the Middle Klamath Area by the harvest in the Estuary Area. This would allow for flow augmentation to be linked to the fall-run Chinook salmon abundance in both the Estuary and Middle Klamath areas. Yurok Tribal biologists expressed concerns with using the Middle Klamath data for a fish metric because the fishing effort is typically lower during the early part of the run, especially when a commercial fishery is occurring, so the data may not be adequate as an indicator for fish abundance.

The relationship between effort and CE were investigated to see if these variables could be used as indicators of abundance. Ideally, CE data could be used as an indicator of the abundance of fish in the Estuary Area; but due to the intensity of the fishery and the variable removal (via harvest and upstream migration) and addition (via fish moving into the Estuary from the ocean) of fish this in not likely the case. It was speculated that increases in effort could indicate when the large numbers of fish were in the estuary due to fishers reacting the presence of fish or that effort could influence CE, possibly decreasing it with the increase in effort. Harvest was not evaluated for these relationships because of the lack of independence between harvest and effort and harvest and CE since these variables are used to calculate harvest (Equation 1):

$$Harvest_t = \sum_{i=1}^{7}(Effort_i * CE_i) \qquad \text{Equation 1}$$

...where harvest in week t is estimated by summing the daily harvest estimates generated by multiplying the effort on day i by the catch-effort (CE_i) on day i.

The object of the fish metric is to initiate fall flow augmentation so increased flows in the lower Klamath River coincide with large numbers of fish exiting the Estuary and migrating into the lower Klamath River. Following the graphical display of data, it appeared that a fish abundance metric could be developed by looking at the large and abrupt increases in harvest or inflection points of cumulative harvest that occur in the Estuary Area fishery.

The cumulative harvest estimates from all years display a very similar pattern: (1) a period of relatively little harvest before the population of returning salmon arrive en masse, (2) a sharp increase in the amount of harvest that continues for several weeks, and (3) a plateau in harvest during the latter part of the harvest season. Being able to estimate when the cumulative harvest curves begin their quick acceleration would allow us to also estimate when the bulk of the population of returning adult salmon were about to be entering the river. Given the common shape-characteristics of the cumulative harvest curves under consideration, we opted to estimate the beginning of the accelerated arrivals of adults using break-point analysis, applying the model and estimation techniques of Muggeo (2003). Rather than considering a year's cumulative harvest as a single curve, we instead considered each as a set of continuous piece-wise linear segments. Each segment potentially has a unique slope, and changes in slopes occur at break-points. For example, consider the segmented relationship between a response variable (Y) and a single, continuous, explanatory variable (X) with a single break-point (ψ). A model for the mean of Y is:

$$E(Y) = \beta_0 + \beta_1 X + \beta_2 (X - \psi)_+$$

where the "+" is a logical expression indicating a 1 if $X - \psi > 0$, and and 0 if not, According to this parameterization, the slope of the relationships between Y and X is β_1 if $X \leq \psi$ and $(\beta_1 + \beta_2)$ if $X > \psi$. While this model can describe the relationship between the response and explanatory variable, the likelihood is not differentiable at the break points. To combat this issue, likelihood estimation is carried out under an iterative procedure based on a first-order Taylor's expansion (Muggeo, 2003).

Results

<u>Estuary Area – Harvest, Effort and Catch-Effort</u>

Harvest, effort and CE data in the Estuary Area show some general trends among the years evaluated but also substantial variability (Figure 5). Harvest data exhibit some distinct peaks in mid-August and early September, possibly coinciding with the peaks of Klamath origin and Trinity origin fish entry into the estuary. The 2007 data are unique in that the run appeared to enter the river later than in the other years. Fishing effort typically has one peak but it occurs over a five week period from early August through early September. The large CE values that occur in July and October can be attributed to low effort inflating the CE estimates. CE was variable with no consistent trend when the analysis t was limited to August and September, with peaks occurring in late August to mid-September (Figure 6). Data on the proportion of harvest and proportion of effort also showed the similar trends in the timing of peak harvest and effort and the variability throughout the season (Figure 7).

Cumulative and cumulative proportion of harvest and effort showed the same general trends in peaks and timing of harvest and effort data although the relative trends from week to week can be distinguished by changes in the slope of the line segments (Figure 8 and 9). The cumulative proportion of harvest in the Estuary Area show that three years (2001, 2003, and 2009) exhibited similar trends in cumulative harvest through late August while the cumulative harvest line is shifted earlier for 2002 and later for 2007. The later run timing observed in 2007 may have been due to the run being composed of primarily Trinity origin fish (61% based on the distribution spawners) which tend to enter the river later and also the development of a berm at the mouth of the Klamath River which is believed to hinder the migration of salmonids into the estuary (Hilliemier pers. com). The later run timing of fall Chinook salmon was also observed by Strange (2008) and a protracted spawning duration in the upper mainstem Klamath River (Gough, pers. com.).

<u>Middle Klamath Area – Harvest, Effort and Catch-Effort</u>

Harvest and CE in the Middle Klamath Area were highly variable in magnitude and timing of peaks (Figure 10). Effort was relatively stable throughout the period evaluated except for July and the large peaks in August and September in 2009. The proportion of harvest and proportion of effort data exhibited high variability throughout the season (Figure 11).

Cumulative harvest indicates that the pattern of harvest was similar up to mid-September in three years (2001, 2002 and 2003) but increased earlier in 2009 and later in 2007 (Figure 12). Cumulative effort showed similar trends except in 2002 when effort was substantially greater than in other years. Cumulative proportion of total harvest shows that increase in harvest in the Middle Klamath Area was variable, occurring from mid-August to mid-September (Figure 13).

<u>Timing of Harvest in the Estuary and Middle Klamath Areas</u>

The Estuary and Middle Klamath areas show similar trends in cumulative proportion of harvest within years, with harvest occurring in the Estuary Area earlier than in the Middle Klamath Area as is expected (Figure 14). Trends are variable across years, with 2001 exhibiting a desirable trend of almost parallel lines while the lines were virtually the same in 2009 (Figure 15). However, sufficient variability in these data preclude using Estuary Area cumulative harvest data to predict when harvest would be expected to increase in the Middle Klamath Area, which would be used as a surrogate for fish abundance as a trigger for implementing fall flow augmentation.

<u>Trends of Catch-Effort and Effort in the Estuary Area in August and September</u>

The relationship between CE and effort was highly variable when data from all years were analyzed together (Figure 16). CE values had greater variability at values of effort below 2,100. Examining these data for individual years, CE was generally low when effort was high and vise-versa in 2001, 2007, and 2009 (Figure 17). This inverse pattern was not evident in 2002 and 2003 data. Only CE and effort data from 2001were significantly correlated ($r=-0.84$, $p=0.005$), with data from 2002 exhibiting a positive relationship ($r=0.64$, $p=0.065$, Table 1). Since the relationships between CE and effort were generally not significant and the relationships were not consistent across years, these data were not further evaluated in developing a fish-based metric for guiding fall flow augmentation.

Changes in Trends of Weekly Harvest as a Fish Metric – Break-Point Analysis

Though several break-points exist in the Estuary Area cumulative harvest data for each year, we focused on the estimates of the break-points where cumulative harvest dramatically increases (Figure 18). Estimates of these break-points ranged from 5.3 to (2002) to 8.5 (2007, Table 2). Three of the break-points (2002, 2003, 2009) occur when cumulative harvest transitions past 5,000 fish while the other two occur the following week as cumulative harvest transitions past 10,000 fish (Table 3). Despite variation in the weeks of the harvest season for which these break points are estimated and variation in the total amount of harvest from year to year, the relative consistency of the break point estimates and the similarity of the general shape of the cumulative harvest curves suggest using this methodology for identifying the fish metric to inform fall flow augmentation is creditable.

Estimation of Fish-Metric for Triggering Fall Flow Augmentation

The break-point analysis provided estimates of transition points along the cumulative harvest relationships for each year (Table 2). Since the data were summarized by week, estimates for the break points were rounded to the nearest integer and the cumulative harvest for that week (t) and the following week ($t+1$) were averaged. Calculating the mean for the rounded break-point estimate (t) and the following week ($t+1$) was done because the break-point estimates the transitional point between the shallow sloped early period and the adjacent period of quickly accelerating harvest. The estimated cumulative harvest for each year using the above procedures were then averaged to estimate the recommended cumulative fish metric,

Using this procedure, a cumulative harvest of Chinook salmon in the Estuary Area of the Yurok Tribal fishery of 7,000 (rounded to the nearest 100) fish, with cumulative counts starting on July 4, would trigger the initiation of fall flow augmentation.

Recommendations:

Fish Metric

- Use of a fish metric entails significant coordination among the Yurok Tribe who collect the fishery data and the federal managers that will be implementing the fall flow augmentation.
- Once the cumulative harvest of Chinook salmon in the Estuary Area by the Yurok Tribal fishery exceeds 7,000 adults fall flow augmentation should commence. The releasing of fall flow augmentation does not need to wait until the end of the sampling week.
- The tallying of cumulative harvest of Chinook salmon in the Estuary Area commences on July 4.
- The 2013 Yurok Tribal commercial fishery in the estuary will start on Aug 10.

Initiation of Fall Flow Augmentation if Fish Metric Is Not Met

- Fall flow augmentation should be initiated by August 22.if the fish metric is not triggered. The reasoning behind this date is:
  - The development of this metric in a short time period has precluded an in-depth evaluation of other datasets, including temperature and flow data, which may have influenced harvest and effort data in the Estuary and Middle Klamath areas, therefore the metric may not be conservative enough to ensure that flow augmentation will occur.
  - It should be anticipated that there will be large numbers of fall Chinook salmon in the Estuary Area due to the large projected inriver run, with expected greater accuracy than the 2012 projection, and the expected greater proportion of Klamath fall Chinook salmon stocks (Shasta River, Iron Gate Hatchery, Bogus Creek, and the mainstem Klamath River) which tend to enter the estuary and river earlier than Trinity stock.
  - In four of the five years (80%) large numbers of fish have been harvested in the estuary area by this date and harvest in the Middle Klamath Area starts to increase in the following weeks, suggesting that the upstream migration of the run has commenced.
  - The second week (*t+i*), ending on August 21, used in estimating the fish metric trigger occurs immediately before August 22 in three of the years (2001, 2003, and 2009) and eight days before August 22 in 2002.

Ending of Fall Flow Augmentation

- Fall flow augmentation should be continued through September 21 and augmentation can end after this date if mean daily water temperature in the lower Klamath River at RKM 13 remained below 23°C (TRRP 2012). If mean daily water temperature remains above 23°C then flow augmentation should continue to meet a minimum of 2,800 cfs in the lower Klamath River through the end of September. After this date, mean water temperature in the lower Klamath River is generally decreasing (Figure 19) due to seasonal changes and most of the fall-run Chinook salmon have commenced their upstream migration based on harvest data from the Middle Klamath Area (Figure 12).

Future Efforts

- Define monitoring needs to better inform future fall flow releases.
- Further evaluate data discussed in this document, and include lower Klamath River creel census data from CDFW as well as data from upstream locations such as the harvest in the Hoopa Tribal fishery, Willow Creek and Shasta River weirs, and Iron Gate and Trinity River hatcheries.
- Incorporate the Trinity River into the RBM10 water temperature model that has been developed for the Klamath River to better predict shifts in water

temperatures in the lower Klamath River that would result from flow releases from the Iron Gate or Lewiston dams.

- Develop the upstream migration model that allows water temperatures and flow releases from both the Trinity and the Klamath to be adjusted and tracks the associated response of upstream migrant adults, such as that being proposed by the Service by the Stream Salmonid Simulator of S^3 Model. This model needs to include fish disease component that focuses on Ich and columnaris.
- Allow ample time to conduct these analyses to inform future years in advance of an "emergency" situation.
- Fund a more complete analysis or model that can be used to make fall flow management decisions.

Citations

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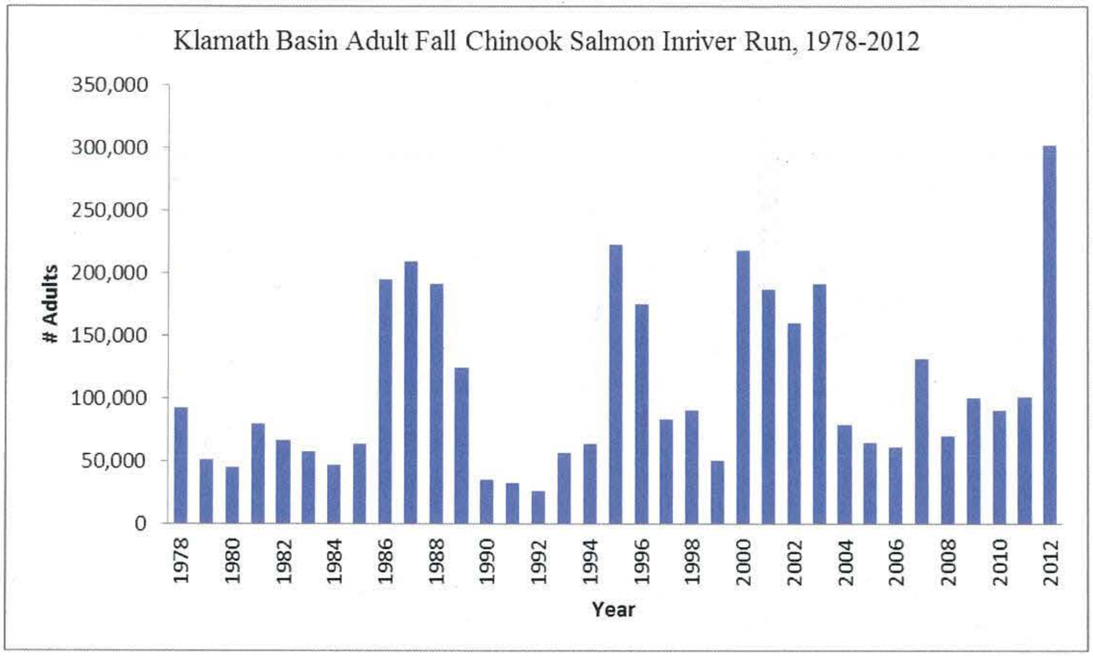


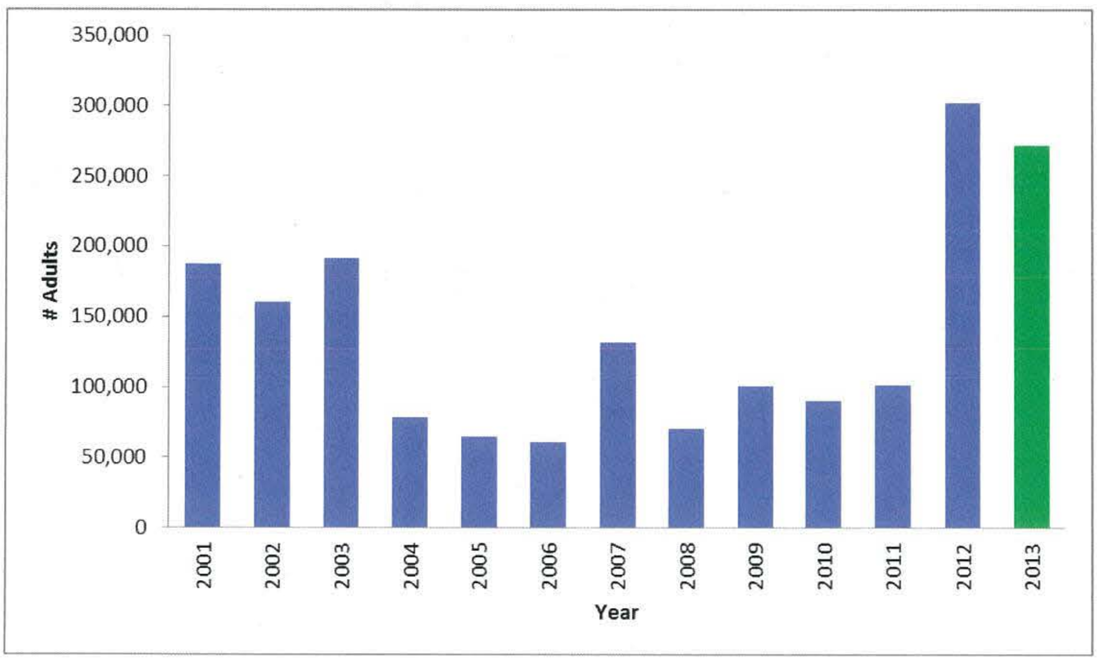


Figure 1. Klamath River adult fall-run Chinook salmon inriver run 1978-2012 (upper) and inriver run for the period 2001-2012 and 2013 projected (green bar) inriver run (lower).

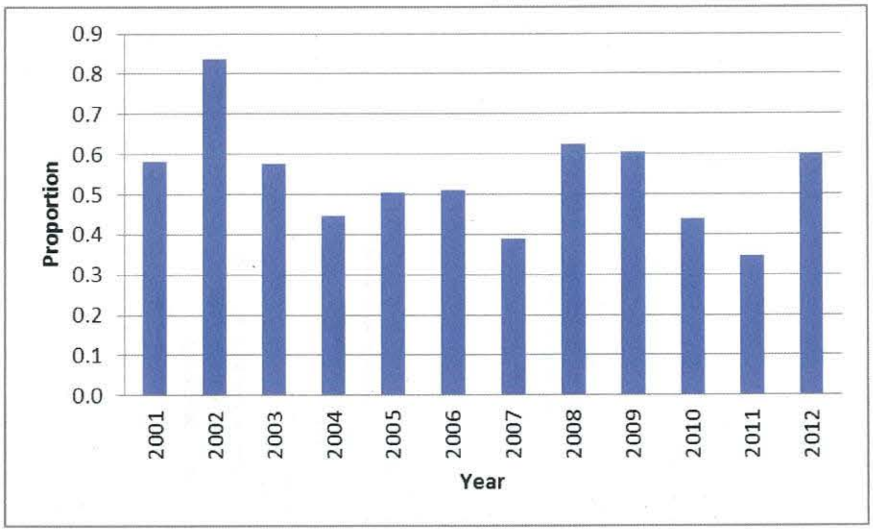


Figure 2. Proportion of Klamath Basin adult fall-run Chinook salmon spawners in the Klamath River, 2001-2012. Klamath River spawners include returns to Iron Gate Hatchery, the mainstem Klamath River and Klamath River tributaries above the confluence of the Klamath and Trinity rivers.

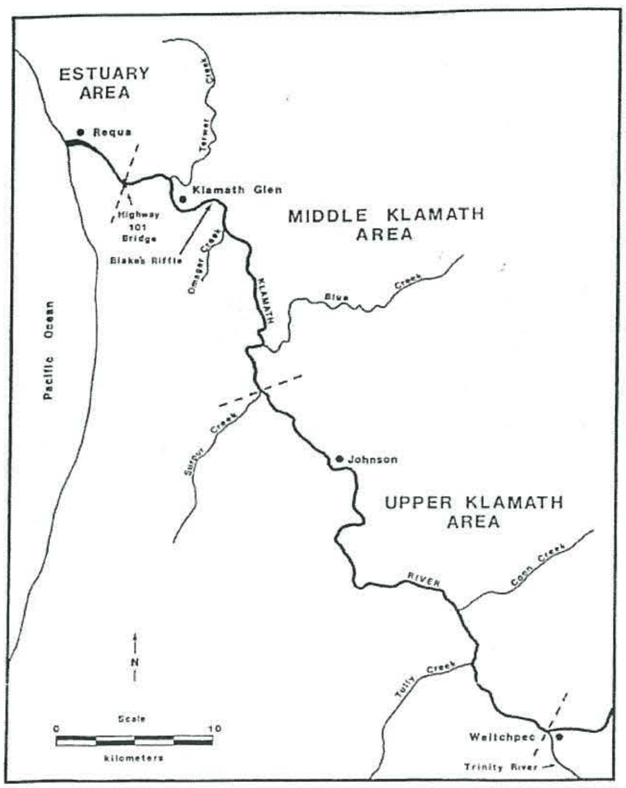
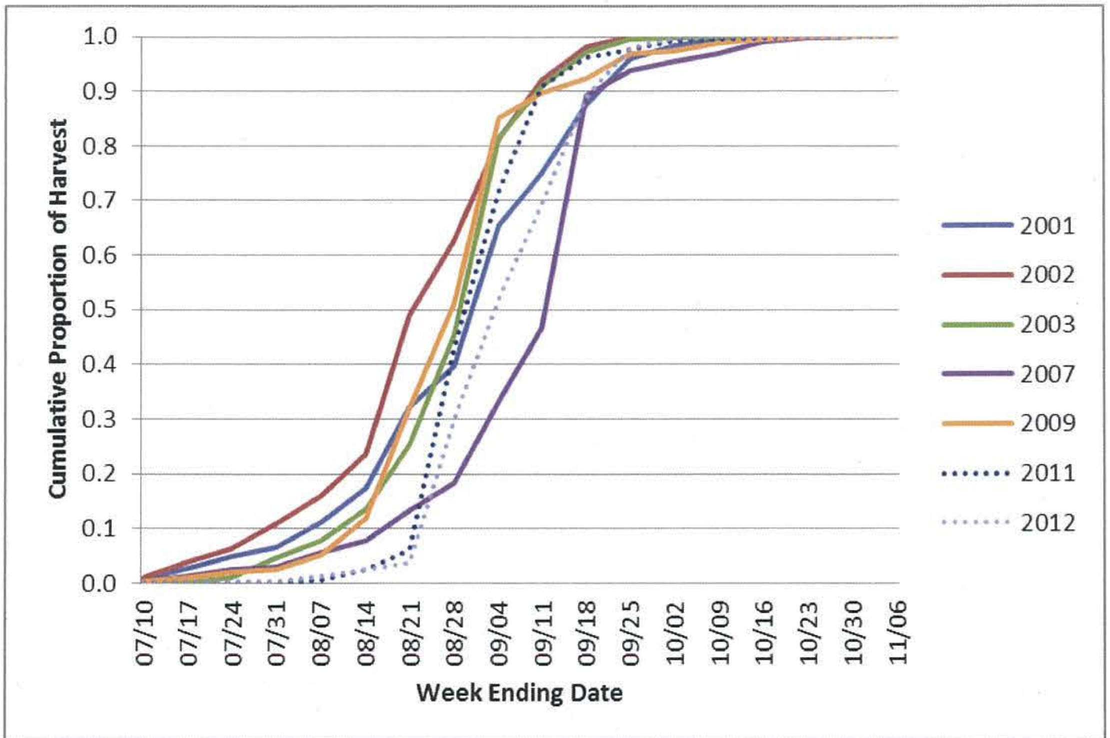


Figure 3. Map of the Yurok Reservation on the lower Klamath River showing harvest monitoring areas.



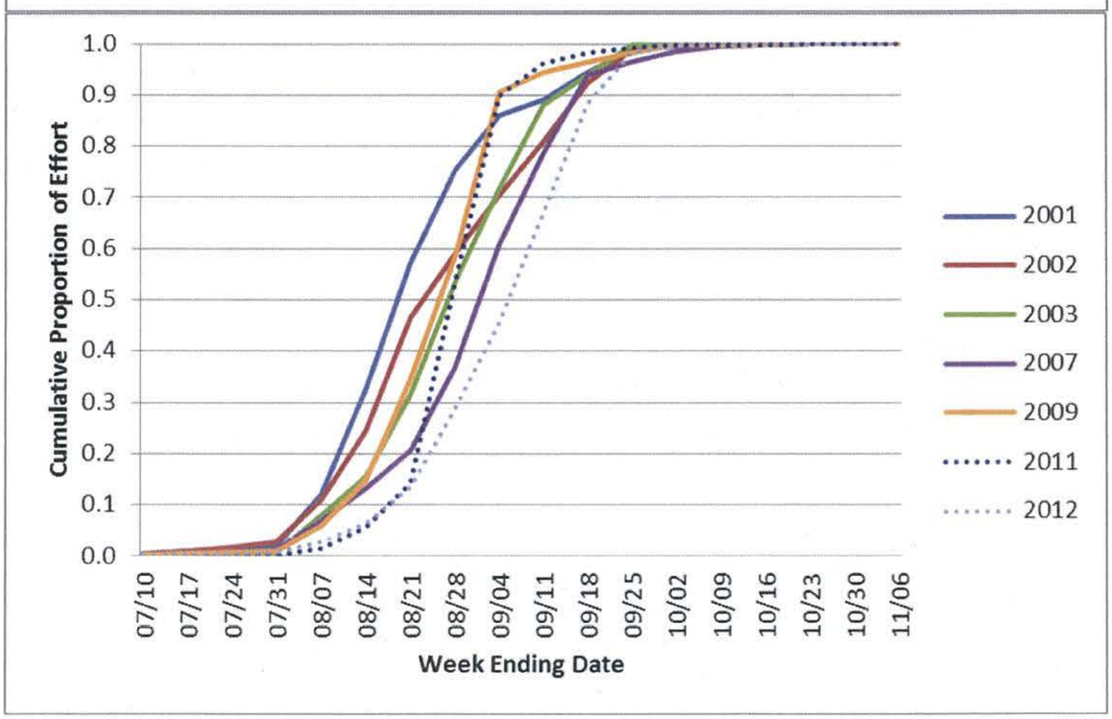


Figure 4. Cumulative fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Estuary Area fishery, 2001-2012. Lines for 2011 and 2012 are dotted to show the influence of the starting date of the commercial fishery on harvest and effort.

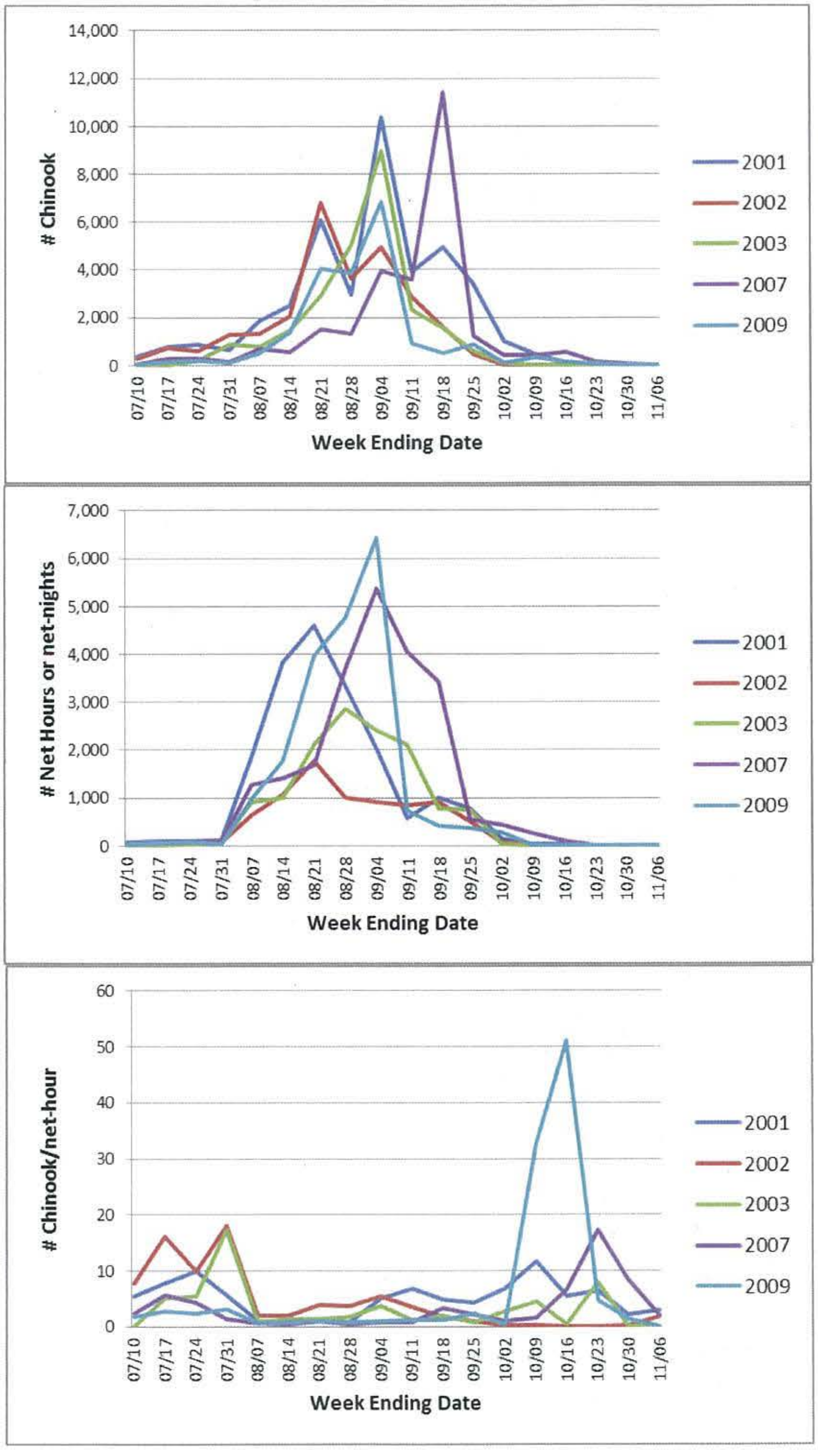


Figure 5. Weekly fall-run Chinook salmon harvest (upper), fishing effort (middle), and catch-effort (lower) for the Yurok Estuary Area fishery, 2001-2003, 2007, and 2009.

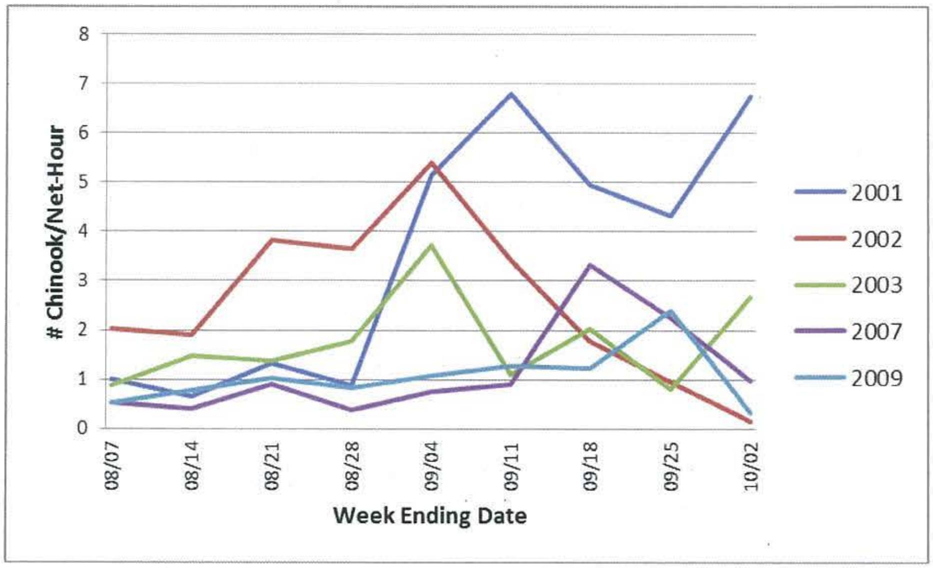


Figure 6. Weekly fall-run Chinook catch-effort for the Yurok Estuary Area fishery for August and September, 2001-2003, 2007, and 2009

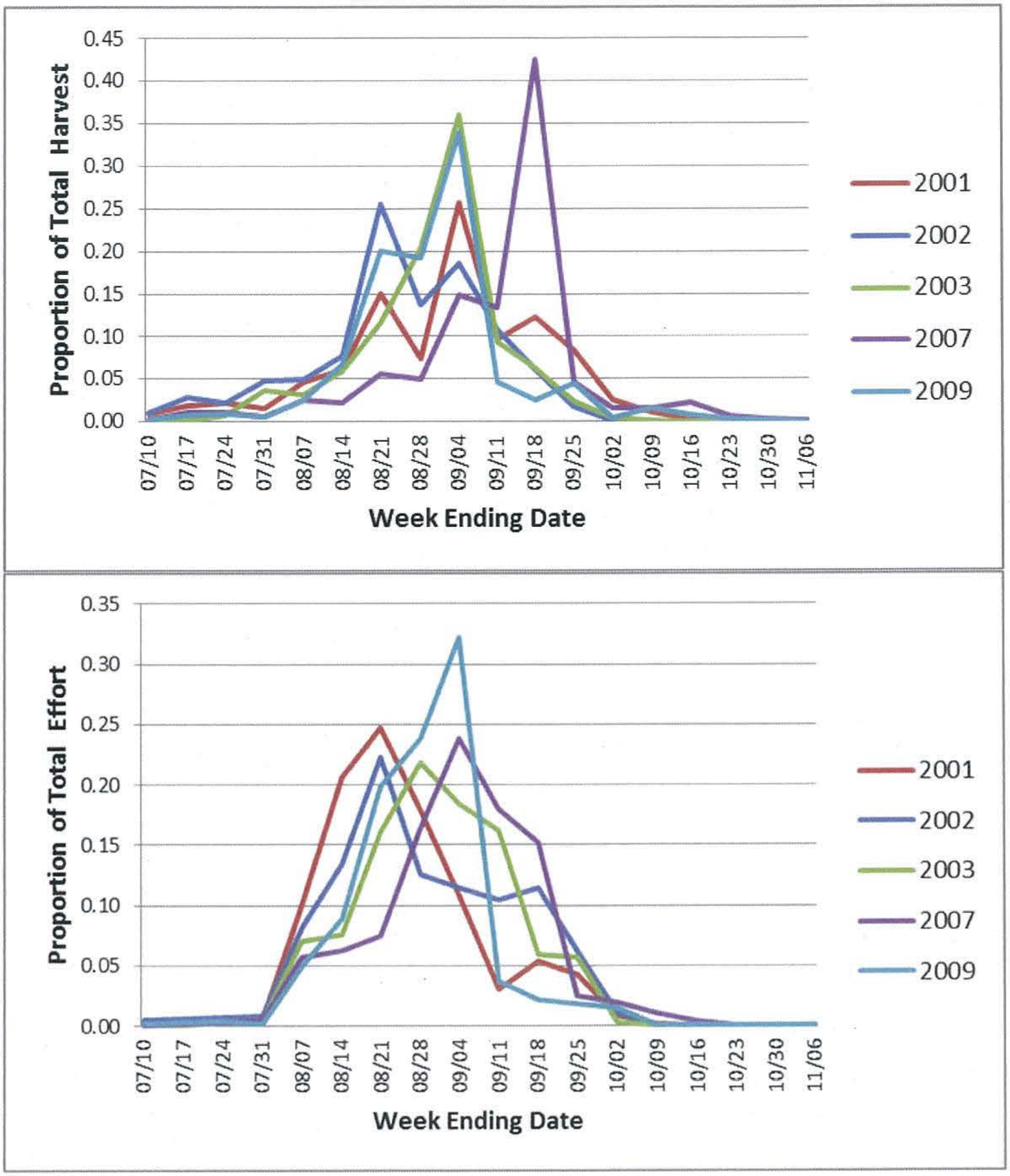


Figure 7. Proportion of annual fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Estuary Area fishery, 2001-2003, 2007, and 2009.

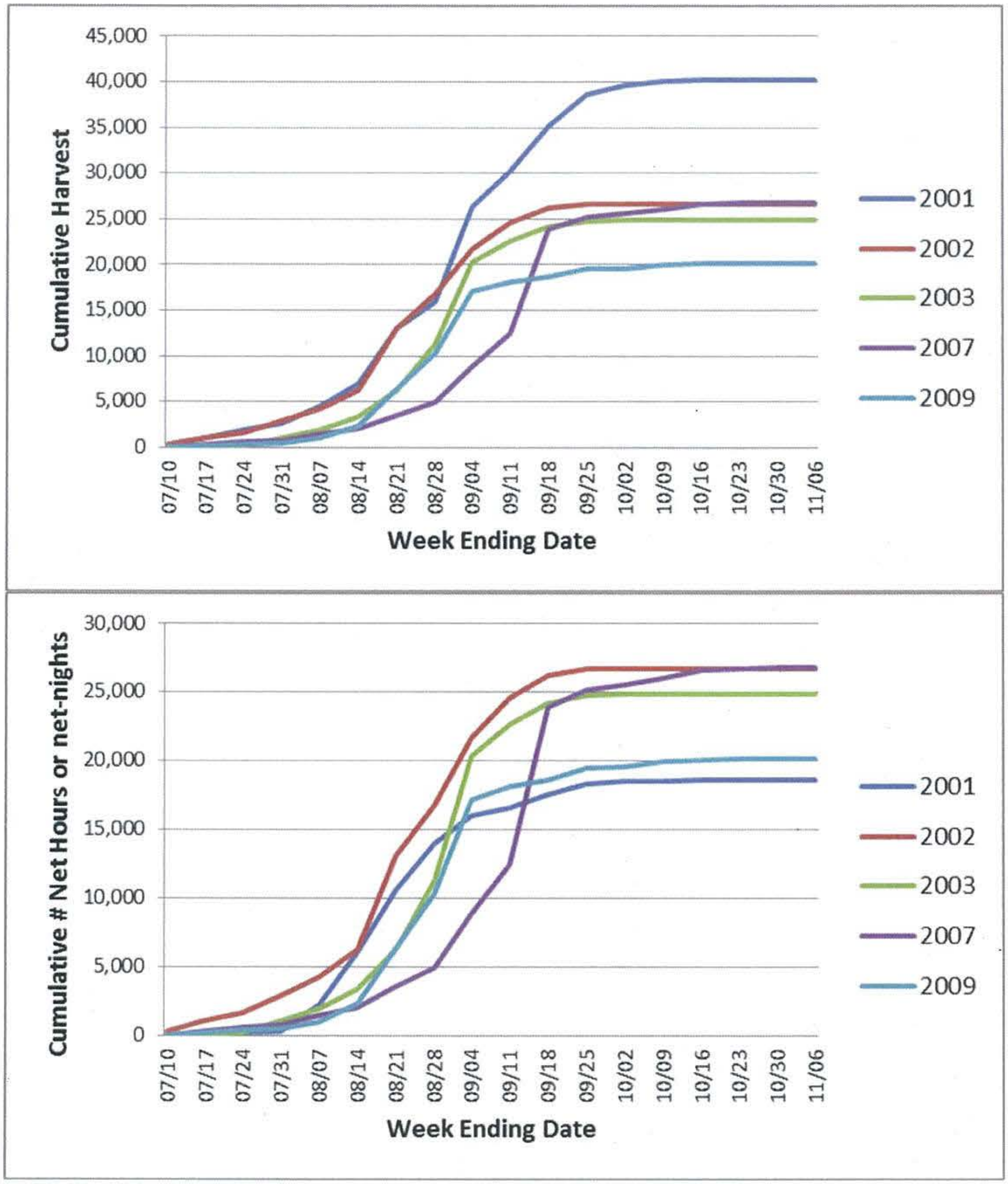


Figure 8. Cumulative weekly fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Estuary Area fishery, 2001-2003, 2007, and 2009.

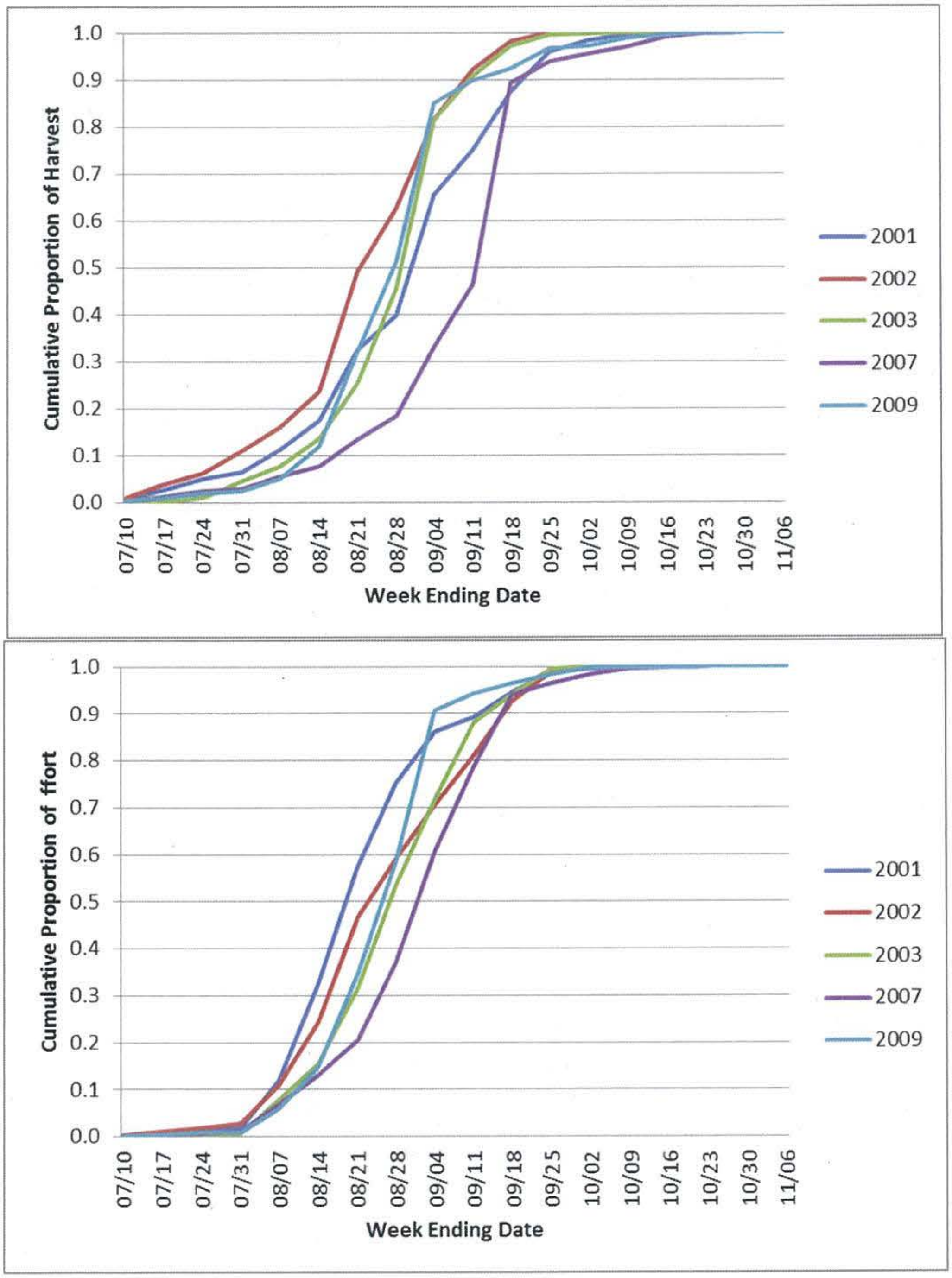


Figure 9. Cumulative proportion of annual fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Estuary Area fishery, 2001-2003, 2007, and 2009.

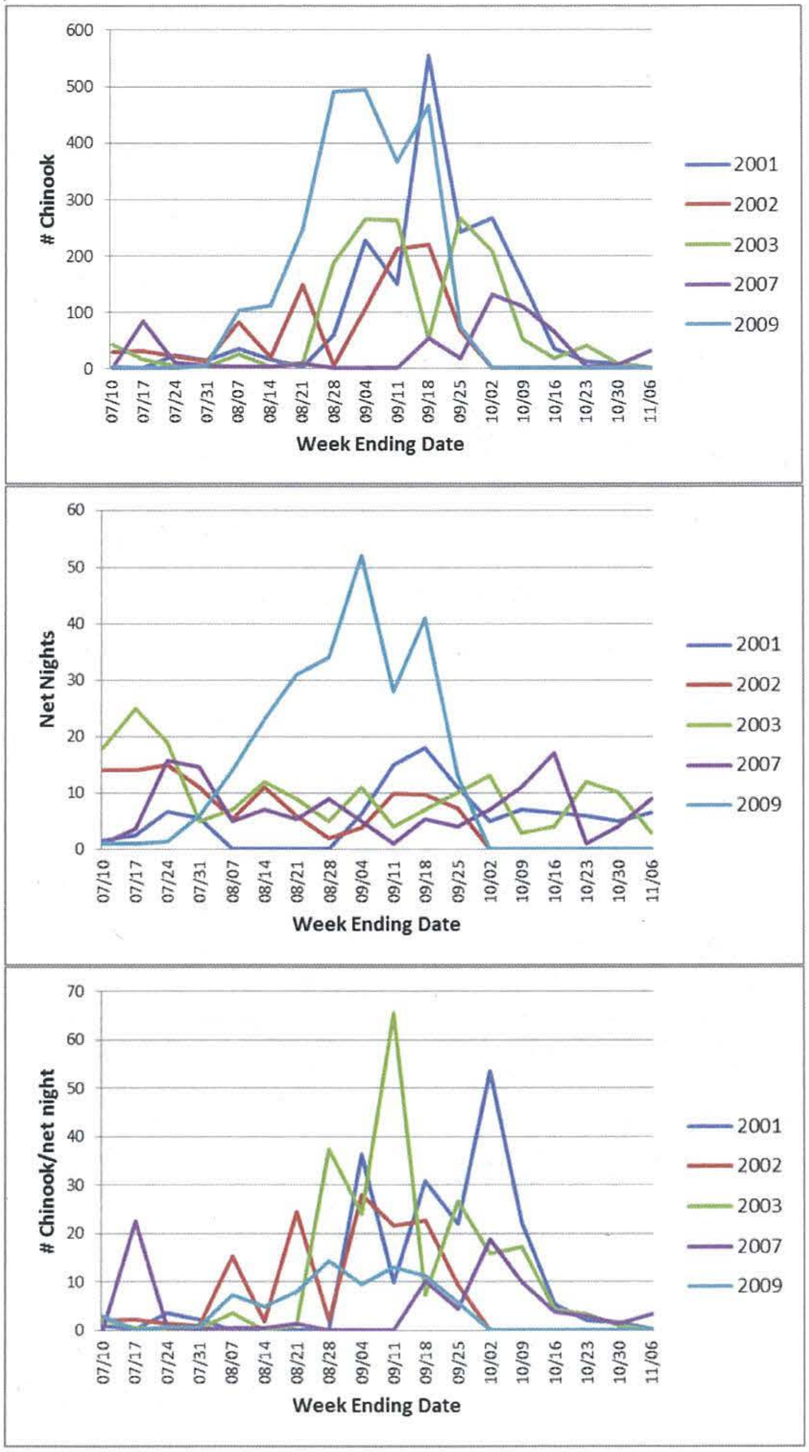


Figure 10. Weekly fall-run Chinook salmon harvest (upper), fishing effort (middle), and catch-effort (lower) for the Yurok Middle Klamath Area fishery, 2001-2003, 2007, and 2009.

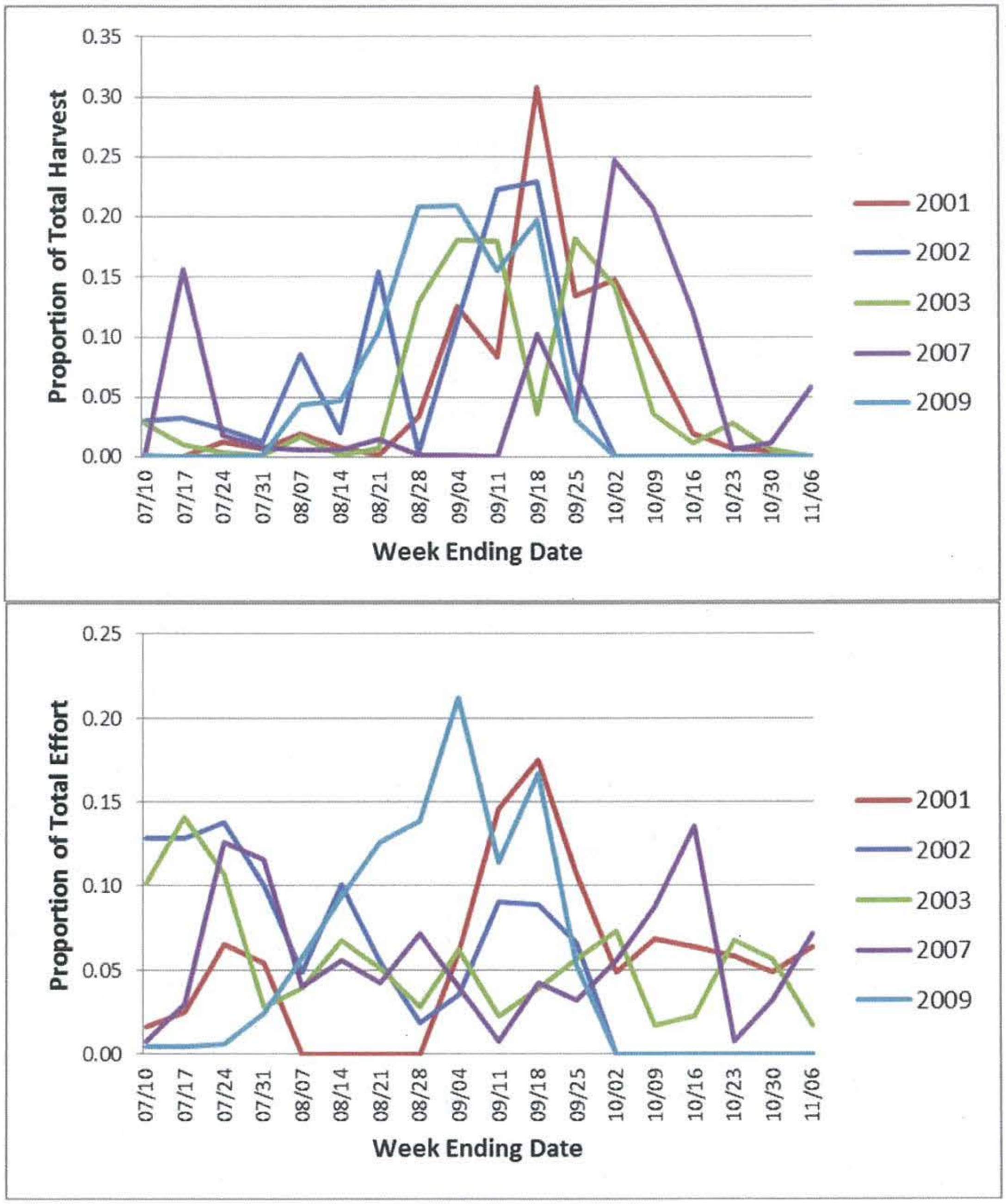


Figure 11. Proportion of annual fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Middle Klamath Area fishery, 2001-2003, 2007, and 2009.

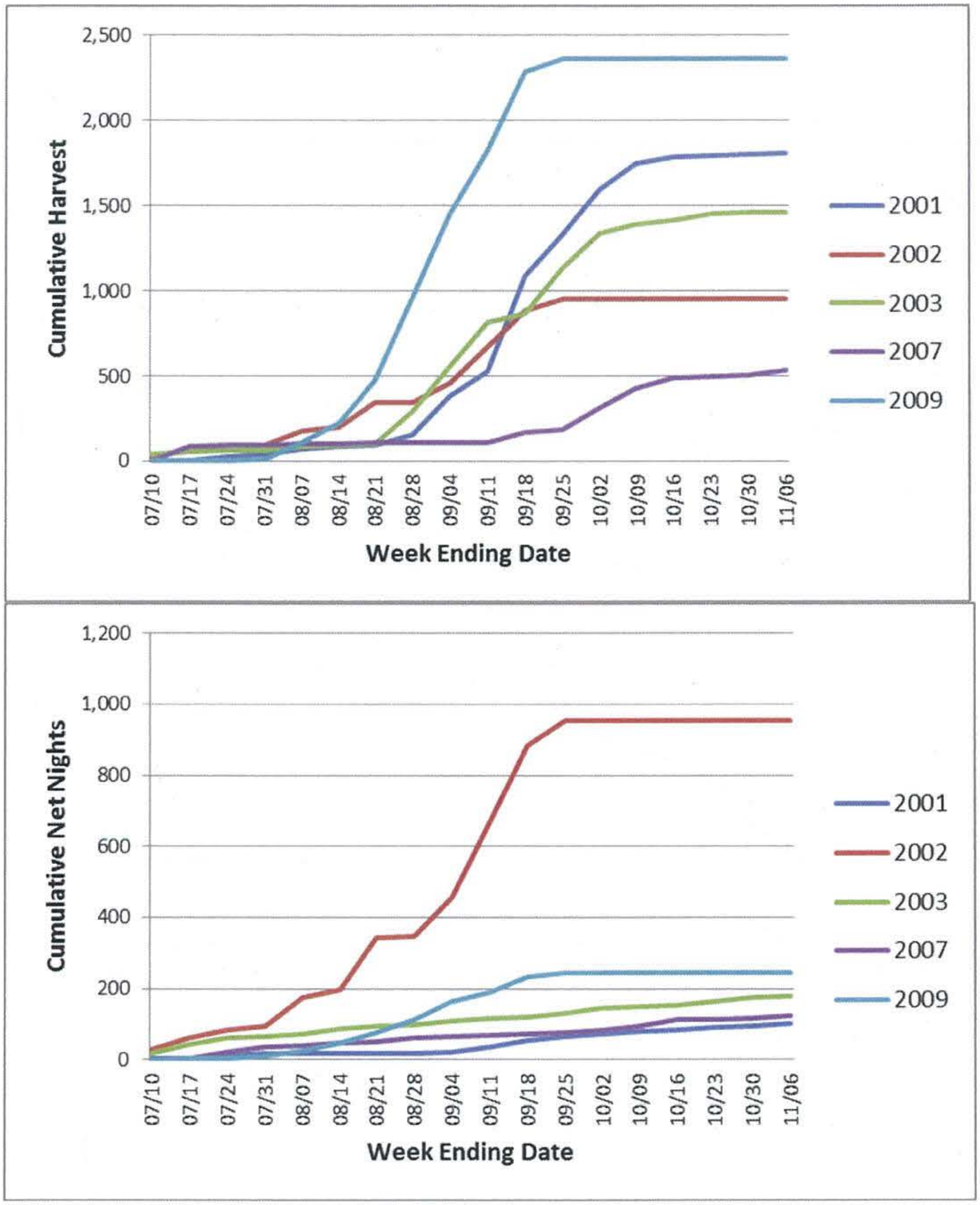


Figure 12. Cumulative weekly fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Middle Klamath Area fishery, 2001-2003, 2007, and 2009.

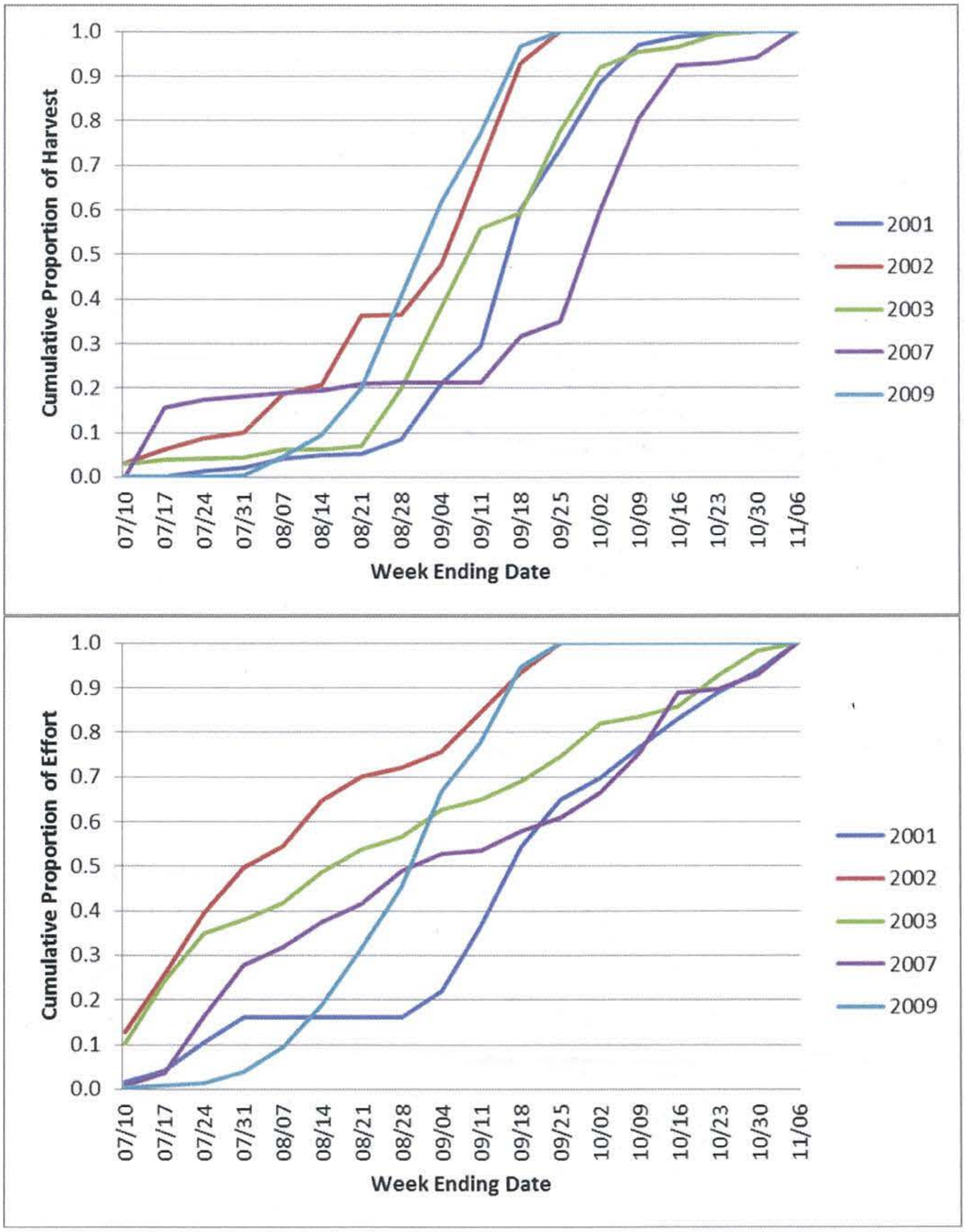


Figure 13. Proportion of annual fall-run Chinook salmon harvest (upper) and fishing effort (lower) for the Yurok Middle Klamath Area fishery, 2001-2003, 2007, and 2009.

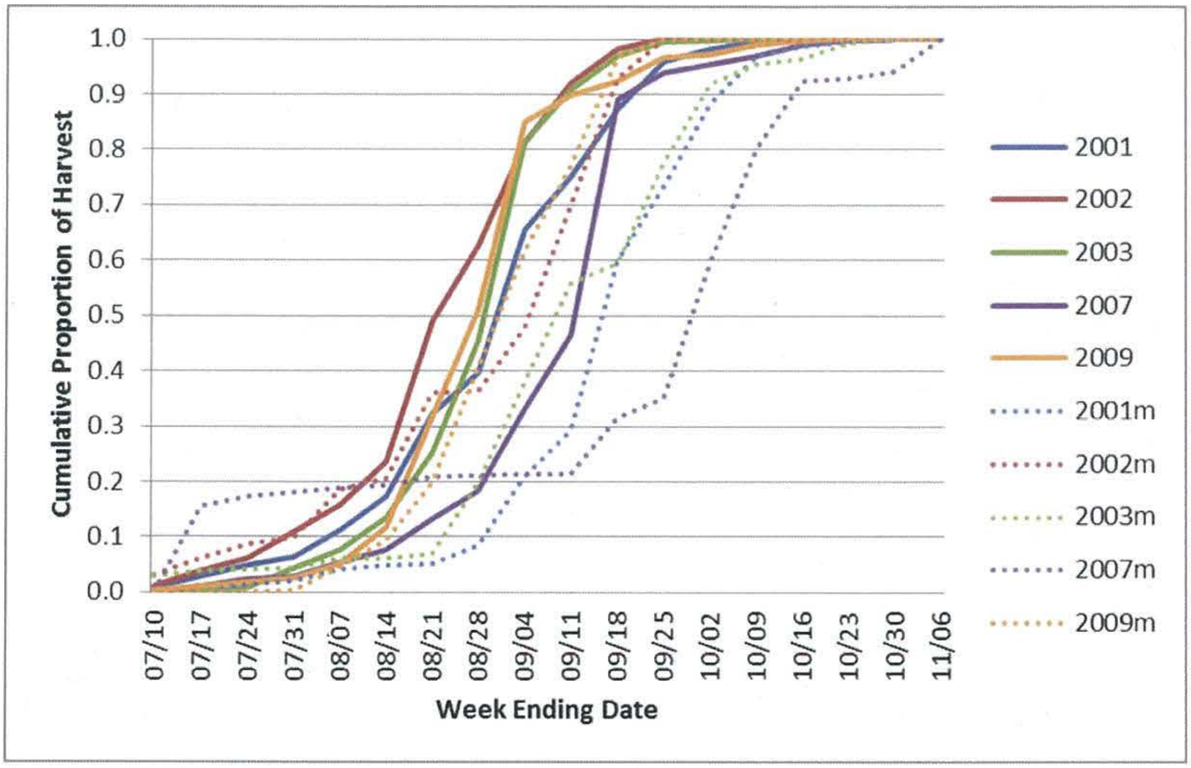


Figure 14. Cumulative weekly fall-run Chinook salmon harvest in the Estuary Area (solid lines) and Middle Klamath Area (dotted lines) of the Yurok fishery, 2001-2003, 2007, and 2009.

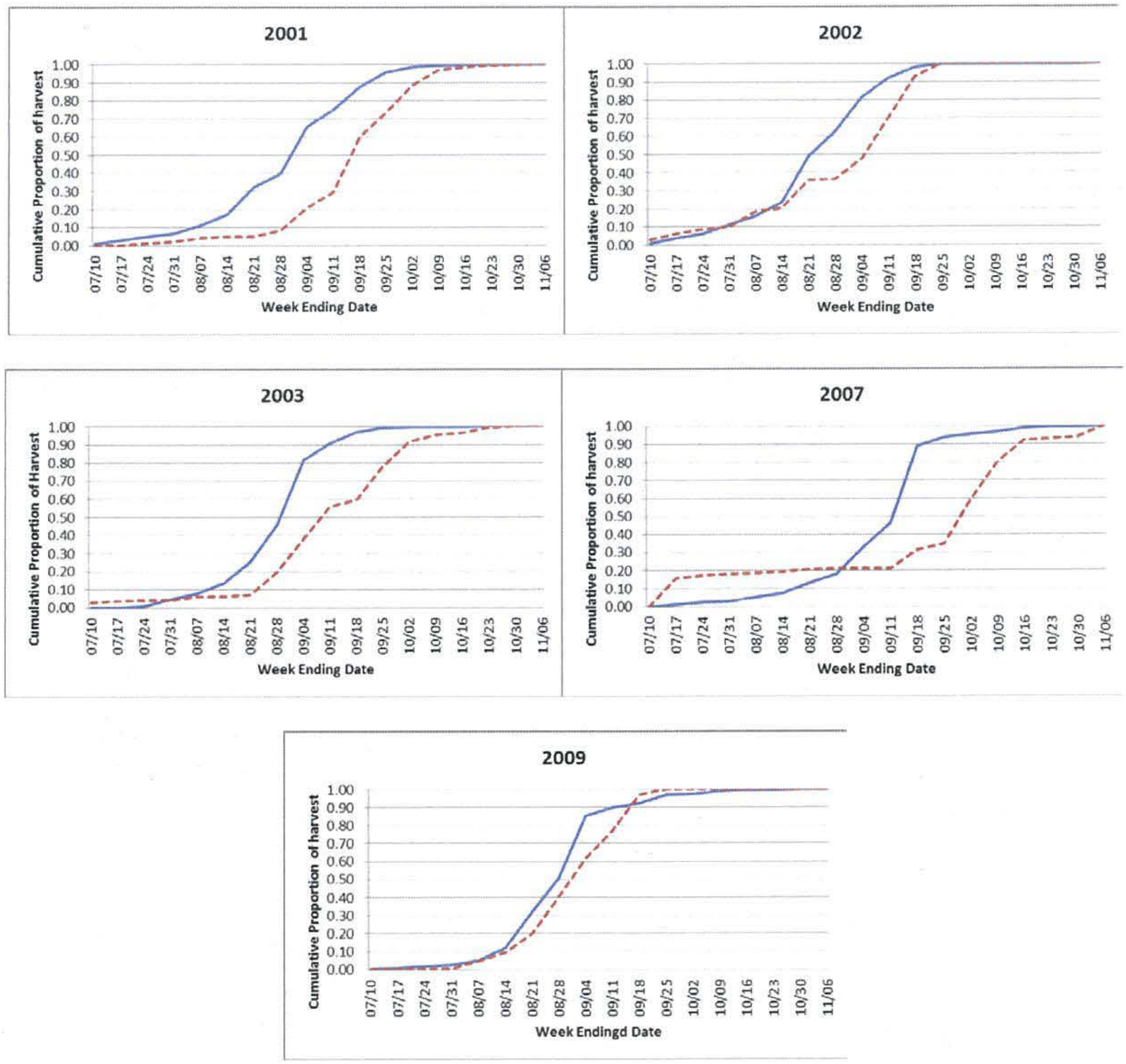


Figure 15. Cumulative weekly fall-run Chinook salmon harvest in the Estuary Area and Middle Klamath Area of the Yurok fishery, for years 2001-2003, 2007, and 2009.

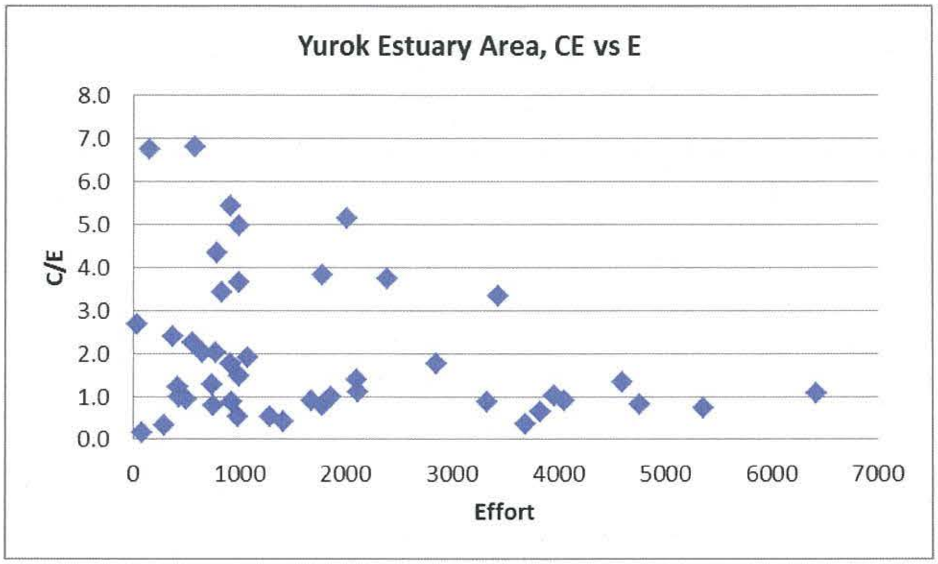


Figure 16. Weekly effort and catch-effort (CE) of fall-run Chinook salmon in the Estuary Area of the Yurok fishery and effort vs. CE for 2001-2003, 2007 and 2009. Data were limited to weeks of August 1 through September 26 when effort (net hours) and catch effort (# fish/net hour) were comparable across years.

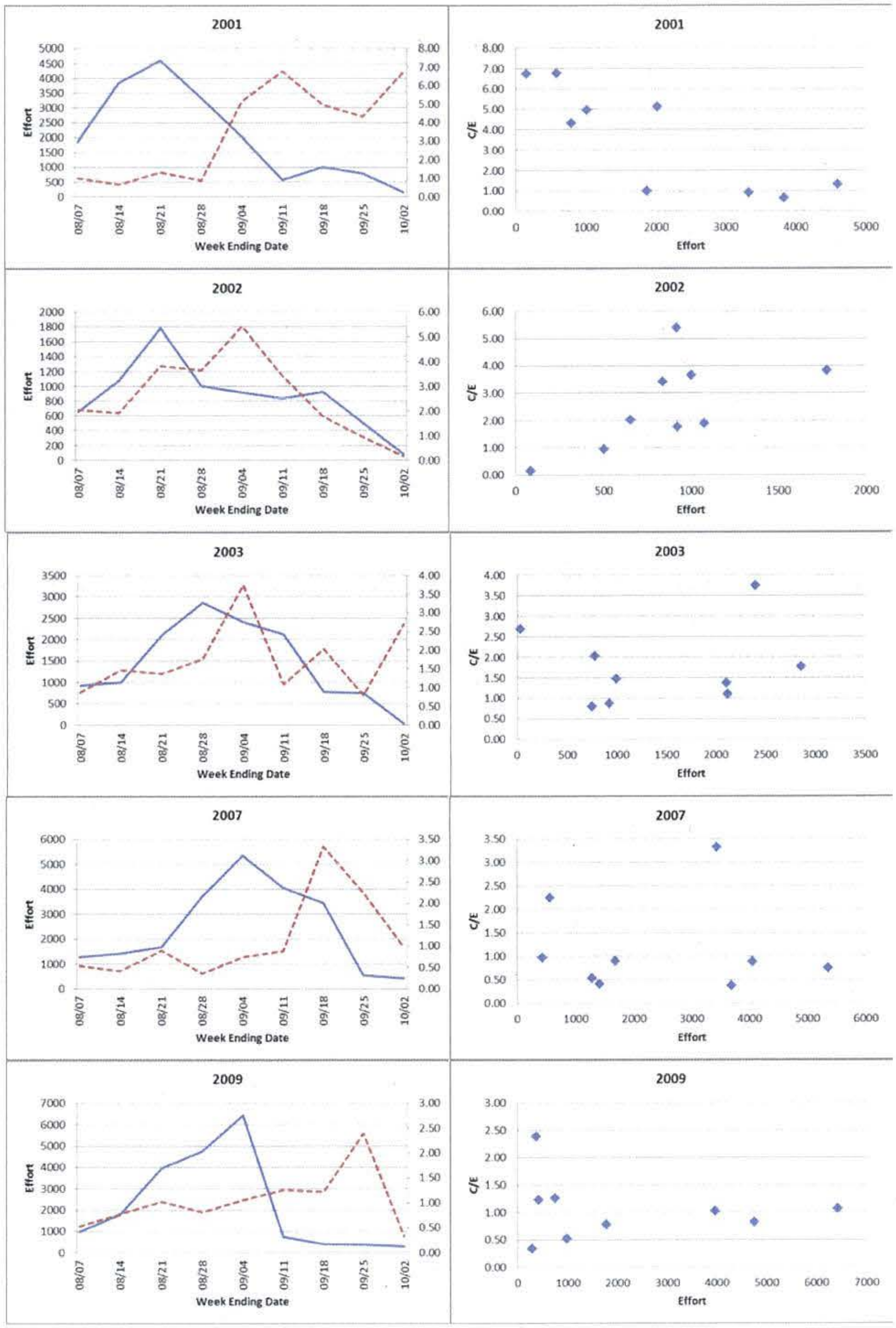


Figure 17. Weekly effort and catch-effort (CE) of fall-run Chinook salmon in the Estuary Area of the Yurok fishery and effort vs. CE for by year, 2001-2003, 2007 and 2009. Data were limited to weeks of August 1 through September 26 when effort (net hours) and catch effort (# fish/net hour) were comparable across years.

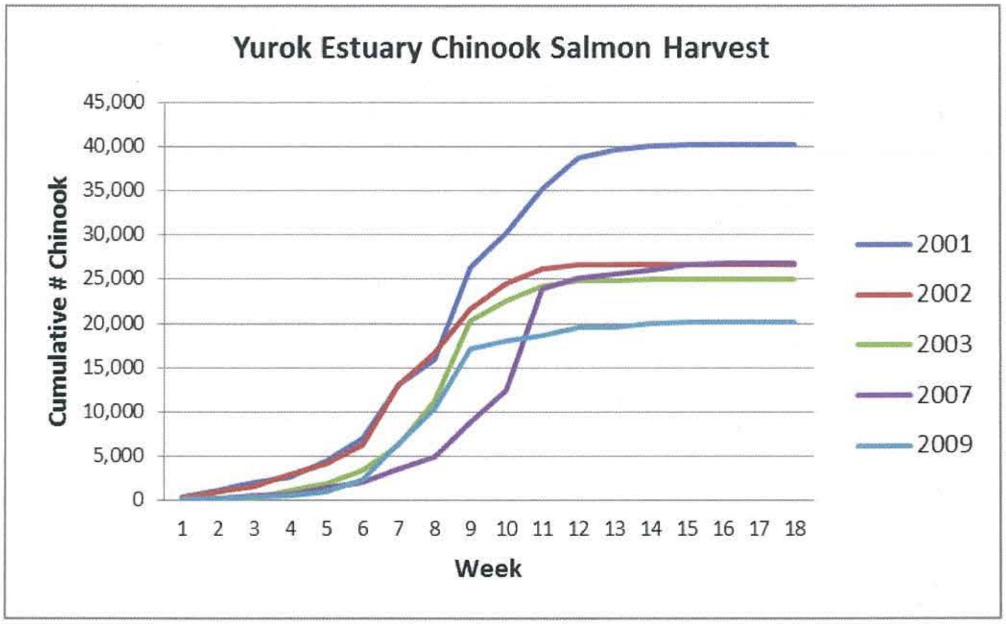


Figure 18. Cumulative harvest of fall-run Chinook salmon in the Estuary Area of the Yurok fishery, 2001-2003, 2007 and 2009.

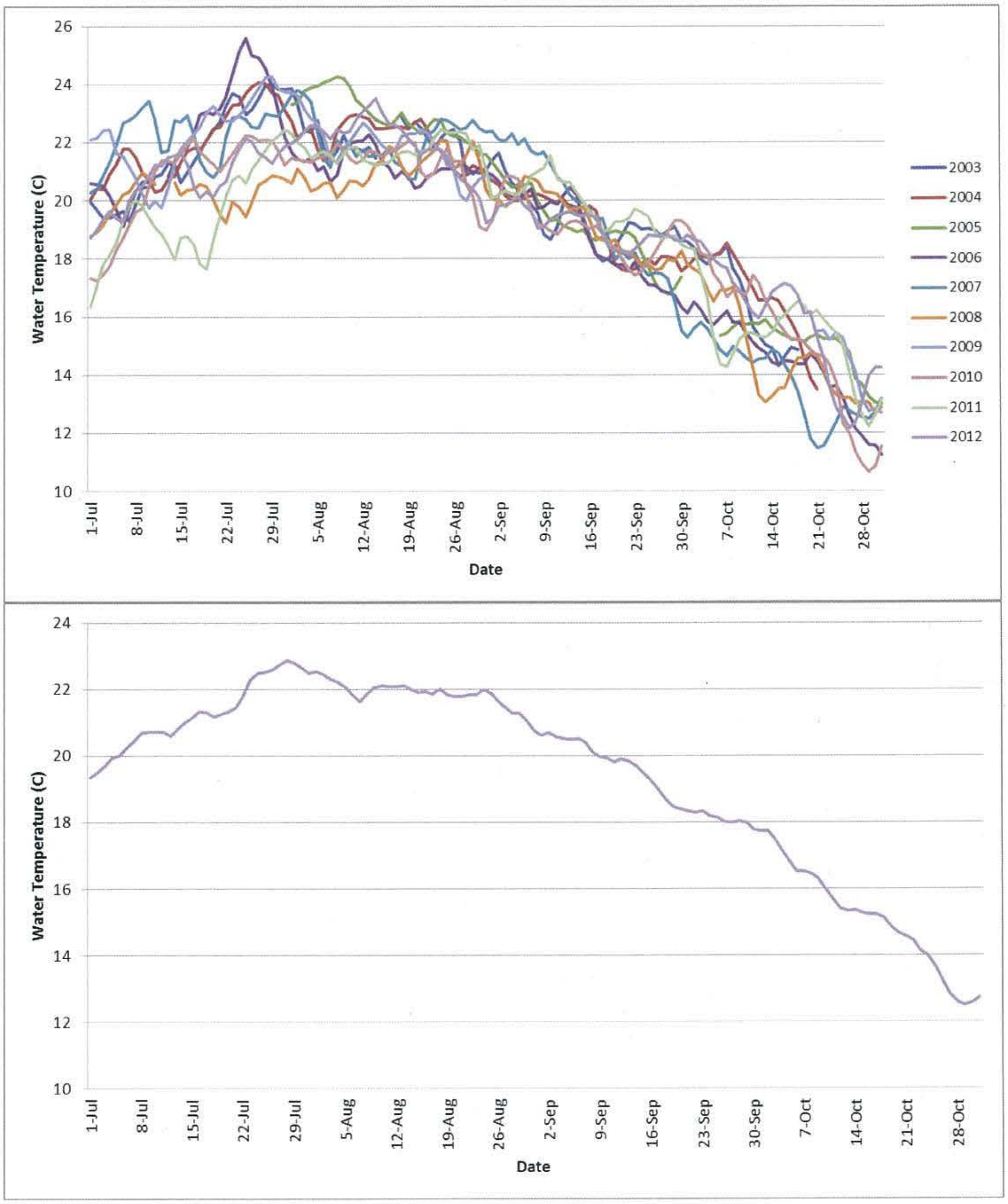


Figure 19. Mean daily later temperature in the lower Klamath River (rkm 13) for 2003-2012 (upper) and mean for all years (lower).

Table 1. Correlation coefficients (r) and significance values (p) for correlation analysis between effort and catch-effort in the Estuary Area fishery by year.

Year	r	N	p
All	-0.28	45	0.062
2001	-0.84	9	0.005
2002	0.64	9	0.065
2003	0.14	9	0.727
2007	-0.04	9	0.927
2009	-0.14	9	0.715

Table 2. Break-point estimates with lower and upper 95% confidence interval bounds.

Year	Break Point	Lower	Upper
2001	5.6	5.1	6.2
2002	5.3	4.9	5.8
2003	5.5	4.6	6.4
2007	8.5	8	9
2009	6.2	5.9	6.6

Table 3. Cumulative harvest of Chinook salmon in the Estuary Area by week, 2001-2003, 2007 and 2009. Highlighted cells were values used to calculate the fish metric. (Mean = 7,047)

Week #	First Day of the Week	Last Day of the Week	Year 2001	2002	2003	2007	2009
1	07/04	07/10	358	294	0	58	66
2	07/11	07/17	1,124	1,057	35	334	204
3	07/18	07/24	2,007	1,663	233	638	382
4	07/25	07/31	2,643	2,927	1,129	785	508
5	08/01	08/07	4,500	4,246	1,930	1,472	1,025
6	08/08	08/14	6,985	6,299	3,389	2,053	2,398
7	08/15	08/21	13,045	13,095	6,282	3,570	6,439
8	08/22	08/28	15,995	16,752	11,339	4,917	10,319
9	08/29	09/04	26,361	21,718	20,315	8,890	17,171
10	09/05	09/11	30,270	24,578	22,630	12,495	18,111
11	09/12	09/18	35,230	26,201	24,204	23,927	18,629
12	09/19	09/25	38,626	26,672	24,796	25,178	19,529

Appendix D. Planned monitoring components for Klamath Basin Adult Fall Chinook Salmon Migration 2013.

1. Adult Chinook Salmon Pathology Monitoring (Yurok Tribe)
    - Mid-August through Mid-October 2013
    - Fish will be captured with gill nets from Techtah Creek rkm 38 to Blue Creek rkm 26
    - Goal of 30 adult fish sampled per week
    - External examination of skin and gills for indication of columnaris and ich infections along with digital imaging and video recordings of ich inside gill arches.
    - Conducted every year since 2003
    - USFWS Pathologist Scott Foott on call
    - Further training for field crews in 2012 with CANFHC

2. Harvest Monitoring/Adult Salmon Abundance
    - Yurok Tribal daily count of fish sold in commercial harvest
    - CDFG weekly summaries of creel surveys of sport catches
    - Summer snorkel surveys of thermal refugia at the mouth of Blue Creek (YTFP)
    - Weir summaries from CDFG

3. Water Temperature and Flow
    - USGS site 11530500 Klamath River near Klamath, CA: http://waterdata.usgs.gov/ca/nwis/uv/?site_no=11530500&PARAmeter_cd=00065,00060
    - Yurok Tribal Environmental Program real time monitoring: http://exchange.yuroktribe.nsn.us/lrgsclient/stations/stations.html
    - California Nevada River Forecast Center advanced hydrologic prediction for USGS site 11530500 Klamath River near Klamath, CA http://www.cnrfc.noaa.gov/espTrace.php?id=KLMC1

4. Coordination and Response
    - Klamath Fish Health Assessment Team (KFHAT) Web Portal: http://www.kbmp.net/collaboration/kfhat

Response to Request for Technical Assistance Regarding 2015 Fall Flow Releases

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United States Department of the Interior

FISH AND WILDLIFE SERVICE

1655 Heindon Road
Arcata, California, 95521
Phone: (707) 822-7201 FAX: (707) 822-8411

In Reply Refer To:
AFWO

Memorandum

TO: Federico Barajas, Reclamation Northern California Area Manager

FROM: Nicholas Hetrick and Joe Polos, Arcata Fish and Wildlife Office

SUBJECT: Response to Request for Technical Assistance Regarding 2015 Fall Flow Releases

CC: Robin Schrock, Executive Director Trinity River Restoration Program

DATE: August 10, 2015

In response to Reclamation's request for technical assistance dated August 6, 2015, we've summarized several factors that we consider important to help inform Reclamation's decision regarding the release of augmented flows from Lewiston Dam in fall 2015, intended to reduce the risk of an adult fish kill occurring in the Klamath River. Much of the information contained in this memo has been previously expressed to Reclamation during co-manager meetings and conference calls regarding 2015 fall flow releases. We have also provided additional information and analyses as needed for clarity and scientific support to aid Reclamation's deliberations in determining appropriate fall flow actions.

In 2013, Reclamation requested that the US Fish and Wildlife Service and the National Marine Fisheries Service provide technical assistance in assessing the current and predicted hydrologic conditions for the time period overlapping the 2013 adult fall-run Chinook Salmon migration in the lower Klamath River, and in developing preventative and emergency measures that would reduce the risk of an adult fish kill. Inherent in this request was the need to be conservative of limited water resources given the dry hydrologic conditions and limited volume of the cold-water pool. As requested, we collaborated with NOAA Fisheries to write a joint memorandum to Reclamation outlining concepts for managing flows with accompanying scientific support pertaining to conditions present in fall 2013 (USFWS and NOAA 2013). This memorandum, referred to hereafter as the 2013 Joint Memo, contained technical analyses regarding flows and adult fall-run Chinook Salmon in the Klamath-Trinity Basin, and included management triggers based on real-time conditions such as run timing, water temperature, and severity of potential Ich infections. The 2013 Joint Memo did not contain analyses regarding the potential effects of fall flow releases on species listed under the Endangered Species Act (ESA) or compliance with the ESA or any biological opinions issued under the ESA.

In meetings and calls held by Reclamation in 2015, the Service has consistently expressed that information contained in the 2013 Joint Memo is largely relevant to this season, with the following clarifications and modifications:

- De-emphasis of the significance of run size,
- Clarification of the "Ich trigger" used to define severity of infections, and
- Alteration of the emergency trigger of "doubling the flow".

Flow Target for the Lower Klamath River

Following the epizootic of Ich and columnaris that resulted in the 2002 fish kill in the lower Klamath River (Guillen 2003a, Guillen 2003b), Reclamation has augmented late-summer/early-fall flow releases from Lewiston Dam to improve conditions in the lower Klamath River to reduce the risk of a major fish kill. Fall flow augmentations were implemented in 2003, 2004, 2012, 2013 and 2014, with release volumes ranging from 17,500 acre feet in 2013 to 64,000 acre feet in 2014 (Table 1). While a major fish kill did not occur during any of these years, or in years since 2002 when flow augmentation was not implemented, a large-scale outbreak of Ich in fall-run Chinook Salmon did occur in 2014 (Belchik 2015). Initial augmentation in 2014 targeted a flow of 2,500 cfs in the lower Klamath River and did not prevent a severe Ich epizootic from occurring, with the magnitude and severity of the outbreak necessitating an emergency release of nearly double the flow in the lower Klamath River for five consecutive days.

While definitive data on the causal relationships between flows in the lower Klamath River and Ich epizootics do not exist, we compared information from 2002, the year of the Klamath fish kill, to five years where flow augmentation actions were implemented. Flow augmentation targets for the lower Klamath River implemented by Reclamation were 3,200 cfs in 2012, 2,800 cfs in 2013, and 2,500 cfs in 2014, with an Ich outbreak only occurring during 2014. Additionally, we examined information from years where flow augmentation actions were not taken. Mean-monthly flow in the lower Klamath River for August was near or below 2,500 cfs during the two years when a severe Ich infestation occurred (2002 and 2014, Table 1). While mean flow for the month of August 2013 was below 2,800 cfs, flow augmentation actions were taken to achieve a flow target of 2,800 cfs in the lower Klamath River, resulting in the mean flow for the period August 15-31 of 2,795 cfs. For all other years that fall flow augmentation was implemented, mean-monthly flows for August in the lower Klamath ranged from 3,003 cfs (2004) to 3,463 cfs (2003).

Mean-monthly flow for August the lower Klamath River for the period of 2002 through 2014 has exceeded the 2,800 cfs level in all years except 2002, 2013 and 2014 (Figure 1). Focusing on the latter half of August, the only years when the 2,800 cfs flow level was not exceeded was in 2002 and 2014 (Figure 2).

Table 1. Volume of augmented flow (thousand acre-feet, TAF), occurrence of Ich infection, mean August and August 15-31 flow in the lower Klamath River (KNK), and in-river adult fall Chinook Salmon in-river run during the augmented flow years (bold) and the fish-kill year (2002).

Year	Augmented Flow (TAF) From Lewiston[1]	Severe Ich Infections (Y/N)	Mean August KNK Flow (cfs)	Mean August 15-31 KNK Flow (cfs)	Inriver Adult Fall Chinook Run[1]
2002	0	Y	2,327	2,161	160,788
2003	38	N	3,463	3,308	191,948
2004	36	N	3,003	3,237	78,943
2012	39	N	3,386	3,458	291,877
2013	17.5	N	2,673	2,795	165,025
2014	64	Y	2,269	2,419	160,444
2015					119,800[2]

[1] USBOR
[2] CDFW 2015
[3] In-river run projection (PFMC 2015)

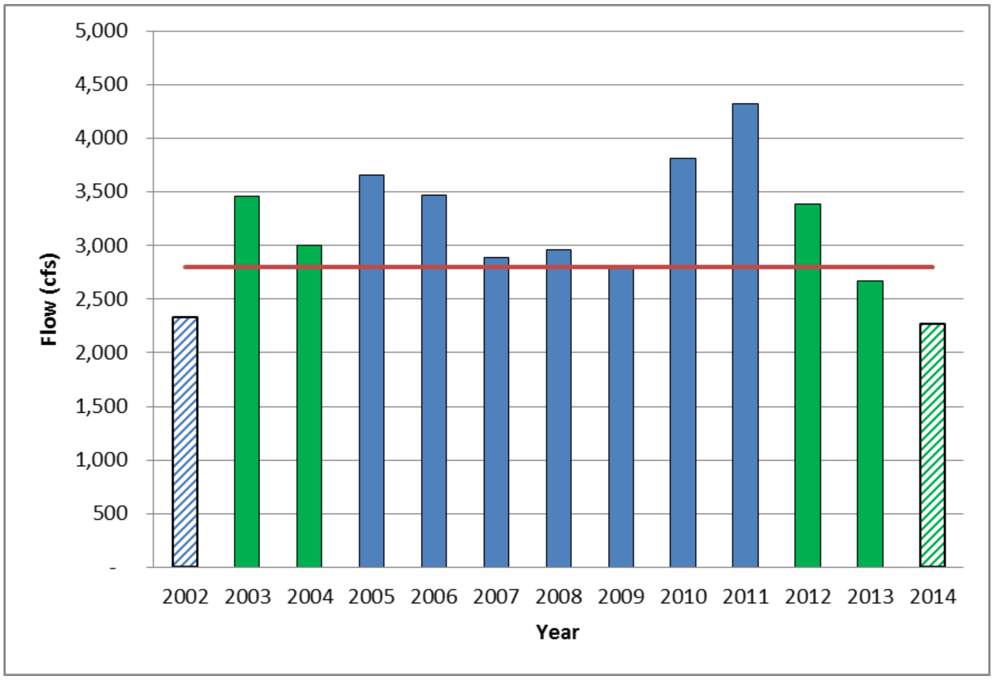

Figure 1. Mean August flow (cfs) in the Lower Klamath River (KNK), 2002-2014. Green bars are years when flow augmentation occurred and hatched bars are years when Ich outbreaks occurred. Horizontal red line represents 2,800 cfs flow.

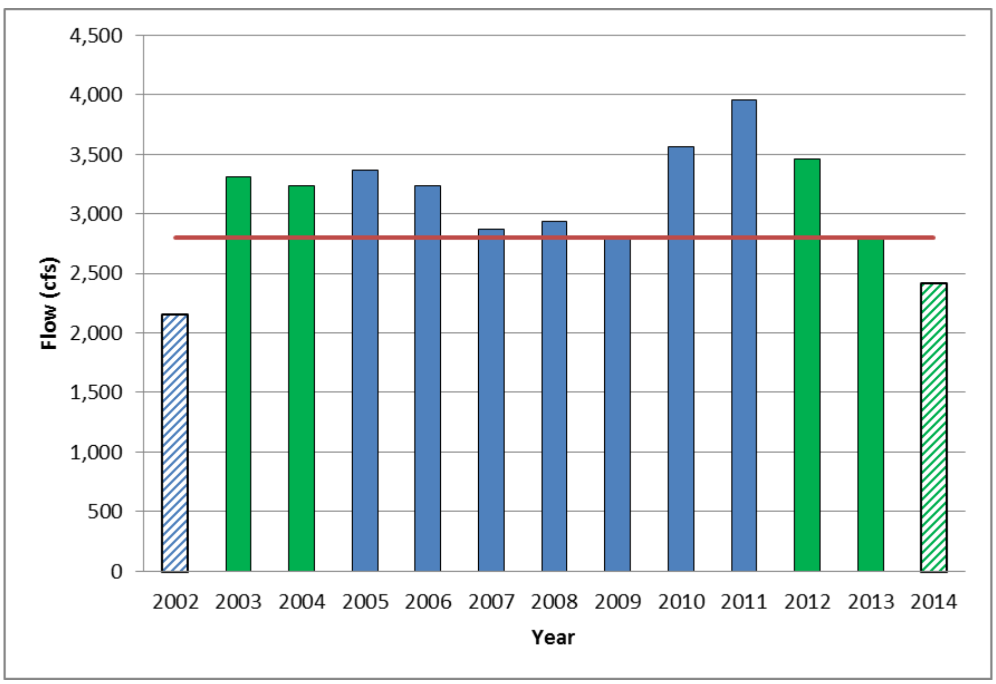

Figure 2. Mean August 15-31 flow (cfs) in the Lower Klamath River (KNK), 2002-2014. Green bars are years when flow augmentation occurred and hatched bars are years when Ich outbreaks occurred. Horizontal red line represents 2,800 cfs flow.

Run Size

Run size has been factor in technical discussions and several whitepapers addressing fall flow augmentation (Turek et al. 2004; Strange 2010a; TRRP 2012a; TRRP 2012b; USFWS and NOAA 2013). However, the Service considers the pattern of upstream migration to be a more important factor in determining disease risk than run size alone. The metric of concern is not run size, but rather the residence time of groups of fish within small confined habitats such as the thermal refugia that exists at Blue Creek in the lower Klamath River. An extended residence time in thermal refugia may occur given small or large runs under certain environmental conditions.

During the period since the 2002 fish kill, the in-river adult fall Chinook Salmon run has ranged from 61,373 in 2006 to 291,877 in 2012 (Figure 3). While run-size has been used as an indicator of the potential need for a flow augmentation action, it should not be used a binary (yes/no) trigger. A number of factors such as the timing of the run, flow, water temperatures, in-river fisheries, etc., can contribute to large congregations of adult salmonids holding for extended periods of time that could potentially trigger an Ich epizootic, and these factors are independent of run size. For example, in 2014 an estimate of about 10,000 adult Chinook Salmon and Steelhead were observed in the lower Klamath River in the thermal refugia near Blue Creek (Belchick 2015). A similar observation of extended residence time occurred in mid to late July in 2015, albeit to a lesser degree (1,000 adults estimated). It’s important to note that these large congregations of fish occurred before the primary onset of the fall-run Chinook Salmon migration in the lower Klamath River.

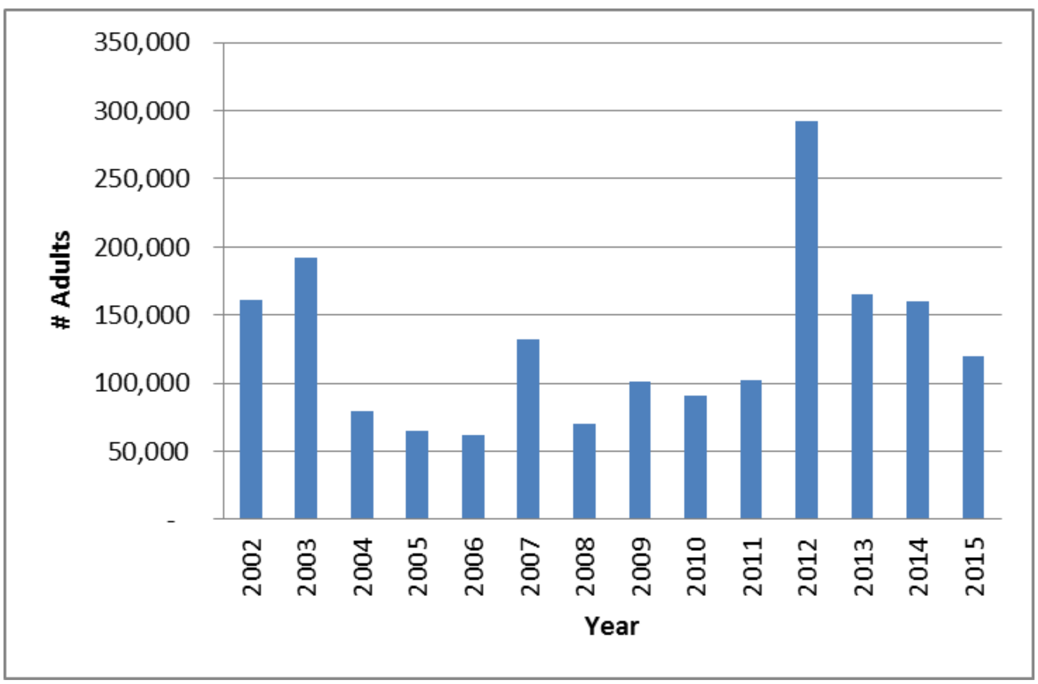

Figure 3. Klamath River adult fall Chinook Salmon in-river run, 2002-2014 and projected 2015 in-river run.

Water Temperature Modelling

To evaluate the potential effects of augmented Lewiston flows on water temperatures in the lower Klamath River, we applied the RBM10 temperature model using climate and accretion data from 1994, a year with meteorological and hydrological conditions similar to that experienced to date in 2015. The RBM10 temperature model has been calibrated, validated, and peer reviewed for the mainstem Klamath River using tributary inputs as boundary conditions. Results of this process suggest that temperature predictions matched historical data to within about 1^o C (Perry et al. 2011). A mainstem Trinity River version of RBM10 has recently undergone calibration and validation, but is not yet published as a peer-reviewed product. Lewiston Dam flow augmentation values were established to achieve discharge targets of 2500, 2800, and 3200 cfs on the mainstem Klamath River near Klamath, CA and were provided to our office by Reclamation. Reclamation also provided release-point water temperatures for the different flow release scenarios, which all incorporated the use of the bypass facilities except for the no action scenario. The Trinity River temperature predictions were then applied as boundary conditions to the Klamath River temperature model to obtain predicted Klamath River temperatures at the USGS gauge site near the town of Klamath, CA.

In evaluating the predicted temperature effects of the various management alternatives, temperatures near or exceeding 23^o C are of particular interest as this has been identified as a threshold for impairing the upstream migration of adult salmon (Strange 2010b), what we refer to as a “thermal migration barrier” in the 2013 Joint Memo. Under the no action scenario, water temperatures in the lower Klamath River were predicted to approach or exceed 23^o C during most of August and early September (Figure 4 top). Results from the model runs incorporating flow augmentation predicted that immediately after Lewiston flows are augmented, temperatures would drop below 23^o C regardless of augmentation level, with cooler temperatures in the lower Klamath River corresponding to the largest Lewiston Dam augmentation releases (Figure 4 top).

Over this same time period, the amount of predicted water temperature cooling is commensurate with flow augmentation level (Figure 4 bottom). During the naturally occurring warmest period of late August, the augmented flows are predicted to be between 1.5^o and 3.5^o C cooler. Given the stated validation precision of the model ($\pm 1^o$ C), results of the simulation suggest more certainty in preventing a thermal migration barrier by water temperature cooling effects associated with the 2,800 and 3,200 cfs scenarios compared to an augmentation level of 2,500 cfs.

The water temperature predictions also demonstrate the relative impacts on water temperatures in the lower Klamath River associated with Lewiston augmentation and use of the bypass. The larger temperature decreases are associated with the discharge augmentations, and water temperatures are predicted to approach those under the no action alternative almost immediately after the augmentation is stopped in the simulations on September 21st, with only modest water temperature cooling ($<1^0$ C) associated with use of the bypass thereafter (Figure 4 top and bottom).

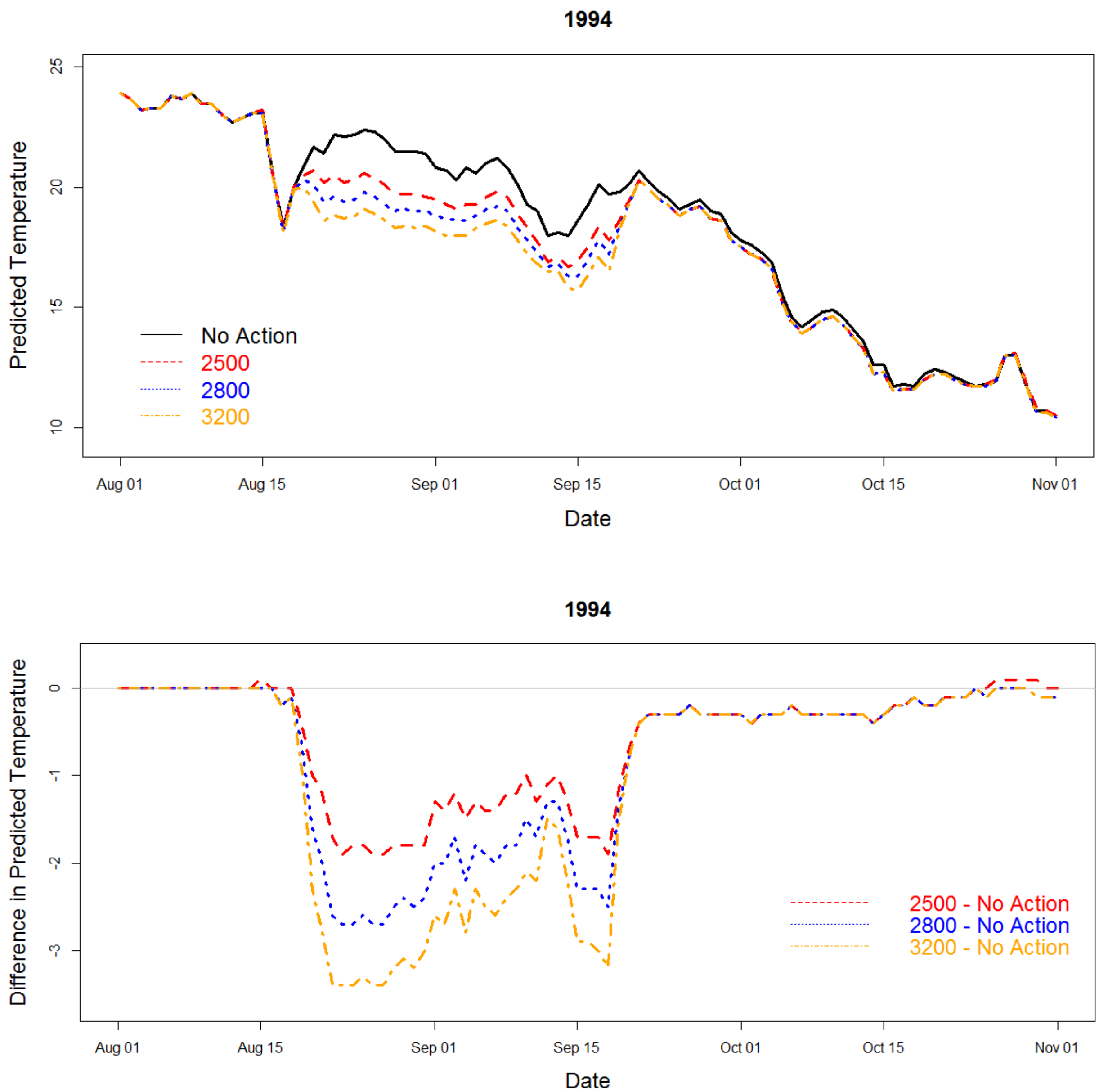

Figure 4. Predicted water temperatures (top) and difference in predicted water temperatures (bottom) in the lower Klamath River near the Klamath gage site, Klamath CA. No action refers to base operation flows from Lewiston Dam without using the bypass facility whereas the three augmented flow release scenarios reflect releases necessary to achieve targeted discharge of 2,500, 2,800, and 3,200 cfs at the Klamath gage site and included use of the bypass.

Tributary Accretions

This year, discharge in the Klamath River above the Trinity River confluence is similar to that observed in 2002, despite flow releases from Iron Gate Dam being significantly lower in 2002 than in 2014 (Figure 5). This difference can be attributed to the lower contributions of inflow from tributaries (Figure 6), which are generally of better water quality and are cooler than water temperatures in the mainstem Klamath River, particularly upstream of the Trinity River confluence. In 2015, cumulative tributary inflows to the Klamath and Trinity rivers are similar to, or lower than, other years when fall flow augmentation occurred (Figure 6). In addition, the low volume of tributary accretions is assumed to result in reduced volume of thermal refugia habitats along the mainstem river. The low tributary inflows provide limited thermal relief, thereby increasing stress of holding fish and minimizing conditions conducive to parasite replication and increased disease transmission due to crowding of fish. If the current drought conditions persist, the overall area of thermal refugia habitats is likely to be less than was available 2002 and similar to that experienced in 2015 due to the low tributary inflow.

Fish Metric

The purpose of the fish metric developed in the 2013 Joint Memo was to establish a real-time measure of the first substantial increase of fall-run Chinook Salmon in the lower Klamath River and was intended to be used as a trigger to initiate fall flow augmentation. The benefit of this real-time management approach is its potential to more efficiently use limited water resources as needed to protect returns of Klamath Basin fall-run Chinook Salmon, rather than relying on fixed dates to start and end flow augmentation. However, it’s critical that an abundance-based metric be conservative so that augmented flows are released in time to protect the run. A metric that is not conservative enough may result in large numbers of adult fall-run Chinook Salmon entering the river and commencing their upstream migration under flow conditions that are similar to those that occurred during the 2002 fish-kill.

A key component of the fish metric was to establish August 22nd as a “back-stop” start date to ensure that augmented flows would reach the lower Klamath River before the peak of the run. Rationale for the August 22nd trigger date are provided in the 2013 Joint Memo, and include the observation that in four of the five years included in the break-point analysis, large numbers of fish had been harvested in the estuary area by this date and harvest in the Middle Klamath Area increased in the following weeks, suggesting that the upstream migration of the run had commenced.

In 2015, operational flows from Lewiston Dam are scheduled to increase on August 16th to provide a peak flow at Hoopa on August 18th for the Hoopa Boat Dance. Given an approximate two-day ramp-down time from the Boat Dance release and a similar two-day ramp-up time to meet the August 22nd suggested mandatory augmentation start date (assuming the 7,000 fish metric target is not met), it’s questionable whether post Boat Dance flows would reach base levels prior to being ramped back up to the target of 2,800 cfs at the lower Klamath Gage site by August 22nd. The “two-fold pulse” in flow increases created by this scenario may trigger more fish to enter the river earlier than they would under the single pulse created by the Boat Dance release and ramping down to meet 2,800 cfs in the lower Klamath River.

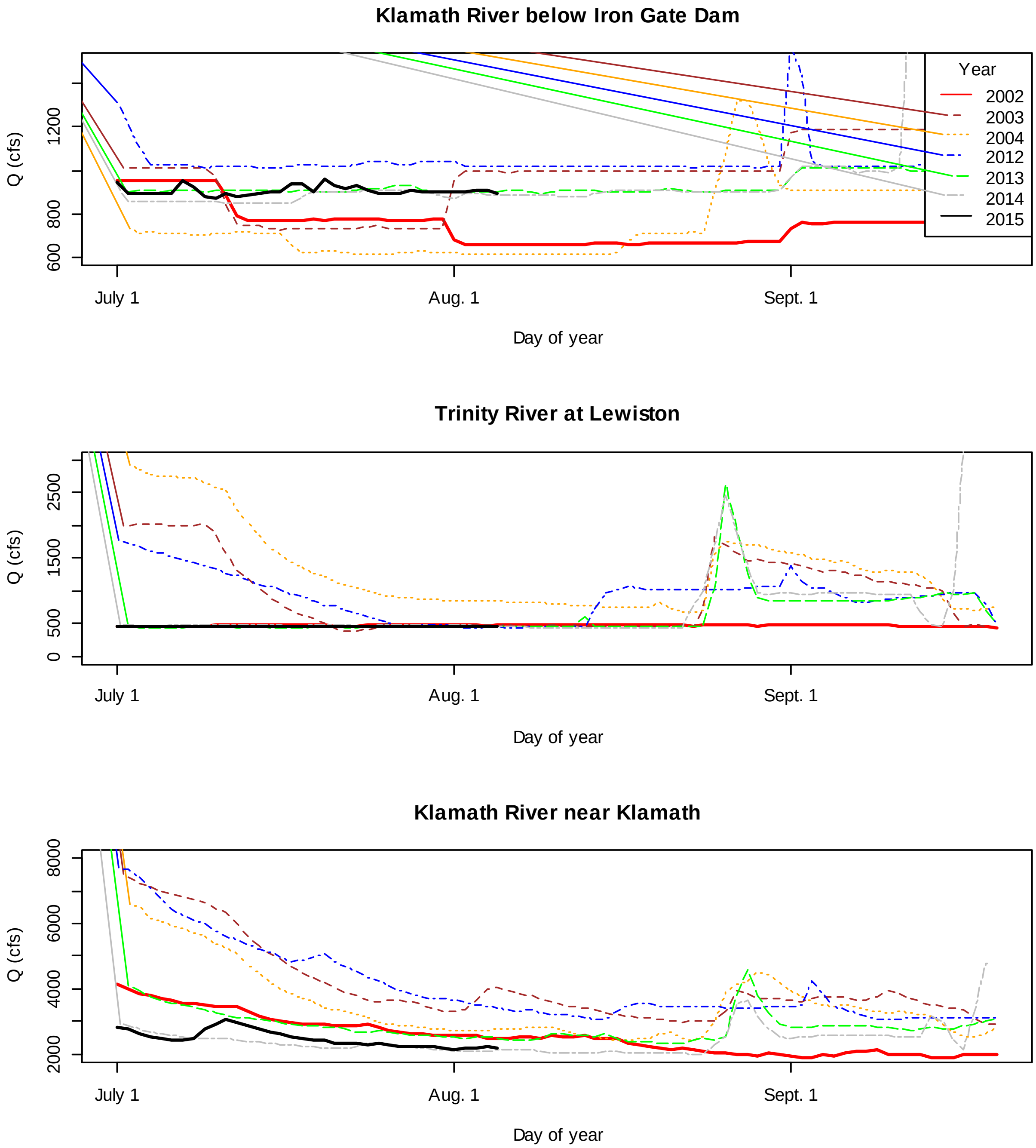

Figure 5. Dam releases and streamflow in the lower Klamath River near Klamath in 2002, 2015 and years with fall streamflow augmentation management actions.

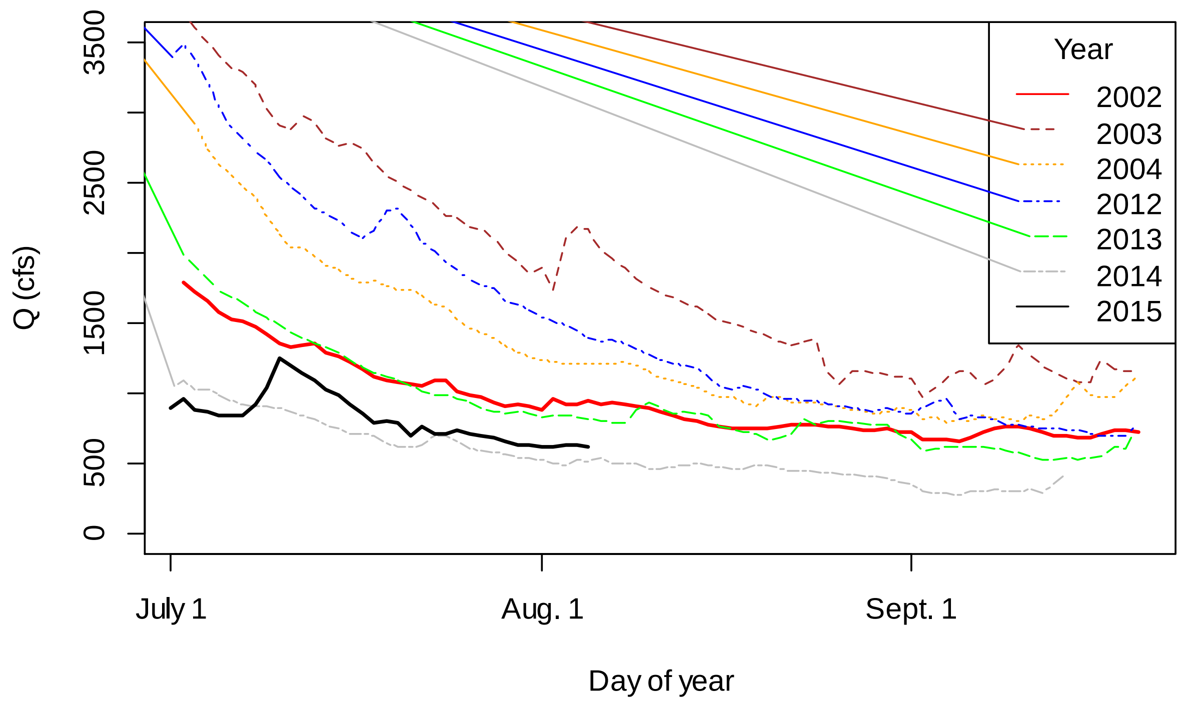

Figure 6. Estimated tributary accretions to the Klamath River downstream of the Trinity River confluence for 2002, 2015 and years where fall flow augmentation actions were implemented. Tributary accretion estimates were developed independently for the Klamath River and Trinity River and then summed. Klamath River tributary accretions were estimated by subtracting mean daily streamflow below Iron Gate Dam from Klamath River near Orleans. Similarly, Trinity River tributary accretions were estimated by subtracting mean daily streamflow below Lewiston Dam from the flow at Hoopa. In each case, calculations were offset by one day to account for travel time between gauges and smoothed to remove anomalies due to imperfect temporal offsets.

Emergency Criteria

In the 2013 Joint Memo, we recommended a two-tiered approach to emergency flow criteria, both of which are intended to minimize the potential for the occurrence of an epizootic disease outbreak and resulting fish-kill. The first phase recommends that flow in the lower Klamath River be increased to 3,200 cfs at rkm 13 when the fish metric criterion is met or exceeded and mean daily water temperature (actual and/or predicted) at rkm 13 is ≥ 23^{o} C for three consecutive days. Based on results of the water temperature modelling, this 3-day temperature criterion is unlikely to be exceeded in 2015 under augmented flow releases intended to meet the 2,800 cfs in the lower Klamath River (Figure 4 top).

The second phase of the emergency release is based on the fish pathology/mortality criteria adopted by the Trinity River Restoration Program - Fall Flow Subgroup's recommendation for 2012 (TRRP 2012a; TRRP 2012b), which recommends a 7-day duration pulsed spike to double pre-existing flows in the Lower Klamath River. This recommendation is based on a management practice often used in hatcheries, with increased flow as a control measure for Ich being well supported in the literature (Reshetnikova 1962; CDFG 1969; Bodensteiner et al. 2000; Hop Wo et al. 2003). However, a definitive target flow has not been determined for the Klamath River and as such, the hatchery practice of "doubling the flow" has been the basis of past recommendations.

In 2014, the emergency management action to double the flow from about 2,500 cfs up to about 5,000 cfs in the lower Klamath River was implemented and a fish kill did not occur. Given this data point, repeating the emergency flow release that occurred in 2014, if needed, is likely better supported than the general "doubling of the flow" as recommended by the Trinity River Restoration Program Fall Flow Work Group (TRRP 2012a, TRRP 2012b) and in the 2013 Joint Memo (USFWS and NOAA 2013). We are, however, receptive to Reclamation convening a workgroup to discuss possible alternatives to this emergency action, such as having two large pulses separated by 5-7 days based on the lifecycle of Ich and real-time water temperatures.

Emergency Ich Criteria

As stated in the 2013 Joint Memo

> *"We recommend the level and severity of an Ich infection that would trigger an emergency release be defined as a confirmed observation of a minimum of 5% of the sampled fish having 30 or more parasites on one gill arch."*

This methodology was developed by Dr. Scott Foott of the Service's CA/NEV Fish Health Lab as a rapid assessment protocol and was used in the baseline Ich monitoring the Service conducted with the Yurok Tribe in 2003. The method was not intended to be a census of Ich or an estimate of the average number of parasites/gill arch. Instead, it was developed as an efficient and rapid methodology to assess the prevalence and severity of infection, which requires recently captured and sacrificed salmon, due to the increased difficulty in identifying and quantifying Ich soon after mortality of the salmon host.

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2015 Lower Klamath River Late-Summer Flow Augmentation from Lewiston Dam Environmental Assessment

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RECLAMATION

Managing Water in the West

Environmental Assessment 2015 Lower Klamath River Late-Summer Flow Augmentation From Lewiston Dam

EA-15-04-NCAO

U.S. Department of the Interior
Bureau of Reclamation

August 2015

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Section 1 Introduction

This Environmental Assessment (EA) examines the potential direct, indirect, and cumulative impacts to the affected environment associated with the Bureau of Reclamation proposal to release supplemental flows from Lewiston Dam to improve water quality and reduce the prevalence of fish disease in the lower Klamath River. The Proposed Action will be implemented in late summer of 2015 to support the health of salmonid fish, including species that return to the Trinity River Basin to reproduce. The area of potential effect includes Trinity Reservoir and the Trinity River from Lewiston Dam to the confluence with the Klamath River, and the Klamath River to the Klamath River estuary near Klamath, California. Additionally, the affected environment includes the Sacramento River Basin as transbasin diversions from Trinity Reservoir via Lewiston Reservoir and the Clear Creek Tunnel to the Sacramento River Basin have occurred historically and are planned to occur throughout the summer (see Figure 1). This EA was prepared in accordance with the National Environmental Policy Act (NEPA), Council of Environmental Quality (CEQ) regulation (40 CFR Parts 1500-1508), and Department of the Interior Regulations (43 CFR Part 46).

Reclamation is currently in preparation of an Environmental Impact Statement (EIS) that examines impacts associated with a Long-Term Plan to Protect Adult Salmon in the Lower Klamath River. The Notice of Intent to prepare a draft EIS was published in the Federal Register. The web address to access this notice is:

> https://www.federalregister.gov/articles/2015/07/14/2015-17208/notice-of-intent-to-prepare-a-draft-environmental-impact-statement-for-the-long-term-plan-to-protect

The draft EIS is anticipated to be released to the public early 2016.

1.1 Need for the Proposal

The State of California is currently experiencing a record-breaking drought. Since the drought began in 2012, and the changing water conditions since then (i.e. decreased flows and increased temperatures), fish pathogens have proliferated compromising fish health. In August and September 2002, a large fall run of Chinook salmon (estimated 170,000) returned to the Klamath River when flows in the lower Klamath River averaged only 2,000 cubic feet per second (cfs). There was a subsequent outbreak of two deadly fish pathogens, *Ichthyophthirius multifiliis* (*Ich*) and *Flavobacterium columnare* (*Columnaris*). This outbreak resulted in a substantial number of premature (prior to successful spawning) adult salmonid deaths. The U.S. Fish and Wildlife Service (USFWS) estimated the number of adult salmonid deaths at 33,500 (Guillen 2003), including an estimated 344 coho salmon listed as threatened under the Endangered Species Act (ESA). These deaths are attributed to: (1) pathogens Ich and Columnaris; and (2) warm water temperatures, low water velocities and volumes, high fish density, and long fish residence times that likely contributed to the disease outbreaks and subsequent mortalities (Guillen 2003; Belchik et al. 2004; Turek et al. 2004). In 2003, 2004, 2012 and 2013, predictions of large runs of fall-run Chinook salmon to the Klamath River Basin and drier than normal hydrologic conditions prompted Reclamation to arrange for late-summer flow augmentation to improve environmental conditions in the lower Klamath River to reduce the probability of a disease outbreak. In these years 38 thousand acre-feet (TAF) of supplemental water was released from Trinity Reservoir in 2003, 36 TAF in 2004, 39 TAF in 2012, and 17.5 TAF in 2013. There were no large pathogen-related fish die-offs in these years.

Due to the prolonged and worsening drought, early to mid-August Klamath River flows in 2014 were even lower than the 2002 flows, averaging 2,088 cfs as opposed to the 2,528 cfs of 2002. Low flows, large fall run sizes, and outbreaks of *Ich* drove the need for two emergency releases from Lewiston Dam in August and September 2014. The first release began August 23, 2014, had a target flow rate of 2,500 cfs (at the Klamath near Klamath [KNK] gage), and was maintained until September 14, 2014. A second, larger release was necessary due to the observed presence of *Ich*. In 2014, the total volume released was 64 TAF. Despite the unprecedented high incidence of infection, the second, emergency release appeared to be successful and no significant mortalities of fish occurred.

Conditions in 2015 reflect the continuation of drought in the area. Klamath River flows in 2015 are anticipated to be 2,000 cfs in late August. This is consistent with flows observed in 2002, the year of the large fish die-off. Because of the extended drought, there is little to no snow pack, and accretions are predicted to be minimal. Therefore, lower Klamath River flows are anticipated to remain low, only getting lower as we approach fall of 2015. The predicted fall run of Chinook is fairly large with 119,000 expected to return to the lower Klamath River. While a predicted run of 119,000 is not as high as the fall run of 2002 (170,000), run-size predictions are difficult to make. It is not uncommon for run predictions to be off by 50,000 fish or more in either direction. Furthermore and perhaps more importantly, the U.S. Fish and Wildlife Service (2015) identified "the pattern of upstream migration to be a more important factor in determining disease risk than run size alone" to suggest that run size should be de-emphasized as an indicator for disease risk.

Ich is already present in the river system. The Yurok Tribe captured six Chinook salmon from Blue Creek, a tributary of the lower Klamath River, on July 22nd and all tested positive for *Ich* infection. One of these fish had a severe infection, with more than 30 *Ich* spots per gill arch. This disease occurrence is a month earlier than that discovered in 2014 when it was first observed on the 27th of August. More recently, the Yurok Tribe reported severe *Ich* presence in adult salmon on August 20. Such high levels of *Ich* present this early in the year indicate a significant risk for a large fish die-off in 2015. The warmer than normal water temperatures, low flows, and presence of *Ich* already in the system all point toward a risk of infection and fish die-off event in 2015. The Proposed Action is needed to reduce the likelihood, and/or severity of any *Ich* and columnaris outbreaks that could lead to associated fish die-offs in 2015.

In 2015, Reclamation requested that the USFWS provide technical assistance to aid Reclamation's deliberations on determining the extent of an action in 2015 to reduce the risk of an adult fish kill in the lower Klamath River (USFWS 2015: Appendix A). This memorandum was produced to be relevant to 2015, providing clarity and modifications to considerations for fall flow augmentation as previously described in joint memorandum by the USFWS and the National Oceanic and Atmospheric Administration (NOAA) (USFWS and NOAA 2013). Three factors that were discussed in this memorandum included de-emphasis of the significance of run size, clarifications to the *Ich* trigger used to define severity of infection, and alteration of the emergency trigger of “doubling the flow”. Otherwise the information as presented in the 2013 memorandum was considered as relevant for consideration in 2015.

In 2015, the Hoopa Valley Tribe commissioned Mr. Josh Strange of Stillwater Sciences to provide a review of the need for a pulse flow in the lower Klamath River in addition to a preventative and emergency flow augmentation actions identified in the draft EA (Strange 2015). This review included evaluating the scientific rationale and evidence for elevated background levels of *Ich* in 2015. This information was taken into consideration for the need for an action.

Additionally, Humboldt County sent a letter dated May 19, 2015, to the Secretary of the Interior requesting that its contract amount of not less than 50,000 acre-feet (AF) be provided to address fisheries needs and to protect human health and safety in the Klamath/Trinity river system. This request is also supported by the recently released Solicitor’s Opinion (M-37030) confirming that the inclusion of the proviso in the 1955 Trinity River Division Act requiring that “not less than 50,000 AF be released annually from the Trinity Reservoir and made available to Humboldt County and downstream water users,” represents a separate and independent limitation on the integration of the Trinity River Division (TRD), and thus the diversion of water to, the Central Valley Project. Therefore, this proviso may require a separate release of water as requested by Humboldt County and potentially other downstream users from that already being made for fish restoration purposes under other provisions of the 1955 Act. The Hoopa Valley Tribe and the Yurok Tribe have also requested in writing that the Humboldt County contract amount be made available for augmenting flows in the lower Klamath River.

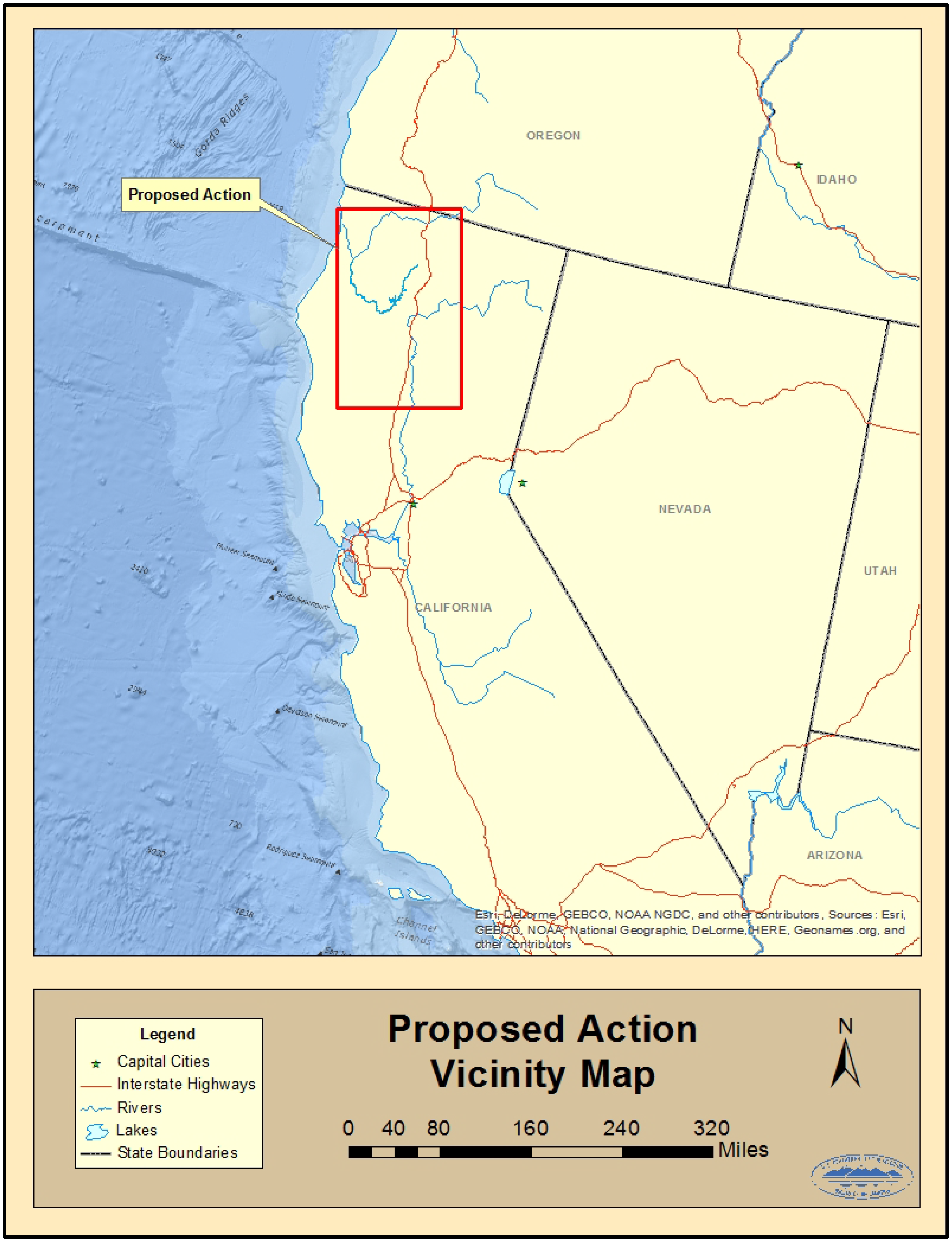


Figure 1. Geographic Scope of the Proposed Action

1.2 Legal and Statutory Authorities

The Trinity River Division Central Valley Project Act of 1955 (P.L.84-386) provides the principal authorization for implementing the Proposed Action. Specifically, Section 2 of the Act limits the integration of the TRD with the rest of the Central Valley Project (CVP) and gives precedence to in-basin needs including that "the Secretary is authorized and directed to adopt appropriate measures to insure preservation and propagation of fish and wildlife…" and "that not less than 50,000 acre-feet shall be released annually from the Trinity Reservoir and made available to Humboldt County and downstream users."[1] The following are also authorities for the Proposed Action: the Trinity River Basin Fish & Wildlife Management Act of 1984 (Act of October 24, 1984 [P.L. 98-541]; as amended by the Act of October 2, 1992 [P.L. 102-377]; Act of November 13, 1995 [P.L. 104-46]; Act of May 15, 1996 [P.L. 104-143]) (directs the Secretary to restore the fish populations impacted by the TRD facilities); the Fish and Wildlife Coordination Act [16 USC 661] and section 3406(b)(1) of the CVPIA. In addition, the Proposed Action is also consistent with Reclamation's obligation to preserve tribal trust resources.

1.3 Resources Analyzed in Detail

The range of potential impacts assesses whether the release of additional flows from Lewiston Dam in late summer 2015 might cause significant effects on the human environment. This EA will analyze the affected environment of the Proposed Action and No Action Alternative in order to determine the potential impacts and cumulative effects to the following environmental resources:

- Water Resources
- Biological Resources
- Indian Trust Assets
- Environmental Justice
- Socioeconomic Resources
- Power Generation
- Global Climate

[1] For the actions implemented in 2012, 2013, and 2014, Reclamation relied primarily on the provision in section 2 of the Trinity River Division Authorization 1955 Act that authorizes and directs the Secretary to insure "the preservation and propagation of fish and wildlife" downstream of the TRD facilities. On October 1, 2014, the U.S. District Court for the Eastern District of California found that this provision of section 2 of the 1955 Act did not provide authority for the 2013 augmentation releases. A notice of appeal has been filed regarding this decision.

Impacts to the following resources were considered and found to be minor or absent. Brief explanations for their elimination from further consideration are provided below:

- **Cultural Resources –** The Proposed Action would not produce any ground disturbances, would not result in the construction of new facilities or the modification of existing facilities, and would not result in changes in land use. Neither the proposed Action nor the No Action Alternative have the potential to cause effects to historic properties, assuming such historic properties were present, pursuant to 36 CFR § 800.3(a)(1).

- **Indian Sacred Sites –** There would be no impact to the Indian sacred sites under the No Action Alternative as conditions would remain the same as existing conditions. Similarly, the Proposed Action would not inhibit access to, or ceremonial use of, an Indian Sacred Site, nor would the Proposed Action adversely affect the physical integrity of such sacred sites. The release of flows from Lewiston Dam would be within the normal release flow range and water levels along the Trinity River and would not exceed the historic range of flows.

- **Floodplains, Wetlands and Waterways –** There would be no impact to floodplains under the No Action Alternative as conditions would remain the same as existing conditions. The Proposed Action does not involve construction, dredging, or other modification of regulated water features. No permits under the Clean Water Act would be needed. Furthermore, the Proposed Action only includes providing controlled reservoir releases that are within the normal operational envelope.

- **Land Use –** There would be no impact to land use under the No Action Alternative as conditions would remain the same as existing conditions. There are also no changes in land use anticipated from implementation of the Proposed Action. The proposed water releases from Lewiston Dam are within the historic range of flows addressed in the Trinity River Mainstem Fishery Restoration Environmental Impact Statement/ Environmental Impact Report (TRMFR EIS/EIR; U.S. Fish and Wildlife Service et al. 2000). In addition, the magnitude and timing of the target flows in the lower Klamath River are well within the range of historic flows resulting from rainstorms, etc. Therefore, no changes in land use near the rivers will be required as a consequence of the Proposed Action.

- **Air Quality –** Section 176 (C) of the Clean Air Act (CAA; 42 U.S.C. 7506 [C]) requires any entity of the Federal Government that engages in, supports, or in any way provides financial support for, licenses or permits, or approves any activity to demonstrate that the action conforms to the applicable State Implementation Plan (SIP) required under Section 110 (a) of the Federal CAA (42 U.S.C. 7401 [a]) before the action is otherwise approved. There would be no impacts to air quality under the No Action Alternative as conditions would remain the same as existing conditions. Under the Proposed Action, no impacts to air quality would be expected. To the extent there may be such impacts, those would be speculative and need not be analyzed. As there would be no impact to the resources listed above resulting from the Proposed Action or the No Action Alternative, they will not be considered further.

Section 2
Proposed Action and Alternatives

2.1 No Action Alternative

Under the No Action Alternative, Reclamation would not release additional flows to avoid a fish disease outbreak and subsequent fish die-off, from the Lewiston Dam in late summer 2015. Current late-summer releases from Lewiston Dam would remain at 450 cubic feet per second (cfs), as prescribed in the Record of Decision for the TRMFR EIS/EIR (U.S. Fish and Wildlife Service et al. 2000). Flow releases at Iron Gate Dam on the Klamath River would be consistent with the 2013 National Marine Fisheries Service (NMFS) and USFWS biological opinion addressing operation of Reclamation's Klamath Project, approximately 900 cfs in August and 1,000 cfs in September. In addition, Reclamation is expected to provide a short-term increase in Lewiston Dam releases to provide for the Hoopa Valley Tribe's Boat Dance Ceremony (Ceremony) as is customary in odd numbered years. In 2015, the Ceremony occurred on August 18th, necessitating the peak flow of 2,650 cfs from Lewiston to occur one day prior to the event to account for travel time from the dam to the ceremonial site. Flow adjustments (also called ramping rates) from the base flow of 450 cfs to the peak and down from the peak to 450 cfs followed contemporary approved rates of change to minimize public and environmental concerns. In total, the implementation of the ceremonial flow above the base flow of 450 cfs will result in a 5-day span of increased flow accounting for approximately 10,900 AF (Figure 4).

Under the No Action Alternative the estimated flows in the lower Klamath River (U.S. Geological Survey [USGS] Site #11530500; KNK gage), and scheduled releases from Lewiston Dam are shown in Figure 4. Forecasted flows at the KNK gage would be approximately 2,000 cfs in the second half of August and through September (not including the Ceremony pulse flow from Lewiston Dam). This flow is based on forecast tributary contributions from the California Nevada River Forecast Center (90 percent exceedance) and planned dam releases from Iron Gate (900 cfs in August and 1,000 in September) and Lewiston (450 cfs in August and September).

Diversion of water from the Trinity River Basin to the Sacramento River Basin via Lewiston Reservoir and the Clear Creek Tunnel would continue as scheduled for 2015. With the current schedule, 97 TAF will be transferred in August, 62 TAF in September, and 20 TAF in October.

Due to regulatory-driven temperature targets in both the Sacramento and Trinity Rivers, flows are anticipated to be released from the auxiliary bypass outlet on Trinity Dam. In other words, colder water from lower reservoir depths will be released directly into the river, bypassing hydroelectric power plant facilities. These bypasses are anticipated to be needed, although the schedule for their need is subject to real-time management and review of thermal regimes and changing river conditions. Preliminary dates to use the auxiliary bypass outlet are from September 11, 2015 until October 12, 2015.

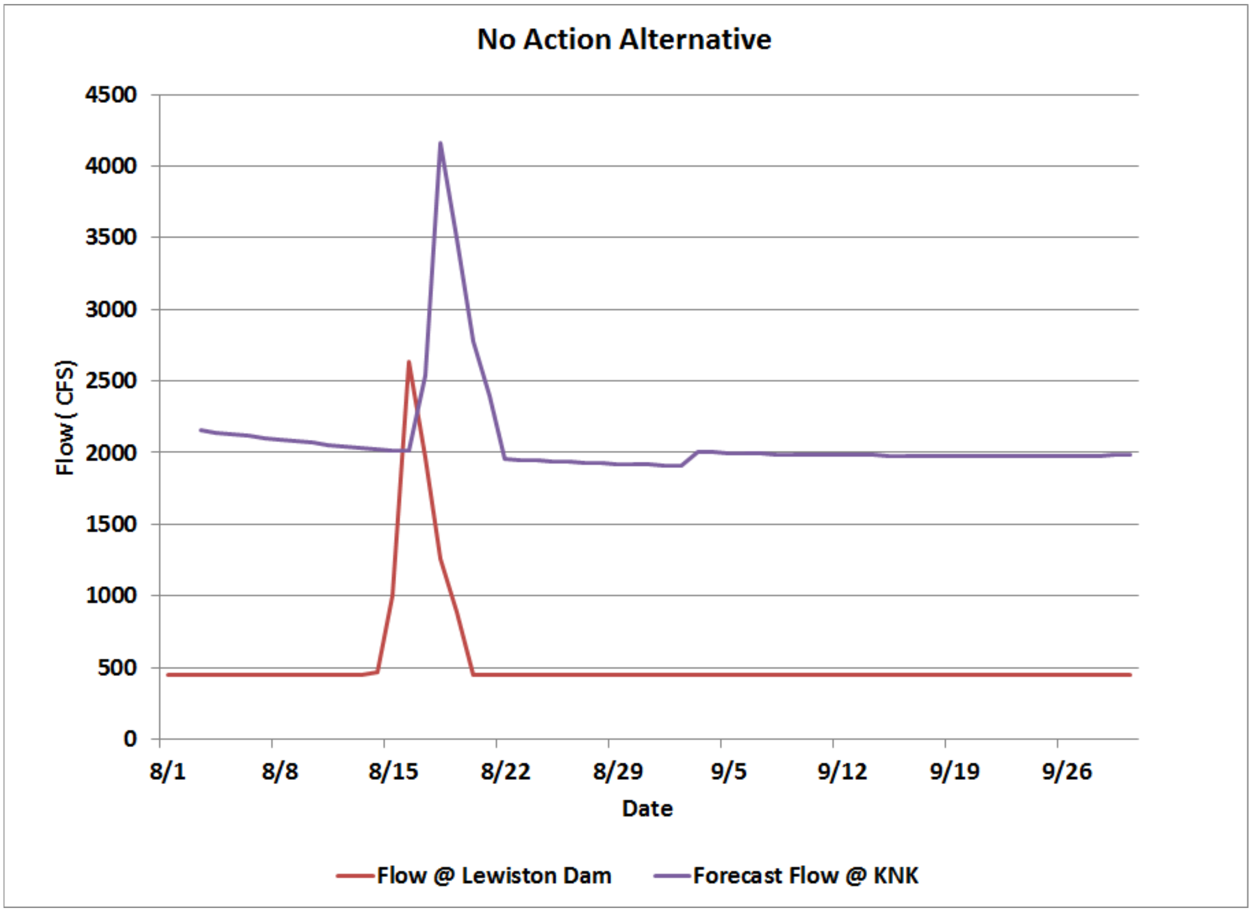


Figure 2. Hydrograph Showing Projected Flows from Lewiston Dam on the Trinity River and the Klamath River near Klamath (KNK), California for the No Action Alternative

2.2 Proposed Action

Continued dry hydrologic conditions and recent discovery of the presence of *Ich*, the fish disease thought primarily responsible for the fish die-off in 2002, has prompted Reclamation to consider supplementing flows to the lower Klamath River in 2015 (Figure 3). The Proposed Action includes supplemental flows (up to 51 TAF) to prevent a disease outbreak (preventative flow), a preventative pulse flow, and a contingency volume (up to 37 TAF) to be used on an emergency basis to avoid a significant die-off of adult salmon. The total volume of the preventative flows with the emergency response would equal 88 TAF. An adaptive management approach that incorporates real-time environmental and biological monitoring by Federal, State and Tribal biologists (technical team) would be used to determine if and when to implement these three components of the Proposed Action. The technical team would be monitoring flow in the lower Klamath River, water temperature, fish residence time, infectivity of fish, and the overall health of the fish in the river. Details of implementing these components of the Proposed Action follow:

Preventative Flow Augmentation:

- Initiate preventative flow augmentation in the lower Klamath River to a target flow of 2,800 cfs at the USGS gage (http://waterdata.usgs.gov/ca/nwis/uv?site_no=11530500) located in the lower Klamath River near Klamath (KNK Gage), when the cumulative harvest of Chinook salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish.

- Initiate preventative flow augmentation releases by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in USWFWS and NOAA 2013).

- Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the KNK Gage through September 20, 2015. Flow from Lewiston Dam to meet a target of 2,800 cfs in the lower Klamath River is anticipated to reduce average daily water temperatures to below 23ºC that may otherwise inhibit adult upstream migration (USFWS 2015).

- Implement fish pathology monitoring to determine the need for a fish pathology/mortality emergency release, and

- Monitor conditions to inform need and timing of emergency flow releases based on real-time environmental conditions.

Preventative Pulse Flow:

- Due to the heightened alert for this year with the recent and continued low level infections of *Ich* observed, a 3- day pulse (including ramping up and down) peaking at 5,000 cfs in the lower Klamath River may be implemented when:

  – the peak of fall run migration (first or second week of September) is identified in the lower Klamath River as indicated by tribal harvest, and

  – low level infections of *Ich* (less than 30 *Ich* per gill) is found on three fall-run adult salmon (of a maximum sample size of 60) captured in the lower Klamath River in one day during the first or second week of September. Sampling and confirmation would follow the methods as described in NOAA and USFWS (2013). The benefit of the pulse is to enhance flushing/dilution of the river of parasites when the bulk of fall run adults are likely to be the lower river. This flow would also further improve water quality and help facilitate movements of adult salmon.

- If rainfall increases the flow in the lower Klamath River to above 5,000 cfs this component would not be implemented.

- If needed, this action may avert the need to apply the emergency criteria.

- Implementation of a pulse flow will be within the Proposed Action volume of 51 TAF.

Emergency Flow Augmentation:

- Initiate emergency flow release to target a flow of 5,000 cfs in the lower Klamath River for up to five days if emergency conditions exist as identified below:
  - Diagnosis of severe *Ich* (30 or more parasites on a gill arch) infection of gills in 5 percent or greater of a desired sample of 60 adult salmonids confirmed by the USFWS Fish Health Center; or
  - Observed mortality of greater than 50 dead adult salmonids in a 20 kilometer reach in 24 hours couples with the confirmed presence of *Ich* by the USFWS Fish Health Center.
- Use the protocol for sharing and confirming information on a real-time basis to determine if and when the emergency flows would be implemented.
  - Key staff members will be on high alert during the flow augmentation action and will be getting timely on the ground monitoring results. The USFWS Fish Health Center will provide a pathology report documenting the findings of diagnostics survey to Reclamation, the technical team, and the Klamath Fish Health and Assessment group. An emergency release will be considered by Reclamation on receipt of a positive pathology report.

Flows prior to the augmentation release beginning August 19 would remain consistent with the No Action Alternative, including the release associated with the Hoopa Valley Tribe's Boat Dance Ceremony, diversions to the Sacramento River Basin, and use of the auxiliary bypass outlet at Trinity Dam to meet regulatory-driven temperature targets. As with the No Action Alternative, the schedule for needing the use of the auxiliary bypass outlet is subject to real-time management and review of thermal regimes and changing river conditions. Preliminary dates when the bypass outlet would be used are September 11, 2015, until October 12, 2015. Transbasin diversions for 2015 have already been determined and would not be altered by the Proposed Action.

In 2015 Reclamation proposes to target a flow rate of 2,800 cfs at the lower Klamath River gage (See Figure 4). This is an increase from the target flow rate of 2,500 cfs used in 2014. The experience in 2014 indicated a flow rate of 2,500 cfs may not have been sufficient to thwart widespread *Ich* infection and a large emergency pulse flow was required. By increasing the target flow to 2,800 cfs the need for a preventative pulse flow and or the emergency flow should be diminished and the overall release should be limited to the 51 TAF used in the preventative portion of the action.

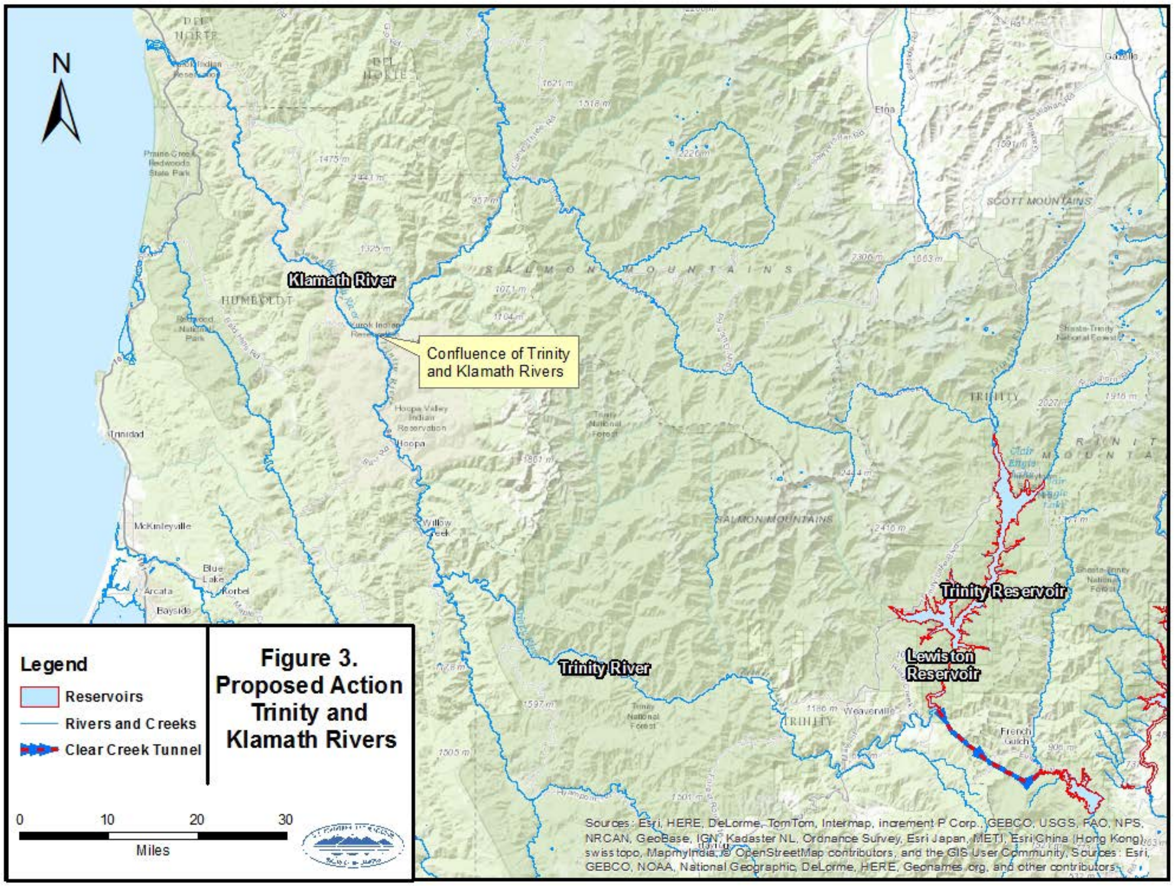
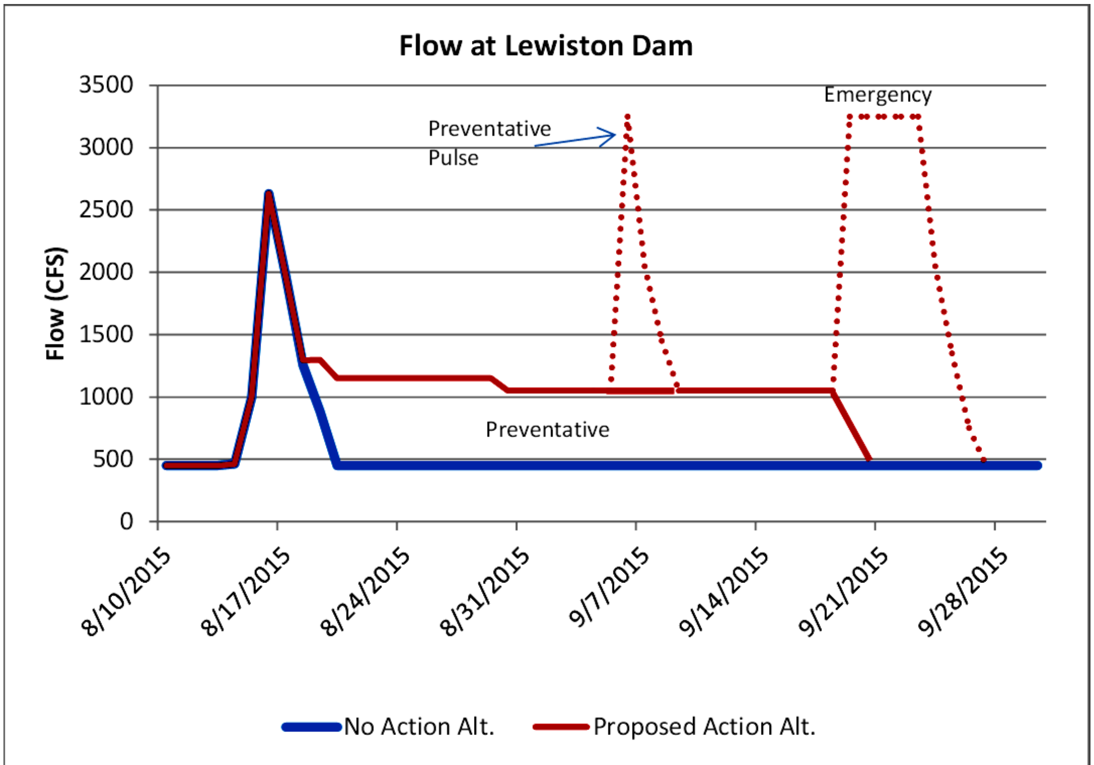
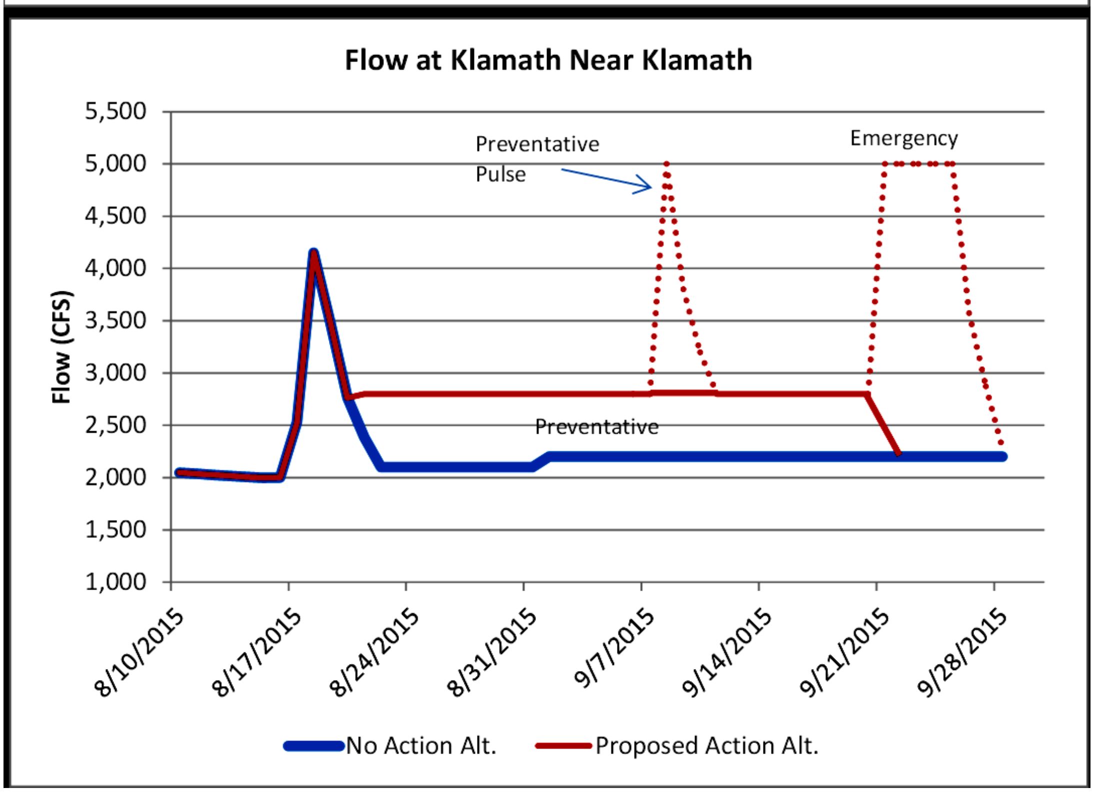


Figure 3. Proposed Action Area of Concern - Trinity and Klamath Rivers





Note: the dashed line represents possible flow augmentation actions and are provided for illustration purposes

Figure 4. Hydrograph Showing Flows at Lewiston Dam (USGS Station #11525500) (top figure) and Klamath River near Klamath (USGS gage #11530500) (bottom figure) for the Proposed Action and No Action Alternatives

2.3 Alternatives Considered But Eliminated From Further Consideration

Reclamation considered one potential alternative source of supplemental water for the lower Klamath River in the late summer. This was water from the Klamath River at the Iron Gate Dam.

The 2015 water supply conditions in the upper Klamath Basin and in the Trinity River Basin have deteriorated throughout the year. In the upper Klamath River basin, a press release from Reclamation on April 7, 2015 stated "Since the start of the water year (October 2014) through April 1, 2015, the Klamath Basin has received 96 percent of average precipitation, but those conditions have come alongside snowpack that is significantly lower than normal at only 7 percent of average. This is the largest disparity on record between precipitation and snowpack, meaning that runoff from snowpack will be extremely limited. The Klamath Project relies on snowpack to sustain inflows to Project reservoirs during the summer months in order to meet the Project's irrigation demands."

After planning for the Klamath River flows below Iron Gate Dam, and Upper Klamath Lake elevation management, consistent with the NMFS and USFWS biological opinion addressing operation of Reclamation's Klamath Project, and providing for limited irrigation water delivery, Reclamation determined that in practical terms, supplemental water for late summer lower Klamath River flows is unlikely to be available from the upper Klamath River. In addition, the Klamath water out of Iron Gate Dam is warmer and generally of lower quality than water from Trinity Reservoir. This can be attributed to the series of four small dams on the Klamath that allow continual warming of the water and algae to proliferate. While water from Iron Gate Dam could provide a dilution benefit and increase water turnover rates in the lower Klamath River similar to water from Lewiston Dam, the water from Lewiston Dam provides a temperature benefit (temperature reduction in the lower Klamath River) that is not available from Iron Gate Dam. This additional benefit from Lewiston Dam water is presently deemed important to increase the effectiveness at ameliorating environmental conditions in the lower Klamath River believed to be responsible for the die-off in 2002.

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Section 3 Affected Environment

3.1 Water Resources

3.1.1 Trinity River Division

Reclamation stores water for several purposes in Trinity and Shasta Reservoirs. These facilities and other Central Valley Project (CVP) facilities are operated in a coordinated fashion to satisfy a number of geographically diverse flood control and environmental requirements, as well as provide water to satisfy water delivery and water rights responsibilities and to generate hydroelectric power. This coordinated, or integrated, operation is subject to certain limitations that require Trinity River origin water to remain in the Trinity basin.

Trinity Reservoir is the primary water storage facility in the TRD of the CVP (Figure 5). At capacity, it stores 2,448 million acre-feet (MAF), and receives an average annual inflow of approximately 1.2 MAF. Water released from Trinity Reservoir flows to Lewiston Reservoir, a re-regulating reservoir formed by Lewiston Dam. From Lewiston Reservoir, water can be diverted for use in the Sacramento River Basin via the 10.7 mile Clear Creek Tunnel, or pass through Lewiston Dam to flow 112 miles before entering the Klamath River at Weitchpec. The Klamath River then flows approximately 43 miles before entering the Pacific Ocean. The Trinity River Hatchery (TRH), located at the base of Lewiston Dam, also diverts a small quantity of water from Lewiston Reservoir in support of fish hatchery operations.

Water flowing through Clear Creek Tunnel enters the Judge Francis Carr Powerhouse to Whiskeytown Reservoir, which also serves as a re-regulating reservoir. Water stored in this reservoir is released through Whiskeytown Dam where it serves to meet environmental requirements in Clear Creek; to generate hydropower by Redding Electric Utility; and provide water for downstream irrigation, municipal, and industrial (M&I) needs. Alternatively, water from Whiskeytown Reservoir can also be diverted through Spring Creek Tunnel to Spring Creek Powerplant, Spring Creek, then into Keswick Reservoir. Keswick Reservoir combines water from the Trinity River with water from Shasta Reservoir, which is then discharged through the Keswick Powerplant to the Sacramento River (Figure 5).

Trinity Reservoir storage is used to meet the needs of the cold-water fish resources in the Trinity River, and those areas within the Sacramento River Basin including Clear Creek that is fed from Whiskeytown Reservoir and the Sacramento River. These needs include meeting certain temperature requirements in both systems for several fish species. Meeting these temperature requirements relies in part on transbasin diversions from Lewiston Reservoir to the Sacramento River basin that reduces the warming potential for water of both Lewiston and Whiskeytown Reservoirs. In turn this continuous flow of water through these re-regulating reservoirs ensures suitably cold water remains available for release to each of the outflow points during the warmer months of the year.

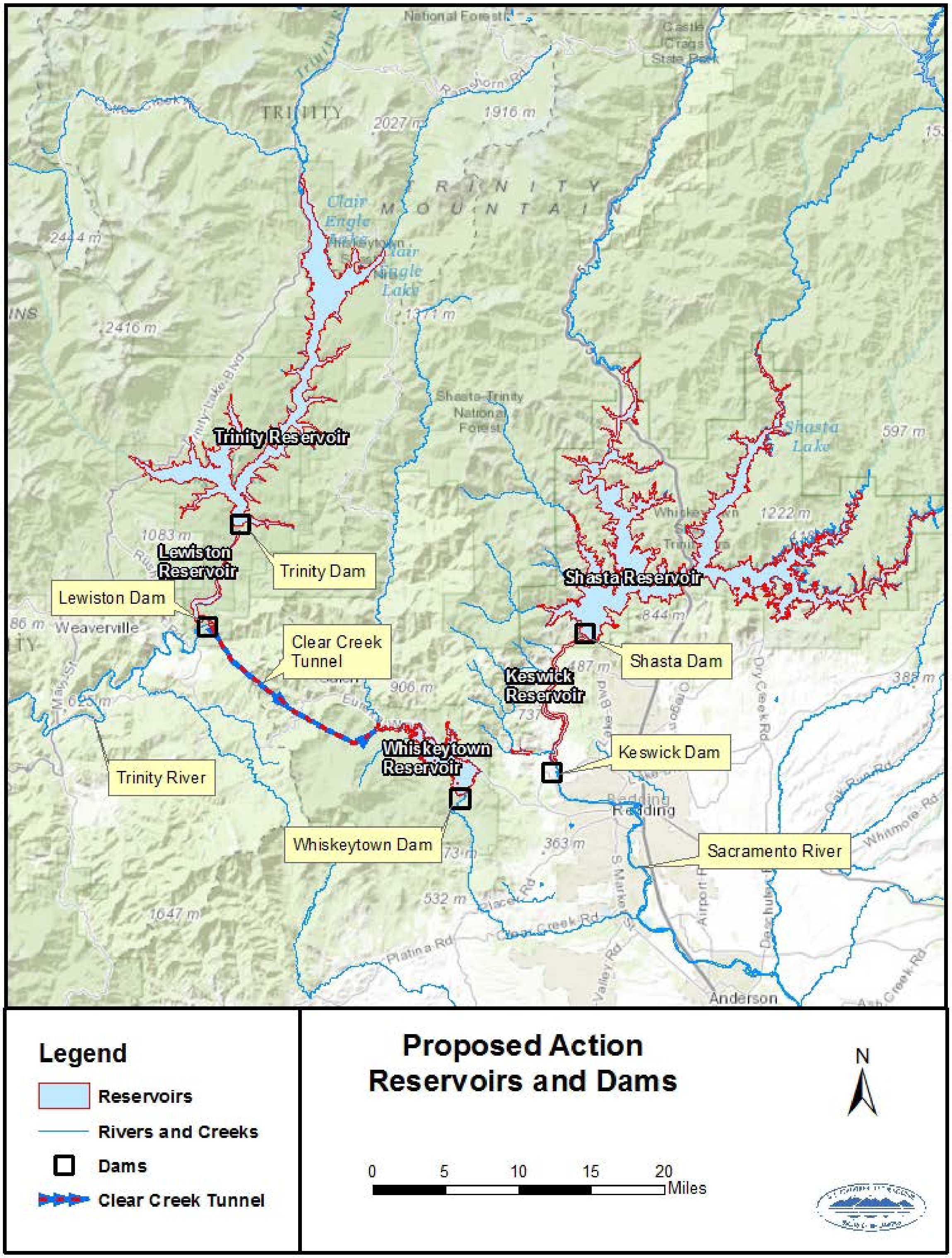


Figure 5. Water Resource Areas of Trinity River Division

Water from the Trinity Reservoir by way of Lewiston Reservoir is released to the Trinity River year-round as prescribed by the TRMFR EIS/EIR Record of Decision. Releases from the deep portions of the reservoir assure release of suitably cold water throughout the year in support of fishery restoration goals as well as assuring suitably cold water is diverted to meet the cold water needs of federally-listed species in the Sacramento River Valley.

Every odd year there is a prescribed release to support the ceremonial needs of the Hoopa Valley Tribe in late summer. This prescribed flow requires up to 11,000 AF of water above base flows to achieve requisite flows on the Hoopa Reservation for the event. This event occurs in August or September.

In years of relatively low storage, water released from Trinity Reservoir may be released through the use of the auxiliary bypass outlet (Elev 1999’) in lieu of the penstock (Elev 2100’), which allows access to the deeper water that is typically much colder. This type of operational change typically only occurs at the end of summer or early fall, a time of minimum pool. As in 2014, the use of the auxiliary bypass would be used in 2015 to access this cold water source. The degree to which it is used is dependent on the volumetric need as the capacity is limited to approximately 2,000 cfs.

3.1.2 Fall Flow Augmentation Actions to the Lower Klamath River

In some years, most notably in dry years when flows in the lower Klamath are projected to be low, Trinity Reservoir water has been sought to augment flows to prevent a significant die-off of adult salmon as occurred in 2002. Years in which flow augmentation from Trinity Reservoir occurred to reduce this risk included 2003, 2004, and 2012-2014. The average quantity of water used from the Trinity in these past five years was 39 TAF. The largest flow augmentation action from Trinity occurred in 2014 when 64,000 AF was released for both a preventative and a first time use of an emergency action. Additionally, in 2014 another 16,000 AF was released from Iron Gate Dam on the mainstem Klamath River. While other water sources have been sought to augment flows in years when augmentation actions have occurred, it was only in 2014 that flows from Iron Gate Dam were available. In all years of an augmentation action, the timing of the need has been focused on the August and September time periods, with diminishing concern occurring in October and later in the year. Greater detail on past flow augmentation actions are provided in the document *Long Term Plan for Protection of Adult Salmon in the Lower Klamath River* (Reclamation 2015).

3.1.3 2015 Water Storage and Diversions from Trinity

Water storage in Trinity Reservoir is influenced by the balance of inflow and outflow throughout the year. During the summer months, storage typically decreases rapidly as inflow rapidly decreases due to lack of precipitation and release from Trinity Dam are used to meet a variety of needs in both the Trinity and Sacramento River basins. Minimum storage in Trinity typically occurs in October or November of each year. The historic average (1963 to 2010) storage for the end of September is approximately 1.67 MAF. In 2015, the 50 and 90 percent exceedance level, the water storage projection for the end of September is approximately 595 TAF and 599 TAF, respectively.

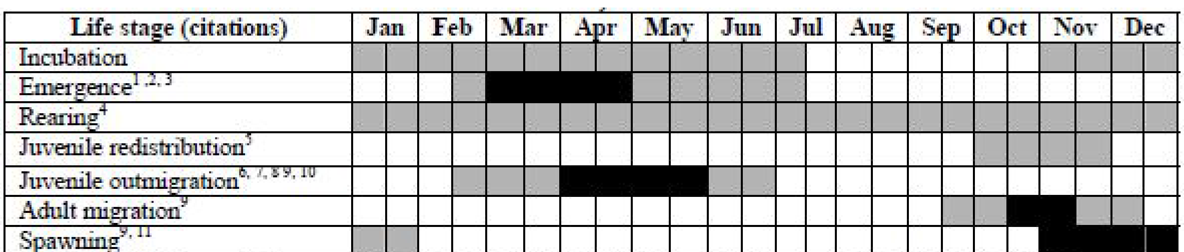
3.2 3.2 Biological Resources

3.2.1 3.2.1 Trinity and Klamath River Basins

Several anadromous fish species use the lower Klamath River and the Trinity River to complete their lifecycles. The life stages of species of interest for this EA include both federally-listed coho salmon (*Oncorhynchus kisutch*) as well as non-listed fish, including the North American green sturgeon (*Acipenser medirostris*), spring- and fall-run Chinook salmon (*O. tshawytscha*), which have tribal, recreational, and commercial value. One or more life stages of each of these species are present in the area of influence of the Proposed Action. The Pacific eulachon, while listed as threatened under the ESA, is not evaluated further because no life stages of this species would be present in freshwater during the period of effect from the Proposed Action. Greater detail on life history timing of considered species follows.

Coho salmon populations in the Klamath River Basin are severely reduced from historical levels and are listed as federally-threatened, part of the Southern Oregon/Northern California Coasts Evolutionarily Significant Unit. Life history timing for coho salmon in the Klamath River are provided in Table 1.

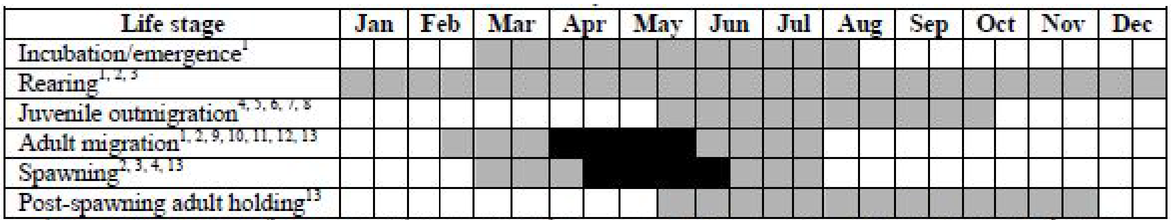
Table 1. Life-history Timing of Coho Salmon in the Klamath River Basin Downstream of Iron Gate Dam. Peak activity is indicated in black (Table, and associated references, are from Stillwater Sciences, 2009)



[1] CDFG (2000, unpubl. data, as cited in NRC 2004); [2] CDFG (2001, unpubl. data, as cited in NRC 2004); [3] CDFG (2002, unpubl. data, as cited in NRC 2004); [4] Sandercock (1991); [5] T. Soto, Fisheries Biologist, Yurok Tribe, pers. comm., August 2008; [6] Scheiff et al. (2001); [7] Chesney and Yokel (2003); [8] T. Shaw (USFWS, unpubl. data, 2002, as cited in NRC (2004); [9] NRC (2004); [10] Wallace (2004); [11] Maurer (2002)

Green sturgeon in the Klamath River Basin are included in the Pacific-Northern Distinct Population Segment (DPS), which also includes coastal spawning populations from the Eel River north to the Klamath and Rogue rivers. While not listed formally under the ESA as threatened or endangered, they are presently designated as a Species of Concern (NMFS 2006). Life-history timing for the various life stages in freshwater are provided in Table 2.

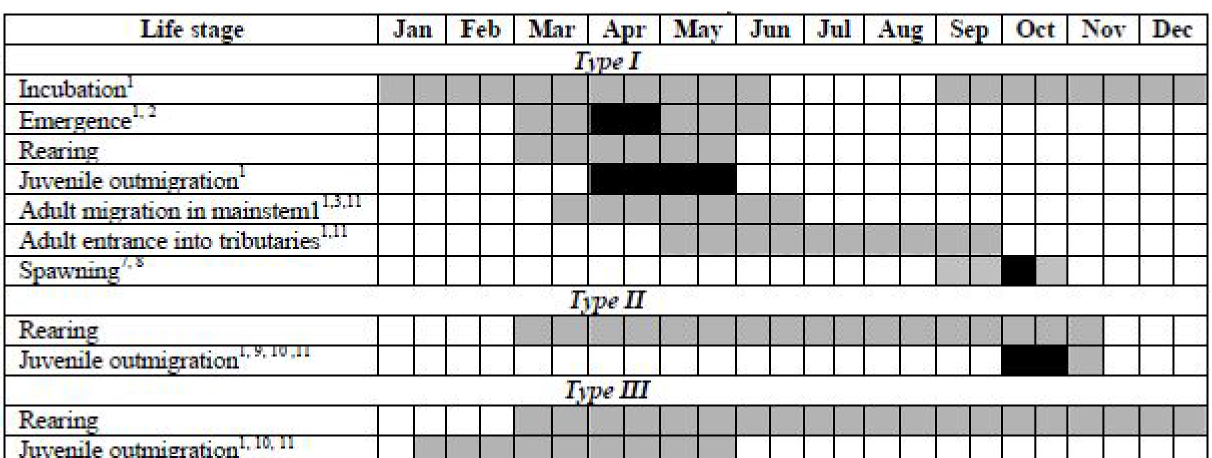
Table 2. Life-history Timing of Green Sturgeon in the Klamath River Basin Downstream of Iron Gate Dam. Peak activity is indicated in black. (Table, and associated references, are from Stillwater Sciences, 2009)



[1] CALFED ERP (2007), [2] NRC (2004), [3] FERC (2006), [4] Emmett et al. (1991, as cited in CALFED ERP 2007), [5] CH2M Hill (1985), [6] Hardy and Addley (2001), [7] Scheiff et al. (2001), [8] Belchik (2005, as cited in CALFED ERP 2007), [9] KRBFTF (1991), [10] Moyle (2002), [11] PacifiCorp (2004), [12] Van Eenennaam et al. (2006), [13] Benson et al. (2007)

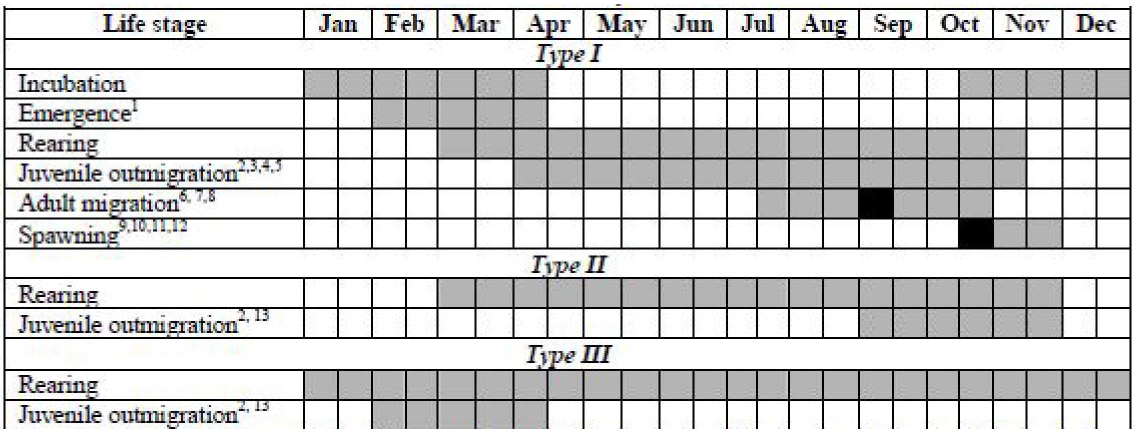
Chinook salmon of the Klamath River Basin are comprised of two runs or races, the spring-run that immigrates during the spring and early summer, and the fall-run that immigrates in the late summer and early fall. Adults of each race use similar habitat areas in the basin, largely separated by timing of use. Adult fall-run immigration into the Klamath River estuary and lower Klamath River can be subjected to environmental stressors that can result in premature mortality, as was documented in 2002. Greater details on life-history timing of the spring- and fall-run are provided in Tables 3 and 4.

Table 3. Life-history Timing of Spring-run Chinook Salmon in the Klamath River Basin Downstream of Iron Gate Dam. Peak activity is indicated in black. (Table, and associated references, are from Stillwater Sciences, 2009)



[1] Olson (1996); [2] West 1991; [3] Tuss et al. (1990, as cited in Olson 1996), [4] NAS (2004, as cited in FERC 2006); [5] Barnhart (1994); [6] NRC (2004); [7] Dean (1995a); [8] Sartori 2006a; [9] Sullivan (1989), [10] Dean (1994); [11] Dean (1995)

Table 4. Life-history Timing of fall-run Chinook Salmon in the Klamath River Basin Downstream of Iron Gate Dam. Peak activity is indicated in black. (Table, and associated references, are from Stillwater Sciences, 2009)



[1] USGS (1998, as cited in NRC 2004); [2] Scheiff et al. (2001); [3] Chesney 2000; [4] Chesney and Yokel 2003; [5] Voight and Gale 1998); [6] NAS (2004, as cited in FERC 2006); [7] USGS (1998, as cited in NRC 2004); [8] Strange (2007); [9] Shaw et al. (1997); [10] Magneson (2006); [11] Lau (CDFG, pers. comm., 1996, as cited in Shaw et al. 1997); [12] Hampton (2002); [13] Wallace 2004

The riparian corridor of the Trinity River, as well as the lower Klamath River system is used by numerous species of amphibians, reptiles, and birds.

3.2.2 Sacramento River Basin

Several anadromous fish species of special concern use the waterways in the Sacramento River Valley in which Trinity River water is used. Species of potential concern include the following federally-listed species: Central Valley steelhead (*O. mykiss*), spring- and winter-run Chinook salmon, and the Southern DPS population of North American green sturgeon (*Acipenser medirostris*).

3.3 Indian Trust Assets

Indian trust assets were described and considered in the TRMFR EIS/EIR and the associated Record of Decision. Specifically relevant to the No Action Alternative and the Proposed Action considered in this EA are the tribal trust fisheries in the Klamath and Trinity Rivers. Multiple court rulings have established the important “Indian purpose” for the Hoopa Valley Indian Reservation and the Yurok Indian Reservations was to reserve tribal rights to harvest fish from the Klamath and Trinity Rivers. The Hoopa Valley Indian Reservation is located on the Trinity River and the Yurok Reservation is on the Klamath to its confluence with the Trinity. Numerous and varied trust assets exist in the vicinity of the Proposed Action including fish, riparian plants and wildlife. The primary Indian Trust Assets with potential to be affected by the Proposed Action are tribal fishing rights. These fishing rights are held in trust by the United States for the benefit of Indians. While the Hoopa and Yurok Tribes are mentioned here, there are also others within the region including the Karuk, Klamath tribes, Resigini Rancheria, and Quartz Valley Indian Tribe.

3.4 Environmental Justice

The Trinity and Klamath Rivers flow through rural areas including Trinity County. In general, Trinity County is a lower-income population and recreational fishing is an important source of revenue. Additionally, these rivers both run through the Hoopa Valley Tribe and Yurok Tribe Reservations. Generally speaking, the Reservations' populations are lower-income and traditionally rely on salmon and steelhead as an important part of their subsistence.

Water from the Trinity Division of the CVP goes in part to farms in the Sacramento River Basin that support low income and/or migrant populations.

3.5 Socioeconomic Resources

Affected socioeconomic resources include commercial, recreational, and tribal salmon and steelhead fisheries on Klamath Basin stocks and the associated economic activities. These activities occur in either the Pacific Ocean or in the estuary or Klamath River Basin. Trinity Reservoir supports tourism, recreation, and fishing. Also, water from Trinity Reservoir is exported to the Central Valley for consumptive use and generation of hydroelectric power.

3.6 Power Generation

The TRD has the capacity to generate substantial hydroelectric power per acre-foot of water diverted because the elevational difference between where it originates in Trinity County to the locations it is delivered. Diversions to the Sacramento River Basin provide for gravitational flow to generate hydropower at several power plants that result in a higher than average rate. In addition to generating power at Trinity and Lewiston Dams in the Trinity Basin, hydropower is also generated at Judge Francis Carr and Spring Creek Powerplants, then at Keswick Powerplant (part of the Sacramento River Division). In total, operations of the TRD alone can account for as much as 30 percent of the total power generation capability of the CVP (TRMFR EIS).

Power generation at Trinity Dam is dependent on storage as well as downstream needs for cold water. Acquiring water through the penstock occurs during periods of higher storage to allow cold water to be withdrawn. In contrast, when the storage gets low enough to entrain water of an unsuitable temperature into the powerplant, Reclamation must switch to use of the auxiliary bypass outlet.

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Section 4 Environmental Consequences

4.1 Water Resources

For purposes of the effects analyses that follow, hydrological forecast information for both short-term and long-term are included. However, it is paramount that the reader understands that hydrologic forecasts can be fairly accurate in the short term but become less so with larger time frames. As such, the long-term forecast information (1 year) provided herein is speculative in nature and considerable uncertainty is likely associated with these values.

4.1.1 No Action Alternative

Selection of the No Action Alternative would result in lower late-summer flows on the Trinity and Klamath rivers. Use of the auxiliary bypass would still be necessary to meet temperature targets.

Under the No Action, flow from Lewiston Dam during August and September would include a one-day pulse (plus ramping up and down) of approximately 2,650 cfs on August 17 to meet a flow requirements for ceremonial purposes at the Hoopa Valley Tribes reservation on August 18. In addition, and outside of this ceremonial need, flow from Lewiston Dam would remain at 450 cfs consistent with the prescription of the Trinity River ROD. During the time of the peak flow arrival, flow of the lower Klamath River at KNK would increase to approximately 4,000 cfs. Thereafter, and barring any precipitation events that may increase flow in the lower Klamath River, flow of the lower Klamath River could continually drop at or slightly below 2,000 cfs during the late summer. This anticipated flow level is similar to what was experienced in 2002, as well as 2014 minus the augmentation action.

4.1.1.1 Coldwater Storage Availability and Water Temperatures

Storage in Trinity Reservoir would remain at approximately 595 TAF at the end of September, which is just slightly lower than the 605 TAF that occurred at the end of September in 2014. The estimate of end of November storage in Trinity Reservoir with a temperature of less than 52 °F would be 176 TAF. These flows and storage volumes are consistent with the existing condition; therefore, there would be no new effects to cold water resources.

There would be no impacts anticipated within the Sacramento River Basin from selection of the No Action Alternative. The quantity and quality (i.e. water temperature) of flow would remain suitable for transbasin diversions to Whiskeytown Reservoir in 2015, representing the source of water for the Clear Creek and Spring Creek diversions to Keswick Reservoir.

Under a 50 and 90 percent probability of exceedance forecasts, the projected storages at the end of September (EOS) for the No Action alternative are 599 and 595 TAF, respectively (Table 5). These values would be similar to that of 2014 (605 TAF), which included the supplemental flows of 64 TAF. Placing these values in context, however, the EOS storages would rank the second lowest storage in the drought years reviewed (Table 6).

In contrast and looking further into the future, under the 50 and 90 percent probability of exceedance forecasts, the end of July (EOJ) storages would be 802 and 357 TAF (Table 5). Placing these projected storage values into the context of what occurred in the past, the 50 and 90 percent forecast values would rank 2nd and 1st in terms of lowest storage, respectively (Table 6).

Table 5. Storage Projections (TAF) of Trinity Reservoir

Time Period	50 Percent (Probability of Exceedance)[b]		90 Percent (Probability of Exceedance)[c]	
	No Action	Proposed Action[d]	No Action	Proposed Action[d]
End of Sept 2015	599	548 (511)	595c	544 (507)
End of Julye 2016	802	751 (714)	357c	306 (269)c

a – all projected storage values assume a Trinity River Record of Decision flow volume for a Dry water year type or 453TAF and the Hoopa Valley Tribal dance flow volume is used in 2015

b – Monthly diversions (TAF) to the Sacramento Basin: Aug- 90, Sept- 61, Oct-40, Nov-19, Dec-1, Jan-1, Feb-0, Mar-3, Apr -26, May - 24, Jun - 93, Jul – 88

c – Monthly diversions (TAF) to the Sacramento Basin: Aug- 89, Sept- 62, Oct-15, Nov-28, Dec-19, Jan-6, Feb-1, Mar-1, Apr -38, May - 37, Jun - 117, Jul – 89

d – Storage volume remaining following the preventative flow (preventative flow plus emergency flow)

e – Hydrologic forecasts this far out are subject to large errors.

Table 6. End Month Storages in Drought Years

Drought Year	End of July Storage (TAF)	End of September Storage (TAF)
1977	535	242
1991	1,048	670
1992	958	838
2009	1,149	919
2012	2,078	1,799
2013	1,590	1,303
2014	865	605
2015	834	595 or 599 (or 544 or 548 with Proposed Action)

Under the Proposed Action, flow from Lewiston Dam would be the same as the No Action Alternative until August 19, After August 19, there are two possible changes to flow releases that depend on whether the fish metric of harvest of 7,000 adult salmon in the lower Klamath has been met or not. If this target is met during the Ceremony, the flow from Lewiston Dam would seamlessly transition from the down-ramping of the Ceremonial flow to a target flow of 2,800 cfs in the lower Klamath River. In the event that this metric is not met, flow from Lewiston Dam would be reduced at prescribed down ramping rates towards a base flow of 450 cfs but then would again be increased from Lewiston on August 22 to meet a target flow of 2,800 cfs in the lower Klamath River. Flow would be regulated to maintain this target through September 20. Based on the July 8 forecast of river flow accretion and expected releases from Iron Gate Dam, the estimate of flow from Lewiston Dam to meet this target flow would likely be between 1,100 and 1,300 cfs. This represents an increase of flow from Lewiston of between 650 to 850 cfs over the No Action alternative. Flows of this magnitude or higher have been observed in the recent past, largely from prior augmentation actions directed at averting a die-off in the lower Klamath River, but also for the support of Tribal ceremonial needs of the Hoopa Valley Tribe in odd numbered years, including this year. Assuming flow to meet the target of 2,800 cfs was needed immediately following the Ceremonial flow and extended through September 20, the volume of water that could be used as a preventative measure would be approximately 51 TAF.

If conditions are met to implement a preventative pulse flow, the pulse flow would commence immediately following the confirmation of *Ich* on at least three adult salmon having low level infections of *Ich* (less than 30 *Ich* parasites on one gill arch) during the first or second week of September. The 3- day pulse (including ramping up and down) peaking at 5,000 cfs in the lower Klamath River would occur during the preventative flow augmentation period. During the one-day peak, the flow from Lewiston could be up to 3,500 cfs. Implementing this action would result in flows from Lewiston being approximately 3,500 cfs. The benefit of the pulse is to enhance flushing of the river of parasites while also facilitating movement of adult salmon in this year of potentially higher *Ich* levels. The pulse flow would constitute a volume of approximately 7 TAF when considering the base flow target of 2,800 cfs is in effect. (Note: The volume needed to potentially meet this need would come from the differences between the old accretion forecast values as included in the Draft Environmental Assessment, which were underestimates, and new estimates of higher accretion that result in a likely reduction of augmentation flow to meet the downstream target: this update on accretion means the evaluations that follow are still under the scope of the total volume considered in the Proposed Action).

In the unlikely event that the emergency portion of the action is implemented, flow from Lewiston Dam could increase up to 3,500 cfs any time after August 19th to meet a target flow in the lower Klamath River of 5,000 cfs. However, based on the preventative flow target of 2,800 cfs in the lower Klamath River it is unlikely that this need would arise (USFWS 2015). In addition, the possible implementation of a preventative pulse flow, would likely further reduce the chance that the emergency flows would be need. Again, real-time monitoring would be used to inform Reclamation as to whether an *Ich* epizootic was occurring and would invoke use of the emergency water.

If implemented, the emergency flows would represent an approximate increase of 3,000 cfs from Lewiston Dam over the No Action Alternative or 3,500 cfs. The duration of this flow would occur over five days and would be subject to Federal biological review of the information at hand including forecast meteorology and fish disease monitoring results (See Section 2.2. Proposed Action). Implementing the emergency component of this action could occur later in September if needed, although based on the period of past augmentation actions, the need for an augmentation beyond early October diminishes as day length decreases, ambient air temperature cool and chances of precipitation increase. Up to 37 TAF could be used if the emergency flows were implemented.

Implementing an emergency action would require rapid planning by Reclamation and other agencies and tribes to identify the response measure that may be needed to avert a die-off, including release of up to 5 days of flow from Lewiston Dam to target a flow of 5,000 cfs in the lower Klamath River. The need for a rapid response is based on the potential for rapid spread of a disease outbreak and the approximate 2-day travel time of water from Lewiston Dam to the lower Klamath River. The implementation of a protocol to ensure timely exchange of information to inform managers of the need to implement the emergency action would occur. The volume of water that may be used in this portion of the action may include up to 37 TAF. In combination with the preventative flows, the Proposed Action could require up to 88 TAF of cold water from Trinity Reservoir.

4.1.1.2 Coldwater Storage Availability and Water Temperatures

Implementation of the Proposed Action is not expected to adversely influence the water temperatures of water released to the Trinity River or that which may be diverted to the Sacramento River in 2015. This conclusion was determined through use of the Sacramento River Temperature Model (SRTM). Through this modeling effort, Reclamation was able to: (1) gain an understanding regarding the sensitivity of water temperature responses to releasing water from Trinity Reservoir through either the power outlet (elev. 2100’) or the auxiliary outlet (elev. 1999’) in 2015; and (2) refine our knowledge of how an augmentation action (up to 88 TAF) could influence the quantity of remaining cold water resource in Trinity Reservoir through 2015. In essence, this modeling effort provided a way to estimate the remaining quantity of suitable cold water to help determine the feasibility of implementing the proposed augmentation action. From this review, Reclamation determined (1) the auxiliary outlet was important for reducing water temperatures at Lewiston Dam and outlets of Whiskeytown including Whiskeytown Dam and Spring Creek Tunnel; and (2) that adequate cold water supply would be available in support of the flow augmentation action as well afterward through November, which is beyond the time of water temperature concern for 2015. Implementing the preventative portion of the Proposed Action would reduce the storage (and in particular the cold water storage) in Trinity Reservoir by up to 51 TAF resulting in an EOS 2015 storage of approximately 544 TAF. In comparison to the No Action Alternative with an estimated 176 TAF of water less than 52 °F at the end of November, the Proposed Action would result in a reduction of approximately 51 TAF, with an estimate of 125 TAF remaining. Placing the EOS storage volumes into a historical context, these projected storage volumes would represent the 2nd lowest EOS storage recorded since the TRD was developed, only rivaled by the 1977 drought when the EOS storage at Trinity was 242 TAF (Table 6). As previously mentioned, however, the long term hydrologic forecast is subject to considerable uncertainty.

Looking further into the future (end of July [EOJ], 2016), the forecasts show more divergence (Table 5). Implementing the Proposed Action would use up to 51 TAF resulting in EOJ storages of 751 and 306 TAF, respectively. Placing the EOJ 2016 storage values in perspective, the 90 percent exceedance projection would, as in the No Action alternative, likely represent the worst storage condition for Trinity Reservoir for this month since the project was developed (See Table 6). As an example, the EOJ storage in 1977, representing the lowest storage years on record, the storage was 535 TAF, which is larger than what is projected under 90 percent condition with or without the Proposed Action.

Again in contrast to the dry year forecast, the situation improves with a median year forecast (50 percent forecast) where storage is projected at 716 TAF at the end of July 2016 after a total release of 88 TAF. In comparison to 2015, this volume would be approximately 115 TAF less than what occurred in 2015 or 834 TAF. Taking this into account as well as the temperature modeling analysis that indicated there would be approximately 100 TAF available at the end of

November 2015, it would suggest that under this forecast (and assuming similar cold water storage as in 2015) there could be enough suitably cold volume to meet the basic water temperature needs in the Trinity through November. As with the dry year forecast (above), if as the year progressed and forecasting becomes more accurate that there may also be a need to re-operate the TRD up to and including altered diversion patterns and schedules to ensure an adequate supply of suitably cold water is available to meet in-basin needs. Compared to the dry year forecast, the potential need to change operations of the TRD would be reduced.

Predicted water temperatures for water released from Lewiston Dam for a No Action alternative and Proposed Action are shown in Figure 6. These results are based on a schedule of release of 83 TAF over the period of August 15 to September 30 to provide an approximation of the water temperatures that could occur this year. Reclamation initially conducted the water temperature assessments on a volume of 83 TAF; however, based on public, agency and tribal review of the 83 TAF proposal, the proposed action has been modified to a maximum of 88 TAF. The change in the proposed action from 83 TAF to 88 TAF is not significant to the sensitivity of the model or the results. Thus, the results of the analysis are believed to be suitable to the new action. These results are based on a suite of assumptions that included foreseeable events and the use of the auxiliary bypass outlet and release of 83 TAF versus what is believed to be more realistic volume to be used in 2015 or up to 51 TAF (USFWS 2015). These results suggest that suitable water temperatures would be available for release in 2015 under either alternative.

If Trinity Reservoir fills during 2016, there would be no effects to water resources available for all potential purposes. In contrast, if Trinity Reservoir does not fill in 2016, some water volume, up to the amount released for supplemental Klamath River flows, may not be available for other potential purposes.

Implementation of the Proposed Action would not affect water supply allocations managed as part of the CVP in 2015, or water operations within the Central Valley. Water allocations for irrigation and M&I deliveries have already been determined for 2015, and the supplemental water would not affect the projected volume of water to be exported to the Sacramento River Basin in 2015. The extent that the flow augmentation releases would affect the 2016 water supply and water allocations is dependent on the water year 2016 hydrology and operational objectives. However, long range predictions of the 2016 hydrology are not expected to be accurate at the time writing this document to be meaningful. This is especially true when the forecast spans a time when rainfall typically occurs.

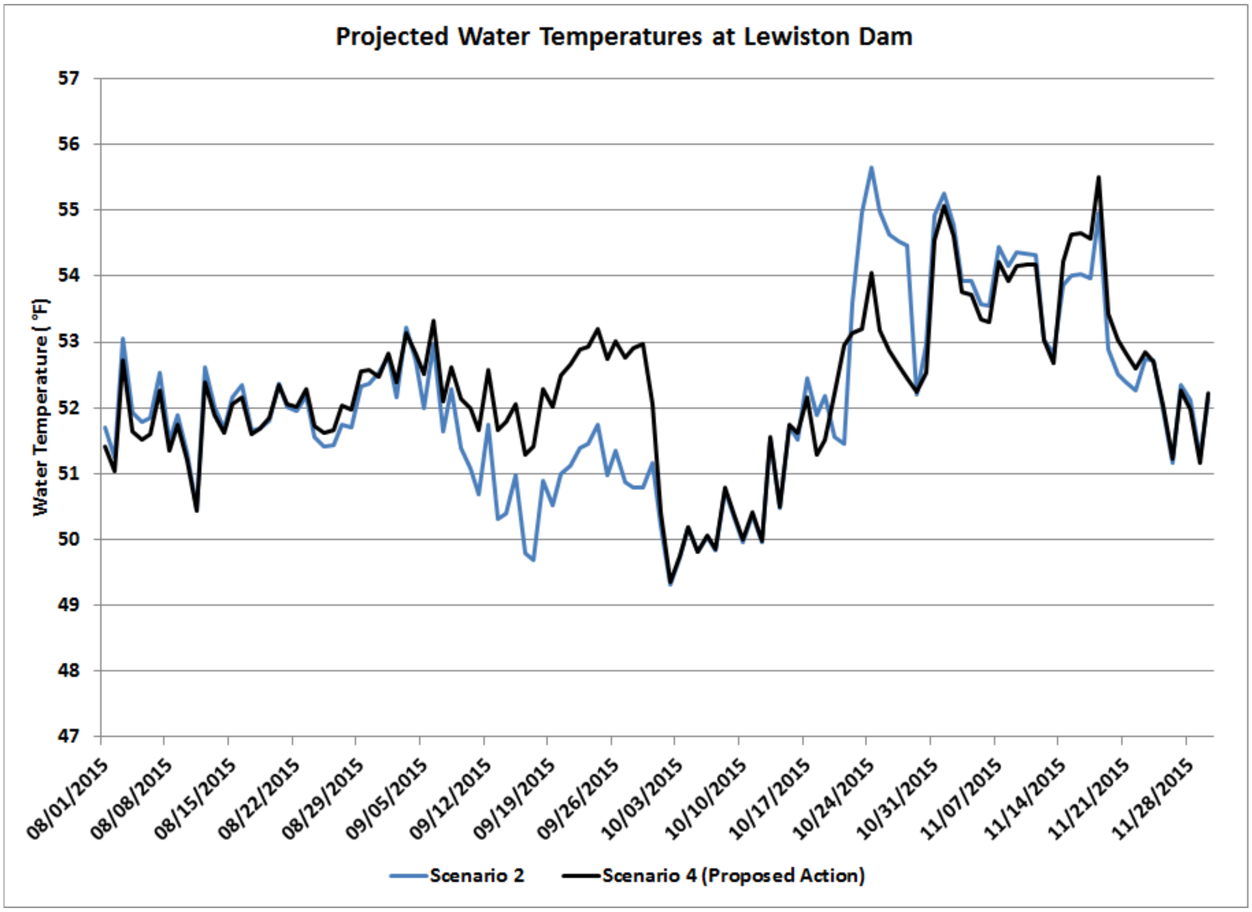

Figure 6. Sacramento River Temperature Model Results Showing the Influence of the Augmentation Action and the Thermal Regime from Lewiston Dam with Scenario 2 (No Action Alternative) and the Scenario 4 (Proposed Action)

With a target flow rate of 2,800 cfs the preventative flows could account for up to 51 TAF of cold water out of Trinity Reservoir. All indications are that a preventative flow rate of 2,800 cfs makes it very unlikely there would be a need for the preventative pulse flow or the emergency flows, so the volume of the Proposed Action is anticipated to be limited to 51 TAF or less. The potential impact looking forward into 2016 could mean 51 TAF less cold water available for transbasin diversion to the Sacramento River Basin but this remains uncertain. If the extreme drought conditions were to continue, the potential impacts of the drought on storage in Trinity Reservoir could result in approximately 306 TAF being left in Trinity Reservoir (total storage volume) by July 2016 after implementation of the 51-TAF preventative flows (See Table 5). However, and as stated at the start of Water Resources section, using forecasts this far into the future become speculative in nature. Therefore, projecting possible storage in 2016 cannot be determined with any precision whether this volume would occur let alone be enough to meet in-basin needs, or to support transbasin diversions. If this situation was to occur, diversion patterns and schedules would need to be altered to ensure an adequate supply of suitably cold water is available to meet in-basin needs.

In the unlikely event that additional releases are needed above the 51 TAF based on the emergency criteria identified in the project description (see Section 2.2) up to 37 TAF of additional cold water may be released. This would be a total reduction in the Trinity cold water pool of up to 88 TAF. This is potentially 88 TAF unavailable for diversion to the Sacramento River Basin. Direct effects of this loss could include reduced amounts of suitably cold water if the drought continues. For example, with a dry forecast (90 percent exceedance), the end of July storage in 2016 could be as low as 270 TAF. In this case, and based on the diversion patterns and quantities that were included in this forecast volume, there would not be an adequate supply of cold water to meet the needs within the Trinity River Basin nor those outside of the basin (i.e. Sacramento River Basin) in 2016. In this case there would be a need to alter operations in the Trinity River Division up to and including altered diversion patterns and schedules to ensure an adequate supply of suitably cold water is available to meet in-basin needs. Trinity water must first be used to support Trinity River Basin needs before transbasin diversions can be considered. However, the degree to which these altered management strategies would be needed would largely depend on future hydrology that is at this time very difficult to accurately predict.

In 2015, recreational activities in Trinity Reservoir are not likely to change to any great extent due to the Proposed Action. In the current year, boat ramp access to the lake is expected to remain the same as the No Action Alternative (see Section 4.5.2 for additional discussion). In contrast, there is a small chance that some boat ramps might not be useable due to a reduced water elevation in the lake during the latter part of summer 2016, should the drought continue. As alluded to earlier, the complexities and uncertainties of accurately predicting water storage, and thus surface elevations, into the long term future precludes Reclamation from providing meaningful estimates.

The significant recreational activities in the Trinity River that may be influenced by the Proposed Action include pleasure rafting and fishing (boating), and recreational fishing. Flows from Lewiston Dam needed to augment the lower Klamath River flow to 2,800 cfs would be expected to continue to provide bank- and boat-based fishing as well as boating opportunities along the entire river. In addition, the greater quantity of water in the lower river would afford greater power boat access to a larger section of the Klamath River thereby expanding fishing opportunities for many.

4.2 Biological Resources

4.2.1 No Action Alternative

Because the projected minimum flow of the lower Klamath River is relatively low, the medium to large run-size projection for fall Chinook salmon, and the presence of *Ich* already in the river system there is an increased risk for a fish die-off in the lower Klamath River in 2015 under the No Action Alternative. While the temporary increase in flow for the tribal Ceremony could provide temporary relief for stressful environmental conditions in the lower Klamath River, the duration of influence of the pulse would likely only last between 5 and 7 days, which would not be long enough to cover the entire period of concern (or mid-August to mid-September). The tribal pulse flow would also occur very early in the fall-run; typically the fall-run does not begin until the last week of August, with federally-listed coho typically entering the Klamath River Basin in September. This pulse flow could help to flush any *Ich* currently in the river, but it would not help during peak run time when fish would likely be in highest concentrations, typically the second week of September. In 2014 levels of *Ich* infection didn't spike until mid-September, necessitating an emergency release.

If a fish die-off similar to that which was experienced in 2002 was to occur, it would be not only devastating this year, but would have lasting impacts to the species. Such a large fish die-off can affect the age class structure of salmon populations for a number of years. The consequences could also prevent the Trinity River Restoration Program (TRRP) from meeting natural fall-run Chinook salmon escapement goals.

4.2.2 Proposed Action

4.2.2.1 Trinity and Klamath River Basins

The difference in flow from implementation of the Proposed Action is not anticipated to affect wildlife species that use riparian corridors along the Trinity and Klamath rivers. This is based on experience and observations from past augmentation actions.

Under the Proposed Action, the susceptibility of returning adult fall Chinook salmon to diseases that led to the 2002 fish die-off would be expected to decrease in the lower Klamath River during late summer of 2015. It is well documented that the Trinity River and lower Klamath River would see a reduction in water temperatures (Magneson and Chamberlain 2015) (see Figure 6). In turn, salmon may experience less physiological stress and vulnerability to disease. In 2003, 2004, and 2012-2014, supplemental flows were implemented, and general observations were that the sustained higher releases from mid-August to mid-September in each year coincided with no significant disease or adult mortalities, with the exception of 2014 when an additional releases of a lower magnitude (less than 2,500 cfs) was required to combat a September *Ich* outbreak.

The estimates of cold water storage available after November if the Proposed Action is implemented (See Section 4.1.2) suggest there is cold water to support an augmentation action of up to 88 TAF. Thus implementing the Proposed Action would not jeopardize the cold water resources for immediate use in 2015. Thermal protection required for coho salmon during late September would still be achievable.

High flows associated with the Proposed Action have the potential to minimally impact coho salmon, by creating a stranding potential. Rearing juvenile coho may be present in the mainstem Trinity River downstream of Lewiston Dam throughout the entire Proposed Action period, with adults entering the Klamath River Basin around mid-September. Estimated base flow releases from Lewiston Dam, as part of the preventative augmentation portion of the Proposed Action, are anticipated to be between 1,100 and 1,300cfs to meet a 2,800 cfs target in the lower Klamath River. This flow rate typically does not create stranding hazards, because downstream flows are not high enough to overtop berms. However, because the Proposed Action will result in cooler temperatures in the upper Trinity River, habitat for rearing juvenile coho salmon will increase longitudinally downstream from the dam because a greater length of river will be at suitable and optimal water temperatures for juvenile coho salmon rearing.

If the preventative pulse flow was used, the overall impact would be anticipated to be positive in nature for the fish species. The pulse flow would be intended to flush and dilute *Ich* parasites and also provide improved water quality and flow to facilitate movement of adult salmon to further help alleviate the potential for disease outbreak. Early signs of *Ich* infections on adult salmon in the Klamath River system have been detected early this year (July 22) as compared to the past to suggest there could be higher levels of *Ich* infectivity this year (Strange 2015).

Although not anticipated being needed, if the preventative pulse flow or the emergency release component is implemented, riparian berms throughout the action area would likely be overtopped. Juvenile fish may distribute themselves into temporarily inundated areas. As flows from Lewiston Dam recede to a baseline level of 450 cfs, these areas could become disconnected from the mainstem and any juveniles in them have the potential to become stranded. The TRRP has completed a significant amount of channel restoration work that has helped to reduce the number of potential stranding locations along the river. Additionally, the potential for stranding will be minimized by implementing conservative flow release changes (ramping rates) that will allow fish to move into the mainstem before connectivity to temporarily inundated areas is lost. Based on the number and location of potential stranding locations and implementation of conservative ramping rates, the proportion of juveniles that may be affected by the Proposed Action is anticipated to be small and will minimally effect the overall freshwater survival of brood year 2014. Based on past augmentation experiences, including 2014 when an emergency flow was released, the benefit to coho as a species from implementation of the Proposed Action outweighs the smaller impact to juveniles.

Given the inherent uncertainties regarding events of this nature, combined with the predicted moderately large fish run size to the Klamath River basin, it is not possible to predict with absolute certainty that the Proposed Action will preclude a fish die-off in 2015, nor is it possible to accurately quantify the reduced disease risk attributed to the increased flows. Given past experiences in 2003, 2004 and 2012-2014, the knowledge of cold water requirements for salmon, and the contributing factors to disease outbreak (warm water temperatures, low water velocities and volumes, high fish density, and long fish residence times (Guillen 2003; Belchik et al. 2004; Turek et al. 2004)), implementation of the Proposed Action or its various components including the preventative, preventative pulse flow or the emergency flows are anticipated to reduce the risk of Ich infection and associated fish die-off fall of 2015. Furthermore, and most importantly, the preventative component of the Proposed Action is believed to be adequate to ensure that a preventative pulse or emergency releases are not needed.

4.2.2.2 Sacramento River Basin

Implementation of the Proposed Action would not affect the quantity and quality (i.e. water temperature) of flow suitable for transbasin diversions to Whiskeytown Reservoir in 2015 (See Section 4.1.2.1).

To assess potential impacts to winter-run Chinook rearing in the Sacramento River Basin, egg and egg-to-fry mortality were estimated for the Clear Creek and Bend Bridge temperature nodes on the Sacramento River using a dynamic simulation framework model developed by Cramer Fish Science (CFS 2010).

This model was developed to estimate winter-run Chinook salmon juvenile production, but provides discretized mortality rate estimates for specific life stages. The model was run for the No Action Alternative without use of the auxiliary bypass, the No Action Alternative with use of the auxiliary bypass, the Proposed Action without use of the auxiliary bypass, and the Proposed action with use of the auxiliary bypass. The model assessed potential impacts through November 2015. Table 1 shows the estimated temperature-induced egg mortality and egg-to-fry survival results for each of the above-mentioned operational scenarios. Differences in effects on early lifestage survival of winter-run Chinook between the scenarios are very small at both modeled locations (Clear Creek and Bend Bridge). For temperature-induced egg mortality, the difference between scenarios was so small it was within the uncertainty in the model, in other words there is no measurable impact to winter-run Chinook in 2015 from implementation of the Proposed Action.

Water temperature predictions used in the modeling reflected a flow augmentation action of 83 TAF. It is important to note that since the time of these model runs that slight modifications to the Proposed Action occurred bringing the total volume up to 88 TAF; however the change in the proposed action from 83 TAF to 88 TAF is not significant to the sensitivity of the model or the results. Furthermore, the proposed action is not likely to require the emergency component so that the amount of water used is likely to be up to 51 TAF. Thus, the results of the analysis are believed to be equally applicable to the new action.

Trinity and Shasta Reservoirs are operated in a coordinated fashion. Depending on the details of future operations and the fill pattern at both reservoirs, the Proposed Action may reduce the available cold water resources used to meet temperature objectives in the Sacramento River in 2016. If the drought persists and the full 88 TAF was used, changes to the ability to achieve temperature objectives would be expected, which could impact ESA-listed salmon and steelhead. It is unlikely the full 88 TAF would be released, and thus the impacts are equally unlikely.

Table 7. Sacramento River Winter-run Chinook Salmon Temperature-induced Egg Mortality and egg-to-fry Survival Estimated from the Cramer Fish Science model (CFS 2010b). These model runs used actual temperatures from April 1 through July 21 and modeled temperatures from July 22 through October 30 (Scenario 2) or November 30 (Scenarios 1, 3-4). CCR = Clear Creek node on the Sacramento River and BND = Bend Bridge.

	Scenarios*							
	1		**2**		**3**		**4**	
	CCR	**BND**	**CCR**	**BND**	**CCR**	**BND**	**CCR**	**BND**
Temperature-induced egg mortality (%)	5.1	86.6	5.0	86.8	5.1	87.1	6.0	87.7
Approximate egg-to-fry survival (%)	20.1	2.8	20.2	2.8	20.1	2.7	19.9	2.6

*Modeling scenarios include Lewiston Dam releases to meet:

1. Base Trinity River Record of Decision flows (ROD flows) and Hoopa Valley Tribal Dance flows (August 15-August 18)
2. Base ROD flows, Hoopa Valley Tribal Dance (August 15-August 18), and Bypass flows (through October 30)
3. Hoopa Valley Tribal Dance flows from August 15-August 18, and a 2,500 cfs target at KNK from August 19-September 20 followed by seven days of releases to meet a 5,000 cfs target at KNK
4. Hoopa Valley Tribal Dance Flows from August 15-August 18; a 2,500 cfs target at KNK from August 19-September 20, followed by seven days to meet a 5,000 cfs target at KNK; and Bypass flows (through November 30)

4.3 Indian Trust Assets

4.3.1 No Action Alternative

Because the projected minimum flow of the lower Klamath River is relatively low, the medium to large run-size projection for fall Chinook salmon, and the potential of Ich presence in the river there is an increased risk for a fish die-off in the lower Klamath River in 2015 if the No Action Alternative is selected. A fish die-off in 2015, regardless of apparent causes, would be devastating for the tribal trust fisheries in the Klamath and Trinity Rivers.

The Hoopa Valley Tribe and the Yurok Tribe both depend on the salmon harvest for subsistence, ceremonial, and commercial needs to maintain a moderate standard of living. These Tribes have fished these rivers for thousands of years and tribal culture is deeply connected to the river and the salmon. Without the harvest, tribal communities would be greatly impacted.

4.3.2 Proposed Action

Under the Proposed Action, it is expected that the risk of disease vulnerability to the returning run of fall Chinook salmon to the lower Klamath River would be decreased, relative to the No Action Alternative. In turn, the risk to the tribal trust fishery would be expected to decrease. In 2003, 2004 and 2012-2014, supplemental flows were implemented, and general observations were that the sustained higher releases from mid-August to mid-September in each year coincided with no significant adult mortalities.

4.4 Environmental Justice

4.4.1 No Action Alternative

Because the projected minimum flow of the lower Klamath River is relatively low, the medium to large run-size projection for fall Chinook salmon, and the potential of *Ich* presence in the river there is an increased risk for a fish die-off in the lower Klamath River in 2015 if the No Action Alternative is selected. A fish die-off in 2015 would negatively impact tribal trust fisheries, commercial, and recreational fisheries in the Klamath and Trinity Rivers. Impacts could also arise in ocean salmon fishing commerce, as a large die-off of salmon in 2015 could result in a diminished brood year and fewer fish returning to the ocean. These impacts could translate into environmental justice impacts, as many of the communities depending on these fisheries are considered low-income and/or are made up of minority populations.

4.4.2 Proposed Action

Under the Proposed Action, it is likely that the run of fall Chinook salmon returning to the lower Klamath River in the late summer would be less susceptible to a disease outbreak similar to that which ultimately caused the 2002 fish die-off. In turn, the risk to the tribal, commercial and recreational fisheries, and the associated environmental justice would be reduced.

Implementation of the Proposed Action would reduce the water storage of Trinity Reservoir by as much as 88 TAF, however Reclamation anticipates only the preventative flows will be required meaning up to 51 TAF would be released. This could reduce transbasin diversions to the Sacramento River Basin in 2016 depending on whether or not the drought persists. In 2014 approximately 602 TAF were diverted from the Trinity River Basin (via Lewiston Reservoir) to the Sacramento River Basin, and in 2015 a total of 425 TAF are anticipated to be diverted, with the decrease in part due to the continued drought. While exports from the Trinity Basin are used for a variety of purposes in the Sacramento River Valley, these diversions likely make up only a small fraction of the total water used. If 2016 is another drought year, the effects to environmental justice would be minor. If 51 TAF is released and a more median winter/spring ensues, implementation of the Proposed Action is anticipated to have even less of an effect on low-income and/or minority populations who depend on CVP water allocations.

4.5 Socioeconomic Resources

4.5.1 No Action Alternative

Because the projected minimum flow of the lower Klamath River is relatively low, the medium to large run-size projection for fall Chinook salmon, and the potential of Ich presence in the river there is an increased risk for a fish die-off in the lower Klamath River in 2015 if the No Action Alternative is selected. A fish die-off in 2015 would negatively impact any fishery-related socioeconomic resources. This includes lost revenue from commercial salmon sales, loss of fishing guide and fishing charter revenue (both on the river and ocean), decreased recreational fishing tourism, and the added cost to the people who rely on the salmon for food and must now purchase other food sources.

Under the No Action Alternative the one public boat ramp currently usable (down to a water elevation of 2,170 ft) at Trinity Reservoir, the Minersville Public Boat Ramp, would remain usable. The 90 percent exceedance forecast for Trinity Reservoir storage volume for end of September is 595 TAF, which equates to a water elevation of 2,201 ft. There is no anticipated socioeconomic impact to communities surrounding Trinity Reservoir under the No Action Alternative.

4.5.2 Proposed Action

Under the Proposed Action, Reclamation anticipates a reduced risk of disease susceptibility to the fall-run Chinook salmon returning to the Klamath River in the late summer. In turn, there may be less potential for adverse effects to fisheries-related socioeconomic resources.

Implementation of the Proposed Action would lower the water level in Trinity Reservoir. There is one public boat ramp currently usable at Trinity Reservoir, the Minersville Public Boat Ramp operated by the U.S. Forest Service. The Minersville Ramp is operable down to a lake elevation of 2,170 ft, which translates to a storage volume of 423.5 TAF. Under the Proposed Action using the 90 percent exceedance forecast, the lake elevation will drop to 2,193 ft with just the preventative flows (totaling 51 TAF) and 2,185 ft if the emergency response is implemented and the full 88 TAF is released (Figure 7). Minersville Ramp would remain operable under the Proposed Action. There could be minor socioeconomic impacts to business owners surrounding Trinity Reservoir from reduction in tourism and associated revenue streams, as well as costs associated with moving private docks and ramps. These impacts would come toward the end of the typical tourist season. Lake tourism generally slows after Labor Day.

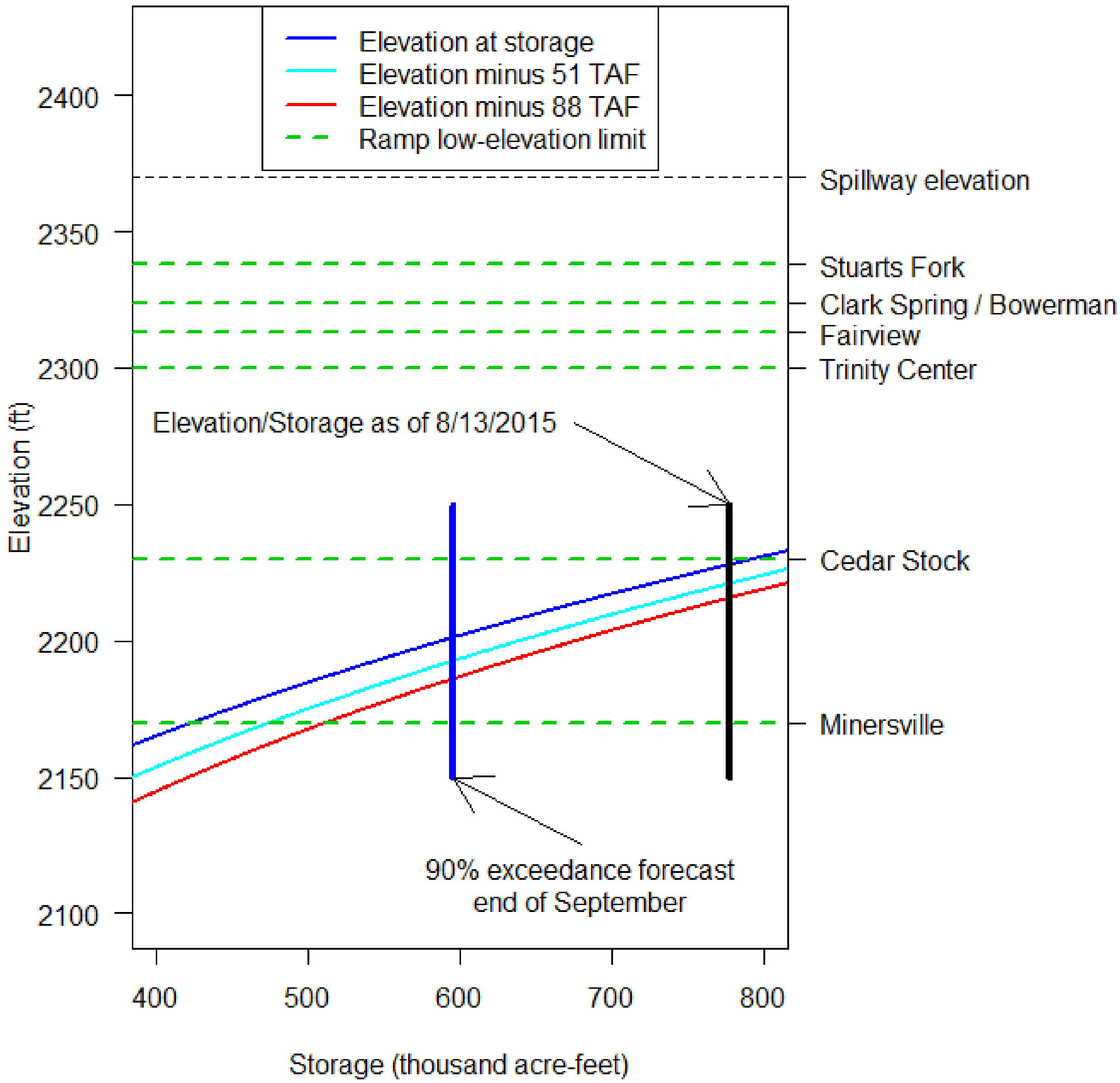

Figure 7. Trinity Reservoir Water Elevation Plotted over Water Storage in TAF for the Proposed Action (both preventative flow and combined with the emergency flow) Showing Boat Ramp Limitations

Depending in part on whether Trinity Reservoir completely fills in water year 2016, there is a possibility that some of the water volume from Trinity Reservoir used to implement the Proposed Action may not be available for other uses in the future. It would be speculative to estimate the amount of water that may be unavailable in the future. However, the amount of water needed for the preventative flows in the lower Klamath River is a small proportion of the total CVP water deliveries. Since the CVP facilities are operated in a coordinated fashion, and annual water allocations to contractors are determined by supply conditions throughout the system, it is unlikely that any allocations to individual contractors would be reduced in the future due to implementation of the Proposed Action.

4.6 Power Generation

4.6.1 No Action Alternative

In order to meet temperature targets on both the Sacramento side and the Trinity side, the auxiliary bypass will be used. Selection of the No Action Alternative will not change this. Use of the auxiliary bypass will release water avoiding the power plants, and thus there is an associated loss in hydropower generation.

Under the No Action Alternative, the flow released from Lewiston Dam into the Trinity River in August and September 2015 would be maintained at 450 cfs, consistent with the flows described in the TRMFR EIS/EIR, in addition to a short term pulse flow from Lewiston Dam to support a one-day ceremonial need of the Hoopa Valley Tribe (see Figure 4). These flows are consistent with the existing condition; therefore, there would be no new effects to hydropower generation.

4.6.2 Proposed Action

Implementation of the Proposed Action will not adversely affect power generation in 2015. The expected schedule for water delivery to the Clear Creek Tunnel has already been developed, and the Proposed Action would not affect these exports. It is anticipated the auxiliary bypass will be used for both the No Action Alternative and the Proposed Action.

If Trinity Reservoir does not fill in water year 2016, some portion of the water that is released through Lewiston Dam to implement the Proposed Action in 2015 may not be available for later release through the Clear Creek Tunnel, Carr Powerplant, the Spring Creek Tunnel and Powerplant and the powerplant at Keswick Dam in 2016. In turn, this may result in decreased power generation. While complex to determine and quantify, depending on the particular refill patterns at Trinity Reservoir, whether safety-of-dams releases occur at Trinity Dam in 2015, and Shasta Reservoir operations, etc.; in very general terms, if 51 TAF were released to the Trinity River to implement the preventative flows under the Proposed Action, future foregone generation could be a maximum of about 56,100 megawatt hours (MWH). At $50 (market estimate based on last year's average rate of $45) per MWH, this equates to a loss in revenue of $2,805,000. However, water levels being as low as they are, it is very unlikely the magnitude of impact would be this large. Use of auxiliary bypass outlet is anticipated regardless of implementation of the Proposed Action. Power generation opportunities are subject to many restrictions and uncertainties unrelated to the Proposed Action. Also, power production patterns are generally driven by water operations decisions. Whether power in excess of Reclamation's water pumping needs is available at a given time, and whether power available for CVP power customers is sufficient for their demands is difficult to predict. In the unlikely event that water operations are changed due to implementation of the Proposed Action, CVP power customers may have to buy power from alternative sources when CVP power would have otherwise been generated using the water that was used to implement the Proposed Action.

4.7 Global Climate

Climate change refers to significant change in measures of climate (e.g. temperature, precipitation, or wind) lasting for decades or longer and is considered a cumulative impact. Many environmental changes can contribute to climate change (changes in sun's intensity, changes in ocean circulation, deforestation, urbanization, burning fossil fuels, etc.) (EPA 2010). Gases that trap heat in the atmosphere are often called greenhouse gases (GHG). Some GHG, such as CO_2, occur naturally and are emitted to the atmosphere through natural processes and human activities. Between 1990 and 2009, CO_2 was the primary GHG (approximately 85 percent) produced in the U.S. due to the combustion of fossil fuels such as coal, natural gas, oil, and gasoline to power cars, factories, utilities and appliances. The added gases, primarily CO_2 and CH_4, are enhancing the natural greenhouse effect and likely contributing to an increase in global average temperature and related climate change.

In 2006, the state of California issued the California Global Warming Solutions Act of 2006, widely known as Assembly Bill 32, which requires California Air Resources Board (CARB) to develop and enforce regulations for the reporting and verification of statewide GHG emissions. CARB is further directed to set a GHG emission limit, based on 1990 levels, to be achieved by 2020. In addition, the EPA has issued regulatory actions under the Federal Clean Air Act as well as other statutory authorities to address climate change issues.

4.7.1 No Action Alternative

Under the No Action Alternative, hydropower generation would occur to some extent depending on the extent of auxiliary bypass use. The amount and timing would vary according to available opportunities and other water release and delivery commitments. CVP power customers would not have to change their power purchase patterns and sources more so than the status quo conditions. Additional hydrocarbon-generated electricity would not have to be purchased in lieu of sustainable sourced power more so than the status quo conditions. Therefore, there would be no additional affects to GHG emissions.

4.7.2 Proposed Action

While no GHG emissions would be generated as a direct result of implementation of the Proposed Action, there may be some broader scale or theoretical effects to GHG emission levels associated with the Proposed Action.

If 51 TAF of water is released from Trinity and Lewiston Reservoirs to augment flows in the lower Klamath River, some of that volume of water may have been exported from the Trinity River Basin at some unknown time in the future, depending on fill patterns for Trinity Reservoir and other operational decisions. In that case, hydroelectric power would have been generated at the J.F. Carr Powerplant, the Spring Creek Powerplant, and likely the Keswick Powerplant. The power generated by this volume of water would have been available for purchase by the CVP preference power customers as available. CVP preference power customers share the CVP energy production that is in excess of Reclamation's water pumping needs. At any given time, CVP power customers may have to purchase power when available CVP power is not sufficient for their demands. This non-CVP power may be hydrocarbon generated. Assuming 51 TAF of water is used for flow augmentation, a maximum of 56,100 megawatt hours of power generation may be foregone at some time in the future. Assuming that power customers would have to replace all of that power with hydrocarbon generated power, an estimated additional 39,581 metric tons of CO_2 equivalent would be emitted. The magnitude and timing of the potential additional CO_2 equivalent is unknown, as are the associated effects on Global Climate. For example, it is unlikely that more than 25,000 metric tons of CO_2 equivalent would be emitted on an annual basis so it is unlikely to have a significant effect on global climate.

4.8 Cumulative Impacts

According to CEQ regulations for implementing the procedural provisions of NEPA, a cumulative impact is defined as “the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions.” Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time.

4.8.1 No Action Alternative

Selection of the No Action Alternative would increase the risk of fish disease outbreak in the lower Klamath River, and could result in a large fish die-off similar to that which was experienced in 2002. If another fish die-off was to occur the effects would be immediate but may also have a lasting effect. The immediate effect would be a reduction of fish to harvest by tribal members as well as recreational fisherman. The longer term effect could include partial loss of a cohort of fish that would impact the next generation of salmon returning to the river system.

4.8.2 Proposed Action

4.8.2.1 Water Resources

There are no anticipated substantial cumulative impacts on Trinity Basin water resources related to the Proposed Action. Although there are a number of relatively small-scale water diversions downstream of Lewiston Dam, no additional impacts are expected to occur compared with recent past years.

The TRD of the CVP is operated in coordination with all the other CVP and State Water Project facilities. Due to the inherent difficulty and uncertainty with forecasting future water supply conditions within this large geographic area, it is not possible to meaningfully evaluate how a potential slightly lower Trinity Reservoir storage in 2015 may exacerbate system-wide supply conditions in the future.

Although there are no adverse impacts associated with implementing the Proposed Action in 2015, there is potential for cumulative effects to consider. As previously stated, water was released from Trinity Reservoir to decrease potential for fish disease outbreaks in 2003, 2004, 2012, 2013, and 2014. With continuing drought conditions, reservoirs have not replenished, and in particular cold water stores are very low (See Section 3.1). Looking forward, Reclamation may be implementing flow augmentation actions in future years. Reclamation is in the early phases of NEPA analysis on the Long-Term Plan to Protect Adult Salmon in the Lower Klamath River (anticipate releasing Public Draft EIS early 2016). One of the alternatives being analyzed involves augmenting flows on an annual basis when certain triggers indicate risk of a large disease-induced fish die-off. In other words, Reclamation has implemented augmentation actions in recent years and may do so again in future years.

Repeated releases from Trinity could deplete cold water stores making it difficult to meet regulatory-driven temperature benchmarks in the Trinity and Klamath Rivers. When cold water storage levels are low, water run through hydropower plants can become too warm for downstream aquatic organisms, including sensitive fish species. In this case, use of auxiliary bypass must be relied on in order to meet temperature goals. There is a subsequent loss of both power and the revenue it generates.

Historically water from Trinity Reservoir has been used in conjunction with water from Shasta Lake, to regulate temperatures in the Sacramento River in support of winter-run and spring-run Chinook. If drought conditions persist, releasing additional flows from Trinity Reservoir could reduce the total volume of water available for diversion to the Sacramento River via the Clear Creek Tunnel, as well as the cold water store that in years past has been used to help control the temperature of the Sacramento River. If cold water storage in the Trinity Reservoir is insufficient to support temperature control of the Sacramento River, Reclamation would then need to rely heavily on Shasta Lake. The cold water pool in Shasta Lake is higher in 2015 as compared to 2014 for the same time of year also suggesting adequate storage will be available to meet Sacramento River needs this year. Repeated releases from Trinity Reservoir with continued drought conditions could result in negative impacts to federally-listed fish species such as winter-run, spring-run Chinook salmon, and Central Valley steelhead. Again, however, it is too early to accurately predict the future water supply so there are no anticipated cumulative impacts.

4.8.2.2 Biological Resources

No additional cumulative impacts to biological resources beyond those described in the TRMFR EIS/EIR are anticipated.

4.8.2.3 Indian Trust Assets (ITA)

Cumulative effects to ITA from future activities are somewhat speculative. Activities of Executive Branch Federal agencies who may affect ITA are carefully scrutinized regarding their affects to these assets. State and local activities that are undertaken on non-Federal land are subject to associated limitations, and the resulting affects to ITA would be speculative.

4.8.2.4 Environmental Justice

Cumulative effects of future activities on minority and low income populations are speculative. Federal agency actions are subject to scrutiny regarding their affects to these populations; however, state and local activities on non-Federal lands are not necessarily subject to the same analyses. Therefore, it is speculative to determine the effects of future, non-Federal activities on minority and low income populations.

4.8.2.5 Socioeconomic Resources

Cumulative impacts of future activities on socioeconomic resources are speculative. Federal agency actions are subject to scrutiny regarding their affects to these resources. State and local activities on non-Federal lands are not necessarily subject to the same analyses, so it is not possible to meaningfully determine the effects of future, non-Federal activities on socioeconomic resources.

Section 5
Consultation and Coordination

5.1 Agencies and Groups Consulted

Reclamation coordinated with the USFWS, NMFS, California Department of Fish and Wildlife (CDFW), Hoopa Valley Tribe, and Yurok Tribe in the preparation of the EA. The draft Environmental Assessment was released for public review from July 31 to August 7, 2015. Comments received on the draft were used in developing this final EA and FONSI. Response to comments received on the draft EA are provided in the Finding of No Significant Impact document.

5.2 Endangered Species Act (16 USC § 1531 et seq.)

Section 7 of the Endangered Species Act requires Federal agencies, in consultation with the Secretary of the Interior (through the Fish and Wildlife Service) and/or Commerce, to ensure that their actions do not jeopardize the continued existence of endangered or threatened species, or result in the destruction or adverse modification of the critical habitat of these species.

The Proposed Action would not affect any federally-listed threatened or endangered species under the jurisdiction of the Fish and Wildlife Service. Therefore, there is no need to consult with the Fish and Wildlife Service pursuant to the ESA.

The affected area includes three river basins, the Klamath, Trinity and Sacramento. Water from the Trinity River Division of the Central Valley Project has a transbasin diversion that supplies water to both the Trinity and Sacramento River Basins that in part are used to meet the needs of several fish species protected under the Endangered Species Act (ESA).

For federally-listed threatened and endangered species under the jurisdiction of the Secretary of Commerce (through the National Marine Fisheries Service or NMFS), Reclamation included the proposed action as an amendment to the modifications to the CVP and SWP operations as an update to the Contingency Plan for operation of the CVP and SWP from July through November 15, 2015, in accordance with the RPA and conference opinion on the long-term operation of the NMFS 2009 Coordinated Long-term Operation of the Central Valley Project (CVP) and State Water Project (SWP) Biological Opinion (NMFS 2009 BiOp). This is detailed in the August 14, 2015, letter to NMFS and the accompanying Biological Review. This analysis concluded that because the proposed action is contemplated within the drought exception procedures as described in the 2009 NMFS BiOp it will not result in violation of the incidental take limit in the NMFS 2009 BiOp, nor jeopardize the continued existence of the listed species or destroy or adversely modify their designated critical habitats. NMFS concurred in this determination by letter, dated August 20, 2015.

Reclamation is currently in consultation pursuant to section 7 of the ESA with NMFS for coho salmon in the Trinity River Basin as documented in a letter and accompanying Biological Review submitted to NMFS on August, 12, 2015. Based on the analysis provided in the

Biological Review and the information contained in this EA, Reclamation has determined that the Proposed Action will not violate section 7(d) of the ESA in that the proposed action would not constitute an irreversible or irretrievable commitment of resources which would have the effect of foreclosing the formulation or implementation of any RPA measures which would violate section 7(a)(2) of the ESA.

Reclamation consulted under the Magnuson-Stevens Act (MSA) for the Sacramento River species in the 2009 Biological Opinion (BiOp) and since there was a determination, concurred with by NMFS, that because the proposed action is contemplated within the drought exception procedures as described in the 2009 NMFS BiOp it will not result in violation of the incidental take limit in the NMFS 2009 BiOp, nor jeopardize the continued existence of the listed species or destroy or adversely modify their designated critical habitats no further consultation under the MSA is needed. As to the coho, the MSA will be conducted as part of the ongoing consultation on the coho. Additionally, as determined in the EA, Reclamation did not identify any adverse effects from the proposed action on essential fish habitat.

5.3 National Historic Preservation Act (54 USC § 300101 et seq.)

54 U.S.C. § 304108, commonly known as Section 106 of the National Historic Preservation Act (NHPA), requires that Federal agencies take into consideration the effects of their undertakings on historic properties. Historic properties are cultural resources that are included in, or eligible for inclusion in, the National Register. The 36 CFR Part 800 regulations implement Section 106 of the NHPA and outline the procedures necessary for compliance with the NHPA. Compliance with the Section 106 process follows a series of steps that are designed to identify if significant cultural resources are present in the Proposed Action project area and to what level they would be affected by the proposed Federal undertaking.

Reclamation determined that the Proposed Action is the type of activity that has no potential to cause effects on historic properties; therefore the California State Historic Preservation Officer was not consulted (See Appendix B).

Section 6
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Frequency of Action Analysis: Preventive Pulse and Emergency Flows

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United States Department of the Interior

BUREAU OF RECLAMATION
Mid-Pacific Region
Northern California Area Office
16349 Shasta Dam Boulevard
Shasta Lake, CA 96019-8400

IN REPLY REFER TO:

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JUN 30 2016

MEMORANDUM

To: File

From: Charles Chamberlain
Fish Biologist

Subject: Frequency of Action Analysis: Preventive Pulse and Emergency Flows

Introduction

The EIS for the Long Term Plan requires a means of determining the impacts of using different water sources for flow augmentation actions as described for each alternative. In order to do these assessments there is a need to define the frequency of implementing the preventive pulse and emergency flow components of the action alternatives. In contrast, the preventive base flow component will be defined by a separate methodology.

Methodology

The potential frequency-of-occurrence of the preventive pulse and emergency components were derived from review of the years in which augmentation actions occurred since the year of the die-off. As such, this analysis looks at a total of 14 years (2002 to 2015) and characterizes the actions actually taken and a retroactive look at the actions that could have been taken given the criteria on which these two components of the action alternatives are based. For purposes of the analysis, we assume that 2002 would have been a year in which all three components (preventive base, preventive pulse flow, and emergency flows) would have been implemented. While it is unknown how implementing these components in that year would have influenced the outcome of that year, we chose to include it in this review because it was extreme in how environmental conditions came together to cause the unprecedented adulated salmon die-off in that year.

Frequency Determinations

The method used to determine the frequency of implementation of the preventive pulse and emergency components for purposes of analysis in the EIS are provided below.

Preventive Pulse Flow

The preventive pulse flow (also called a secondary treatment) was determined to only be implemented in some subset of the years when the preventive base flow was implemented. In addition, it was recognized that there were not likely be a need for this pulse flow in every year that a primary base flow action occurred because the criteria for implementing a secondary preventive pulse flow (as described in Reclamation 2015) would not have been met in every year. This would seem appropriate anticipating that in some flow augmentation years the preventive base flow would be adequate to thwart the need for this secondary response action. With this in mind, we examined existing *Ich* monitoring results for the lower Klamath River (Yurok Tribe Ich monitoring data) for each year that a flow augmentation release occurred (2003, 2004, 2012 – 2015) and for three additional years that would have met the primary base flow action criteria (2007, 2008, and 2009; see Table 1). Using this approach, three years (2003, 2014, and 2015) were identified when a pulse flow would likely have been implemented because the threshold for low level infection and other criteria (as defined by Reclamation 2015) are anticipated to have been met. When we include 2002 as a year that a preventive pulse would likely have been needed, we identify 4 of 10 years or 40% of the time when a preventive pulse would be needed (See Table 2).

Table 1. Ich monitoring results for years when flow augmentation actions occurred (or would have occurred under the actions alternatives)

Augmentation Year	**Ich Counts**[d]	**Preventive Pulse Triggered (Y/N)**	**Data Source**
2002[a]	Likely	Y	Guillen (2003); CDFS (2004); YTFP (2004a)
2003	Counts > 50 observed; weekly average as high as 24/gill arch	Y	YTFP (2004b), Foott (2003)
2004[b]	0[b]	N	YTFP (2005)
2007	0	N	YTFP (2008)
2008	0	N	YTFP (2009)
2009	0	N	YTFP (2010)
2012	0	N	YTFP (2012)
2013	0	N	YTFP (2014)
2014	Counts > 600 observed	Y	YTFP (2014)
2015[c]	Average counts > 20 week of Aug 17. Max counts > 600	Y	YTFP (In progress); CDFW 2016
Events		4	
Sample Size		10	
Frequency (%)		40	

a) assumption made that ich counts would have met the criterion

b) 2004 monitoring mentioned in a Yurok Tribe report on 2005 monitoring, but full 2004 results not reported.

c) the first year that a preventive pulse flow was formally implemented

d) Counts are qualified by criteria as defined by Reclamation (2015), where low level infection (less than 30 Icn trophonts per gill arch) occur in the first two weeks of September on three adult salmon in one day.

Emergency Flows

The emergency flow (or tertiary treatment) was determined to only be implemented in years when the preventive pulse flow was implemented. Again, the same logic is used (as for the preventive pulse flow) that only if the prior treatment is used and not successful will the next level of treatment be implemented. Using this logic, the emergency flow treatment is anticipated to be used when the secondary treatment was not effective. To determine the frequency of need, we examined the years when emergency releases were used (2014) or in the case of 2002, when we anticipate they would have also been used due to the large mortality of adult salmon in that year. Using this information, 2 of 10 years would have used an emergency flow, which equates to a frequency of need of 20% when preventive pulse flows are implemented.

Conclusion

After the determination of the years in which a base flow augmentation would be implemented, these percentages can be applied to determine the volumes of water that could be used in an augmentation action over the period of review. While we acknowledged the uncertainty of the future needs of these components of the action and potentially the sequence and volumetric needs as we continually learn more with time, this analysis provides a basis upon which quantitative review of impacts can be assessed.

In summary, the logic is that of the 100% of years when a preventive base flow is implemented (as determined through another exercise) that 40% of those years would require a preventive pulse flow, and of those years that require a preventive pulse flow that 20% of those years would require an emergency release. Placing the frequency of need of an emergency release in the context of when a preventive base flow augmentation release is implemented, in general, the frequency of need for an emergency action is 8% (product of 40% * 20%) of the time.

Table 2. Actual and projected occurrence of preventive pulse and emergency flow actions based on prior flow augmentation years, 2003, 2004 and 2012 – 2015.

Augmentation	Actual		Action alternatives – Retroactive	
Year	Preventive pulse	Emergency Flow	Preventive pulse	Emergency Flow
2002*	0	0	1	1
2003	1	0	1	0
2004	1	0	0	0
2007	0	0	0	0
2008	0	0	0	0
2009	0	0	0	0
2012	0	0	0	0
2013	0	0	0	0
2014	1	1	1	1
2015	1	0	1	0
Events	4	1	4	2
Sample Size	10	10	10	10
Frequency (%)	40	10	40	20

* Assume criteria for Preventive Pulse Flow and Emergency pulses would have been met in 2002.

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RECLAMATION
Managing Water in the West

Long-Term Plan to Protect Adult Salmon in the Lower Klamath River

Attachment D – Individual Reports from Independent Science Peer Reviewers

Independent Scientific Peer Review
Northern California Area Office, Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation

October 2016

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Contents

Figures

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Reviewer 1

The purpose of this independent scientific peer review is to evaluate the scientific basis for the criteria that have been developed to prevent a recurrence of the epizootic of the parasitic protozoan *Ichthyophthirius multifiliis* (Ich) and the associated die-off in Klamath River fall-run Chinook Salmon documented in fall 2002. The premise, established in the earliest document provided for review (Memorandum to TRRP Fall Flow Workgroup from Joe Polos, 28 May 2012), is that the Ich epizootic and associated mortality were the result of the interactions of low flow, high temperature, and a large number of returning Klamath River fall-run Chinook Salmon. Based on historical information for these factors in the Klamath River basin, and knowledge about the behavior and physiology of Chinook Salmon at high temperatures and the life history of Ich, criteria were developed to identify environmental conditions conducive to an outbreak of Ich and responses to prevent an epizootic. This review considers the evidence for factors, the conclusions from which they are drawn, and the chronological, sequential development of the proposed actions based on these factors by assessing the scientific basis provided in the six documents submitted for review.

The six documents that were provided for review, in chronological order, are:

- Memorandum, 13 May 2012, To B. Person, From Fall Flow Subgroup
- Memorandum, 28 May 2012, To TRRP Fall Flow Workgroup, From J. Polos
- Memorandum, 12 August 2013, To B. Person, From I. Lagomarsino and N. Hetrick
- Memorandum, 10 August 2015, To F. Barajas, From N. Hetrick and J. Polos
- Bureau of Reclamation. August, 2015. Environmental Assessment: 2015 lower Klamath River late-summer flow augmentation from Lewiston Dam. EA-15-04-NCAO. U.S. Department of the Interior, Washington.
- Memorandum, 30 June 2016, From C. Chamberlain, To File

In addition, I accessed other documents to better understand the development of the proposed actions to prevent an outbreak of Ich and consulted with the former hatchery manager in Illinois, who implemented increased flow as both a preventative and treatment for Ich at Little Grassy State Fish Hatchery. The principal documents I used were:

Allison, R., and H.D. Kelly. 1963. An Epizootic of *Ichthyophthirius multifiliis* in a River Fish Population. Progressive Fish-Culturist 25:149-150.

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Valtonen, E.T., and A. Keranen. 1981. Ichthyophthiriasis of Atlantic Salmon, *Salmo salar* L., at the Montta Hatchery in Northern Finland in 1978-1979. Journal of Fish Diseases 4:405-411.

Ventura, M.T., and I. Paperna. 1985. Histopathology of *Ichthyophthirius multifiliis* Infections in Fishes. Journal of Fish Biology 27:185-203.

The review is presented in the order of actions presented in the scope of work, and each action is identified by a heading corresponding to that in the scope of work.

Preventive Base Flow Augmentation (primary response):
Initiate preventive base flow augmentation from Lewiston Dam when:
Flow in the lower Klamath River is projected to be less than 2,800 cfs at the Klamath, California gage (gage # 11530500) in August and September (USFWS 2015).

The historical record provides the scientific basis to support the use of flow to prevent an epizootic of Ich.

- *Comments*: The size and nature of the Klamath River preclude the use of chemical treatments to prevent an Ich epizootic and reduce infection rates. Therefore, an appropriate physical treatment that can be used within the constraints imposed by a large river appears to be the only option. The two typically used types of physical treatments in aquaculture are reducing exposure to Ich or increasing the temperature to 29-30°C.

- Since temperatures of this magnitude are both logistically precluded by the size and nature of the river and physiologically precluded for Chinook Salmon, exposure to Ich must be reduced. One method that is used in intensive aquaculture is to conduct several successive daily transfers of fish to Ich-free environments to decrease or even prevent exposure of fish to the infective theronts. This can be accomplished by transferring fish to an Ich-free environment for five to seven days at warmer temperatures or longer in cool water. This would likely be unsuccessful even if feasible since the fish are already under considerable stress from multiple sources; additional stress caused by handling would likely result in catastrophic rates of mortality.

- The remaining option is to increase the water exchange in relation to the location of the fish with the purpose being to reduce the density of theronts by flushing. This has been accomplished by increasing the rate and volume of water moving past a fish. In one of a handful of documented studies of the effect of flowing water on Ich, the spring-time Ich epizootics in channel catfish juveniles held in production raceways at a state hatchery in Illinois were used to identify appropriate rates of water exchange to accomplish both treatment and prevention (Sheehan et al. 1989). Prior to implementation of flow treatments epizootics caused significant loss of fingerling channel catfish, reaching 50 percent in some years. Since the hatchery water source limited the volume of flow that could be used in the 3 feet by 10-12 feet by 80 feet concrete raceways, effective rates of exchange could not be achieved under typical operating conditions. Exchange rates were further increased by reducing the water level in a raceway by about one-third, in effect reducing the cross-sectional area of the water column and overall volume in a raceway. This increased both the velocity and the exchange rate by 50 percent for a given input flow. Because of its effectiveness the treatment was adopted as standard practice. In subsequent years several “cleaning weirs” were also placed in each raceway at critical seasonal periods for Ich epizootics to increase the benefits of higher velocity. These weirs concentrated down-raceway flow to the bottom portion of the water column causing settled particulates to be re-suspended and transported out of the raceway via flow. Presumably this would include tomonts attempting to settle and theronts searching for hosts. The weirs appear to enhance the effects of increased flow on reducing Ich infestation (Sheehan et al. 1989; personal communication, Alan Brandenburg, manager (retired), Little Grassy State Fish Hatchery, Sept, 2016).

- Unlike the Klamath River fall-run Chinook Salmon, channel catfish fingerlings experienced Ich epizootics during the period of rapidly rising water temperature in the spring, which appeared to tip the balance of immune response by the fish with the infectivity of Ich in favor of the parasite. Likely the temperature-related increase in immunological response in channel catfish lags behind the temperature-dependent shortening of the production cycle of Ich theronts. In contrast Klamath River fall-run Chinook Salmon demonstrate Ich epizootics at the end of summer, when temperatures are peaking and then falling. Fish are exposed to warm water because they are migrating into the river driven by their mature reproductive condition. A water temperature of 23°C has been clearly identified as a barrier to upstream movement and causes fish to cease migrating until temperatures cool (Strange 2010). When temperatures fall below 23°C, fish disperse upstream away from the concentration of Ich that is present in the areas of congregation to areas that have at most a low level in hosts and in the environment; essentially, the fish are engaged in a treatment that is analogous to the treatment type that prevents ongoing exposure to theronts by moving fish among a successive series of tanks. In this case the fish are accessing Ich-free environments by moving upriver against a current that prevents concurrent movement by theronts. Infections on a given fish are resolved as trophonts mature and leave the fish as tomonts to settle and produce infective theronts. In the considerably reduced density of fish and higher velocities encountered in the main channel and upriver, the probability of theronts re-infecting the original host or infecting other fish is much reduced.

- Dispersing fish from areas that are sources of infection and reducing thermally-induced stress levels in fish to enhance immunological response appear to align well with the history of previous incidents as the primary cause of the reduction in Ich infections in 2014 and prevention of epizootics after 2002 based on the information provided in the documents for review.

- Information about Ich outbreaks on which to base preventative actions using flow is limited to an epizootic in 2002 and to an epizootic in 2014. In 2002, mean monthly flows dropped from 3,187 cfs in July to 2,327 cfs in August, and 1,993 cfs in September 2. In 2014, the Ich outbreak occurred when mean August flow was 2,419 cfs and flow for the latter half of the month averaged 2,419 cfs, so the target flow of 2,500 cfs did not prevent an epizootic. When minimum flows were targeted at 3,200 cfs in 2012 and 2,800 cfs in 2013, Ich epizootics did not develop. These two episodes of an Ich epizootic bracket 2,800 cfs as a minimum flow that is not associated with an Ich epizootic. This flow level is about 10 percent higher than that at which Ich outbreaks occur and appears sufficiently protective by reducing the probability of an epizootic.

- In 2014, after the Ich epizootic was discovered, flows were nearly doubled for five days, and subsequently the Ich epizootic subsided with no major fish die-off. This supports the contention that higher flows reduce and prevent Ich infections and promote higher survival.

- Because of the limited occurrence of epizootics under various combinations of run sizes, water flows, and water temperature conditions during the period of record from 1978 to 2014, factors that may interact with flow are challenging to assess at this point; thus the flows at which the two outbreaks did occur have been adopted as the basis for determining an action level. The recommended augmentations have evolved from one that incorporated numbers of fish through a two-tier minimum flow approach based on a threshold of 170,000 fish based on the premise that larger runs increase the density of fish in the river and the ease of transmission of Ich among hosts to the most recent recommendation that de-emphasizes the role of fish numbers in flow management. The outbreaks of Ich in 2002 and 2014 occurred when in-river numbers of adult fall-run Chinook Salmon were ~160,000. No epizootics have occurred during the ten years when in-river numbers exceeded 160,000, including 2012 when the record run was ~292,000, so the de-emphasis on run size is appropriate. In addition, lower numbers of fish than those present in 2002 and 2014 have an unknown risk of an Ich epizootic, and an epizootic may have a proportionally greater adverse impact on smaller runs. Therefore, use of a single minimum flow level should be at least as equally protective of smaller runs as large ones.

Ich infection of adult salmon or steelhead is identified in July and early August suggesting a low level of infection is present that could worsen with poor environmental conditions.

Assessing fish for infection so that appropriate responses can be undertaken is supported by the science.

Comments: Early detection of the disease is crucial to taking remedial action. The duration of the Ich life cycle shortens as water temperature increases. At 20°C it averages seven days and at 23°C it takes about 4.5 days. This is reflected in time to maturation of the trophont stage on the fish host from various published studies (Figure 1-1; Dickerson and Dawe 1995). Each adult form of the parasite (trophont) produces 200 to 800 of the infective stage in a life cycle (Nigrelli et al. 1976). With a large pool of available hosts the increase in the number of infected fish is initially exponential, so epizootics and infection severity to the point of causing mortality can occur rapidly.

With early detection a higher level of scrutiny and earlier action can be taken to prevent an epizootic from developing. Earlier treatment reduces stress inflicted directly and indirectly on fish by Ich. This prevents a further degradation in the state of health of fish and reduces the risk of a significant die-off.

Thermal regime of the lower Klamath River is inhibitory to the upstream migration of infected adult salmon.

Inhibition of upstream movement by high temperatures is supported by the science.

Comments: The thermal regime is likely the singular factor responsible for an outbreak of Ich. Strange et al. (2010) clearly demonstrated that upriver migration of Klamath River fall-run Chinook Salmon is completely inhibited at 23°C.

Adult salmon are showing abnormal signs of behavior, crowding at tributary mouths, or are not migrating out of the lower Klamath River on a volitional basis.

Using observations of salmon behavior to determine when an Ich outbreak may be occurring is supported by the science.

Comments: Behavior is probably the single-most important indicator of the potential for an Ich outbreak. Crowding caused by congregation in the tributary mouths to access thermal refuges and inhibition of upstream migration are key factors in promoting an epizootic of Ich. The other factor is the duration of this behavior. If fish are exhibiting behaviors indicating that a thermal barrier is present and mainstem conditions are thermally stressful, then immediate implementation of preventive actions is critical. The progression of the disease to epizootic proportions relates to the effect of temperature on the life cycle of Ich and on the behavior and health of the potential hosts, summarized below.

Ich Life cycle – 7 days at 20°C to 4.5 days at 23°C with up to 800 infective theronts produced per mature trophont

Ich is a single-celled ciliated obligate parasitic protozoan with a life cycle that has four stages. The trophont stage is often evident as a pustule or encysted cell on the skin or gill tissue of a fish. It feeds on fish tissue until it becomes large enough to be viable to enter the free-living stage. After it leaves the epithelial layer of a fish, it becomes a motile tomont that swims about, secreting a gelatinous cyst so it can settle and attach to a substrate. The tomont typically undergoes a series of eight or nine mitotic divisions without increasing in size to produce 200 to 800 daughter cells that are referred to as tomites. The tomites differentiate into theronts which are released from the cyst as the infective stage. Theronts are motile, swimming rapidly toward light and toward areas where unidentified chemicals associated with fish are present. When a theront contacts a fish, it attaches and bores through the epithelium to the basement membrane, where it transforms into a trophont and begins feeding (Dickerson and Dawe 1995).

The complete life cycle through the four stages is affected by temperature. Colder temperatures protract the life cycle; at 11°C it is 35 days, and as temperature increases, it shortens to as little as four to five days near 30°C. Each life stage has temperature-dependent characteristics that affect its function. Trophonts have to grow to a minimum size to mature and become viable as tomonts. At 27°C this takes 2 days, with growth occurring at a rate of 5.9 percent per hour; at 22°C this increases to three days at a rate of 8.3 percent per hour, at 20°C seven days, and at 7°C 20 days, so the relationship of time to maturation to water temperature appears to be an exponential function. This is likely the case for other life history stages although information may be lacking to assess this. A trophont may remain on a fish for a longer period than needed for viability, which increases its ability to leave the epithelium more quickly, but all trophonts leave upon the death of the host fish. After the trophont has exited the epithelium and transformed into a tomont, it swims in search of a substrate. At 21 to 23°C an hour may elapse before it secretes a sticky matrix to protect it and enable it to attach to any substrate. Once attached to a substrate, the tomont within the secreted gelatinous cyst begins a series of binary divisions. At 23°C the first division occurs between 30 and 75 minutes after attachment with the usual eight to nine divisions completed in 18 to 24 hours. Tomonts change shape and develop structures to enable penetration and feeding on fish as they become theronts. The first theronts to complete differentiation bore out of the cyst, with others following. The theronts swim rapidly in search of a fish host, with viability increasing from 10 hours at 27°C to 3 days at 19°C. Theronts are killed by high temperatures, in the range of 29 to 30°C, and high temperature is one recommended treatment that is used for fish tolerant to these temperatures (Nigrelli et al. 1976; McCallum 1992).

Summing the times required by the four life stages at temperatures in the mid-20°C degree range yields a minimum life cycle time in the range of 4.5 days (2.5 days as trophont; 1 day as tomont; ~1 day as theront), which corresponds well with reports of the entire life cycle duration.

Predisposing Factors to Ich Epizootics – hosts, crowding, and stress

Host range – all freshwater fishes around the world

Ich can infect all freshwater fish and now appears to occur wherever there are freshwater fish (Nigrelli et al. 1976; Valtonen and Keranen 1981). Although no species is inherently naturally resistant, genetics, parasite strain, and environmental conditions have all been implicated in the susceptibility of a population of fish to infection. Epizootics often occur in a single species in a given body of water, but likely as a reflection of the physiological state of the affected fish population rather than genetic makeup. Stress is a major factor in increasing susceptibility to infection, so any factor that increases stress increases the likelihood that infection and death may occur.

Stress – temperature, reproductive status, Dissolved Oxygen, and crowding

Stress and temperature are the two major factors associated with an outbreak of Ich infection and development of an epizootic (Allison and Kelly 1963). Stress results in the secretion of adrenocorticosteroids, with one of the effects of these hormones being a decrease in immune function. In some cases gender specific epizootics have been documented, with nearly all stricken fish being male or female. In most instances this has been associated with sexual maturation and spawning and seems to reflect the relative stress experienced by the particular gender leading up to and during reproduction (Pickering and Christie 1980). Reproduction is associated with increases in these stress-related hormones and would account for the differential mortality. Other common sources of stress include high temperatures and low dissolved oxygen relative to tolerances, and crowding. Although density of fish has not been found to affect whether Ich infection becomes established, it does directly relate to occurrence of an epizootic (McCallum 1982).

Immunity – reduction by stress hormones

Survivors of infection develop immunity to Ich (Bauer 1953). Since it has no resistant resting stage, naïve fish presumably serve a role in sustaining the presence of Ich in a watershed. Although the dynamics of the Ich population between periods of epizootics are not understood, the lack of host species specificity may enable a low level of infection to persist among members of all the species within a water body. This may be especially important in fish communities that include species with anadromous life history patterns since free-living life stages of Ich do not tolerate the salinity of the marine environment. Given this, occurrence of an Ich epizootic in most salmon populations would depend on the presence of other fish species as suitable hosts, the presence of juveniles whose life history in fresh water overlaps two successive annual adult migration periods, or a combination of both. The reviewed documents refer to stocking of fish by the Trinity River Hatchery; the hatchery fish may be a potential reservoir for a low level of Ich infection and may be a potential source of Ich to infect adults returning to freshwater depending on timing of smoltification and outmigration.

Life cycle and predisposing factors to Ich epizootics in Klamath River Fall-Run Chinook Salmon

The high temperatures in August and September in the Klamath River cause Klamath River fall-run Chinook Salmon to congregate into small areas of cooler water, and this proximity facilitates transmission of Ich and other potential pathogens. Stress resulting from high temperatures, crowding, decreased ability to respire, and sexual maturation inhibits the immunological response to pathogens. Warm water favors growth and reproduction by Ich and by secondary opportunist pathogens such as bacteria and fungi (Ventura and Paperna 1985). Occasionally, fall-run Chinook Salmon in the Klamath River confine themselves to thermal refuges to reduce their exposure to higher, more stressful temperatures. In these refuges they may experience all these sources of stress, and these conditions present a perfect storm for the outbreak of an epizootic of Ich and Ich-related mortality.

The migration barrier imposed by a 23°C water temperature on fall-run Chinook Salmon causes fish to congregate in the lower reach of the Klamath River, awaiting the onset of cooler temperatures conducive to swimming upriver. The result is an increasing density of fish in the lower river, exacerbated by the tendency of these fish to seek the cooler waters present at the confluences of tributaries such as Blue Creek. This crowding enhances the transmission of Ich and increases the infection rate, as well as increases the physiological stress level of the fish. Under stress, fish produce immune-suppressing steroid hormones in response. Water temperatures near the upper lethal limit for Klamath River fall-run Chinook Salmon further add to the stress on the fish. Conversely, a water temperature of 23°C is in the ideal range for Ich in terms of shortening the duration of its life cycle and causing the highest production of theronts, the infective stage, by individual tomonts as well as by the entire Ich population.

Although measurements of dissolved oxygen in the river have not indicated that stressful levels are present, infected fish may still experience respiratory distress. Ich infections on gill lamellae, where oxygen and metabolic waste product exchange occur, cause tissue deformation and destruction (Dickerson and Dawe 1995). The result is that as the severity of Ich infection increases on the gills of a fish, the ability of the fish to take up oxygen and remove physiologically harmful waste products decreases, the end result being an increase in the sources and amount of stress the fish is being subjected to. Mortality as a result of Ich infection has been attributed in part to suffocation because of an inability to take up adequate oxygen.

Secondary infections by always-present bacteria and fungi are a significant cause of Ich-related mortality, as exemplified by the outbreak of Columnaris during the Ich epizootic in the Klamath River in 2002. Damage to epithelial tissue on the skin and gills of host fish by Ich trophonts provides sites for opportunistic invasion by these ubiquitous organisms (Ventura and Paperna 1985). Their metabolism is also temperature-mediated, with warmer temperatures such as typically occur in the lower Klamath in August and September favoring growth and reproduction.

The cumulative harvest of Chinook Salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish (see National Marine Fisheries Service (NMFS) and USFWS 2013).

Use of cumulative harvest of Chinook Salmon as an index of the timing of the annual run into the lower river is supported by the science.

Comments: Within the range of options that were explored to determine when flow augmentation should occur, a trigger based on the presence of fish is better than one based on calendar dates. It improves the likelihood that action can be taken when fish are present, reducing the risk of an Ich outbreak. Use of the Yurok Tribal fishery is advantageous in that it occurs in proximity to where fish may be adversely affected by environmental conditions in the river, it has historical records of timing and abundance of catch, and during the fishing season the catch numbers are updated on a daily basis, enabling a rapid response if adverse environmental conditions coincide with fish presence.

The use of harvest as an index of when fish will occur in the lower river presents some challenges. It is subject to annual variations in timing of entry into the estuary, duration of time spent in the estuary, and variation in timing and intensity of fishing effort. Normalizing catch to catch per effort proved not to be a suitable index of numbers of fish present, but harvest does show a relationship to number of fish present.

However, use of harvest does present some challenges. First, it is estimated by multiplying an estimate of effort by an estimate of catch per effort. Given the use of estimates to calculate harvest, confidence intervals for the harvest statistic would provide context for the criterion of 7,000 fish.

Two more challenges to using reports of tribal catch are: 1) the long-term obligation of the tribe as an independent national entity to share data with State and Federal agencies; and 2) the potential conflict of the economic interests of the tribe with the collection and reporting of catch data. As with any data collected by a non-governmental entity, a quality assurance/quality control plan should be considered for inclusion in this criterion. This may entail finding a second surrogate or index as an indicator of fish presence in the lower river.

Finally, the challenge to using a fixed harvest number is that small runs may not receive the appropriate timing of implementation of preventive actions and thus level of protection from an Ich outbreak because cumulative catch may take longer to reach 7,000 as a result of any of lower catch, lower effort, and lower catch per effort. This is addressed in part by including a calendar date criterion as a backstop if the harvest criterion is not met.

An alternative that could address some of the challenges of using a fixed number for cumulative harvest would be to use proportion of harvest based on catch divided by pre-run estimates of run size. Based on historical data catches rapidly increase after 10 to 20 percent of the cumulative harvest (Figure 15 in the Memorandum to Person from Lagomarsino and Hetrick, 12 August 2013). However, one would have to use pre-run estimates of numbers to determine appropriate percentiles since total harvest would not be known.

Initiate preventive base flow augmentation release by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in NMFS and USFWS 2013).

The provision for initiating preventive base flow is supported by the science.

Comments: The fish harvest metric of a cumulative catch of 7,000 fish may not be met during the first three weeks of August because of low run size, late run timing, low fish catch, and low fishing effort, but adverse environmental conditions conducive to an epizootic of Ich may be present prior to the harvest-related trigger being met.

Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the Klamath, California gage through September 21. Continue to implement fish pathology monitoring to determine the potential need for the secondary flow augmentation action (preventive pulse flow).

The science supports ensuring flows remain at a minimum of 2,800 cfs in the lower Klamath River through September 21.

Comments: The temperature conditions that cause both crowding of and physiological stress in fish and that are conducive to outbreaks of Ich because of the shortened life cycle may be present in the lower Klamath River through the third week of September.

The need for preventive base flow augmentation is expected to occur during years with limited or low precipitation levels in the Klamath River basin (e.g., dry conditions). Since the fish die-off in 2002, Reclamation has made preventive base flow augmentation releases in six years over a 13 year period. However, criteria for preventive flow augmentation have changed over this period. Based on the above criteria, it is estimated that preventive base flow augmentation would have occurred in approximately three of the 13 years, or about 20 to 25 percent of the years.

Comment: I am unclear on how to respond because this does not appear to be an Implementation Criterion.

General comments on aspects of the scientific evidence:

1) Predictive power and reliability of estimates for numbers of fish

- The moderate predictive power of the models used to estimate salmon numbers in the Klamath River system and the increasing uncertainty as numbers increase are typical of the methods used to assess salmon run sizes. However, the graphs and tables do not include estimates of accuracy of numbers.

- An expression of confidence intervals such as 95 percent, or some other standard reflection of variability of estimates, would provide meaningful insight for the reader as to the overall accuracy of model predictions.

- To assess the effect of this inclusion, I duplicated Figure 6 from the 13 May 2012 memorandum using measurements of the graph and locations of the points to assess what the accuracy of estimates would be like for adult spring-run Chinook Salmon based on pre-season estimates of fall-run Chinook Salmon (Figure 1-2a). My replicated model had parameters for the linear trend similar to those in the document. For the entire range of run sizes as portrayed in Figure 6 in the memo, the estimates of spring-run Chinook Salmon using the linear model that predicts numbers of spring-run Chinook Salmon based on pre-season estimates of fall-run Chinook Salmon have 95 percent confidence intervals just over +/- 4,000 for each estimate. However, as indicated in the memorandum the estimates from the linear model become far more variable at higher pre-season estimates of fall-run Chinook Salmon so I calculated variability for numbers greater than 150,000 (n=8); the linear regression model does not fit the data well, showing an inverse slope and low R-squared, and the 95 percent confidence interval increases to more than +/- 14,000 (Figure 1-2b).

2) River temperature data to accompany flow data

- Although flow is the only practical means to address the potential for an Ich epizootic, integrating the thermal effects on the observed behavior and known physiology of Klamath River fall-run Chinook Salmon with those on the life history of Ich suggests that temperature may be the most important variable in the development of an epizootic. If so, minimum flow levels during critical periods may need to be adjusted so as to achieve temperatures downriver that do not promote outbreaks of Ich. The other aspect of this is duration of exposure to crowded, high temperature conditions is a key factor in development of an epizootic because proximity of hosts and the infective stage of parasites facilitates transmission and infection.

- I recommend that the RBM10 temperature model for the Klamath River, and the corresponding model being developed for the Trinity River, be explored for potential integration into the trigger criteria for ensuring maintaining minimal flow levels.

3) Flow as a treatment

- In the memorandum of 31 May 2012 the stated purpose of maintaining a minimum base flow is stated as "not necessarily" to reduce water temperatures or provide migration cues but to reduce the infectivity of Ich. The mechanisms identified as causing reduced infectivity are reducing the density of theronts by increasing the volume of water, decreasing the ability of theronts to attach to fish by increasing the velocity of water, and reducing the density of fish by increasing the volume of available habitat.

- Higher flow rates appear to have prevented development of Ich epizootics, and in 2014 flows were increased to successfully eliminate an Ich epizootic. The high mortality caused by the Ich epizootic in 2002 was associated with a low flow rate. This has naturally led to the conclusion that the occurrence of epizootics is directly related to flow. The proposed mechanism through which infection rates are kept low by higher flows is the flushing of tomonts and theronts down river. In addition, congregated fish disperse upriver in response to reductions in temperature below 23°C, reducing the proximity of the infective life stage of the parasite and the hosts, and thus reducing infection rates.

- Increased velocity resulting from increased flow may alleviate increases in Ich infections, but velocity and flushing may not be the primary agents in effectively preventing and treating an outbreak of Ich infections and development of an epizootic. First, the historical record of mean monthly flows in August and September show several years when flow was less than 2,000 cfs, and Ich epizootics were not reported. Second, for the apparent threshold in the mid-2,000-3,000 cfs range to be effective in preventing or treating Ich, all fish would need to be consistently exposed to some minimum velocity associated with that flow. If fish move along a variety of routes across the span of the river and at different rates upriver, then not all fish may experience the same velocity conditions. River reaches with higher and lower velocities are probably distributed throughout the river on a small scale, and even more so within areas of thermal refuges, so individual members within a congregation of fish likely experience a widely varying range of velocities. Under these conditions, a gradation in the distribution of Ich among fish and severity of infections within individual fish seems more likely than a uniform distribution of Ich infections.

- Although flow is essential in addressing the potential for an Ich epizootic, the evidence is ambiguous with respect to the role it plays in preventing and treating Ich outbreaks. The principal effect of flow with respect to Ich infections may also be attributable to its relation to water temperature rather than dilution and interference with attachment by theronts. Water temperature is inherently tied to flow in the lower Klamath River in August and September. Ambient temperatures in the lower Klamath River around 23°C in August and September act in three ways; they thermally stress the fish reducing immune response, enhance the production of the parasite, and inhibit upstream migration by Chinook Salmon causing a congregation of fish that enhances transmission and infection rates of the parasite. Outbreaks of Ich are also related to residence time of congregated fish confined to small areas of habitat, with respect to the number of generations of Ich that are produced based on a life cycle of one week or less at temperatures in the 20-23°C range.

Addendum

The documents indicate that Klamath River fall-run Chinook Salmon seek thermal refuges when confronted with river temperatures approaching 23°C based on Strange (2010), who reported that fish would cease to migrate upriver at temperatures above 23°C.

> *"During the first week (168 h) of migration, mean average body temperature was 21.98°C, mean average minimum daily body temperature was 20.68°C, and mean average maximum daily body temperature was 23.18°C. Temperatures above these levels appeared to completely block migration in almost all circumstances (Strange 2010)."*

Addendum

Chinook Salmon use thermal refuges provided by tributaries while migrating upriver during periods of high temperatures in the mainstem Klamath River. Blue Creek is indicated as the principal thermal refuge in terms of frequency of use among the tributaries below the Trinity River confluence.

> *"En route thermal refuge habitats at the confluences of cool tributaries, as opposed to reach- or segment scale thermal refuges, appear to serve a vital role in providing emergency relief from excessively high water temperatures for a relatively small but important portion of migrating adult Chinook Salmon within the Klamath River basin (Strange 2010)."*

> *"The Blue Creek thermal refuge was the most frequently used en route habitat, representing 100% of the substantial refuge use (>12 h) and 67% of the total en route refuge use (Strange 2010)."*

For a thermal refuge from high temperatures to exist in a dynamic riverine environment, the cooler waters require some feature that prevents them from mixing with warmer waters. Isolation may result from topographical features that separate the body of cooler water from the warmer one, such as may occur in a backwater receiving groundwater inputs or in the lower reach of a cooler tributary. In the absence of physical isolation, a cooler tributary entering a warmer mainstem would need sufficient flow to create a volume of cooler water at and directly below the confluence that does not immediately mix with the warmer water. In the case of Blue Creek I do not find an indication of how it is used as a thermal refuge— whether Chinook Salmon remain in Klamath River but gather at the mouth of the creek in a cool plume or whether they leave the Klamath River and enter the lower reach of the creek. Their behavior with respect to utilizing this thermal refuge on a very fine spatial scale may be important to understanding both how Ich epizootics occur and how flow reduces the risk of Ich-related mortality.

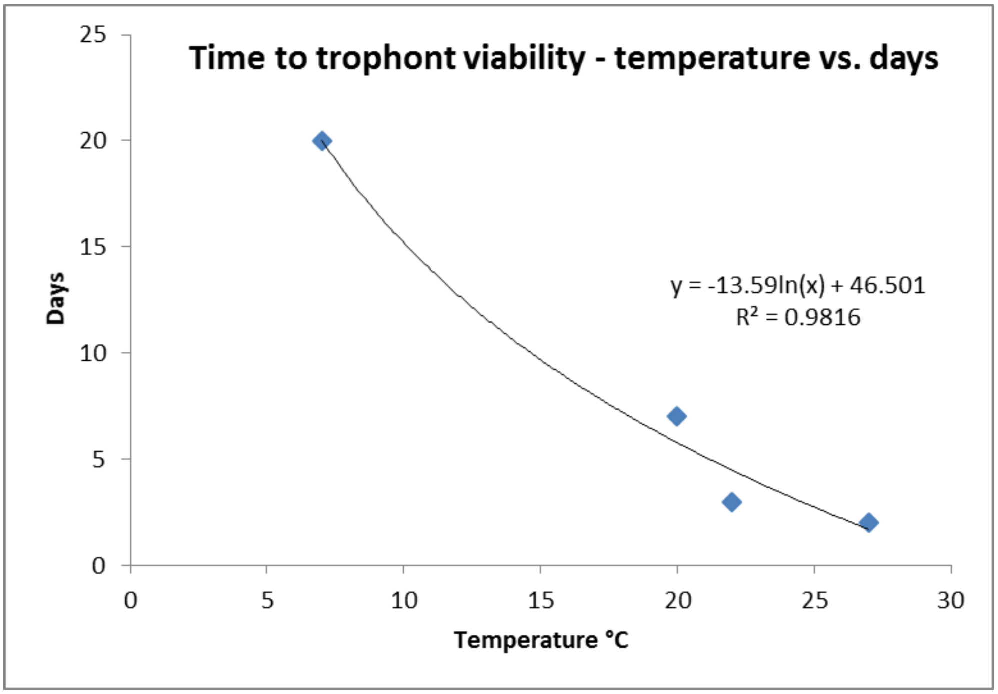
The congregation of Chinook Salmon is a key factor in promoting an epizootic. Absent the congregation, Ich infection is unlikely to reach levels that adversely affect fish health since the probability of encountering an infective stage is considerably reduced by reduced density of fish, decreased proximity to infected fish, and the one-way, downriver dispersion of tomites. The effect of flow on Ich may be direct, as suggested in the documents provided for review, by dispersing infective stages downstream and by reducing their ability to attach to fish in the face of higher velocity, or it may simply be a matter of cooling mainstem temperatures to the point that fish disperse from the thermal refuge as they resume upriver migration.

Given how thermal refuges exist and persist in warmer rivers, separated from mixing with the flow and heat in the mainstem river, then the fish in a thermal refuge must also be isolated from the mainstem flow. In view of the fact that Ich is likely always present but below a pathological level, an epizootic requires a buildup of the population of Ich trophonts on the fish, an increase in the number of infective tomites, and a high probability that a tomite will encounter a host fish. Conditions that are necessary for this to occur are a congregation of fish in an environment with a low linear velocity so infective stages are not dispersed downriver and the continued presence of the congregated fish for a duration that allows Ich to reach pathological levels. If the location of the thermal refuge that is being used is on the channel margin of the mainstem Klamath River and downstream of the Blue Creek confluence, then the likelihood that an epizootic could initially develop depends on a very low velocity in this habitat. If that is the case, then the role that increased flow in the mainstem plays in preventing or reducing an Ich outbreak is ambiguous. It may be that the increased velocity is having a direct effect on Ich infection. However, it may also be that cooler temperatures in the Klamath River caused by increasing the flow using supplementation by lower temperature water is allowing fish to disperse and move upriver. If Chinook Salmon are moving out of the Klamath River and into the tributary, then they are not being exposed to mainstem flow, so increasing mainstem flow would not seem to directly interrupt the infection cycle of Ich. The premise that the effect of flow is indirect in that it causes thermal conditions that cause fish to move back into and upriver in the Klamath River.

As an alternative to increasing and maintaining flow at a fixed level, such as the proposed 2,800 cfs, on or before August 22 to prevent an outbreak of Ich, one might incorporate a temperature-based model for determining when and how much flow supplementation should occur. Using the RBM10 models for the Klamath and Trinity Rivers, flow rates could be determined based on either maintaining temperatures less than some maximum temperature, such as the 22-23°C that creates a thermal barrier to upstream migration, or dispersing that barrier by some date, such as August 22, the proposed backstop date in the proposal. The advantage of using temperature criterion, rather than a flow criterion, is that it can remain effective even in the face of climate change when warmer river temperatures than have been recorded historically may occur.

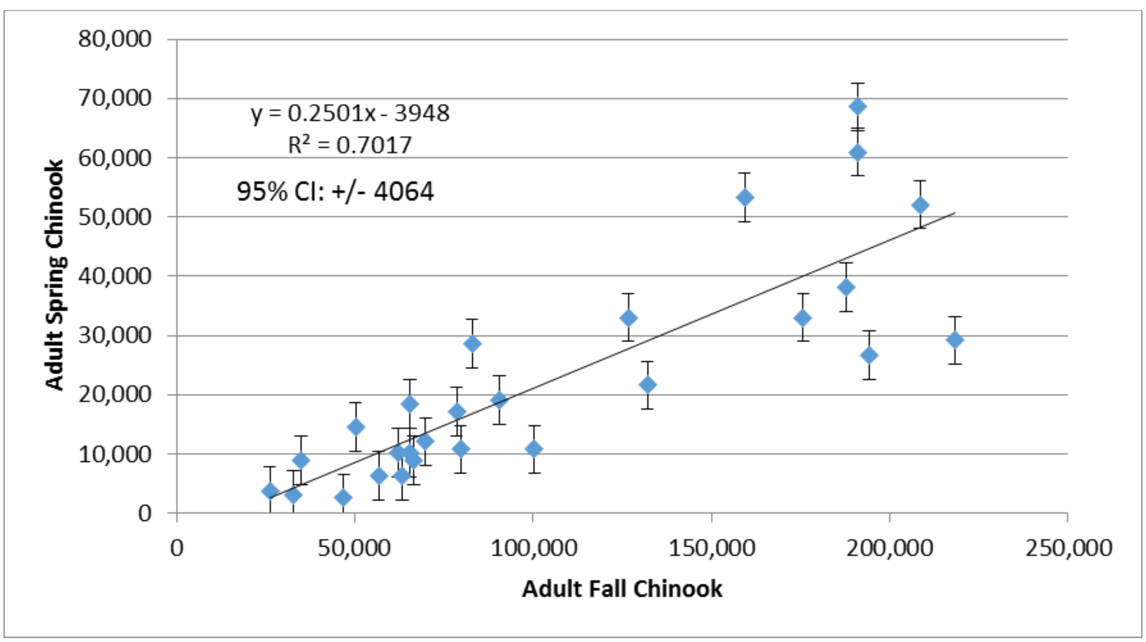
A temperature criterion has several advantages over a fixed flow criterion: 1) it enables conservation of water by not supplementing flows during years with cooler summer temperatures when no thermal barrier to upstream migration of Chinook Salmon may be present; 2) it enables use of more water if needed during years with warmer conditions; 3) it is adaptive over the long term to climatic warming since water use is tied to temperature conditions, which may alleviate the need to periodically increase flow supplementation criteria; 4) thermal barrier conditions are as easily identified as deployment of real-time temperature gauging stations; and 5) it may be directly addressing the cause of Ich epizootics.

Conditions that promote an outbreak of Ich can be identified by monitoring temperatures in the thermal refuge provided by Blue Creek and in the adjacent mainstem Klamath River. Given the nature of the development of an Ich epizootic, it seems likely that the onset of it occurs with the congregation of even just a few fish in a thermal refuge area. This allows an initial proliferation of Ich that could lead to a subsequent epizootic if the duration that fish are congregated is extended. If so, then the need for determining when some proportion of the spawning population of fish is expected to be present in the lower Klamath River above the estuary may be superseded by a need to determine when the fish first begin to occupy the confines of a thermal refuge. Again, rather than using a criterion based on the number of fish within certain dates, a temperature criterion could be applied through temperature monitoring in refuge area(s) and in the mainstem Klamath River.



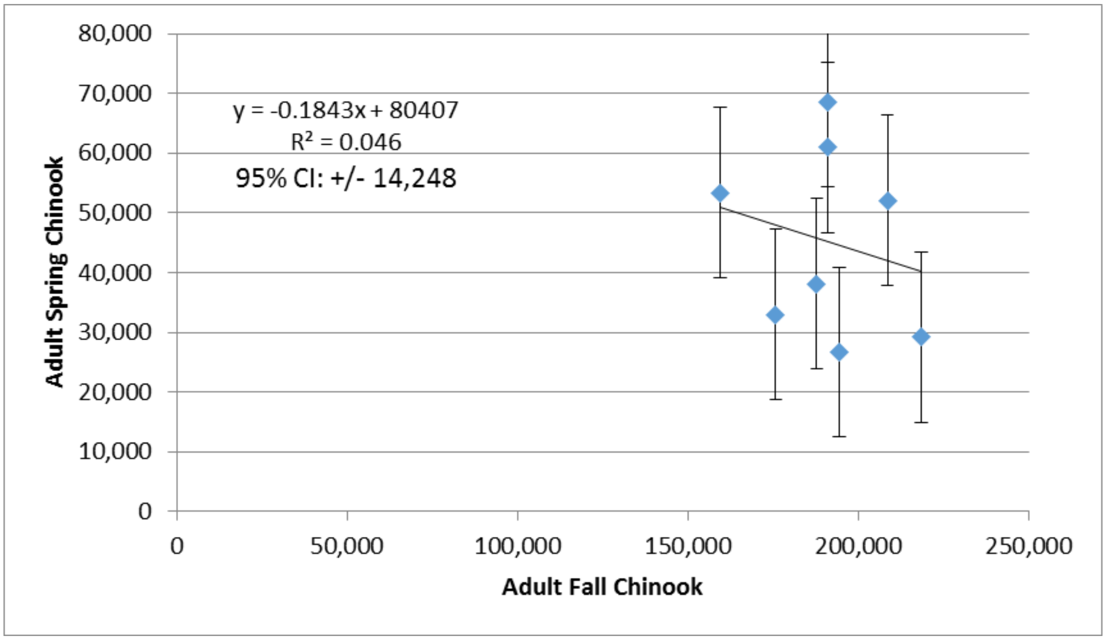
Various authors

Figure 1-1. Time After Infection by an Ich Tomite to When the Adult Trophont is Viable to Excyst and Produce the Next Generation of Infective Tomites According to Water Temperature



Note: Reproduction is based on measurements of Figure 6 from 13 May 2012 memorandum with inclusion of estimated 95% confidence intervals. Linear regression parameters differ from Figure 6 because of small measurement errors in placement of points.

Figure 1-2a. Reproduction of Relationship of Run Size of Adult Klamath River Spring-run Chinook Salmon from Numbers of Klamath River Fall-run Chinook Salmon



Note: Linear regression line and 95% confidence intervals have been added.

Figure 1-2b. Reproduction of Relationship of Run Size of Adult Klamath River Spring-run Chinook Salmon from Numbers of Klamath River Fall-run Chinook Salmon When Adult Fall-run Chinook Salmon Run Sizes Exceeds 150,000

Preventive Pulse Flow Augmentation (secondary response)

The use of a preventive one-day pulse flow release during the presence of the peak numbers of fall-run Chinook Salmon entering the Klamath River estuary is supported by the science.

Comments: The use of the one-day pulse flow in excess of minimum flow levels is supported by the observed behavior of Chinook Salmon under high temperature conditions and the infectivity of Ich at high temperatures. High temperatures cause fish to congregate in thermal refuges and inhibits upstream migration by means of a thermal barrier that exists when temperatures are ~23°C. Crowding under these conditions would be greatest when the largest number of fish are present, as at the peak of the run. The Ich life cycle would be the shortest and production of infective theronts the highest under these conditions, so the potential for an epizootic is greatest during this period. With the documented presence of a low level of Ich infection already present in the fish, the pulse flow is justified to prevent an exponential increase in the numbers of trophonts on each fish and the proportion of fish that are infected. The pulse flow should eliminate the thermal barrier, causing fish to disperse and continue to migrate upriver. Ich tomonts from existing infections on fish will be widely dispersed or carried down river so that potential for resulting theronts will be much reduced.

Emergency Flow Augmentation (tertiary response)

The use of an emergency five-day flow release when severe infections are present in fall-run Chinook Salmon in the lower Klamath River is supported by the science.

When severe infections are present as indicated by a high load of parasites on the gills or by the presence of dead fish with Ich infections present, then immediate action is essential to eliminate conditions conducive to continued infection by Ich to reduce mortality. These conditions are high temperatures and crowding of fish. As with the preventive pulse flow augmentation secondary response, the 5,000 cfs flow would eliminate the thermal barrier and fish will resume upriver migration. Extending the emergency flow augmentation for five days will encompass one life cycle of Ich, which is 4.5 days at 23°C. This ensures that nearly all the trophonts will have matured and been released from the fish as tomonts. The flows will cause tomonts to be carried downriver thoughout this period at the same time as fish are moving upriver, reducing the probability of a infective tomite encountering a host fish. The increased flow will also dilute the density of tomites encountered by fish because of the increased volume of water. Higher velocities may also inhibit the attachment by theronts to fish epithelium, but the evidence for this is speculative.

The effectiveness of the emergency flow release is highly dependent on rapid detection and response to severe Ich infections that will require a dedication to coordination and cooperation among individuals and agencies for implementation. Field sampling protocols will need to be designed to ensure that dead and dying fish are detected. A high degree of alertness will need to be maintained despite the infrequent occurrence of the need for flows, and this will be especially challenging.

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Reviewer 2

I have completed reviewing the six documents provided to me, and provided additional details for the final question as requested. In addition I have read and reviewed a number of other documents referenced in the documents and some others not referenced. My responses are provided in a memo to you regarding the two broad questions:

- Are the implementation criteria supported by the science?
- Have the assumptions and uncertainties associated with using the flow criteria been appropriately characterized?

My response herein addresses the scientific support for these criteria and comments about the uncertainties. My review required more extensive examination of the fish health records of the assessment team and the limited primary literature. I did not feel these six documents provided adequate information to answer either question.

Furthermore, I believe this review would benefit by a group discussion of the components with other panel members. It has been a difficult task for someone that is out of basin to get up to speed with the issues, and understand all components of these management criteria and their implications.

<u>Summary comments to the two key questions:</u>

The implementation criteria provided are a series of measurable efforts and thus are attractive to managers. The implementation criteria consider river flows, river temperature, and fish density. In addition the criteria are arranged as a decision tree approach to provide an adaptive management response. This approach is highly laudable as an effort to address a very difficult problem. However, the complexity of the problem, and the management criteria and responses are complicated by the fact that few studies of fish disease have been conducted to support these mitigation criteria. Each of these options and criteria has a hypothesis for which there are few data points or may have not been tested. The options proposed are based on some limited correlations, and basic principles of physiology and fish health, but they suffer from a major lack of peer reviewed publications and studies to support or disprove the hypotheses. Intuitively, these actions make a lot of sense, but there is uncertainty because this mass mortality has not been repeated in subsequent years, and one year even when infective agents were abundant.

The massive mortality observed in 2002 identified two pathogens that were found associated with the massive fish kill. Both *Ichthyophthyrius multifiliis* or Ich, and *Flavobacterium columnare* or columnaris disease were identified in the salmon following the fish kill. The fish in the 2002 kill showed high measures of gill hyperplasia. Equally plausible hypothesis may be that a combination of factors and pre-disposition led to this massive fish kill, and any single factor may not repeat the response. Other fish diseases have been investigated in the watershed that were not fully addressed in the reports provided. They include studies by the Klamath Fish Health Assessment Team of *Parvicapsula minibicornis,* and *Ceratonova shasta* in juvenile salmonids. The association of parasite loads from these pathogens with susceptibility to Ich has not been well addressed. Moreover, the potential for immune response in the fish to Ich is also possible, but has not been addressed.

Since the event, the tribes and other cooperators have initiated a comprehensive monitoring and data sharing program in the lower Klamath River based on real time monitoring and response decision criteria. This is an impressive effort, and especially the vigilance of the Yurok Tribe should be recognized.

Higher infestations of Ich in 2014 were associated with lower flows, with a similar size run as in 2002, but additional emergency water releases were provided. There were no massive mortalities, and into late September, the infestation was still considered severe. What are the reasons for this finding? Was this due to the flushing flows or were there other factors that have not been identified? Were these fish not affected by columnaris? Is that a co-factor to the disease response? The monitoring identified a high infestation of this parasite, and this would not be considered good for fish health, but why was there not hyperplasia response in the gills of infested fish and not mortality? The samples of broodstock Chinook Salmon examined at Iron Gate Hatchery were reported with some columnaris, and very low Ich.

Principles of epidemiology mandate disease cannot occur unless a susceptible host and pathogen are together in the right environment. Moreover, Ich infections are dependent on adequate density of fish hosts as they have no intermediate non-fish host. I have little first-hand knowledge of this river system, but in accepting these criteria, additional adaptive management needs to occur. I would advise that each of these criteria should be considered a hypothesis, and followed up with monitoring and controlled studies to improve understanding of the details regarding the outcome. The periodic migration of adult salmon into the river each year does not provide the opportunity for year-around support for the pathogen. More effort should be placed to determine potential hot spots for the pathogen that would be associated with typical salmon holding areas. The small study conducted and reported in the technical report by Foott et al. (2016) using resident and sentinel Speckled dace (*Rhinichthys osculus*) in the lower Klamath River (August 5- September 9, 2015) provides some insight into ways to address potential reservoirs for this infection. Their study used exposure cages and beach seining of naturally occurring populations. Dace are known to inhabit slower moving waters along shoreline areas or slack water. They therefore could provide a more available reservoir of Ich.

The flow and temperature criteria are important, but velocities for mitigation are proposed considering the entire river flow, when likely specific holding areas could have very different velocities that could favor infection of adult salmon. The few published papers on the velocity effect on Ich include the study by Bodensteiner et al. 2000 (Journal of Aquatic Animal Health 12:209–219). This study showed that control of infection in catfish within hatchery raceways could be achieved with elevated water turnover rates > 1.9/h, and pulse flows provided as prophylactic treatments (> 85 cm/min, turnover rate. 2.1/h). Hatchery raceways are very uniform systems, and operate as plug flow systems. However, the riverine environment of the Klamath River is not similar to a raceway, as there are side channels, and holding areas, and cooler inflows such as the well discussed Blue Creek refugia.

What are the flows that are measured in those holding areas? What is the behavior of the migrating fish as they move upstream at different flows? We have some information on temperatures and migration, but flows proposed should be evaluated. To improve the understanding and provide more certainty in management options, telemetry studies of adult migrants should be initiated under these different regimes. The Strange (2010) study of thermal behavior indicated that his study was part of a larger biotelemetry study in which adult Chinook Salmon were tagged in the lower Klamath River and its estuary during 2002 through 2006. I could not find evidence of other reports from this study in the documents that I evaluated. Were there other evaluations of fish response to flows in the basin? He made note that the fish that successfully migrated to hatchery or spawning did not show disease conditions. Clearly his study demonstrated that 23°C was the limit to volitional migration, and thermal refugia were sought at temperatures above this. This finding supports the criteria for decision to supplement the river with cool water.

In summary I will comment on each of the criteria. My comments follow each of the bullets, and the bullets are italicized.

- *Flow in the lower Klamath River is projected to be less than 2,800 cfs at the Klamath, California gage (gage # 11530500) in August and September (USFWS 2015).*

Not strong evidence but a reasonable precautionary response.

- *Ich infection of adult salmon or steelhead is identified in July and early August suggesting a low level infection is present that could worsen with poor environmental conditions.*

There have been infections that did not show mortality, and that did not subside following flow releases. However no mortality occurred in 2014 and 2015.

- *Thermal regime of the lower Klamath River is inhibitory to the upstream migration of infected adult salmon.*

Yes, shown in the Strange (2010) article, however, all but two of the fish in that study were from the Trinity River summer Chinook Salmon stocks.

- *Adult salmon are showing abnormal signs of behavior, crowding at tributary mouths, or are not migrating out of the lower Klamath River on a volitional basis.*

Telemetry studies would improve these relationships.

- *The cumulative harvest of Chinook Salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish (see National Marine Fisheries Service (NMFS) and USFWS 2013).*

High densities are definitively a requisite to pathogen amplification.

- *Initiate preventive base flow augmentation releases by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This* *date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in NMFS and USFWS 2013).*

This seems reasonable to provide impetus to migrate. However it appears that the stocks will hold in the system for some time if thermal conditions are not sufficient.

- *Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the Klamath, California gage through September 21. Continue to implement fish pathology monitoring to determine the potential need for the secondary flow augmentation action (preventive pulse flow).*

Pathology monitoring should be ongoing in any management regime and will provide important information for future analyses.

- *The need for preventive base flow augmentation is expected to occur during years with limited or low precipitation levels in the Klamath River basin (e.g., dry conditions). Since the fish die-off in 2002, Reclamation has made preventive base flow augmentation releases in six years over a 13 year period. However, criteria for preventive flow augmentation have changed over this period. Based on the above criteria, it is estimated that preventive base flow augmentation would have occurred in approximately three of the 13 years, or about 20 to 25 percent of the years.*

The reworking of these criteria seem appropriate. Again, my earlier comments provide more detail on the lack of mortality and possible other factors affecting this. Flow augmentations have been helpful in initiating fish migrations, and the evidence in the years during which this was provided was positive.

- *Preventive Pulse Flow Augmentation:*

The preventive pulse flow augmentation is considered an emergency measure and is based on the flows needed to flush the parasites, and also provide stimulus for migration as well as thermal mitigation of the river. These are not fully understood, due to the microhabitat of the basin that may still provide reservoirs of infection. However, moving fish out of holding areas likely occurs during pulse flows, and there is support for them as a normal factor during rain events.

- *Emergency Flow Augmentation (tertiary response):*

The emergency flow augmentation proposal is the highest level response, and appears to have the least scientific support. It is considered the last available management option. I realize that the hypothesis is that if the pulse flows appear to be ineffective, some logic supports this option of higher flows, but I cannot find adequate scientific data to support this action. Again, the need to understand locations of parasite amplification are important to management of the health of the salmon population. More scientific investigations need to be conducted to address the microhabitat characteristics of the vulnerable areas, and how this proposed elevated flow will affect these areas. What are the other factors that affect mortality, should the target salmon be affected by Ich? Throughout the document 2015 Reclamation EA Document (EA-15-04-NCAO), the authors state that this emergency option would be unlikely, due to water /air temperature decreases. The authors state that real-time monitoring would be used to inform the decision. Real-time monitoring of fish other than salmonids and of other disease agents may be appropriate.

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Reviewer 3

To review the Draft Long-Term Plan for Protecting Late Summer Adult Salmon in the Lower Klamath River (Draft LTP), I was provided with the draft plan, six supporting documents, and ample time. The Draft LTP consists of a set of three relatively integrated responses (i.e., primary, secondary, and tertiary) that are intended to protect returning adult Chinook Salmon from epizootic disease outbreaks and mass mortality events. The Draft LTP developers are to be commended for their thoroughness in drafting these criteria. However, many—if not most—of the studies and analyses cited in the supporting documentation consist of grey literature, such as annual reports and memos. This substantially weakens the scientific support for the criteria, in particular the secondary and tertiary responses. This is discussed in detail below. To strengthen the development of future conservation criteria, the relevant management agencies should place a greater emphasis on publishing the results of studies in peer reviewed scientific outlets.

The following review of the trigger criteria focuses on the strength of their scientific basis. Non-biological objectives (e.g., economic concerns) or constraints (e.g., funding limits) were not considered as part of the review. Reviewers were requested to specifically consider two scientific aspects of the criteria and supporting documentation. These are encapsulated in the following two questions:

1) Are the implementation criteria supported by the science?

2) Have the assumptions and uncertainties associated with using the flow criteria been appropriately characterized?

Below, I address these two questions point by point for each response and criterion. My comments are provided in normal text immediately below each of the criteria that are included in *italics*.

Preventive Base Flow Augmentation (primary response):

Initiate preventive base flow augmentation from Lewiston Dam when:

- *Flow in the lower Klamath River is projected to be less than 2,800 cfs at the Klamath, California gage (gage # 11530500) in August and September (USFWS 2015).*

Information provided in the supporting documentation and peer reviewed literature strongly support the idea that increased flows in the lower Klamath River during low flow years will lead to lower disease prevalence and disease-related mortality in adult Chinook Salmon present during the late summer. However, the support for the specific discharge threshold of 2,800 cfs in late August and September appears to be based on observations over a relatively short time line (14 years) and is primarily driven by observations from two years with no detectable mass mortality and that had the lowest flows. Therefore, the scientific evidence that the specific 2,800 cfs threshold chosen is adequate for protecting adult salmon is relatively weak.

The authors of the documentation do not explicitly identify the assumptions regarding how the threshold was determined, nor do they provide estimates of uncertainty around value chosen (e.g., confidence limits). Therefore, these aspects could not be assessed.

- *Ich infection of adult salmon or steelhead is identified in July and early August suggesting a low level infection is present that could worsen with poor environmental conditions.*

There is insufficient information on the effectiveness of providing additional flow in reducing *Ich* infection and mass mortality events. The documentation and peer reviewed literature (cited below) suggests that pulsed flows may dilute parasites/pathogens and transport them downstream. The susceptibility of returning adult salmon to pathogens also is known to be affected by stressors, such as high temperatures (Jeffries et al. 2012). The mechanism of scientific basis behind this criterion, however, was not provided in the documentation. Therefore, it was not possible to evaluate the scientific support for this criteria.

Similar to above, the authors of the documentation do not explicitly identify the assumptions regarding the mechanisms behind this criteria, nor do they provide estimates of uncertainty in the response of fish (e.g., estimates of change in Ich prevalence). Therefore, these aspects could not be assessed.

- *Thermal regime of the lower Klamath River is inhibitory to the upstream migration of infected adult salmon.*

There is strong scientific support that high temperatures can inhibit the upstream migration of adult Chinook Salmon in the lower Klamath River (Strange 2010) and other systems (Williams 2006). The effects of fish crowding on pathogen prevalence in Chinook Salmon also has been documented in the peer reviewed literature (Ogut and Reno 2004). Therefore, the assumption that reducing temperatures would allow fish to migrate past potential thermal barriers, reducing crowding and exposure to pathogens is scientifically supported.

- *Adult salmon are showing abnormal signs of behavior, crowding at tributary mouths, or are not migrating out of the lower Klamath River on a volitional basis.*

As discussed above, crowding or concentrating adult salmon can increase their susceptibility to pathogens. Increasing flows would presumably facilitate migration, increase the total amount of habitat available to adult fish and reduce crowding. These assumptions are scientifically supported by the literature (cited above) and are included in the documentation.

- *The cumulative harvest of Chinook Salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish (see National Marine Fisheries Service (NMFS) and USFWS 2013).*

This is not a scientific criterion and will not be addressed in this review.

- *Initiate preventive base flow augmentation releases by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This*

> *date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in NMFS and USFWS 2013).*

As discussed in the documentation, the harvest data used in this assessment was probably a reasonable index of run timing in the lower Klamath River given the unavailability of any other data. The analysis of that data also was sound and thorough. Therefore, the August 22 date is a reasonable date and supported scientifically. However, no estimates of uncertainty are provided.

- *Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the Klamath, California gage through September 21. Continue to implement fish pathology monitoring to determine the potential need for the secondary flow augmentation action (preventive pulse flow).*

These steps appear to be sound and justified based on the documentation provided. However, assumptions regarding the ability to detect pathogens for the given monitoring design and the ability to reverse or prevent further infections using flows are poorly documented. This is discussed in the secondary response, below.

- *The need for preventive base flow augmentation is expected to occur during years with limited or low precipitation levels in the Klamath River basin (e.g., dry conditions). Since the fish die-off in 2002, Reclamation has made preventive base flow augmentation releases in six years over a 13 year period. However, criteria for preventive flow augmentation have changed over this period. Based on the above criteria, it is estimated that preventive base flow augmentation would have occurred in approximately three of the 13 years, or about 20 to 25 percent of the years.*

The flow frequency analyses in the documentation support this supposition. However, as the Reclamation (2015) report suggests, the evaluations of effects of augmentation on cold-water pools, and the need for augmentation were based on limited range of years and did not take into account the effect of long-term (multi-year) cumulative drought in the evaluations. The evaluation would have been much sounder had it included the period of record for the relevant gages.

Preventive Pulse Flow Augmentation (secondary response):

During the preventive base flow period, a preventive pulse flow targeting a flow of 5,000 cfs for one 24 -hour period at the Klamath, California gage would occur when the peak of fall run migration (typically the first or second week of September) is identified in the lower Klamath River as indicated by tribal harvest. This flow level is based upon the experience of 2015, which was intended to use a small volume of water to provide a change to the environmental conditions of the lower Klamath River to further reduce the risk of an Ich infection that could result in a disease outbreak (see Reclamation 2015). Specifically, the anticipated benefit of the pulse is to enhance flushing and dilution of the river of parasites when the bulk of fall run Chinook Salmon adults are likely to be in the lower river while also facilitating movement of adult salmon to reduce the potential for crowding. Conditional release of this pulse flow requires low level Ich infections (less than 30 Ich per gill arch) that are confirmed on three fall-run adult salmon (of a maximum sample size of 60) captured in the lower Klamath River in one day during this time of *typical peak migration. Disease sampling and confirmation of disease findings would follow the methods as described in NMFS and USFWS (2013).*

The secondary response requires the fulfillment of several unstated and largely unsupported assumptions in order to be effective treatment for preventing or minimizing epizootic disease outbreaks and mass mortality events. First, the response assumes that the occurrence of the pathogens can be detected with certainty, which is usually not the case (McClintock et al. 2010). Detection of a pathogen in Chinook Salmon depends on several factors including true prevalence, the number of animals surveyed, and the ability to detect the pathogen when present (Colvin et al. 2015). The documents provide a rough estimate of the number of fish to be surveyed (maximum of 60) but do not report how this value was determined nor do they relate this to the true prevalence or take into account incomplete detection. Such information is essential in assessing the adequacy of the monitoring and response. The second assumption is that the pulsed flow treatment would be successful in preventing an outbreak and mass mortalities beyond the effects of the flow augmentation. The potential success of this treatment is primarily based on one observation (2015) and a hypothesis based on one year of data in the Northeast North America (Jessop 1995). Previous studies with Klamath River parasites suggest that pulsed flows decrease the amount of parasites in the environment through dilution but have not demonstrated a reduction in infection (Bjork and Bartholomew 2009). These assumptions were not addressed in the documentation and are required to evaluate the strength of the scientific basis for the secondary response.

Emergency Flow Augmentation (tertiary response):

Initiate emergency flow release to target a flow of 5,000 cfs in the lower Klamath River for up to five days in August or September if emergency conditions exist as identified by USFWS and NMFS (2013b):

- *Diagnosis of severe Ich (30 or more parasites on a gill arch) infection of gills in 5 percent or greater of a desired sample of 60 adult salmonids confirmed by the USFWS California Nevada (CA-NV) Fish Health Center, or*

- *Observed mortality of greater than 50 dead adult salmonids in a 20 kilometer reach in 24 hours coupled with the confirmed presence of Ich by the USFWS CA-NV Fish Health Center.*

Use the protocol for sharing and confirming information on a real-time basis to determine if and when the emergency flows would be implemented.

- *Key staff members would be on high alert during the flow augmentation action and would be getting timely monitoring results. The USFWS CA-NV Fish Health Center would provide a pathology report documenting the findings of diagnostics survey to State, Federal, and Tribal fish biologists and pathologists (LTP Technical Team), and the Klamath Fish Health Assessment Team (KFHAT). An emergency release would be considered by Reclamation on receipt of a positive pathology report.*

The need for emergency flow augmentation is expected to be low considering the infrequent use in the past (only once in 6 years of implementing an action since 2002) and the knowledge gained from these previous years regarding the dynamics of Ich infection and environmental variables that include flow."

The assumptions needed for the tertiary response are similar to the secondary response regarding the detection of pathogens and interpretation or expansion to the adult Chinook Salmon population in the lower Klamath River. The assumptions regarding use or choice of 50 dead fish as a trigger also were unstated and require estimates on the probability of detecting dead fish in order to be interpretable at the population level and therefore, scientifically justifiable. Finally, the ability to reverse an existing epizootic disease outbreak using emergency flow augmentation is weakly supported by a single year of data. As stated above, these assumptions and others regarding the dynamics of the pathogen populations indicated that the scientific basis for this response is weak.

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Reviewer 4

This requested review focuses on the applied science to be utilized for the development of the Draft Long-Term Plan for Protecting Late Summer Adult Salmon in the Lower Klamath River—a proposal for the protection of late summer spawning salmon stock of Chinook Salmon (*Oncorhynchus tshawytscha*) within the Klamath River watershed. The Bureau of Reclamation (Reclamation) of the U.S. Department of the Interior developed certain *trigger* criteria to aid in determining when flows from upstream reservoirs would be made available to the lower Klamath River to mitigate an epizootic disease outbreak that may seriously affect the adult fall-run Chinook Salmon (FRCS) that are entering the lower watershed prior to their upstream movements for spawning. This review will consider the applied science that was employed to develop the trigger criteria, with a focus on the use of flow criteria and its applications, to prevent the potential for epizootic disease(s) outbreaks in the FRCS and to allow successful migration and spawning of FRCS within the Klamath River watershed.

This review is to provide analyses and responses to two fundamental questions: (I) are the implementation criteria supported by the science?; and (II) have the assumptions and uncertainties associated with using the flow criteria been appropriately characterized?

I. Are the implementation criteria supported by the science?

Three responses (A-C) were developed to implement flow augmentation to the lower Klamath River based on work on the FRCS from 2012 to 2016 (1-6).

A. ***Preventive Base Flow Augmentation (Primary Response)*** *- The proposed primary response was to initiate a preventive base flow augmentation from the Lewiston Dam when: (a) flows in the lower Klamath River are projected to be less than 2,800 cfs, based on measured stream flows at the Klamath, California USGS gauge (#11530500), in August and September (4); (b) the Ichthyophthirius multifiliis (Ich) infection of adult salmon (or steelhead) is identified in July and early August suggesting that a low level infection is present in the system; (c) the thermal regime present in the lower Klamath River is inhibiting the upstream migration of any infected (or non-infected) salmon stocks; (d) the FRCS adults are exhibiting abnormal behavior, crowding at tributary mouths (colder water sources), or not migrating out of the lower Klamath River; and (e) the cumulative harvest of FRCS in the Yurok Tribal fishery (the estuarine area) is meeting or exceeding a total of 7,000 fish.*

This primary response is well supported by the information developed for the FRCS. Needless to say, the management of salmon stocks along the west coast of North America is based on an extensive, and often very intensive, body of science developed over time on their complex life histories, in addition to the development of fisheries management plans for each salmon species of concern, and their stocks. (As a personal aside, my graduate advisor was a major researcher on the biology of Alaskan red salmon, so I did learn salmon biology through osmosis from him, as well as in one graduate animal ecology seminar, and through teaching fishery courses in my career and pursuing outside readings.) Furthermore, recent advances of molecular techniques in fisheries' genetics and the use of stable isotopes has allowed for greater differentiation of separate salmon stocks (runs) so that management efforts for Pacific salmon may be accomplished at very fine assessment levels, especially for mixed-stock salmonid fisheries.

Based on the FRCS information developed (1-6), the five triggers for the primary response are acceptable for the potential protection of this important run through flow releases from Lewiston Dam, assuming that there will always be an adequate supply of cold water available. However, I feel that there needs to be some exploration as to the best pattern of flow releases for the Klamath River ecosystem— this is discussed further in this FRCS review.

In particular, the Yurok Tribal FRCS fishery in the estuary serves as an excellent indicator of the health of the FRCS, and serves as the first key indicator. Obviously, the first trigger is a flow trigger to be employed when the Klamath River flows are less than 2,800 cfs, and is independent of the parasite loading in the FRCS, and is independent of pre-spawning salmon behavior. So, the physical measure of flow and the summer-fall temperature regime in the Klamath River are two excellent real-time indicators for the initiation of water releases to protect the FRCS in their spawning migration, no matter what the biological indicators may suggest. Consequently, excellent yearly management of the FRCS may be attained based solely on flow and temperature parameters, although another important trigger is the harvest of FRCS by the Yurok Tribe in the estuarine zone of the Klamath River.

By monitoring the FRCS harvest by the Yurok Tribe in the estuary, the preventive base flow augmentation releases (2,800 cfs) by August 22, with a continuing flow pattern through September 21 (this time frame was developed based on historical data of flow in the Klamath River), would provide suitable conditions for the migration of FRCS, as well as minimize any fish mortalities associated with Ich and *Flavobacter columnare* (columnaris) disease. It is important to note that, if the fish harvest quota is not met, this flow regime would be immediately instituted. I agree that this is a very important part of the management plan. Part of this primary flow augmentation regime requires real-time fish pathology monitoring to determine the potential prerequisite for the secondary flow augmentation action. The importance of this real-time disease analysis cannot be understated, and I would only assume that all resources that are needed will always be available for the FRCS fishery.

There were three flow scenarios developed in attachment two for the FRCS (2). These flow models considered a series of managed flow patterns (sustained, pulsed and hybrid pulsed/sustained). The hybrid pulsed/sustained scenario (third model) was recommended by the biologists who developed these three models and has several positive aspects, as well as a few negative aspects, to protect the FRCS from Ich and columnaris during their pre-spawning period in the lower Klamath River (the first two models also appear to be acceptable, but I do prefer the approach used for the third model). My major concern is that the ascending limb and the descending limb of each of the proposed pulses (Figure 3 in Attachment 2 of reference 2) are too rapid, and may be detrimental to the entire complex of the stream biotic assemblages other than salmon. This management element of rapid increases (and decreases) in the pulsed water discharge would be of concern to me for any flow regime developed for the lower Klamath River to protect FRCS.

The same factor is also evident in the increasing and decreasing limbs of the sustained pulse, although the sustained pulse will level off at 1,500 cfs over the critical time for FRCS (Figure 3 in Attachment 2 of reference 2). My recommendation would be to damp out the discharge for the ascending limb over two to three days unless this would not be feasible based on the current operational procedures employed at the Lewiston Dam. In addition, the flow reduction of the descending limb also needs to be spread over a longer time frame if possible. Obviously, this modification of the descending limb may result in the use of more hectare-meters of water from Lewiston Dam. However, that extra water demand may be offset by spreading out the release time for the ascending flow limb, and would balance the total flow releases.

No matter what flow pattern is instituted for the lower Klamath River, it is important to ramp up slowly, and to ramp down slowly, based on hydrology and biology work done at other riverine systems in the United States that have major dams present in their watersheds. Rapid increases in flow or decreases in flow from reservoir systems do not mimic natural systems very well, and create unrealistic flow patterns. However, the biologists working with the FRCS may develop a sense of what works best for the mitigation of the disease potential, as well as what works best for the maintenance of stream structure and function that may affect other important fishery resources.

B. Preventive Pulse Flow Augmentation (Secondary Response): *During a preventive base flow period, a pulsed flow (secondary response) of 5,000 cfs for one 24-hour period at the Klamath, California gauge would occur when the peak of FRCS migration is identified in the lower Klamath River, presumably by the Yurok Tribe estuarine fishery for FRCS. The anticipated benefit of the pulse is to enhance the flushing and dilution of disease factors, especially Ich, when the bulk of FRCS adults are likely to be present in the lower Kamath River, while also facilitating the movement of FRCS to reduce overcrowding. The conditional pulse release requires the identification of low-level Ich infections, < 30 per gill arch as confirmed on three FRCS, from a maximum sample size of 60 fish captured in the lower Klamath River in one day during typical peak migration (3).*

Obviously, this secondary response is tied to the observed peak of FRCS migration, and I assume that this migration peak would be easily identified based on the early Yurok Tribal fishery in the estuary. So, my first comment on the FRCS peak is whether or not the Yurok Tribe has developed a strong historical data base for determination of the time frame when the FRCS peak migration in the Klamath River would occur, within some statistical limits, augmented with additional data as to the temperature regime present in the river and local climatic conditions during peak migration, as well as to any correlations with flow patterns in the Klamath River. In essence, how does the yearly flow regime affect the peak of FRCS staging and migration?

The secondary response has two very positive benefits, and is an applicable adaptive management tool for FRCS. First, it would trigger a pulsed flow that hopefully would reduce the potential for Ich disease in the salmon population, as well as minimizing columnaris effects; however, this needs to be carefully studied in the future if implemented. Second, this 5,000 cfs pulse should eliminate any overcrowding by stimulating the upstream movement of staging FRCS to their upstream spawning grounds. I concur that this secondary response is a very valuable tool for FRCS management.

C. Emergency Flow Augmentation (Tertiary Response): *The tertiary response is to initiate an* <u>*emergency*</u> *flow release of 5,000 cfs in the lower Klamath River for up to five days in August or*

September if emergency conditions exist based on the diagnosis of a severe Ich gill infection in 5 percent, or greater, of a sample of 60 FRCS, or the observed mortality of greater than 50 dead FRSC in a 20 km reach in 24 hours coupled with the confirmed presence of Ich (3). The use of the tertiary response (considered to be a low probability occurrence based on past experience since 2002) by Reclamation centers on real-time reporting to the LTP Technical Team and the Klamath Fish Health Assessment Team, and would be based on the positive pathology of Ich as described above.

This is the "doomsday" real-time response to the presence of severe Ich in the lower Klamath River FRCS, but is also an important management tool that could possibly mitigate these severe disease effects to a degree. My question here would be if there were, or will be, follow-up studies if the tertiary response was employed? Was there an increased escapement of the FRCS smolts (from the spawning cohort of the year when the tertiary response was used) to the estuary following any tertiary response, and perhaps even the secondary response? Perhaps, I am stretching this a little by assuming that there is monitoring of salmon escapement in the Klamath River system, but I know that management plans for many salmon stocks along the Pacific coast use escapement parameters as part of their population modeling, and then predict subsequent fishing allocations (commercial, recreational, subsistence and cultural) based on the projected returns of a salmon stock (run).

Another question is what are the key stimuli for the occurrence of massive Ich infections and why? Is it always associated with low flow and increased temperature in the lower Klamath River, and is there enough research into all disease factors affecting FRCS as well as other fisheries resources in the watershed?

Summary Comments (IA-C): Facing a multitude of human demands, the Klamath River system is a highly-managed watershed with an abundance of dams present throughout the watershed. Furthermore, past and present human activities within this watershed such as hydropower development and generation, inter-basin transfer of water, timbering, mineral extraction, and agriculture have affected aquatic resources especially the salmonid fishery and presumably other aquatic resources. Added to these previous factors, both urban and periurban development, with their increasing use of water resources and alteration of the landscape and stream hydrology, also affect the biotic resources present in the watershed (7).

However, the three responses developed to mitigate problems associated with the FRCS are an excellent example of adaptive management in real-time. These responses are based on a solid core of knowledge about the biology of FRCS over years of observation within the Klamath River watershed. Given these approaches to mitigating effects on FRCS, it would be assumed that fine-tuning may occur in the future given the importance of these salmonid stocks (8, 9). Since there are at least two teams (the LTP Technical Team and the Klamath Fish Health Assessment Team) that focus on the FRCS, new information could easily be factored into management strategies for this salmon and allow for even better assessment in the future.

II. Have the assumptions and uncertainties associated with using the flow criteria been appropriately characterized?

A. I would agree that the assumptions on employing the flow criteria are more than adequately met. For protection of the FRCS, there is an excellent body of work developed over time that supports using managed flow regimes to mitigate the potential disease problems in this very important fish stock throughout the Klamath River watershed. Because of the value of salmon to the fisheries economy of the Northwest, as well as its importance to Native Americans both as a food source and for their cultural heritage, there is tremendous scientific interest in these salmonid species and the management of the salmon fisheries, especially in light of the salmonid stocks at very high risk throughout the Pacific Northwest (8, 9). However, there appears to be the looming specter of competing water interests that may well undermine any attempts to protect and preserve salmon stocks in California.

B. One serious uncertainty to FRCS is climate change (there is obviously more than enough scientific evidence to support this critical concept that rapid climate change is occurring; however, there is still debate on the magnitude of estimated temperature increases and this temperature effect globally, as well as the effects of ocean acidification, linked to increasing atmospheric carbon dioxide, on oceanic fish stocks) and how it will affect salmon stocks in the Pacific Ocean in the future (10). For example, USGS predicts that the Klamath River temperatures are increasing at approximately 0.5°C per decade or 1-2.3°C over the next 50 years—these temperature increases will potentially have a strong influence on biotic assemblages present in the watershed as well as strong shifts in precipitation and hydrologic regimes of the Klamath River.

In particular, climate change may affect salmon stocks strongly in the southern part of their range (especially the Northwest salmonid populations, and California and southern Oregon stocks in particular). This statement centers on the basic ecological tenet that populations of a species are more vulnerable at the periphery of their range (one aspect of metapopulational theory), and may face extinction depending on the stressors present (disease, climate, predation, inbreeding, etc.) over time. However, if the core population(s) of a species is stable, there is always the possibility of recolonization of previously occupied marginal habitat. Because of the strong fidelity of salmon to their natal spawning area in a stream, this recolonization process may occur over a very long time span, or perhaps not at all.

In addition, major climate drivers such as El Niño (the warm phase of the El Niño Southern Oscillation phase) and La Niño (the cool phase of the El Niño Southern Oscillation) may be effectively altering the life histories of salmonid species during their marine regime. These two drivers strongly affect the regional climate in the eastern Pacific, with El Niño linked to drought conditions, especially the long-running arid conditions in the Pacific Northwest. If these drought conditions persist, there is a strong probability that water resources that are needed to protect the FRCS through flow mitigation may be made available to other competing interests, much to the continuing detriment of salmonid stocks. For example, water from the Trinity River is often diverted from the coast range to users in the Central Valley of California, with observed declines in the Klamath River salmon stocks possibly attributable to this increased demand for regional water resources. Since many of the disease factors affecting the Klamath River salmon are linked to temperature and flow, it is imperative to maintain an adequate flow regime within the watershed to protect the entire suite of salmon stocks present.

The need for preventive base flow augmentation is expected to occur during years with either limited or low precipitation levels in the Klamath River watershed. Since 2002, the BOR did preventive base flow augmentation releases in 6 years over 13 years. However, the criteria for preventive flow augmentation evolved, and it is now estimated that flow augmentation would have occurred in approximately 3 of the 13 years, or about 20-25% of the years, lower than what was done over the 13 year period. Consequently, it would be a worthwhile exercise to model expected flow release patterns to mitigate parasite loading and to effect spawning migrations with predictions of future climate change, perhaps not as easy as it sounds although there appears to be enough of a data base on FRCS, and other salmon stocks and species to do this analysis.

D. There still remains a major question about the future of instream flows in the Klamath River watershed and the overall effect on all salmonid stocks (11, 12, 13). With competing water demands, especially of concern to climate change factors in the Pacific Northwest, there are proposed models for implementing and quantifying water transaction programs that could potentially assist in eliminating the water quality limitations for FRCS with an assumed reduction in disease (11). The results of these water transaction models indicate a reduction in residence time in holding habitat, especially when there are low flows (with potentially increased river temperature), holding habitats are saturated, and water quality parameters (temperature, dissolved oxygen, etc.) are suboptimal (11). Coupled with in-stream temperature forecasting for better water allocation decisions by the fishery managers in the Klamath River watershed (12, 13), these models would certainly increase the protection of FRCS.

Summary Comments (IIA-D): Obviously, there is no one perfect solution to mitigating disease outbreaks in the lower Klamath River, or the entire watershed, and there needs to be a number of fisheries management options for the protection of FRCS, as well as other fish species of concern along the Pacific coast. However, this is clearly a case of real-time adaptive fisheries management that is doing its best to maintain an important fisheries resource along the west coast, and the information assembled to date is robust. I consider that the assumptions and uncertainties associated with using the flow criteria have been appropriately characterized.

One other overriding concern, and an important uncertainty, is the presence of ceratomyxosis, another disease vector that is caused by the myxozoan parasite Ceratonova shasta, in the Klamath River watershed, and its effect on the population dynamics of FRCS juveniles (14, 15). The infection rate of this parasite, and subsequent mortality, is also related to elevated temperature regimes (and exposure dose) in the watershed (15), and must now be taken into account for any population modeling of FRCS, especially since ceratomyxosis reduces juvenile salmon survival that will affect the future spawning abundances of FRSC (15).

I need to make a few comments on the genetics of Chinook Salmon along the Pacific Coast since data from this increasing body of work is important to the overall management goals for FRCS as well as other Northwest salmon stocks (16, 17, 18, 19). There now exists considerable information on the genetic structure of salmonid stocks along the Pacific Northwest— this information needs to be factored (or at least considered) into management plans, especially since there are mixed salmon stocks present. It does not need to be a major part of any LTP, but at a minimum it should be discussed as to its potential applicability.

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Note: The Institute for Scientific Information (ISI) database (as well as Google Scholar) was accessed for recent papers on Klamath River Chinook Salmon. There were 66 citations (last accessed and searched on 9.20.16) obtained from the ISI database using the search phrase "Klamath River Chinook Salmon." Only pertinent papers (such as pdfs) were downloaded through the University of Maryland System electronic journal holdings; if the journal was unavailable, direct contact with the author through e-mail was undertaken to obtain the paper. Only those papers newer than the Strange (2012) paper were used to supplement the findings and conclusions as presented in references 1-6 for FRCS, although a few papers older than the Strange paper were also cited.

Reviewer 5

Please find below my peer review of the *Draft Long-Term Plan for Protecting Late Summer Adult Salmon in the Lower Klamath River* flow criteria intended to prevent epizootic disease outbreak proposed by the Bureau of Reclamation. Below I have provided responses inserted directly into the Scope of Work. First, I provide broad response to the two guiding questions, then provide comments on the implementation criteria, and finally, provide some detailed comments on individual review documents.

Peer Review Scope: The subject of this review will consider the science used to develop the trigger criteria. In turn it will inform the decision to implement an alternative.
This review is focused solely on the use of flow criteria in its application to prevent an epizootic disease outbreak in the lower Klamath River.

Peer reviewers are asked to provide responses relative to the following questions:

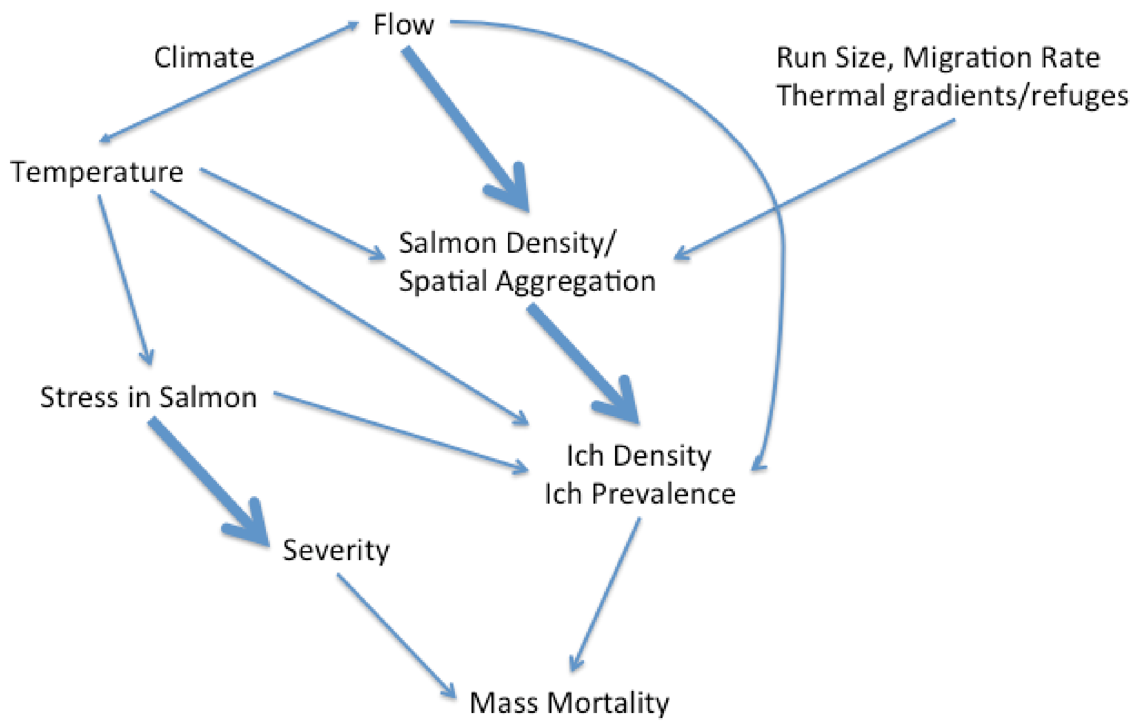
Question 1. Are the implementation criteria supported by the science?

Overall, the implementation criteria are supported by available science on the disease ecology of adult salmon in freshwater, including known or well-supported relationships between temperature and disease transmission and pathogenesis. The criteria also use assumptions about the effects of flow on salmon behaviors that are generally well supported. The criteria also rely on a key assumption that increased flow decreases Ich abundance, transmission and pathogenesis. While there is a high likelihood that the general assumption is true (the relationship is intuitive, supported by limited data from other systems, and is consistent with the very limited and observational data available from the Klamath River), the details of the relationship are important and represent a substantial area of uncertainty.

<u>Regardless, the underlying mechanisms and assumptions are broadly plausible. The suggestions and comments below are primarily aimed at future evaluation and refinement of the criteria.</u>

The implementation criteria appear to be built explicitly and implicitly on assumptions about several interacting mechanisms, which I summarize and address below. While largely sound, I note that I did not find a synthesized conceptual framework for understanding the relationship between the proposed action(s) and epizootics. I have inserted a draft diagram from my notes (Figure 5-1), which may or may not be useful. Regardless, the overall management process may benefit from a clear conceptual model of underlying mechanisms that would: 1) allow for more mechanistic predictions; 2) refine qualitative understanding of key system drivers and uncertainties in a complex system; 3) assist in designing efficient effectiveness monitoring; 4) serve as the basis for formal quantitative or statistical models; and 5) aid in the assessment of the relative potential benefits of alternative actions. Specifically, such a model may help evaluate the effects of temperature and flow separately to determine the most efficient use of water releases whereas the current plan targets flow primarily. Similarly, such a model may help refine future data collection efforts to determine the factors causing prolonged (weeks) aggregation of adult salmon in specific locations that allow the buildup of Ich and development of epizootics—the factor identified as the key biological mechanism, but for which few data are available to understand how large scale flow releases will affect salmon aggregation behaviors.

Epizootic episodes require high incidence rate, high prevalence and high average intensity/severity in hosts (full-blown pathogenesis). Transmission dynamics determine both prevalence and maximum potential intensity in a non-proliferative pathogen such as Ich (non-proliferative = not able to complete reproduction/division solely within the host), and are determined by a complex mix of biotic and abiotic factors. Intensity and pathogenesis are determined primarily by host response/immunity to a given exposure level for non-proliferative pathogens and pathogenesis is strongly mediated by environmental conditions in fishes. Therefore, I attempt to address the likely effects of the criteria on transmission and pathogenesis separately by each key assumption in the next section.



Note: Arrow weight indicates the presumed importance of that factor. Colors (not used here) could be used to indicate confidence level.

Figure 5-1. Draft Conceptual Model for Hypothesized Mechanisms Among Factors Considered in Development of Criteria

Question 2. Have the assumptions and uncertainties associated with using the flow criteria been appropriately characterized?

As noted above, the flow criteria appear to have been developed using the following set of assumptions:

<u>Direct effects of flow rate/discharge (holding temperature constant):</u>

Assumption 1) Higher flows reduce the rate of transmission by reducing numbers of Ich tomonts (stage shed from host), tomites (reproductive/division stage) and theronts (infective stage; duration of all three stages ~10 days at 20°C; theront stage = 2-3 days) via flushing (downstream transport rate).

The transport dynamics of free-living stages of Ich and other pathogens are not well understood in relation to infection and are a complex function of shedding rate from the host, host density and location (which are functions of freshwater entry rate and migration rate), water velocity, and duration of the infective stage outside of the host. The situation for Ich is further complicated by the complex life cycle of Ich, which includes a benthic proliferation stage (i.e., benthic densities may be relatively independent of flow rate) — see comments on pathogen flux below. Thus, the assumption that discharge will reduce transmission and infection rate is plausible, but challenging to directly evaluate. Several studies were cited in support of this assumption, the best being Bodensteiner et al. (2000). Unfortunately, that study was in hatchery channels and focused on catfish hosts. Thus, how increases in flow rate caused the decline in Ich in that study are difficult to transfer directly to Klamath River Chinook Salmon for at least two reasons: 1) species specific responses to parasites across velocities may differ (i.e., infection rates) and 2) whether effective flushing rates in natural and much more heterogeneous habitats, often with circling fish, would be similar to the linear hatchery raceways is unknown. In conclusion, it is highly likely that this assumption is true, but there is high uncertainty about how a specific increase in flow rate would affect Ich dynamics in Chinook Salmon hosts.

Assumption 2) Higher flow rates increase river volume, reducing the density of infective theronts encountered by salmon. Reduced pathogen density (pathogens/liter) reduces infection rate.

It is highly plausible increased flow will result in lower volumetric density of both proliferative and non-proliferative pathogens (pathogens/liter). Net effects on salmon of this mechanism are difficult to assess because of the effect of increased discharge on water velocity (See Assumption 4 below).

Assumption 3) Higher flows increase salmon migration rate through the lower river. Increased migration rate decreases lower river residence time, thereby reducing exposure time to any given density of infectious pathogen.

Assuming higher flows maintain or induce upstream migration, Assumption #3 is highly likely to provide a benefit. Note, #3 reduces the number of salmon per volume for a given river entry rate, which may also reduce pathogenesis of proliferative pathogens, but may not against non-proliferative pathogens (see #4 below). However, Strange (2010) found the effects of declining temperature better explained migratory movements rather than discharge per se.

Assumption 4) Higher flows increase total river volume and thus decrease salmon volumetric density (salmon/cubic meter). Reduced number of salmon per volume decreases transmission rate.

Assumption #4 may hold for proliferative pathogens, but may not for non-proliferative pathogens. Specifically, instantaneous host density of migrating salmon will not directly affect the local density of infective stages in Ich, which require days to weeks outside the host before becoming infective. This is in contrast to bacterial and other pathogens, which may immediately infect new hosts upon release, and thus, increases in salmon density will then increase proliferative pathogen infection rate through density/proximity effects. Thus, the effects will depend on the duration of increased flow in relation to the duration of the salmon run and (relatively long) generation time of Ich.

Note that infection rate for salmon should be primarily related to encounter rate or pathogen flux (number pathogens encountered * salmon surface area^{-1} * time^{-1}). Thus there is considerable uncertainty about how increased pathogen velocity would play off the benefits of reduced pathogen volumetric density at higher discharge, if salmon migration rate remained constant. In other words, the encounter rate of pathogens will increase at higher water velocities and the benefit of reduced pathogen density at higher discharge may be a wash (pardon the pun). Importantly, the spatial aggregation behaviors of salmon may have the largest influence, and how the formation and location of aggregations change, with changes in discharge, will likely have the largest effects on development of high theront densities and encounter rates with salmon.

Effects of temperature (holding discharge constant)

Assumption 5) Higher temperature increases transmission rates, all else equal, because higher temperatures reduce pathogen generation time, increase pathogen density, and increase pathogen activity rates (i.e., ciliate swimming rate).

This assumption is well supported in a wide variety of taxa including salmon and Ich.

Assumption 6) Higher temperatures increase host stress and reduce immune resistance, thereby increasing the probability and severity of pathogenesis.

This assumption is well-supported for temperatures encountered by salmon in the lower Klamath River. In a wide variety of systems, negative effects of temperature on salmon are manifest at 18-20°C, though Klamath River populations appear to have somewhat higher temperature tolerance (e.g., Strange 2010).

Assumption 7) High temperatures (~>21°C in most Chinook Salmon; >23°C in Klamath River Chinook Salmon; Strange 2010) block migration or reduce salmon migration rate, thereby increasing both physiological stress and probability of prespawn mortality, as well as exposure time to high pathogen density habitats (i.e., Assumption #5).

The behavioral assumption is well supported. A general relationship between temperature and prespawn mortality is also well supported, though underlying mechanisms vary by year and location.

Overall, this evaluation suggests that flow augmentation may provide benefits indirectly through the amelioration of temperature effects on salmon behavior, especially reducing aggregation.

Assumption 8) The hydrologic and thermal time series are representative of future conditions.

Finally, the development of criteria relied heavily on recent conditions to infer the frequency of future events, which is not unreasonable given the available data. The past time series is recent and relatively short and relevant caveats were clearly stated. However, important elements of uncertainty were not identified. To what degree the available time series will accurately reflect future conditions is unknown due to interannual, potential decadal-scale climatic regime shifts, and long-term directional climate warming. Such considerations do not compromise the approach used, but several points may be useful to consider, as noted below in the detailed comments.

<u>Assumption 9) The trigger(s) will initiate Preventative Base Flow Augmentation at the beginning of the adult salmon run.</u>

A key aim of the criteria is to provide a framework that implements flow augmentation at an ecologically relevant time in the run season, i.e., during a period affecting the onset and severity of pathogenesis. The tiered approach should initiate flow augmentation early in the run for average to large run sizes using the cumulative fisheries harvest. The trigger threshold appears reasonable given available data and monitoring infrastructure (minor suggestions below). The secondary trigger of 22 August should provide flows in the event of a small or late run.

Implementation Criteria:

Preventive Base Flow Augmentation (primary response):

Initiate preventive base flow augmentation from Lewiston Dam when:

- Flow in the lower Klamath River is projected to be less than 2,800 cfs at the Klamath, California gage (gage # 11530500) in August and September (USFWS 2015).

This criterion is well supported by correlations between flow, Ich and run size.

- Ich infection of adult salmon or steelhead is identified in July and early August suggesting a low level infection is present that could worsen with poor environmental conditions.

This criterion is reasonable given the relatively long generation time of Ich.

- Thermal regime of the lower Klamath River is inhibitory to the upstream migration of infected adult salmon.

This criterion is supported by Assumptions 7, 3 and 4.

- Adult salmon are showing abnormal signs of behavior, crowding at tributary mouths, or are not migrating out of the lower Klamath River on a volitional basis.

This criterion is supported by Assumptions 7, 3 and 4. The trigger criteria are qualitative and may be difficult to reliably classify. Specific quantitative metrics could be helpful.

- The cumulative harvest of Chinook Salmon in the Yurok Tribal fishery in the estuary area meets or exceeds a total of 7,000 fish (see National Marine Fisheries Service (NMFS) and USFWS 2013).

As noted above, this criterion is reasonable. See detailed comments for minor suggestions.

- Initiate preventive base flow augmentation releases by August 22 to meet the target flow (2,800 cfs) in the lower Klamath River, if the fish harvest metric above is not met. This date is selected based on historical harvest information in the estuary and the middle Klamath River area (as summarized in NMFS and USFWS 2013).

- *The ”back-stop” criterion is an excellent safeguard in the event of an especially late run or issues with accurately assessing the run from fisheries' efforts.*

- Continue flow augmentation to target a flow of 2,800 cfs in the lower Klamath River, as measured at the Klamath, California gage through September 21. Continue to implement fish pathology monitoring to determine the potential need for the secondary flow augmentation action (preventive pulse flow).

- *The selection of a hard date for this criterion was somewhat unclear and the use of a combined date-temperature metric may be more efficient.*

- The need for preventive base flow augmentation is expected to occur during years with limited or low precipitation levels in the Klamath River basin (e.g, dry conditions). Since the fish die-off in 2002, Reclamation has made preventive base flow augmentation releases in six years over a 13 year period. However, criteria for preventive flow augmentation have changed over this period. Based on the above criteria, it is estimated that preventive base flow augmentation would have occurred in approximately three of the 13 years, or about 20 to 25 percent of the years.

See detailed comments, especially regarding climate regime(s) during the period of record.

Preventive Pulse Flow Augmentation (secondary response):

During the preventive base flow period, a preventive pulse flow targeting a flow of 5,000 cfs for one 24 -hour period at the Klamath, California gage would occur when the peak of fall-run migration (typically the first or second week of September) is identified in the lower Klamath River as indicated by tribal harvest. This flow level is based upon the experience of 2015, which was intended to use a small volume of water to provide a change to the environmental conditions of the lower Klamath River to further reduce the risk of an Ich infection that could result in a disease outbreak (see Reclamation 2015). Specifically, the anticipated benefit of the pulse is to enhance flushing and dilution of the river of parasites when the bulk of fall-run Chinook Salmon adults are likely to be in the lower river while also facilitating movement of adult salmon to reduce the potential for crowding. Conditional release of this pulse flow requires low level Ich infections (less than 30 Ich per gill arch) that are confirmed on three fall-run adult salmon (of a maximum sample size of 60) captured in the lower Klamath River in one day during this time of typical peak migration. Disease sampling and confirmation of disease findings would follow the methods as described in NMFS and USFWS (2013).

This criterion is well supported by Assumptions 5-7 (temperature effects); the potential benefits via flushing are less supported (i.e., Assumption 4).

Emergency Flow Augmentation (tertiary response):

Initiate emergency flow release to target a flow of 5,000 cfs in the lower Klamath River for up to five days in August or September if emergency conditions exist as identified by USFWS and NMFS (2013b):

- Diagnosis of severe Ich (30 or more parasites on a gill arch) infection of gills in 5 percent or greater of a desired sample of 60 adult salmonids confirmed by the USFWS California Nevada (CA-NV) Fish Health Center, or

- Observed mortality of greater than 50 dead adult salmonids in a 20 kilometer reach in 24 hours coupled with the confirmed presence of Ich by the USFWS CA-NV Fish Health Center.

Use the protocol for sharing and confirming information on a real-time basis to determine if and when the emergency flows would be implemented.

- Key staff members would be on high alert during the flow augmentation action and would be getting timely monitoring results. The USFWS CA-NV Fish Health Center would provide a pathology report documenting the findings of diagnostics survey to State, Federal, and Tribal fish biologists and pathologists (LTP Technical Team), and the Klamath Fish Health Assessment Team (KFHAT). An emergency release would be considered by Reclamation on receipt of a positive pathology report.

The emergency flow criterion will also likely provide benefit. Again, incorporating a tiered set of criteria that also addresses temperature may be desirable. Additionally, identifying key staff positions at each agency and notification pathways, etc., may also be useful given staff turnover and the substantial need for in-season coordination, etc.

The need for emergency flow augmentation is expected to be low considering the infrequent use in the past (only once in 6 years of implementing an action since 2002) and the knowledge gained from these previous years regarding the dynamics of Ich infection and environmental variables that include flow.

Concur. See Assumption 8 and notes below for minor comments.

Documents to be reviewed:

Trinity River Restoration Program Fall Flow Subgroup. 2012. 2012 Fall Flow Release Recommendation. 20 pages. (Referred to above as the Trinity River Restoration Program (TRRP) Fall Flow Subgroup recommendations developed May 31, 2012.)

Page 4: "The purpose of higher base flows is not necessarily to reduce water temperatures or to provide migration cues but to achieve the associated increased water velocities and higher turnover rates of water in holding areas, which should reduce the ability of Ich to find and attach to a host fish during its free swimming infectious stage (known as a "theront").

This mechanism is plausible. However, the key factor is reducing adult density AND preventing prolonged holding by adults in restricted locations, given the ~10 days required between initial salmon infection and production of new infectious stages (Matthews 2005). In other words, available data suggest that achieving increased flushing flows or increased velocities may not be as important as reducing aggregations in fixed locations. Similarly, inducing upstream movement/migration may not be as important as inducing movement out of and/or reducing holding time in high density holding locations/pools. Regardless, increased discharge is highly probable to provide benefit.

Page 5: "For example, Jessop (1995) suggested that high discharge may flush the infective stages of Ich downstream." I found the evidence and relevance of the Jessop (1995) data to be tenuous at best. I found the following two quotes from Jessop (1995) to be most relevant: "The environmental conditions favorable to epizootics of *I. multifiliis* in the wild remain uncertain and unquantified" (in the last sentence of the discussion) and "High river discharge during June-July, but not water temperature (April-May), may have contributed to the development of the epizootic of *I. multifiliis* in 1993." (In the last sentence of the abstract.)

The latter statement was related to the putative movement of Ich downstream over a dam to the head of tide where eels were then thought to be infected, but there was no direct evidence.

Traxler et al. (1998) found that prolonged and high densities of sockeye salmon in restricted locations induced epizootic at moderate temperatures (14-15°C), again highlighting the dual importance of density and restricted movement.

USFWS. 2012. Summary of Klamath River Chinook Salmon in-River Run Size Data and Lower Klamath River Flows to Support TRRP Fall Flow Planning Efforts in 2012. 39 pages. (Referred to above as the May 28, 2012 TRRP Fall Flow Workgroup Summary.)

No substantive comments.

NMFS and USFWS. 2013. 2013 Fall Flow Release Recommendation. 46 pages. (Referred to above as the 2013 Joint Memorandum).

Page 9: Temperature criterion using 3 consecutive days with mean daily temperature > 23°C. Minor concern that a three consecutive day rule could result in substantial thermal accumulation with fluctuating temperatures for series such as: 25, 24, 22.5, 23.5, 23.7, 22.5… etc. Examination of Figure 4 indicates that some years have considerable daily fluctuations that could produce such series. I recommend considering the use of a 3-day rolling average, perhaps with two days past and one day predicted as the trigger metric.

Pages 9-10: The pathology metric trigger points are reasonable, though the background rationale is not as well developed as other trigger points. Also, it may be worth considering more explicitly how to handle low sample sizes, for example 2 infected fish in a sample of 20.

Page 11: I concur with the statement that the flow plan could represent a substantial departure from the natural flow regime. I agree with the statement that the proposed releases would likely have minimal cascading effects on this regulated system given the magnitude, thermal effects, and timing of the flows.

Appendix C:

Page 22: Break-point analysis. The selection of break-points was somewhat unclear and thus seemed somewhat arbitrary. In terms of future refinement of the trigger, a metric based on cumulative curves might be useful. Retrospectively, it appears that the large acceleration in catch rates commences consistently when 20 to 25 percent of the total annual catch has been caught (Figure 19). Thus, taking the average total run captured at the 20th percentile could produce a metric that is somewhat more transparent and adaptive to additional data. Regardless, examination of Table 3 indicates the approach used is sensible and both methods would likely produce similar outcomes.

Page 23: Ending of fall flow augmentation. Given a 3+ week variation in the date of cooling to a given temperature (e.g., 18°C), why not simply constrain the end of releases to a temperature threshold, particularly given the potential for late-cooling events?

USFWS. 2015. Response to Request for Technical Assistance Regarding 2015 Fall Flow Releases. 11 pages. (Referred to above as the 2015 U.S. Fish and Wildlife Service Memo.)

Page 4: Run Size: This section identifies the likely key factor driving Ich outbreaks: prolonged aggregation of salmon in specific locations that can then accumulate high Ich densities.

The key uncertainties are also identified here: “A number of factors such as the timing of the run, flow, water temperatures, in-river fisheries, etc., can contribute to large congregations of adult salmonids holding for extended periods of time that could potentially trigger an Ich epizootic, and these factors are independent of run size.”

For this reason, I found it surprising that flow and temperature were not jointly analyzed in the section above given the strong potential for temperature to mediate Ich generation time and salmon stress.

Page 7: “A key component of the fish metric was to establish August 22 as a ‘back-stop’start date to ensure that augmented flows would reach the lower Klamath River before the peak of the run.” I strongly concur with the need for this trigger.

Page 10: The doubling of flow for a 7-day pulse spike is reasonable and is conservative. As noted, this is an area of uncertainty with very limited observational data from the Klamath River system or from inferences drawn from hatchery examples, the best of which is from catfish (Bodensteiner et al. 2000). There is considerable scope for refinement; nonetheless available data do support continuation of emergency pulsed flows of the recommended magnitude.

Reclamation. 2015. 2015 Lower Klamath River Late-Summer Flow Augmentation from Lewiston Dam. Environmental Assessment. 46 pages. (Referred to above as the 2015 Environmental Assessment for Flow Augmentation.)

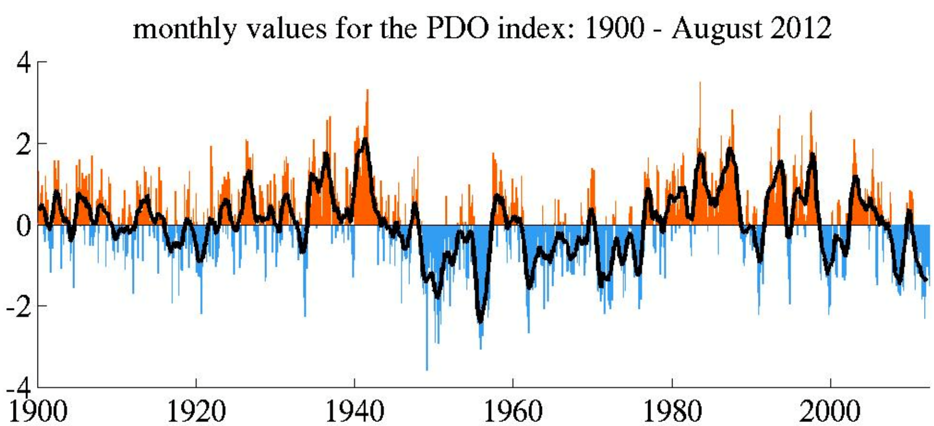
No additional comments.

Reclamation. 2016. Frequency of Action Analysis: Preventive Pulse and Emergency Flows. 5 pages. (Referred to above as the 2016 Frequency Technical Memo.)

Conclusion, final sentence: "Placing the frequency of need of an emergency release…." This conclusion appears in conflict with the last sentence of the previous section. Specifically, the conclusion that emergency flows would be implemented in 8 percent of years with preventive base flows appears to be erroneous because the 2/10 years (20 percent) were not for years with only preventive pulse, but rather all ten years with preventive base flow. In other words, 0.4*0.2 is incorrect and only 0.2 should be used. Eight percent underestimates the frequency of emergency flows from the time series. My apologies if I've missed something.

More broadly, the analysis should explicitly address climate projections and near-term (decadal) impacts of warming on the frequency of reaching trigger conditions.

Implicitly, the estimated probabilities assume the time series is representative in terms of climate cycles (PDO, ENSO, etc.). Even a cursory assessment of whether the time series includes multiple states or not is important because a future change in regional climate regime could markedly change the probability of reaching trigger criteria within a year. A quick comparison of PDO and ENSO suggest that both cold and warm periods were captured in the time series, which is good:



http://research.jisao.washington.edu/pdo/img/pdo_latest.jpeg

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

I agree with the authors that estimating probabilities from a short time series is tenuous and fraught with uncertainty. The point estimates from the analysis are useful, but some statement about alternative scenarios or a range of probable true probabilities could help capture the true future outcome, i.e., calculating CIs for binomial outcomes.

Finally, some assessment of needs under future warming scenarios seems warranted, unless the intent is to modify the current criteria in an adaptive manner that will address a shifting baseline.