Klamath River Expert Panel

FINAL REPORT

Scientific Assessment of Two Dam Removal Alternatives on Lamprey

January 14, 2010

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With the assistance of:

PBS&J

an Atkins company

THE FINDINGS AND CONCLUSIONS IN THIS REPORT ARE THOSE OF THE AUTHORS AND DO NOT NECESSARILY REPRESENT THE VIEWS OF THE FUNDING AGENCY (U.S. FISH AND WILDLIFE SERVICE).

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1.0 INTRODUCTION

The allocation of water among competing uses in the Klamath Basin (Figure 1) has often been contentious. In recent years, stakeholders began discussions to reach a settlement agreement that would equitably resolve water resource management conflicts in the basin. In February 2010, this goal was reached when two settlement agreements were signed. The Klamath Hydroelectric Settlement Agreement (KHSA) would result in the removal of Iron Gate, Copco 1, Copco 2, and J. C. Boyle dams (Figure 2), facilities of the Klamath Hydroelectric Project located on the Klamath River and operated by PacificCorp, to provide for upstream anadromous fish passage to historically occupied habitat. The Klamath Basin Restoration Agreement (KBRA) addresses basin-wide environmental restoration and resource management issues. The Secretary of the Department of the Interior is required by March 31, 2012 to decide if implementation of the settlement agreements is: 1) in the public's best interest; and 2) would help restore federally-listed populations of native fish species.

1.1 Secretarial Determination

There are two alternative management scenarios before the Secretary of the Interior that must be addressed in the Secretarial Determination:

> **Conditions with Dams**: No change from current management; and
>
> **Conditions without Dams and with KBRA**: Removal of the lower four Klamath River dams that are part of the Klamath Hydroelectric Project and the full range of actions/programs to implement the KBRA.

To evaluate the impacts of these alternative scenarios on native fish resources in the Klamath River Basin, the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) determined that existing and new scientific information regarding native fishes and environmental conditions must be reviewed and evaluated by expert fish panels followed by peer reviews of the expert panel work products.

The expert panels are expected to provide opinions to the Secretary on the effects of the two management scenarios on fish populations. It is anticipated that these reports may also be used for National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) documents generated for the KHSA and KBRA. Consequently, four expert panels were created to address native fish issues as they are impacted by the two alternative scenarios. These four panels are: 1) Lamprey; 2) Resident Fishes; 3) Coho Salmon/Steelhead; and 4) Chinook Salmon. This report presents the findings of the expert lamprey panel (Panel).

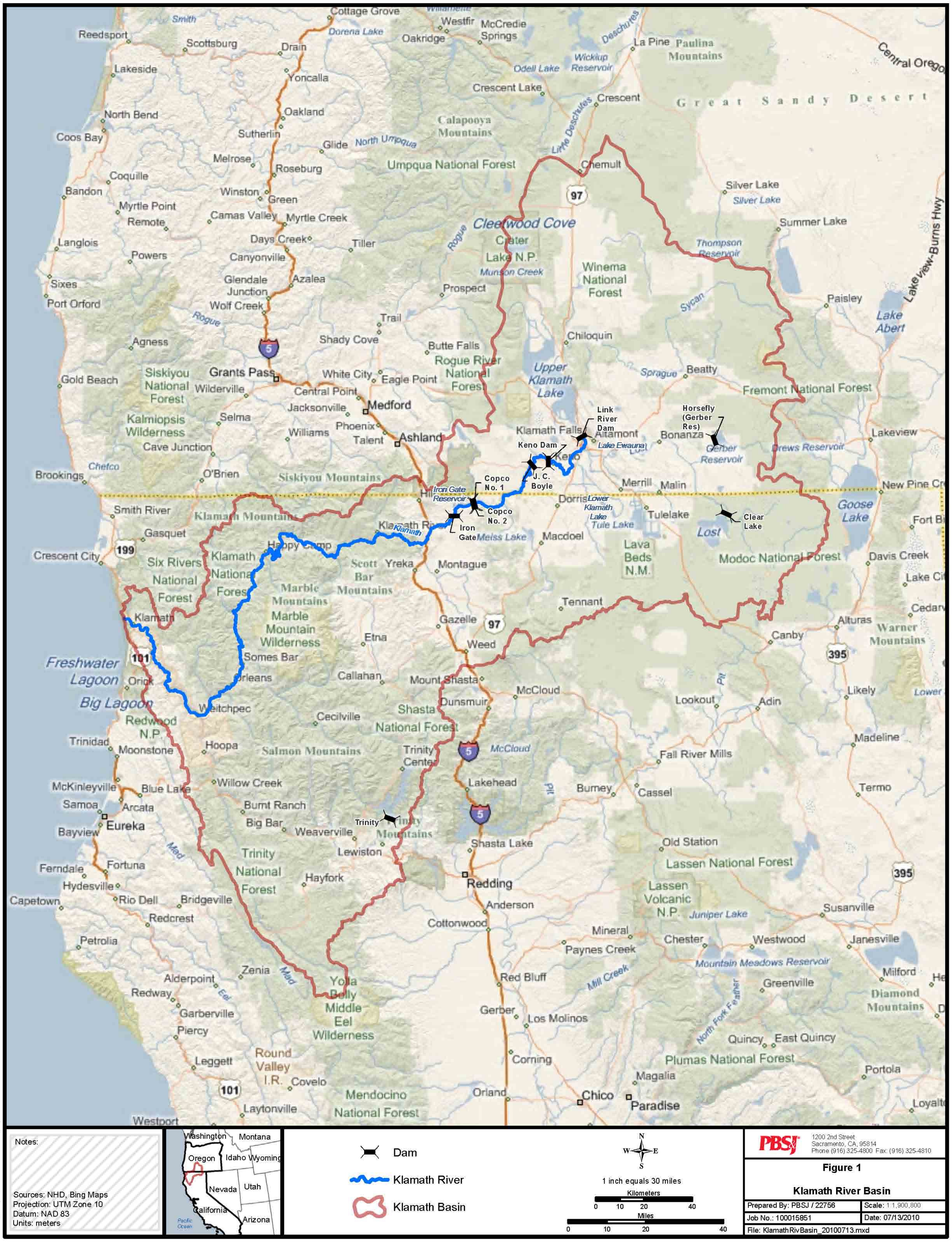
Link River Dam
Keno Dam
J. C. Boyle
Copco No. 1
Copco No. 2
Iron Gate
Horsefly (Gerber Res)
Clear Lake
Trinity
Klamath Falls
Upper Klamath Lake
Lake Ewauna
Iron Gate Reservoir
Lower Klamath Lake
Tule Lake
Happy Camp
Klamath
Weitchpec
Orleans
Somes Bar
Yreka
Medford
Ashland
Redding
Eureka
Crescent City
Chemult
Crater Lake N.P.
Winema National Forest
Fremont National Forest
Modoc National Forest
Klamath National Forest
Six Rivers National Forest
Shasta National Forest
Trinity National Forest
Rogue River National Forest
Siskiyou National Forest
Notes:
Sources: NHD, Bing Maps
Projection: UTM Zone 10
Datum: NAD 83
Units: meters
Washington
Montana
Oregon
Idaho
Wyoming
Nevada
Utah
California
Arizona
Dam
Klamath River
Klamath Basin
1 inch equals 30 miles
Kilometers
0 10 20 40
Miles
0 10 20 40
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Figure 1
Klamath River Basin
Prepared By: PBSJ / 22756
Scale: 1:1,900,800
Job No.: 100015851
Date: 07/13/2010
File: KlamathRivBasin_20100713.mxd

Figure 2

Dam Locations

1.2 Expert Panel

At the request of the USFWS, PBS&J convened an independent expert panel to evaluate the potential effects of the two alternative scenarios on all seven lamprey species in the Klamath River Basin. In order to ensure that the panelists and their work products were not biased, it was PBS&J's responsibility to: 1) manage the process in which panelists were screened and selected; 2) facilitate the Panel deliberations; and 3) assist with the preparation of the Panel's conclusions in a report to the USFWS.

Through existing contacts and referral networking, PBS&J identified a pool of 30 potential panelists. Prior to commencing the screening process, PBS&J had no working relationship, and only limited direct knowledge of the panelists' expertise or professional affiliations. Attempts were made to contact all potential candidates for the expert lamprey panel. The goal was to provide a balanced panel of four experts. The Panel was designed to include an ecohydrologist, fish ecologist, and two lamprey experts.

Two additional criteria required of each panelist were:

- Ability to meet the tight timeframe for the review process; and
- Ability to provide an expert review that would be widely regarded as both credible and independent.

Initial contacts with the pool of candidates resulted in numerous people who either declined to participate because of the schedule or who were considered to have conflicts of interest (e.g., professional working relationships, past or present, with stakeholders with a perceived interest in the outcome of the Secretarial Determination). Those candidates with conflicts of interest were eliminated from further consideration.

Brief biographies for each of the panelists selected for the expert lamprey panel are as follows (full resumes have been provided previously to the USFWS and are included in Appendix A):

- **Dr. David Close**, Director of the Aboriginal Fisheries Research Unit, Fisheries Center, University of British Columbia. Dr. Close is also a faculty member in the Department of Zoology. Dr. Close received his PhD from Michigan State University in 2007. He is a citizen of the Cayuse Nation located on the Confederated Tribes of the Umatilla Indian Reservation. Dr. Close has been working in Aboriginal Fisheries for over 10 years. His research is focused on answering biological questions directed towards sustainable aboriginal fisheries. His current research focuses primarily on lamprey which is a culturally important food to the aboriginal peoples along the West Coast of North America. He conducts interdisciplinary research in the areas of aquatic ecology, fish physiology, chemical ecology, and integrating traditional knowledge and fisheries science.

- **Dr. Margaret Docker**, Assistant Professor, Department of Biological Sciences, University of Manitoba, Winnipeg. Dr. Docker received her PhD in 1992 from the University of Guelph, Ontario, for work with sex determination in lamprey. Since then she has published extensively on lamprey taxonomy, genetics, population structure, and ecology. She is a referee for 17 professional journals and was a peer reviewer for the recent American Fisheries Society proceedings on the *Biology,* *Management, and Conservation of Lamprey in North America* (Brown et al. 2009).

- **Dr. Thomas Dunne**, Professor, Donald Bren School of Environmental Science and Management, and Department of Earth Science, University of California, Santa Barbara. He received his PhD from The Johns Hopkins University. Dr. Dunne conducts field and theoretical research in fluvial geomorphology and in the application of hydrology, sediment transport, and geomorphology to landscape management and hazard analysis. He is an internationally recognized expert in fluvial geomorphology with dozens of publications to his credit and has served on over 40 national and international science committees.
- **Dr. Greg Ruggerone**, Vice President, Natural Resource Consultants, Inc., Seattle, Washington. Dr. Ruggerone received his PhD in Fisheries from University of Washington where he is currently an affiliated research scientist with the School of Fisheries. Dr. Ruggerone brings 30 years of experience in anadromous fisheries ecology and management to this project. He has conducted applied research in salmonid predator-prey interactions, species competition, climate change effects on salmon production in the ocean, effects of habitat changes on salmonid production, limnological studies, effects of hydropower operations on downstream smolt and upstream adult migrations, and harvest management. He has participated in extensive field studies in applied fisheries biology and management in Alaska and the Pacific Northwest.

The opinions presented in this report reflect those of the panelists and not the views of their respective employers or professional affiliations.

1.3 Review Process

PBS&J was awarded the contract to conduct the expert panel work for all four panels on June 15, 2010. At that time, PBS&J staff began assembling a pool of potential candidates for the lamprey panel. The final expert lamprey Panel was confirmed on July 2, 2010. Background files were provided by the USFWS and submitted to the Panel for review on July 7, 2010. The Panel members convened for an in-person meeting in Medford, Oregon, on July 19 through 23, 2010. The first day of the meeting (July 19) consisted of briefings provided to the Panel by members of the Technical Management Team (TMT) subgroups and interested stakeholders. The Panel worked on its report in private for the remainder of the week.

The Panel took a field trip to Iron Gate Dam and Reservoir, Fall Creek, and the Klamath River downstream of Iron Gate Dam on the afternoon of July 20, 2010. John Hamilton, USFWS Assistant Field Supervisor of the Yreka, California office, provided guidance to features and answered a host of questions that had been developed by the Panel during the first day of discussions.

During the course of their work the Panel relied on numerous documents as cited in this report. Key documents reviewed by the Panel included:

- Presentations from the TMT subgroups and stakeholders on July 19 (referenced in the text by author's last name and 'PPT Presentation');

- KHSA, February 18, 2010;
- KBRA, February 18, 2010;
- Synthesis of the Effects of two Management Scenarios for the Secretarial Determination on Removal of the Lower Four Dams on the Klamath River, Draft dated July 16, 2010 (Hamilton et al. 2010a);
- Klamath River Dam Removal Study: Sediment Transport DREAM-1 Simulation (Stillwater 2008);
- Effects of Sediment Release Following Dam Removal on the Aquatic Biota of the Klamath River (Stillwater 2009);
- Anticipated Sediment Release from Klamath River Dam Removal within the Context of Basin Sediment Delivery (Stillwater 2010); and
- Compilation of Information to Inform USFWS Principals on the Potential Effects of the Proposed Klamath Basin Restoration Agreement (Draft 11) on Fish and Fish Habitat Conditions in the Klamath Basin with Emphasis on Fall Chinook Salmon (*aka* the 'White Paper,' Hetrick et al. 2009).

During the meeting, each panelist took responsibility for specific sections of this report and provided a draft of their text to the other Panel members. PBS&J staff facilitated the meeting but provided no substantive technical input. By the completion of the meeting, this Draft Expert Panel Report had been reviewed and approved by each Panel member. PBS&J staff reviewed the entire document for formatting and style before creating a draft report. The draft report was posted for stakeholder and agency comment on July 26, 2010. Comments received through August 2, 2010, were cataloged, reviewed and responded to as appropriate by the Panel to create this final report. The final version was delayed by problems discovered with the hydrology modeling conducted for the proposed action. The conclusions in this report were reviewed by the Panel in December 2010 following completion of a revised set of hydrology information as presented in Hamilton et al. (2010b).

1.4 Panel Role and Nature of Report

Table 1 indicates that the task of the expert lamprey panel occurs chronologically at a very early stage in the decade-long process of decision-making, planning, and design leading up to a potential 2020 initiation of dam removal. The Panel is asked to make a scientific assessment of the impact of two strategies for river management (with dams versus without dams and with the KBRA) on the seven species of lamprey that are believed to occupy undefined portions of the Klamath River Basin.

There are no current status assessments for any of the Klamath lamprey species and little is known of their biology or sensitivity to environmental changes in the Klamath drainage. No estimates of spawning and rearing habitat for lamprey have been conducted within the basin. This is particularly true of the five freshwater-resident lamprey in the Upper Klamath Basin; more is known of the biology of the more widely distributed Pacific and western brook lampreys, for which inferences will be made largely from other river systems. For the Klamath River system, only flow data have been systematically collected and analyzed, permitting quantitative analyses related to the issue of dam removal that involve flow and physical characteristics closely related to flow (e.g., water temperature and sediment transport). Some data related to water quality (e.g., dissolved oxygen and nutrient levels) are also available. The future condition of these physical and chemical variables will depend on drivers such as regional climate change, the stochastic nature of weather and hydrology, regional economic and land-use change, and evolving political and regulatory philosophies of natural resource management.

Faced with the responsibility to initiate such an early scientific assessment of the alternatives on seven lamprey species in the virtual absence of quantitative data, particularly on the biological targets of the entire restoration activity, agencies have analyzed the sparse information available and recruited consultants to make quantitative estimates (e.g., sediment transport, extensions of range) based on modeling, supported by brief data collection campaigns. These reviews and analyses primarily concern environmental conditions that might be relevant to fish habitat and production, rather than directly focusing on the fish under discussion. Reports of these technical analyses and literature reviews developed by the agencies, together with briefings by agency personnel, constitute the raw material for this evaluation.

The Panel members bring to the process their general knowledge of lamprey biology, river characteristics and behavior, and their experience in environmental analysis in other river systems, including rivers that have been disturbed or actively managed. Their method of assessment involves assimilating the agency-supplied material described previously, and some limited number of original documents and computational models used as the basis for the agency and consultants' reports. The Panel members can also supply their knowledge of other literature and case studies of similar issues elsewhere. The Panel has no time or resources for original data collection or analysis, even when such actions seem straightforward and necessary for the assigned task. Thus, the analytical method of the Panel involves assessing and interpreting the likely reliability and relevance of the technical information supplied to them, evaluating its relevance to lamprey biology, and predicting the impacts of the two alternative scenarios on lamprey biology implied in the questions about potential harvest based on the best available information.

Information available at such an early stage in a process if this kind is invariably inadequate for a rigorous scientific assessment. Thus, the assessment as conducted by this Panel combined qualitative, quantitative, and professional experience to estimate potential outcomes of the two alternatives which in turn allowed the Panel to address the assigned questions. This assessment, however, can act as a guide for systematic data collection to reduce uncertainty in the future.

Table 1. Summary of Klamath Basin Fisheries Program Milestones	
Year	**Milestones and Actions**
2010	● Klamath Basin Restoration Agreement signed on 18 February (Effective Date). ● **Lamprey Expert Panel Meeting July 19-23.** ● Final Drought Plan by November 30.
2011	● Draft Phase I Fisheries Restoration Plan by 18 February. ● Draft Fisheries Monitoring Plan by 18 February. ● Draft Phase I Oregon Fisheries Reintroduction Plan. ● Initiate reintroduction activities in Oregon.

Table 1. Summary of Klamath Basin Fisheries Program Milestones	
Year	**Milestones and Actions**
2012	● Initiate assessment of risks and potential impacts of climate change on management of Klamath Basin Resources. ● Finalize NEPA for Phase I Fisheries Restoration Plan by 31 March. ● Finalize CEQA for Phase I Fisheries Restoration Plan by 31 March. ● Final Phase I Fisheries Restoration Plan by 31 March. ● Final Fisheries Monitoring Plan by 31 March. ● Detailed Plan for Facilities Removal on for before 31 March. ● **Secretarial Determination made by 31 March**.
2013	● Final Phase I Oregon Fisheries Reintroduction Plan. ● Draft Phase I California Fisheries Reintroduction Plan (presumed). ● Dam Removal Entity (DRE) develops Definite Plan for Dam Removal (presumed).
2014	● Final Phase I California Fisheries Reintroduction Plan.
2019	● Draft Phase II Fisheries Restoration Plan
2020	● Target date to begin decommissioning the facilities is 1 January. ● Target date for completion of facilities removal is 31 December, at least to a degree sufficient to enable a free-flowing Klamath River allowing volitional fish passage. ● Review of fisheries outcomes by 30 June and recommendations for additional measures, if needed.
2020-2021	● Keno Dam fish passage improvements occur.
2022	● Final Phase II Fisheries Restoration Plan by 31 March.
2022	● Finalize NEPA for Phase II Fisheries Restoration Plan by 31 March.
Post-2022	● Draft and Final Anadromous Fish Conservation Plans to be developed by ODFW. ● Draft and Final Phase II Fisheries Reintroduction Plan to be developed by ODFW.
2030	● Review of fisheries outcomes by 30 June and recommendations for additional measures, if needed.
Source: KBRA	

2.0 BACKGROUND

2.1 Questions

Two sets of questions were provided to the Panel. The first set consisted of general questions developed by the TMT and stakeholders. The second set focused on lamprey-specific questions developed by the TMT. In the following narrative, the general questions are identified by G-1 through G-10. Lamprey-specific questions are identified by L-1 through L-9. Because the Panel's assignment was to assess the effects of the two management alternatives on the various lamprey species, the Panel addressed the general questions from a lamprey-centric viewpoint, recognizing that some of the general questions clearly raised questions about salmonids. The Panel was not charged with addressing salmonid issues.

The original set of questions included extensive background information and commentary. The Panel edited the questions to reduce them to the main points which are presented here. The original questions including all the introductory material are presented in Appendix B. The report sections where answers to the questions are found are referenced below and provided in the narrative in Sections 4.0 through 7.0.

2.2.1 General Questions

G-1) Geomorphology: How will alternatives affect geomorphology in the short-term (1-2 years) and over the 50-year period of interest? What are the expected short-term effects of dam removal on the fish abundance and how long will it take these populations to return to baseline levels? Question G-1 is addressed in Sections 4.0 and 5.3.

G-2) Water quality: Given the possible trends in water quality during the 50-year period of interest, how will the two alternatives differ in reaching the goal of harvestable fish populations? Question G-2 is addressed in Sections 5.3.3 and 7.0.

G-3) Water temperature: What are the likely effects of the water temperature regimes under the two alternatives on rearing, spawning, and use of thermal refugia by native salmonids that might be manifest in harvestable fish? Question G-3 is addressed in Sections 5.3.3 and 7.0.

G-4) Habitat and restoration (KBRA): The two proposed alternatives will result in different paths and timelines for habitat management. What are the likely effects of the two alternative habitat management paths on the recovery of ESA-listed fish or in the level of harvest of fish populations? Question G-4 is addressed in Sections 4.0, 6.0, and 7.0.

G-5) Climate change: To what extent might potential changes in habitat, the hydrograph, and thermal refugia mitigate the effects of climate change under the two alternatives? What are the likely effects of climate change on the harvest levels of fish under the two alternatives? Question G-5 is addressed in Sections 4.2, 5.3.3, 6.0, and 7.0.

G-6) Abundance: How will the two alternatives affect abundance of the fish population and what are the expectations for the enhancement of the fisheries? This question may have several milestones along a timeline or population trajectory. For example, inasmuch as some fish populations have been extirpated from the upper Klamath Basin for more than 90 years, when might fish be available for tribal ceremonial use within the upper Klamath Basin? Using a time trajectory, when will a sustainable fishery start and at what levels? Question G-6 is addressed in Sections 5.3.3 and 7.0.

G-7) Productivity: What are the most likely expectations for productivity over time and what is the effect of productivity on the number of harvestable fish? What is the role of hatcheries in relation to productivity? Question G-7 is addressed in Sections 5.3.2, 5.3.3, and 7.0.

G-8) Diversity: What will the effect of the two alternatives be on diversity of fish populations? How will the resulting diversity be manifest in the harvestable population of fish? How will potentially low baseline populations and/or introductions of hatchery fish affect diversity under the two alternatives? Except for the question of hatchery fish which does not apply to lamprey, Question G-8 is addressed in Sections 5.1, 5.2 and 5.3.

G-9) Spatial structure: Will the two alternatives result in improved spatial structure of fish populations and to what extent is that improved structure likely to result in harvestable fish? Question G-9 is addressed in Sections 5.1, 5.2, 5.3.1, 5.3.3, and 7.0.

G-10) Ecosystem restoration: How do the proposed alternatives address ecosystem function and connectivity sufficiently to recover the lost harvest opportunities of fish populations? Question G-10 is addressed in Sections 4.0, 5.1, 5.2, 5.3.1, 5.3.2, and 7.0.

2.2.2 Lamprey-specific Questions

L-1) Endemic lamprey diversity: Can conclusions such as the percent increase or decrease in abundance of individual lamprey species be drawn for the two proposed alternatives over a 50-year period? If distribution and abundance information is inadequate to reach conclusions about individual species, can an alternative grouping such as anadromous and non-anadromous species be used to draw conclusions regarding the affect of the two alternatives upon the abundance and spatial distribution of these groupings: whether these conclusions be quantitative (i.e., percent increase or decrease) or a more qualitative anticipated trajectory? The effects of dam removal on endemic lamprey diversity (Question L-1) are addressed in Sections 5.2 and 5.3. As suggested in the question, anadromous forms are discussed separately from resident forms in Sections 5.2 and 5.3 and population trends are discussed in Section 7.0.

L-2) Lamprey harvest: What is the most likely effect of the two proposed alternatives during the 50-year period on the harvestable population of Pacific lamprey? Question L-2 is addressed in Section 7.0.

L-3) Fish Passage: Please compare and contrast the likely response of Pacific lamprey populations under the two proposed alternatives with respect to adult and juvenile lamprey passage. Question L-3 is addressed in Sections 5.2.1 and 5.2.2.

L-4) Riverine processes: Given the relation between the lamprey and their dependence on the use of sediments for rearing and spawning, what is the likely effect of the two alternatives on the abundance of lamprey over the 50-year period? Question L-4 is addressed in Sections 4.0 and 5.3.

L-5) Water temperatures: What are the risks or benefits to lamprey abundance associated with water temperatures under the two proposed alternatives? Question L-5 is addressed in Section 5.3.3.

L-6) Ecosystem function: Given the habitat predictions for salmonid populations under the two alternatives, what inferences can be drawn about the likely population response of lamprey in the 50-year period of interest?

If a more functional ecosystem is restored under the action alternative (i.e., Condition without Dams and with the KBRA), what percent change (or more qualitative trajectory) in lamprey abundance can be expected after 50 years compared to the no action alternative? The first part of Question L-6 is addressed in Sections 5.1, 5.2, 5.3.1, 5.3.2, and 7.0. The second part of the question is addressed in Section 7.0.

L-7) Extirpation, recolonization, and reintroduction: What are the timelines and population trajectories of lamprey recolonization under the two proposed alternatives in river reaches where lamprey have been extirpated? What percent of the area where Pacific lamprey are currently extirpated will be recolonized under the two alternatives at the end of the 50-year period? Question L-7 is addressed in Sections 5.3.1, 5.3.3, and 6.0.

L-8) Marine hosts: Given that the ocean phase of the life history of Pacific lamprey has many uncertainties, what are the risks and benefits that might result from the two proposed alternatives? Question L-8 is addressed in Sections 3.2 and 6.0.

L-9) Non-native species: Do non-native fish species represent a survival risk or a possible limiting factor for endemic lamprey in the project area? What is the likely effect of the two proposed alternatives on non-native species and their interactions with lamprey? Question L-9 is addressed in Section 5.3.3.

2.2 Description of Alternatives

There are two alternatives being considered by the Secretary of the Interior. These are described in detail here along with the Panel's interpretation of what is included within these alternatives.

Conditions With Dams

Condition with Dams: No change from current management, which includes on-going programs under existing laws and authorities that contribute to the continued existence of listed threatened and endangered species and Tribal Trust species. The Panel interprets the **Condition with Dams** to include:

1) Continued operation of the Klamath Hydroelectric Project (Federal Energy Regulatory Commission [FERC] Project No. 2082) in the same manner it is currently operated without any new operating requirements related to the relicensing of the project by FERC;
2) Implementation of Non-Interim Conservation Plan (ICP) Interim Measures (PacifiCorp 2008);

3) Implementation of the *Upper Klamath Lake Drainage Total Maximum Daily Load* (TMDL) *and Water Quality Management Plan* (WQMP) as required by the Oregon Department of Environmental Quality (ODEQ) (ODEQ 2002);
4) Implementation of the *Action Plan for the Klamath River TMDLs Addressing Temperature, Dissolved Oxygen, Nutrient, and Microcystin Impairments in the Klamath River in California and Lower Lost River Implementation Plan* required by the California North Coast Regional Water Quality Control Board (CNCRWQB 2010);
5) Various fishery management plans prepared by the Oregon Department of Fish and Wildlife (ODFW) and the California Department of Fish and Game (CDFG); and
6) Predictions of the effects of climate change on streamflow and water temperature for the Klamath River watershed. Streamflow analysis presented by Blair Greimann, U.S. Bureau of Reclamation (unpublished 2010).

Condition Without Dams and With the KBRA

Condition without Dams and with the KBRA: Removal of the lower four Klamath Hydroelectric Project dams (Iron Gate, Copco 1, Copco 2, and J.C. Boyle), currently facilities of the Klamath Hydroelectric Project, and the full range of actions/programs to implement the KBRA. The Panel interprets the **Condition without Dams and the KBRA** to include:

1) Removal of the four dams listed previously, thereby opening the Klamath River to lamprey access upstream in the mainstem river as far as Keno Dam, currently a facility of the Klamath Hydroelectric Project;
2) Implementation of various KBRA restoration actions that could benefit lamprey listed in Appendix C-2 of the *Klamath Basin Restoration Agreement for the Sustainability of Public and Trust Resources and Affected Communities* (Klamath Agreement 2010; Hampton PPT presentation) including, but not limited to: water quality remediation actions, aquatic and riparian habitat restoration, water conservation and water right acquisition, addition of large wood and gravel, channel and floodplain reconfiguration, erosion control, fish passage (including at Keno Dam), and restoration of natural fire regimes;
3) Implementation of ICP Interim Measures (PacifiCorp 2008);
4) Implementation of the two TMDLs cited previously; and
5) Predictions of the effects of climate change on streamflow and water temperature for the Klamath River watershed. Streamflow analysis presented by Blair Greimann, U.S. Bureau of Reclamation (all five scenarios encompassing a range of possibilities, unpublished 2010).

3.0 LAMPREY BACKGROUND

3.1 Lamprey Species in the Klamath Basin

Seven lamprey species are known to occur in the Klamath River Basin, including one as-yet unnamed species in Upper Klamath Lake (Table 2). The Pacific lamprey (*Entosphenus*[1] *tridentatus*) is the only anadromous species; the others are all freshwater resident taxa. There are no reports of the anadromous river lamprey (*Lampetra ayresii*) in the Klamath River Basin; its range is broadly sympatric with that of the western brook lamprey (*Lampetra richardsoni*) (which has been found in two small tributaries near the mouth of the Klamath River) but it is generally thought to occur only as widely separated populations, generally associated with larger estuarine systems (Moyle et al. 1995). Pacific and "Klamath Lake lamprey" (*Entosphenus* sp.) make significant migrations. Pacific lamprey are genetically distinct from all freshwater-resident lamprey in the Klamath River Basin (Lorion et al. 2000), although all but the western brook lamprey are closely-related and the freshwater-resident *Entosphenus* species are presumably derived from the anadromous Pacific lamprey (Docker 2009).

The Pacific lamprey is widely distributed. In North America, it occurs from the Aleutian Islands south along the Pacific coast to Baja California, Mexico, and inland to the upper reaches of most rivers draining into the Pacific Ocean (Ruiz-Campos and Gonzalez-Guzman 1996); in Asia, it is found as far south as Japan (Scott and Crossman 1973). The western brook lamprey is also widely distributed, occurring in freshwater drainages from Alaska to California (e.g., Page and Burr 1991; Moyle et al. 2009). The Pit-Klamath brook lamprey (*Entosphenus lethophagus*) is thought to occur in both the Pit and Klamath river basins, but all other Klamath River Basin lamprey are not found outside the Klamath River Basin.

Table 2. List of lamprey species in the Klamath River Basin, life history information and distribution within the Klamath River Basin. (P = parasitic as adults, NP = non-parasitic; FW = freshwater-resident; A = anadromous. Asterisk (*) indicates species found only in the Klamath River Basin.)

Species	Life History	Distribution	Comments
Pacific lamprey, *Entosphenus tridentatus*	P, A	CURRENTLY DOWNSTREAM OF IRON GATE DAM Presumably within the current range of anadromous salmonids; Confirmed upstream limit in mainstem Klamath River is Bogus Creek and up to Lewiston Dam in the Trinity River; Reported also in Shasta and Scott rivers and Clear and Dillon creeks (Goodman et al. 2008).	

[1] Although Nelson et al. (2004) treats *Entosphenus* as a subgenus within *Lampetra* - thus recognizing Pacific lamprey as *Lampetra tridentata* - the American Fisheries Society Endangered Species Committee considered *Entosphenus* as a genus in their list of imperiled North American freshwater and diadromous fishes (Jelks et al. 2008). Thus, we likewise treat *Entosphenus* as a genus (see Renaud et al. 2009).

Table 2. List of lamprey species in the Klamath River Basin, life history information and distribution within the Klamath River Basin. (P = parasitic as adults, NP = non-parasitic; FW = freshwater-resident; A = anadromous. Asterisk (*) indicates species found only in the Klamath River Basin.)

Species	Life History	Distribution	Comments
		HISTORICALLY UPSTREAM OF IRON GATE DAM Presumably at least to Spencer Creek; Historical records from upstream of Iron Gate Dam appear to be resident predatory forms; Upper Klamath Lake represents anomalous habitat but it is possible that Pacific lamprey were once in the Upper Basin.	
Klamath lamprey, *Entosphenus similis**	P, FW	UPSTREAM AND DOWNSTREAM OF IRON GATE DAM In Klamath River from Spencer Creek downstream (e.g., Seiad and Beaver creeks) (Lorion et al. 2000), although apparently less common in lowest reaches near mouth; Adults reported in the Klamath River mainstem as well as in lakes and reservoirs (Hamilton et al. 2010a); In Trinity River (e.g., at Pigeon Point), including upstream of Lewiston and Trinity reservoirs; Also reported in Upper Klamath Basin (e.g., Link River) (Lorion et al. 2000).	
Miller Lake lamprey, *Entosphenus minimus**	P, FW	UPPER KLAMATH BASIN Historically from Miller Lake in upper Williamson River sub-basin; Current range includes Miller Creek, Jack Creek, and upper sections of Williamson and Sycan rivers (Lorion et al. 2000). POTENTIALLY DOWNSTREAM OF IRON GATE DAM This species or similar form in Scott, Shasta and Klamath rivers mainstem between Interstate Highway 5 and Iron Gate Dam.	
"Klamath Lake lamprey," *Entosphenus* sp.*	P, FW	UPPER KLAMATH BASIN Adults in Upper Klamath Lake migrate upstream to spawn in Sprague River.	Undescribed taxon generally reported as landlocked Pacific Lamprey but genetically distinct from anadromous Pacific lamprey (Lorion et al. 2000).

Table 2. List of lamprey species in the Klamath River Basin, life history information and distribution within the Klamath River Basin. (P = parasitic as adults, NP = non-parasitic; FW = freshwater-resident; A = anadromous. Asterisk (*) indicates species found only in the Klamath River Basin.)

Species	Life History	Distribution	Comments
Pit-Klamath brook lamprey, *Entosphenus lethophagus*	NP, FW	UPSTREAM OF KENO DAM Mid-elevation streams in Upper Klamath Basin (e.g., Williamson and Sprague river tributaries) (Lorion et al. 2000) and spring-fed streams surrounding Upper Klamath Lake.	
Modoc brook lamprey, *Entosphenus folletti**	NP, FW	UPSTREAM OF IRON GATE DAM Reported from a tributary to Lost River (Clear Lake Basin); Potentially also Fall Creek (tributary to Copco Reservoir).	Systematic status uncertain; Was synonimized with Pit-Klamath brook lamprey by American Fisheries Society (Robins et al. 1980).
Western brook lamprey, *Lampetra richardsoni*	NP, FW	LOWER KLAMATH RIVER Known only from Hunter and McGarvy creeks near mouth of the Klamath River.	
Source: Reid (2010) unless otherwise indicated.			

3.2 Pacific Lamprey Life History

Pacific lamprey spend the early part of their life in freshwater, burrowed in fine silt or sand, filtering detritus and other particulate matter. After an extended time (approximately 4 to 6 years), larvae go through metamorphosis which includes major morphological and physiological changes to adapt to saltwater and a parasitic feeding strategy. The juveniles then move to the ocean to feed on the blood and other body fluids of fish and other vertebrates before returning as adults for reproduction after 1 to 3 years; they spawn in the spring and die shortly afterwards (Figure 3). The life cycle and general biology of the Pacific lamprey will be described; variations seen in the other Klamath River Basin lamprey, as far as is known, will be discussed in the following section. There are no known relationships between flow and lamprey habitat as are common for salmonids.

3.2.1 Larval Stage

Pacific lamprey exhibit a protracted freshwater residence as blind, filter-feeding larvae in the stream benthos. The larvae (often referred to as ammocoetes) leave the nest approximately two or three weeks after hatching in the late spring or early summer, drift downstream, and settle in slow depositional areas such as pools and eddies (Pletcher 1963). The larval stage has been estimated to range from 4 to 6 years (Pletcher 1963; Kan 1975; Richards 1980), although it may extend up to 8 years (Beamish and Northcote 1989; Beamish and Levings 1991) and Close et al. (2009) hypothesized that Pacific lamprey larvae in the Umatilla River, Oregon, metamorphosed at 3 to 4 years (due to fast growth rates observed after reintroduction of the species). A single population will have more than one age class undergoing metamorphosis in a given year (Beamish and Levings 1991) and it appears that time to metamorphosis is largely determined by size (van de Wetering 1998). During this time, larval lamprey are capable of passive downstream migration (Desrosier et al. 2007), but do not actively swim upstream; downstream drift occurs at night (Brumo and Markle 2006; Petersen Lewis 2009).

Larval Pacific lamprey can represent a large portion of the biomass in streams where they are abundant, thus making them an important component along with aquatic insects in processing nutrients, nutrient storage, and nutrient cycling (Kan 1975). Larvae facilitate the conversion of the nutrients derived from detritus and algae into stored biomass, while the undigested material is processed into fine particulate matter. The reduced matter is then exported from the system or taken up by other organisms such as filter-feeding insects (Merritt et al. 1984). Furthermore, larval Pacific lamprey constitute a food source for other animals (Cochran 2009), predominantly during emergence from their nests and during scouring events that dislodge the larvae from their burrows. For example, Pfeiffer and Pletcher (1964) found that coho salmon (*Oncorhynchus kisutch*) fry ate emergent larval lamprey, and Brumo (2006) observed speckled dace (*Rhinichthys osculus*) feeding on the eggs.

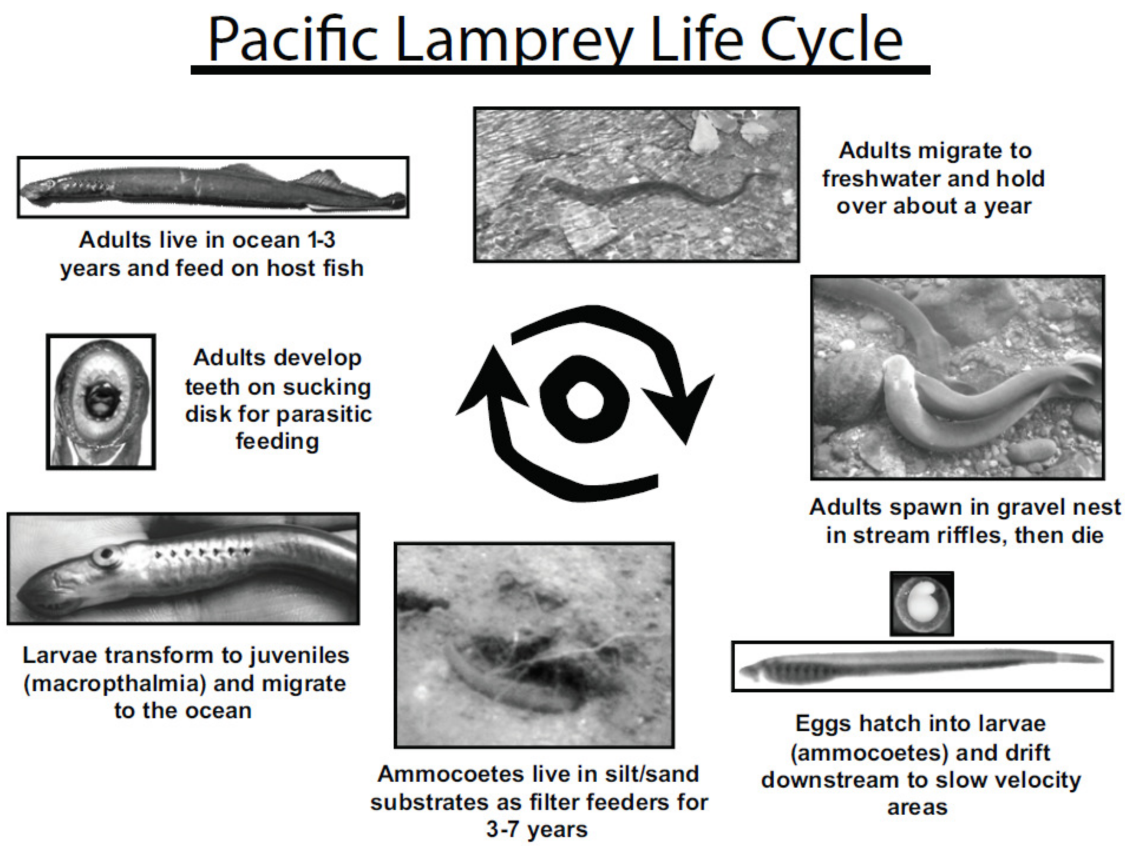

Figure 3. Diagram of Pacific Lamprey Life Cycle (from Streif 2009).

3.2.2 Downstream Migrants

During metamorphosis, the larvae go through morphological (e.g., appearance of the eye and oral disc) and physiological changes to prepare for a parasitic lifestyle in saltwater. Transformation of Pacific lamprey from the larval to young adult life stage generally occurs during July through November (Pletcher 1963; Richards and Beamish 1981); saltwater tolerance and the ability to feed parasitically are developed by approximately September (Richards and Beamish 1981).

Young adult lamprey begin their migration to the Pacific Ocean in the fall and continue through the spring (Beamish and Levings 1991); pulses of outmigration appear to be correlated with abrupt increases in discharge (Beamish and Levings 1991). Time of entrance into saltwater may differ among populations of Pacific lamprey due to environmental conditions (R.J. Beamish, pers. comm., Pacific Biological Station, Nanaimo, B.C., Canada), and Kan (1975) suggested that coastal populations enter saltwater in the late fall while inland populations delay until spring. In the Nicola River of British Columbia, 99 percent of all metamorphosed lamprey had migrated by April and May (Beamish and Levings 1991). In the lower Klamath River, Pacific lamprey outmigration may occur in the late fall into the winter when the waters are higher (Petersen Lewis 2009) or in the spring (Larson and Belchik 1998).

Young adult lamprey migrating downstream may buffer salmonid juveniles from predation by fishes and birds. Pacific lamprey are found in the diets of northern pikeminnow (*Ptychocheilus oregonensis*) and channel catfish (*Ictalurus punctatus*) in the mainstem Snake River (Poe et al. 1991), and Merrell (1959) found that lamprey comprised 71 percent by volume of the diets in California gulls (*Larus californicus*), ring-billed gulls (*Larus delawarensis*), western gulls (*Larus occidentalis*), and Foster’s tern (*Sterna forsteri*) in the mainstem Columbia River during early May. Feeding-phase and upstream migrating Pacific lamprey are also fed on by marine mammals and other predators (see Section 3.2.4).

3.2.3 Ocean Life

The ocean life history stage of Pacific lamprey is not well understood, but the duration of ocean residency may vary. The parasitic-phase has been estimated to last for periods of up to 3.5 years for Pacific lamprey returning to streams in British Columbia (Beamish 1980). Off the coast of Oregon, the duration of the ocean phase was estimated to range from 20 to 40 months (Kan 1975). Parasitic-phase Pacific lamprey have been collected at distances ranging from 10 to 100 kilometers (km) off the Pacific coast and at depths ranging from 70 to 800 meters (m) (Kan 1975; Beamish 1980).

Although some anadromous lamprey can feed in freshwater and become landlocked (e.g., the sea lamprey (*Petromyzon marinus*) in the Great Lakes), several studies suggest that Pacific lamprey cannot complete their life cycle in freshwater. Pacific lamprey populations have become extirpated after they were disconnected from the ocean through river impoundment (Beamish and Northcote 1989), and juvenile Pacific lamprey held in the laboratory in freshwater fed poorly and ultimately died (Clarke and Beamish 1988). Some populations of lacustrine, non-migrating forms once considered to be dwarf or landlocked races of Pacific lamprey have been elevated to species status (e.g., Beamish

1982), including the Miller Lake lamprey (*Entosphenus minimus*) in the Klamath River Basin (Bond and Kan 1973).

The Pacific lamprey preys on a variety of fish species and marine mammals in the Pacific Ocean. Beamish (1980) reported five salmonid and nine other fish species (e.g., Pacific hake, *Merluccius productus*, and walleye pollock, *Theragra chalcogramma*) that are known prey of Pacific lamprey. In addition, Pacific lamprey have been reported to feed on finback (*Balaenoptera physalus*), humpback (*Megaptera nodosa*), sei (*Balaenoptera borealis*), and sperm (*Physeter catodon*) whales (Pike 1951). However, anadromous Pacific lamprey should not be viewed as a pest species like sea lamprey of the Laurentian Great Lakes (Coble et al. 1990). In the Great Lakes, an entire community of native prey was exposed to an exotic predator, whereas Pacific lamprey have co-evolved with their prey.

3.2.4 Spawning Migration

Pacific lamprey enter the Klamath River on their spawning migration starting in winter and continuing through spring (Larson and Belchick 1998; Petersen Lewis 2009). In other streams along the coast, Beamish (1980) suggested that returning adult lamprey enter freshwater between April and June (in the year prior to spawning) and complete migration into streams by September. Pacific lamprey then overwinter in freshwater (e.g., hiding under stones) (Scott and Crossman 1973) before spawning the following spring (Beamish 1980). In southern California, Chase (2001) reported that Pacific lamprey began their initial migration during mid-December to mid-May. Upstream migration occurs almost exclusively at night (Robinson and Bayer 2005).

Pacific lamprey do not feed after the start of the upstream migration (i.e., for approximately one year prior to spawning). They utilize stored carbohydrates, lipids, and proteins for energy (Read 1968). Beamish (1980) observed a 20 percent shrinkage in body size from the time of freshwater entry to spawning; females exhibit greater shrinkage than males.

Returning adult Pacific lamprey are an important part of the food web for many species of freshwater fishes, birds, and mammals. For example, Steller sea lions (*Eumetopias jubatus*) at the mouth of the Klamath River feed largely on upstream migrating Pacific lamprey (Beamish 1980).

3.2.5 Spawning

Pacific lamprey along the coast of Oregon usually begin to spawn in May when water temperatures reach 10° Centigrade (C) to 17°C and continue to spawn through July (Brumo 2006; Stone 2006). In the Babine River system in British Columbia, Pacific lamprey were observed spawning from June through the end of July (Farlinger and Beamish 1984). Pacific lamprey have been observed to spawn in clear gravel-bottomed streams, generally at the upstream edge of riffles (Scott and Crossman 1973); lampreys of the genus *Ichthyomyzon* have been found spawning in pockets of suitable substrate concealed in crevices among boulders (Cochran and Gripentrog 1992), but whether Pacific lamprey also use other types of habitat is unknown. Spawning occurs during daylight hours (Applegate 1950), during which predation by birds and mammals may occur (see Beamish 1980; Close et al. 2002). Eggs which overflow the nests are actively eaten by rainbow trout (*Oncorhynchus mykiss*) and speckled dace in the Umatilla and South Fork rivers (J. Bronson, pers. comm., Confederated Tribes of the Umatilla Indian Reservation, Tribal Fisheries Program; Brumo and Markle 2006).

After spawning, Pacific lamprey die within 3 to 36 days (Pletcher 1963; Kan 1975). Adult carcasses are likely a major contributor of nutrients in oligotrophic streams (see Close et al. 2002).

3.2.6 Fecundity

Wolf and Jones (1989) reported the Pacific lamprey has very high fecundity compared to North American Pacific salmon species. Whereas fecundities for five North American Pacific salmon species ranged from 1,200 to 17,000 eggs per female (e.g., Burgner 1991; Healey 1991), Scott and Crossman (1973) reported an average lamprey fecundity of 34,000 eggs, with a maximum of 106,000 eggs for a 406-millimeter (mm) female; fecundity for Pacific lamprey in Oregon streams ranged from 98,000 to 238,400 eggs per female (Kan 1975). Little is known about Pacific lamprey spawning success but, under some conditions, it can be high (Brumo and Markle 2006); in Great Lakes the survival of sea lamprey eggs deposited in the nests was estimated to be up to 90 percent (Manion and Hanson 1980).

3.2.7 Orientation to Spawning Streams

Although many species of fish, most notably salmonids, use olfactory cues to locate their natal streams to spawn (Dittman and Quinn 1996), several lines of evidence suggest that anadromous lamprey do not home to (i.e., preferentially select) their natal streams. For example, a mark-recapture study found that upstream migrating Great Lakes sea lamprey randomly distributed themselves among tributaries instead of returning to their natal streams (Bergstedt and Seelye 1995). Radio-tracking of displaced adult Pacific lamprey likewise suggests a lack of homing (Hatch and Whiteaker 2009). It appears instead that upstream migrating lamprey select streams with quality spawning and rearing habitat by orienting to a pheromone produced by larval lampreys (Sorensen and Hoye 2007; Wagner et al. 2009). The sea lamprey migratory pheromone is composed of at least three separate bile acid compounds (Sorensen et al. 2005), and appears to work in concert with other factors like rheotaxis (Vrieze et al. 2010) and temperature (Binder and McDonald 2008). Nine other species of lamprey from four genera, including the Pacific lamprey, have also been shown to produce petromyzonol sulfate (Fine et al. 2004), and adult Pacific lamprey are sensitive to and attracted by the pheromone during the migratory period (Robinson et al. 2009).

Genetic evidence likewise suggests that anadromous sea lamprey do not home to their natal streams; a lack of genetic differentiation among locations along the Atlantic coast of North America suggests gene flow among these locations (Waldman et al. 2008; Bryan et al. 2005). The evidence against natal homing is less conclusive for Pacific lamprey. Beamish (1980), for example, found differences in body size among river systems in British Columbia, suggesting that at least some lamprey return to their native streams to spawn. Lin et al. (2008), using genetic evidence, used amplified fragment length polymorphisms (AFLPs) to provide evidence of weak stock structure in adults of this species from Japan, Alaska, the Pacific Northwest, and within the Pacific Northwest.

Mitochondrial and microsatellite DNA markers found that genetic differentiation among Pacific lamprey from different locations between southern British Columbia and central California was low, suggesting gene flow among the locations (Goodman et al. 2008; Spice 2010). Although additional research needs to be done, this indicates that Klamath River Pacific outmigrants will not necessary return to the Klamath River, but that adequate larval populations within the basin should attract spawning migrants. Likewise, adult lamprey produced in other watersheds may return to spawn in the Klamath River Basin.

3.3 Life History of Other Klamath River Basin Lamprey

The general life cycle of the other lamprey in the Klamath River Basin is similar to that of the Pacific lamprey (e.g., they all pass through a filter-feeding larval stage prior to metamorphosis, and they all spawn in the spring and then die). The larval phase of the life cycle is the same as that of the Pacific lamprey, with the possible exception of the length of the larval period. Age at metamorphosis is not known in these species, but it has been suggested that non-parasitic lamprey (e.g., the Pit-Klamath brook lamprey) have a longer larval phase relative to closely-related parasitic species (see Docker 2009).

It is after metamorphosis that the other species diverge in their life cycles. None of the other Klamath River Basin lamprey species migrate to the sea (Table 2); the "Klamath Lake lamprey" (which apparently spawns and rears in the Sprague River) migrates downstream in the spring to Upper Klamath Lake, where it feeds on resident fish until returning upstream to spawn. The other lamprey species all apparently undergo very limited migrations (e.g., migrating upstream at spawning to counteract the downstream drift that occurs during the larval phase); the Miller Lake and Klamath lampreys feed within the river or creek and the brook lamprey do not feed at all following metamorphosis.

The length of the adult phase of these species is reduced relative to the Pacific lamprey (particularly in the non-parasitic brook lamprey, which all spawn and die the spring following metamorphosis) and size at maturity (total length) is correspondingly smaller: Klamath lamprey: 136–269 mm (Vladykov and Kott 1979); Miller Lake lamprey: 72–126 mm (Lorion et al. 2000); Klamath Lake lamprey: approximately 200–270 mm (Docker, unpublished); Pit-Klamath brook lamprey: 116–142 mm (Docker 2009); Modoc brook lamprey (*Entosphenus folletti*): approximately 200 mm (Docker et al. 1999); and western brook lamprey: 101–172 mm (Docker 2009).

Fecundity will also be reduced, given the reduction in body size. Although fecundity values have not been published for these species, lamprey of sizes equivalent to those seen in the three Klamath River Basin brook lamprey and the Miller Lake lamprey have fecundities ranging from approximately 1,000 to 3,000 eggs per female, whereas other freshwater-resident parasitic species of sizes similar to Klamath river and Klamath Lake lampreys have approximately 20,000 eggs per female (Vladykov 1951). However, given the lack of the marine feeding phase and prolonged upstream migration, these freshwater-resident lampreys presumably have a greatly reduced mortality rate relative to the Pacific lamprey (Docker 2009).

4.0 HABITAT DESCRIPTION AND FUNCTION

4.1 Existing Conditions

The Klamath Basin occupies approximately 15,700 square-miles of land. The headwaters of the eastern-most tributaries of the Klamath River are located in the Fremont and Modoc national forests. These flow into Upper Klamath Lake, the outfall of which is the official headwater of the Klamath River. The largest tributaries downstream of Iron Gate Dam are the Shasta, Scott, and Trinity rivers. The Klamath River flows generally south and west, cutting through the Coast Range Mountains before reaching the Pacific Ocean at Klamath.

4.1.1 Upstream of Keno Dam

Upper Klamath Lake is located 22 river-miles (RM) upstream of Keno Dam. Its elevation is controlled by Link River Dam. A relatively new state-of-the-art fish ladder allows for fish passage past Link River Dam. Upper Klamath Lake is shallow, warm, hypereutrophic, and polluted, but attempts to improve these habitat characteristics are underway and planned through restoration and TMDL processes. Although the drainage density of streams is low in the volcanic terrain of the upper basin, two significant tributaries enter the lake: Williamson and Wood rivers. The Sprague River is a notable tributary to the Williamson River.

The three streams are fed by supplies of cold groundwater from springs, which support reliable, natural hydrographs. Some of the streamflow is diverted for irrigation and water quality is lowered by nutrients, sediment, and reduced dissolved oxygen levels. The Panel has not been able to locate descriptions of the gradient, channel plan form, or sediment texture for these tributaries, but they are reported to have favorable habitat for resident fish and to have provided habitat for anadromous fish within the pre-historic and historical periods. However, Fortune et al. (1966), who conducted the most thorough on-the-ground survey of habitat availability and quality in these tributaries, reported significant limitations on the area of spawning gravels because of the shortage of gravel supply from the catchment, and the widespread occurrence of pumice and silt. Other limitations on habitat quality included low dissolved oxygen, high temperatures between spring-fed reaches, and some barriers to fish passage.

4.1.2 Keno Dam to Iron Gate Dam Reach

The 45-mile reach of the Klamath River between Keno and Iron Gate dams is generally steep (gradient ~0.005-0.01), and extensively confined by bedrock canyon walls. This reach has a sediment supply much lower than the river's transporting capacity. Stillwater Sciences (2010) estimated from various sources that the sediment supplied to this reach comprised only 24,000 tons of sand-gravel per year and 127,000 tons of silt-clay. Thus, gravel bed-material storage on the free-flowing reaches between reservoirs is sparse, being confined to generally lower gradient reaches such as the Frain Ranch area (RM 218) and the mouths of a few tributaries. However, most of this bed material is in the 100-500 mm range, and only the finer 15-20 percent of it is in the range 10-100 mm (Greimann PPT Presentation). Before impoundment of the Klamath River by Copco I

Dam there was a distinctively low-gradient reach at the site of Copco Reservoir (*aka* Copco Lake) where the river flowed in a valley–wide meander belt through a floodplain containing old channel scars with varying degrees of connection to the current channel. Elsewhere, the free-flowing reach comprises long rapids, runs, and pools among large boulders. There was also a low-gradient channel reach at the site of J. C. Boyle reservoir, but the sediment supply to this reach was very low because of the presence of Upper Klamath Lake.

Between the quiescent impoundments, free flowing reaches have generally high velocities with rapid fluctuations of discharge between 350 and 2,400 cubic-feet per second (cfs) and of velocity during summer because of peaking power production. These fluctuations inundate the substrate with fast-flowing water and then dry it out on a daily basis. Iron Gate Reservoir re-regulates these flows into a hydrograph that propagates some minor fluctuation tens of kilometers downstream during summer low flows. The flow regime of this downstream reach is dominated by late-winter peaks of 5,000-30,000 cfs and extended low flows regulated to at least 700-1,300 cfs during the rest of the year (Hardy et al. 2006).

Water temperatures in this reach are out of phase with the natural temperature regime and are particularly high during late summer and fall, and may fluctuate by as much as 12°C during power peaking though they are stabilized in some parts of the reach by flow from large springs and coldwater tributaries. Chemical water quality in this reach is severely degraded at some seasons by outflow from Upper Klamath Lake and inflows from various point discharges draining into Keno Reservoir. Dissolved oxygen levels are generally low and the water contains algae washed downstream from Upper Klamath Lake and the artificial reservoirs.

This reach also contains several steep tributaries. Some gravel bed material is stored at the mouths and lower reaches of these streams which, therefore, would provide some adult spawning gravel, but little fine-grained substrate for larval lamprey burrows.

4.1.3 Downstream of Iron Gate Dam

Downstream of Iron Gate Dam the Klamath River has a gradient of approximately 0.0025 and a cobbly surface with a subsurface median grain size in the 10-20 mm range. The mainstream has a wandering habit with broad, irregular bends and occasional anastomosing side channels.

The average annual sediment supply to this reach increases slowly with increasing distance downstream of Iron Gate Dam as the river enters more erodible terrain, so some riffles and bars form in the relatively low-gradient reach beginning at the R-Ranch downstream of Iron Gate Dam. However, the sediment supply remains low until it is strongly augmented at the Scott, Salmon and Trinity rivers, which although they are heavily impacted by water withdrawals and other management actions, provide large sediment supplies to the Klamath River. The sediment supply favors the development of pool and riffle habitat along with significant (but as yet unmapped) fine sediment deposits along channel margins that are important burrowing habitat for larval lamprey. The channel downstream of Iron Gate Dam is simple in form and wide enough to be essentially unshaded. High water temperatures result from reduced flows and a lack of shade. Instream dissolved oxygen concentrations can vary greatly through the day and may at times be reduced to approximately 6 milligram per liter (mg/L) because the abundance of aquatic plants and algae undergo complex diel cycles of photosynthesis and respiration during summer months (P. Zedonis, USFWS, pers. comm. 2010).

4.2 Future Condition With Dams

In the absence of dam removal, the habitat conditions described previously will persist with only subtle changes due to foreseeable hydrological changes. For example, some habitat improvements such as local gravel augmentation are already planned in a general way (no details on amounts or specific locations of gravel placement were available to the Panel) in reaches downstream of J. C. Boyle Dam that are not accessible to the anadromous Pacific lamprey, but could benefit the resident Klamath lamprey. Other habitat improvements are also planned in a general way that may gradually extend small areas of both spawning and rearing conditions for resident lamprey in the sediment-starved Upper Klamath Lake Basin and spawning conditions in the Klamath River downstream of Iron Gate Dam. Various strategies involved in TMDLs in the basin should also make some improvements to water quality, especially in the Upper Klamath Lake Basin and perhaps the in the river reach between Upper Klamath Lake and Iron Gate Dam, but since the Panel was provided with no concrete information about TMDL actions, it is not possible to assess whether such effects are likely to be recognizable downstream of Upper Klamath Lake without more specific information about the TMDL actions.

There are well documented reasons to expect both persistent droughts (a characteristic of the region) and climate change of some kind, driven by anthropogenic warming. Hetrick at al. (2009, pages 3-14) summarize the various ways in which agencies assess, predict, and respond to shortages of flow.

The effects of climate change are more difficult to predict, but a general consensus has been developed by atmospheric scientists and hydrologists about the general nature of likely changes on the west coast of North America. It is expected, for example that average annual air and water temperatures will increase by several degrees at this latitude. The increase in air temperature is likely to be accompanied by at least small increases in total precipitation, but various climate model simulations predict increases or decreases according to the particular model used and the socio-economic future scenario being simulated. Bureau of Reclamation scientists have, quite reasonably used the median precipitation predictions to model the impact of climate change on streamflow into the impounded reach (Greimann PPT presentation), but they acknowledge the risk of precipitation reductions.

A more significant and more secure prediction region-wide is for a decrease in the proportion of snowfall and snow storage to total precipitation. The latter trend over the past 50 years has been documented by several studies across western North America (e.g., Science 2004), and the correlation of winter precipitation and snowpack with runoff has been documented (e.g., Leung and Wigmosta 1999). However, the upper Klamath River watershed has several geographical characteristics that will tend to buffer the effects of earlier snowmelt and increased evapotranspiration. A large fraction of the watershed is underlain by deep, permeable volcanic deposits. Fall and winter precipitation and snowmelt recharge these deep aquifers. This water is protected from evapotranspiration by the fact that much of the storage is at depth and because the generally low temperatures at high elevation and generally thin soils with sparse vegetation keep evapotranspiration rates low during the spring and summer. A portion of autumn rainfall will still run off from less permeable parts of the watershed so streamflow may rise earlier in the season than at present. But the effect on peak timing will likely be smaller than in most hydrogeological environments of the western region. The model predictions by Greimann (PPT Presentation) are generally consistent with these expectations. Hetrick et al. (2009) summarize local and regional studies of recent trends and model-based projections; their literature review indicates a significant range of possible precipitation, and expectations will have to be refined as the anthropogenic climate changes unfold and interact with long-established climate dynamics of the region that are known to generate large inter-annual and inter-decadal swings in precipitation.

4.3 Future Conditions Without Dams and With the KBRA

Certain flow characteristics downstream of Upper Klamath Lake are predictable, regardless of climate change. It is expected that removal of dams on the Klamath would have only very small effects on peak flows, because of the small size of the reservoirs, and would cause an increase in spring-fall streamflow because of the removal of at least 5,780 acre-feet of evaporation per year once the reservoirs are removed (equivalent to about 15 cfs over 200 days). Increased water releases from the upper basin as part of the KBRA is expected to increase spring-summer low flows downstream of Upper Klamath Lake.

However, only a general statement of principles to govern the release of these flows has been established, so it is difficult to assess the likely size of their impact except to say that the direction of the changes are likely to improve conditions for lamprey through their effect on ameliorating thermal stress and possibly disease.

Hamilton et al. (2010) summarize the predicted changes to water quality that are expected from dam removal (Table 4). With regards to temperature, they predicted that, with dam removal, temperatures below the Iron Gate Dam will be more variable and higher in the spring and summer by approximately 2 to 4°C and lower in the fall and winter (by 4-5°C to at least 60 miles below Iron Gate Dam). The simulated hourly water temperatures given in Hamilton (2010; Figure 12) are based on 2002 conditions, which was defined as a dry water year, but maximum summer temperatures under existing conditions are approximately 22.5°C in late July and early August; maximum projected temperatures without the dams and with KBRA are 25°C (in late July). Minimum winter temperatures are approximately 3-4°C with the dams and close to 0°C without the dams. With dam removal, dissolved oxygen would increase by 3-4 mg/L immediately downstream of Iron Gate Dam, there would be increased assimilation of the river's nutrient load over the long term, and there would be a reduction in the abundance of toxic blue green algae (Hamilton et al. 2010a).

4.3.1 Extent and Nature of Habitat in Short- and Long-Term

The immediate and simplest change in habitat will be the opening of approximately 69 miles of potential lamprey habitat along the Klamath River mainstem and along the lower reaches of several tributaries between the former site of Iron Gate Dam and Keno Dam (see Section 5.2). An important characteristic of this expanded range is the potential for thermal refuges resulting from the presence of large, reliable springs with excellent water quality. However, the quality of this habitat for lamprey at earlier life stages is not likely to be high except locally. The reach will continue to receive only a very small amount of sediment because of the resistant rocks and the proximity of Keno Dam and Upper Klamath Lake, which will continue to interrupt sediment supplies. The sediment supply will continue to be far less than the river's sediment transport capacity, and only the cobbles and coarsest gravel will travel slowly enough and intermittently so that it will be stored temporarily to provide a discontinuous substrate on the channel bed and some bars. Currently, the material on the bed in these reaches between reservoirs is mainly in the cobble-boulder range (Greimann PPT Presentation). The most likely sites for significant sediment storage will be the several tributary junctions and about 4 miles around the current site of Copco Reservoir, where a floodplain with active and abandoned meanders had created significant sediment storage and morphological complexity before impoundment. Both kinds of sites will probably also temporarily store small amounts of fine–grained sediment that could provide patches of burrowing habitat for larval lamprey.

Gravel augmentation, planned as part of the KHSA's ICP interim measures, will provide some expansion of gravel bars, but the river will continue to have a high capacity for transporting that gravel away from augmentation sites, and amounts of money currently envisioned for this activity ($150,000 per year for about10 years) is sufficient to provide only several thousand cubic yards per year, which is a small amount relative to the river's transport capacity and the extent of the valley floor in the currently impounded reach. Selection of low-gradient sites might provide favorable sites for such gravel augmentation.

The extent of habitat downstream of the Iron Gate Dam site will not be strongly affected by dam removal. However, several dramatic short- and subtle long-term changes resulting from sediment release are evaluated in sections 4.3.3 and 4.3.4. Habitat modifications are likely to be limited by sediment supply, rather than by changes in flood regime.

4.3.2 Flow Regimes in both Short- and Long-Term

Dam removal will put an end to rapid fluctuations of flow for peaking of power production in the impounded reach. Halting of this practice will remove the frequent alternation of hours of high flow velocities followed by rapid dewatering of channel margins. Total annual and seasonal flows are unlikely to be affected by removal of these small reservoirs, although there will probably be only a slight increase in the magnitude of flood peaks that are currently modulated slightly by the small attenuation capacity of the reservoirs. Low flows are currently fixed by mandated instream flow requirements.

On the 50-year time scale, climate changes will alter flows as previously described for the Condition with Dams case, but there is no basis for confident predictions of channel-altering changes in the flood regime.

4.3.3 Short-term Effects of Sediment Release

Geotechnical surveys of the magnitude and grain size of sediments stored behind the four dams have documented approximately 8.1 million tons of impounded sediment, approximately 84 percent of which is in the silt-clay size range. Stillwater Sciences (2008, 2009, 2010) and the Bureau of Reclamation (Greimann PPT presentation) have estimated the fraction of this sediment that will be eroded out of the impoundment sites under various conditions of flow and reservoir management. There are important differences between the timing of the sediment releases between the various simulations that the groups have made in their separate preferred release strategies, based on engineering logistics and fish protection. However, the major results are consistent and in agreement with the qualitative interpretations made by earlier consultants (e.g., Shannon and Wilson 2006, pp 9-10).

Stillwater Sciences (2008) predict that a channel with assigned dimensions will cut down through the deposits in each reservoir at a rate that will depend on (i) the inflow rate, (ii) the rate of reservoir lowering (to be managed, but vulnerable to unpredictable flood flows), and (iii) the low concentration of sand and gravel in the deposit in each reservoir. It is likely that within the first year (or two if drought intervenes) 1.4-3.2 million tons of the sediment (biased toward the finer component) will be flushed downstream of Iron Gate Dam. This would leave 60-83 percent of the sediment in place along the margins of the new channel that would require rapid revegetation under adverse soil and moisture conditions in order to avoid problems with invasive weeds and dust, as well as chronic erosion of fine sediment into the Klamath River. The amount of sand-gravel flushed from the reservoirs in the first year is predicted to be in the range 300,000-600,000 tons.

The predicted first-year total of flushed sediment is smaller than the total amount transported during major floods on the river, although the transport would occur over a much longer time period and at much lower discharges in the dam removal case.

The Stillwater modeling of deposit erosion predicts that winter concentrations of suspended (dominantly silt-clay) sediment downstream of Iron Gate Dam will range up to 10,000 mg/L at Iron Gate Dam site (3,000 mg/L at Orleans), declining to 2,000 mg/L at Iron Gate Dam site (500 mg/L at Orleans) in the following spring. The concentrations are computed to remain chronically within a range of several thousand to several hundred mg/L for periods of up to six weeks for two seasons at least (November-December and May-June) between periods of reservoir filling.

Fine sediments carried downstream have the potential to lower dissolved oxygen as a result of biochemical oxygen demand (BOD). The degree to which this BOD reduces oxygen in the water column is under investigation (P. Zedonis PPT Presentation). However, water turbulence in the free-flowing river and input of oxygen rich water from tributaries should help reduce the potential effect of BOD on oxygen content of the river when sediment is released.

This silt-clay fraction is not represented in the channel bed downstream of Iron Gate Dam. It is expected that this “washload” will be transported far downstream by even low flows, and will be flushed rapidly to the ocean by typical annual and larger floods. This reasonable approximation was used in the simulation model runs by Stillwater Sciences (2008, 2009, 2010), who also interpreted that, there will also be some deposition of this fine sediment along the channel margins and in the floodplain that was not represented in the model simulations. The amount of this sediment storage will be greatest in low-gradient, sinuous reaches of the lower Klamath River.

The flushing events will also involve considerable amounts of suspended sand, some of which is likely to permeate the channel bed and reduce the quality of spawnable gravels. Calculations by Ayres Associates (1999) indicate that the channel bed in this reach should be mobilized by flood flows with recurrence intervals of about two years. Therefore, the bed fining caused by the flushing event should be reversed within a few years.

4.3.4 Long-term Effects of Sediment Release

After the first year or two, the chronically high suspended sediment concentrations will decline to much lower levels, fed by slow erosion of the floodplain and banks of the new channels through the former reservoir sites. As the dams are removed, there will no longer be reservoir filling periods to interrupt sediment flushing, which will thus be driven by the seasonal and storm runoff regime. It is likely that there will have been some fining of the channel bed during the initial sediment release and that tendency may continue for several years, but not for decades as the sediment supply from the reservoir is likely to have stabilized at a low level on that time scale. However, calculations of the likely frequency of bed mobilization by Klamath River flows by Ayres Associates (1999) predict bed mobilization every few years in the reach between the Iron Gate Dam site and the Salmon River confluence with the Klamath River.

The wave of coarser bed material released by dam removal will attenuate strongly during its passage down river, and it is unlikely to be recognizable after a decade. However, it will have contributed subtly to the mobile store of gravel that will maintain spawning habitat for lamprey in the generally sediment-starved reach of the Klamath River between Iron Gate Dam and the Salmon River. Its role in bar augmentation will also contribute to remobilizing bend growth and migration with its attendant undercut banks, causing a minor enrichment of the quality of rearing habitat for lamprey and other species.

The fine sediment that is likely to be stored along the channel margins and floodplains of the lower Klamath River during the first couple of years of sediment flushing will gradually be remobilized and flushed to the ocean. However, the major sources of sediment in the lower Klamath River have always been the Trinity, Scott, and Salmon rivers, and this fact will dominate the availability of burrowing habitat for larval lamprey in the lower Klamath River.

5.0 ELEMENTS OF POTENTIAL IMPACT

5.1 Introduction

Key characteristics used to evaluate viability of fish populations include abundance, productivity, diversity, and spatial structure (McElhany et al. 2000). Abundance of a population is largely influenced by the amount and quality of available habitat that can support the population (capacity) and the productivity of the population in response to habitat conditions throughout all life stages. For this analysis, the Panel assumed that population diversity and spatial structure of the lamprey populations will increase to the extent that the two dam management alternatives improve habitat availability and productivity for lamprey.

The analysis evaluates the two alternatives by comparing the proposed Conditions without Dams and with KBRA alternative (referred to as Conditions without Dams) against the Conditions with Dams alternative. The Panel's assessment is largely qualitative because few data are available on lamprey in the watershed and because many details of the Conditions without Dams alternative have yet to be described. Nevertheless, the Panel used projected changes in habitat area and quality as a means to assess effects of the Conditions without Dams alternative relative to the Conditions with Dams alternative. The Panel's evaluation considers both the near-term and long-term potential effects of the alternatives on anadromous and resident lamprey species.

The Panel began the evaluation with the potential immediate and near-term effects of the Conditions without Dams alternative relative to the Conditions with Dams alternative. Then the Panel evaluated potential long-term outcomes of removing the four dams on the abundance and productivity of lamprey, including an estimate of time for population recovery after dam removal and associated sediment impacts based on current assumptions regarding time for recovery of the Klamath River channel. The Panel's evaluation does not consider various potential options for the sequence and timing of sediment releases. Nevertheless, the Panel recognized that details of sediment releases might have a significant influence on lamprey and that a thorough evaluation needs to consider dam removal options and trade-offs that may exist on potential impacts.

5.2 Habitat Capacity Change

The following discussion addresses the predicted changes in the extent of accessible habitat for Pacific lamprey and the freshwater-resident Klamath River Basin lamprey: 1) between Iron Gate Dam and Keno Dam; and 2) upstream of Keno Reservoir. Pacific lamprey are discussed first in the more downstream reaches, given that considerably more is known about the Pacific lamprey in these reaches compared to the freshwater-resident lamprey species in the upper Klamath River Basin. Predicted changes to productivity and habitat quality are described Section 5.3.

5.2.1 Between Iron Gate Dam and Keno Dam

Pacific lamprey are currently extirpated above Iron Gate Dam; they are unable to pass the dam and the confirmed upstream limit in the mainstem Klamath River is Bogus Creek (about 100 meters downstream of Iron Gate Dam) and up to Lewiston Dam in the Trinity

River. Hamilton et al. (2010) estimated that an additional 69 miles of Pacific lamprey habitat will be opened up by removal of the four lower Klamath River dams. This includes (but is not limited to) 37 miles of the mainstem Klamath River up to Spencer Creek including historical anadromous fish habitat in areas currently inundated by the reservoirs (Hetrick et al. 2009), and an additional 23 miles of tributaries. A partial inventory of tributary habitat includes 9 miles of Spencer Creek up to the barrier falls, above which the habitat is also considered marginal, 2.7 miles of accessible habitat in Shovel Creek, approximately 1.2 miles in Fall Creek, and approximately 1 mile in Jenny Creek (Hamilton et al. 2010a). Predictions regarding the amount of sediment that will accumulate in this reach (see Section 4.3) indicate that most of the Klamath River mainstem reach above Iron Gate Dam will not constitute high-quality larval lamprey habitat, but freshwater-resident lamprey currently occur in the tributaries (Reid 2006) and Pacific lamprey historically used at least some of these areas (Hamilton et al. 2010a). Spencer, Shovel, Fall, and Jenny creeks supply cold, spring-fed water to this reach of the river (Hamilton et al. 2010a). The most promising reaches for lamprey use lie between the J.C. Boyle powerhouse and Caldera rapids and in the low-gradient reach currently inundated by Copco Reservoir.

As previously stated, the current upstream limit on the occurrence of Pacific lamprey is Bogus Creek (RM 189.6) in the mainstem Klamath River; this species also occurs up to Lewiston Dam in the Trinity River and in Salmon, Shasta, and Scott rivers, and Clear and Dillon creeks (Table 2) giving approximately 310 miles of inhabited tributaries downstream of Iron Gate Dam. Dam removal would then increase the extent of potential mainstem habitat by approximately 14 percent[2].

It is not known if there will be a change in the extent of habitat in the Klamath River reach above Iron Gate Dam for the freshwater-resident Klamath lamprey, since so little is known about the biology of this species. It is largely non-migratory, but is found both above (e.g., in Spencer Creek) and below (e.g., Seiad Creek, Trinity River) the Iron Gate Dam; thus dam removal is expected to restore connectivity among these disjunct populations. Klamath lamprey adults have also been found in lakes and reservoirs in the Klamath Basin (Hamilton et al. 2010a), but the overall effect of dam removal on the extent of this species' range is difficult to predict.

5.2.2 Upper Klamath River Basin Upstream of Keno Dam

With the fish passage modifications planned for Keno Dam by the KBRA, Pacific lamprey could presumably access the upper Klamath River Basin. It is not known with certainty, however, whether the Pacific lamprey historically occurred above Keno Dam; Upper Klamath Lake has been inaccessible to anadromous fishes since the construction of Copco I Dam in 1918 if not earlier (Hetrick et al. 2009). However, several species of freshwater-resident lamprey are found in the upper Klamath River Basin (Table 2), including a large migratory form in Upper Klamath Lake (which spawns in the Sprague River and can reach lengths of at least 280 mm), and small non-migratory species in the

[2] Calculated as 69 miles of newly available habitat divided by 500 miles of the Klamath mainstem and tributary streams which are currently inhabited by Pacific lamprey downstream of Iron Gate Dam; the total accessible length of each river or stream currently occupied was used because distribution within each reach or stream is not known

Wood, Williamson, Sycan, Sprague, Lost, and Link rivers and Miller Creek. Lamprey spawning and rearing habitats are therefore available within the upper Klamath River Basin. Hetrick et al. (2009) estimated that over 420 miles of interconnected river and stream channels currently exist upstream of Iron Gate Dam that may provide functional spawning and rearing habitats for anadromous fish species, including Pacific lamprey; the Panel could not confirm this statement which is at odds with the field surveys by Fortune et al. (1966) who reported that only a portion of assessable streams have suitable spawning and rearing habitat for salmonids. Huntington et al. (2006) made qualitative field assessments in general agreement with the descriptions above, and then utilized model-based predictions of the extent and quality of existing potential spawning and rearing habitat for various anadromous species. The areas predicted to be of relatively high quality were somewhat larger than the spawning areas described by Fortune et al. (1966) from field measurements, but the distribution of the two sets of predicted areas are similar. However, Huntington et al. (2006) repeatedly stressed that even the limited favorable reaches would require significant habitat improvements in order to support returning fish populations.

There is significant spring contribution to the flow of upper Williamson River during the spring months, and water quality is generally good (supporting a world-class fishery for redband trout and historically supporting anadromous fishes); conditions in Wood River are similar (Hamilton et al. 2010a). The Sprague River is currently listed as water-quality impaired and shows habitat degradation in some areas, but it historically provided excellent habitat for anadromous fishes. The KBRA includes plans for aquatic habitat restoration in the Sprague, Wood, and Williamson rivers and Upper Klamath Lake (Table 3), and Hetrick et al. (2009) estimated that up to an additional 60-235 miles of potential habitat exists in the upper Klamath River Basin that could be rehabilitated into a functional condition for use by anadromous fish species (Hetrick et al. 2009).

Table 3. Summary of KBRA Measures that May Improve Lamprey Productivity.

Program	Project	Years	Total Cost Estimate ($2007 Thousands)
Restoration	Williamson River Aquatic Habitat Restoration	2013-2021	8,000
Restoration	Sprague River Aquatic Habitat Restoration	2013-2021	63,570
Restoration	Wood River Aquatic Habitat Restoration	2013-2021	13,700
Restoration	Williamson/Sprague/Wood Screening Diversions	2012-2014	3,000
Restoration	Upper Klamath Lake Aquatic Habitat Restoration	2013-2021	12,700
Restoration	Screening of Upper Klamath Lake Pumps	2012-2014	500
Restoration	Keno Reservoir Water Quality Remediation Actions	2013-2020	50,000
Restoration	Keno to Iron Gate Mainstem Restoration	2013-2021	1,650
Restoration	Keno to Iron Gate Tributaries – Diversions and Riparian	2016-2018	1,500

Restoration	Mid Klamath River and Tributaries Aquatic Habitat Restoration	2013-2021	10,950
Restoration	Lower Klamath River and Tributaries Aquatic Habitat Restoration	2013-2021	15,190
Water Resources	Keno Dam Fish Passage	2020-2021	3,500
Regulatory Assurances	Keno Reservoir KIP Screening	2019-2020	25,000
Source: KBRA Appendix C			

It is not known, however, to what extent this habitat in the upper Klamath River Basin would be accessible to Pacific lamprey, particularly whether water quality (temperature and dissolved oxygen) and fishways at Keno Dam and Upper Klamath Lake would permit passage of upstream migrating lamprey during the spring months. Downstream movement of outmigrating juvenile Pacific lamprey in the spring, however, would occur when flows in the upper Klamath River Basin are high and water conditions in the lake are suitable. No physical barriers were historically present to movement in the upper Klamath River Basin and upstream migration of Pacific lamprey through large lakes has been observed in the Babine Lake system (Farlinger and Beamish 1984; see Section 5.3.1).

Given this uncertainty regarding access to and extent of accessible and suitable habitat for Pacific lamprey in the upper Klamath River Basin, the Panel can only say that dam removal would allow access to additional areas, currently unoccupied. In addition full implementation of the KBRA could potentially increase the capacity of Pacific lamprey habitat upstream of Keno Dam, but the Panel does not know to what extent this would occur. If the increase in accessible habitat predicted for anadromous salmonids is suitable for Pacific lamprey, this could represent a large increase in the habitat for lamprey species.

It is not known whether there would be potential competitive interactions between the Pacific lamprey and the freshwater-resident species (e.g., competition for spawning or larval habitat) or interspecific hybridization. Evidence suggests that size-assortative mating in lamprey would prevent hybridization between the large Pacific lamprey and the smaller freshwater-resident lamprey (see Docker 2009), but whether hybridization would occur in the upper Klamath River Basin is not known. Genetic data show an absence of the Pacific lamprey haplotype in the freshwater-resident lampreys in the upper Klamath River Basin (Lorion et al. 2000; Docker unpublished data). If Pacific lamprey historically were found in the upper basin, this suggests that there was no significant hybridization between the anadromous and freshwater-resident species prior to dam construction. Studies on hybridization in the lower basin, where Pacific and Klamath lampreys co-occur, have not yet been completed (Docker unpublished data).

Since very little is known about the biology or habitat requirements for the freshwater-resident lamprey species in the upper Klamath River Basin, it is difficult to predict whether there would be a significant change in the habitat capacity for these species with dam removal. Because their ranges are restricted, dam removal itself is unlikely to change habitat capacity for resident lamprey. There may be some expansion of their ranges as habitat improves following implementation of the KBRA aquatic habitat restoration measures but, without specifics of the restoration actions expected through the KBRA or knowledge of the biology of these species, the extent to which range expansion and resultant increases in lamprey production might occur is unknown. It is not expected that extensive colonization of new tributaries will occur given that these are largely non-migratory species, but this is not known.

5.2.3 Summary

Capacity for Pacific lamprey in the Klamath River system is predicted to increase by a maximum of 14 percent (based on analysis of mainstam habitat), with potentially more if habitat in the upper Klamath River Basin is accessible and suitable. Capacity for the freshwater-resident lamprey species in the upper Klamath River Basin is not expected to change significantly with dam removal, but may increase somewhat with implementation of the KBRA aquatic habitat restoration measures.

Utilization of the newly accessible habitat by Pacific lamprey will largely depend upon the rate at which this habitat is recolonized by spawning adults (see Section 5.3.2) and the extent of the spawning habitat enhancements (e.g., gravel enhancement downstream of J.C. Boyle Dam) prior to dam removal.

5.3 Lamprey Productivity

5.3.1 Recolonization Potential

Pacific lamprey were reported by Farlinger and Beamish (1984) to colonize new habitats in the Babine Lake system in British Columbia; colonization occurred in areas upstream of the existing populations and upstream of Babine Lake. In addition, a small portion of adults recolonized the lower Umatilla River after being extirpated in the 1970s (Close et al. 2009). Therefore, it is expected that adult Pacific lamprey will recolonize the newly opened habitat after dam removal. The recolonization may be facilitated by larval pheromones produced by existing lamprey populations in the upper reaches of the Klamath River Basin. It appears that the larval pheromone guides returning migrants to a particular river or stream, but not necessarily to specific locations within the stream (Wagner et al. 2009; Vrieze et al. 2010). Therefore, it is expected that larval populations (including other species because the pheromone is not species-specific; Fine et al. 2004) in other regions of the Klamath River Basin could attract upstream migrants.

However, the passive recolonization may occur only slowly. The 1980, Mt. St. Helens eruption devastated the Toutle River in Washington. Adult lamprey were found to have recolonized the North Fork Toutle within 10 years after the eruption. Farlinger and Beamish (1984) report recolonization to occur within 10-20 years following removal of a rockslide barrier in the Kispiox River, British Columbia. Therefore, adult lamprey may take decades to naturally recolonize. Currently, Pacific lamprey distribution is almost to Iron Gate Dam, which suggests that recolonization will likely occur in a much shorter time span than decades. However, the Fish Managers might consider active reintroduction after some amount of time if natural recolonization is slow. Active introduction has been shown to be successful for seeding vacant habitat with larvae (Close et al. 2009).

The Conditions without Dams alternative may provide a improve habitat conditions for Klamath lamprey and Pacific lamprey by reconnecting previously fragmented habitat. This may be important to reduce the risk of losing specific resident populations of the Klamath lamprey.

5.3.2 Short-term Productivity and Species Recovery

Pacific lamprey larvae utilize soft fine substrate for approximately 4-6 years in freshwater streams. Because they live burrowed in the soft sediments, there will likely be minimal increases in larval mortality rates of existing Pacific lamprey larvae in the mainstem Klamath River after dam removal. The larvae will likely relocate or adjust their burrow tubes to maximize feeding and respiration. The increased sediment loads will not affect the Klamath lamprey and western brook lamprey since they are located off the mainstem in tributary habitats. It is not known whether two 6-week periods of high sediment loads might result in gill abrasion or decreases to feeding efficiency, but the high sediment concentrations predicted by Stillwater Sciences (2008) were for silt-clay only, which is not usually abrasive. The concentrations of abrasive suspended sands was not predicted. Should mortality occur downstream of Iron Gate Dam from increased sediment load and deposition, it is expected that populations of larval lamprey found in the unaffected tributaries would recolonize these areas during normal lifecycle movements.

Pacific lamprey larval rearing capacity downstream of Iron Gate Dam will be increased during the short-term after dam removal and with implementation of the KBRA because of the added fine sediment loading following dam removal. The available burrowing habitat for larvae will subsequently decrease through time, but will likely remain higher than current conditions.

Model simulations from Stillwater Sciences (2008, 2009, 2010) suggest that approximately 40 percent of all sediments in the impoundments will be flushed downstream to the ocean as suspended load during the first year; however, it is acknowledged that a small portion of this sediment will be stored for unpredicted periods of time along the margins of the channel and floodplain of the lower Klamath River. It is reasonable to expect that this fine-grained sediment will be re-mobilized over a period ranging from years to decades. The long term prospect is for an increase of approximately 127,000 tons per year of fine sediment from the currently impounded reach, but it is probably negligible compared to the supply from the Scott, Salmon, and Trinity rivers. The sediment will not be conducive for larval rearing between Iron Gate Dam and Keno Dam, except for some small patchy low-gradient areas in the Copco Reservoir reach.

The fine sediments will likely increase and be retained in the lower Klamath River Basin by the meandering portions of the river. Based on Shannon and Wilson (2006), sediment-derived contaminants should not be a problem for larval lamprey. .

Beamish (2001) suggested that increasing siltation of lakes and rivers may increase habitat for larval Cowichan lamprey (*Entosphenus macrostomus*), but a concomitant loss of shallow water gravel areas used for spawning that would resulting from this increased siltation would presumably have an adverse effect. Pacific lamprey require clean gravels for spawning during the spring. Brumo (2006) reported that, in the South Fork Coquille

River, this species spawned in areas containing gravel/cobble (4-15 centimeter diameter) embedded in finer gravel/sand at depths of 0.3-1.0 meter. Close et al. (2009) found Pacific lamprey egg viability to range from 81 to 93 percent in clean gravels in the Umatilla River. The increased sediment load (depending on what time of year the dams are removed) may affect lamprey egg viability in the nests. Therefore, the timing of dam removal is important, especially to reduce the chances of smothering the eggs in nests from May through July (see Section 3.2.5).

5.3.3 Long-term Productivity and Species Recovery

The sections below describe how changes in key variables (streamflow, water quality, spawning habitat, rearing habitat, non-native fishes, and disease) in response to the Conditions without Dams and with KBRA Alternative might affect lamprey downstream of Keno Dam (dam removal reach) and upstream of Keno Dam.

5.3.3.1 Downstream of Keno Dam

Streamflow. Pacific lamprey are adapted to seasonal and short-term variations in discharge. For example, the South Fork Coquille River is described by Brumo and Markle (2006) as a “flashy” system, with order of magnitude changes in discharge during the spawning season. Beamish and Levings (1991) likewise report large variations in water discharge in tributaries to the Fraser River in British Columbia; key stages in the life cycle (particularly downstream migration of the juveniles) are generally correlated with these abrupt changes in discharge. Controlled flow that greatly reduces these pulses or shifts their seasonality can alter the timing of these events in lamprey (e.g., Beamish and Levings 1991) but, as described, the changes in flow between the two management alternatives in the Klamath Basin are predicted to be relatively small.

There are no significant changes to the hydrograph with dam removal and the KBRA (Hamilton et al. 2010b) that would negatively affect Pacific lamprey or the resident lamprey species. In general, mean monthly flows under the conditions without dams and with KBRA are relatively similar to those under the conditions with dams as guided primarily by the salmon biological opinions (see Figure 7 in Hamilton et al. 2010b).

Water Quality and Temperature. The changes to water quality that are predicted to occur with dam removal and the KBRA (Section 4.3) that are particularly relevant to lamprey include changes to water temperature and dissolved oxygen levels. It is anticipated that the higher temperatures in the spring and summer predicted with dam removal could constrain lamprey productivity. Embryonic development in Pacific lamprey is particularly susceptible to high temperatures. The optimal temperature for survival of early life stage Pacific lamprey is 18–19ºC. At higher temperatures (22ºC), survival was significantly reduced and developmental abnormalities increased (Meeuwig et al. 2005). Spawning generally occurs in the spring so that the embryos are produced during optimal temperatures for development. Pacific lamprey along the coast of Oregon usually begin to spawn in May when water temperatures reach 10°C to 17°C and continue to spawn through July (Brumo 2006; Stone 2006), with peak spawning occurring at 13-16 ºC. Spawning time is determined primarily by water temperatures rather than photoperiod (Larsen 1980; Binder et al. 2010), so that spawning time is expected to adjust to changes in seasonal temperatures. According to the simulated temperatures near Iron Gate Dam in Hamilton et al. (2010; Figure 12), peak spawning temperatures will occur in early May to early June under both management alternatives; eggs hatch approximately 15 days following spawning and larvae emerge approximately 15 days after that (Brumo and Markle 2006). Thus, for the 30 days following the 13-16ºC period, temperatures range from approximately 13-20ºC under the Condition with Dams Alternative and approximately 11-24ºC for the Conditions without Dams and with the KBRA Alternative. Thus, in the Conditions without Dams and with the KBRA Alternative, larval survival would be expected to be reduced and developmental abnormalities increased in some years. With dam removal, however, over-summering lamprey may make use of thermal refugia in tributaries upstream of the current location of Iron Gate Dam (e.g., Big Springs and Spencer, Fall, and Jenny creeks) (Hamilton et al. 2010a), thus potentially mitigating the effect of higher spring and summer temperatures.

Larger larvae are presumably more tolerant of high temperatures. In larvae of other lamprey species (sea lamprey and European brook lamprey), ultimate incipient lethal levels of 29.2-31.4ºC were observed (Potter and Beamish 1975) and the closely-related Pit-Klamath brook lamprey does very well in the mainstem Pit River in California, where summer temperatures reach the high 20sºC (S. B. Reid, pers. comm., Western Fishes, Ashland, Oregon). Pacific lamprey ammocoetes have been reported in relatively few rivers in southern California (e.g., Chase 2001); this implies that they are able to tolerate fairly warm water temperatures to some extent but likely not to a great extent. No information is available on the temperature tolerances of metamorphosing and downstream migrant Pacific lamprey.

Upstream migrants, however, will also be affected by an increase in temperature but, in this case, it may be affecting the rate at which energy stores are mobilized during the non-feeding freshwater period. Pacific lamprey lose 18-30 percent of their body length between the start of the initial migration and after spawning (Beamish 1980; Chase 2001) and females shrink more than males (F.W.H. Beamish 1980). An increase in temperature during the course of the 1-year freshwater-residency period would be expected to increase the extent to which Pacific lamprey shrink (Clemens et al. 2009), although the predicted increase in spring and summer temperatures that would accompany dam removal would likely be balanced by the decrease in fall and winter temperatures. Whether Pacific lamprey actively seek refugia (cooler in the summer or warmer in the fall) during the freshwater phase is unknown. Increased spring and summer temperatures, however, could result in greater susceptibility of the upstream migrants and spawners to disease (see Disease below).

Changes in the temperature regime resulting from dam removal could conceivably change the growth rate of the larval lamprey, thus affecting productivity and age at metamorphosis. In other lamprey species, food during the larval phase is not thought to be a limiting factor (Moore and Mallatt 1980) but cooler temperatures can reduce growth rates (Murdoch et al. 1992). Temperatures predicted for the area affected by dam removal are not expected to swing well beyond what would be expected in a natural setting such as this. Regardless, the net effect of warmer spring and summer temperatures relative to the cooler fall and winter temperatures, however, is unknown.

The foregoing discussion specifically describes Pacific lamprey downstream of Iron Gate Dam. Other lamprey species in the Klamath River Basin (e.g., the Klamath lamprey in tributaries of the Klamath River downstream of Iron Gate Dam and the western brook lamprey in tributaries near the mouth of the Klamath River) are not expected to be affected by water quality changes under the Condition without Dams given their locations. This conclusion is also expected to be the case for lamprey that may be present between Iron Gate Dam and Keno Dam, where current water temperature conditions show that maximum temperatures do not exceed 18°C.

Under the Condition without Dams and with the KBRA Alternative, increases in dissolved oxygen levels are expected to improve habitat productivity for Pacific and other Klamath River Basin lamprey species. Under existing conditions, Hamilton et al. (2010; Figure 19) show dissolved oxygen levels below Iron Gate Dam to range from 8-12 mg/L in the winter and as low as 4-5 mg/L in the summer under existing conditions. With Condition without Dams and with KBRA Alternative, dissolved oxygen levels are predicted to range from 10-14 mg/L in the winter and between 7-8 mg/L in the summer. This is expected to be a dramatic improvement for lamprey. Although larval lamprey have relatively low oxygen consumption rates (approximately 20-30 microgram (µg) per gram body weight per hour) (Lewis and Potter 1977), their oxygen consumption rates double at metamorphosis (Lewis and Potter 1977) and their tolerance for low oxygen decreases (Hill and Potter 1970). Adult lamprey have similar oxygen consumption rates to juvenile lamprey and likewise have a lower tolerance for hypoxic conditions than do larvae.

It is expected that there might be short-term negative affects to water quality due to increased sedimentation following dam removal (See Section 5.3.2). Larval Pacific lamprey are typically found in clear, low gradient streams and are not very tolerant of waters with excessive amounts of dissolved or suspended solids. Adult lamprey spawning occurs in clear gravel-bottomed streams. Over the long-term, however, sedimentation and high turbidity are not expected to be significant problems. In fact, increased sedimentation following dam removal will likely be beneficial in creating new larval habitat. Implementation of the KBRA is expected to reduce nutrients in the system and thus also reduce the blooms of blue green algae. Blue green algae are currently very abundant in Keno Reservoir (and its outflow) in July–September as well as in Copco and Iron Gate reservoirs (Zedonis PPT Presentation) and downstream of Iron Gate Dam. The future reduction in blue green algae is expected to improve productivity of fish in the Klamath River Basin, since blue green algal blooms increase pH and there is currently evidence of toxin accumulation in fish and invertebrate tissues resulting from such blooms. It is not known whether lamprey can detoxify blue green algae.

Overall, the Conditions without Dams and with the KBRA alternative is expected to improve water quality (particularly dissolved oxygen), but there may be some negative effects of increased spring and summer water temperatures.

Lamprey Spawning and Rearing Habitat. Changes in sedimentation (both on the short-term and long-term) in this reach have been previously discussed (Sections 4.3.3 and 4.3.4). Briefly, some gravel bed material will be stored at the mouths of tributary streams and in the lower reaches of the Klamath River, but there will be relatively little fine-grained substrate for larvae lamprey habitat. Larval lamprey, however, may occur in patches of high density. This is particularly true of small larvae, and there is a gradual (passive) downstream movement of larvae such that larger larvae accumulate in the lower (more productive) reaches of the river. Most of the burrowing habitat in the Klamath River occurs downstream of the Scott River confluence and this would not change regardless of the management alternative and increased access to spawning habitat upstream of Iron Gate Dam to Keno Dam would increase the overall production of the system. In addition to increased access to open, shallow, gravel-bottomed stretches of streams that are considered typical Pacific lamprey spawning habitat, in high-energy reaches where this sort of habitat is limited (such as might become available under the Condition without Dams alternative), it might be possible for some spawning to occur in pockets of suitable substrate concealed in crevices among boulders, as reported for some freshwater-resident lamprey species in the eastern U.S. (Cochran and Gripentrog 1992; see Section 3.2.5).

For salmonids, Hetrick et al. (2009) suggested that access to the reach above Iron Gate Dam, in providing an increase in the amount of available spawning habitat, could reduce redd superimposition, thus potentially increasing survival. Little is known about the biology of Pacific lamprey in the Klamath River, but Brumo (2006) reported a greater superimposition of lamprey nests in the South Fork Coquille River during periods of higher spawning activity; Brumo and Markle (2006) found that spawning success of this species in the South Fork Coquille River decreased at high density. Pacific lamprey larval production in this system was related, in part, to spawner density (Brumo 2006). Productivity of the Klamath River Basin in general could therefore be increased by providing access to additional spawning habitat upstream of Iron Gate Dam to Keno Dam that could seed the more downstream sediment-rich reaches. There is not sufficient information, however, to evaluate the likelihood or extent of downstream seeding.

Non-native Fishes. Non-native fishes are recognized as a major threat to indigenous fishes in the Pacific Northwest. For example, Sanderson et al. (2009) concluded that non-native species have a major effect on salmonids protected by the Endangered Species Act. Of particular importance are non-native predators of indigenous fishes. Sanderson et al. (2009) reported that the construction of reservoirs associated with hydrosystem projects has facilitated the spread and establishment of many aquatic non-native species, including key non-native piscivores such as smallmouth and largemouth bass (*Micropterus dolomieui* and *Micropterus salmoides*) that consume virtually any prey smaller than the size of their gape. In areas where freshwater bass have been introduced, predation by bass has contributed to the decline of native fishes, frogs, and salamanders.

Many non-native fishes inhabit the Klamath River Basin. Eighteen species of fish in the Upper Klamath Lake basin are exotic (NRC 2004). Some key piscivores in the watershed that could consume lamprey include largemouth bass, channel catfish (*Ictalurus punctatus*), brown bullhead (*Ameiurus nebulosus*), eastern brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), black and white crappie (*Pomoxis nigromaculatus* and *Pomoxis annularis*), and yellow perch (*Perca flavescens*). Primary non-native piscivores in the reservoirs between Iron Gate and Keno dams include largemouth bass, yellow perch, and brown bullhead.

Although non-native fishes may prey on a few lamprey, including larvae, in the watershed, it is unlikely that the predation rate would significantly change between the two alternatives. Presently, only the Klamath lamprey adults are located in the reservoirs that would be removed as part of the Conditions without Dams Alternative. Abundance of non-native fishes in the reservoirs would likely decline significantly if the dams are removed because the key non-native fishes prefer reservoir habitats. However, most Klamath lamprey likely live in free-flowing tributaries where fewer non-native fishes occur. The two alternatives would likely have little effect on non-native fishes in the mainstem downstream of Iron Gate Dam. Nevertheless, as noted by Sanderson et al. (2009), it is important to control the abundance and spread of non-native fishes that can be significant predators on native fishes.

Disease. According to Scott and Crossman (1973), the incidence of parasites in Pacific lamprey is unusually low; they describe only two parasites from this species (*Eustrongylides* sp. and *Phyllobothrium* sp.), both of which they probably got from their hosts. An additional parasite, a new unnamed monorchiid digenean which uses the freshwater torrent sculpin (*Cottus rhotheus*) as a host, is also listed by Appy and Anderson (1981) as occurring in this lamprey species. No parasites have been identified in the Pit-Klamath brook lamprey, and lamprey which do not have an adult feeding phase were observed with just over half as many parasites as those with an anadromous feeding phase (Appy and Anderson 1981).

Pacific lamprey are susceptible to disease during the summer months in the Columbia River Basin. If Pacific lamprey are stressed by exceedingly high temperatures, they can develop furunculosis (*Aeromonas salmonicida*). It is uncertain if the other resident species of lamprey are susceptible to this disease. Increases in temperature associated with dam removal could increase the rate of furunculosis infection during May to early July; however, dam removal also increases access to cold-water refugia thereby minimizing this risk.

5.3.3.2 Upstream of Keno Dam

Although the Panel does not know to what extent Pacific lamprey would use the available habitat upstream of Keno Dam, the KBRA is expected to increase habitat productivity for the freshwater-resident lamprey species. Habitat requirements are largely unknown for these species, although the Panel can extrapolate from the Pacific lamprey. Some of these species (e.g., the Pit-Klamath brook lamprey), however, appear to be tolerant to a range of water conditions. Larval Pit-Klamath brook lamprey can be found in the mainstem Pit River in California where there is high turbidity (S. B. Reid, pers. comm.), and they seem to survive in streams that become intermittent during the summer (S. B. Reid, pers. comm.).

The expected increase in productivity is predominantly the result of the restoration efforts rather than dam removal; restoration efforts aimed at improving water quality and habitat for salmonids will generally benefit lamprey. The restoration efforts are expected to stabilize summer water levels, improve water quality, and provide habitat restoration. For example, Hamilton et al. (2010; Figure 2) predicted that lake levels of the Upper Klamath Lake between 1977 and 2009 would be more stable (and higher, where they diverged) with implementation of the KBRA than with the current management scenario. There would likely be incremental improvements to water flow conditions as well; flow into Upper Klamath Lake is predicted to be 1,345,000 acre-feet with the KBRA implementation versus 1,315,000 acre-feet without (Greimann PPT Presentation).

It is expected that KBRA implementation (e.g., revegetation) will decrease spring and summer temperatures upstream of Keno Reservoir (Zedonis PPT Presentation). Since lamprey embryonic development is negatively affected by spring and summer temperatures in excess of 22°C (Meeuwig et al. 2005), decreased temperatures are predicted to increase lamprey productivity in the upper Klamath River Basin. Likewise, dissolved oxygen levels are expected to improve as well. Under current conditions, Keno Reservoir is extremely anoxic in the summer months. Hamilton et al. (2010; Figure 3) indicate that dissolved oxygen levels drop precipitously in June-July and range from 0-4 mg/L throughout the summer and into the fall. This is expected to improve with implementation of the KBRA. Likewise, restoration efforts in the upper Klamath River Basin are expected to improve water quality for the freshwater-resident "Klamath Lake lamprey." This may be particularly important in the Sprague River, where the migratory "Klamath Lake lamprey" spawn. The Sprague River is currently listed as water-quality impaired, but it historically provided excellent habitat for anadromous fishes. The KBRA has budgeted for extensive aquatic habitat restoration in the Sprague River (Table 3).

Increased habitat quality is also expected to increase connectivity for the freshwater-resident species. If poor habitat quality is resulting in the isolation of several small populations, they may be more susceptible to local extirpations.

6.0 CLIMATE CHANGE

Warming of global climate during the past century or more is unequivocal. During 1995-2006, eleven of the twelve years ranked among the warmest years in the instrumental record of global surface temperature since 1850 (IPCC 2007 in ISAB 2007). Global average air and ocean temperatures have increased, leading to widespread melting of snow and ice. The Pacific Northwest has warmed about 1.0°C since 1900, or about 50 percent more than the global average warming over the same period (Mote 2003). The mean water temperature in the Klamath River has increased 0.5°C per decade in response to warming trends in the region and to anthropogenic uses of the watershed (Bartholow 2005 *in* Hamilton et al. 2010a). Snow water equivalent (April 1) in the Klamath River Basin has declined significantly since 1950, especially at elevations less than 6,000 feet (Mayer and Naman 2010a and 2010b *in* Hamilton et al. 2010a). A somewhat abrupt decline in annual flows into Upper Klamath Lake (Greimann PPT Presentation) occurred in 1977, corresponding with the 1976/1977 ocean regime shift (significant influence on many marine species) and the shift in the Pacific Decadal Oscillation (PDO).

The warming rate for air temperature in the Pacific Northwest over the next century is projected to be approximately 0.1-0.6°C per decade (ISAB 2007). Since temperature of spring and groundwater input to rivers typically approximates annual air temperature, spring and groundwater input to rivers and streams is expected to rise correspondingly. It does not appear that changes to groundwater temperature have been incorporated into projections. Precipitation is expected to increase approximately 2 percent, on average, by 2030-2060 (range -4 to +9 percent). Streams in California are expected to be warmer and drier during the summer and fall in response to reduced snow pack and reduced precipitation in summer (Hamilton et al. 2010a). Recent projections indicate the past trend of increasingly earlier peak river flows will continue and timing of peak flows in the western United States could shift to earlier by 30-40 days (Hamilton et al. 2010a). In the Klamath River Basin, these impacts will be more apparent in streams draining lava-rich and metamorphic terrain with relatively shallow aquifers (e.g., Salmon and Scott rivers in the Klamath Terrain) than those fed primarily by deep aquifers in the volcaniclastic rocks of the High Cascades (e.g., Williamson and Wood rivers). Greimann (PPT Presentation) modeled the hydrology of the Klamath River Basin under five climate change scenarios compared with no climate change and with the assumption that July through September flows are mandated by the NMFS Biological Opinion for coho salmon (*Oncorhynchus kisutch*). During October to June, flows downstream of Iron Gate Dam were projected to be equal to or higher than without climate change because of the expected increase in precipitation and intensified snowmelt. The timing of peak flows did not change apparently because the reservoirs, lakes, groundwater, and intentional management of flows buffer fluctuations in flows near Iron Gate Dam.

Future climate change will influence the productivity of the ocean, including the abundance of salmon and marine fishes upon which parasitic lamprey depend. Regional fish production is influenced by the California Current, which flows southward from approximately southern British Columbia and to southern Baja California, Mexico. The strength of the California Current and associated upwelling of deep, cold, and potentially nutrient-rich water are influenced by wind strength from the north and water column stratification. Greater upwelling generally leads to greater zooplankton production, and greater growth and survival of salmon in the region (Scheurell et al. 2005; Wells et al. 2008). Inter-annual and inter-decadal trends in climate in the Pacific Northwest, including oceanographic characteristics, are partially associated with broad-scale climate patterns such as the tropical Pacific El Niño Southern Oscillation (ENSO) and the extra-tropical PDO. The warm-phase of the PDO is often associated with reduced upwelling and reduced salmon production but this pattern can be influenced by other factors.

Global climate change in the Pacific Northwest, including the Klamath region, is predicted to result in changes in coastal ecosystems and salmon production that may be similar to potentially even more severe than those experienced during past periods of strong El Niño events and warm phases of the PDO (ISAB 2007). These conditions would lead to warmer sea surface temperatures, increased stratification of the water column and decreased productivity along the coast. However, a lack of certainty in future wind and weather patterns produces large uncertainties for future changes in the characteristics of fish habitat in the northeast Pacific Ocean (ISAB 2007). For example, greater stability of the water column may reduce the degree of upwelling. Alternatively, winds may become more intense, leading to upwelling that is often favorable for salmon production, but the timing for the upwelling season could change in response to timing shifts in upwelling wind patterns. Warmer ocean temperatures may cause a shifts in the size and species composition of zooplankton to smaller, low-lipid zooplankton instead of large, lipid-rich, cool-water species. These changes may cause forage fishes to decline but warm-water predators to increase (ISAB 2007).

6.1 Climate Change Impacts

Climate shifts will undoubtedly influence productivity and abundance of lamprey. The climate change scenarios that were chosen by the U. S. Bureau of Reclamation for modeling illustrated the potential for both higher and lower inflows into Upper Klamath Lake (Greimann PPT Presentation).

6.2 Downstream of Keno Dam

A key question is the extent to which climate change will differentially influence lamprey during the Conditions with Dams alternative versus the Conditions without Dams and with the KBRA alternative. As discussed herein, in response to climate change, the Panel expects the Conditions without Dams alternative to have a slight positive effect on lamprey habitat and lamprey inhabiting areas downstream of Iron Gate Dam, including effects on spawning and rearing conditions when compared to the Conditions with Dams alternative. In the reach between Iron Gate Dam and Keno Dam, the Panel expects that significant cold water refugia (e.g., Big Springs, Spencer Creek, Fall Creek, Jenny Creek, and Shovel Creek) would benefit adult Pacific lamprey which hold in the river throughout summer prior to spawning during the following spring. This could lead to an increase in survival of adult lamprey. The significance of the area upstream of Iron Gate Dam would increase to the extent that more lamprey utilize this reach of the Klamath River.

Climate change is expected to produce warmer air and water temperatures, which would exacerbate chemical water quality problems. Without climate change, the Conditions without Dams alternative is projected to provide slightly higher water temperatures from approximately February through mid-July and considerably cooler temperatures during the remaining months (Hamilton et al. 2010a; Figure 12). Climate change would exacerbate the higher spring temperatures associated with the Conditions without Dams alternative, possibly leading to increased embryonic mortality and greater susceptibility to disease during peak summer temperatures. Lethal water temperatures for eggs and embryos is near 22°C (Meeuwig et al. 2005) and these high temperatures may occur during late June to early August. However, spawning time is determined primarily by water temperatures rather than photoperiod (Larsen 1980; Binder et al. 2010), so that spawning time is expected to occur earlier (in April and May) when temperatures are higher (see Section 5.3.3.1). Therefore, the Panel expects that embryos, which hatch approximately 15 days after spawning, would be hatched by this high-temperature period and the larvae would be able to cope with the increased temperatures (see Section 5.3.3). Furthermore, nothing is known about the genetic capacity of lamprey to adapt to climate change over periods of years or decades; this may also moderate some of the negative effects of climate change.

Adult lamprey hold in the Klamath River for approximately one year before spawning. On average, adult lamprey would encounter slightly cooler water under the Conditions without Dams alternative because mainstem water temperature would be considerably cooler after late July (Hamilton et al. 2010a; Figure 12). Cooler water would enable a lower metabolic rate of the non-feeding adults, and potentially higher body condition prior to spawning during the following spring. Adult lamprey would have access to cool water refuges upstream of Iron Gate Dam if the dams were removed.

Low dissolved oxygen in areas downstream of Keno Dam could be further reduced by climate change and associated warmer water temperatures. At Iron Gate Dam, dissolved oxygen is expected to be approximately 1-3 mg/L higher from mid-April through December under the Conditions without Dams alternative (Hamilton et al. 2010a; Figure 19). The greatest benefit would occur during late July to mid-September when dissolved oxygen is often below 6 mg/L during the Conditions with Dams alternative. Therefore, during expected climate change scenarios, the Conditions without Dams alternative would provide higher dissolved oxygen for both adults and for larvae during mid-summer. However, the benefit of higher dissolved oxygen during the Conditions without Dams alternative is likely limited to the reach immediately downstream of Iron Gate Dam, in addition to the upstream reach made available by dam removal.

The Conditions without Dams alternative would enable access of lamprey (primarily Pacific but also Klamath lamprey that currently inhabit Spencer Creek) to thermal refugia provided by springs and cold water streams (e.g., Big Springs, Spencer Creek, Fall Creek, Jenny Creek, and Shovel Creek) that presently enter the reach between Keno Dam and Iron Gate Dam. These sources of relatively cold water produce significant flows, e.g., approximately 220 cfs at Big Springs (Turaski 2003) and approximately 30 cfs at Fall Creek (J. Hamilton, pers. comm.). Access to cold water refugia would be more beneficial under the projected warming climate scenario.

Warming water temperatures in response to climate change could exacerbate algal blooms, including toxic blooms, in the reservoirs. The Conditions without Dams alternative may reduce overall blooms to the extent that several reservoirs are removed.

Water quality conditions (including phosphorus and nitrogen loadings) in Keno Reservoir are expected to improve faster and reach higher quality under the Conditions without Dams alternative, although water quality is still expected to remain low (Zedonis PPT presentation). Under the Conditions with Dams alternative and projected climate change, water quality would likely decline more than during the Conditions without Dams alternative.

During climate change scenarios, the flows downstream of Iron Gate Dam are expected to be similar during July to September (operation minimum flows) or possibly higher during other months (Greimann PPT Presentation). Without climate change, natural summer flows downstream of Iron Gate Dam (and Keno Dam) would be expected to be somewhat lower during the Conditions without Dams alternative but agency-required minimum flows are expected to produce similar summer flows under both alternatives, including projected climate change scenarios (Greimann PPT Presentation). This finding is based on the assumption that the KBRA would enhance flows into the Upper Klamath Lake, thereby allowing minimum flows in the Klamath River to be achieved.

6.3 Upstream of Keno Dam

Climate change will influence lamprey species in Upper Klamath Lake and its tributaries. In this region, the Conditions without Dams alternative primarily involves habitat restoration activities provided by the KBRA. This alternative might provide a small additional benefit for lamprey under projected warming associated with climate scenarios.

Climate change is expected to lead to higher summer water temperatures in tributaries of Upper Klamath Lake, especially for streams and lakes not directly influenced by springs and groundwater inflow. Increased temperature in streams during summer may be slightly moderated under the Conditions without Dams alternative to the extent that planting of riparian vegetation reduces water temperature in the streams. Riparian vegetation may be more important during warmer climate conditions. Nevertheless, access to abundant cool spring water is likely a key habitat characteristic supporting lamprey in the upper Klamath River Basin, especially during the projected warming climate scenarios.

6.4 Ocean Impacts of Climate Change

Ocean conditions, including the number of host fishes available to parasitic lamprey, has undoubtedly influenced the number of lamprey returning to the Klamath River each year. Climate change will affect ocean conditions, including the abundance of salmon and other host species for lamprey (see Section 3.2). The Panel notes that the significant decline in Pacific lamprey counts at Bonneville Dam on the Columbia River were high immediately before the 1976/1977 ocean climate shift that affected the abundances of many marine fishes (Anderson and Piatt et al. 1999; Benson and Trites 2002), then significantly lower during the first available counts after the regime shift (Close et al. 1995). Some projections suggest salmon production may decline in response to climate change, but there is significant uncertainty in this projection. Also, it is not known to what extent other non-salmonid hosts may increase or decrease. Pacific lamprey appear to feed at depths within and below the deep scattering layer. Key prey include Pacific hake, walleye pollock, and possibly Chinook salmon (Beamish 1980; R. Beamish, CDF&O, pers. comm.). Pacific hake is a potentially key prey of lamprey from the Klamath River and hake abundance may be significantly influenced by commercial fishing in addition to changes in the ocean. The directional effect of climate change on adult returns of lamprey to the Klamath River is not known, but climate change will likely cause significant fluctuations in adult lamprey abundance to the extent the it alters habitat conditions in freshwater and the availability of hosts (prey) in the ocean.

Abundant, high quality freshwater habitat is especially important for maintaining viable lamprey populations during periods when ocean conditions are unfavorable. Furthermore, abundant and high quality habitat in freshwater is key for providing the potential for high returns of lamprey to the Klamath River watershed when ocean conditions become more favorable.

Ocean conditions have the potential to differentially influence production of Pacific lamprey under the two alternatives. For example, if production of Pacific lamprey increases substantially in response to ocean conditions, then colonization of habitats upstream of Upper Klamath Lake is more likely, assuming lamprey dispersal is greater when abundance and densities are higher. Thus, if lamprey can gain access to tributaries of the Upper Klamath Lake (Condition without Dams and with the KBRA), then colonization of the upper Klamath River Basin could be rapid under favorable ocean conditions for lamprey, whereas colonization would be slow or even nil if ocean conditions and lamprey abundances remain low.

7.0 CHANGE IN HARVEST

The focus of this discussion is on the harvest of Pacific lamprey. Tribes in the lower Klamath River Basin have and continue to harvest Pacific lamprey. Upper Klamath River Basin tribes harvested lamprey, called "gawi" in their language. Lampreys were harvested at Chilliquin Dam on the Sprague River until removal of dam occurred in 2008 (Jeff Mitchell, Klamath Tribes, 2010). Lampreys were also harvested at Link River, lower Williamson River, and at the mouth of Shovel Creek (Jeff Mitchell, Klamath Tribes, pers comm. 2010). These were likely resident lamprey species. In addition to harvest, however, lamprey are also of value in maintaining ecological function (e.g., in terms of nutrient cycling), are important in terms of biodiversity (particularly given the unparalleled number of freshwater-endemic species in the Klamath River Basin), and are of scientific importance (e.g., as one of the oldest living groups of vertebrates).

Since virtually nothing is known about historical harvest rates, productivity, or production of lamprey in Klamath River Basin, it is difficult to predict how much Pacific lamprey harvest would be anticipated under the two management scenarios. However, the Panel assumed that changes in harvest under Conditions without Dams and with the KBRA, relative to Conditions with Dams, will be proportional to the changes in lamprey production which in turn will be proportional to the changes in the extent and quality of lamprey habitat. In part because of their small size and limited distribution, resident lamprey are unlikely to be the focus of substantial harvest. Nevertheless, the abundance and spatial distribution of resident forms may be increased under Conditions without Dams and with the KBRA because dam removal reconnects Klamath lamprey to the upper watershed and KBRA has the potential to improve habitat quantity and quality.

Because lamprey do not selectively return to their natal streams, an increase in larval and outmigrant production in a system will not necessarily result in a proportional increase in returning adults available for harvest in that system. As with the case of any anadromous fish, ocean conditions will greatly affect survivorship during the feeding phase, which will be independent of changes to the Klamath River Basin environment. However, because evidence suggests that upstream migrants are attracted to pheromones produced by freshwater-resident larval populations, the Panel assumed that an increase in larval habitat and larval biomass in the Klamath River Basin will result in an increase in the number of spawning adults attracted to the watershed. Furthermore, potential increase in salmonids through implementation of the Conditions without Dams and with KBRA Alternative might lead to greater yield of Pacific lamprey returning to the Klamath River.

Predicted change in harvest as a result of Conditions without Dams and with the KBRA implementation is considered both for downstream of Keno Dam (subdivided into below Iron Gate Dam and between Iron Gate Dam and Keno Dam) and upstream of Keno Dam.

7.1 Downstream of Keno Dam

Increased extent of habitat (capacity) for Pacific lamprey as the result of implementation of the Conditions without Dams and with the KBRA alternative was estimated approximately at 14 percent (Section 5.2.1). However, larval habitat quality in the reach between Iron Gate Dam and Keno Dam will be less desirable than in downstream reaches currently available to anadromous lamprey, making the increase in lamprey production as the result of dam removal and KBRA in this reach alone less than 14 percent. When also considering that Conditions without Dams and with the KBRA might lead to an increase in productivity below Iron Gate Dam also (due to a potential increase in spawning habitat upstream of Iron Gate Dam and reestablishment of natural sediment dynamics downstream of Iron Gate Dam), the Panel then roughly estimated that there might be a total increase of production of outmigrant lamprey (and hence harvest potential) in the range of 1 to 10 percent relative to Conditions with Dams. Within the range of 1 to 10 percent, the production of lamprey in this extended range downstream of Keno Dam will depend on the survival of adults in the ocean and the success of the KBRA.

In the first decade following the Secretarial Determination to remove dams, the Panel anticipates the harvest rates would not change because the dams remain in place. Implementation of the KBRA would improve habitat quality primarily for salmonids that would also benefit Pacific lamprey; however, the long-life cycle of Pacific lamprey would mean that it could be a decade before KBRA alone could result in an increase in harvestable lamprey. In the second decade following the Secretarial Determination, there could be a short-term decline in outmigrant lamprey numbers resulting from sediment transport, smothering, and scour immediately following dam removal (depending on timing for dam removal; Section 5.3.2). Year class mortality would likely be worse if sediment release occurs in spring because of negative effects on eggs. The Panel does not expect, however, that the decline in lamprey outmigrants, should it occur, would reduce the total production of Klamath River Basin outmigrants to abundance levels less than occurred under baseline conditions (i.e., abundance of outmigrants at the time of the Secretarial Determination in 2012). In the third through fifth decade, there could be a gradual increase resulting from recolonization of the reach between Iron Gate Dam and Keno Dam and improved habitat quality. The rate of this increase would depend on ocean conditions, but might reach 10 percent by the end of 50 year period relative to Conditions with Dams (Figure 4, Arrow B).

7.2 Upstream of Keno Dam

There is uncertainty regarding access to and the extent of suitable habitat for Pacific lamprey upstream of Keno Dam. This area was historically accessible to anadromous fishes, but the historical occurrence by Pacific lamprey is unresolved and investigations have only confirmed Pacific lamprey up to at least Spencer Creek. Nevertheless, improvements to fish passage scheduled for Keno Dam may open the upper Klamath River Basin to Pacific lamprey irrespective of their historical occurrence. With the Conditions without Dams alternative, future habitat suitable for anadromous salmonids is projected to be extensive (Hetrick et al. 2009). However, the Panel can only say that dam removal and the success of the KBRA in the upper Klamath River Basin could potentially lead to some increases in the capacity and productivity of Pacific lamprey, but the Panel does not know to what extent or over what time frame such increases could translate into increased harvest potential. Colonization of this area could be greater in both rate and magnitude under favorable ocean conditions because more lamprey would be available to access this area. Should this scenario occur, more lamprey would be potentially available for harvest (Figure 4, Arrow A).

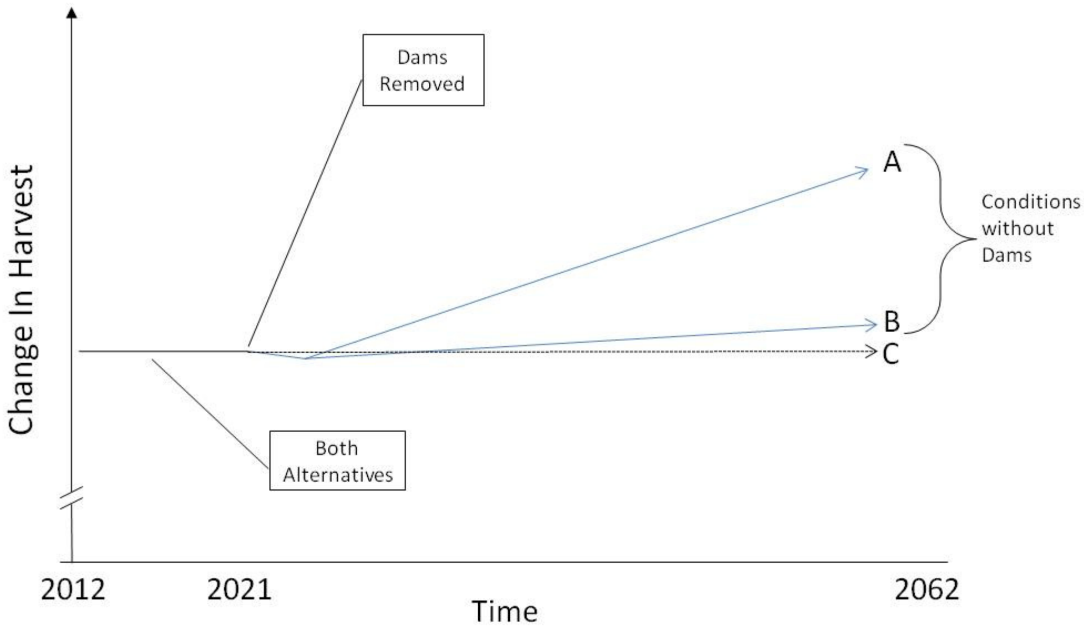

Figure 4. Schematic of General Trends in Lamprey Available for Harvest in the Klamath River Basin for Conditions Without Dams and with KBRA (A and B) as Compared to Conditions with Dams (C) [A: With colonization upstream of Keno Dam coupled with a high success rate of the KBRA measures in increasing lamprey productivity in the watershed and with favorable ocean conditions. B: No successful colonization upstream of Keno Dam coupled with a low success rate of the KBRA measures in increasing lamprey productivity in the watershed and with poor ocean conditions. C: Conditions with Dams.]

8.0 INFORMATION GAPS

As discussed above, very little information exists regarding the status, distribution, and general biology of lamprey in the Klamath River Basin. Larson and Belchik (1998) and Robinson Lewis (2009) offer some information on the biology of Pacific lamprey specific to the Klamath River Basin, but most of the Panel's assessment has been based on extrapolations about this species in other systems. Likewise, very little is known about the status and biology of the freshwater-resident lamprey species, four of which are found only in the Klamath River Basin.

Following is a brief list of some of the areas where more information is critical before quantitative predictions of the effect of dam removal on Klamath River Basin lamprey can be made:

1) Current distribution of Pacific lamprey ammocoetes within the lower Klamath River Basin and its relationship to habitat characteristics.
2) Spawning and overwintering locations for Pacific lamprey in the lower Klamath River and the timing of these events relative to water temperature,
3) Population estimates for Pacific lamprey in the lower Klamath River Basin (e.g., total number of upstream migrants returning to the basin, number of downstream migrants leaving the basin, density estimates and age composition for larval populations).
4) Estimates of current harvest rates for Pacific lamprey in the Klamath River Basin (total numbers and as a percentage of the upstream migrants returning to the basin).
5) Taxonomy, distribution, status, and biology of the freshwater-resident lamprey in the Klamath River Basin.
6) Possible interaction between anadromous Pacific lamprey and the freshwater-resident lamprey in the Klamath River Basin, particularly those in the upper basin (e.g., competition for spawning or larval rearing habitat, interspecific hybridization).

This information will also be critical before quantitative monitoring of the changes realized by dam removal can be made.

9.0 REFERENCES

Anderson, P. J., and J. F. Piatt. 1999. Community reorganization in the Gulf of Alaska following ocean climate regime shift. Marine Ecology Progress Series. 189:117-123.

Applegate V. C. 1950. Natural history of the sea lamprey, *Petromyzon marinus*, in Michigan. U.S. Fish and Wildlife Service Special Scientific Report: Fisheries 55:1-237.

Appy, R. G. and R. C. Anderson. 1981. The parasites of lamprey. pp. 1-42 *in*: H.W. Hardisty and I. C. Potter (eds.), The Biology of Lamprey, Volume 3. Academic Press, London.

Beamish, F. W. H. 1980. Biology of the North American anadromous sea lamprey, *Petromyzon marinus*. Canadian Journal of Fisheries and Aquatic Sciences 37:1924-1943.

Beamish, F. W. H. and J. Jebbink. 1994. Abundance of lamprey larvae and physical habitat. Environmental Biology of Fishes 39: 209-214.

Beamish, F. W. H. and S. Lowartz. 1996. Larval habitat of American brook lamprey. Canadian Journal of Fisheries and Aquatic Science 53: 693-700.

Beamish, R. J. 1980. Adult biology of the river lamprey (*Lampetra ayresi*) and the Pacific lamprey (*Lampetra tridentata*) from the Pacific coast of Canada. Canadian Journal of Fisheries and Aquatic Sciences 37:1906-1923.

Beamish, R. J. 1982. *Lampetra macrostoma*, a new species of freshwater parasitic lamprey from the west coast of Canada. Canadian Journal of Fisheries and Aquatic Sciences 39:736-747.

Beamish, R. J. and C. D. Levings. 1991. Abundance and freshwater migrations of the anadromous parasitic lamprey, *Lampetra tridentata*, in a tributary of the Fraser River, British Columbia. Canadian Journal of Fisheries and Aquatic Science 48: 1250-1263.

Beamish, R. J. and T. G. Northcote. 1989. Extinction of a population of anadromous parasitic lamprey, *Lampetra tridentata*, upstream of an impassable dam. Canadian Journal of Fisheries and Aquatic Science 46: 420-425.

Beamish, R.J. 2001. Updated status of the Vancouver Island Lake Lamprey, *Lampetra macrostoma*, in Canada. Canadian Field-Naturalist 115: 127-130.

Bergstedt, R. A. and J. G. Seelye. 1995. Evidence for lack of homing by sea lamprey. Transactions of the American Fisheries Society 124: 235-239.

Binder, T. R., and D. G. McDonald. 2008. The role of temperature in controlling diel activity in upstream migrant sea lamprey (*Petromyzon marinus*). Canadian Journal of Fisheries and Aquatic Sciences 65:1113-1121.

Binder, T. R., R. L. McLaughlin, and D. G. McDonald. 2010. Relative importance of water temperature, water level, and lunar cycle to migratory activity in spawning-phase sea lamprey in Lake Ontario. Transactions of the American Fisheries Society 139:700-712.

Bond, C. E. and T. T. Kan. 1973. *Lampetra (Entosphenus) minima* n. sp., a dwarfed parasitic lamprey from Oregon. Copeia 1973: 568-574.

Brown L.R., S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Brumo, A.F. 2006. Spawning, Larval Recruitment, and Early Life Survival of Pacific Lampreys in the South Fork Coquille River, Oregon, Unpublished MSc thesis, Oregon State University.

Brumo, A.F. D.F. Markle. 2006 Spawning, larval drift, early mortality, and ecological role of Pacific lampreys in the South Fork Coquille River. Final Report for Oregon Lamprey Species Project. Oregon Department of Fish and Wildlife and U.S. Fish and Wildlife Service.

Bryan, M. B., D. Zalinksi, K. B. Filcek, S. Libants, W. Li, and K. T. Scribner. 2005. Patterns of invasion and colonization of the sea lamprey (*Petromyzon marinus*) in North America as revealed by microsatellite genotypes. Molecular Ecology 14:3757-3773.

Burgner, R. L. 1991. Life history of sockeye salmon (Oncorhynchus nerka). Pages 3-117 in C. Groot and L. Margolis, eds. Pacific salmon life histories. UBC Press, Vancouver, British Columbia. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Chase, S.D. 2001. Contributions to the life history of adult Pacific lamprey (*Lampetra tridentate*) in the Santa Clara River of Southern California. Southern California Academy of Sciences Bulletin 100:74-85.

Clarke, W. C., and R. J. Beamish. 1988. Response of recently metamorphosed anadromous parasitic lamprey (*Lampetra tridentata*) to confinement in fresh water. Canadian Journal of Fisheries and Aquatic Sciences 45:42-47.

Clemens, B. J., S. J. van de Wetering, J. Kaufman, R. A. Holt, and C. B. Schreck. 2009. Do summer temperatures trigger spring maturation in adult Pacific lamprey, *Entosphenus tridentatus*? Ecology of Freshwater Fish 18:418-426.

Close, D. A., K. P. Currens, A. Jackson, A. J. Wildbill, J. Hansen, P. Bronson, and K. Aronsuu. 2009. Lessons from the reintroduction of a noncharismatic, migratory fish: Pacific lamprey in the Upper Umatilla River, Oregon. Pages 233-253 *in* L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Coble, D. W., R, E. Bruesewitz, T. W. Fratt, and J. W. Scheirer. 1990. Lake trout, sea lampreys, and overfishing in the upper Great Lakes: a review and reanalysis. Transactions of the American Fisheries Society 119:985-995. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Cochran, P.A. 2009. Predation on lampreys. Pages 139-151 *in* L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Cochran, P.A. and A.P. Gripentrog 1992. Aggregation and spawning by lampreys (genus *Ichthyomyzon*) beneath cover. Environmental Biology of Fishes 33: 381-387.

Derosier, A. L., M. L. Jones, and K. T. Scribner. 2007. Dispersal of sea lamprey larvae during early life: relevance for recruitment dynamics. Environmental Biology of Fishes 78(3): 271-284.

Dittman, A.H., and T.P. Quinn. 1996. Homing in Pacific salmon: mechanisms and ecological basis. Journal of Experimental Biology 199: 83-91.

Docker, M. F., J. H. Youson, R. J. Beamish, and R. H. Devlin. 1999. Phylogeny of the lamprey genus *Lampetra* inferred from mitochondrial cytochrome *b* and ND3 gene sequences. Canadian Journal of Fisheries and Aquatic Science 56:2340-2349.

Docker, M.F. 2009. A review of the evolution of nonparasitism in lamprey and an update of the paired species concept. Pages 71-114 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, P.B. Moyle. Editors. biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72.

Farlinger, S. P. and R. J. Beamish. 1984. Recent colonization of a major salmon-producing lake in British Columbia by Pacific lamprey (*Lampetra tridentata*). Canadian Journal of Fisheries and Aquatic Science 41: 278-285.

Fine, J. M., L. A. Vrieze, and P. W. Sorensen. 2004. Evidence that Petromyzontid lamprey employ a common migratory pheromone that is partially comprised of bile acids. Journal of Chemical Ecology 30: 2091-2110.

Goodman, D. H., S. B. Reid, M. F. Docker, G. R. Haas, and A. P. Kinziger. 2008. Mitochondrial DNA evidence for high levels of gene flow among populations of a widely distributed anadromous lamprey *Entosphenus tridentatus* (Petromyzontidae). Journal of Fish Biology 72(2): 400-417.

Hamilton, J., M. Hampton, R. Quiñones, D. Rondorf, J. Simondet, and S. Stresser. 2010a. Synthesis of the Effects of two Management Scenarios for the Secretarial Determination on Removal of the Lower Four Dams on the Klamath River, Draft dated July 16, 2010.

Hamilton, J., R. Quinones, D. Rondorf, K. Schultz, J. Simondet, and S. Stresser. 2010b. Biological synthesis for the secretarial determination on potential removal of the lower four dams on the Klamath River. Draft report. Prepared by the Biological

Subgroup for the Secretarial Determination Regarding Potential Removal of the Lower Four Dams on the Klamath River. Dated November 23, 2010.

Hatch, D. R., and J. M. Whiteaker. 2009. A field study to investigate repeat homing in Pacific lamprey. Pages 191-202 *in* L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Healy, M. C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 *in* C. Groot and L. Margolis, eds. Pacific salmon life histories. UBC Press, Vancouver, British Columbia. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Hetrick et al. 2009. Compilation of information to inform USFWS Principles on the Potential Effects of the Proposed Klamath Basin Restoration Agreement (Draft 11) on Fish and Fish Habitat Conditions in the Klamath Basin, with Emphasis on Fall Chinook Salmon

Hill, B. J. and I. C. Potter. 1970. Oxygen consumption in ammocoetes of lamprey *Ichthyomyzon hubbsi* Raney. Journal of Experimental Biology 53: 47-57.

Huntington, C.W., E.W. Claire, F.A. Espoinosa, Jr, and R. House. 2006. Reintroduction of anadromous fish to the uper Klamath Basin: an evaluation and conceptual plan. Prepared for Klamath Tribes and Yurok Tribes.

ISAB (Independent Science Advisory Board). 2007. Climate Change Impacts on Columbia River Basin Fish and Wildlife. Northwest Power and Conservation Council, Columbia River Basin Indian Tribes, and National Marine Fisheries Service. Portland, OR.

Kan, T. T. 1975. Systematics, Variation, Distribution and Biology of Lamprey of the genus *Lampetra* in Oregon. Ph.D. Dissertation, Oregon State University, Corvallis, Oregon.

Larsen, L. O. 1980. Physiology of adult lamprey, with special regard to natural starvation, reproduction, and death after spawning. Canadian Journal of Fisheries and Aquatic Science 37: 1762-1779.

Larson, Z.S. and M.R. Belchick. 1998. A preliminary status review of eulachon and Pacific lamprey in the Klamath River Basin. Yurok Tribal Fisheries Program.

Lewis, S.V. and I.C. Potter. 1977. Oxygen consumption during the metamorphosis of the parasitic lamprey *Lampetra fluviatilis* (L.) and its non-parasitic derivative, *Lampetra planeri* (Block). Journal of Experimental Biology. 69:187-198.

Lin, B., Z. Zhang, Y. Wang, K. P. Currens, A. Spidle, Y. Yamazaki, and D. A. Close. 2008. Amplified fragment length polymorphism assessment of genetic diversity in Pacific lamprey. North American Journal of Fisheries Management 28:1182-1193.

Lorion, C. M., D. F. Markle, S. B. Reid, and M. F. Docker. 2000. Redescription of the presumed-extinct Miller Lake lamprey, *Lampetra minima*. Copeia 2000:1019-1028.

Manion, P. J., and L. H. Hanson. 1980. Spawning behavior and fecundity of lamprey from the upper three Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences 37:1635-1640.

McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42,156 p.

Meeuwig, M. H., J. M. Bayer, and J. G. Seelye. 2005. Effects of temperature on survival and development of early life stage Pacific and western brook lamprey. Transactions of the American Fisheries Society. 134:19-27.

Merrell, T. R. 1959. Gull food habits on the Columbia River. Fish Commission of Oregon Research Briefs 7(1):82. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Merritt, R. W., K. W. Cummins, and T. M. Burton. 1984. The role of aquatic insects in the processing and cycling of nutrients. Pages 134-163 *in* V H. Resh and D. M. Rosenberg, eds. The ecology of aquatic insects. Praeger Publishers, New York. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Moore, J. W. and J. Mallatt. 1980. Feeding of larval lamprey. Canadian Journal of Fisheries and Aquatic Science 37:1658, 1664.

Mote, P. W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. Northwest Science 77: 271-282.

Moyle, P. B., L. R. Brown, S. D. Chase, and R. M. Quiñones. 2009. Status and conservation of lamprey in California. Pages 279-292 *in* L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Moyle, P.B., Yoshiyama, R.M., Williams, J.E., Wikramanayake, E.D., 1995. Fish Species of Special Concern in California. Second Edition. Prepared for California Department of Fish and Game, Rancho Cordova. Contract No. 2128IF.

Mundahl, N. D., C. Erickson, M. R. Johnston, G. A. Sayeed, and S. Taubel. 2005. Diet, feeding rate, and assimilation efficiency of American brook lamprey larvae. Environmental Biology of Fishes 72: 67-72.

Murdoch, S. P., M. F. Docker, and F. W. H. Beamish. 1992. Effect of density and individual variation on growth of sea lamprey (*Petromyzon marinus*) larvae in the laboratory. Canadian Journal of Zoology 70:184-188.

PacifiCorp 2008. Interim conservation plan – Klamath Hydroelectric Project, Project No. 2082. Submitted to the USFWS and NMFS on November 10 and FERC on November 25, 2008.

Page, L. M. and B. M. Burr. 1991. A field guide to freshwater fishes. Houghton Mifflin Company, Boston, New York.

Petersen Lewis, R. S. 2009. Yurok and Karuk traditional ecological knowledge: insights into Pacific Lamprey populations of the Lower Klamath Basin. Pages 1-39 *in* L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Pfeiffer, W., and T. E Pletcher. 1964. Club cells and granular cells in the skin of lampreys. Journal of the Fisheries Research Board of Canada 21:1083-1088. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Pletcher, T. F. 1963. The life history and distribution of lampreys in the Salmon and certain other rivers in British Columbia, Canada. M. S. thesis. University of British Columbia, Vancouver. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Potter, I. C. and F. W. H. Beamish. 1975. Lethal temperatures in ammocoetes of four species of lampreys. Acta Zoologica 56: 85-91.

Read, L. J. 1968. A study of ammonia and urea production and excretion in the fresh-water adapted form of the Pacific lamprey, *Entosphenus tridentatus*. Comparative Biochemistry and Physiology 26:455-466. As cited in Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

Reid, S.B. 2006. Lamprey Survey: Tributaries of the Klamath River from Iron Gate Dam to the California/Oregon border 5 August 2006. Western Fishes – Lamprey Program. Ashland, Oregon

Reid, S. B. 2010. Distribution of lampreys in the Klamath Basin. Western Fishes – Lamprey Program. Ashland, Oregon.

Renaud, C.B., M.F. Docker, and N.E. Mandrak. 2009. Taxonomy, distribution, and conservation of lampreys in Canada. Pages 293–309 in L.R. Brown, S.D. Chase, P.B. Moyle, R.J. Beamish, and M.G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland

Richards, J. E. and F. W. H. Beamish. 1981. Initiation of feeding and salinity tolerance in the Pacific lamprey *Lampetra tridentata*. Marine Biology 63(1): 73-77.

Richards, J.E. 1980. Freshwater life history of the anadromous Pacific lamprey Lampetra tridentata. M.Sc. thesis, University of Guelph, Guelph, Ontario.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada, 4 ed. American Fisheries Society, Bethesda.

Robinson, T. C., and J. M. Bayer. 2005. Upstream migration of Pacific lamprey in the John Day River, Oregon: behavior, timing, and habitat use. Northwest Science 79:106-119.

Robinson, T.G., P.W. Sorenson, J.M. Bayer, and J.G. Seelye. 2009. Olfactory sensitivity of Pacific lamprey to lamprey bile acids. Transactions of the American Fisheries Society 138:144-152.

Ruiz-Campos G. and S. Gonzalez-Guzman. 1996. First freshwater record of Pacific lamprey, *Lampetra tridentata*, from Baja California, Mexico. California Fish and Game 82: 144-146.

Scheuerell, M. D., and J. G. Williams. 2005. Forecasting climate induced changes in the survival of Snake River spring/summer Chinook salmon (Oncorhynchus tshawytscha). Fisheries Oceanography 14(6):448–457.

Scott, W. B. and E. J. Crossman. 1973. Freshwater Fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa.

Shannon & Wilson, Inc. 2006. Sediment sampling, geotechnical testing, and data review report: segment of Klamath River, Oregon and California. Report 21-1-12195-001 to California State Coastal Conservancy,18 pp plus appendices.

Sorensen, P. W. and T. R. Hoye. 2007. A critical review of the discovery and application of a migratory pheromone in an invasive fish, the sea lamprey *Petromyzon marinus* L. Journal of Fish Biology 71:100-114.

Sorensen, P. W., J. M. Fine, V. Dvornikovs, C. S. Jeffrey, F. Shao, J. Wang, L. A. Vrieze, K. R. Anderson, and T. R. Hoye. 2005. Mixture of new sulfated steroids function as a migratory pheromone in the sea lamprey. Nature Chemical Biology 1: 324-328.

Spice, Erin. 2010. Population structure of the Pacific lamprey, *Entosphenus tridentatus*, along the west coast of North America: evidence against natal homing. Honours Thesis, University of Manitoba, Winnipeg, Manitoba [on CD as Spice 2009]

Stillwater Sciences. 2008. Klamath River dam removal study: sediment transport DREAM-1 simulation. Technical Report. Prepared by Stillwater Sciences, Berkeley, California for State Coastal Conservancy, Oakland, California.

Stillwater Sciences. 2009. Effects of sediment release following dam removal on the aquatic biota of the Klamath River. Final Technical Report. Prepared by Stillwater Sciences, Arcata, California for State Coastal Conservancy, Oakland, California. January. 185 pp.

Stillwater Sciences. 2010. Anticipated sediment release from Klamath River dam removal within the context of basin sediment delivery. Prepared by Stillwater Sciences, Arcata, California for California Coastal Conservancy, Oakland, California

Stone, J. 2006. Observations on nest characteristics, spawning habitat, and spawning behavior of Pacific and western brook lamprey in a Washington stream. Northwestern Naturalist 87: 225-232.

Streif, B. 2009. Considering Pacific lamprey when implementing instream activities. Pages 255-268 *in* L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lamprey in North America. American Fisheries Society Symposium 72, Bethesda, Maryland.

Turaski, M. 2003. 2002 and 2003 Upper Klamath River Water Temperature Monitoring. Bureau of Land Management, Lakeview District, Klamath Falls Office.

van de Wetering S.J. 1998. Aspects of life history characteristics and physiological processes in smolting Pacific lamprey (Lampetra tridentata) in a central Oregon coast stream. MS Thesis, Oregon State University, Corvallis, OR. 59 pp.

Vladykov, V. D. 1951. Fecundity of Quebec lamprey. Canadian Fish Culturist 10: 1-14.

Vladykov, V. D. and E. Kott. 1979. A new parasitic species of the holarctic lamprey genus *Entosphenus* Gill, 1862 (*Petromyzonidae*) from Klamath River, in California and Oregon. Canadian Journal of Zoology. 57: 808-823.

Vrieze, L. A., R. Bjerselius, and P. W. Sorensen. 2010. Importance of the olfactory sense to migratory sea lamprey *Petromyzon marinus* seeking riverine spawning habitat. Journal of Fish Biology 76(4): 949-964.

Wagner, C. M., M. B. Twohey, and J. M. Fine. 2009. Conspecific cueing in the sea lamprey: do reproductive migrations consistently follow the most intense larval odour? Animal Behavior 78(3): 593-599.

Waldman, J., C. Grunwald, and I. Wirgin. 2008. Sea lamprey *Petromyzon marinus*: an exception to the rule of homing in anadromous fishes. Biology Letters 4(6): 659-662.

Wells, B.K., C.B. Grimes, J.G. Sneva, S. McPherson, and J.B. Waldvogel. 2008. Relationships between oceanic conditions and growth of Chinook salmon (Oncorhynchus tshawytscha) from Alaska, Washington, and California, USA. Fisheries Oceanography 17:101-125

Wolf, B.O., and S.L. Jones. 1989. Great blue heron deaths caused by predation on Pacific lamprey. The Condor 91:482-484. As cited in: Close, D. A., M. S. Fitzpatrick, and H. W. Li. 2002. The ecological and cultural importance of a species at risk of extinction, Pacific Lamprey. Fisheries 27:19-25.

APPENDIX A
Panelists' Curricula Vitae

CURRICULUM VITAE
OF
DAVID ALAN CLOSE

EDUCATION AND TRAINING

Ph.D. Fisheries Science, Michigan State University, 2007.

M.Sc. Fisheries Science, Oregon State University, 2001.

B.Sc. Fishery Resources, University of Idaho, 1994.

A.A. Liberal Arts, Blue Mountain Community College, 1991.

TITLE OF DISSERTATION AND NAME OF SUPERVISOR

"Characterization of an ancestral glucocorticoid hormone and its cognate receptor in the sea lamprey."
Supervisor: Dr. Weiming Li

PROFESSIONAL EXPERIENCE

Assistant Professor Distinguished Science Professor of Aboriginal Fisheries, Aboriginal Fisheries Research Unit, Fisheries Centre, University of British Columbia, March 2008.

Fisheries Research Scientist, Pacific Lamprey Research and Restoration Project, Freshwater Mussel Project, Confederated Tribes of the Umatilla Indian Reservation, Department of Natural Resources, Tribal Fisheries Program, September 2003 to 2008.

Graduate Research Assistant, Michigan State University, Department of Fish and Wildlife, September 2003 to 2007.

Fisheries Biologist III, Confederated Tribes of the Umatilla Indian Reservation, Department of Natural Resources, Tribal Fisheries Program, 1998 to September 2003.

Graduate Research Assistant, Oregon State University, Department of Fisheries and Wildlife, Oregon Cooperative Fishery Research Unit, September 1994 to May 1998.

Fisheries Biologist, US Geological Survey/Biological Resources Division, Columbia River Research Laboratory, June-September 1994.

LEADERSHIP EXPERIENCE

Aboriginal Fisheries Research Unit Leader, Fisheries Centre, University of British Columbia.
2008 Aboriginal Fisheries Research Unit.

Project Leader, Confederated Tribes of the Umatilla Indian Reservation.
1998-2003 Pacific Lamprey Research and Restoration Project.
2002 Freshwater Mussel Project.

Team Leader, Columbia River Basin Pacific Lamprey Technical Workgroup.
1999-2002 Workgroup included tribal, state, and federal fisheries agencies.

Leader, led efforts to establish projects for the Confederated Tribes of the Umatilla Indian Reservation's interest in restoring subsistence foods such as Pacific lamprey and freshwater mussels in the Columbia River Basin.

AWARDS AND HONORS

National Institute of Health (NIH), 2007 Training Fellowship, Neuroscience Program, Michigan State University.

Protectors of the Earth, 2005 Certificate of Appreciation for "valuable contribution to the 5th Annual Protectors of the Earth Camp at Sugar Island, Sault Ste. Marie Tribe of Chippewa Indians."

Michigan State University, 2005 Undergraduate Researchers in Plant Sciences Mentor Award for "providing outstanding service as a mentor."

Protectors of the Earth, 2004 Certificate of Appreciation for "valuable contribution to the 4th Annual Protectors of the Earth Camp at Sugar Island, Sault Ste. Marie tribe of Chippewa Indians."

Native American Fish and Wildlife Society, 2004 Chief Sealth Award (National Award) for "outstanding contributions toward the preservation, protection, and prudent conservation of this nation's vital fish and wildlife resources."

Michigan State University, 2003-2006 Diversity and Pluralism Fellowship, College of Agriculture and Natural Resources.

American Indian Science and Engineering Society, Second place for best scientific oral presentation at 1997 National Conference, Houston, Texas.

University of Idaho, 1994 Student Support Services Personal and Outstanding Academic Achievement Honor.

GRANTS RECEIVED (Total $5,416,000)

Principal Investigator, Bonneville Power Administration, Pacific Lamprey Research and Restoration Project.

2007	$395,000 for one year.
2006	$501,000 for one year.
2005	$501,582 for one year.
2002-2004	$1,454,381 for three years.
1999-2001	$1,154,547 for three years.
1995	$17,490 for one year.

Co-Principal Investigator, Bonneville Power Administration, Characterize Genetic Differences and Distribution of Freshwater Mussels.

2007	$233,000 for one year.
2006	$237,000 for one year.
2005	$237,000 for one year.
2002-2004	$685,000 for three years.

PEER-REVIEWED PUBLICATIONS

Close, D.A., S-S. Yun, A. Wildbill, and W. Li. *in prep*. "Migratory and sex pheromones in Pacific lamprey." For submission to *Steroids*.

Close, D.A., S-S. Yun and W. Li. *in prep*. "Characterization of an ancestral glucocorticoid hormone and its cognate receptor." For submission to *Proceedings of the National Academy of Sciences*.

Close, D.A., A.D. Jackson, K.P. Currens, A.J. Wildbill, J.T. Hanson, J.P. Bronson, and K. Aronsuu. *in review*. "Reintroduction of Pacific lamprey in the upper Umatilla River." *in* L.R. Brown, editor. Biology, management and conservation of lampreys in North America. American Fisheries Society, Bethesda, Maryland.

Lin B., Y. Wang, Z. Zhang, K. Currens, A. Spidle, Y. Yamazaki, and **D.A. Close**. *in press*. "AFLP Assessment of Genetic Diversity of Pacific Lamprey." *North American Journal of Fisheries Management*.

Brim Box, J., J. Howard, D. Wolf, C. O'Brien, D. Nez and **D.A. Close**. (2006). "Freshwater mussels (Bivalvia: Unionoida) of the Umatilla and Middle Fork John Day rivers in eastern Oregon." *Northwest Science* 80(2):95-107.

Bryan, M.B., B.A. Young, **D.A. Close**, J. Semeyn, T.C. Robinson, J. Bayer, and W. Li. (2006). "Comparison of synthesis of 15α-hydroxylated steroids in males of four

North American lamprey species." *General and Comparative Endocrinology* 149: 149-156.

Close, D.A., A.D. Jackson, B.P. Conner, and H.W. Li. (2004). "Traditional Ecological Knowledge of Pacific lamprey (*Entosphenus tridentatus*) in Northeastern Oregon and Southeastern Washington from Indigenous Peoples of the Confederated Tribes of the Umatilla Indian Reservation." *Journal of Northwest Anthropology* 38(2):141-162.

Torgersen, C.E., and **D.A. Close**. (2004). "Influence of Habitat Heterogeneity on the Distribution of Larval Pacific Lamprey (*Lampetra tridentata*) at two spatial scales." *Freshwater Biology* 49: 614-630.

Close, D.A., M.S. Fitzpatrick, C.M. Lorion, H.W. Li, C.B. Schreck. (2003) "Effects of Intraperitoneally Implanted Radio Transmitters on the Swimming Performance and Physiology of Pacific Lamprey." *North American Journal of Fisheries Management* 23:1184-1192.

Moser, M.L., and **D.A. Close**. (2003). "Assessing Pacific Lamprey Status in the Columbia River Basin." *Northwest Science* 77(2):116-125.

Yun, S.S., A.P. Scott, J.M. Bayer, J.G. Seelye, **D.A. Close**, and W. Li. (2003). "HPLC and ELISA analyses of larval bile acids from Pacific and western brook lampreys." *Steroids* 68: 515-523.

Close, D.A., M.S. Fitzpatrick, and H.W. Li. (2002) "The Ecological and Cultural Importance of a Species at Risk of Extinction, Pacific Lamprey." *Fisheries* 27(7):19-25.

PROFESSIONAL CONFERENCE PRESENTATIONS

"First Nations, First Foods: In the classroom," presented at the 2007 National Conference of American Indian Science and Engineering Society in Phoenix, Arizona.

"Contaminants in lamprey from the Columbia River Basin: What is the risk to Native American Health?" presented at the 2007 Annual Meeting of the American Fisheries Society in San Francisco, California.

"Reintroduction of Pacific lamprey in the upper Umatilla River in Northeast Oregon," presented at the 2007 Annual Meeting of the American Fisheries Society in San Francisco, California.

"First Nations, First Foods: Implications for Sovereignty," presented at the 2007 Earth Day Conference at the Center for the Study of Indigenous Border Issues, Michigan State University, East Lansing, Michigan.

“The cultural and ecological importance of lamprey to tribal peoples,” presented at the 2006 Annual Great Lakes Regional Conference of the Native American Fish & Wildlife Society in Manistee, Michigan.

“Native Freshwater Mussels: A reserved treaty resource,” presented at the 2006 Annual Great Lakes Regional Conference of the Native American Fish & Wildlife Society in Manistee, Michigan.

“Reintroduction of Pacific lamprey in the Umatilla River, Oregon: A case study,” presented at the 2004 Lamprey Technical Workshop in Vancouver, Washington.

“Reintroduction of Pacific lamprey in the Umatilla River, Oregon: A case study,” presented at the 2003 Annual Conference of the Oregon Chapter American Fisheries Society in Eugene, Oregon.

“Ecological and Cultural Importance of Pacific Lampreys,” presented at the 2001 Annual Conference of the Oregon Chapter American Fisheries Society in Portland, Oregon.

“Effects of Acute Stress on the Physiology of Pacific Lampreys,” presented at the 2001 Annual Conference of the Oregon Chapter American Fisheries Society in Portland, Oregon.

“Effects of Intraperitoneally Implanted Radio Transmitters on the Swimming Performance and Physiology of Pacific Lampreys,” presented at the 2001 Annual Conference of the Oregon Chapter American Fisheries Society in Portland, Oregon.

“Pacific Lamprey Technical Workgroup Regional Planning,” presented in 2000 to the Northwest Power Planning Council, Portland, Oregon.

“Stress Physiology and Swimming Performance of Radio-tagged Pacific Lamprey (*Lampetra tridentata*),” presented at the 1997 National Conference of American Indian Science and Engineering Society in Houston, Texas.

“Status and Biology of Pacific Lampreys in the Columbia River Basin,” presented at the 1996 Pacific Region Conference Native American Fish and Wildlife Society in Pendleton, Oregon.

“Status of Pacific Lamprey in the Columbia River Basin,” presented in 1995 to the Northwest Power Planning Council, Portland, Oregon.

ADVISORY AND TECHNICAL ASSISTANCE

Journal of Fish Biology – manuscript reviewer.

Great Lakes Fishery Trust – research proposal reviewer.

Great Lakes Fishery Commission – research proposal reviewer.

Northwest Power Planning and Conservation Council- Columbia River

Basin Pacific Lamprey Technical Workgroup-prioritized research needs.

TEACHING RESPONSIBILITIES

Guest Lecturer for Native American Studies IAH 211C, Ecological Perspectives of Native Americans, Michigan State University 2007. "First Nations First Foods."

Guest Lecturer for Native American Studies 303, Ecological Perspectives of Native Americans, Michigan State University 2007. "First Nations First Foods."

Guest Lecturer for Fish & Wildlife 473, Environmental Fish Physiology, Michigan State University 2007. "Endocrinology of Stress."

Guest Lecturer for Fish & Wildlife 205, Principles of Fish and Wildlife Mgt., Michigan State University 2007. "Native American Perspectives in Fish and Wildlife and Treaty Reserved Fishing Rights."

Mentored and taught laboratory techniques to Native American student from the Umatilla Indian Reservation at Michigan State University's Department of Fish and Wildlife from May 2006 to present.

Guest Lecturer for the Department of Fish & Wildlife Seminar, Michigan State University 2006. "Native American Perspectives on Fish and Wildlife Conservation/Management."

Guest Lecturer for Fish & Wildlife 205, Principles of Fish and Wildlife Mgt., Michigan State University 2006. "Native American Perspectives in Fish and Wildlife and Treaty Reserved Fishing Rights."

Guest lecturer for Plant Biology 499, Michigan State University 2004. "Is there a connection between traditional ecological knowledge, western science, religion and myth?"

Guest lecturer for Plant Biology 499, Michigan State University 2004. "Ethno biology and the importance of Traditional Ecological Knowledge."

Mentored and taught fisheries techniques to Native American fisheries technicians and students from 1998 through 2003, Tribal Fisheries Program, Department of Natural Resources, Confederated Tribes of the Umatilla Indian Reservation.

Mentored and taught laboratory techniques to Native American students from the Umatilla Indian Reservation and Warm Springs Reservation at Oregon State University's Department of Fish and Wildlife during summer of 1997.

SERVICE

2006-2007 Graduate Student Representative for the Fish and Wildlife Graduate Committee, Department of Fish and Wildlife, Michigan State University.

PROFESSIONAL SOCIETIES

Native American Fish and Wildlife Society

American Fisheries Society

American Indian Science and Engineering Society, Sequoyah Fellow

REFERENCES

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ACADEMIC INFORMATION

Post-Secondary Education:
1985 BSc (Marine Biology), University of Guelph, Ontario
1992 PhD (Fisheries and Aquatic Sciences), University of Guelph, Ontario, *Labile Sex Determination in Lampreys: The Effect of Larval Density and Sex Steroids on Gonadal Differentiation*

Areas of Expertise:
Fish biology, lamprey biology, evolutionary biology, molecular systematics, conservation genetics

Positions Held Since Completion of PhD:

2006 – present	Assistant professor	Department of Biological Sciences, University of Manitoba
2004 – 2006	Maternity leave	
2000 – 2004	Postdoctoral fellow	Great Lakes Institute for Environmental Research, University of Windsor
1997 – 2000	Sessional lecturer	Biology Programme, University of Northern British Columbia
1995 – 1997	Visiting scientist	Department of Zoology, University of New Hampshire
1994 – 1995	Postdoctoral researcher	West Vancouver Laboratory, Fisheries and Oceans Canada
1992 – 1994	Visiting fellow	Pacific Biological Station, Fisheries and Oceans Canada

RESEARCH PUBLICATIONS AND PRESENTATIONS

Publications:
<u>Refereed Chapters (in Books or Proceedings)</u>:

1. **Docker, M.F.** 2009. A review of the evolution of nonparasitism in lampreys and an update of the paired species concept. Pages 71–114 *in* L.R. Brown, S.D. Chase, P.B. Moyle, R.J. Beamish, and M.G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

2. Goodman, D.H., A.P. Kinziger, S.B. Reid, and **M.F. Docker**. 2009. Morphological diagnosis of *Entosphenus* and *Lampetra* ammocoetes (Petromyzontidae) in Washington, Oregon, and California. Pages 223–232 *in* L.R. Brown, S.D. Chase, P.B. Moyle, R.J. Beamish, and M.G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

3. Renaud, C.B., **M.F. Docker**, and N.E. Mandrak. 2009. Taxonomy, distribution, and conservation of lampreys in Canada. Pages 293–309 *in* L.R. Brown, S.D. Chase, P.B. Moyle, R.J. Beamish, and M.G. Mesa, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

<u>Refereed Articles in Academic or Professional Journals</u>:

Journal Articles (Submitted):

1. **Docker, M.F.**, N.E. Mandrak, and D.D. Heath. Mitochondrial DNA and microsatellite markers suggest limited divergence between "paired" silver (*Ichthyomyzon unicuspis*) and northern brook (*I. fossor*) lampreys. Submitted to Conservation Genetics, June 2010.

2. Spice, E.K., T.A. Whitesel, C.T. McFarlane, and **M.F. Docker**. Characterization of nine microsatellite loci for the Pacific lamprey (*Entosphenus tridentatus*) and cross amplification in five other lamprey species. Submitted to Conservation Genetics Resources, June 2010.

3. Boguski, D.A., S.B. Reid, D.H. Goodman, and **M.F. Docker**. Genetic diversity, endemism, and phylogeography of lampreys within the genus *Lampetra sensu stricto* (Petromyzontiformes: Petromyzontidae) in western North America. Submitted to Molecular Phylogenetics and Evolution, June 2010.

4. Backhouse, S.M. and **M.F. Docker**. Using mitochondrial and microsatellite DNA variation to investigate population structure of walleye (*Sander vitreus*) in Lake Winnipeg. Submitted to the Journal of Great Lakes Research, April 2010.

5. Clemens, B.J., T.R. Binder, **M.F. Docker**, M.L. Moser, and S.A. Sower. Similarities, differences, and unknowns in biology and management of three parasitic lampreys of North America. Submitted to Fisheries, May 2009; revisions submitted May 2010.

6. Reid, S.B., Boguski, D.A., D.H. Goodman, and **M.F. Docker**. Validity of *Lampetra pacifica* (Petromyzontiformes: Petromyzontidae), a brook lamprey described from the lower Columbia River Basin. Submitted to Zootaxa, March 2010.

7. Helou, L., **M.F. Docker**, and D.D. Heath. Mutation analysis of the major histocompatibility (MH) genes in Chinook salmon (*Oncorhynchus tshawytscha*). Submitted to Gene, May 2010.

Journal Articles (Published):

1. Luzier, C.W., **M.F. Docker**, and T.A. Whitesel. 2009. Characterization of ten microsatellite loci for western brook lamprey *Lampetra richardsoni*. Conservation Genetic Resources (published online December 20; DOI 10.1007/s12686-009-9155-z).

2. McFarlane, C.T. and **M.F. Docker**. 2009. Characterization of 14 microsatellite loci in the paired lamprey species *Ichthyomyzon unicuspis* and *I. fossor* and cross amplification in four other *Ichthyomyzon* species. Conservation Genetic Resources 1: 377–380.

3. D.H. Goodman, S.B. Reid, **M.F. Docker**, G.R. Haas, and A.P. Kinziger. 2008. Evidence for high levels of gene flow among populations of a widely distributed anadromous lamprey *Entosphenus tridentatus* (Petromyzontidae). Journal of Fish Biology 72: 400-417.

4. Heath, D.D., S. Jamieson, I. Stasiak, C.M. Bettles, and **M.F. Docker**. 2008. Genetic differentiation among sympatric migratory and resident life-history forms of *Oncorhynchus mykiss* in British Columbia. Transactions of the American Fisheries Society 137: 1268-1277.

5. **Docker, M.F.**, G.R. Haas, D.H. Goodman, S.B. Reid, and D.D. Heath. 2007. PCR-RFLP markers detect 29 mitochondrial haplotypes in Pacific lamprey (*Entosphenus tridentatus*). Molecular Ecology Notes 7: 350-353.

6. Neave, F.B., N.E. Mandrak, **M.F. Docker**, and D.L. Noakes. 2007. Differentiating sympatric *Ichthyomyzon* ammocoetes using meristic, morphological, pigmentation and gonad analyses. Canadian Journal of Zoology 85: 549-560.

7. Roy, D., **M.F. Docker**, G.D. Haffner, and D.D. Heath. 2007. Body shape vs. colour associated initial divergence in the *Telmatherina* radiation in Lake Matano, Sulawesi, Indonesia. Journal of Evolutionary Biology 20: 1126-1137.

8. **Docker, M.F.** (2006) Bill Beamish's contributions to lamprey research and recent advances in the field. Guelph Ichthyology Reviews 7:1-52.

9. Neave, F.B., N.E. Mandrak,, **M.F. Docker**, and D.L. Noakes (2006) Effects of preservation on pigmentation and length measurements in larval lampreys. Journal of Fish Biology 68: 991-1001.

10. Heath, D.D., J.M. Shrimpton, R.I. Hepburn, S.K. Jamieson, S.K. Brode, and **M.F. Docker** (2006) Population structure and divergence using microsatellite and gene locus markers in Chinook salmon (*Oncorhynchus tshawytscha*) populations. Canadian Journal of Fisheries and Aquatic Sciences 63: 1370-1383.

11. Bettles, C.M., M.F. Docker, B. Dufour, and D.D. Heath. 2005. Hybridization dynamics between sympatric species of trout: loss of reproductive isolation. Journal of Evolutionary Biology 18: 1220-1233.

12. Therriault, T.W., M.I. Orlova, M.F. Docker, H.J. MacIsaac, and D.D. Heath. 2005. Invasion genetics of a freshwater mussel (*Dreissena rostriformis bugensis*)) in Eastern Europe: high gene flow and multiple introductions. Heredity 95: 16-23.

13. Bettles, C.M., **M.F. Docker**, B. Dufour, and D.D. Heath. 2005. Hybridization dynamics between sympatric species of trout: loss of reproductive isolation. Journal of Evolutionary Biology 18: 1220-1233.

14. Therriault, T.W., M.I. Orlova, **M.F. Docker**, H.J. MacIsaac, and D.D. Heath. 2005. Invasion genetics of a freshwater mussel (*Dreissena rostriformis bugensis*)) in Eastern Europe: high gene flow and multiple introductions. Heredity 95: 16-23.

15. Roy, D., **M.F. Docker**, P. Hehanussa, D.D. Heath, and G.D. Haffner. 2004. Genetic and morphological data supporting the hypothesis of adaptive radiation in the endemic fish of Lake Matano. Journal of Evolutionary Biology 17: 1268-1276.

16. Maeva, E., I. Bruno, B.S. Zielinski, **M.F. Docker**, F.M. Severin, and R.G. Maev. 2004. The use of pulse-echo acoustic microscopy to non-invasively determine sex of living larval sea lamprey, *Petromyzon marinus*. Journal of Fish Biology 65: 148-156.

17. Therriault, T.W., **M.F. Docker**, M.I. Orlova, D.D. Heath, and H.J. MacIsaac. 2004. Molecular resolution of Dreissenidae (Mollusca: Bivalvia) including the first report of *Mytilopsis leucophaeata* in the Black Sea basin. Molecular Phylogenetics and Evolution 30: 479-489.

18. **Docker, M.F.**, A. Dale, and D.D. Heath. 2003. Erosion of interspecific reproductive barriers resulting from hatchery supplementation of rainbow trout sympatric with cutthroat trout. Molecular Ecology 12: 3515-3521.

19. **Docker, M.F.**, S.A. Sower, J.H. Youson, and F.W.H. Beamish. 2003. Future sea lamprey control through regulation of metamorphosis and reproduction: A report from the SLIS II New Science and Control workgroup. Journal of Great Lakes Research 29 (Supplement 1): 801-809.

20. **Docker, M.F.**, and D.D. Heath. 2003. Genetic comparison between anadromous steelhead and freshwater-resident rainbow trout in British Columbia, Canada. Conservation Genetics 4: 227-231.

21. **Docker, M.F.**, and D.D. Heath. 2002. PCR-based markers detect genetic variation at growth and immune function-related loci in chinook salmon (*Oncorhynchus tshawytscha*). Molecular Ecology Notes 2: 606-609.

22. Lorion, C.M., D.F. Markle, S.B. Reid, and **M.F. Docker.** 2000. Re-description of the presumed-extinct Miller Lake lamprey, *Lampetra minima*. Copeia 2000: 1019-1028.

23. **Docker, M.F.**, J.H. Youson, R.J. Beamish, and R.H. Devlin. 1999. Phylogeny of the lamprey genus *Lampetra* inferred from mitochondrial cytochrome *b* and ND3 gene sequences. Canadian Journal of Fisheries and Aquatic Sciences 56: 2340-2349.

24. Kent, M.L., **M. Docker**, J. Khattra, C.R. Vossbrinck, D.J. Speare, and R.H. Devlin. 1999. *Microsporidium prosopium* n. sp. (Microsporidia) from the musculature of the mountain whitefish *Prosopium williamsoni* from British Columbia: Morphology and phylogeny. Journal of Parasitology 85: 1114-1119.

25. **Docker, M.F.**, M.L. Kent, D.M.L. Hervio, J.S. Khattra, L.M. Weiss, A. Cali, and R.H. Devlin. 1997. Ribosomal DNA sequence of *Nucleospora salmonis* Hedrick, Groff and Baxa, 1991 (Microsporea: Enterocytozooidae): Implications for phylogeny and nomenclature. Journal of Eukaryotic Microbiology 44: 55-60.

26. **Docker, M.F.**, R.H. Devlin, J. Richard, and M.L. Kent. 1997. Sensitive and specific polymerase chain reaction assay for detection of *Loma salmonae* (Microsporea). Diseases of Aquatic Organisms 29: 41-48.

27. Shaw, R.W., M.L. Kent, **M.F. Docker**, A.M.V. Brown, R.H. Devlin, and M.L. Adamson. 1997. A new species of *Loma* (Microsporea) in shiner perch (*Cymatogaster aggregata*). Journal of Parasitology 83: 296-301.

28. Kent, M.L., D.M.L. Hervio, **M.F. Docker**, and R.H. Devlin. 1996. Taxonomy studies and diagnostic tests for myxosporean and microsporidian pathogens of salmonid fishes utilising ribosomal DNA sequence. Journal of Eukaryotic Microbiology 43: S98-99.

29. **Docker, M.F.**, and F.W.H. Beamish. 1994. Age, growth, and sex ratio among populations of least brook lamprey, *Lampetra aepyptera*, larvae: an argument for environmental sex determination. Environmental Biology of Fishes 41: 191-204.

30. Murdoch, S.P., **M.F. Docker**, and F.W.H. Beamish. 1992. Effect of density and individual variation on growth in sea lamprey (*Petromyzon marinus*) larvae in the laboratory. Canadian Journal of Zoology 70: 184-188.

31. Murdoch, S.P., F.W.H. Beamish, and **M.F. Docker**. 1991. Laboratory study of growth and interspecific competition in larval lampreys. Transactions of the American Fisheries Society 120: 653-656.

32. **Docker, M.F.**, and F.W.H. Beamish. 1991. Growth, fecundity, and egg size of least brook lamprey, *Lampetra aepyptera*. Environmental Biology of Fishes 31: 219-227.

33. **Docker, M.F.**, T.E. Medland, and F.W.H. Beamish. 1986. Energy requirements and survival in embryo mottled sculpin (*Cottus bairdi*). Canadian Journal of Zoology 64: 1104-1109.

34. Wong, P.T.S., Y.K. Chan, J.S. Rhamey, and **M. Docker**. 1984. Relationship between water solubility of chlorobenzenes and their effects on a freshwater alga. Chemosphere 13: 991-996.

Refereed Reports:

1. **Docker, M.F.** Update COSEWIC Status Report on Vancouver Lamprey *Lampetra macrostoma*, prepared for Committee on the Status of Endangered Wildlife in Canada, Environment Canada, Gatineau, Quebec. Revised draft submitted December 2007. v + 35 pp.

Book Reviews:

1. **Docker, M.F.** 2008. Book critique: Hardisty shares his final thoughts on lampreys. Environ. Biol. Fishes 82: 11-15. *Invited book review.*

Conference Presentations:

Invited Conference Presentations:

1. **Docker, M.F.**, D.A. Boguski, D.H. Goodman, and S.B. Reid. 2010. Mitochondrial and nuclear genetic markers suggest several cryptic brook lamprey species (genus *Lampetra*) on the west coast of North America. 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba, January 2010.

2. **Docker, M.F.** 2006. Genetic data suggest that northern brook and silver lampreys are a single species. Great Lakes Fishery Commission Annual Meeting, Traverse City, Michigan, June 2006.

3. **Docker, M.F.** 2005. Bill Beamish's contributions to lamprey research and recent advances in the field. 58th Canadian Conference for Fisheries Research, Windsor, Ontario, January 2005.

4. **Docker, M.F.** 2004. Genetic markers to distinguish among west coast lamprey species and the population structure of these species. Columbia River Basin Lamprey Workshop, Vancouver, Washington, February 2004.

5. **Docker, M.F.** 2002. Genetic tools used in fish biology: Conservation, aquaculture, and phylogenetics. Beckman Coulter Advanced Technology Seminar Series, Detroit, Michigan, April 2002.

6. **Docker, M.F.** 2002. Applications of the CEQ™ 8000 to conservation genetic studies at the Great Lakes Institute for Environmental Research. Beckman Coulter Genetic Analysis Forum. Fullerton, California, July 2002.

7. **Docker, M.F.** 1999. Lampreys of the Klamath and Goose Lake basins of Oregon. Oregon Department of Fish and Wildlife 1999 Fish Biology Meeting, Bend, Oregon, June 1999.

8. **Docker, M.F.** 1992. Labile sex determination in lampreys. Vertebrate Sex Determination/Differentiation Workshop, Great Lakes Fishery Commission, Chicago, Illinois, March 1992.

<u>Other Oral Conference Presentations</u>:

1. **Docker, M.F.** 2010. Divergent feeding types in lampreys: the repeated evolution of nonparasitism. 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba, January 2010.

2. Backhouse, S. and **M.F. Docker**. 2010. Using microsatellite and mitochondrial DNA variation to investigate population structure of walleye (*Sander vitreus*) in Lake Winnipeg. 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba, January 2010.

3. Schroeder, B.S., R.D. Mooi, and **M.F. Docker**. 2010. An isolated population of threespine stickleback in Nueltin Lake, Manitoba: post-glacial dispersal and population relatedness. 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba, January 2010.

4. Backhouse, S.M. and **M.F. Docker**. 2009. Walleye population structure and identification in Lake Winnipeg using microsatellite DNA variation. 139th American Fisheries Society Annual Meeting, Nashville, Tennessee, August 2009.

5. McFarlane, C.T. and **M.F. Docker**. 2009. Testing the phylogenetic and biological species concepts in the paired lamprey species, *Ichthyomyzon unicuspis* and *I. fossor*. 139th American Fisheries Society Annual Meeting, Nashville, Tennessee, August 2009.

6. Boguski, D.A., S.B. Reid, D.H. Goodman, and **M.F. Docker**. 2008. Genetic diversity, endemism, and biogeography of the western brook lamprey (*Lampetra richardsoni*). 9th International Congress on the Biology of Fish, Portland, Oregon, July 2008.

7. Renaud, C.B. **M.F. Docker**, and N.E. Mandrak. 2008. Lampreys in Canada: Changes since 1973. 138th American Fisheries Society Annual Meeting, Ottawa, Ontario, August 2008.

8. **Docker, M.F.**, N.E. Mandrak, and D.D. Heath. 2007. Polyphyly and absence of fixed sequence differences suggest that "paired" species in the lamprey genus *Ichthyomyzon* represent two feeding

types of a single species. 87th Joint Meeting of Ichthyologists and Herpetologists, St. Louis, Missouri, July 2007.

9. Boguski, D.A, D.H. Goodman, S.B. Reid, and **M.F. Docker**. 2007. Brook lamprey diversity along the Pacific coast of North America. 87th Joint Meeting of Ichthyologists and Herpetologists, St. Louis, Missouri, July 2007.

10. **Docker, M.F.** 2007. The evolution of nonparasitism in lampreys: An update on the paired species concept. 137th American Fisheries Society Annual Meeting, San Francisco, California, September 2007.

11. Renaud, C.B., **Docker, M.F.**, and N.E. Mandrak. 2007. Taxonomy, distribution and conservation of lampreys in Canada. 137th American Fisheries Society Annual Meeting, San Francisco, California, September 2007.

12. Goodman, D.H., A.P. Kinziger, S.B. Reid, and **M.F. Docker**. 2007. Morphological diagnosis of *Entosphenus* and *Lampetra* ammocoetes (Petromyzontidae) in Washington, Oregon and California. 137th American Fisheries Society Annual Meeting, San Francisco, California, September 2007.

13. Reid, S.B., D.H. Goodman, D. Boguski, and **M.F. Docker**. 2007. Unparalleled diversity of lamprey species from the west coast of North America. 137th American Fisheries Society Annual Meeting, San Francisco, California, September 2007.

14. S. Reid, D. Goodman, **M. Docker**, and D. Markle. 2005. The inland lampreys: diversity in the Klamath and Goose Basins. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon, September 2005.

15. Goodman, D.H., S. Reid, **M.F. Docker**, and A.P. Kinziger. 2005. Phylogeography of *Entosphenus tridentatus* (Petromyzontidae). American Society of Ichthyologists and Herpetologists, Tampa, Florida, July 2005.

16. **Docker, M.F.**, S.B. Reid, and D.F. Markle. 2005. Are lampreys with different adult life history types really different species? California-Nevada Chapter of the American Fisheries Society Symposium and 39th Annual Meeting, Sacramento, California, April 2005.

17. Goodman, D., S. Reid, and **M. Docker**. 2005. A phylogeographic study of Pacific Lamprey. California-Nevada Chapter of the American Fisheries Society Symposium and 39th Annual Meeting, Sacramento, California, April 2005.

18. Reid, S.B., D.H. Goodman, and **M. Docker**. 2005. The Western Lamprey Project. California-Nevada Chapter of the American Fisheries Society Symposium and 39th Annual Meeting, Sacramento, California, April 2005.

19. Heath, D., S. Jamieson, I. Stasiak, C. Bettles, and **M. Docker**. 2004. Population genetics of sympatric migratory and resident life history rainbow trout (*Oncorhynchus mykiss*) in British Columbia. 134th American Fisheries Society Annual Meeting, Madison, Wisconsin, September 2004.

20. Roy, D., **M.F. Docker**, P. Hehanussa, D.D. Heath, and G.D. Haffner. 2004. Associations in colouration patterns, morphology and genetic structure of a radiating freshwater fish genus from an ancient tropical island lake. Symposium for the Society for the Study of Evolution, Fort Collins, Colorado, June 2004.

21. Maeva, E., I. Bruno, F. Severin, R. Gr. Maev, B. Zielinski, and **M. Docker**. 2003. Method of acoustic microscopy for sex determination of living sea lamprey larvae, *Petromyzon marinus*. Canadian Association of Physicists Annual Congress, Charlottetown, Prince Edward Island, June 2003.

22. Heath, D.D., J.M. Shrimpton, C.R. Busch, and **M.F. Docker**. 2003. Using functional versus neutral genetic markers for stock identification: natural selection in harness. 133th American Fisheries Society Annual Meeting, Quebec City, Quebec.

23. **Docker, M.F.**, M. Nurse, C.R. Busch, and D.D. Heath. 2003. Improving natural disease resistance in farmed chinook salmon, *Oncorhynchus tshawytscha*, using marker-assisted selection. 56th Canadian Conference for Fisheries Research, Ottawa, Ontario, January 2003.

24. Bettles, C.M., **M.F. Docker**, B. Dufour, and D.D. Heath. 2003. A genetic investigation of hybridization between cutthroat and rainbow trout. 56th Canadian Conference for Fisheries Research, Ottawa, Ontario, January 2003.

25. Roy, D., **M. Docker**, P. Hehanussa, G.D. Haffner, and D. Heath. 2003. Genetic evidence of adaptive radiation in a continental island lake. 56th Canadian Conference for Fisheries Research, Ottawa, Ontario, January 2003.

26. **Docker, M.F.**, B. Young, and D.D. Heath. 2002. Disease resistance and MHC genotype in an alternative male reproductive strategy in chinook salmon. Ecological and Evolutionary Ethology of Fishes, Quebec City, Quebec, August 2002.

27. Heath, D.D., R. Hepburn, S. Brode, and **M. Docker**. 2002. Rapid genetic divergence among salmon populations at functional marker loci relative to neutral loci. Symposium for the Society for the Study of Evolution. Urbana-Champaign, Illinois, June 2002.

28. **Docker, M.F.**, and D.D. Heath. 2001. Genetic comparison between sympatric life histories of *Oncorhynchus mykiss* (anadromous steelhead and freshwater-resident rainbow trout) in British Columbia. 54th Canadian Conference for Fisheries Research, Toronto, Ontario, January 2001.

29. D. Roy, **M. Docker**, D. Heath, and G.D. Haffner. 2001. Can empty water be a barrier? Population structure of telmathrinids (sailfins) and oryzias (ricefish) in an ancient continental island lake, Lake Matano, Sulawesi, Indonesia. Symposium for the Society for the Study of Evolution. Knoxville, Tennessee, June 2001.

30. Reid, S., C. Lorion, D. Markle, **M. Docker**, T. Forbes, and S. Peets. 1999. Rediscovery of the Miller Lake lamprey, *Lampetra minima*. 1999 Desert Fish Council Meeting. Ciudad Victoria, Tamaulipas, Mexico, November 1999.

31. **Docker, M.F.**, J.H. Youson, R.J. Beamish, and R.H. Devlin. 1995. Phylogeny of the lamprey genus *Lampetra* inferred from cytochrome b and ND3 gene sequences. 7th Annual Meeting, Gilbert Ichthyological Society, University of Washington, Seattle, Washington, October 1995.

32. **Docker, M.F.**, M.L. Kent, D.M.L. Hervio, and R.H. Devlin. 1995. Ribosomal DNA sequence of *Nucleospora salmonis* (Microsporea: Enterocytozooidae) and a PCR test for its detection in chinook salmon. BC Parasitologists Meeting. University of British Columbia, Vancouver, BC, March 1995.

33. **Docker, M.F.** and F.W.H. Beamish. 1987. Sex ratio variations in larval least brook lamprey. 49th Midwest Fish and Wildlife Conference, Milwaukee, Wisconsin, December 1987.

<u>Poster Presentations</u>:

1. R.D. Mooi, Schroeder, B.S., and **M.F. Docker**. 2010. An isolated and differentiated population of *Gasterosteus aculeatus* (Gasterosteidae: Gasterosteiformes) from Nueltin Lake in northwestern Manitoba. 90th Joint Meeting of Ichthyologists and Herpetologists, Providence, Rhode Island, July 2010.

2. Spice, E. and **M.F. Docker**. 2010. Population structure of Pacific Lampreys (*Entosphenus tridentatus*) along the west coast of North America. 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba, January 2010.

3. McFarlane, C.M. and **M.F. Docker**. 2010. Detection of selection for feeding type in paired lamprey species. 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba, January 2010.

4. **Docker, M.F.** 2007. Heterochrony and the evolution of nonparasitism in lampreys. 1st General Meeting of the Canadian Society for Ecology and Evolution, Toronto, Ontario, May 2007.

5. **Docker, M.**, Maeva, E., Zielinski, B., Bruno, I., Maev R.G. 2005. Non-invasive sex determination of larval sea lampreys using acoustic microscopy. 58th Canadian Conference for Fisheries Research, Windsor, Ontario, January 2005.

6. **Docker, M.**, F. Neave, N. Mandrak, and D. Noakes. 2004. Identification of native lampreys: the enigma of *Ichthyomyzon* species. Sea Lamprey Research Priorities Working Group Meeting, Guelph, Ontario, September 2004.

7. Therriault, T., M. Orlova, **M. Docker**, H. MacIsaac, and D. Heath. 2004. Genetic identity and invasion dynamics of the quagga mussel in the Volga River basin and Great Lakes as revealed by microsatellite analyses. 13th International Invasive Species Conference, Ennis, Ireland, September 2004.

8. Roy, D., **M. Docker**, P. Hehanussa, D.D. Heath, and G.D. Haffner. 2004. Colouration patterns do not fall along genetic species lines in *Telmatherina*, a tropical island radiating freshwater fish genus from Sulawesi. 29th Congress of the International Association of Limnology, Helsinki, Finland, August 2004.

9. Youson, J.H., **M. Docker**, and S.A. Sower. 1995. Concentration of gonadotropin-releasing hormones in brain of larval and metamorphosing lampreys of two species with different adult life histories. 5th International Symposium, Reproductive Physiology of Fish, University of Texas,

Austin, Texas, July 1995.

10. **Docker, M.F.** and F.W.H. Beamish. 1989. Effects of gonadal steroids on sexually differentiated sea lamprey, *Petromyzon marinus*. XIth International Symposium on Comparative Endocrinology, Malaga, Spain, May 1989.

Invited Departmental Seminars:

1. **Docker, M.F.** 2007. Paired lamprey species and the repeated evolution of nonparasitism. Department of Biology, University of Regina, October 2007.

Research Reports:

1. Mandrak, N.E., **M.F. Docker**, and D.D. Heath. 2004. Native *Ichthyomyzon* lampreys of the Great Lakes: development of genetic markers and a morphological key to ammocoetes. Great Lakes Fishery Commission Project Completion Report, Ann Arbor, Michigan. 114 pp.

2. **Docker, M.F.**, N.E. Mandrak, D.D. Heath, and K.T. Scribner. 2005. Genetic markers to distinguish and quantify the level of gene flow between northern brook and silver lampreys. Great Lakes Fishery Commission Project Completion Report, Ann Arbor, Michigan. 37 pp.

RESEARCH FUNDING

1. **Docker, M.F.** (PI)
   High-throughput molecular genetics facility (2010)
   Canada Foundation for Innovation (Leaders Opportunity Fund)
   $594,836 (pending)

2. **Docker, M.F.** (PI), S. Whyard, T.B. Steeves, and W. Li
   Detection and identification of lampreys in streams using environmental DNA (2011 – 2013)
   Great Lakes Fishery Commission (Sea Lamprey Research Program)
   $83,475 (pending)

3. **Docker, M.F.** (PI)
   Gene expression differences between feeding types in the paired lampreys *Ichthyomyzon unicuspis* and *I. fossor* (2011 – 2013)
   Great Lakes Fishery Commission (Sea Lamprey Research Program)
   $20,000 (pending)

4. **Docker, M.F.** (PI)
   Microsatellite analysis on Pacific lamprey from the Willamette Basin (2010 – 2011)
   Columbia River Inter-Tribal Fish Commission
   $15,394 USD (pending)

5. **Docker, M.F.** (PI)
Microsatellite analysis on Pacific lamprey along the west coast of North America (2010 – 2011)
U.S. Fish and Wildlife Service
$13,000 USD

6. S. Whyard and **Docker, M.F.** (co-investigator)
Gene silencing technologies to control sea lamprey – a proof-of-concept (2009 – 2011)
Great Lakes Fishery Commission (Sea Lamprey Research Program)
$93,014

7. **Docker, M.F.** (PI)
Methow lamprey inventory and assessment (Washington) (2009)
National Fish and Wildlife Foundation
$4,000 USD

8. **Docker, M.F.** (PI)
Testing the congruence of independent DNA markers in phylogeny reconstruction (2008 – 2010)
University of Manitoba University Research Grants Program (URGP)
$6,605

9. Neave, F.B., Steeves, T.B., **Docker, M.F.** (co-investigator), Pratt, T.C., and R.L. McLaughlin
An investigation of a potential morphotype trigger in two *Ichthyomyzon* species (2007 – 2013)
Great Lakes Fishery Commission (Sea Lamprey Research Program)
$140,030 total ($91,530 for Docker's portion)

10. **Docker, M.F.** (PI)
Disruptive selection and the genetic basis for repeated evolution of nonparasitism in lampreys (2007 – 2012)
NSERC Discovery Grant
$86,600

11. **Docker, M.F.** (PI)
Evaluating the population structure of lamprey, *Lampetra richardsoni* and *Entosphenus tridentatus* (2007 – 2011)
U.S. Fish and Wildlife Service
$43,000 USD

12. **Docker, M.F.** (PI)
Population structure and stock identification of walleye in Lake Winnipeg using microsatellite DNA variation (2007 – 2009)
Manitoba Fisheries Enhancement Fund
$65,750

13. **Docker, M.F.**, S. Whyard, and G. Valdimarsson (co-applicants)
Refrigerated tabletop centrifuge with microplate capacity for use in DNA sequencing and other molecular genetic studies (2007)
NSERC Research Tools and Instruments Grant
$13,886

14. **Docker, M.F.** (PI)
    Genetic study of isolated brook lamprey populations along the west coast of North America: Identification of potential new species (2006)
    University of Manitoba University Research Grants Program (URGP)
    $5,904

15. **Docker, M.F.** (PI), N.E. Mandrak, D.D. Heath, and K.T. Scribner
    Genetic markers to distinguish northern brook and silver lampreys (2003 – 2004)
    Great Lakes Fishery Commission (Sea Lamprey Research Program)
    $17,850 USD

16. Mandrak, N.E., **M.F. Docker** (co-investigator), and D.D. Heath
    Native *Ichthyomyzon* lampreys of the Great Lakes Basin: Development of genetic markers and a morphological key to ammocoetes (2002 – 2003)
    Great Lakes Fishery Commission (Sea Lamprey Research Program)
    $67,463 USD

17. Haas, G. and **M.F. Docker** (co-PI)
    Status and conservation of biodiversity in lamprey species in BC (2000 – 2001)
    Habitat Conservation Trust Fund
    $30,000

18. **Docker, M.F.** (co-PI), S.B. Reid, and D.F. Markle
    Status of the presumed extinct Miller Lake lamprey, *Lampetra minima*, in the Klamath Basin, Oregon (1998 – 1999)
    U.S. Fish and Wildlife Service (Species at Risk Program)
    $29,336 USD

19. **Docker, M.F.** (PI)
    Goose Lake lamprey study (1996 – 1999)
    Oregon Department of Fish and Wildlife
    $38,000 USD

20. Sower, S.A., **M.F. Docker** (co-investigator), and A. Gorbman
    Hormonal sterilization of early lamprey larvae (1994 – 1996)
    Great Lakes Fishery Commission (Sea Lamprey Research Program)
    $17,000 USD

TEACHING ACTIVITIES

Undergraduate Courses:
University of Manitoba:
1. BIOL 2210: Chordate Zoology (Winter 2008, Winter 2009, Winter 2010)
2. BIOL 3300: Evolutionary Biology (Fall 2006, Fall 2007, Fall 2008, Fall 2009)
3. BIOL 4212: Systematics and Biogeography of Fishes (Fall 2008)

University of Northern British Columbia:
1. BIOL 100: Introduction to Biology (Fall 1998, Winter 1999, Fall 1999, Winter 2000)
2. BIOL 307: Ichthyology and Herpetology (Fall 1997)
3. BIOL 311: Cell and Molecular Biology (Winter 1998)
4. BIOL 406: Fisheries Ecology (Fall 1997, Fall 1998)
5. BIOL 411: Conservation Biology (Winter 1999)

Graduate Courses:
University of Manitoba:
1. ZOOL 7220: Advanced Topics in Zoology: Aquatic Biology (Fall 2008, Winter 2009)

SUPERVISION OF GRADUATE AND UNDERGRADUATE RESEARCH

Graduate Students:
Supervised:
University of Manitoba:
1. Postma, Lianne (PhD); Genetic monitoring and conservation of beluga whales (*Delphinapterus leucas*) in the western Canadian Arctic (May 2010 – present)
2. McFarlane, Craig (MSc); Genetic basis of feeding type in paired species of lamprey (Sept 2009 – present)
3. Kowalchuk, Matthew (MSc); Taxonomic and phylogenetic analysis of North American Dolly Varden (*Salvelinus malma*) using mitochondrial and nuclear markers (Jan 2009 – present)
4. Backhouse, Stephanie (MSc); Using microsatellite and mitochondrial DNA variation to investigate population structure of walleye (*Sander vitreus*) in Lake Winnipeg (Sept 2007 – Dec 2009; completed)
5. Boguski, David (MSc); The genetic diversity of brook lampreys genus *Lampetra* (Petromyzontidae) along the Pacific coast of North America (Jan 2007 – Aug 2009; completed)

Advisory Committee Member:
University of Manitoba:
1. Klassen, Cheryl (PhD); Means and persistence of growth rate variability within juvenile lake sturgeon cohorts: implications for natural and artificial recruitment (in progress)
2. McDougall, Craig (MSc); Investigating downstream passage of lake sturgeon over a hydroelectric generating station (in progress)
3. Pawlychyn, Zoya (MSc); Adaptation and habitat selection during the migration of an Arctic anadromous fish, broad whitefish, *Coregonus nasus* (Pallas 1776) (in progress)
4. Penton, Paulette (PhD); An elucidation of the factors responsible for the presence of two spawning strategies in capelin (*Mallotus villosus*) in coastal Newfoundland (in progress)
5. Schroeder, Bethany (MSc); Postglacial history of three-spined stickleback (*Gasterosteus aculeatus*) in Nueltin Lake, MB and Nunavut (in progress)

Other Universities:
1. Goodman, Damon (MS); Evidence for high levels of gene flow among populations of a widely distributed anadromous lamprey; Humboldt State University, Arcata, California (completed 2006)
2. Roy, Denis (PhD); The evolutionary history and ecology of *Telmatherina* in Lake Matano:

An example of adaptive radiation in an ancient lake; University of Windsor, Windsor, Ontario (completed 2006)
3. Neave, Fraser (MSc); The utility of meristic, morphometric, pigmentation and gonad analysis in the identification of *Ichthyomyzon* larvae; University of Guelph, Guelph, Ontario (completed 2004)

Undergraduate Honours Students:

Supervised:

University of Manitoba:

1. McFarlane, Craig (Undergraduate Honours Thesis); Testing the phylogenetic and biological species concepts in the paired lamprey species, *Ichthyomyzon unicuspis* and *I. fossor* (2008 – 2009)
2. Spice, Erin (Undergraduate Honours Thesis); Population structure of the Pacific lamprey, *Entosphenus tridentatus*, along the west coast of North America: evidence against natal homing (2009 – 2010)

Advisory Committee Member:

University of Winnipeg:

1. Groening, Laura (Undergraduate Honours Thesis); Variation of Dolly Varden *Salvelinus malma* in Northwestern North America (2007 – 2008)

SERVICE TO THE PROFESSION

Professional Societies:

Treasurer–Secretary of the Mid-Canada Chapter (MCC) of the American Fisheries Society (2009 – present)

Journal Referee for:

Acta Zoologica
Canadian Field-Naturalist
Canadian Journal of Fisheries and Aquatic Sciences
Comparative Biochemistry and Physiology
Copeia
Environmental Biology of Fishes
Evolutionary Ecology
Genetica
Journal of Biomedical Sciences and Engineering
Journal of Experimental Zoology
Journal of Fish Biology
Journal of Great Lakes Research
Marine and Freshwater Research
Molecular Ecology
North American Journal of Fisheries Management
Proceedings of the Royal Society B: Biological Sciences
Transactions of the American Fisheries Society

Peer Reviewer for:
American Fisheries Society "Biology, Management, and Conservation of Lampreys in North America" symposium proceedings

Technical Reviewer for:
National Recovery Team for Morrison Creek Lamprey
National Recovery Team for Vancouver Lamprey

Grant Proposal Reviewer for:
Alberta Innovates – Technology Futures: Ingenuity New Faculty Award Proposal
Canada Foundation for Innovation (CFI)
Great Lakes Fishery Commission
Habitat Conservation Trust Fund
Natural Sciences and Engineering Research Council (NSERC)
Portuguese Science Foundation

Conference Organization:
Organizers of the "Biology of Lampreys: From Ecology to Genomics" symposium at the International Congress on the Biology of Fish, Portland, Oregon (July 2008)
Organizer of the "Divergent Morphotypes in Temperate Species: Resources and Evolution" symposium at the 63rd Canadian Conference for Fisheries Research, Winnipeg, Manitoba (January 2010)

Other Service to the Profession:
COSEWIC (Committee on the Status of Endangered Wildlife in Canada) Freshwater Fishes Species Specialist Subcommittee (2007 – present)
Invited expert to participate in a pre-COSEWIC assessment meeting on silver lamprey; Fisheries and Oceans Canada, Burlington, Ontario (March 2007)
Invited expert to participate in a workshop entitled, "The Interaction between Sea Lamprey Control and Species listed under the Canadian Species at Risk Act;" Fisheries and Oceans Canada, Sarnia, Ontario (March 2008)

THOMAS DUNNE: CURRICULUM VITAE

ADDRESS

Donald Bren School of Environmental Science & Management
University of California Santa Barbara
Santa Barbara, CA 93106
Tel: 805-893-7557
tdunne@bren.ucsb.edu

PROFESSIONAL PREPARATION:

Cambridge Univ., Geography, B.A. 1964
Johns Hopkins University, Geography, Ph.D. 1969

APPOINTMENTS:

1995- Professor, Donald Bren School of Environmental Science and Management, and Department of Earth Science, University of California, Santa Barbara
1973-1995 Asst. Prof. to Professor, Dept. of Geological Sciences, Univ. of Washington (Chair 1984-1989)
1971-1973 Assistant Professor, Department of Geography, McGill University, Canada,
1969-1971 Visiting Professor, Department of Geography, University of Nairobi, Kenya.
1968-73 (WAE) Research Hydrologist, Water Resources Division, US Geological Survey, Washington DC
1966-1968 Research Associate, Agricultural Research Service, US Department of Agriculture, Vermont

CURRENT RESEARCH INTERESTS IN HYDROLOGY AND GEOMORPHOLOGY

1. Field and theoretical studies of drainage basin and hillslope evolution

2. Hydrology, sediment transport, and sedimentation in river channels and floodplains

3. Sediment transport, channel migration, and oxbow lake sedimentation in rivers of the Central Valley, California.

Thomas Dunne is a Professor of Environmental Science and Management, and of Earth Science at the University of California Santa Barbara. He conducts field and theoretical studies of drainage-basin, hillslope, and fluvial geomorphology, and in the application of hydrology, sediment transport, and geomorphology to landscape management and hazard analysis.

While working for the USDA Agricultural Research Service (1966-1969) and McGill University (1971-1973), he conducted research on the effects of topography, soil characteristics, and vegetation on runoff processes under rainfall and snowmelt in Vermont and Canada. While teaching at the University of Nairobi, Kenya (1969-1971), he initiated a long-running research interest in African environments, including experimental studies of runoff and erosion processes, and statistical studies and field surveys of the effects of land use on hillslope erosion and river-basin sediment yields. He continues to use data from the experimental studies to model sediment transport and hillslope evolution, one of his long-term research interests. He also conducted occasional studies of reservoir sedimentation, water quality, and erosion due to charcoal production and grazing. This work was supported by the Rockefeller, Guggenheim, and Beijer Foundations, the United Nations Development Programme, U.S. National Science Foundation, and Kenya government agencies between 1969 and 1991.

While teaching in the Department of Geological Sciences at the University of Washington (1973-1995), he studied landsliding and debris flows; drainage-basin sediment budgets in natural and managed forests; tephra erosion and debris-flow sedimentation on active volcanoes; and sediment transport and channel morphology in sand-bed and gravel-bed river channels. He also conducted several studies related to resource management, such as the impacts of gravel harvesting on the river-channel sedimentation and morphology; impacts of timber harvest on erosion and sedimentation; and effects of flow diversion and reservoir management on sedimentation. The work was funded by NSF, and various state agencies (Depts. of Ecology and of Natural Resources), and federal agencies (USFS, USGS, FEMA).

Since moving to California he has studied hydrology, sediment transport, and floodplain sedimentation in the Amazon River of Brazil and in the Andes Range and adjacent floodplains of eastern Bolivia. His work, funded by NSF and NASA, involved studies of runoff processes in forest and pastures, modeling of the runoff response of the Amazon River, channel and bed material surveys, floodplain coring to measure rates of sediment accumulation with isotopes, measurement and interpretation of channel change and floodplain features from satellite images, flow and sediment transport modeling in channels and floodplains, and erosion of the Andes Range and sedimentation in the adjacent foreland basin with meteoric and cosmogenic isotopes.

He and his students have studied runoff and erosion on rangeland hillslopes and small wildland and urbanized watersheds around Santa Barbara, and as well as sediment transport, channel change and oxbow lake sedimentation along the Sacramento River and its floodplain. With five biologist colleagues in the Bren School, his group now studies how physical and biological processes interact to create and maintain habitat for fish and their food sources in the Merced and San Joaquin Rivers, CA. Funds are provided by the California Bay-Delta Restoration Science Program and the California Department of Water Resources.

He has gained experience with geomorphic and hydrologic processes through research and consultation in many parts of the world, and has expressed some of that experience in teaching courses, advising government and international agencies, publishing journal articles, and co-authoring two textbooks.

HONORS

Fulbright Scholar, 1964
Robert E. Horton Award, American Geophysical Union, 1987
Member, National Academy of Sciences, 1988
Fellow, American Geophysical Union, 1989
Guggenheim Fellowship, 1989
Fellow, American Academy of Arts and Sciences, 1993
Fellow, California Academy of Sciences, 1996
National Research Council Wolman Distinguished Lecturer, 1997
National Academy of Sciences Warren Prize for Fluviatile Geology, 1998
Bren School Distinguished Teaching Award, 2002, 2008
American Geophysical Union Langbein Lecturer, 2003
Geological Society of America Easterbrook Distinguished Scientist Award, 2003
Borland Distinguished Lecturer in Hydraulics, Colorado State University, 2007
Linton Award, British Society for Geomorphology, 2008.
Elected Honorary Member, Japanese Geomorphological Union, 2009

SOME RECENT PUBLICATIONS

T. Dunne, J. A. Constantine, and M. B. Singer, The Role of Sediment Transport and Sediment Supply in the Evolution of River Channel Complexity and Floodplain Evolution, **Transactions Japanese Geomorphological Union**, 2010.

T. Dunne, D. V. Malmon, and S. M. Mudd, A rainsplash transport equation assimilating field and laboratory measurements, **Journal of Geophysical Research – Earth Surface,** 2009.

J. A. Constantine, T. Dunne, H. Piégay, and G. M. Kondolf, Controls on the alluviation of oxbow lakes by bed-material load along the Sacramento River, California, **Sedimentology**, 2009.

J. A. Constantine, S. R. McLean, T. Dunne, A Mechanism of Chute Cutoff along Large Meandering Rivers with Uniform Floodplain Topography, **Geological Society of America Bulletin**, 2009.

C. R. Constantine, T. Dunne, and G. J. Hanson, Examining the physical meaning of the bank erosion coefficient used in meander migration modeling, **Geomorphology**, 106, 242-252, 2009.

R. E. Beighley, K. G. Eggert, T. Dunne, Y. He, V. Gummadi and K. L. Verdin, Simulating Hydrologic and Hydraulic Processes Throughout the Amazon River Basin, **Hydrological Processes,** 23, 1221-1235, DOI: 10.1002/hyp.7252, 2009

J. A. Constantine and T. Dunne, Meander Cutoff and the Controls on the Production of Oxbow Lakes, **Geology**, 2008.

R. E. Beighley, T. Dunne and J.M. Melack**,** Impacts of climate variability and land use alterations on frequency distributions of terrestrial runoff loading to coastal waters in southern California, **Journal of the American Water Resources Association**, 44(1), 62-71, 2008.

T. W. Biggs, T. Dunne, D. Roberts, and E. Matricardi, The rate and extent of deforestation in watersheds of the southwestern Amazon basin: implications for regional stream biogeochemistry, **Ecological Applications**, 18(1), 31–48, 2008.

L. A. K. Mertes and T. Dunne, The effects of tectonics, climatic history, and sea-level history on the form and behavior of the modern Amazon River, In: **Large Rivers** (ed. A. Gupta), Wiley & Sons, pp. 115-144, 2007

D. Alsdorf, P. Bates, J. Melack, M. Wilson, and T. Dunne, Spatial and temporal complexity of the Amazon flood measured from space, **Geophysical Research Letters**, 34, L08402, doi:10.1029/2007GL029447, 2007

E. B. Safran, A. Blythe, T. Dunne, Spatially Variable Exhumation Rates in Orogenic Belts: An Andean Example, **Journal of Geology**, 114, 665-681, 2006.

R. E. Aalto, T. Dunne, and J-L Guyot, Geomorphic controls on Andean denudation, **Journal of Geology,** 114, 85-99, 2006.

J. M. de Moraes, A. E. Schuler, T. Dunne, R. O. Figueiredo, and R. L. Victoria, Water storage and runoff processes in plinthic soils under forest and pasture in Eastern Amazonia, **Hydrological Processes**, 20 (12), 2509-2526, 2006

M. B. Singer and T. Dunne, Modeling the decadal influence of river rehabilitation scenarios on flow and sediment transport in large, lowland river basins, **Water Resources Research**, 42, W12415, doi:10.1029/2006WR004894, 2006

E. B. Safran, P. Bierman, R. Aalto, T. Dunne, K. X Whipple, and M. Caffee, Erosion rates driven by channel network incision in the Bolivian Andes, **Earth Surface Processes and Landforms**, 30 (8):1007-1024, 2005.

D. V. Malmon,S. L. Reneau, T. Dunne, D. Katzman, and P. G. Drakos, Influence of sediment storage on downstream delivery of contaminated sediment, **Water Resources Research,** 41, W05008, doi:10.1029/2004WR003288, 2005

D. V. Malmon, S. L. Reneau, and T. Dunne, Sediment sorting by flash floods, **Journal of Geophysical Research – Earth Surface**, 109(F2), 2004**.**

E. J. Gabet and T. Dunne, A stochastic sediment delivery model for a steep, Mediterranean landscape, **Water Resour. Res.,** 39, doi:10.1029/2003 R00234, 2003.

OTHER PROFESSIONAL ACTIVITIES

National Research Council Committees

Environmental Aspects of National Materials Policy, 1972-73
International Environmental Programs, 1979-82
Working Group on Managemt of Renewable Natural Resources in Nepal, Kathmandu, 1981
U. S. Army Basic Research, 1983-88
U. S. Geological Survey Water Resources Research, 1987-89
Opportunities in the Hydrological Sciences, 1987-89
Alluvial Fan Flooding, 1994-96
Future Roles, Challenges, and Opportunities for the U.S. Geological Survey, 1998-2000
Water Resources Activities of the U.S. Geological Survey, 2006-2009
Challenges and Opportunities in Earth Surface Processes, 2007-2009

Missouri River Recovery and Associated Sediment Management Issues, 2008-2010
U.S. National Committee for the lnternational Union of Geological Sciences, 2009-13
Sustainable Water and Environmental Management in the California Bay-Delta, 2010-2013

United Nations

UNESCO Research team on Nzoia R., Kenya, 1970-71
FAO Consultant on Soil Erosion and Desertification in Kajiado District, Kenya, 1976
FAO Committee on Soil Erosion and Soil Conservation in Developing Countries, Rome, 1976
FAO/UNEP Committee on a Methodology for Assessing World Soil Degradation, Rome, 1978

Other Committees

Kenya National Committee on the Human Environment, Nairobi, 1970-71
Washington State Governor's Commission on Snohomish R. Basin, 1975
International Geographical Union, Commission on Field Experiments in Geomorphology, 1976-84 (Secretary, 1980-84).
Geological Society of America, Committee on the Penrose Medal, 1988-1990; Co-chair of Program Committee for 1994 Annual Meeting.
American Geophysical Union, Committee on the Horton Medal, 1990-1994, (Chair 1992-1994); Union Committee of Fellows (1992-1994)
Oregon State Legislature, Blue Ribbon Panel on Anadromous Fish Populations and Forest Practices, 1993-1995.
State of California Bay-Delta Ecosystem Restoration Program, Scientific Review Panel, 1997.
MEDEA Project on the Use of Remote Sensing in Environmental Analysis, 1997-2000
California Department of Forestry and Fire Protection/Univ. of California Committee on the Scientific Basis on the Prediction of Cumulative Watershed Effects (chair), 1998-2001.
State of Washington Panel on Salmon Conservation Validation Monitoring, 2000.
State of California Bay-Delta Ecosystem Restoration Program Science Board, 2000-2005.
U.S. Fish and Wildlife Service, Adaptive Management Forum for San Joaquin River Restoration, 2001-2003.
Sustainable Ecosystems Institute, Portland, Scientific Panel on the Columbia River Channel Improvement Project, 2001.
State of California Bay-Delta Program Independent Science Board, 2003- 2005(Chair).
Iraq Foundation, Eden Again Project, Technical Advisory Panel on Restoration of the Mesopotamian Marshlands, 2003.
National Academy of Sciences Warren Award Committee (Chair 2004, 2006)
American Institute of Hydrology Award Committees (Theis Award 2006; Linsley Award 2007)
Sustainable Ecosystems Institute, Portland, Scientific Panel to Review the Missouri River Pallid Sturgeon Restoration Project (2008)
National Science Foundation Steering Committee for the Community Surface Dynamics Modeling System (2007-2009)
National Science Foundation, Steering Committee for MARGINS (2008-2009).
National Science Foundation, Review Committee for the Hydrological Synthesis Project (2008-2011)
California Bay-Delta Conservation Program -- Independent Science Advisor on Adaptive Management (2008-2009)
US Department of the Navy, Naval Research Laboratory, Marine Geosciences Division, External Review of Research Program on Battlespace Environments and Undersea Warfare Technology (2009)

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CURRICULUM VITAE

GREGORY T. RUGGERONE

EDUCATION

Ph.D. Fisheries, University of Washington, 1989.
M.S. Fisheries, University of Washington, 1981.
B.S. Biological Sciences, University of California, Irvine, 1978.

EXPERIENCE

1993-present Vice-President, Fisheries Scientist, Natural Resources Consultants, Inc. Responsible for salmon investigations in the Pacific Northwest and Alaska. Affiliated research scientist, Alaska Salmon Program, School of Fisheries, University of Washington.

1990-1993. Principal Fisheries Biologist. University of Washington, Fisheries Research Institute. Project Leader/ Co-PI, Alaska Salmon Program. Responsible for directing several research projects at FRI's Alaska field stations and supervision of graduate students.

1989-1990. Senior Fisheries Biologist. University of Washington, Fisheries Research Institute. Project Leader for the Alaska Salmon Program (see above responsibilities).

1984-1989. Predoctoral Research Associate. University of Washington, Fisheries Research Institute. Project Leader for the Chignik Lakes Salmon Research Program. Responsible for directing research projects and supervision of students.

1982-1984. Fisheries Biologist. Jones & Stokes Associates, Inc. Responsible for environmental studies related to fish and fisheries in Alaska, Washington and California.

1982. Consultant. BioSonics, Inc. Examined juvenile salmon migration at a Columbia River dam using hydroacoustic techniques.

1979-1981. Research Assistant. University of Washington, Fisheries Research Institute. Field research on salmon at the Wood River lakes, Alaska.

1978-1979. Biologist. California Department of Fish and Game. Assisted several marine fisheries projects, including the annual CALCOFI anchovy survey.

1978. Biologist. University of California, Irvine. Department of Ecology and Evolutionary Biology. Received Student-Originated-Studies grant from the National Science Foundation to examine the effects of groundwater removal on natural spring communities in the Owens Valley, CA.

1977-1978. Lab Technician. University of California, Irvine. Department of Ecology and Evolutionary Biology. Field biologist for rocky intertidal studies.

PROFESSIONAL SERVICE

Society Memberships

American Institute of Fishery Research Biologists, NW District Director (1993-1994), Regional Director (1994-1995)
American Fisheries Society

Scientific Referee

Aquatic Living Resources
Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative
American Fisheries Society
Canadian Journal of Fisheries and Aquatic Sciences
First International Symposium on GIS in Fishery Science
Fisheries Oceanography
Fishery Bulletin
Fourth World Fisheries Congress, American Fisheries Society
Gulf of Alaska Ecosystem Monitoring Program (GEM)
Gut Shop 1993
Marine Stewardship Council
National Science Foundation
Nature
North American Journal of Fisheries Management
North Pacific Research Board
North Pacific Anadromous Fish Commission
Marine Stewardship Council
Ohio Sea Grant College Program
Pacific Salmon and Their Ecosystems: Status and Future Options
PICES
Reviews in Fish Biology and Fisheries
Transactions of the American Fisheries Society
West Coast National Undersea Research Center, NOAA

Committees
Science Technical Committee, Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative
Chignik Regional Aquaculture Association, Scientific Advisor
Independent Scientific Advisory Board, Columbia River, Ad Hoc member

AWARDS AND SCHOLARSHIPS

American Institute Fisheries Research Biologists, Research Award, 1992 (Visiting scientist in Russia)
John Cobb Memorial Scholarship, 1989
American Institute Fisheries Research Biologists, Research Award, 1988
Seattle Poggie Club (Fisheries) Scholarship, 1986
National Science Foundation Student-Originated-Studies Grant, 1978
University of California, Irvine President's Council Grant, 1977
Dean's Honor List: 1974, 1975, 1976, 1977

SUPERVISION OF GRADUATE STUDENT RESEARCH

Griffiths, J. 2009. Assessing the implications of changing geomorphology and climate on the habitat characteristics of Black Lake, Alaska. M.S. Thesis. University of Washington, Seattle.

Westley, P. 2007. Biocomplexity and rapid natural habitat change in the Chignik Lake system, Alaska. M.S. Thesis. University of Washington, Seattle.

Chasco, B. 2004. Inseason run size forecasting of Chignik sockeye salmon. M.S. Thesis. University of Washington, Seattle.

Harvey, C.J. 1994. Upstream migration of fishes in Black River, Chignik Lakes, Alaska. M.S. Thesis. University of Washington, Seattle. 154 p.

Bumgarner, J.D. 1993. Long-term trends in the growth of sockeye salmon from the Chignik Lakes, Alaska. M.S. Thesis. University of Washington, Seattle. 86 p.

Hanson, R. 1992. Brown bear (*Ursus arctos*) predation on sockeye salmon spawners in two tributaries of the Wood River Lake system, Bristol Bay, Alaska. M.S. Thesis. University of Washington, Seattle. 124 p.

Berejikian, Barry A.. 1992. Feeding Ecology of Rainbow Trout with Comparisons to Arctic Char in Iliamna Lake, Alaska. M.S. Thesis. University of Washington, Seattle. 72 p.

Zimmermann, M. 1991. Trends in the freshwater growth of sockeye salmon from the Wood River Lakes and Nushagak Bay, Alaska. M.S. Thesis. University of Washington, Seattle. 119 p.

PUBLICATIONS

Journals and Book Chapters

Ruggerone, G.T., J.L. Nielsen, and B.A. Agler. 2009. Linking marine and freshwater growth in western Alaska Chinook salmon, *Oncorhynchus tshawytscha*. Journal of Fish Biology 75: In press.

Ruggerone, G.T., J.L. Nielsen, and B.A. Agler. 2009. Climate, growth and population dynamics of Yukon River Chinook salmon. North Pacific Anadromous Fisheries Commission Bulletin. In Press.

Ruggerone, G.T., and J.L. Nielsen. 2009. A review of growth and survival of salmon at sea in response to competition and climate change. American Fisheries Society Symposium 70: In press.

Ruggerone, G.T., R.M. Peterman, B. Dorner, and K.W. Myers. 2009. Magnitude and trends in abundance of hatchery and wild pink, chum, and sockeye salmon in the North Pacific Ocean. In review.

Ruggerone, G.T., S. Goodman, and R. Miner. 2009. Behavioral response and survival of juvenile coho salmon to pile driving sounds. In review.

Westley, P.A.H., R. Hilborn, T.P. Quinn, G.T. Ruggerone, and D.E. Schindler. 2008. Long-term changes in rearing habitat and downstream movement by juvenile sockeye salmon (*Oncorhynchus nerka*) in an interconnected Alaska lake system. Ecology of Freshwater Fish 17:443-454.

Ruggerone, G.T., J.L. Nielsen, and J. Bumgarner. 2007. Linkages between Alaskan sockeye salmon abundance, growth at sea, and climate, 1955-2002. Deep Sea Research II 54:2776-2793.

Rand, P.S., C.P. Kellon, X. Augerot, M. Goslin, J.R. Irvine, and G.T. Ruggerone. 2007. Comparison of sockeye salmon (*Oncorhynchus nerka*) monitoring in the Fraser River basin, British Columbia, Canada and Bristol Bay, Alaska. North Pacific Anadromous Fish Commission Bulletin 4:271-284.

Nielsen, J.L. and G.T. Ruggerone. 2007. Climate Change and a Dynamic Ocean Carrying Capacity: Growth and Survival of Pacific Salmon at Sea. *Proceedings Pacific Salmon Environment and Life History Models: Advancing Science for Sustainable Salmon.* American Fisheries Society Symposium, Anchorage, AK. September, 2005. In press.

Ruggerone, G.T. and F. Goetz. 2004. Survival of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) in response to climate-induced competition with pink salmon (*O. gorbuscha*). Canadian Journal Fisheries and Aquatic Sciences 61:1756-1770.

Ruggerone, G.T., and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Reviews in Fish Biology and Fisheries. 14:371-390.

Ruggerone, G.T., M. Zimmermann, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbuscha*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fisheries Oceanography. 12:3:209-219.

Nielsen, J. L. and G. T. Ruggerone. 2005. Global change, anthropomorphic effects and nonlinearity in Bering Sea sockeye salmon populations. *In* V.R. Burkett, D. A. Wilcox, R. Stottlemyer, W. C. Barrow, D. B. Fagre, J. Barton, J. Price, J. L. Nielsen, C. Allen, D. L. Peterson, G. Ruggerone, and T. Doyle. Nonlinear dynamics in ecosystem response to climate change: Case studies and resource management implications. Ecological Complexity 2: 357-394.

Ruggerone, G.T., E. Farley, J. Nielsen, and P. Hagen. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (*Oncorhynchus nerka*) in relation to competition with Asian pink salmon (*O. gorbuscha*) and the 1977 ocean regime shift. Fishery Bulletin 103:2:355-370.

Ruggerone, G.T., and D. Rogers. 2003. Multi-year effects of high densities of sockeye salmon spawners on juvenile salmon growth and survival: a case study from the *Exxon Valdez* oil spill. Fisheries Research. 6:379-392.

Quinn, T.P., S.M. Gende, G.T. Ruggerone and D.E. Rogers. 2003. Density dependent predation by brown bears (*Ursus arctos*) on sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 60: 553-562.

Ruggerone, G.T., J. Nielsen, E. Farley, S. Ignell, P. Hagen, B. Agler, D. Rogers, J. Bumgarner. 2002. Long-term trends in annual Bristol Bay sockeye salmon scale growth at sea in relation to sockeye abundance and environmental trends, 1955-2000. North Pacific Anadromous Fish Commission Tech. Rept. 4:56-58.

Ruggerone, G.T., R. Hansen and D. Rogers. 2000. Selective predation by brown bears (*Ursus arctos*) foraging on spawning sockeye salmon. Canadian Journal of Zoology 78:6:974-981.

Ruggerone, G.T. 2000. Differential survival of juvenile sockeye and coho salmon exposed to low dissolved oxygen during winter. Journal Fish Biology 56:1013-1016.

Mahnken, C., G. Ruggerone, W. Waknitz, and T. Flagg. 1998. A historical perspective on salmonid production from Pacific rim hatcheries. North Pacific Anadromous Fish Commission Bulletin 1:38-53.

Harvey, C.J., G.T. Ruggerone, and D.E. Rogers. 1997. Migrations of three-spined stickleback, nine-spined stickleback, and pond smelt in the Chignik catchment, Alaska. Journal of Fish Biology. 50: 1133-1137.

Ruggerone, G.T and C.J. Harvey. 1995. Age-specific use of habitat by juvenile coho salmon and other salmonids in the Chignik Lakes Watershed, Alaska. Pages 45-60 *in* Salmon Ecosystem Restoration: Myth and Reality (M.L. Keefe, ed.). Proceedings of the 1994 Northeast Pacific Chinook and Coho Salmon Workshop. American Fisheries Society. Eugene, OR.

Rogers, D.E. and G.T. Ruggerone. 1993. Factors affecting the marine growth of Bristol Bay sockeye salmon. Fisheries Research 18: 89-103.

Ruggerone, G.T and D.E. Rogers. 1992. Predation of sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: implications for salmon management. North American Journal of Fisheries Management. 12: 87-102.

Ruggerone, G.T. 1992. Threespine stickleback aggregations create potential predation refuge for sockeye salmon fry. Canadian Journal of Zoology 70: 1052-1056.

Ruggerone, G.T. 1992. Predation on sockeye salmon by fish and wildlife in Alaska. Pp. 20-21. In C.D. Levings and G.A. Hunter (eds), An Account of a Workshop on Research Approaches to Predation/Competition Questions in River Fish Communities. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2150.

Rogers, D.E., and G.T. Ruggerone. 1992. FRI forecasts of the 1992 sockeye run to Bristol Bay. Pp. 13-16 *in* 1992 Alaska Salmon Markets, G. Knapp (ed.). University of Alaska, Fairbanks.

Ruggerone, G.T. 1991. Salmon redux (salmon population resilience and habitat in Alaska). BioScience 41: 284.

Ruggerone, G.T. 1991. Partial xanthism in an adult chum salmon (*Oncorhynchus keta*) near Chignik, Alaska. California Fish and Game 77: 55-56.

Ruggerone, G.T, T.P. Quinn, I. McGregor and T.D. Wilkinson. 1990. Horizontal and vertical movements of maturing steelhead trout, *Oncorhynchus mykiss*, in Dean and Fisher channels, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 47: 1963-1969.

Ruggerone, G.T. 1989. Coho salmon predation on juvenile sockeye salmon in the Chignik Lakes, Alaska. Ph.D. Dissertation. University of Washington, Seattle. 151 p.

Ruggerone, G.T. 1989. Gastric evacuation of single and multiple meals by piscivorous coho salmon, *Oncorhynchus kisutch*. Environmental Biology of Fishes 26: 143-147.

Ruggerone, G.T. 1989. Gastric evacuation rates and daily ration of piscivorous coho salmon (*Oncorhynchus kisutch*) Walbaum. Journal of Fish Biology 34: 451-463.

Ruggerone, G.T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115: 736-742.

Perkins, D.J., B.N. Carlsen, R.N. Miller, C.M. Rofer, G.T. Ruggerone, M.F. Fredstrom, and C.S. Wallace. 1984. Effects of groundwater removal on natural spring communities in the Owens Valley, CA. Pp. 515-527 *in* R. E. Warner and K.M. Hendrix, eds. California Riparian Systems: Ecology, Conservation, and Productive Management. University of California Press, Berkeley, CA.

Ruggerone, G.T. and D.E. Rogers. 1984. Arctic char predation on migrating sockeye smolts at Little Togiak River, Alaska. Fishery Bulletin 82: 401-410.

Technical Reports

Rogers, D.E. and G.T. Ruggerone. 1980. Alaska salmon studies: The study of red salmon in the Nushagak District. Ann. Rep. FRI-UW-8019. University of Washington, Seattle. 48 p.

Ruggerone, G.T. 1981. Arctic char predation on migrating sockeye smolts at Little Togiak River, Alaska. M.S. Thesis. Fisheries Research Institute, University of Washington, Seattle. 57 p.

Ruggerone, G.T. 1982. Salmonid habitat quality of 22 creeks in the Mt. Baker/Snoqualmie National Forest, Washington. Prepared for the U.S. Forest Service with Jones & Stokes Associates, Bellevue, WA. 40 p.

Ruggerone, G.T. and R. Denman. 1982. Salmonid spawning and rearing habitat survey: Illabot Creek. Prepared for Seattle City Light with Jones & Stokes Associates, Bellevue, WA. 15 p.

Ruggerone, G.T. 1983. Fishery enhancement potential of the Hanford Reach, Columbia River. Prepared for U.S. Army Corps Engineers, Seattle District, with Jones & Stokes Associates, Bellevue, WA. 64 p.

Van Veldhuizen, H. and G.T. Ruggerone. 1983. Analysis of Ocean Discharge Criteria Evaluation limitations for the St. George Basin (Lease Sale 70, southeastern Bering Sea). Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA.

Van Veldhuizen, H. and G.T. Ruggerone. 1983. Analysis of Ocean Discharge Criteria Evaluation limitations for Navarin Basin (Lease Sale 83, Bering Sea). Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA. 37 p.

Van Veldhuizen, H., J. Cabreza, G.T. Ruggerone and others. 1983. Ocean Discharge Criteria Evaluation: Diapir Field OCS Lease Sale 71 (Arctic Ocean). Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA. 175 p.

Ruggerone, G.T., and M. Green. 1984. San Antonio Creek hydroelectric project: Exhibit E. Application for exemption for a small hydroelectric project from licensing. Prepared for Jones & Stokes Associates, Sacramento, CA. 22 p. 1984.

Ruggerone, G.T. 1984. Review of the Draft EIS (fisheries section) for the Susitna River, Alaska, hydroelectric project. Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA. 41 p.

Van Veldhuizen, H., R. Denman, G.T. Ruggerone and A. Godbey. 1984. Environmental assessment of alternative seafood waste disposal methods at Akutan Harbor, Alaska. Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA. 97 p.

Van Veldhuizen, H., J. Cabreza, G.T. Ruggerone and others. 1984. Ocean Discharge Criteria Evaluation: Gulf of Alaska- Cook Inlet OCS Lease Sale 88 and state lease sales located in Cook Inlet. Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA. 230 p.

Conrad, R.H., and G.T. Ruggerone. 1985. Stock composition of the 1984 sockeye salmon run to the Chignik Lakes estimated using scale patterns and linear discriminant functions. Alaska Dept. Fish and Game Technical Report No. 151. 43 p.

Ruggerone, G.T., and D.E. Rogers. 1986. Chignik Sockeye Studies: Aerial survey of spawning coho salmon along the southern Alaska Peninsula. FRI-UW-8607. University of Washington, Seattle. 40 p.

Ruggerone, G.T., Q. Stober and H. Senn. 1986. An environmental assessment of the resident trout hatchery on the Colville Indian Reservation. Prepared for the Bonneville Power Administration with Jones & Stokes Associates, Bellevue, WA. 59 p. + appendices.

Ruggerone, G.T., B. Smith and S.B. Mathews. 1986. Effects of water flow fluctuations caused by hydropower operations on sport catches of steelhead trout in the Cowlitz River, Washington. Data report prepared for the City of Tacoma.

Van Veldhuizen, H., G.T. Ruggerone and others. 1988. A best professional judgment on Quartz Hill mine tailings disposal in Boca de Quadra, Alaska with reference to Ocean Discharge

Criteria. Final Report. Prepared for the Environmental Protection Agency with Jones & Stokes Associates, Bellevue, WA. 125 pp. + appendices.

Ruggerone, G.T., and D.E. Rogers. 1988. Chignik Sockeye Studies: gastric evacuation rates and daily ration of juvenile coho salmon. FRI-UW-8810. University of Washington, Seattle. 27 p.

Ruggerone, G.T., and D.E. Rogers. 1989. Chignik Sockeye Studies: consumption of sockeye salmon fry by juvenile coho salmon in the Chignik Lakes, Alaska: implications for salmon management.. Ann. Rept. to Nat. Mar. Fish. Serv. FRI-UW-8914. University of Washington, Seattle. 31 p.

Ruggerone, G.T., S.B. Mathews, T. Iverson and R.W. Tyler. 1989. Annotated bibliography: predator control programs and methods for capturing northern squawfish. Pp. 319-354 *in* A.A. Nigro, ed. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia River Basin. Bonneville Power Administration, Portland, OR.

Mathews, S.B., T. Iverson and R.W. Tyler and G.T. Ruggerone. 1989. Evaluation of harvesting technology for potential northern squawfish commercial fisheries in Columbia River reservoirs. Pp. 278-318 *in* A.A. Nigro, ed. Developing a predation index and evaluating ways to reduce salmonid losses to predation in the Columbia River Basin. Bonneville Power Administration, Portland, OR.

Rogers, D.E., and G.T. Ruggerone. 1989. Bristol Bay salmon forecasts for 1990 and statistics of North American salmon. Annual Report to Pacific Seafood Processors Association. University of Washington, Seattle. 21 p.

Ruggerone, G.T., and R. Denman. 1990. Hydrological characterization of lower Alec River and Black Lake near Chignik, Alaska. Progress report to the Chignik Seiners Association. 10 p.

Alverson, D.L., D.E. Rogers, J.A. Crutchfield, D.W. McNair, J.A. June, J.B. Suomala and G.T. Ruggerone. 1990. Preliminary 1987 Cook Inlet oil spill studies. Prepared with Natural Resources Consultants for Faegre and Benson. 136 p.

June, J.A., G.T. Ruggerone and D.E. Rogers. 1990. Report on the upper Cook Inlet 1987 sockeye salmon season. Prepared with Natural Resources Consultants for Faegre and Benson. 56 p.

Rogers, D.E., and G.T. Ruggerone. 1990. Bristol Bay salmon forecasts for 1991 and statistics of North American salmon. Annual Report to Pacific Seafood Processors Association. University of Washington, Seattle. 21 p.

Rogers, D.E., B. Rogers, G. Ruggerone, D. Helton, L. Patterson and M. Zimmermann. 1990. Alaska salmon research. Annual Report (1989) to Pacific Seafood Processors Association. FRI-UW-9002. University of Washington, Seattle. 27 p.

June, J.A., G.T. Ruggerone and D.E. Rogers. 1991. Report on the upper Cook Inlet 1989 sockeye salmon season. Prepared with Natural Resources Consultants for Faegre and Benson. 97 p.

Rogers, D.E., B. Rogers, G. Ruggerone, L. Patterson and M. Zimmermann. 1991. Alaska salmon research. Annual Report (1990) to Pacific Seafood Processors Association. FRI-UW-9101. University of Washington, Seattle. 31 p.

Ruggerone, G.T. 1991. Evidence for morphological and behavioral responses of juvenile sockeye salmon to size-biased predation. Ann. Rept. to Nat. Mar. Fish. Serv. FRI-UW-9107. University of Washington, Seattle. 18 p.

Ruggerone, G.T., D. Helton and D.E. Rogers. 1991. Potential factors influencing the large annual fluctuations of adult sockeye salmon returning to Black Lake, Alaska. FRI-UW-9117. University of Washington, Seattle. 15 p.

Rogers, D.E., and G.T. Ruggerone. 1991. Bristol Bay salmon forecasts for 1992. Annual Report to Pacific Seafood Processors Association. University of Washington, Seattle. 27 p.

Ruggerone, G.T., C. Harvey, J. Bumgarner. and D.E. Rogers. 1992. Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska. FRI-UW-9211. University of Washington, Seattle. 30 p.

Ruggerone, G.T. 1992. Winter ecology of sockeye salmon in the Chignik Lakes, Alaska. FRI-UW-9214. University of Washington, Seattle. 33 p.

Ruggerone, G.T. 1993. 1989 Chignik salmon harvest had there been no *Exxon Valdez* oil spill. Prepared for Exxon Plaintiff's Litigation Joint Venture by Natural Resources Consultants, Inc.

Ruggerone, G.T. 1993. 1989 Balboa-Stepovak harvest had there been no *Exxon Valdez* oil spill. Prepared for Exxon Plaintiff's Litigation Joint Venture by Natural Resources Consultants, Inc.

Ruggerone, G.T., C. Harvey, J. Bumgarner. and D.E. Rogers. 1993. Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 1992. FRI-UW-9302. University of Washington, Seattle. 59 p.

Rogers, D.E., T. Quinn, B. Rogers, and G. Ruggerone. 1993. Alaska salmon research in 1992: Bristol Bay. FRI-UW-9303. University of Washington, Seattle. 36 p.

Ruggerone, G.T. 1993. Winter investigations of salmon in the Chignik Lakes, Alaska, during 1993. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Inc. 41 p.

Ruggerone, G.T., and J. June. 1994. Effects of the *Braer* oil spill on the marine resources of the Shetland Islands. Prepared for the Shetland Seafood Consortium by Natural Resources Consultants, Inc. 120 p.

Denman, R.A., and G.T. Ruggerone. 1994. Effects of beaver colonization on the hydrology and spawning habitat of sockeye salmon in the Chignik Lakes, Alaska. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Inc. 56 p.

Ruggerone, G.T., and D.E. Rogers. 1994. Harvest rates of Upper Cook Inlet-bound sockeye salmon in the Kodiak Management Area's commercial salmon fishery. Prepared for the Kodiak Island Borough Salmon Working Group by Natural Resources Consultants, Inc. 46 p.

Ruggerone, G.T. 1994. Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 1993. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Inc. 111 p.

Ruggerone, G.T. and S. Ralph. 1994. Initial water quality assessment of the Upper Hood Canal Watershed. Prepared for Kitsap County Department of Community Development, Port Orchard, WA. Natural Resources Consultants, Inc. 54 p + appendix.

Ruggerone, G.T., S. Kuchta, D. Bregar, and H. Senn, and G. Morishima. 1995. Database of propagated anadromous Pacific salmon, steelhead and cutthroat trout, 1950-1993. Prepared for the Northwest and Alaska Fisheries Science Center, National Marine Fisheries Service, Seattle, WA.

Ruggerone, G.T. 1995. Investigation of salmon at Enatai Beach Park, Lake Washington. Prepared for the City of Bellevue by Natural Resources Consultants, Seattle, WA. 45 p.

Simpson, P.K., G.T. Ruggerone, M. Freeberg. 1995. Fish return forecasting with neural networks. Phase I Final Report prepared by Scientific Fishery Systems and Natural Resources Consultants for Small Business Innovative Research Program (SBIR), National Science Foundation (DMI-9461197). 29 p.

Ruggerone, G.T. 1995. Preseason forecast of sockeye salmon run timing in Bristol Bay, Alaska, 1995. Prepared for Pacific Seafood Processors Association by Natural Resources Consultants, Seattle, WA. 16 p.

Ruggerone, G.T. 1995. Winter investigations of salmon in the Chignik Lakes, Alaska, during 1995. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Seattle, WA. 51 p.

Ruggerone, G.T. 1996. Evaluation of escapement levels to maximize returns of Kenai River sockeye salmon and maintain habitat quality. Prepared for Kenai River Sportfishing Association, Inc. by Natural Resources Consultants, Seattle, WA. 43 p.

Rogers, D.E., B. Rogers, J. Miller, D. Peterson, and G. Ruggerone. 1996. Chignik Lakes Research: Data summary of historical research. FRI-UW-9608. University of Washington, Seattle. 29 p.

Ruggerone, G.T. and J. June. 1996. Pilot Study: survival of chinook salmon captured and released by a purse seine vessel in Southeast Alaska. Prepared for Southeast Alaska Seiners Association and Purse Seine Vessel Owners' Association. Natural Resources Consultants, Inc. 10 p.

Ruggerone, G.T. 1996. Preseason forecast of sockeye salmon run timing in Bristol Bay, Alaska, 1996. Prepared for Bristol Bay salmon processors by Natural Resources Consultants, Seattle, WA. 18 p.

Ruggerone, G.T. 1997. Straying of coho salmon from hatcheries and net pens to streams in Hood Canal and Grays Harbor, Washington. Prepared for Pacific States Marine Fisheries Commission by Natural Resources Consultants, Seattle, WA. 75 p.

Ruggerone, G.T. 1996. Winter investigations of salmon in the Chignik Lakes, Alaska, during 1996. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Seattle, WA. 46 p.

Ruggerone, G.T. and D.L. Alverson. 1996. Technical review of sockeye salmon studies associated with water diversion in the Nechako River, Fraser River Basin, British Columbia. Prepared for Private Client. Natural Resources Consultants, Inc. 20 p.

Ruggerone, G.T. 1997. Winter investigations of salmon in the Chignik Lakes, Alaska, during 1997. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Seattle, WA.

Ruggerone, G.T. 1997. Preseason forecast of sockeye salmon run timing in Bristol Bay, Alaska, 1997. Prepared for Bristol Bay salmon processors by Natural Resources Consultants, Seattle, WA.

Alverson, D.L., and G.T. Ruggerone. 1997. Escaped farm salmon: environmental and ecological concerns. Prepared for the Environmental Assessment Office, Government of British Columbia, by Natural Resources Consultants, Seattle, WA. 100 p.

Ruggerone, G.T. and J. June. 1997. Pilot Study: survival of chinook salmon captured and released by a purse seine vessel near Sitka, Southeast Alaska. Prepared for Southeast Alaska Seiners Association and Purse Seine Vessel Owners' Association. Natural Resources Consultants, Inc. 15 p.

Ruggerone, G.T. 1997. Genetic Baseline Investigation of Chignik Sockeye Salmon: Operational Plan and Fish Sampling. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Seattle, WA. 15 p.

Ruggerone, G.T. and D.L. Alverson. 1997. Technical review of chinook salmon studies associated with water diversion in the Nechako River, Fraser River Basin, British Columbia. Prepared for Private client. Natural Resources Consultants, Inc. 20 p.

Ruggerone, G.T., and D.E. Rogers. 1998. Historical analysis of sockeye salmon growth among populations affected by large escapements associated with the *Exxon Valdez* oil spill. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 96048-BAA), Natural Resources Consultants, Seattle, WA.

Ruggerone, G.T., J. June, and J. Crutchfield. 1998. Reconstruction of chinook and steelhead runs to the Clearwater River, Idaho, during 1910-1995 and estimated lost tribal harvests associated with Lewiston and Harpster Dams. Prepared for Bogle and Gates by Natural Resources Consultants, Inc.

Ruggerone, G.T. 1998. Preseason forecast of the 1999 Bristol Bay sockeye salmon run adjusted for 1997 and 1998 marine survival conditions. Pp 1-4 *in* The 1999 FRI preseason forecast of the Bristol Bay sockeye run using an alternative approach. FRI-UW-9819. Fisheries Research Institute, University of Washington, Seattle.

Ruggerone, G.T. 1999. Winter investigations of salmon in the Chignik Lakes, Alaska, during 1998. Prepared for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Seattle, WA.

Ruggerone, G.T., R. Steen, and R. Hilborn. 1999. Chignik Salmon Studies: Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 1998. (includes salmon forecast). University of Washington, Fisheries Research Institute. FRI-UW-9907. University of Washington, Seattle.

Ruggerone, G.T. 1999. Temperature effects on salmon in the Green River associated with water removal from the Black Diamond Springs. Prepared for Black Diamond Associates and the City of Black Diamond by Natural Resources Consultants, Seattle, WA.

Ruggerone, G.T. 1999. Abundance and stock origin of coho salmon on spawning grounds of lower Columbia River tributaries. Prepared for Pacific States Marine Fisheries Commission by Natural Resources Consultants, Seattle, WA. 54 p. + appendices.

Ruggerone, G.T. 1999. Photographic documentation of stream scour and sedimentation impacts on coho and chinook salmon redds in lower Columbia River tributaries. Prepared for Pacific States Marine Fisheries Commission by Natural Resources Consultants, Seattle, WA. 18 p.

Ruggerone, G.T. 1999. Potential Effects of the Proposed Cross-Cascade Pipeline on Salmonid Resources. Prepared for Washington State Office of the Attorney General by Natural Resources Consultant, Inc. Seattle, WA. (http://www.efsec.wa.gov/oplarchive/pftarchive.html)

Ruggerone, G.T., R. Steen, and R. Hilborn. 2000. Chignik Salmon Studies: Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 1999. (includes salmon forecast). University of Washington, Fisheries Research Institute. SAFS-UW-2002. University of Washington, Seattle.

Weitkamp, D. and G.T. Ruggerone. 2000. Factors influencing chinook salmon populations in proximity to the City of Seattle. Prepared for the City of Seattle by Parametrix, Natural Resources Consultants, and Cedar River Associates. 224 p. *(International Water Association Award Finalist)*

Ruggerone, G.T. and B. Spelsberg. 2000. Salmon habitat in proximity to the City of Everett and along the Everett water transmission routes. Prepared for the City of Everett by Golder Associates and Natural Resources Consultants, Seattle, WA. 44 p.

Ruggerone, G.T. and B. Spelsberg. 2000. Bull trout habitat in proximity to the City of Everett and along the Everett water transmission routes. Prepared for the City of Everett by Golder Associates and Natural Resources Consultants, Seattle, WA. 44 p.

Ruggerone, G.T. 2001. Estimated Harvest of Natural Salmon and Steelhead by the Skokomish Indian Tribe had the Cushman Hydroelectric Project Not Been Built, 1926-1998. Prepared for Gordon, Thomas, Honeywell, Malanca, Peterson & Daheim, P.L.L.C., Tacoma, WA.

Ruggerone, G.T. 2001. Ability of Salmon and Steelhead to Pass Big Falls on the North Fork Skokomish River Prior to Construction of the Cushman Hydroelectric Project. Prepared for Gordon, Thomas, Honeywell, Malanca, Peterson & Daheim, P.L.L.C., Tacoma, WA.

Ruggerone, G.T. 2001. Effects of water diversion by the City of Bellingham on streamflows in the Lower Middle Fork and Mainstem Nooksack Rivers. Draft. Prepared for Anchor Environmental, Seattle, WA.

Ruggerone, G.T. 2001. Evaluation of Skokomish Bull Trout Status and Historical Migration Over Big Falls, and Effects of Introducing Anadromous and Resident Salmonids into Lake Cushman. Prepared for Tacoma Public Utilities. Tacoma, WA.

Rogers, D.E., B. Rogers, R. Steen, W. Lew, R. Hilborn, G.T. Ruggerone, T. Rogers, C. Boatright, B. Chasco, B. Ernst. 2001. Operations manual for Fisheries research Institute field camps in Alaska. 3rd Edition. School of Fisheries and Aquatic Sciences, University of Washington, Seattle.

Ruggerone, G.T., B. Chasco, and R. Hilborn. 2001. Chignik Lakes Research: Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 2000.

(includes salmon forecast). University of Washington, Fisheries Research Institute. SAFS-UW-0102. University of Washington, Seattle.

Hagen, P., B. Agler, D. Oxman, B. Smoker, G. Ruggerone, J. Nielsen. 2002. Salmon scales as dataloggers: an image analysis approach for data extraction. 2002 *Exxon Valdez* conference, Anchorage, Ak.

Chasco, B., G.T. Ruggerone, and R. Hilborn. 2003. Chignik Lakes Research: Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 2000-2002. (includes salmon forecast). University of Washington, Fisheries Research Institute. SAFS-UW-0303. University of Washington, Seattle. (www.fish.washington.edu/Publications/frireps.html)

Ruggerone, G.T. 2003. Rapid natural habitat degradation and consequences for sockeye salmon production in the Chignik Lakes System, Alaska. SAFS-UW-0309. University of Washington, Seattle. (www.fish.washington.edu/Publications/frireps.html).

Ruggerone, G.T. 2004. Estimated harvests of salmon and steelhead by the Tulalip Indian Tribe had the Everett Diversion Dam (Sultan River) not been built in 1916. Prepared for City of Everett by Natural resources Consultants, Seattle.

Schiewe, M., G. Ruggerone, and P. Schlenger. 2003. Toward an understanding of functional linkages between habitat quality, quantity, and distribution; and sustainable salmon populations: a review of analytical approaches and recommendations for use in WRIA 9. Prepared for WRIA 9 Technical Committee c/o King County Water and Land Resources Division. Prepared by Anchor Environmental LLC and Natural Resources Consultants, Inc. Seattle, Washington.

Nelson, T.S., G. Ruggerone, H. Kim, R. Schaefer and M. Boles. 2004. Juvenile Chinook migration, growth and habitat use in the Lower Green River, Duwamish River and Nearshore of Elliott Bay 2001-2003, Draft Report. King County Department of Natural Resources and Parks. Seattle, Washington.

Ruggerone, G.T., D. Weitkamp, and WRIA 9 Technical Committee. 2004. WRIA 9 Chinook Salmon Research Framework: Identifying Key Research Questions about Chinook Salmon Life Histories and Habitat Use in the Middle and Lower Green River, Duwamish Waterway, and Marine Nearshore Areas. Prepared for WRIA 9 Steering Committee. Prepared by Natural Resources Consultants, Inc., Parametrix, Inc., and the WRIA 9 Technical Committee. Seattle, WA. (ftp://dnr.metrokc.gov/dnr/library/2004/kcr1613.pdf)

Ruggerone, G.T and E. Jeanes. 2004. Salmon utilization of restored off-channel habitats in the Duwamish Estuary, 2003. Prepared for Environmental Resource Section, U.S. Army Corps of Engineers, Seattle District. Prepared by Natural Resources Consultants, Inc. and R2 Consultants, Inc. Seattle, WA.

Ruggerone, G.T. and E.C. Volk. 2004. Residence time and growth of natural and hatchery Chinook salmon in the Duwamish Estuary and Elliott Bay, Washington: an application of otolith chemical and structural attributes. Prepared for U.S. Army Corps of Engineers, Seattle District, and Port of Seattle. Prepared by Natural Resources Consultants, Inc. and Washington Dept. Fish and Wildlife. Seattle, WA.

Ruggerone, G.T. 2004. Pre-season forecast of sockeye salmon migration timing in Bristol Bay, Alaska, based on oceanographic and biological variables. NRC report prepared for North Pacific Research Board, Anchorage, AK. (http://doc.nprb.org/web/03_prjs/r0317_final.pdf)

SAIC, R2, and G. Ruggerone. 2005. Salmonid Presence and Habitat Use in the Lower Duwamish River, Winter 2004/2005. Prepared by SAIC for U.S. Army Corps of Engineers, Seattle District.

Schiewe, M., G. Ruggerone, and P. Schlenger. 2005. WRIA 9 conservation hypotheses: functional linkages phase 2. Prepared for WRIA 9 Technical Committee c/o King County Water and Land Resources Division. Prepared by Anchor Environmental LLC and Natural Resources Consultants, Inc. Seattle, Washington.

Schiewe, M., G. Ruggerone, and P. Schlenger. 2005. Evaluation and assessment of hatchery and wild fish interactions in WRIA 9. Prepared for WRIA 9 Technical Committee c/o King County Water and Land Resources Division. Prepared by Anchor Environmental LLC and Natural Resources Consultants, Inc. Seattle, Washington.

Ruggerone, G.T. 2005. Biological Evaluation: Fishermen's Terminal docks 5 through 10 reconstruction, replacement, and dredging. Prepared by Natural Resources Consultants, Inc. for the Port of Seattle.

Ruggerone, G.T. 2006. Evaluation of salmon and steelhead migration through the upper Sultan River canyon prior to dam construction. Prepared for City of Everett, WA. (http://www.snopud.com/water/relicensing/history/existing/fish.ashx?p=3378)

Ruggerone, G.T. and M.L. Link. 2006. Collapse of Kvichak sockeye salmon production during brood years 1991-1999: population characteristics, possible factors, and management implications. Prepared for North Pacific Research Board and the Bristol Bay Science and Research Institute. Anchorage, AK. (http://doc.nprb.org/web/03_prjs/r0321_final1.pdf)

Ruggerone, G.T. 2006. Abundances of wild and hatchery salmon by region of the Pacific Rim. Draft. Prepared for the Moore Foundation by Natural Resources Consultants, Inc., Seattle, WA.

Ruggerone, G.T., T. Nelson, J. Hall, and E. Jeanes. 2006. Habitat utilization, migration timing, growth, and diet of juvenile Chinook salmon in the Duwamish River and estuary. Prepared by Natural Resources Consultants, Inc. for the King Conservation District and Salmon Recovery Funding Board. ftp://dnr.metrokc.gov/dnr/library/2006/kcr1953.pdf

Gaudet, D. and G.T. Ruggerone. 2007. Forecasting coho salmon run timing in Southeast Alaska. Prepared for the Southeast Sustainable Salmon Fund. Juneau, AK.

Ruggerone, G.T. J.L. Nielsen, and B. Agler. 2007. Retrospective analysis of AYK Chinook salmon growth. Prepared for the Arctic Yukon Kuskokwim Sustainable Salmon Initiative, Anchorage, AK. (http://www.aykssi.org/docs/Project_Docs/Final_Reports/107.pdf)

Chaffee, C., G. Ruggerone, R. Beamesderfer, and L.W. Botsford. 2007. The Commercial Alaska Salmon Fisheries Managed by the Alaska Department of Fish and Game A 5-Year Re-Assessment Based on the Marine Stewardship Council Program. Prepared for Alaska Department of Fish and Game and the Marine Stewardship Council. (http://eng.msc.org/)

Mantua, N.J., N.G. Taylor, G.T. Ruggerone, K.W. Myers, D. Preikshot, X. Augerot, N.D. Davis, B. Dorner, R. Hilborn, R.M. Peterman, P. Rand, D. Schindler, J. Stanford, R.V. Walker, and C.J. Walters. 2007. The salmon MALBEC project: a North Pacific-scale study to support salmon conservation planning. NPAFC Doc. 1060. 49 pp. School of Aquatic and Fishery Sciences,

University of Washington, Seattle, WA 98195-5020, U.S.A.
(http://www.npafc.org/new/publications/Documents/PDF 2007/1060(USA).pdf)

Ruggerone, G.T. 2007. Evaluation of salmon and steelhead migration after a landslide on the Sultan River. Prepared for Snohomish County Public Utility District.

Ruggerone, G.T. 2008. Recolonization of benthic invertebrates after dredging of Fishermen's Terminal, Washington. Prepared for Port of Seattle, WA.

Ruggerone, G.T., S, Goodman, and R. Miner. 2008. Behavioral response and survival of juvenile coho salmon exposed to pile driving sounds. Prepared by Natural Resources Consultants for the Port of Seattle, WA.

Ruggerone, G.T. and B.A. Agler. 2008. Retrospective analysis of AYK chum and coho salmon. Prepared for the Arctic Yukon Kuskokwim Sustainable Salmon Initiative, Anchorage, AK. (http://www.aykssi.org/Research/project_profile.cfm?project_id=124)

Ruggerone, G.T., B. Agler, S. Gilk, D. Molyneaux, D. Costello, D. Young. 2008. Habitat and Growth of River-Type Sockeye Salmon in the Kuskokwim Watershed, Alaska. Prepared for the Arctic Yukon Kuskokwim Sustainable Salmon Initiative, Anchorage, AK.

Ruggerone, G.T., T. Loughlin, and D. Norman. 2009. Biological Assessment: Navy Puget Sound Kinetic Hydropower system (NPS-KHPS) Demonstration Project. In preparation. Prepared by Natural Resources Consultants.

INVITED PRESENTATIONS

The use of salmon scales to test hypotheses about salmon growth, climate, and ocean carrying capacity. 4th International Otolith Symposium, August 24-28, 2009; Monterey, California. Keynote presentation.

Growth and Survival of Salmon in Response to Competition at Sea and Climate Change. State of Salmon 2009 Conference, *Bringing the Future into Focus.* Innovative Approaches to Applying Conservation Principles. February 2-5, 2009. Vancouver, BC

Abundance and relative contribution of hatchery and wild salmon in the North Pacific Ocean. NPAFC International Symposium on the Bering-Aleutian Salmon International Surveys (BASIS): Climate Change, Production Trends, and Carrying Capacity of Pacific Salmon in the Bering Sea and Adjacent Waters. November 23-25, 2008. Seattle, WA, USA

Management Data for Long-term Monitoring of Salmon Growth and Survival versus Climate Change. Long Term Research and Monitoring Project (LRMP), North Pacific Anadromous Fish Commission. April 7-11, 2008. Sokcho, South Korea.

Growth and Survival of Salmon in Response to Competition and Climate Change: Implications for Interactions of Wild and Hatchery Salmon. Symposium: Population Growth, Climate Change and Fish Habitat in the Columbia River Basin. American Fisheries Society Western Division Conference, May 4-9, 2008; Portland, OR.

Climate change, salmon interactions, and implications for salmon recovery. Pacific Salmonid Recovery Conference. November 6-9, 2007. Seattle, WA

Growth and Survival of Salmon in Response to Competition and Climate Change. AYK SSI Symposium on the Sustainability of the AYK Salmon Fisheries. February 6-9, 2007; Anchorage, AK.

Growth and Survival of Salmon in Response to Competition and Climate Change: Implications for Interactions of Wild and Hatchery Salmon. Current Issues Facing Salmon Hatcheries in the Russian Far East. Petropavlovsk-Kamchatsky, Russia. November 30, 2006. Invited by World Wildlife Fund and the Wild Salmon Center.

Growth, Abundance, and Survival of Salmon in Response to Climate Change. World Wildlife Fund, Climate Camp Alaska. Homer, AK. October 30, 2006.

The Kvichak Decline: Is there anything we can do about it? Dillingham & Naknek, AK. October 19 & 20, 2006.

Growth and Survival of Salmon in Response to Competition and Climate Change. AYK SSI Symposium on the Sustainability of the AYK Salmon Fisheries. Anchorage, AK February, 2007.

Survival of Puget Sound chinook salmon in response to climate-induced competition with pink salmon. Lake Washington Salmon Workshop. Seattle, WA. February 2004.

Evidence for Competitive Dominance of Pink Salmon Over Other Salmonids in the North Pacific Ocean. 2003 Annual Meeting of American Fisheries Society Meeting, San Diego, CA. April 2003.

Linkages between climate, growth, competition, and production of sockeye salmon populations in Bristol Bay, Alaska, 1955-2000. USGS Global Change Project Review and Planning Meeting. Phoenix, AZ. March 2003.

Survival, growth, and age at maturation of Puget Sound chinook salmon released during odd- versus even-numbered years: evidence for interspecific competition with pink salmon during early marine life. Northwest and Alaska Science Center, NMFS, Seattle, WA. November 2002.

Differential Marine Growth of Sockeye Salmon During Odd and Even Years: Evidence for Density-Dependent Effects of Asian Pink Salmon Abundance on Bristol Bay Sockeye Salmon, 1955-1997. Bristol Bay Salmon Science Symposium, Dillingham, Alaska. May 2001.

Abundance and stock origin of coho salmon on spawning grounds of lower Columbia River tributaries and photographic documentation of habitat disruption. Presentation to Columbia River Coho Salmon Working Group (NMFS, WDFW, ODFW). Portland, OR. February 1999.

Effects of farmed salmon on wild salmon stocks in the Pacific Northwest. Pacific International Council for the Exploration of the Sea (PICES). Fairbanks, AK. October, 1998.

Historical Growth of Sockeye Salmon Affected by Large Spawning Escapement in 1989. 1998 *Exxon Valdez* Restoration Workshop. Anchorage, AK, January 1998.

Past, present and future of salmon runs in the Chignik Lakes, Alaska. First Annual Conference of the Alaska Peninsula. Chignik Lake, AK. February 1997.

Factors influencing the survival of sockeye salmon in Alaska. Presentation to the Coastal Zone and Estuarine Studies Division, National Marine Fisheries Service. Seattle, WA. March 1995.

Age-specific use of habitat by juvenile coho salmon in the Chignik Lakes Watershed, Alaska. 1994 Northeast Pacific Chinook and Coho Salmon Workshop. Salmon Ecosystem Restoration: Myth and Reality. Eugene, OR. November 1994.

Preseason and inseason forecasts of sockeye salmon returning to Bristol Bay, Alaska. The 7th Annual Bristol Bay Fisheries Conference. Dillingham, AK. April 1992.

Preseason and inseason forecasts of sockeye salmon returning to Bristol Bay, Alaska. The 6th Annual Bristol Bay Fisheries Conference. Dillingham, AK. April 1991.

Influence of predation on salmon populations. School of Fisheries, University of Washington. Seattle, WA. May 1991.

Predation on sockeye salmon by fish and wildlife in Alaska. Department Fisheries and Oceans Canada. Cultus Lake, British Columbia. February 1991.

Preseason forecast of Bristol Bay salmon runs, 1990. The 5th Annual Bristol Bay Fisheries Conference. Dillingham, AK. April 1990.

Predator-prey interactions and fisheries management. Joint Institute for Marine and Atmospheric Research and National Marine Fisheries Service Seminar. Honolulu, HI. July 1989.

CONFERENCE AND SEMINAR PRESENTATIONS

The salmon MALBEC project: a North Pacific-scale study to support salmon conservation planning. American Fisheries Society North Pacific International Chapter Annual Meeting. Tacoma, WA. June 6-8, 2007. Introduction presented by N. Mantua.

Hatchery Versus Wild Salmon Production in the North Pacific Ocean. American Fisheries Society North Pacific International Chapter Annual Meeting. Tacoma, WA. June 6-8, 2007.

Hatchery Versus Wild Salmon Production in the North Pacific Ocean. 9th Salmon Ocean Ecology Meeting. Newport, OR. March 14-16, 2007.

Ocean Climate Change and Collapse of the World's Largest Sockeye Salmon Population. 9th Salmon Ocean Ecology Meeting. Newport, OR. March 14-16, 2007.

Salmon MALBEC: Model for Assessing Links Between Ecosystems. (N. Taylor- presented). 9th Salmon Ocean Ecology Meeting. Newport, OR. March 14-16, 2007.

Retrospective Analysis of Yukon and Kuskokwim Chinook Salmon Growth. AYK SSI Symposium on the Sustainability of the AYK Salmon Fisheries. Anchorage, AK. February 6-9, 2007.

Growth and survival of salmon in response to climate change, competition, and a dynamic ocean carrying capacity. Global Challenges Facing Oceanography and Limnology. American Society of Limnology and Oceanography, June 2006.

Salmon age structure and variable resilience of Bristol Bay sockeye salmon to climate change. Pacific Salmon Environment and Life History Models: Advancing Science for Sustainable Salmon in the Future. 135th Annual Meeting American Fisheries Society, September 2005.

Growth and survival of salmon in response to climate change and a dynamic ocean carrying capacity. The Evolution and Ecology of Biocomplexity as Key to Fisheries Sustainability. 135th Annual Meeting American Fisheries Society, September 2005.

Linkages between climate, growth at sea, and abundance of sockeye salmon in Bristol Bay, Alaska, 1955-2000. GLOBEC Symposium: Climate Variability and Sub-Arctic Marine Ecosystems. Victoria, B.C. May 2005.

Survival and Growth of Puget Sound Chinook Salmon in Response to Climate-induced Competition with Pink Salmon: Implications for Habitat Protection and Restoration. Sustainability and Restoration: a practical partnership for the 21st. Society for Ecological Restoration. Seattle, WA. April, 2005.

Top-down and bottom-up linkages among climate, growth, competition, and production of sockeye salmon populations in Bristol Bay, Alaska, 1955-2000 (S2-2068). North Pacific Marine Science Organization (PICES) 13th annual meeting. Honolulu, HI. (Presented by J. Nielsen). October, 2004.

Survival of Puget Sound chinook salmon in response to climate-induced competition with pink salmon. Northwest Salmonid Recovery Conference. Seattle, WA. October, 2004.

Linkages between climate, growth, competition, and production of sockeye salmon populations in Bristol Bay, Alaska, 1955-2000. Study of Environmental Arctic Change (SEARCH) open science meeting, Office of Polar Processes, National Science Foundation. Seattle, WA. (Presented by J. Nielsen). (http://siempre.arcus.org/4DACTION/wi_pos_displayAbstract/7/601). October 2003.

Survival, growth, and age at maturation of Puget Sound chinook salmon released during odd- versus even-numbered years: evidence for interspecific competition with pink salmon during early marine life. 5th Annual Salmon Ocean Ecology Meeting. Newport, OR. February, 2003.

Seasonal marine scale growth of Bristol Bay sockeye salmon during odd- and even-numbered years: evidence for competition with Asian pink salmon and seasonal food web dynamics in the North Pacific Ocean and Bering Sea. 5th Annual Salmon Ocean Ecology Meeting. Newport, OR. February, 2003.

Long-term trends in annual Bristol Bay sockeye salmon scale growth at sea in relation to sockeye abundance and environmental trends, 1955-2000. 4th Annual Salmon Ocean Ecology Meeting, 15-16 January, 2002, Santa Cruz, CA.

Differential Marine Growth of Sockeye Salmon During Odd and Even Years: Evidence for Density-Dependent Effects of Pink Salmon Abundance on Nushagak Bay and Chignik Sockeye Salmon, 1955-1997. Pink and Chum Salmon Workshop. University of Washington, Seattle. March 2001.

Natural Habitat Degradation in a Major Salmon Watershed: A Lesson in Salmon Population Resilience and Decline. Washington Lakes Protection Association Conference. SeaTac, WA 2000.

Historical analysis of sockeye salmon growth among populations affected by large escapements associated with the Exxon Valdez oil spill. Legacy of an oil spill: ten years after the Exxon Valdez oil spill. Anchorage, AK. March 1999.

A historical perspective on salmonid production from Pacific rim hatcheries. First Symposium of the North Pacific Anadromous Fish Commission. Hokkaido, Japan. w/ C. Mahnken, NMFS. October 1996.

Factors influencing the survival of salmon in Alaska and the Pacific Northwest. Visitation Retreat & Cultural Center, City of Federal Way, WA. October 1995.

The application of remotely-sensed data to salmon harvest management and operational planning of the salmon industry in Alaska. Third Thematic Conference: Remote Sensing for Marine and Coastal Environments. Seattle, WA. September 1995.

Initial water quality assessment of the Upper Hood Canal Watershed. Presentation to the Upper Hood Canal Watershed Management Committee. Seabeck, WA. November 1994.

Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 1993. Chignik Regional Planning Team. Anchorage, Alaska. December 1993.

Population dynamics and winter ecology of sockeye salmon. 1993 Sockeye-Kokanee Workshop. Richmond, British Columbia. March 1993.

Long-term trends in the growth of sockeye salmon from the Chignik Lakes, Alaska. 1993 sockeye-kokanee workshop. Presented by J. Bumgarner. Richmond, British Columbia. March 1993.

Migrations of juvenile sockeye salmon and other fishes into and out of Black Lake, AK. Chignik Regional Aquaculture Association. Everett, WA. December 1992.

Factors affecting the early marine growth of Bristol Bay sockeye salmon. Workshop on the growth, distribution, and mortality of juvenile Pacific salmon in coastal waters. Sidney, British Columbia. October 1992.

Migrations of juvenile sockeye salmon and other fishes into and out of Black Lake, AK. Chignik Regional Planning Team. Anchorage, AK. October 1992.

Sockeye salmon run fluctuations and winter habitat quality of Black Lake, Ak. Chignik Regional Planning Team. Anchorage, AK. April 1992.

Habitat and sockeye salmon dynamics in a unique Alaskan lake. The 54th Annual Meeting of Pacific Fishery Biologists. Semi-am-hoo Resort, Blaine, WA. March 1992.

Responses of juvenile salmon to low oxygen levels in Black Lake during February 1992 and the forecast of adult sockeye returning to Chignik in 1992. Chignik Seiners Association, Shilshole Marina, Seattle, WA. March 1992.

The Alaska Salmon Program of the Fisheries Research Institute, University of Washington. Poster presentation at FISH EXPO 1991. Seattle, WA. October 1991.

Enhancing harvests of Chignik salmon through predator control and habitat rehabilitation: a cost-benefit analysis. Chignik Seiners Association. Seattle, WA. January 1991.

Rehabilitation and enhancement of sockeye salmon returning to Black Lake, Alaska. Chignik Regional Aquaculture Association. Seattle, WA. November 1990.

Factors influencing the large fluctuations of adult sockeye returning to Black Lake, Alaska: results of the 1990 winter investigation. Chignik Seiners Association. Chignik, AK. June 1990.

Bycatch of Pacific salmon by the domestic trawl fishery. The 5th Annual Bristol Bay Fisheries Conference. Dillingham, AK. April 1990.

Salmon projects of the Fisheries Research Institute in Alaska. Annual Meeting of the National Food Processors Association. Seattle, WA. March 1990.

Predator impacts on salmon populations. Annual Meeting of the National Food Processors Association. Seattle, WA. March 1989.

Threespine stickleback (Gasterosteus aculeatus) *aggregations as a refuge from predation for sockeye salmon fry* (Oncorhynchus nerka). National meeting of the Animal Behavior Society. Missoula, MO. August 1988.

Forecasts of Chignik salmon and the effects of predation by coho on sockeye survival in the Chignik Lakes, Alaska. Presentation to the Chignik Seiners Association and salmon processors. Chignik, AK. June 1988.

Salmon forecasts and research activities of the Fisheries Research Institute in the Chignik Lakes, Alaska. Presentation to the Chignik Seiners Association and salmon processors. Chignik, AK. June 1987.

Evaluation of the fisheries monitoring program to determine effects of the proposed Navy Home Port, Everett, WA. Presentation to Engineers and Navy personnel. Federal Way, WA. Oct. 1987.

Salmon forecasts and research activities of the Fisheries Research Institute in the Chignik Lakes, Alaska. Presentation to the Chignik Seiners Association and salmon processors. Chignik, AK. June 1986.

Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Meeting of the Northwest Chapter, American Fisheries Society. Bellingham, WA. March 1986.

Alaska salmon research by the University of Washington. Seattle Poggie Club. Seattle, WA. April 1986.

Predator-prey interactions of piscivorous coho salmon and juvenile sockeye salmon in the Chignik Lakes, Alaska. Fisheries Research Institute Seminar, University of Washington. October 1986.

Salmon Research in Alaska: Past, Present, and Future. Organized seminar series at Fisheries Research Institute, University of Washington. October- December, 1986.

Salmon forecasts and research activities of the Fisheries Research Institute in the Chignik Lakes, Alaska. Presentation to the Chignik Seiners Association and salmon processors. Chignik, AK. June 1985.

EXPERT WITNESS TESTIMONY

Dam effects on salmon	Reconstructed salmon harvests by Tulalip Tribe had Sultan Diversion Dam not been built in 1916. Estimated fish passage through high gradient cascades. (case mediated & settled, 2005).
Exxon Valdez Oil Spill	Effects of oil spill on salmon tenders in Alaska (deposition, case settled) 2003.
Skokomish Tribe v. Tacoma Power	Tribal harvests had the dams not been built, 1926-1998. Ability of salmon to pass Big Falls prior to inundation by reservoir. (report, deposition, case removed in summary judgment) 2001.
Salmon Forecast Accuracy	Preseason and inseason run size forecast accuracy; insurance claim for 1998 Bristol Bay run failure (report, case settled) 2000.
Calkins v. Burger King	Probability of biotoxin accumulation in pollock from the Bering Sea (report, case settled) 2000-2001.
Proposed Cross Cascade Pipeline	Effects of refined oil pipeline on salmon and habitat (report, deposition, pipeline explosion ended proposed pipeline) 1999.
Dam Effects on Salmon	Chinook and steelhead runs reconstructed to estimate historical (85 yr) runs and harvests had dams not been built. (report, mediation settlement) 1998.
Exxon Valdez Oil Spill	Effects of oil spill on salmon harvests in Alaska (reports, deposition, trial testimony) 1994.
Glacier Bay Oil Spill	Effects of oil spill on salmon harvests in Cook Inlet, Alaska (report, deposition) 1989.
Touchet River Chemical Spill:	Effects of ammonia spill on salmonids in Touchet River, WA (deposition) 1983.

APPENDIX B
Panel Review Questions

General Questions for Klamath Review Panels

As part of the Secretarial Determination on the removal of four lower dams on the Klamath River, expert panels will be asked to conduct a scientific assessment. The panels will be asked to determine the most likely effects of the two proposed alternatives on the harvest of selected fish species, mostly salmonids. The two alternatives are:

No Action: No change from current management conditions, which includes ongoing programs under existing laws and authorities that contribute to the continued existence of listed threatened and endangered species and Tribal Trust species. This Alternative would be realized if a negative determination is made. This Alternative is referred to herein as the Current Conditions Alternative (Hamilton et al. 2010a).

Proposed Action: Removal of the lower four Klamath River dams and the full range of actions/programs to implement the Klamath Basin Restoration Agreement (KBRA). This Alternative would be realized if a positive determination is made. This Alternative is referred to herein as the Dams-out Alternative.

The products or opinions from the panels will be used by the Economic Sub Team to evaluate the economics of the fisheries. In response to the needs for economic evaluation, the Biological Sub Team included questions of a quantitative nature that would be useful in the evaluation of salmonid fisheries enhancement as required in the Klamath Hydropower Settlement Agreement (KHSA). Inasmuch as the KBRA is part of an alternative under review, we used the broad definition of fish from the KBRA to mean: "the historic complement of species (including races) of fish that naturally occupied the Klamath River Basin". Furthermore, the KBRA defined harvest opportunities to mean: full participation in Tribal, ceremonial, and commercial, ocean-commercial and recreational harvest; and inriver recreational harvest opportunities for anadromous fish species. The time period for the evaluation of the alternatives is 50 years from 2012 to 2062.

We will pose general questions and species-specific questions to the panels. The species specific questions might address a life history attribute or habitat requirement unique to that species. General questions fall into two themes. The first theme examines future habitat conditions and the second theme the viability of fish populations associated with those habitat conditions. Selected questions on habitat address hydrology, water quality, habitat, habitat restoration, ecosystem function, and climate change. The second theme is the biological viability of fish populations as indicated by criteria such as those proposed by Williams et al. (2008): 1) abundance, 2) productivity, 3) diversity, and 4) spatial structure. We propose to use these criteria because they are a conceptually intuitive link to salmonid population size, to the recovery of ESA listed species, and to the potential for harvest resulting in an economic or cultural benefit.

The signatories to the KBRA acknowledged the federal ESA listed status of coho salmon, Lost River and shortnose suckers, and bull trout and the Biological Sub Team recognizes those species have been subject to prior ESA reviews. While the earlier reviews create a data rich record, we encourage the panels to conduct a diligent review of the best available information on each of the species with respect to the two alternatives and the 50 year time horizon which are unique to this review process. Furthermore, we recognize the incongruous nature of the current listing status and the request of projections of future harvest opportunities, but do the best you can.

Ideally, each projection of the fish population abundance, harvestable fraction, and spawning escapement would be provided on an annual basis over the 50 year analytical horizon with some estimate of uncertainty. While such a quantitative estimate may be ideal for economic analysis, the Biological Sub Team and Economics Sub Team recognize projection of fish population abundance may be largely unachievable for most of the species reviewed. Our expectations are that in lieu of quantitative estimates, ranked value of abundance or an expression of change such as "two fold increase" could be used. Also useful is the trajectory of population abundance over time, such as declining or increasing under each of the proposed alternatives. Furthermore, if mileposts along the 50 year timeline marking significant events such as the salmonid populations reaching self-sustaining status, a harvestable surplus, or escapement goals can be identified, then these can be applied to further analysis. Because all ecosystem components can not be quantified, the review panels are encouraged to express qualitative values when predicting quantitative values is not prudent.

Questions:

1) Geomorphology: The two alternatives will result in very different geomorphic dynamics of the Klamath River down stream of Keno Dam. We recognize that the dams are associated with bed starvation of gravels and removal of dams may mobilize sediments over the short-term and over decades. How will alternatives affect geomorphology in the short-term (1-2 years) and over the 50 year period of interest? Included in this question are the potential effects of KBRA restoration activities on geomorphology of tributaries throughout the Klamath Basin and subsequent effects on harvestable populations of fish. What are the expected short-term effects of dam removal on the fish abundance and how long will it take these populations to return to baseline levels?

2) Water quality: The panels will be provided with information on numerous water quality issues from throughout the basin including dissolved oxygen, pH, ammonia, blue green algae, microsystin toxin, phosphorus loading, and Total Maximum Daily Loads (TMDL). Water quality in the Klamath Basin presents a multiplicity of challenges to restoration of fish populations. The Stakeholders and Water Quality Subgroup will provide some insight concerning the likely trends in water quality during the 50 year period of interest. Under these water quality scenerios, how will the two alternatives differ in reaching the goal of harvestable fish populations?

3) Water temperature: If reviewers consider the broad distribution of salmonids, salmonids in the Klamath River Basin are at the southern limit of their range.

Furthermore, the removal of dams is predicted to alter the seasonal pattern of water temperatures with higher spring and summer temperatures and cooler fall water temperatures. What are the likely effects of the water temperature regimes under the two alternatives on rearing, spawning, and use of thermal refugia by native salmonids that might be manifest in harvestable fish?

4) Habitat and restoration (KBRA): Habitat is essential to productive fish populations and the stakeholders have recognized this critical linkage in the crafting of the Klamath Basin Restoration Agreement. The review panel will receive information on the use of Ecosystem Diagnosis and Treatment (EDT) method for tributaries above Upper Klamath Lake and the 2-D model of mesohabitats in the project reach to estimate aquatic habitat under the two alternatives. In addition, the panel will be provided a description of KBRA effects on habitat in the Klamath River Basin. The two proposed alternatives will result in different paths and timelines for habitat management. What are the likely effects of the two alternative habitat management paths on the recovery of ESA-listed fish or in the level of harvest of fish populations?

5) Climate change: We recognize a high level of uncertainty is associated with climate change during the 50 year period we are studying for the Secretarial Determination. The review panel will receive information on predicted hydrology and temperature for several climate change scenarios that have been downscaled for the Klamath River Basin. To what extent might potential changes in habitat, the hydrograph, and thermal refugia mitigate the effects of climate change under the two alternatives? What are the likely effects of climate change on the harvest levels of fish under the two alternatives.

6) Abundance: How will the two alternatives affect abundance of the fish population and what are the expectations for the enhancement of the fisheries? This question may have several milestones along a timeline or population trajectory. For example, inasmuch as some fish populations have been extirpated from the upper Klamath Basin for more than 90 years, when might fish be available for tribal ceremonial use within the upper Klamath Basin? Using a time trajectory, when will a sustainable fishery start and at what levels? We recommend the Panel consider abundance at different time scales ranging from seasonal, inter-annual, and to decadal trends. Economic concerns are that extreme variation in fish populations can affect economic stability of fisheries and fishing communities or slow recovery of fish populations and will delay any economic benefits.

7) Productivity: The metrics of productivity of fish populations may be measured several different ways. These methods include: 1) number of recruit spawners produced per parent spawner at low abundance, 2) juvenile outmigrants per adult spawner, or 3) redd counts per redd count of the previous generation. Each of these examples may be expressed through commonly used stock-recruitment models, such as the Beverton-Holt or Ricker curves. We recognize that conditions resulting from the proposed alternatives may not restore fish productivity to levels associated with historical pristine conditions. What are the most likely expectations for productivity over time and what is the effect of productivity on the number of harvestable fish? (role of hatcheries and productivity?)

8) Diversity: Diversity refers to the variation in phenotypic characteristics such as individual size, fecundity, run timing, and life history patterns of fishes. Collective diversity of groups of subpopulations will reflect the diversity in the selective environments across the range of a fish species. The diversity enables the individuals to respond to changes resulting from subtle to catastrophic events across space and time. For populations lacking diversity the seasonal availability of adult (harvestable) fish to fisheries might result in very short and highly regulated harvest seasons. Historically, diversity of the salmonid populations may have been an important determinant of the seasonal patterns of harvest, the range in size of harvestable adults, and perhaps other characteristics of the fisheries. What will the effect of the two alternatives be on diversity of fish populations? How will the resulting diversity be manifest in the harvestable population of fish? How will potentially low baseline populations and/or introductions of hatchery fish affect diversity under the two alternatives?

9) Spatial structure: Spatial structure of the fish populations refers to the distribution of fish in various habitats used throughout their life history. Spatial structure enables fish populations to respond to localized catastrophic events across the landscape or to long-term changes in the environment. For a fishery, spatial structure of the population may stabilize the opportunity to produce harvestable fish. Will the two alternatives result in improved spatial structure of fish populations and to what extent is that improved structure likely to result in harvestable fish?

10) Ecosystem restoration: Numerous small dams across the U.S. have already been removed and several large dams in the West such as the Elwha Dam (105 ft) and Glines Canyon Dam (210 ft) in Washington State are scheduled for removal in the future. The goals of these dam removal projects range from restoring volitional movement of fish to restoration of entire ecosystems. One of the goals of the KBRA is to restore and maintain ecological functionality and connectivity of historic fish habitats. However, in most drainages, in addition to dams, widespread degradation of habitat and other forms of human perturbations have contributed to the decline of harvestable populations of salmonids. The signatories to the KHSA recognized that dam removal on the Klamath River is perhaps not a panacea for restoration of fisheries, and therefore also proposed the restoration activities of KBRA in an attempt to provide participation in harvest opportunities for fish species. How do the proposed alternatives address ecosystem function and connectivity sufficiently to recover the lost harvest opportunities of fish populations?

Literature Cited:

Hamilton, J., R. Quinones, D. Rondorf, K. Schultz, J. Simondet, S. Stressor. 2010. Biological synthesis for the Secretarial Determination on potential removal of the lower four dams on the Klamath River. Biological Subgroup for Secretarial Determination. Draft May 27, 2010. 128 pp.

Williams, T.H., et al. 2008. Framework for assessing viability of threatened coho salmon in the Southern Oregon/Northern California Coast Evolutionary Significant Unit. NOAA-TM-NMFS-SWFSC-432 NOAA Technical Memorandum NMFS:113.

Questions for Review Panel on Lamprey in the Klamath River Basin

The following questions were prepared for the Secretarial Determination to serve as guidance to the review panel on anadromous and non-anadromous endemic lampreys of the Klamath River Basin. The questions below are intended to be specific to one or more endemic species of lamprey in the Basin. The questions may be considered along with a set of general questions provided to each of the four panels convened for the Secretarial Determination. The questions are not in order of priority and are not intended to constrain the discussion by the review panel or limit the final product.

1) Endemic lamprey diversity: Hamilton et al. 2010a listed six species of native lamprey in the Klamath Basin in a recent report synthesizing the information on the Klamath River. The species diversity of lamprey in the Klamath River Basin is relatively high compared to the 20 recognized species in North America listed in Mesa and Copeland (2009; 4 species of 20 Table 1). The complexity of speciation in lampreys is further evident in Docker et al. (2009) where they review the concept of paired species in parasitic forms of lampreys that feed as adults and non-parasitic forms that apparently do not. Given the relatively high number of species, but limited knowledge on some species of lamprey in the Klamath Basin, can conclusions such as the percent increase or decrease in abundance of individual lamprey species be drawn for the two proposed alternatives over a 50 year period? If distribution and abundance information is inadequate to reach conclusions about individual species, can an alternative grouping such as anadromous and non-anadromous species be used to draw conclusions regarding the affect of the two alternatives upon the abundance and spatial distribution of these groupings: whether these conclusions be quantitative (i.e., percent increase or decrease) or a more qualitative anticipated trajectory?

2) Lamprey harvest: Harvest of Pacific lamprey has played an important part in the ceremonial and subsistence harvest by Tribal members in the Northwest (Close et al. 2004). Native people of the Klamath River Basin have harvested Pacific lamprey, locally known as “eel”, for thousands of years. In a recent review, Petersen Lewis (2009) described the traditional ecological knowledge of the Pacific lamprey and the harvest by the Yurok and Karuk Tribes in the middle and lower Klamath River. Petersen Lewis (2009) also attempted to quantify the precipitous decline in the number of Pacific lamprey harvested in the last 40 years. The KBRA defined harvest opportunities to mean: full participation in Tribal, ceremonial, and commercial, ocean-commercial and recreational harvest; and inriver recreational harvest opportunities for anadromous fish species. What is the most likely effect of the two proposed alternatives during the 50 year period on the harvestable population of Pacific lamprey?

3) Fish Passage: Significant progress has been made during the last decade in understanding the fish passage requirements of adult Pacific lamprey at Columbia River hydroelectric dams (Moser and Mesa 2009). However, the efficacy of downstream fish passage for ammocoetes and macrophthalmia of Pacific Lamprey through reservoirs and past dams has not been well documented (Table 1). Juvenile passage devices designed to safely pass juvenile salmon at dams may provide inadequate passage for macrophthalmia

of Pacific Lamprey based on our current knowledge. For the no action alternative on the Klamath River, dams would remain in place and generally with the current fish passage capabilities. Please compare and contrast the likely response of Pacific lamprey populations under the two proposed alternatives with respect to adult and juvenile lamprey passage.

4) Riverine processes: Dams and their associated impoundments usually reduce the frequency of mobilization of sediments, starve rivers of sediment, alter the flood plain, and create a more incised channel in rivers downstream (Table 1). A Subgroup will present information on the sediment loads and frequency of mobilization of sediments under the two proposed alternatives for the Klamath River. The life history of lamprey is closely linked to stream sediments during the larval rearing and spawning stages. During the larval or ammocoete stage of their life history, lampreys rear and use burrows in the fine sediments of streams and rivers. We expect the Dams-out Alternative will affect the sediment budget and geomorphology of the main stem Klamath River by dam removal and restoration of tributaries primarily through KBRA. Given the relation between the lamprey and their dependence on the use of sediments for rearing and spawning, what is the likely effect of the two alternatives on the abundance of lamprey over the 50 year period?

5) Water Temperatures: The review panel will be presented with predictions for water temperatures in the Klamath River on time scales ranging from seasonal and annual to decadal changes under several climate change scenarios for the two proposed alternatives. We hypothesize lamprey ammocoetes may have limited mobility but must find acceptable food resources, temperature, and sediments to successfully rear in tributaries and streams. Furthermore, Meeuwig et al. (2005) identified onset of death and deformation of eggs and ammocoetes at about 22 C in the laboratory. What are the risks or benefits to lamprey abundance associated with water temperatures under the two proposed alternatives?

6) Ecosystem function: The Klamath Hydropower Settlement Agreement identifies the restoration of salmonid fisheries with a harvestable population as a metric for the two proposed alternatives. To evaluate the two alternatives, habitat predictions for salmonid populations are being developed using the Ecosystem Diagnosis and Treatment (EDT) method for tributaries upstream of Upper Klamath Lake and using a 2-D model of mesohabitats for the impounded reaches of the four dams. Many activities related to habitat restoration under the KBRA are aimed at restoring or increasing harvestable populations of salmonids by restoring a functioning ecosystem. Given these habitat predictions for salmonid populations under the two alternatives, what inferences can be drawn about the likely population response of lamprey in the 50 year period of interest? If a more functional ecosystem is restored under the action alternative, what percent change (or more qualitative trajectory) in lamprey abundance can be expected after 50 years compared to the no action alternative.

7) Extirpation, re-colonization, and reintroduction: We know that Pacific lamprey have been extirpated from parts of the historical range in the Northwest, and that may be true for some endemic species of lamprey in the Klamath River Basin. Some evidence indicates that spawning adult lamprey may cue on pheromones released by ammocoetes to select spawning areas (Robinson et al. 2009). If lamprey are extirpated from reaches of river systems and the pheromones released by ammocoetes are absent, then the mechanism of re-colonization may be uncertain. An alternative may be to re-introduce sexually mature adult lamprey to areas that are currently inaccessible, such as has been done on the Umatilla River (Close et al. 2004). What are the timelines and population trajectories of lamprey re-colonization under the two proposed alternatives in river reaches where lampreys have been extirpated? What percent of the area where Pacific lamprey are currently extirpated will be re-colonized under the two alternatives at the end of the 50 year period?

8) Marine hosts: Marine hosts of Pacific lamprey, such as Pacific salmon and Pacific hake, have declined significantly in abundance during the last century (Table 1). The effects of the declines of host species on Pacific lamprey is not well documented, but the decline may effect lamprey survival, growth, and perhaps reproductive success. Similarly, decadal changes in ocean conditions that have affected salmon may also affect Pacific lamprey. Given that the ocean phase of the life history of Pacific lamprey has many uncertainties, what are the risks and benefits that might result from the two proposed alternatives?

9) Non-native species: Non-native aquatic species are associated with the decline of threatened and endangered species in many areas (Sanderson et al. 2009). Furthermore, in the Northwest, impoundments often create habitats that non-native bass, sunfish, walleye and catfish have colonized (Table 1). Ammocoetes and macrophthalmia may be vulnerable to predation by non-native fish species, particularly in highly modified habitats such as reservoirs. Under the no action alternative reservoirs would remain upstream of the four dams and under the action alternative the reservoirs would be removed. Do non-native fish species represent a survival risk or a possible limiting factor for endemic lamprey in the project area? What is the likely effect of the two proposed alternatives on non-native species and their interactions with lamprey?

Literature Cited

Close, D.A.,A.D. Jackson, B.P. Conner, and H.W. Li. 2004. Traditional ecological knowledge of Pacific lamprey (*Entosphenus tridentatus*) in northeastern Oregon and southeastern Washington from indigenous people s of the Confederated Tribes of the Umatilla Indian Reservation. Journal of Northwest Anthropology 38(2):141-162.

Close, D.A., K.P. Currens, A. Jackson, A.J. Wildbill, J. Hansen, P. Bronson, and K. Aronsuu. 2009. Lessons from the reintroduction of a noncharismatic, migratory fish: Pacific lamprey in the upper Umatilla River Oregon. Pages 233-253 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, P.B. Moyle. Editors. biology, management, and conservation of lampreys in North America. American Fisheries Society Symposium 72.

Docker, M.F. 2009. A review of the evolution of nonparasitism in lampreys and an update of the paired species concept. Pages 71-114 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, P.B. Moyle. Editors. biology, management, and conservation of lampreys in North America. American Fisheries Society Symposium 72.

Hamilton, J., R. Quinones, D. Rondorf, K. Schultz, J. Simondet, S. Stressor. 2010. Biological synthesis for the Secretarial Determination on potential removal of the lower four dams on the Klamath River. Biological Subgroup for Secretarial Determination. Draft May 27, 2010. 128 pp.

Meeuwig, M.H., J.M. Bayer, and J.G. Seelye. 2005. Effects of temperature on survival and development of early life stage Pacific and western brook lampreys. Transactions of the American Fisheries Society 134:19-27.

Mesa, M.G., and E.S. Copeland. 2009. Critical uncertainties and research needs for the restoration and conservation of native lampreys in North America. Pages 311-321 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, P.B. Moyle. Editors. biology, management, and conservation of lampreys in North America. American Fisheries Society Symposium 72.

Moser, M.L., and M.G. Mesa. 2009. Passage considerations for anadromous lampreys. Pages 115-124 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, P.B. Moyle. Editors. biology, management, and conservation of lampreys in North America. American Fisheries Society Symposium 72.

Petersen Lewis, R.S. 2009. Yurok and Karuk traditional ecological knowledge: insights into Pacific lamprey populations of the lower Klamath Basin. Pages 1-39 *In* L.R. Brown, S.D. Chase, M.G. Mesa, R.J. Beamish, P.B. Moyle. Editors. biology, management, and conservation of lampreys in North America. American Fisheries Society Symposium 72.

Robinson, T.G., P.W. Sorenson, J.M. Bayer, and J.G. Seelye. 2009. Olfactory sensitivity of Pacific lampreys to lamprey bile acids. Transactions of the American Fisheries Society 138:144-152.

Sanderson, B.L., K.A. Barnas, and A.M. Wargo Rub. 2009. Nonindigenous species of Pacific Northwest: An overlooked risk to endangered salmon? BioScience 59:245-256

USFWS (U. S. Fish and Wildlife Service). 2008. Outline of the Pacific Lamprey Conservation Plan Draft. U. S. Fish and Wildlife Service, Pacific Region Fishery Resources, Portland, Oregon. Available: http://www.fws.gov/pacific/fisheries/sp_habcon/lamprey/index.html (February 2008)

Table 1. Identified threats and their effects to Pacific lampreys, draft (USFWS 2008).

Threat	**Effects of the Threat**
Passage (dams, culverts, water diversions, tide gates, other barriers)	Artificial barriers can impede upstream migrations by adult lampreys and downstream movement of ammocoetes and macropthalmia. Downstream migrating macropthalmia may be entrained in water diversions or turbine intakes and due to their size and weak swimming ability, they are often impinged on the diversion and intake screens resulting in injury or death. Many fish ladders and culverts designed to pass salmonids do not effectively pass lampreys due to sharp angles and high water velocities. Lampreys travel deeper in the water column (no air bladder) compared to salmonids, therefore, traditional spill gates may block passage. Culverts that have a drop at the outlet or insufficient resting areas will block passage. Pacific lamprey populations persist for only a few years above impassable barriers before dying out.
Dewatering and flow management (reservoirs, water diversions, instream projects).	Fluctuations in reservoir and stream water levels, irrigation diversions, and stream dewatering can strand ammocoetes in the substrate. A single event can have a significant effect on a local lamprey population.
Dredging (channel maintenance and mining)	Many age classes of ammocoetes in stream substrates can be impacted by mining or dredging activities. Suction-dredge mining may be one of the reasons for the loss of lampreys in the John Day River basin.
Chemical poisoning (accidental spills, chemical treatment)	Ammocoetes are relatively immobile in the stream substrates and tend to concentrate in areas that include many age classes making them susceptible to chemical spills or chemical treatment (rotenone) targeting other species. They spend 3-7 years filter feeding and accumulate chemicals such as PCB's, mercury and other heavy metals.
Ocean conditions (loss of prey, change in conditions)	Pacific salmon, Pacific hake, and other fish have declined in numbers; reductions in the availability of these host/food species may be affecting adult lamprey survival and growth. No information exists on lamprey use of the ocean, hence unknown ocean conditions could be affecting their survival.
Poor water quality	Water temperatures of 72°F (22°C) may cause significant death or deformation of eggs or ammocoetes. Accumulated toxins in the lower reaches of streams/rivers may affect ammocoetes because they are often found in these areas.
Disease	The pathogen that causes furunculosis has been detected in lamprey in the Columbia River Basin and western Oregon. Disease may influence lamprey health resulting in reduction in their ability to reproduce and survive.
Harvest	Harvest of lamprey can change population structure and alter distribution thus reducing population numbers.
Predation by nonnative species	Nonnative fishes such as bass, sunfish, walleye, striped bass, and catfish, among others prey upon lampreys. As Pacific lampreys migrate through reservoirs, they may be more susceptible to predation.
Stream and Floodplain degradation (channelization, loss of side channel habitat, scouring)	Many age classes of ammocoetes in stream substrates can be affected by channel alterations. The loss of riffle and side channel habitats may reduce areas for spawning and ammocoete rearing.

APPENDIX C
Comments and Responses on Draft Report

Comments on the Draft Report: Scientific Assessment of Two Dam Removal Alternatives on Lamprey by Klamath River Expert Panel, dated July 26, 2010

Comment Number	Comment Author	Page, Paragraph	Comment	Panel Response
1	M. Mesa	4,3	Very little, if any, information exists regarding key items of interest for lampreys in the Klamath basin (e.g., status, biology, habitat surveys, etc.). Therefore, much of the panel's assessment will be predictive—or "educated guesswork". In this case, without hard data, where do you give "the benefit of the doubt?" A somewhat rhetorical question, yes, but food for thought as you work through this process.	Comment noted
2	M. Mesa	9, section 2.2	It would be nice to have a map of the Klamath basin, showing all relevant features, here	Maps added
3	M. Mesa	27, 1	When you talk about the "upstream extent of habitat" for Pacific lamprey, what type of habitat are you referring to—larval or adult?	All habitats. Access upstream of Iron Gate is blocked.
4	M. Mesa	29,2	This paragraph states that the panel does not know the extent of habitat increase for Pacific lamprey if the dams are removed. Based on my read, you do know something—that is, new access to about 70 miles of habitat. What you don't know is access and use of habitat in the upper basin. This should be clarified.	Edited
5	M. Mesa	29,5	You state that habitat capacity for FW-resident lamprey is not likely to change with dam removal. Yet, in the previous paragraph, you state that you know very little about the biology of these species. These two notions seem at odds with one another. Please recast.	Text edited
6	M. Mesa	32,2	Why do you expect a broader range of temperatures—whit higher maximums—under the dam removal scenario? It seems this information is coming from	Max temperatures are higher because fall flows are lower.

Comment Number	Comment Author	Page, Paragraph	Comment	Panel Response
			other modeling exercises, but to me it doesn't make sense. Why will max temperatures be higher in the free-flowing river?	
7	M. Mesa	40,3	Regarding climate change, two pieces of information are key, in my opinion. First, we need to know the thermal tolerance limits of lampreys, both young and adult fish. Some of this is known. Second, we need more information on the genetic capacity of lampreys to adapt to climate change over periods of years or decades. I suspect, given how old these species are, this isn't the first time they've had to deal with a changing climate. Food for thought.	Comment noted.
8	M. Mesa	40, section 6.4	The section on Ocean Impacts of Climate Change seems beyond the scope of this assessment.	The ocean impacts of climate change were considered by the Panel to be very important. No changes made to text.
9	J. Hamilton	Cover page (and all pages)	Revise disclaimer on the cover and each page to read: *"The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the funding agency (U.S. Fish and Wildlife Service)."*	Edited
10	J. Hamilton	Page 1, Section 1.1	Add: *"Expert Panels are expected to provide opinions to the Secretary on the effects of the two management scenarios for various fish populations. It is anticipated that these reports may also be used for National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) documents generated for the KHSA and KBRA."*	Edited
11	J. Hamilton	Page 3, section 1.3	The version of the synthesis document (Hamilton et al. 2010) may change for future panels.	Comment noted.
12	J. Hamilton	Page 4, section 1.3	The date for this needs to be provided. The same document is also referred to as Hetrick et al. 2009 (page 34 and elsewhere). Reference should be consistent.	Edited

Comment Number	Comment Author	Page, Paragraph	Comment	Panel Response
13	J. Hamilton	Page 4, section 1.4	It is worth noting here that we are not aware of any flow/habitat relationships for any Klamath River lamprey species	Added to Section 3.2
14	J. Hamilton	Page 9, section 2.2	#2, Implementation of Non-ICP interim measures needs a cite.	Edited
15	J. Hamilton	Page 10, section 2.2	#6 Be more specific about the version of the climate change information used	Not necessary. Climate change is discussed in more detail in Section 6.0 including scenarios.
16	J. Hamilton	Page 10, section 2.	#3, Implementation of ICP interim measures needs a cite.	Edited
17	J. Hamilton	Page 11, section 3.1	Good idea to define Klamath River Basin	Edited
18	J. Hamilton	Page 13, Section 3.2.1	Somewhere in the document should be discussion about whether or not larvae from tribs might recolonize mainstem if year 1 removal mortality was 100%	See Section 5.3.1
19	J. Hamilton	Page 20, section 4.1.3	Isn't the last sentence supposed to read " the channel below Iron Gate…? There is no mention of the current anoxic conditions of substrate immediately below Iron gate Dam (IGD).	Section substantially edited and revised
20	J. Hamilton	Page 23, section 4.3.2	Pls clarify what is meant by 'more modest' daily fluctuations.	Edited
21	J. Hamilton	Page 23, section 4.3.3	Reference to 'qualitative interpretation made by earlier consultants' should cite earlier work.	Added

Comment Number	Comment Author	Page, Paragraph	Comment	Panel Response
22	J. Hamilton	Page 28, section 5.2.2	A more conservative estimate of additional habitat that could be rehabilitated into a functional condition for anadromous fish (about 60 miles of 'recoverable' habitat) is found in Huntington 2006 (table 1). Sent to Demian 8/1/10.	Edited
23	J. Hamilton	Page 29, para 1	If there are examples of lamprey migrating through large lakes in the literature, please cite.	Citations added
24	J. Hamilton	Page 30, section 5.3.1	If the Babine system is an example of lamprey migrating through large lakes, please cite	Citation added
25	J. Hamilton	Page 30, section 5.3.2	Extra period at the end of page.	Edited
26	J. Hamilton	Page 31, section 5.3.2	Larval rearing capacity will be increased during the short term where? Below IGD? In PR?	Downstream of IGD. Edited.
27	J. Hamilton	Page 31, section 5.3.2	Extra period at the end of para 3.	Edited
28	J. Hamilton	Page 31, section 5.3.2	There is more contaminant information released just this week; I have asked Chauncey Anderson to send to Demian.	Not yet received in time for the Panel to address. No changes made to report.
29	J. Hamilton	Page 32, section	The reference to the hydrograph at the end of this section may have a better cite; check with Greiman or me.	Hydrographs updated to reflect new hydrology as presented in revised Synthesis Report (Hamilton 2010b)

Comment Number	Comment Author	Page, Paragraph	Comment	Panel Response
		5.3.3.1	Para 3. If Pacific lampey occur as far south as Baja California, they must tolerate some fairly warm stream temps. Isn't there more info on this? If so it should be mentioned here.	Edited
30	J. Hamilton	Page 32, section 5.3.3.1, end of 2nd complete para.	Thermal refugia > IGD also include Big Springs in the J.C. Boyle bypassed reach.	Edited
31	J. Hamilton	Page 33, 3rd complete para.	DO levels of 1014 and 78 mg/L need to be corrected. Again, there is no mention of the current anoxic conditions of substrate immediately below IGD.	Edited
32	J. Hamilton	Page 35	Smallmouth bass, while present in Howard Prairie Reservoir on Jenny Creek, have yet to be documented in the Klamath River to my knowledge. If you are reporting striped bass and walleye in Howard Prairie Reservoir there should be a cite.	Text edited and citation added.
33	J. Hamilton	Page 37, para 2	If ISAB reference is to air temperature warming it should say so.	Text edited.
34	J. Hamilton	Page 38, section 6.2	Reference to cold water refugia between IGD and Keno should be specific: Fall, Jenny, Shovel creeks, and Big Springs.	Refugia locations added
35	J. Hamilton	Page 39, section	Are there examples of lamprey or other anadromous fish shifting timing of spawning in response to changes in temperature regime? If so, cite that here. Can the	Spawning reference removed.

Comment Number	Comment Author	Page, Paragraph	Comment	Panel Response
		6.2, top of page	Panel be more specific about when they expect embryos would be hatched?	Timing discussion added to text.
36	J. Hamilton	Page 38, section 6.2, para 3	Include Shovel Creek in list of cold water streams	Edited
37	J. Hamilton	Page 41, section 7.0, para 1	Please provide cite for harvest of Klamath Lake Lamprey	Added citation
38	J. Hamilton	Page 42, section 7.0	Section 7 does not address endemic lamprey diversity as claimed on page 8, Section 2.2.2, L-1.	The response has been clarified to indicate that 7.0 discusses anadromous lamprey.
39	J. Hamilton	Page 43, section 7.1, para 1	If increase might reach 10 percent (Figure 2, Arrow B), then why not put percent on 'Change in Harvest' Axis?	The actual estimate was a range of 1-10 percent. It is not possible to indicate this graphically in a manner that is not subject to mis-interpretation.
40	J. Hamilton	Page 44, section 7.2, para 1	Again, be consistent with reference (Hetrick et al. 2009 versus USFWS 2010)	Edited

August 2, 2010

Note: In the following text, the major peer review points were responded to by the Panel. The responses are indicated in **bold font** indented below the main comment.

Review of:
Klamath River Expert Panel Draft Report
Scientific Assessment of Two Dam Removal Alternatives on Lamprey

Summary of Comments from Peer Reviewers

General Comments:

The two peer reviewers felt that that the panel makeup was appropriate for assessing the impact of dam removal alternatives on lamprey and that good use was made of the currently available information on the species. They concurred that the overall report was well organized and written. Importantly one the reviewers observed that the authors of the report were appropriately conservative in estimating the influence of dam removal on the population dynamics of the species. Taken in their entirety, the reviews were positive and suggestions for improving the report were minor.

Editorial Suggestions and Comments:

1. Limit the use of abbreviations to make reading of the report easier.
    a. **Text edited**
2. The addition of a simple map of the Klamath drainage related to the text would be informative.
    a. **Added figures**
3. Table 2 could be improved by indicating which species are endemic to the Klamath drainage.
    a. **Table 2 edited to include endemic status**
4. Several citations were missing. See reviewer's comments.
    a. **Citations completed**
5. The addition of a concluding section would be helpful. Information gaps could be summarized there.
    a. **The questions posed to the Panel related mostly to harvest and the Panel considered the harvest section to essentially be the conclusion of the report.**
6. In the initial section, it is misleading to suggest that Pacific lamprey's life span is from 4 to 6 years. State that this is a guess and that no one knows for sure.
    a. **Edited introduction to life history to reflect approximate amounts of time at different stages.**
7. The typical description of spawning habitat may be biased. Spawning may take place in other areas. See reviewer's comments.

   a. **Text edited**

8. In the climate change section, indicate how is it known that "climate shifts" will undoubtedly influence the abundance and productivity of lamprey.
   a. **Text edited**
9. Under the climate change section, it might be noted that fishing may be a greater threat as it relates to prey, possibly Pacific hake.
   a. **The discussion addresses the impacts from commercial fishing including the hake fishery.**
10. Clarify whether or not the effect of climate change on groundwater temperatures was incorporated into projections.
    a. **The Bureau of Reclamation was responsible for all hydrologic and climatological monitoring. It does not appear that modeling of groundwater changes in response to climate change was conducted. The report does state that groundwater temperatures should track air temperatures, but the report was clarified to indicate that this information was not included in the projections.**
11. Under the condition without dams alternative, indicate that hybridization potential between Pacific lamprey and freshwater-resident lamprey probably existed prior to dam construction.
    a. **Report edited**
12. The harvest section does not directly address the topic.
    a. **Report edited to clarify connection to harvest**