Summary Report of Independent Peer Reviews for Bureau of Reclamation *"Measures to Reduce Ceratanova shasta Infection of Klamath River Salmonids: A Guidance Document"*

August 2018

FORWARD

Atkins North America (Atkins), was retained by the Bureau of Reclamation to facilitate an independent scientific review of the *Measures to Reduce* Ceratanova shasta *Infection of Klamath River Salmonids: A Guidance Document* (Guidance Document), January 2017 and supporting technical memoranda. Atkins believes the peer reviewers have successfully met the Bureau of Reclamation charge for their reviews, which provide opinions and or detailed analysis on the scientific data and interpretation of the data in the Guidance Document. Reviewer comments are focused on seven questions related to the Guidance Document objectives: oversights or omissions, use of best available science, clearly stated assumptions and methods, strength of its scientific foundations, as well as identification and characterization of uncertainties and their implications. Overall, the peer reviewers' responses indicate that the Guidance Document includes scientific data that would support the management guidance actions to mitigate the effects of *C. shasta* infection rates in Klamath River coho and Chinook salmon downstream of Iron Gate Dam.

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1.0 INTRODUCTION

1.1 Background

In July 2016, a Disease Technical Advisory Team (DTAT) was formed and comprised of representatives from Federal and state agencies and the Yurok, Karuk, and Hoopa Valley Tribes (Tribes) due to unique hydrologic conditions and associated high prevalence of infection observed in juvenile salmonids in the Klamath River in 2014 and 2015. The purpose of the DTAT was to synthesize information provided in existing literature and from a series of four technical memoranda prepared by the U.S. Fish and Wildlife Service's Arcata Office. Based on a synthesis of these materials, Tribal representatives prepared a document titled 'Measures to Reduce *Ceratanova shasta* (*C. shasta*) Infection of Klamath River Salmonids: A Guidance Document' (Guidance Document) that included specific management guidance actions intended to mitigate the effects of *C. shasta* infection rates in Klamath River coho and Chinook salmon downstream of Iron Gate Dam. The Guidance Document includes six management measures, as well as four control measures that were considered but eliminated from further consideration. The Bureau of Reclamation requested a formal, external, and independent scientific peer review of the Guidance Document and supporting technical memoranda.

1.2 Purpose and Scope of Peer Review

The purpose of this review is to provide a formal and independent summary of the external scientific peer reviews that were prepared based upon the information in the Guidance Document and supporting technical memoranda. The Guidance Document review was conducted to evaluate the best scientific data available for management guidance actions to mitigate the effects of *C. shasta* infection in Klamath River coho and Chinook salmon downstream of the Iron Gate Dam. Peer reviewers were charged with reviewing and assessing the sufficiency of the report's conclusions to determine the validity and/or effectiveness of the management measures within the Guidance Document.

The Bureau of Reclamation asked Atkins to ensure that the reviewers addressed the scientific merit of the Guidance Document, which provides the basis for the Bureau of Reclamation decision to implement the proposed mitigation measures. The reviewers were instructed to provide a written review of the Guidance Document, with special emphasis on answering the key questions related to the effectiveness of the management measures for coho and Chinook salmon separately. The reviewers did not have a defined format, and were free to comment on any aspects of the Guidance Document and supporting data to which they felt a comment was warranted. Comments on the Guidance Document were directed to focus specifically on whether the best available information was used, the quality of the scientific information, and the author's interpretation and analyses of the data with regard to the conclusions of the Guidance Document. Reviewers were encouraged to seek additional references as necessary, as well as utilizing references provided by the Bureau of Reclamation.

Specifically, the Bureau of Reclamation requested that the peer reviewers consider and respond to the questions listed below, at a minimum, in their reviews. For questions 1-4, both the six management measures, and the four control measures considered, but eliminated were discussed.

1. Of the management measures contained within the Guidance Document, which measures can be expected to have the greatest influence on reducing the prevalence and severity of *C. shasta* infections within Klamath River salmonids?
    a. Conversely, which management measures can be expected to have the least influence on reducing the prevalence and severity of *C. shasta* infections within Klamath River salmonids?
    b. How might the effectiveness of the management measures vary year-to-year based on hydrologic conditions, size and health of salmon runs, or other factors?

2. Are the management measures contained within the Guidance Document supported by the best available science and monitoring data?

3. What are the assumptions and uncertainties associated with the management measures and the four control measures that were "considered but eliminated from further consideration," and have they been adequately characterized?

4. What is the level of scientific support for eliminating the four control measures that were "considered but eliminated from further consideration"?

5. Specific to management measures within the Guidance Document:
    a. Are the flow magnitudes identified within management measures 1 and 2 (6,030 cfs and 11,250 cfs, respectively) better supported than any other value within the range of surface flushing flows (5,000 - 8,700 cfs) and deep flushing/armor disturbance flows (8,700 - 11,250 cfs)?
    b. What scientific support exists for implementing surface and deep flushing flows at a frequency other than the natural recurrence interval based on geomorphic assessments of the Klamath River? Please consider that flows of this magnitude have not occurred at the natural recurrence interval in the recent past.
        i. If there is scientific support for implementing these flows at a frequency other than the natural recurrence interval, at what point is a return to the natural recurrence interval appropriate?
    c. To what degree do hatchery management practices contribute to the transmission of *C. shasta* between salmonids and polychaetes? Please consider both inter- and intra-annual effects.
    d. What is the level of scientific support for using spore dilution as a mechanism to minimize and/or reduce the prevalence of infection in out-migrating salmonids? If support exists:
        i. How is the effectiveness of management measure 4 expected to change longitudinally along the Klamath River?
        ii. Would the inclusion of temperature and/or specific monitoring location as additional triggers for implementation of management measure 4 better predict salmonid prevalence of infection (POI)?

iii. How does a non-genotypic-specific spore concentration and trigger relate to POI within Chinook and coho salmon?

iv. Is a non-genotypic spore concentration greater than 5 spores/L an accurate indicator of increasing POI in both Chinook and coho salmon?

6. Are the triggers included in Management Guidance 4 for implementing an emergency dilution flow indicative of imminent increases in salmonid POI?

a. Referencing the spore and fish infection technical memos and the associated actinospore and Klamath River flow data (2005-2017), how would the emergency dilution flows have influenced spore concentrations in the Klamath River below Iron Gate Dam? Given the varying distribution of the 'infectious zone' and river flows at which the triggers have been exceeded in the period of record (2005-2017), can emergency dilution flows be reasonably expected to measurably decrease the prevalence of *C. shasta* in outmigrating salmon? If so, what is the minimum Iron Gate Dam flow that would be beneficial?

7. What level of scientific support exists for the need to implement the management measures in the absence of the four hydroelectric dams (i.e., after Klamath River dam decommissioning)?

2.0 PEER REVIEW PROCESS

Atkins was retained by the Bureau of Reclamation to facilitate the peer review process. The terms of the contract include the following:

- select peer reviewers;
- organize, structure, lead and manage the scientific review;
- summarize the individual peer reviews and prepare a summary report for the Bureau of Reclamation;
- facilitate specific follow-up questions/answers between the Bureau of Reclamation and the reviewers, without attribution;
- prepare and submit a Final Report and Administrative Record to the Bureau of Reclamation;

Atkins project manager Matt Cusack with the assistance of Atkins senior scientists Ben Cogdell, Don Deis and Shelly Fisher facilitated this review (i.e., Atkins Team).

2.1 Selection of Reviewers

Atkins was instructed to determine the necessary experience and qualifications of the reviewers based on the content of the report to be reviewed. Suggested areas of expertise included:

- Salmonid Ecology;
- Aquatic invertebrate parasitology
- Sediment transport;
- Analytical reasoning of biological fisheries sciences;

The Atkins Team screened each candidate for potential conflicts of interest and made sure the final composition was balanced in terms of field specialization, affiliation, and scientific perspective. The Bureau of Reclamation awarded the contract for three reviewers, and the Atkins Team identified three individuals who met the selection criteria that were willing and available to participate in the review. The reviewers and their areas of expertise are listed below in alphabetical order; their resumes/CVs are included in Appendix A:

- Dr. Kenneth D. Cain, fish health and disease management
- Dr. Christopher C. Caudill, fish and wildlife science
- Dr. Christopher M. Whipps, fish health, genetics, and parasitology

2.2 Document Review and Report Development

Upon award of the contract, the Atkins Team coordinated with Bureau of Reclamation technical representative Tara Jane Campbell Miranda to discuss the scope of the review and address any questions. Ms. Miranda distributed the Guidance Document and technical memorandum to Atkins for performance of the peer review, and reviewed the draft scope of services for the peer reviewers prior to its distribution.

The Atkins Team coordinated individually with the reviewers to describe the scope of services, including the charge to the reviewers and peer review schedule. The Atkins Team coordinated with the reviewers prior to distributing the Guidance Document and technical memoranda to answer any questions. Following that coordination, the Guidance Document and technical memoranda was distributed to all the reviewers and the independent desk reviews commenced.

Reviewers submitted their individual review comments to the Atkins Team by June 22, 2018. Atkins submitted the unmodified reviews to the Bureau of Reclamation on June 18, 2018 (Reviewers 01), June 19, 2018 (Reviewer 02), and June 25, 2018 (Reviewers 03) as they were received. All attribution was removed and replaced with a number based on the order in which their reviews were received (i.e., Reviewer 1, Reviewer 2, etc.). On July 6, 2018 a teleconference was held between Atkins and the Bureau of Reclamation where the Bureau of Reclamation provided comments and requested clarification from Reviewer responses. The Bureau of Reclamation provided additional reports and summary data for the Reviewers to consider in their updated responses. This information was provided to the Reviewers on July 9, 2018. Updated responses were provided to the Bureau of Reclamation from the Reviewers on July 11, and July 16, 2018.

The compiled individual reviews are included in this document as Appendix B. In the Results section, the Atkins Team summarizes the responses to the seven questions posed to the reviewers.

3.0 RESULTS

Detailed comments were provided by the three reviewers that addressed the questions they were asked. Overall, the reviewers agreed that the Guidance Document was comprehensive, scientifically sound, and that the DTAT made a credible effort to assess the effect of each of the six proposed management measures. The recommended management measures are well supported by available scientific data, and that the authors clearly identified areas of uncertainty and potential for negative effects of a given action. All proposed management measures were reasonable with some more likely to have an impact on the transmission of the parasite than others.

Below are brief summaries of the individual reviewers' responses to the seven questions posed by the Bureau of Reclamation. This section is not intended to be a comprehensive summary, but rather attempts to capture some of the primary comments in each reviewer's response to the individual questions, as well as any themes that emerged or comments that were raised by more than one reviewer independently. For the reviewers' full comments, see Appendix B.

Question 1: Of the management measures contained within the Guidance Document, which measures can be expected to have the greatest influence on reducing the prevalence and severity of C. shasta infections within Klamath River salmonids?

- ***a. Conversely, which management measures can be expected to have the least influence on reducing the prevalence and severity of C. shasta infections within Klamath River salmonids?***
- ***b. How might the effectiveness of the management measures vary year-to-year based on hydrologic conditions, size and health of salmon runs, or other factors?***

All three reviewers agreed that the deep flushing (MG2 and MG3) were expected to have the greatest influence on reducing the prevalence and severity of *C. shasta* infections. There were varying opinions on which management measures would have the least influence, Reviewer 1 and Reviewer 3 both agreed MG6, while Reviewer 2 identified MG5 (Fall flows) as having little to no influence. All three reviewers concluded the effectiveness of the management measures will vary year to year based on weather (rainy cool years vs drought conditions), water temperature, and flow rates affecting sediment transport. A summary of the three reviewers' responses and assessment of how the effectiveness of the management measures may vary from year to year is provided below.

Reviewer 1- The proposed management measures (ranked in order of effectiveness) MG3 and 2 MG1, MG4, MG5, and MG6 are reasonable and clear arguments are made for their inclusion. While MG2 and 3 are most likely to reduce disease issues through disruption of the *C. shasta* lifecycle, it appears there are substantial operational challenges in implementing MG3. As such, MG2 may be a better option to accomplish the disease-reduction goals, but in an operationally feasible manner. MG1 is the next most likely to decrease disease conditions by mobilizing fine sediment and reducing food sources, though the actual effects should be monitored carefully. The theory supporting spore dilution through MG4 is sound, though it is unclear if the proposed volume is sufficient. Regardless, the need for MG4 may be reduced if MG1 and MG2 are implemented on a regular basis. While the theory behind MG5 is sound, there is little data to support its effectiveness. There is substantial uncertainty associated with MG6, however, if effective, it would likely be most pertinent to type I *C. shasta* and thereby most beneficial to Chinook given

Iron Gate Hatchery production is largely Chinook.

Year to year variation in management measures is likely to depend on the effectiveness of the measures themselves. Additionally, the size of the run and health of fish should not matter for a given year for MG1-3. MG5 would be effective regardless of run size. Rainy and cool years would likely increase the effectiveness of the proposed measures given increases in natural flows in the river system. Finally, longer holding times in the hatchery increases the chances of losses due to other pathogens if an outbreak occurs in these confined conditions.

Reviewer 2- MG3 then MG2 then MG1 are most likely to effectively reduce C. shasta prevalence and severity, MG4 and 6 are likely to be moderately effective, and MG5 is likely to be the least effective of the proposed management measures. MG1-3 are well supported given the low uncertainty that reduced mean flow magnitude and loss of geomorphically relevant flushing flows have contributed to increased polychaete populations. With respect to MG4, there is strong evidence, both theoretical and empirical, that increasing flow will dilute actinospore concentrations and reduce infection rate. However, given that mortality increases at temperatures above 15 degrees C, the dilution effects of increased flows may be minimal in cooler years and greater in warm years. Relative to MG6, there is little uncertainty that earlier hatchery releases at times when POI, spore concentration, and water temperatures are lower will reduce POI in hatchery smolts. While MG5 is intuitive, it is generally not well supported by direct evidence at this time.

For all proposed management actions, there is a high probability that effectiveness will vary from year to year, namely due to the effects of temperature on spore production, disease transmission, mortality rate, and possibly juvenile outmigration timing. Additionally, there is uncertainty regarding how MG4 timing, flow magnitude, and water temperature interactions will reduce C. shasta spore concentration, and subsequently POI. The effect of MG6 will be greatest under conditions favoring outbreaks (low water, warm springs, etc). Finally, MG5 is most likely to be effective in years when adult POI is high and/or adult spawning densities are highest.

Reviewer 3- MG2, 3, and 4 are most likely to reduce POI, though it is clear that deep flushing and other high magnitude flows are likely to provide the greatest benefit. MG1, 5, and 6 are likely to be least effective. There is clear support for MG4 based on studies completed to date, however, increasing water temperatures during implementation of MG4 (as a result of shallow releases from Iron Gate Dam) could increase risk of infection rather than lower it. MG1 may be beneficial if implemented annually in the late spring and in conjunction with MG2 and/or 3. MG5 may have limited impact, if implemented alone, due to uncertainties and limited information about the effectiveness of this action in redistributing carcasses. Additionally, it is possible that the timing of this flow could differentially effect Chinook and coho given their slightly different spawning times. MG6 should have positive effects, but there may be challenges meeting the criteria put forth and ensuring that release times and strategies are consistent between years.

Relative to variation between years, the effectiveness will be widely influenced annually due to (among other things): (1) drought conditions that would limit the ability to implement flow related management measures, (2) unidentified refuge areas for polychaetes are present where flow increases would not mobilize sediment in a way needed to flush polychaetes downstream, (3) infected salmon returning and contributing excessive myxospore loads, and (4) excessive juvenile out-migrants becoming infected during some years, which could result in high juvenile mortality

(and spore contribution) or high spore loads once adults return.

Question 2: Are the management measures contained within the Guidance Document supported by the best available science and monitoring data?

All three reviewers agreed the science and monitoring data used to support the development of the management measures in the Guidance Document used the best available data. The preliminary data summaries provided by Bartholomew et al (2018), data from 2017, and data collected in previous years are consistent with the conclusions forwarded in the Technical Memorandums and incorporated in the Guidance Document. Reviewer 3 also added that recent and future monitoring data is critical to applying an adaptive management approach to reduce fish disease conditions in the Klamath River. Reviewer 2 confirmed full support of Reveiwer 3 statement for an adaptive management approach.

Question 3: What are the assumptions and uncertainties associated with the management measures and the four control measures that were "considered but eliminated from further consideration," and have they been adequately characterized?

Note that Reviewers 1 and 2 include some information relative to this question in their responses to question 1.

All three reviewers generally noted that high flow actions (MG1-3) assume that: (1) Klamath River flows have been below-average, particularly in the winter, since approximately 2000; (2) the population dynamics of the polychaete host are affected by flow regime through habitat and food web disturbances; (3) high winter/spring flows reduce polychaete habitat. Uncertainties associated with MG2 and 3 are largely related to implementation (i.e., infrastructure capacity, safety, hydrologic support), though Reviewer 2 also notes there is uncertainty regarding displacement and mortality of polychaetes downstream during high flow events (this reviewer also lists five specific uncertainties relevant to geomorphology and parasite biology as well; see Reviewer 2 response to question 1 in Appendix B). Additionally, Reviewers 2 and 3 note for MG1 there are uncertainties related to mobilization of specific sediments and habitats, and whether or not this measure would be effective if implemented in the absence of MG2 and 3. Generally, the reviewers noted that the assumptions and uncertainties were adequately characterized in the Guidance Document for MG1-3.

Reviewers agreed that MG4 assumes that by increasing flows in the spring, there will be spore dilution (and hence lower spore concentrations) and a subsequent reduction in POI. Uncertainties associated with MG4 primarily focus on the unknown interactions between flow timing and magnitude, and water temperature. Additionally, Reviewer 2 states that the primary uncertainty is the biological effectiveness of a given flow level (i.e., specific Iron Gate Dam discharge targets as outlined in the Guidance Document). The reviewers questioned the exclusion of temperature as a trigger for MG4 and Reviewer 3 was also concerned that a cut-off for implementation of MG4 was 80% outmigration of wild fish; Reviewer 3 notes that this may not account for the large flux of hatchery fish still to come. Finally, Reviewer 1 also questions whether the proposed flow of water is sufficient.

Reviewers suggested that MG5 assumes salmon carcasses will be redistributed by implementing fall/winter flushing flows. A key uncertainty described in the Guidance Document is a lack of

information on how effective this measure would be in distributing carcasses and myxospores. Other uncertainties include how differential spawn timing in Chinook and coho, and different carcass decomposition rates across sites and years may affect spore concentration within carcasses, and carcass abundance at a given time and place.

Finally, the reviewers agreed that MG6 assumes that an earlier hatchery release period (and releasing some yearlings in November) would reduce disease risk by exposing hatchery fish to lower water temperatures upon release. Reviewer 3 in particular noted that the uncertainties related to this measure were not clearly laid out in the Guidance Document. Specifically, Reviewer 3 noted there were many more than the two uncertainties listed (adult infection risk and impacts to wild/natural fish). Finally, Reviewers 1 and 2 noted their relatively low ranking of this measure was primarily due to the great number of uncertainties, specifically the uncertain role of hatchery fish in propagating *C. shasta*.

In addition to the management measures proposed in the Guidance Document, four control measures were eliminated from final consideration. These were: 1) dewatering, 2) manual carcass removal, 3) direct sediment introduction, and 4) channel restoration. For each of these measures, the assumptions and uncertainties from the three reviewers is summarized below.

Reviewer 3 noted generally that assumptions and uncertainties associated with the four eliminated measures were only minimally described. Reviewer 3 notes that most of these four eliminated measures were not considered feasible from an implementation standpoint and/or would become obsolete following dam removal. Reviewers 1 and 2 provided additional information, as detailed below.

Dewatering

Reviewer 1 and Reviewer 2 noted that dewatering to lower water levels assumed the elimination or significant reduction in polychaete density through direct desiccation and loss of habitat, however there is great uncertainty and concern regarding the additional ecological impacts this would impose on the system.

Manual Carcass Removal

Reviewer 1 and Reviewer 2 agreed it was assumed carcass removal would reduce the number of myxospores available to infect polychaetes. However, the manual removal of carcasses would be labor-intensive with uncertainty as to the number of carcasses that would actually have to be removed to noticeably disrupt the lifecycle of *C. shasta*.

Direct Sediment Introduction

Reviewer 1 and Reviewer 2 had similar assessments regarding the assumptions and uncertainties as it relates to the direct sediment introduction control measure. The assumption that the direct sediment introduction measure would cause changes in sediment/substrate to disrupt polychaete habitat to lessen the number of alternate hosts for *C. shasta* is questionable. Further, the absence of information for methods proposed for sediment introduction make it difficult to understand how this measure would be executed to disrupt polychaete habitat to effectively reduce polychaetes.

Channel Restoration

There was general agreement among all three reviewers that the assumption behind channel restoration lacks details and data that would support this control measure as an effective action to reduce polychaete habitat. Each reviewer referenced the future dam removal and impacts to the channel as a result of the removal would make restoration efforts redundant.

Question 4: What is the level of scientific support for eliminating the four control measures that were "considered but eliminated from further consideration"?

All three reviewers agreed that the measures eliminated from consideration were largely discounted due to infeasibility, cost, and/or failure to remain viable after dam removal. Regardless, the reviewers also agreed that there is little scientific information to support further consideration of the four eliminated measures.

Question 5: Specific to management measures within the Guidance Document:

a. Are the flow magnitudes identified within management measures 1 and 2 (6,030 cfs and 11,250 cfs, respectively) better supported than any other value within the range of surface flushing flows (5,000 - 8,700 cfs) and deep flushing/armor disturbance flows (8,700 - 11,250 cfs)?

For MG1, Reviewers 1 and 2 agree that 6,030 cfs is supported based on past monitoring and summary information in the Sediment Transport Technical Memo indicating that numerous geomorphological studies employing different methods converged on values near 6,000 cfs for mobilization of fine sediment. Reviewer 3 noted that the most supported flow is the deep flushing flow and therefore did not offer a specific opinion relating to MG1.

For MG2, Reviewers 1 and 2 indicated 11,250 cfs was supported as it was very near the minimum value from two studies cited in the Technical Memo, and noted that lower values are unlikely to have the intended effect. Reviewer 3 did not offer a specific opinion other than to state that the deep flushing flow in general is well supported.

b. What scientific support exists for implementing surface and deep flushing flows at a frequency other than the natural recurrence interval based on geomorphic assessments of the Klamath River? Please consider that flows of this magnitude have not occurred at the natural recurrence interval in the recent past.

i. If there is scientific support for implementing these flows at a frequency other than the natural recurrence interval, at what point is a return to the natural recurrence interval appropriate?

All three reviewers agree that there is scientific data that support implementing surface and deep flushing flows at frequencies other than the natural recurrence interval. Reviewer 1 notes there are years when the parasite appears to recover quickly, which would support higher-frequency flow control measures. Reviewer 1 specifically references the data from 2017, where a deep flow event occurred, and notes the data from 2018 and 2019 will be critical in evaluating the effectiveness of such flows, and the longevity of their influence. Reviewer 2's assessment is that additional flow events may be required to achieve substantial reductions in polychaetes given the long-term

alteration of the flow regime and sediment budgets. Reviewer 3 supports frequency greater than the natural recurrence interval based on the scientific information showing parasite levels that are historically high, presumably due to the unnatural hydrologic regime of the system over the past 2 decades.

c. To what degree do hatchery management practices contribute to the transmission of C. shasta between salmonids and polychaetes? Please consider both inter- and intra-annual effects.

Reviewers 1 and 3 agree that hatchery contribution and effects may be minimized by releasing hatchery fish earlier in May when water temperatures and spore concentrations are typically low, rather than in June when the opposite is true. Reviewer 1 indicated impacts from hatchery fish tend to be low as the documentation suggests that adult carcasses contribute the majority of myxospores. Reviewer 3 supports the release of hatchery fish during spring flushing flows.

Reviewer 2 stated there was limited information provided to assess hatchery management practices beyond those discussed in Action 6. However, the reviewer's discussion in previous questions for MG6 implies there is little uncertainty that earlier releases when POI and temperatures are lower will reduce POI in hatchery smolts, particularly in warm and/or high actinospore concentration years. To what degree juvenile carcasses contribute to myxospore production is largely unknown, but potentially important because juvenile carcasses become available as temperatures are rising and flows are decreasing.

d. What is the level of scientific support for using spore dilution as a mechanism to minimize and/or reduce the prevalence of infection in out-migrating salmonids?

All three reviewers agree that there is scientific support for using spore dilution to reduce POI in fish. Specifically, Reviewer 1 states that the concept is theoretically sound with no direct evidence against it. Reviewer 1 also notes that there is also a lack of strong evidence showing it would certainly be effective. Reviewer 2 indicates that spore dilution is well supported, as indicated by previous responses, and references the Oregon State Univeristy 2018 preliminary data in support of spore dilution. Finally, Reviewer 3 suggests that reducing the infective *C. shasta* dose is scientifically justified as a mechanism to lower POI in fish.

If support exists:

i. How is the effectiveness of management measure 4 expected to change longitudinally along the Klamath River?

Reviewers 1 and 3 largely agreed that tributary inflow was likely to decrease the relative contribution from Iron Gate Dam, though Reviewer 1 noted that if the main hot spot for *C. shasta* is near Iron Gate Dam, then MG4 should effectively dilute spores. Reviewer 2 also noted that spatial variation in actinospore production and release may also influence MG4 longitudinally. Finally, Reviewer 1 suggested that the greatest confounding factor in assessing this question with available data is that the current PCR test for water does not distinguish myxospores, viable actinospores, and/or dead actinospores. Reviewer 2 noted that while the dilution effect by tributaries occurs, the available spore concentration data indicate the magnitude of MG4's effect would likely remain relatively constant longitudinally, given the consistent longitudinal pattern in

infection rates (peaking at Beaver Creek and decreasing both above and below this site) and the spatial patterns in 2018 spore concentrations. All three reviewers urge continued monitoring throughout the river to better assess the outright effectiveness of MG4 and longitudinal changes in effectiveness.

ii. Would the inclusion of temperature and/or specific monitoring location as additional triggers for implementation of management measure 4 better predict salmonid prevalence of infection (POI)?

All three reviewers recommended including additional data such as temperature as triggers for MG4. Reviewer 3 also suggested that inclusion of additional monitoring sites would be beneficial. Reviewer 2 recommended consideration metrics of thermal regime (e.g, of degree day), rather than outright water temperature, data to better inform implementation of MG4.

iii. How does a non-genotypic-specific spore concentration and trigger relate to POI within Chinook and coho salmon? AND

Reviewers 1 and 2 cite Hallett et al. (2012), documenting that 5 Type II spores/L, and 10 Type I spores/Lliter are correlated with 40% mortality in coho and Chinook, respectively, at water temperatures above 15 degrees C.

All three reviewers agreed that a genotype-specific spore concentration test is ideal given different genotypes and concentrations of concern for Chinook and coho, with Reviewer 1 further suggesting that a non-genotype-specific 5 spores/L trigger presents many uncertainties. Reviewer 3 implies that theoretically, if 5 spores/L were all Type II, then coho may be impacted the most, but given the likely mix of spore types in the samples it seems unlikely that all spores would be of Type II genotype. Regardless, all three reviewers agreed that in the absence of a genotype-specific test, 5 spores/L was appropriately conservative to protect coho.

iv. Is a non-genotypic spore concentration greater than 5 spores/L an accurate indicator of increasing POI in both Chinook and coho salmon?

v.

Generally, all three reviewers indicated that there was support to suggest non-genotypic spore concentrations greater than 5 spores/L were an accurate indicator of increasing POI in both fish species. Specifically, Reviewer 1 notes that as spore concentrations increase, sentinel fish mortality increases (with some noted exceptions), indicating a link between increasing spore concentrations and POI. Furthermore, Reviewer 1 notes that even in years when spore concentrations of any genotype are low, mortality was observed in coho, suggesting coho are particularly sensitive to *C. shasta*. Reviewer 2 points to recent OSU monitoring reports supporting the link between increasing spore concentrations and POI in both species. Similarly, Reviewer 3 indicates non-genotypic spore concentrations above 5 spores/L are a good indicatory of risk in both species, though they also reiterate the importance of determining spore genotype, if feasible.

Question 6: Are the triggers included in Management Guidance 4 for implementing an emergency dilution flow indicative of imminent increases in salmonid POI?

All three reviewers agree that the triggers for MG4, as described in the Guidance Document, have scientific support, suggesting that triggers are indicative of increasing POI in fish. However, all reviewers also acknowledge the need to include other components, such as water temperature. Reviewer 1 notes that although True et al. (2013) is cited in the Guidance Document, there is not a clear explanation of why 20% POI was specifically chosen as a trigger for MG4. Reviewer 1 acknowledges the effect of water temperature on POI, indicating that in low flow years, acting quickly to implement MG4 after POI increases above 20% is likely critical. Conversely, Reviewer 1 notes that in cooler years with higher flow, an additional week of sampling may be necessary given week to week variation in POI in such years. Reviewer 1 also acknowledges that estimates of POI are heavily influenced by sample size, noting that sample sizes greater than 20 fish are necessary to ensure that confidence intervals are sufficiently narrow. Finally, Reviewer 3 suggests the triggers are indicative of increases in salmonid POI, but other triggers such as temperature and spore concentration at other monitoring sites may provide a further indication of the imminent risk of increasing POI in out-migrating fish. The emergency dilution flows would have most likely influenced spore concentration (reduced) in years listed where flows never reached a 6,030 cfs.

a. Referencing the spore and fish infection technical memos and the associated actinospore and Klamath River flow data (2005-2017), how would the emergency dilution flows have influenced spore concentrations in the Klamath River below Iron Gate Dam? Given the varying distribution of the 'infectious zone' and river flows at which the triggers have been exceeded in the period of record (2005-2017), can emergency dilution flows be reasonably expected to measurably decrease the prevalence of C. shasta in outmigrating salmon? If so, what is the minimum Iron Gate Dam flow that would be beneficial?

All three reviewers largely agree that MG4 would most likely have reduced spore concentration, but also discuss caveats. Additionally, all three reviewers agree that MG4 will be most effective when flows are low and water temperatures are high. Reviewer 2 suggests that while MG4 will plausibly result in dilution, the effectiveness of this measure will be largely dependent on spore concentration (dilution will be more effective at higher spore concentrations) and water temperature (dilution will be more effective at higher water temperatures). Additionally, Reviewer 2 notes that dilution flows are a function of a relative increase in volume, rather than a prescriptive flow at Iron Gate Dam. Reviewer 3 indicates that it is difficult to foresee the magnitude or spatial effects downstream of Iron Gate Dam. If other measures are simultaneously implemented, it's reasonable to assume that measureable decreases in POI would be observed in out-migrating fish, as a result of MG4. Reviewer 3 further suggests that 3,000 cfs at Iron Gate Dam may indeed reflect a minimum necessary flow for implementation of MG4, and indicates the requirement to increase flow to 4,000 cfs is supported. However, Reviewer 3 acknowledges there is still substantial uncertainty with MG4. Namely, the effect of MG4 on temperature is important and if implementation of MG4 results in increased water temperatures, the measure may be counterproductive.

Question 7: What level of scientific support exists for the need to implement the management measures in the absence of the four hydroelectric dams (i.e., after Klamath River dam decommissioning)?

Reviewer 1 states the implementation of all of the management measures except MG6 (changing hatchery practices) involve regulating water flow at the Iron Gate Dam, which would not be possible as described once dams are removed. Furthermore, dam removal creates connectivity for the spread of the parasite from the upper to mid and lower basins, but potentially spreads it out, reducing "hot spots" for spore releases as seen in areas below Iron Gate Dam. A return to more 'natural' flows may reduce polychaete habitat as well as flush spores from the system. The removal of dams may also decrease an important food source for polychaetes by reducing the amount and intensity of algal blooms that currently occur in reservoirs created by the dams.

Reviewer 2 infers there may need to be augmentation to the management measures as a result of alterations to the physio-chemical condition in the river with the dam removal. The reviewer noted it would be challenging to predict whether specific actions would be needed in the absence of the dams. The flow management and nutrient inputs from the upper basin would continue to affect the lower Klamath River ecosystem. Consequently, actions aimed at mimicking key elements of the flow regime would likely be needed given the eutrophication present in the upper system if those elements were not restored with dam removal.

Reviewer 3 believes the scientific support for the need to implement the described management measures in the absence of the four hydroelectric dams is minimal at this time. When the dams are fully decommissioned, it is assumed that the Klamath River would have seasonal high and low flows characteristic of historic natural river conditions. As such, the occurrence of disease caused by C. shasta would be expected to be cyclic and follow a similar pattern seen historically based on flow and temperature, and be exacerbated during drought conditions.

4.0 REFERENCES

The following references were cited in Section 3.0 above. The citations for numerous other references recommended by the reviewers are included in their individual comments in Appendix B.

Ayres and Associates, Geomorphic and Sediment Evaluation of the Klamath River in California below Iron Gate Dam. 1999.

Bartholomew, J., Hallett, S., Holt, R., Alexander, J., Atkinson, S., Craig, R., Javaheri, A. and Babar-Sebens, M. Klamath River Fish Health Studies: Salmon Disease Monitoring and Research. Oregon State University, BOR/USGS Interagency Agreement #R15P00065 FY2017 April 01, 2017 – March 31, 2018 Annual Report Draft.

Craig, S., Belchik M., Hillemeir D., Ledwin S. and Soto T. Measures to Reduce Ceratanova shasta Infection of Klamath River Salmonids: A Guidance Document. January 17, 2017.

Hallett, S., Ray R., Hurst, C., Holt R., Buckles G., Atkinson S. and Bartholomew, J. 2012. Density of the Waterborne Parasite Ceratomyxa Shasta and its Biological Effects on Salmon. Applied and Environmental Microbiology 78:3724—3731. doi: 10.1128/AEM.07801-11.

Oregon State University Annual Reports. 2008-2016. Long-Term Fish Disease Monitoring Program in the Lower Klamath River. Cooperative Agreement R09AC20022, CESU # 3FC810873.

5.0 APPENDICES

Appendix A: Reviewer CVs/Resumes
Reviewer 01: A-3 through A-19
Reviewer 02: A-20 through A-73
Reviewer 03: A-74 through A-115

Appendix B: Individual Reviewer Comments
Reviewer 01: B-2 through B-18
Reviewer 02: B-19 through B-30
Reviewer 03: B-31 through B-53

APPENDIX A: REVIEWER CVS/RESUMES

CHRISTOPHER M. WHIPPS, Ph.D.

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College of Environmental Science & Forestry
246 Illick, 1 Forestry Dr.
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CURRENT POSITION

Associate Professor, State University of New York College of Environmental Science and Forestry (SUNYESF), Department of Environmental and Forest Biology (Aug 2013 – present). Diseases of Fish and Wildlife; Molecular Biology.

Director of the SUNY Center for Applied Microbiology (Feb 2013 – present)

Editor, World Register of Marine Species, Myxozoans (Aug 2015 – present)

Associate Editor, Journal of Parasitology (Nov 2015 – present)

Section Editor, Parasitology Research, Fish Parasitology (Jun 2017 – present)

EDUCATION

Ph.D. Microbiology, Oregon State University, Corvallis, Oregon (completion date: February 26, 2004).

B.Sc. Biology (with Distinction), University of Victoria at Malaspina University-College (now Vancouver Island University), Nanaimo, British Columbia, Canada. (1997).

PROFESSIONAL EXPERIENCE

Assistant Professor, State University of New York College of Environmental Science and Forestry (SUNYESF), Department of Environmental and Forest Biology (Jan 2008 – Aug 2013)

Chair, Institutional Animal Care and Use Committee, SUNY-ESF (Aug 2011-present).

Chair, EFB Cranberry Lake Biological Research Station Undergraduate Research Fellowship Program, SUNY-ESF (Dec 2009-Jan 2012).

Post Doctoral Research Associate, Oregon State University, Corvallis, Oregon. (Mar 2004 – Jan 2008):

Fisheries Molecular Biologist, Pacific Biological Station, Nanaimo, British Columbia. (May 1997 - Dec 1999).

AQUAVET II: Comparative Pathology of Aquatic Animals. Presented by the School of Veterinary Medicine University of Pennsylvania, and the College of Veterinary Medicine Cornell University. Woods Hole, MA. (May 17-31, 2008).

SCIENTIFIC SESSIONS CHAIRED Aug 1, 2002. Impacts of Myxozoan Parasites in Wild and Farmed Fish. Nanaimo, B.C. Session Chair. Sept 2-6, 2006. 5th International Symposium on Aquatic Animal Health, San Francisco, CA. *Mycobacteria 2/ Miscellaneous Bacteria*, Session Chair.
Jun 27-30, 2008. 83rd Annual Meeting, American Society of Parasitologists, Arlington, Texas. *Phylogenetics and Systematics*.

Peer Reviewer (over 127 reviews)
Journals
Acta Parasitologica; Aquaculture; Biological Invasions; Diseases of Aquatic Organisms; Folia Parasitologica;
Infection, Genetics and Evolution; Integrative and Comparative Biology; International Journal for Parasitology;
Journal of Afrotropical Zoology; Journal of Aquatic Animal Health; Journal of Eukaryotic Microbiology;
Journal of Parasitology; Journal of the World Aquaculture Society; Molecular Phylogenetics and Evolution; Parasites and Vectors; Parasitology; Parasitology International; Parasitology Research; PLoS ONE; Systematic Parasitology; Veterinary Parasitology; Veterinary Pathology.

Grants
ESF McIntire-Stennis Program; Sea Grant; National Science Foundation.

.0FACULTY COMMITTEES *Ongoing*
ESF Institutional Animal Care and Use Committee (Aug 2011-present). **Chair: Christopher Whipps** ESF Honors Program Faculty Council (Aug 2011-present). Director: William Shields.
ESC Health and the Environment Curriculum Group Participant (Mar 2011-present) ESF Academic Research Building Core Team (Apr 2010-present)

Past
EFB Curriculum Committee (Jan-Feb 2008, Aug 2008-Aug 2016). Chair: Kim Schulz.
EFB Disease Ecology/Epidemiology Search Committee (Oct2015-Apr2016). **Chair: Christopher Whipps** EFB Microbiology Search Committee (Oct 2013-Apr 2014). Chair Lee Newman.
EFB Toxicology Search Committee (Oct 8, 2012-May 2013). Chair Tom Horton.
ESF Committee on Curriculum (Aug 2010-May 2013). Chair: John Hassett.
ESF Committee on Curriculum, General Education subcommittee (Sept 2010-May 2013). Chair: Doug Daley.
EFB Cranberry Lake Biological Research Station Undergraduate Research Fellowship Program (Dec 2009-Jan

.02012). **CHAIR: CHRISTOPHER WHIPPS** ESF Environmental Health Curriculum Planning Committee (Nov 2010-Jun 2011). Chair: John Castello. ESF Committee on Promotion and Tenure Policies and Procedures (Feb 2008 – Feb 2011). Chair: Don Leopold.
EFB Space Committee (Feb 2008 – Aug 2010). Chair: John Farrell.
EFB Outstanding PhD Student Selection Committee (May 2008). Chair: Danny Fernando.
EFB Graduate Program Advisory Committee (Aug 2008-Sept 2010). Chair: Karin Limburg.
EFB Molecular/Cell Biologist Search Committee (Feb 2009-Apr 2009). Chair: William Powell.
ESF Environmental Health Program Feasibility Program (Sept 2009-Jan 2010). Chair: John Castello. EFB Molecular/Cell Biologist Search Committee (Nov 2009-Apr 2010). Chair: William Powell.

.0PROFESSIONAL COMMITTEES American Fisheries Society Fish Health Section *Technical Standards Committee* (appointment June 2010-Jun 2014) Chair (2012-13).

Handbook Revision and Oversight Committee Co-Chair (June 2012-June 2013)

American Fisheries Society Fish Health Section (AFS-FHS) Executive Committee (June 2012-June 2013).

.0PROFESSIONAL MEMBERSHIPS

American Fisheries Society (2001-present), American Society of Parasitologists (2002-present), American Society for Microbiology (2005-2007, 2014-present), International Society of Protistologists (2008-2010), Wildlife Disease Association (2008-2010), World Aquaculture Society (2007).

TEACHING EXPERIENCE

.0COURSES Ecological Monitoring and Biodiversity Assessment EFB 202, SUNY-ESF
Molecular Biology Techniques BTC401/EFB601, SUNY-ESF
General Biology II: Cell Biology and Genetics EFB103, SUNY-ESF
Emerging Diseases of Fish and Wildlife EFB496/796, SUNY-ESF
Parasitology EFB 453/653 SUNY-ESF

.0SEMINARS Population Genetics and Molecular Biology EFB797, SUNY-ESF
Topics in Applied Microbiology EFB797, SUNY-ESF
Infectious Diseases EFB797, SUNY-ESF
Health and Disease of Captive and Wild Fishes EFB797, SUNY-ESF
Population Genetics EFB797, SUNY-ESF
Host Pathogen Interactions EFB797, SUNY-ESF

.0HEALTH AND COLONY MANAGEMENT OF LABORATORY FISH (SEPTEMBER 17-21, 2007)

A short course for principal investigators, technicians, or core managers who utilize or plan to utilize fish models in laboratory research.

.0STUDENTS MENTORED Graduate Students

Megan Kirchgessner DVM, Ph.D. June 2012. Spatial Epidemiology of Bovine Viral Diarrhea Virus and *Coxiella burnetii* Seroprevalence in White-Tailed Deer (*Odocoileus virginianus*) in New York.

Eric Bauer, MS. July 2013. Cascades Of Enemy Release: Impacts of An Invasive Species (*Neogobius melanostomus*) on the Parasite Communities of Two Native Predators (*Micropterus dolomieu* and *Micropterus salmoides*).

Emily Ogburn, MS (co-advise with Dr. Karin Limburg). January 2014. Banded Killifish (*Fundulus diaphanus*) Parasite Communities of the Hudson River Estuary: A Prelude to Restoration.

Joelle Chille, MPS. (co-advise with Dr. Melissa Fierke) May 2014. New Biological and Cultural Control Methods of the Non-Native Nursery Pest *Xylosandrus germanus*.

William Helenbrook, Ph.D. (co-advise with Dr. William Shields) October 2014. Effects Of Ecological Disturbance On Parasite Communities In Both People And Mantled Howler Monkeys (*Alouatta palliata aequatorialis*) Living In Ecuador.

Katrina Alger, MS. November 2015. Lymphoproliferative disease virus (LPDV) in wild turkeys (*Meleagris gallopavo*) in New York State: Diagnostic methoeds, prevalence, and spatial distribution of a newly discovered pathogen.

Kelly Huffman, MPS (co-advise with Dr. John Farrell). June 2016. Applied Ecology coursework option.

Cassandra Elliott, MPS. December 2016. Internship option at Upstate Medical University.

Emily Gavard, MPS (co-advise with Dr. Sadie Ryan). May 2017. Gastrointestinal Parasites of the New England Cottontail (*Sylvilagus transitionalis*) and Eastern Cottontail (*Sylvilagus floridanus*) In The Hudson Valley,
New York

Carolyn Chang, Ph.D. December 2017. Controlling Infectious Disease in Laboratory Zebrafish (*Danio rerio*).

In Progress

Samantha Mello, MS sought. Start Aug 2015 (co-advise with Dr. Jonathan Cohen)

Undergraduate:

Meng Lin (Fall 2008, Spring 2009, Fall 2009) - *Winner of Second Place 'Best Poster', ESF Spotlight on Student Research.* Tiffany Brookins-Little (Fall 2008, Spring 2009), Andrew DiMezza (Spring 2009, Fall 2009), Alexander
Farewell-Prisaznuk (Spring 2009), Jacqueline Zalizniak (Spring 2009, Fall 2009), Jessica Mays (Fall 2009, Spring
2010), Amanda Diebel (Spring 2009, Fall 2009, Spring 2010), Andrew Underwood (Spring 2010), Eric Bauer
(Spring 2010, Summer 2010, Fall 2010, Spring 2011), Jenelle Hanson (Fall 2010 - Spring 2012), Samantha Page
(Summer 2011 - Spring 2014), Deneva Smith (Fall 2011), Jenna Sanford (Fall 2011, Spring 2012) - *Winner of*
Third Place 'Best Poster', ESF Spotlight on Student Research. Brooke Clemons (Fall 2012-Spring 2015); Erica Colicino

(Fall 2013, Spring 2014); Elizabeth DiPaola (Fall 2013, Spring 2014); Tiquasha Thompson (Fall 2014, Spring
2015); Elle Palmer (Fall 2014, Spring 2015); Kristen Doerr (Fall 2014 - Spring 2016); Julia Williamson (Summer
2015-Fall 2017); Elizabeth Mardy (Summer 2015, Fall 2015, Spring 2016); Ashley Adler (Fall 2015, Spring
2016); Kensey Portman (Fall 2015); Melanie Wilson (Fall 2015, Spring 2016); Ilana Weinstein (Spring 2016Spring 2018); Omar Alsafadi (Summer 2016-Spring2017); Jet Lewis (Summer 2016-Spring 2018); Natalee Wrege (Fall 2017-Spring 2018); Madison Fagant (Spring 2018).

.0GRANTS

NIH Resource Related Research Projects for Development of Animal Models and Related Materials (R24) (07/1/2017 -06/30/2021) $887,946 (SUNY Subaward $346,336). Control and Impact of Diseases in Zebrafish.
Kent ML, **Whipps CM**, Sanders J, Sharpton TJ, Watral, VG, Gaulk CA

USDA-CREES/McIntire-Stennis Program (8/15/2015 – 9/30/2017). $51,042. Assessing Use of NewlyRestored Early Successional Forest by the Imperiled New England Cottontail, Using Genetic Dispersal Analysis. Cohen J, **Whipps CM**, Ryan SJ.

Syracuse City School District – Smart Scholars Program (07/01/14-08/31/14). $6,214. Smart Scholars Biotechnology Camp Week. **Whipps CM**, Beal, RE.

New York Department of Environmental Conservation (04/01/14-03/31/16) $13,148. Lymphoproliferative Disease Virus (LPDV) in Wild Turkeys (*Meleagris gallopavo*) in New York State, U.S.

New York Department of Environmental Conservation (04/01/14-03/31/16) $132,222. Increasing Capacity for Genetic Analysis at SUNY ESF. **Whipps CM**

NIH Resource Related Research Projects for Development of Animal Models and Related Materials (R24) (07/1/2013 -06/30/2017) $858,720 (SUNY Subaward $370,950). Control and Impact of Diseases in Zebrafish. Kent ML, **Whipps CM**, Dolan B, Tanguay R.

USDA-CREES/McIntire-Stennis Program. (05/01/13-09/30/15) - $52,000. Development of Molecular Techniques to Inform Management of *Sirex noctilio*, an Introduced Woodwasp. **Whipps CM**, Fierke MK, Parry D.

New York Department of Environmental Conservation (03/31/2013 – 03/31/2016) - $715,001. St. Lawrence River Fisheries Management and Research. (2% AY) Farrell J, Kapsinski K, **Whipps CM.**

New York Department of Environmental Conservation (8/1/12-4/30/2016) $854,516. Factors Limiting New England Cottontail (*Sylvilagus transitionalis*) Populations in New York: Implications for Habitat Restoration. Cohen J, Ryan S, **Whipps CM**.

SUNY-ESF Seed Grant Program (04/01/11-09/30/12) - $8,000. Molecular Prospecting: Genomic DNA Sequence Data for Myxozoan. **Whipps CM**

National Science Foundation (1/1/10-12/31/12) $1,757,801. Renovation of Wet Labs and Cyber-Infrastructure to Enhance Integrated Research and Teaching in Aquatic Science at ESF. Ringler, Schulz, Farrell, Leopold, **Whipps** (5% AY – Co-Investigator. Role: Provide specifics and design for animal rooms, isolation room, microscope rooms).

NIH Subaward P0274A-A (3/1/10 - 2/28/12) $60,000. Characterizing *Mycobacterium* species from zebrafish and diagnostic development. (1% AY). **Whipps, CM**

SUNY-ESF Seed Grant Program (3/1/09 - 12/31/2010) - $8,000. Systematics and Biodiversity of the Myxozoa. **Whipps, CM**

USDA-CREES/McIntire-Stennis Program (8/15/09 – 9/30/11) - $50,500 Monitoring populations of elusive forest wildlife: a modern approach using noninvasive genetic techniques (Co-investigator with Jacqueline Frair) (5% AY). Frair, JL & **Whipps, CM**

Yukon River Drainage Fisheries Association (February 2007) - $4,000 donation to study the distribution of and genetically characterize the parasite *Ichthyophonus hoferi* in Alaskan fishes. **Whipps, CM**

.0PUBLICATIONS

Book Chapters

Atkinson, S.D., Bartošová-Sojková, P., **Whipps, C.M.** (2015) Approaches for Characterizing Myxozoan Species. In: Myxozoan Evolution, Ecology and Development, Edited by B. Okamura, A. Gruhl, J.L. Bartholomew. pp 111-123; Springer International Publishing.

Fiala, I., Bartošová-Sojková, P., **Whipps, C.M.** (2015) Classification and Phylogenetics of Myxozoa. In: Myxozoan Evolution, Ecology and Development, Edited by B. Okamura, A. Gruhl, J.L. Bartholomew. pp 85110; Springer International Publishing.

.0REVIEWED JOURNALS (WEB OF SCIENCE BASED ON 76 DOCUMENTS – CITED A COMBINED 1703 TIMES, H-INDEX=26)

Berkman, L.K., Frair, J.L., Marquardt, P.E., Donner, D.M., Kilgo, J.C., **Whipps, C.M.** (In Review) Spatial analysis reveals genetic admixture among coyotes (*Canis latrans*) in New York State. The Wildlife Society Bulletin.

Gavard, E.J., **Whipps, C.M.**, Cohen, J., Ryan, S.J. (In Review) Gastrointestinal parasites of the New England cottontail (*Sylvilagus transitionalis*) and eastern cottontail (*Sylvilagus floridanus*) in the Hudson Valley, New York. Journal of Parasitology

Peneyra, S.M., Cardona-Costa, J., White, J., **Whipps, C.M.**, Riedel, E.R., Lipman, N.S., Lieggi, C. 2018. Transmission of *Pseudoloma neurophilia* in laboratory zebrafish (*Danio rerio*) when using mass spawning chambers and recommendations for chamber disinfection. Zebrafish. 15(1):63-72.

Vidal, L.P., Iannocone, J., **Whipps, C.M.**, Luque, J.L. 2017. Synopsis of the Species of Myxozoa Grassé, 1970 (Cnidaria: Myxosporea) in the Americas. Neotropical Helminthology. 11(2): 405-543.

Helenbrook, W.D., Stehman, S.V., Shields, W.M., **Whipps, C.M.** 2017. Association of Anthropogenic Disturbances and Intestinal Parasitism in Ecuadorian Mantled Howler Monkeys, *Alouatta palliata aequatorialis*. Folia Primatologica (Basel). 88(3):307-322.

Chang, C.T., Doerr, K.M., **Whipps, C.M.** 2017. Antibiotic treatment of zebrafish mycobacteriosis: tolerance and efficacy of treatments with tigecycline and clarithromycin. Journal of Fish Diseases. 40(10):1473-1485.

Alger, K.E., Bunting, E., Schuler, K., **Whipps, C.M.** 2017. Risk factors and spatial distribution of Lymphoproliferative Disease Virus (LPDV) in wild turkeys (*Meleagris gallopavo*) in New York State. Journal of Wildlife Diseases. 53(3): 499-508.

Youker-Smith, T.E., **Whipps, C.M.**, Ryan, S.J. 2016 Detection of an FV3-like Ranavirus in Wood Frogs (*Lithobates sylvaticus*) and Green Frogs (*Lithobates clamitans*) in a Constructed Vernal Pool Network in Central New York State. Herpetological Review. 47(4): 595-598.

Ryan, S.J., Gavard, E.J., Cheeseman, A.M., Cohen, J.B., **Whipps, C.M.** 2016. Reference and baseline hematocrit measures for the threatened New England cottontail (*Sylvilagus transitionalis*). Journal of Zoo and Wildlife Medicine. 47(2): 659-662.

Chang, C.T., Amack, J.D., **Whipps, C.M.** 2016. Zebrafish embryo disinfection with povidone iodine: evaluating an alternative to chlorine bleach. Zebrafish. 13 (Suppl 1): S96-S101.

Mason, T., Snell, K., Mittge, E., Melancon, E., Montgomery, R., McFadden, M., Camoriano, J., Kent, M.L., **Whipps, C.M.**, Peirce, J. 2016. Strategies to Mitigate a *Mycobacterium marinum* Outbreak in a Zebrafish Research Facility. Zebrafish. 13 (Suppl. 1): S77-S87.

Zhai, Y., **Whipps, C.M.**, Gu, Z., Guo, Q., Wu, Z., Wang, H., Liu, Y. 2016. Intraspecific morphometric variation in myxosporeans. Folia Parasitol (Praha). 63:1-7

Foelker, C.J., Fierke, M.K., Standley, C.R., Parry, D., **Whipps, C.M.** 2016. Host tissue identification for cryptic hymenopteran parasitoids associated with *Sirex noctilio*. Agricultural and Forest Entomology. 18:91-94

Alger, K.E., Bunting, E., Schuler, K., Jagne, J., **Whipps, C.M.** 2015. Diagnosing Lymphoproliferative Disease Virus in Live Wild Turkeys (*Meleagris gallopavo*) Using Whole Blood. Journal of Zoo and Wildlife Medicine. 46(4):806-814.

Chang, C.T., Colicino, E.G., DiPaola, E.J., Al-Hasnawi, H.J., **Whipps, C.M.** 2015. Evaluating the effectiveness of common disinfectants at preventing the propagation of *Mycobacterium* spp. isolated from zebrafish. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology. 178:45-50.

Torruella, G. de Mendoza, A., Grau-Bové, X., Chaplin, M. A., del Campo, J., Eme, L., Pérez-Cordón, G.
Whipps, C. M., Nichols, K. M., Paley, R., Sitjà-Bobadilla, A., Roger, A. J., Donachie, S., Ruiz-Trillo, I. 2015. Phylogenomics reveals convergent evolution of lifestyles in close relatives of animals and fungi. Current Biology. 25(18):2404-2410.

Nogueira, C.L., **Whipps, C.M.**, Matsumoto, C.K., Chimara. E., de Freitas, D., Sampaio, J.L., Cnockaert, M., Palomino, J.C., Martin, A., Vandamme, P., Leão, S.C. (2015). Description of *Mycobacterium saopaulense* sp. nov., a rapidly growing mycobacteria closely related with members of the *Mycobacterium chelonae-M. abscessus* group. International Journal of Systematic and Evolutionary Microbiology. 65:4403-4409

Whipps, C. M., Zhao, Y. 2015. Synopsis of the species of the genus *Sphaeromyxa* Thélohan, 1892 (Myxosporea: Bivalvulida: Variisporina: Sphaeromyxidae). Systematic Parasitology. 92(2):81-99

Bauer, E.F., **Whipps, C.M.** 2015. The bass parasites of Oneida Lake, eighty years later. Journal of Parasitology. 101(5):505-513.

Chang, C.T., **Whipps, C.M.** 2015. Activity of antibiotics against *Mycobacterium* species commonly found in laboratory zebrafish. Journal of Aquatic Animal Health. 27(2):88-95.

Helenbrook, W.D., Shields, W.M., **Whipps, C.M.** 2015. Characterization of *Blastocystis* species infection in humans and mantled howler monkeys, *Alouatta palliata aequatorialis*, living in close proximity to one another. Parasitology Research. 114(7):2517-2525

Helenbrook, W.D., Wade, S.E., Shields, W.M., Stehman, S.V., **Whipps, C.M.** 2015. Gastrointestinal parasites of Ecuadorian mantled howler monkey (*Alouatta palliata aequatorialis*) based on fecal analysis. Journal of Parasitology. 101(3):341-350.

Whipps, C.M., Murray, K.N., Kent, M.L. 2015. Occurrence of a myxozoan parasite *Myxidium streisingeri* n. sp. in laboratory zebrafish *Danio rerio*. Journal of Parasitology. 101(1):86-90.

Liu, Y., **Whipps, C.M.**, Nie, P., Gu, Z.M. 2014. *Myxobolus oralis* sp. n. (Myxosporea: Bivalvulida) infecting the palate in the mouth of gibel carp *Carassius auratus gibelio* (Cypriniformes: Cyprinidae). Folia Parasitologica. 61(6):505-511.

Whipps, C.M., Moss, L.G., Murray, K.N., Moss, J.B. 2014. Detection of autofluorescent *Mycobacterium chelonae* in living zebrafish. Zebrafish. 11(1):76-82.

Schaefer, J.J., Kirchgessner, M.S., **Whipps, C.M.**, Mohammed, H.O., Bunting E.M., Wade, S.E. 2013. *Toxoplasma gondii* seroprevalence in New York State white-tailed deer (*Odocoileus virginianus*) Journal of Wildlife Diseases. 49(4):940-945.

Bauer, E.F., **Whipps, C.M.** 2013. Comparative analysis of native fish parasite communities of Adirondack lakes with and without introduced fish species. Journal of Parasitology. 99(4):603-609.

Kirchgessner, M.S. Dubovi, E.J., **Whipps, C.M.** 2013. Disease Risk Surface for *Coxiella burnetii* Seroprevalence in White-Tailed Deer. Zoonoses and Public Health. 60(7):457-460.

Reeve, B.C., Crespi, E.J., **Whipps, C.M.,** Brunner, J.L. 2013. Natural stressors and ranavirus susceptibility in larval wood frogs (*Rana sylvatica*). EcoHealth. 10(2):190-200.

Peterson, T.S., Kent, M.L., Ferguson, J.A., Watral, V.G., **Whipps, C.M.** 2013. Comparison of fixatives and fixation time for PCR detection of *Mycobacterium* in zebrafish *Danio rerio*. Diseases of Aquatic Organisms. 104(2):113-120.

Whipps, C.M., Font, W.F. 2013. Interaction of two Myxozoan parasites from naked goby *Gobiosoma bosc*, in Lake Pontchartrain, Louisiana. Journal of Parasitology. 99(3):441-447.

Kirchgessner, M.S., Freer, H., **Whipps, C.M.,** Wagner, B. 2013. Detection of *Borrelia burgdorferi* outer surface protein antibodies in wild white-tailed deer (*Odocoileus virginianus*) in New York and Pennsylvania, USA. Veterinary Immunology and Immunopathology. 153, 165-169.

Kirchgessner, M.S. Dubovi, E.J., **Whipps, C.M.** 2013. Spatial point pattern analyses of Bovine viral diarrhea virus infection in domestic livestock herds and concomitant seroprevalence in wild white-tailed deer (*Odocoileus virginianus*) in New York State, USA. Journal of Veterinary Diagnostic Investigation. 25(2), 226-233.

Liu, Y., **Whipps, C.M.**, Gu, Z.M., Huang, M.J., He, C., Yang, H.L., Molnár, K. 2013. *Myxobolus musseliusae* (Myxozoa: Myxobolidae) from the gills of common carp *Cyprinus carpio* and revision of *Myxobolus dispar* recorded in China. Parasitology Research. 112(1), 289-296.

Kirchgessner, M.S. Dubovi, E.J., **Whipps, C.M.** 2012. Seroepidemiology of *Coxiella burnetii* in wild white-tailed deer (*Odocoileus virginianus*) in New York, United States. Vector-Borne and Zoonotic Diseases. 12(11), 942-947.

Whipps, C.M., Lieggi, C., Wagner, R.A. 2012. Mycobacteriosis in zebrafish colonies. Institute for Laboratory Animal Research Journal. 53(2), 95-105.

Kirchgessner, M.S., Dubovi, E.J., Porter, W.F., Zylich, N.C., **Whipps, C.M.** 2012. Prevalance and spatial distribution of antibodies to Bovine Viral Diarrhea Virus and *Coxiella burnetii* in white-

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Gozlan, R.E., **Whipps, C.M.,** Andreou, D., Arkush, K.D. 2009. Identification of the cyprinid rosette-like agent as *Sphaerothecum destruens*, a multihost fish pathogen. International Journal for Parasitology. 39(10), 1055-1058.

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Sanders, G.E., Spitsbergen, J.M., **Whipps, C.M.** 2009. Recommendations for Control of Pathogens and Infectious Diseases in Fish Research Facilities. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology. 149(2), 240–248.

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Ostland, V.E., Watral, V.G., **Whipps, C.M.**, Austin, F., St. Hilaire, S., Westerman, M.E., and Kent, M.L. 2008. Biochemical, molecular, and virulence studies of select *Mycobacterium marinum* strains in hybrid striped bass (*Morone chrysops x M. saxatilis*) and zebrafish (*Danio rerio*). Diseases of Aquatic Organisms. 79(2), 107-118.

Zhao, Y., Zhou, Y., Kent, M.L., and **Whipps, C.M.** 2008. Replacement of the preoccupied name *Davisia* Laird 1953, and description of a new myxozoan species (Myxosporea: Sinuolineidae) from *Sebastiscus marmoratus* (Cuvier, 1829) in the East China Sea. Journal of Parasitology. 94(1), 269-279.

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Whipps, C.M., Dougan, S.T., and Kent, M.L. 2007. *Mycobacterium haemophilum* infections of zebrafish (*Danio rerio*) in research facilities. FEMS Microbiology Letters. 270(1), 21-26.

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Gunter, N.L., Cribb, T.H., **Whipps, C.M.**, and Adlard, R.D. 2006. Characterisation of *Kudoa monodactyli* n. sp. (Myxosporea: Multivalvulida) from the Muscle of *Monodactylus argenteus* (Teleostei: Monodactylidae) from Moreton Bay, Queensland, Australia. Journal of Eukaryotic Microbiology. 53(5), 374-378.

Jirků, M., Bolek, M.G., **Whipps, C.M.,** Janovy, J., Kent, M.L., and Modrý, D. 2006. A new species of *Myxidium* (Myxosporea: Myxidiidae), from the western chorus frog, *Pseudacris triseriata triseriata*, and Blanchard's cricket frog, *Acris crepitans blanchardi* (Hylidae) from eastern Nebraska USA: morphology, phylogeny and critical comments on amphibian *Myxidium* taxonomy. Journal of Parasitology. 92(3), 611-619.

Whipps, C.M., and Diggles, B.K. 2006. *Kudoa alliaria* in flesh of ArgentinianHoki *Macruronus magellanicus* (Gadiformes; Merlucciidae). Diseases of Aquatic Organisms. 69(2-3), 259-263.

Poort, M.J., **Whipps, C.M.,** Watral, V.G. Font, W.F., and Kent, M.L. 2006. Description of a *Mycobacterium* species in non-native poeciliids in Hawaii using DNA sequences. Journal of Fish Diseases. 29(3), 181-185.

Whipps, C.M., Burton, T., Watral, V.G., St-Hilaire, S., and Kent, M.L. 2006. Assessing the accuracy of a polymerase chain reaction test for *Ichthyophonus hoferi* in Yukon River Chinook salmon (*Oncorhynchus tshawytscha*). Diseases of Aquatic Organisms. 68(2), 141-147.

Whipps, C.M., and Kent, M.L. 2006. Polymerase chain reaction detection of *Pseudoloma neurophilia*, a common microsporidian of zebrafish (*Danio rerio*) reared in research laboratories. Journal of the American Association for Laboratory Animal Science. 45(1), 36-39.

Adlard, R.D., Bryant, M.S., **Whipps, C.M**. and Kent, M.L. 2005 Multivalvulid myxozoans from eastern Australia: Three new species of *Kudoa* from scombrid and labrid fishes of the Great Barrier Reef, Queensland Australia. Journal of Parasitology. 91(5), 1138-1142.

Garner, M.M., Bartholomew, J.L., **Whipps, C.M.**, Nordhausen, R.W., and Raiti, P. 2005. Renal myxozoanosis
in Crowned River turtles *Hardella thurjii*: description of the putative agent, *Myxidium hardella* n. sp. by histopathology, electron microscopy, and DNA sequencing. Veterinary Pathology. 42, 589-595.

Kent, M.L., **Whipps, C.M.**, Matthews, J.L., Florio, D., Watral, V.G., Bishop-Stewart, J.K., Poort, M.J., and Bermudez, L. 2004. Mycobacteriosis in zebrafish (*Danio rerio*) research facilities. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology. 138(3), 383-390.

Kent, M.L., Watral, V.G., **Whipps, C.M.**, Cunningham, M.E., Criscione, C.D., Heidel, J.R., Curtis, L.R., Spitsbergen, J., and Markle, D.F. 2004. Digenean metacercariae and a myxozoan (*Myxobolus* sp.) associated with skeletal lesions in cyprinid fishes from the Willamette River, Oregon. Journal of Aquatic Animal Health. 16(3), 116-129.

Diamant, A., **Whipps, C.M.**, and Kent M.L. 2004. A new species of *Sphaeromyxa* (Myxosporea: Sphaeromyxina: Sphaeromyxidae) in devil firefish, *Pterois miles* (Scorpaenidae), from the northern Red Sea: morphology, ultrastructure, and phylogeny. Journal of Parasitology. 90(6), 1434-1442.

Koie, M., **Whipps, C.M.**, and Kent, M.L. 2004. *Ellipsomyxa gobii* (Myxozoa: Ceratomyxidae) in the common goby *Pomatoschistus microps* (Teleostei: Gobiidae) uses *Nereis* spp. (Annelida: Polychaeta) as invertebrate hosts. Folia Parasitologica 51, 14-18.

Whipps, C.M., El-Matbouli, M., Hedrick, R.P., Blazer, V., and Kent, M.L. 2004. *Myxobolus cerebralis* internal transcribed spacer 1 (ITS-1) sequences support recent spread of the parasite to North America and within Europe. Diseases of Aquatic Organisms. 60(2), 105-108.

Yokoyama, H., **Whipps, C.M.**, Kent, M.L., Mizuno, K. and Kawakami, H. 2004. *Kudoa thyrsites* from Japanese flounder and *Kudoa lateolabracis* n. sp. from Chinese sea bass: Causative myxozoans of post-mortem myoliquefaction. Fish Pathology (Gyoby o Kenky u). 39(2), 79-85.

Whipps, C.M., Grossel, G., Adlard, R.D., Yokoyama, H., Bryant, M.S., Munday, B.L., and Kent M.L. 2004.
Phylogeny of the Multivalvulidae (Myxozoa: Myxosporea) based upon comparative rDNA sequence analysis. Journal of Parasitology. 90(3), 618-622.

Blaylock, R.B., Bullard, S.A., and **Whipps, C.M.** 2004. *Kudoa hypoepicardialis* n. sp. (Myxozoa: Kudoidae) and associated lesions from the heart of seven perciform fishes in the northern Gulf of Mexico. Journal of Parasitology. 90(3), 584-593.

Whipps, C.M., Adlard, R.D., Bryant, M.S., Lester, R.J.G., Findlay, V. and Kent, M.L. 2003. First Report of Three *Kudoa* Species from Eastern Australia: *Kudoa thyrsites* from Mahi mahi (*Coryphaena hippurus*), *Kudoa amamiensis* and *Kudoa minithyrsites* n. sp. from Sweeper (*Pempheris ypsilychnus*). Journal of Eukaryotic Microbiology. 50 (3), 215-219.

Whipps, C.M., Watral, V.G., and Kent M.L. 2003. Characterization of a *Mycobacterium* sp. in rockfish, *Sebastes alutus* (Gilbert) and *Sebastes reedi* (Westrheim & Tsuyuki), using rDNA sequences. Journal of Fish Diseases. 26, 241-245.

Whipps, C.M., Adlard, R.D., Bryant, M.S. and Kent, M.L. 2003. Two unusual myxozoans, *Kudoa quadricornis* n. sp. (Multivalvulida) from the muscle of goldspotted trevally (*Carangoides fulvoguttatus*) and *Kudoa permulticapsula* n. sp. (Multivalvulida) from the muscle of Spanish mackerel (*Scomberomorus commerson*) from the Great Barrier Reef, Australia. Journal of Parasitology. 89(1), 168-173.

Criscione, C.D. Watral, V., **Whipps, C.M.**, Blouin, M.S., Jones, S.R.M., and Kent, M.L. 2002. Ribosomal DNA sequences indicate isolated populations of *Ichthyophonus hoferi* in the northeastern Pacific Ocean. Journal of Fish Diseases. 25(10), 575-582.

Shaw, R.W., Kent, M.L., Brown, A.M.V., **Whipps, C.M.,** Adamson, M.L. 2000. Experimental and natural host specificity of *Loma salmonae.* Diseases of Aquatic Organisms. 40(2), 131-136.

.0TECHNICAL REPORTS AND OTHERS

Kent, M.L., **Whipps, C.M.** 2010. Taxonomy, host specificity, and development of *Kudoa thyrsites* (Myxozoa), an important cause of post-harvest myoliquefaction in pen-reared Atlantic salmon. Proceedings of the *Kudoa* Workshop. Afonso, L.O.B, and Jones, S.R.M. (eds.) 7-8 Dec 2010. Campbell River, BC. Canada. p. 17-19.

Kent, M.L., **Whipps, C.M.**, Watral, V.G. 2004. Development of a non-lethal, PCR based test for *Ichthyophonus hoferi*. Alaskan Department of Fish and Game Technical Report.

Whipps, C.M., Kent, M.L. 2003. Screening Chinook salmon in Oregon hatcheries for *Nucleospora salmonis* (Microsporidia). Oregon Department of Fisheries and Wildlife Technical Report.

Kent, M.L., Criscione, C., **Whipps, C.,** Watral, V., Blouin, M., Jones, S.M., Dawe, S.C. 2002. rDNA sequences indicates that *Ichthyophonus* from rockfish is different from those of Pacific herring and chinook. American Fisheries Society Fish Health Newsletter 30(2): 22-23.

Whipps, C.M., Smith, P., Kent, M.L. 2001. A *Kudoa* species in pen-reared Atlantic salmon (*Salmo salar*) from Chile. American Fisheries Society, Fish Health Newsletter. 29(1), 5-6.

.0INVITED SPEAKER

June 26-27, 2017. Hands-On Workshop on Advancing Zebrafish Health Programs. Lisbon, Portugal.

April 24-25, 2017. Workshop: World Register of Parasites of Marine Species. Oostende, Belgium. *Myxosporean*
Diversity.

February 19-22, 2017. Aquaculture America 2015. San Antonio, TX. *Mycobacteriosis: Studies on Surface Biofilms and Implications for Monitoring*.

January 27, 2017. The 10th Annual Swiss Zebrafish Meeting. Bern, Switzerland. *Impact and Control of Diseases in Zebrafish Research Facilities*.

February 19-22, 2015. Aquaculture America 2015. New Orleans, LA. *Efficacy Of Disinfectants Used For Surface Disinfection Of Eggs Against* Mycobacterium *Species.*

April 28-May 2, 2014. 39th Annual Eastern Fish Health Workshop, Shepherdstown, WV. Linking Mycobacterium *Infections In Zebrafish (*Danio rerio*) With Surface Biofilms: Does Eradication Work?*

April 28-May 2, 2014. 39th Annual Eastern Fish Health Workshop, Shepherdstown, WV. *Renal Myxosporidiosis Of Laboratory Zebrafish*, Danio rerio.

February 9-12, 2014. Aquaculture America 2014. Seattle, WA. *Mycobacteria in zebrafish: Resolving Strain and Isolate Differences with* M. marinum.

January 24, 2014. From Lab to Landscape:Integrated Infectious Disease Research, Syracuse, NY. *Fins, feathers and fur: tracking pathogens in fish and wildlife*.

July 10, 2013. Cornell Biological Field Station, NY. 2013 Summer Seminar Series. *Fish health and the ecology of parasitic diseases in Northeast fishes*.

February 22, 2013. Aquaculture America 2013. Nashville, TN. *Mycobacteria – Chlorine disinfection, facility clean-up, and autofluorescence.*

October 31, 2011. University of Oregon, Eugene, OR. *Mycobacterial Disease in Zebrafish: Epidemiology, Detection, Prevention*

October 20, 2011. New York Zebrafish Conference. New York, NY. *Mycobacteriosis in zebrafish colonies: characterization and control*.

March 1, 2011. Aquaculture America 2011. New Orleans, LA. *Mycobacteriosis in Zebrafish Facilities*.

April 24, 2009. NCRR-NIH Workshop: Detection, Impact and Control of Specific Pathogens in Animal Resource Facilities. Bethesda, MD. *Specific Infectious Disease Agents and Their Impact on Research: Mycobacterial Infections in Fish*.

February 20, 2009. The Wildlife Society, New York Chapter Annual Meeting, Syracuse, NY. *Status of Wildlife Diseases.*

April 6, 2006. Oregon State University, Biomedical Sciences Graduate student and Post Doc Luncheon.

Nov 15, 2005. Oregon State University, College of Veterinary Medicine, Biomedical Sciences, Guest Speaker Series. *Mycobacteriosis in Zebrafish.*

CONFERENCE PRESENTATIONS (Other than invited)

.0INTERNATIONAL AND NATIONAL CONFERENCE PRESENTATIONS

July 13 – 15, 2015. Annual Meeting of the Fish Health Section of the American Fisheries Society. Ithaca, NY. *Strain Typing* Mycobacterium marinum *from outbreaks at zebrafish research facilities*

June 18-20, 2013. 54th Joint Western Fish Disease Workshop & AFS Fish Health Section Meeting, Port Townsend, WA. *Efficacy Of Surface Disinfection Of Zebrafish Eggs Against* Mycobacterium *Species.*

June 18-20, 2013. 54th Joint Western Fish Disease Workshop & AFS Fish Health Section Meeting, Port Townsend, WA. *The Bass Parasites Of Oneida Lake, Eighty Years Later*.

May 24-28, 2010. 35th Annual Eastern Fish Health Workshop, Shepherdstown, WV. *Tracking Mycobacterial Infections in Laboratory Zebrafish (*Danio rerio*).*

Apr 27-30, 2009. 34th Annual Eastern Fish Health Workshop, Lake Placid, NY. The curious case of fish apicomplexa; molecular systematics shed light on this enigmatic group.

Sept 2-6, 2006. 5th International Symposium on Aquatic Animal Health, San Francisco, CA. *Phylogeography of the cosmopolitan parasite* Kudoa thyrsites *reveals cryptic species*.

June 26-28, 2006. 47th Western Fish Disease Workshop, Victoria, British Columbia. *Resurrection of a species: molecular systematics support the validity of* Mycobacterium salmoniphilum.

May 21-25, 2006. American Society of Microbiology, Orlando, FL. Molecular systematics support the validity of *Mycobacterium salmoniphilum*, a species closely related to *Mycobacterium chelonae*.

Oct 30-Nov 2, 2005. Aquatic Animal Models of Human Disease Conference, Athens, GA. *Mycobacterial Infections in Zebrafish Facilities*.

July 8-11, 2005. 80th Annual Meeting of the American Society of Parasitologists, Mobile, AL. *Host range of an unusual apicomplexan from Hawaiian fishes; systematics of* Goussia *and* Calyptospora *spp.* **Whipps, C.M.**, Keafer, B., Work, T.M., Rameyer, B., Fournie, J.W., Kent, M.L. (not given due to hurricane).

June 27-29, 2005. 46th Western Fish Disease Workshop, Boise, ID. *Something Old, Something New: Mycobacteriosis in Salmon and Zebrafish*.

Aug 2004. 79th Annual Meeting of the American Society of Parasitologists, Philadephia, PA. *Phylogeography of the Marine Myxozoan* Kudoa thyrsites.

Aug 1-5, 2003. 78th Annual Meeting of the American Society of Parasitologists, Halifax, Nova Scotia. *The Phylogeny of the Multivalvulida (Myxozoa: Myxosporea) Based Upon Comparative rDNA Sequence Analysis.*

July 15-17, 2003. American Fisheries Society, Fish Health Section Meeting and 44th Western Fish Disease Workshop. Seattle, Washington. *Analysis of Myxozoan Ribosomal DNA Sequences Supports Recent Spread of* Myxobolus cerebralis *from Europe to North America.*

Aug 4-9, 2002. 10th International Congress of Parasitology. Vancouver. B.C. *Intraspecific Variation Among Populations of the Marine Myxozoan Parasite* Kudoa thyrsites.

Jul 31-Aug 2, 2002. Impacts of Myxozoan Parasites in Wild and Farmed Fish. Nanaimo, B.C. *Phylogeography of* Kudoa thyrsites *(Myxozoa: Multivalvulida).*

Jun 25-26, 2002. 43rd Western Fish Disease Workshop. Corvallis, Oregon. *Genetic Variation Among Worldwide Representatives of the Marine Myxozoan Parasite* Kudoa thyrsites.

Aug 26-30, 2001. 20th Annual Meeting of the Willi Hennig Society. Corvallis, Oregon. *Advances in our Understanding of the Myxozoa and Relationships among Parasites of the Order Multivalvulida.*

Jun 26-29, 2001. American Fisheries Society Fish Health Section Meeting and 42nd Western Fish Disease Workshop. Victoria, British Columbia. *Phylogenetic Analysis of* Kudoa thyrsites *worldwide and new Myxozoan parasites of the Great Barrier Reef.*

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.0EDUCATION Ph.D., 2002, Department of Entomology, Cornell University, Ithaca, N.Y. Dissertation: *Metapopulation biology of the mayfly* Callibaetis ferrugineus hageni *in high-elevation beaver ponds.* Advisor: Barbara Peckarsky.

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

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

.0PROFESSIONAL POSITIONS Assistant Professor (2013-present) and Director/Lead Scientist, Fish Ecology Research Laboratory (FERL; 2008-present). Department of Fish and Wildlife Sciences, University of Idaho.

Research Assistant Professor, Sept 2009-Aug2013.

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

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

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

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

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

.0TEACHING Assistant Professor, University of Idaho, 2013-present
Fish Ecology (300-level undergraduate; 4 credit, Fall 2013);

Animal Movement, Dispersal, and Migration (Graduate; 2 credit, Fall 2014; 3 credit Fall 2016); *Statistical Analysis of Ecological Data* (Graduate; 1 credit co-taught with M. Wiest, Spring 2015).

Fish and Wildlife in a Changing World (200-level undergraduate for non-majors, 3 credit co-taught with J. Rachlow, Fall 2015, 2016)

Climate Change and the Conservation and Management of Populations (Graduate, 1 credit with on-line option, Fall 2015 [sole instructor]; Spring 2017 [co-instructor])

Ichthyology (400-level undergraduate; 4 credit with lab, Spring 2016, 2017, 2018)

Instructor, University of Idaho, 2006-7.

Fish and Wildlife Population Ecology (upper-level undergraduate course co-taught with O. Garton and C. Peery, Fall 2007)

Cumulative Watershed Processes (graduate seminar co-taught with T. Link, Spring 2007).

Limnology (upper-level undergraduate/graduate course with lab co-taught with C. Peery Fall 2006).

Models of Cause and Correlation in Biology: Structural Equation Modeling for Non-experimental Systems (graduate seminar co-taught with O. Garton, Spring 2006).

Instructor, Georgia Institute of Technology, 2002-2003.

Aquatic Chemical Ecology Laboratory (graduate course co-taught with Mark Hay and Julia Kubanek, School of Biology, Fall 2002).

Biological Applications of Fluid Dynamics (graduate course co-taught with Phil Roberts, School of Civil Engineering, Spring 2003).

Instructor, Rocky Mountain Biological Laboratory, 2002.

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

.0MENTORING ACTIVITIES Post-doctoral advisor:

Geoff Moret, 2009-2014. Project title: Developing long term monitoring protocols for aquatic resources in the Mojave Network of the NPS Inventory and Monitoring Program. Current position: Southern Nevada Projects Chief, USGS Nevada Water Science Center

Tracy Bowerman, 2013-2016. Project title: Prespawn mortality in Chinook salmon of the Columbia Basin. Current position: Instructor, Salish Kootenai College, Pablo, MT.

Dana Weigel Sheedy, 2017-present. Project title: Genetic evaluation of interactions between native

ESA-listed winter steelhead and non-native hatchery summer steelhead in the Willamette Basin Jens Hegg, 2018-present. Project title: Characterizing life history variation in Willamette Valley Chinook salmon.

Graduate committee chair, current:

Matthew Dunkle, Ph.D., Fish and Wildlife Sciences

Nathan Fuchs, M.S., Fish and Wildlife Sciences
Sarah Hanchett, M.S., Fish and Wildlife Resources
Sammy Matsaw, Ph.D., Water Resources
Adam Wicks-Arshack, Ph.D., Water Resources
Kimberly Clark, M.S. (non-thesis), Environmental Science
Keith Kistler, M.S. (non-thesis), Environmental Science

Graduated:

Matthew Dunkle (M.S., Fisheries Resources, 2017)
Charles Erdman (M.S., Fisheries Resources, 2017)
James "Channing" Syms (M.S., 2016; Civil Engineering, co-advised w/ Daniele Tonina)
Mark Kirk (M.S. Fisheries Resources 2015)
Samuel Bourret (M.S. 2013; co-advised with B.P. Kennedy)
Christopher Noyes (M.S., 2013)
Hattie Zobott (M.S. Civil Engineering 2013, co-advised with R. Budwig)
Adrienne Roumasset (M.S., 2012; Water Resources)
Brian McIlraith (M.S., 2011; co-advised with B.P. Kennedy)

Graduate committee member: Current: Laura Jenkins (Ph.D., U.I. Biology), Stacey Feeken, (M.S., U.I. Fish & Wildlife Sciences), Bernadette Johnson (Ph.D., U.I. Biology). Past: Zachary Beard (M.S., 2017 U.I.
Fish & Wildlife Sciences), Francine Mejia (Ph.D., 2016, U.I. Fish & Wildlife Sciences), Adrianne
Zuckerman (M.S. 2015, U.I. Fish & Wildlife Sciences), Anthony Prisciandaro (M.S. 2015, U.I. Fish &
Wildlife Sciences), K. Marius Myrvold (Ph.D. 2014, U.I. Fish & Wildlife Sciences), Karen Laitala (M.S. 2007, U. I. Plant Science)

Undergraduate research advisees: Ryan Dunbeck, summer 2016-current, UI-NSF MILES Summer Fellow; Kristin Hall, Environmental Science, 2017-present; Alexis Litty, 2016-2017, U.I. Environmental
Sciences; Keala Bush, supported by UI Office of Undergraduate Research, spring 2016; Robert Hogg, U.I. Environmental Sciences/NSF REU mentor, summer 2007; Eva Sebesta, U.I. McNair Scholar Program mentor (with Ed Galindo and Aaron Haines), summer 2007.

.0PUBLICATIONS PEER-REVIEWED PUBLICATIONS (*INDICATES STUDENT AUTHOR)

65. Erdman*, C., C. C. Caudill, G.P. Naughton, and M. Jepson. Release of hatchery-origin steelhead for angler opportunity increases potential for interactions with endemic steelhead. *In press, Ecosphere.* March 2018.

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upstream migration and estimated environmental temperatures in Lower Granite Reservoir during cold water releases from Dworshak Reservoir, 20012002. Report for US Army Corps of Engineers, Walla Walla District.

Caudill, C.C. and C.A. Peery 2006. "FEEDBACK: Idaho researchers discuss adult salmon survival" Column appearing in the 30 July 2006 edition of the Columbia Baisn Fish and Wildlife News Bulletin.
http://cbbulletin.com/Free/172679.aspx

Garrett, L., T. Rodhouse, L. Svancara, and C.C. Caudill. 2005**.** Phase II Vital Signs Monitoring Plan. Upper Columbia Basin Network. National Park Service Draft Report 1 June, 2005.

Caudill, C.C. 2002. Scent and taste of the deep blue sea: Book review of *Marine Chemical Ecology* (McClintock and Baker, eds.). Ecology **83**: 3238-3240.

PRESENTATIONS AT SCIENTIFIC MEETINGS, 2008-present. *First author was presenter unless noted, * indicates student researcher.*

2018

Caudill, C.C., G.P. Naughton, T. Blubaugh, T. Clabough, M.L. Keefer, M. Jepson, C.T. Boggs, and G. Brink.
2017. Evaluation of adult Chinook Salmon behavior at the Foster Dam Adult Fish Facility and in Foster Dam Reservoir on the South Santiam River, 2017. 2018 USACE Willamette Fisheries Science Review, Corvallis, OR.

Weigel-Sheedy, D., I. Koch, S.R. Narum, C. Sharpe, F. Monzyk, J. Nagler, and C.C. Caudill. 2017. Evaluation of adult winter steelhead outplanting above Foster Dam on the S. Santiam River using genetic parentage analysis, 2016-2017. 2018 USACE Willamette Fisheries Science Review, Corvallis, OR.

Caudill, C.C. 2018. Migration in the modern world: a review of UI Fish Ecology Research Lab results. 2018 Idaho Fish and Game Anadromous Section Meeting, Boise, ID. Invited, 1-hour presentation for ~100 IDFG Biologists.

2017

Keefer, M.L., T.C. Clabough, M. Jepson, S. Hanchett*, and C.C. Caudill. 2017. Adult salmonid interactions with two new lamprey passage structures at Bonneville Dam. USACE 2017 Anadromous Fish Evaluation Program Research Review, Richland, WA.

Keefer, M.L, Migration of adult salmonids in the Federal Columbia River Power System: radiotelemetry metadata and synthesis, USACE 2017 Anadromous Fish Evaluation Program Research Review, Richland, WA.

Dunkle, Matthew R. and Christopher C. Caudill. Can a specifically-timed resource lessen early life-history density dependence? Exploring the response of juvenile salmon to a historic marine-derived nutrient subsidy. 2017 Annual Meeting Ecological Society of America, Portland, Oregon

Caudill, C.C., T. Bowerman, M. Keefer, L. Crozier. 2017. Prespawn mortality in Pacific salmon: Patterns, methods, mechanisms, and potential consequences. 2017 Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Dunkle, M.R.*, C.C. Caudill, R.T. Lampman, A. Jackson, and B.J. McIlraith. 2017. Missing nutrients from Pacific Lamprey: insights from translocation into historic spawning reaches. 2017 Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Fuchs, N*. A. Murdoch, B. Truscott, M. Jepson, and C.C. Caudill. 2017. Evaluation of migration behavior survival and distribution of adult upper Columbia summer steelhead using radiotelemetry. 2017 Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Dunbeck, R.*, M.R. Dunkle*, C.C Caudill, and R.T. Lampman. 2017. Quantifying the response of benthic macroinvertebrates to post-spawn Pacific Lamprey carcasses in an interior Columbia Basin stream.
(Poster). 2017 Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Matsaw, S.*, T. Copeland, C.C. Caudill. 2017. Local status of a traditional First Food: patterns of distribution in native freshwater mussels in the Salmon and Clearwater river basins. (Poster). 2017 Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Wicks-Arshack, A.*, M. Dunkle*, S. Matsaw*, and C.C. Caudill. 2017. An ecological, cultural, and legal review of Pacific Lamprey in the Columbia River Basin. (Poster). 2017 Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Matsaw, S*, Wicks-Arshack, A.*, and C.C. Caudill. 2017. Honoring the culture and science of native freshwater mussels, salmon, and Indigenous Peoples. 2017 Annual Meeting of the Oregon Chapter of the American Fisheries Society, Bend, OR.

Caudill, C.C., D. Thompson, T. Blubaugh, T. Clabough, G. Naughton, and M. Keefer. 2017. Evaluation of adult Chinook Salmon behavior at the Foster Dam

Adult Fish Facility on the South Santiam River, 2016. 2017 USACE Willamette Fisheries Science Review, Corvallis, OR.

Bowerman, T., M.L. Keefer, C.C. Caudill, and L. Crozier. 2017. Processes affecting prespawn mortality in Chinook Salmon throughout the Columbia River Basin. 2017 USACE Willamette Fisheries Science Review, Corvallis, OR.

Keefer, M.L., T.C. Clabough, M.A. Jepson, and C.C. Caudill. 2017. The value of 'big data': Insights from two decades of Columbia River fish passage research. 2017 International Conference on Engineering and Ecohydraulics for Fish Passage, Corvallis Oregon.

Keefer, M.L., C.C. Caudill, L. Crozier, T. Bowerman, and B. Burke. 2017. High stakes steeplechase in a changing climate: predicting travel time and prespawn mortality in spring/summer Chinook salmon in the Columbia-Snake hydrosystem and Salmon River Basin. 2017 International Conference on Engineering and Ecohydraulics for Fish Passage, Corvallis Oregon.

Keefer, M.L, C.C. Caudill, and T. Bowerman. 2017. Prespawn mortality of Chinook salmon and impacts of warming rivers on adult salmon and steelhead. NOAA-Fisheries 2017 Snake River Basin Research, Monitoring and Evaluation Workshop, Boise, ID, 18 April 2017.

Keefer, M.L., and C.C. Caudill. Cold water refuges: critical temporary habitats for migrating salmon and steelhead. Columbia River Federal Caucus Meeting, Portland, OR, 21 March 2017.

2016

Keefer, M.L. C.C. Caudill, T. Clabough, K. Collis, A. Evans, C. Fitzgerald, M. Jepson, G. Naughton, R.
O'Connor, and Q. Payton. 2016. Summary of adult steelhead behavior and survival in the Federal Columbia River Power System. USACE 2016 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Moser, M., S. Corbett, K. Frick, M. Keefer, C. Caudill, and S. Tackley. 2016. Providing refuges for Pacific Lamprey in Lower Columbia River fishways. Fish Passage 2016 International Conference on River Connectivity, Amherst, MA.

Erdman, C.S*. and Caudill, C.C. 2016. Steelhead seasonal marine growth and variability in age at return. Annual meeting of the Idaho Chapter of the American Fisheries Society. Coeur d'Alene, ID.

Erdman, C.S*., Caudill, C.C., Naughton, G.P., Jepson, M.A. 2016. Movement and fate of recycled hatchery- origin summer steelhead in theWillamette River, Oregon. Annual meeting of the Idaho Chapter of the American Fisheries Society. Coeur d'Alene, ID.

Bush, K*., Erdman, C.S.*, and Caudill, C.C. 2016. Evaluating the consistency of scale-derived steelhead *Oncorhynchus mykiss* seasonal growth estimations across multiple readers (poster). Annual meeting of the Idaho Chapter of the American Fisheries Society. Coeur d'Alene, ID.

Bowerman, T.E., C.C. Caudill, M.L. Keefer, and L. Crozier. 2016. Chinook salmon pre-spawn mortality patterns and process in the Columbia River Basin. 2016 Upper Columbia Science Conference, Wenatchee, WA.

Caudill, C.C., M. Jepson, M.L. Keefer, C. Erdman*, J. Adams, S. Lee, T. Blubaugh, G. Naughton, T. Clabough, M. Knoff, M. Morasch, L. Waits, and C. Sharpe. 2016. Multi-year summary of Chinook salmon and steelhead migration in the Willamette River with emphasis on reach-specific survival, genetic stock identification of steelhead, and fate of recycled steelhead. 2016 Willamette Fisheries Science Review, Corvallis, OR.

Keefer, M.L., G. Naughton, C.C. Caudill, T. Clabough, G. Taylor, T. Blubaugh, M. Morasch, and C. Sharpe. 2016. Spawning success of spring Chinook salmon in Fall Creek, North Fork Middle Fork Willamette, and South Santiam Rivers, 2008-2015. 2016 Willamette Fisheries Science Review, Corvallis, OR.

Caudill, C.C., S.L. Bourret, M.L. Keefer, B.J. Clemens, B.P. Kennedy, G.A. Taylor, C. Sharpe. 2016. Identifying life history variation to inform recovery planning for upper Willamette River Chinook salmon. 2016 Willamette Fisheries Science Review, Corvallis, OR.

2015

Caudill, C.C., M.L. Keefer, M. Jepson, T. Clabough, E. Johnson, S. Lee, B. Burke, and K. Frick. 2015.
Conversion of radio-tagged adult salmon and steelhead through the lower Federal Columbia River Power System (FCRPS): 2013-2014. USACE 2015 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Keefer, M.L., T. Clabough, M. Jepson, C.C. Caudill, B. Burke, and K. Frick. 2015. Overwintering distribution and behavior of adult steelhead in the Federal Columbia River Power System (FCRPS): migration years 2013-2014 and 2014-2015. USACE 2015 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Bowerman, T.E., M.L. Keefer, C.C. Caudill, and L. Crozier. 2015. Patterns and process in prespawn mortality of Columbia River Basin spring and summer Chinook Salmon. USACE 2015 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Stevens, P.M., C.A. Peery, I. Courter, T. Clabough, D. Joosten, C.C. Caudill, and S. Juhnke. 2015. Evaluation of upstream migration and dam passage by adult Pacific

lamprey in the lower Snake River, 2015. USACE 2015 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Thompson, D., C. Negrea, F. Loge, C. Boggs, C.C. Caudill, and A.E. Evans. 2015. Evaluation of adult fish ladder modifications to improve Pacific Lamprey at McNary Dam, 2015. USACE 2015 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Zobott*, H., R. Budwig, C.C. Caudill, M.L. Keefer, and W. Basham. 2015. Drag force physical modeling for use in design of Lamprey Passage Structures (LPSs). 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Kirk, M.A.*, and C.C. Caudill. 2015. Network analyses reveal differences in the behavior of Pacific lamprey and Chinook salmon at a complex migration barrier. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Caudill, C.C., S.L. Bourret, M.L. Keefer, B.J. Clemens, B.P. Kennedy, G.A. Taylor, and C.S. Sharpe. 2015. Identifying life history variation to inform recovery planning for upper Willamette River Chinook Salmon (poster). 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Caudill, C.C., M.L. Keefer, M. Moser, K. Frick. 2015. Upstream migration of adult Pacific Lamprey in the Columbia and Snake rivers. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Syms, J*., M.A. Kirk, C.C. Caudill, D. Tonina, and R. Budwig. 2015. The effect of turbulence in hydropower dam fish passageways on Pacific Lamprey passage. 145th Annual Meeting of the American Fisheries Society, Portland, OR (nominated for best student talk).

Dunkle, M*. C.C. Caudill, A.S. Fremier, J.R. Bellmore. 2015. Using a food web model to explore the ecosystem response to Pacific Lamprey restoration (poster). 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Bowerman, T., C.C. Caudill, M.L. Keefer, and L. Crozier. 2015. Effects of stream temperature on Chinook Salmon bioenergetics and prespawn mortality in the Columbia River Basin. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Frick, K., S. Corbett, M. Hanks, M. Moser, and C.C. Caudill. 2015. Passage options for climbing lamprey: if you build it, they will come. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Erdman, C.S.*, and C.C. Caudill. 2015. What a long strange trip it's been: growth history and variability in age at return of steelhead (poster). 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Zobott, H.*, C.C. Caudill, M.L. Keefer, R. Budwig, K. Frick, and M. Moser. 2015. Design guidelines for Pacific Lamprey passage structures (poster). 2015. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Erdman, C.S.*, C.C. Caudill, G.P. Naughton, M.A. Jepson, M. Knoff, and M. Morasch. 2015. Steelhead 'recycling' to improve angler opportunity: how can we alter these programs to maximize harvest and minimize impacts to native populations? 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Keefer, M.L. M.A. Jepson, G.P. Naughton, T.S. Clabough, T.J. Blubaugh, and C.C. Caudill. 2015. Adult salmon and steelhead in hot water: insights from individual-based biotelemetry and archival temperature loggers (poster). 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Keefer, M.L, C.T. Boggs, B.J. Burke, T.S. Clabough, T. Dick, K. Frick, M.A. Jepson, D.C. Joosten, S.R. Lee, G.P. Naughton, and C.C. Caudill. 2015. Upstream migration in the Columbia River basin: lessons learned from two decades of adult salmon and steelhead radiotelemetry projects. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

McIlraith, B., C.A. Peery, D. Statler, J.E. Hess, C.C. Caudill, B.P. Kennedy, and E. Crow Jr. 2015. Distribution and behavior of adult Pacific Lamprey (Entosphenus tridentatus) translocated into tributaries of the Snake and Clearwater rivers, ID. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Stevens, P. C.A. Peery, T.S. Clabough, D.C. Joosten, I. Courter, and C.C. Caudill. 2015. Evaluation of upstream migration and dam passage by adult Pacific Lamprey in the lower Snake River, 2014. 145th Annual Meeting of the American Fisheries Society, Portland, OR.

Zobott*, H., R. Budwig, C.C. Caudill, M.L. Keefer, and W. Basham. 2015. Drag force physical modeling for use in design of Lamprey Passage Structures (LPSs). Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Syms, J*., M.A. Kirk, C.C. Caudill, D. Tonina, and R. Budwig. 2015. The effect of turbulence in hydropower dam fish passageways on Pacific Lamprey passage. Annual Meeting of the Idaho Chapter of the American Fisheries Society, Boise, ID.

Keefer, M.L., S.L. Bourret, C.C. Caudill, B.P. Kennedy, G.A. Taylor, B.J. Clemens, and C.S. Sharpe. 2015 Towards reconstructing life history variation, composition and fitness differences among subbasin populations of Upper Willamette River Chinook Salmon. USACE Willamette Fisheries Science Review, Portland, OR.

Keefer, M.L., G.P. Naughton, C.C. Caudill, T. Clabough, G.A. Taylor, M. Knoff, M. Morasch, and C.S. Sharpe. 2015. Spawning success of spring Chinook salmon

in Fall Creek, North Fork Middle Fork Willamette, and South Santiam rivers, 2008-2014. USACE Willamette Fisheries Science Review, Portland, OR.

Erdman, C*, Keefer, M.L., C.C. Caudill, M.A. Jepson, S.R. Lee, M. Knoff, M. Morasch, and C.S. Sharpe. 2015. Migration behavior and distribution of adult winter and summer steelhead radio-tagged at Willamette Falls and of 'recycled' summer steelhead at Foster and Dexter dams in 2012-2014. USACE Willamette Fisheries Science Review, Portland, OR.

Keefer, M.L., M.A. Jepson, C.C. Caudill, S.R. Lee, T. Blubaugh, M. Knoff, and M. Morasch. 2015. Migration behaviors and distribution of adult spring Chinook salmon radio-tagged at Willamette Falls in 20112014. USACE Willamette Fisheries Science Review, Portland, OR.

2014

M. Keefer, C.C. Caudill, M. Jepson, T. Clabough, E.L. Johnson, S.R. Lee, B.J. Burke & K. Frick. 2014.

Conversion of radio-tagged adult Chinook salmon and steelhead through the Federal Columbia River Power System (FCRPS), 2013-2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR. 10-11 December, 2014.

Caudill, C.C., E. Johnson, T. Clabough, M. Jepson, M. Keefer, S. Lee, J. Garnett, L. Layng, T. Dick, B. Burke, and K. Frick. 2014. Evaluation of adult salmon and steelhead passage behavior and success in relation to fishway modifications at Bonneville Dam. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Frick, K.E., Burke, B.J., C.C. Caudill, E. Johnson, T. Clabough, M. Jepson, M. Keefer, S. Lee, J. Garnett, L. Layng, and T. Dick. 2014. Evaluation of adult salmon and steelhead passage behavior in relation to fishway modifications at The Dalles and John Day dams, 2013-2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Keefer, M., T. Clabough, M. Jepson, and C.C. Caudill. 2014. Overwintering distribution and behavior of adult steelhead in the Federal Columbia River Power System (FCRPS): 2013-2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Keefer, M., C.C. Caudill, M. Jepson, T. Clabough, E.L. Johnson, C. Noyes, S. Corbett, and K. Frick. 2014. The 2014 adult Pacific lamprey migration: HD-PIT and radiotelemetry summaries. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Noyes, C., C.C. Caudill, D. Joosten, T. Clabough, and E. Johnson. 2014. Using the Juvenile Salmon Acoustic Telemetry (JSATS) system to evaluate adult Pacific

lamprey movements and fate in Columbia River reservoirs, 2011-2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Corbett, S., K.E. Frick, and C.C. Caudill. 2014. Modification and evaluation of lamprey passage structures (LPSs) at Bonneville Dam and the John Day south fishway collection trap, 2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Caudill, C.C., H. Zobott, J. Syms, R. Budwig, M. Kirk, C. Noyes, E. Johnson, and S. Lee. 2014. Development and use of lamprey passage structures at the Bonneville Dam Lamprey Flume System and John Day Dam North Fishway Entrance, 2013-2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Frick, K.E., S. Corbett, M. Hanks, and C.C. Caudill. 2014. If you build it they will come: an experimental vertical climbing wall. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Kirk, M. and C.C Caudill. 2014. Use of network theory to evaluate fish passage behavior at Bonneville Dam. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Kirk, M. A., C. C. Caudill, J. Syms, D. Tonina, and N. Hubbard. 2014. Pacific Lamprey swimming behavior and performance in relation to passage barrier velocity, distance and turbulence in an experimental flume, 2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Loge, F., D. Thompson, and C.C. Caudill. Evaluation of adult fish ladder modifications to improve Pacific lamprey passage at McNary and Ice Harbor dams. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Peery, C.A., P. Stevens, T. Clabough, D. Joosten, I. Courter, and C.C. Caudill. 2014. Evaluation of upstream migration and dam passage by adult Pacific lamprey in the lower Snake River, 2014. USACE 2014 Anadromous Fish Evaluation Program Research Review, Portland, OR.

Caudill, C.C., 2014. Pattern and process in upstream migration of steelhead in the Columbia and Snake rivers.

Mid-Columbia Adult Steelhead Bypass Workshop, Walla Walla, WA 19 Nov 2014. http://www.dfw.state.or.us/fish/CRP/mid_columbia_river_plan_WASTB_workshop.asp

Caudill, C.C., 2014. Potential demographic consequences of straying on donor and recipient populations in the Columbia-Snake Basin: case studies from the John Day and Deschutes basins. Mid-Columbia Adult Steelhead Bypass Workshop, Walla Walla, WA 19 Nov 2014.

http://www.dfw.state.or.us/fish/CRP/mid_columbia_river_plan_WASTB_workshop.asp

Bowerman, T., M.L. Keefer, and C.C. Caudill. 2014. Patterns of spring Chinook prespawn mortality within the Columbia River Basin. Ecological Society of America Annual Meeting, Sacramento, CA.
http://eco.confex.com/eco/2014/webprogram/Paper48643.html

Syms, J.C.*, M.A. Kirk*, D. Tonina, C.C. Caudill. 2014. The effect of turbulence in hydropower dam fish passageways on Pacific lamprey passage. International Conference on Engineering and Ecohydrology for Fish Passage, Madison, WI.

Keefer, M.L., and C.C. Caudill. 2014. Metrics to identify fishway passage bottlenecks in the multi-species Columbia River. International Conference on Engineering and Ecohydrology for Fish Passage, Madison, WI.

Kirk, M.A.*, and C.C. Caudill. 2014. Using network theory to formulate behavioral inferences from differences in the movement patterns of Chinook salmon and Pacific lamprey at Bonneville Dam, USA. International Conference on Engineering and Ecohydrology for Fish Passage, Madison, WI.

Caudill, C.C., M.L. Keefer, T.S. Clabough, G.P. Naughton, B.J. Burke, and C.A. Peery. 2014. Indirect effects of impoundment on migrating fish: temperature gradients in fish ladders slow dam passage by adult Chinook salmon and steelhead. International Conference on Engineering and Ecohydrology for Fish Passage, Madison, WI.

Herron, C.*, M. Colvin, M. Kent, C.C. Caudill, C.S. Schreck. 2014. *Nanophyetus salminocola* burdens in Chinook salmon (*Oncorhynchus tshawytscha*) prior to spawning in the Willamette Basin. Ecological and Evolutionary Ethology of Fishes, Corvallis, OR.

Hess, J.E., C.C. Caudill, D. Close, M.L. Keefer, B. McIlraith, M.L. Moser, and S.R. Narum. 2014. Genes That Predict Large-Bodied Pacific Lamprey Go the Distance: An Adaptive Context for Conservation
Management Applications. American Fisheries Society Annual Meeting, Quebec City, Quebec.

Moser, M.L., M.L. Keefer, C.C. Caudill, and B.J. Burke. 2014. Evidence of effects of temperament on lamprey migration rate. Ecological and Evolutionary Ethology of Fishes, Corvallis, OR.

Keefer, M.L. and C.C. Caudill. 2014. Cold water refuges: critical temporary habitats for migrating salmon and steelhead. 2014 Columbia River Estuary Workshop: Forging Links in the Columbia River Estuary, Lower Columbia River Estuary Partnership, Astoria, OR

Caudill, C.C., M.A. Jepson, M.L. Keefer, S. Lee, T. Blubaugh, M. Knoff, M. Morasch, and C. Sharpe. 2014. Migration behavior and distribution of adult winter and summer steelhead radio-tagged at Willamette Falls in 2013. USACE Willamette Fisheries Science Review, Portland, OR.

Caudill, C.C., G.P. Naughton, M.L. Keefer, T. Clabough, G. Taylor, M. Knoff, and C. Sharpe. 2014. Spawning success of spring Chinook Salmon in Fall Creek, North Fork Middle Fork Willamette and South Santiam rivers, 2008-2013. USACE Willamette Fisheries Science Review, Portland, OR.

Keefer, M.L., M.A. Jepson, C.C. Caudill, S. Lee, T. Blubaugh, M. Knoff, and M. Morasch. 2014. Migration behavior and distribution of adult spring Chinook Salmon radio-tagged at Willamette Falls, 2011-2013. USACE Willamette Fisheries Science Review, Portland, OR.

Colvin, M.E., J.T. Peterson, C. Sharpe, S. Benda, M. Kent, B. Dolan, C.C. Caudill, and C. Schreck. 2014. Integrating Science, management, and monitoring: a decision tool for optimizing annual spring Chinook Salmon outplanting strategies and prioritizing future research. USACE Willamette Fisheries Science Review, Portland, OR.

Frick, K., M.L. Moser, C.C. Caudill, and M.L. Keefer. 2014. Improving adult Pacific lamprey passage using Lamprey Passage Structures and refuges. Oregon Division, American Fisheries Society meeting, Eugene, OR.

2013

Keefer, M.L., C.C. Caudill. 2013. Estimating iteroparity in Columbia River steelhead using records archived in the PIT tag information system (PTAGIS). USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Caudill, C.C., E. Johnson, T. Clabough, M. Jepson, M. Keefer, S. Lee, J. Garnett, L. Layng, T. Dick, B. Burke, and K. Frick. 2013. Evaluation of adult salmon and steelhead passage behavior and success in relation to fishway modifications at Bonneville Dam. USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Burke, B., K. Frick, C.C. Caudill, E. Johnson, T. Clabough, M. Jepson, M. Keefer, S. Lee, J. Garnett, L. Layng, and T. Dick. 2013. Evaluation of adult salmon and steelhead passage behavior in relation to fishway modifications at The Dalles and John Day dams. USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Caudill, C.C., and M. Keefer. 2013. Conversion of radio-tagged adult Chinook salmon and steelhead through the Federal Columbia River Power System (FCRPS).

USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Keefer, M., C.C. Caudill, L. Sullivan, and K. Hatch. 2013. Adult Chinook salmon, sockeye salmon, and steelhead conversion through the lower Snake River: a summary of PIT-tag data from 2002-2013. USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Caudill, C.C., H. Zobott*, J. Syms*, R. Budwig, M. Kirk*, C. Noyes, E. Johnson, S. Lee, and M. Moser. 2013. Development and use of lamprey passage structures at Bonneville and John Day dams. USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Keefer, M., C.C. Caudill, S. Corbett, and M. Moser. 2013. General migration and upstream passage patterns in HD PIT-tagged adult Pacific lamprey. USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.
Noyes, C. C.C. Caudill, D. Joosten, T. Clabough, and E. Johnson. 2013. Using the Juvenile Salmon Acoustic Telemetry (JSATS) system to evaluate adult Pacific lamprey movements and fate in Columbia River reservoirs. USACE 2013 Anadromous Fish Evaluation Program Research Review, Walla Wall, WA.

Caudill, C.C. and M.L. Keefer. 2013. Measuring outside the box: an example of delayed effects associated with fish passage in steelhead. International Conference on Engineering and Ecohydrology for Fish Passage, Corvallis, OR.

Kirk, M.A.*, C.C. Caudill, E. Johnson, P. Johnson, M.L. Keefer, T.C. Clabough, M.A. Jepson, and W. Nagy. 2013. Evaluation of Pacific lamprey behavior in fishway environments of two Columbia River dams using Dual-Frequency Identification Sonar (DIDSON) acoustic imaging. International Conference on Engineering and Ecohydrology for Fish Passage, Corvallis, OR.

Zobott, H*. C.C. Caudill, M.L. Keefer, and R. Budwig. 2013. Development of 3-D modeling tools to document fish passage information and prioritize improvements at lower Columbia River Dams, 2012. International Conference on Engineering and Ecohydrology for Fish Passage, Corvallis, OR.

Keefer, M.L., C.C. Caudill, and M. Moser. 2013. Fish passage bottlenecks and prioritization planning: a Pacific lamprey case study. International Conference on Engineering and Ecohydrology for Fish Passage, Corvallis, OR.

Caudill, C.C. 2013. Migration syndromes and "success" in migratory fishes. NOAA-Northwest Fisheries Science Center "Monster Jam" Invited Seminar, 16 May, 2013, Seattle, WA.

Caudill, C.C., M.L. Keefer. 2013. A review of adult salmon and steelhead straying in the Columbia River Basin. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Keefer, M.L., C.C. Caudill, and C.A. Peery. 2013. Adult Pacific salmonids in hot water: behavior and survival studies from the Columbia River basin. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Keefer, M.L., C.C. Caudill, C.A. Peery, M. Higgs, and M. Moser. 2013. Identifying fishway passage bottlenecks at large dams: a Pacific lamprey case study. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Caudill, C.C., M.L. Keefer, T. Clabough, E.L. Johnson, M. Jepson, C.T. Boggs, and M. Moser. 2013. Pacific lamprey passage at Columbia River dams: highlights from a 15-year data synthesis. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Noyes, C.*, C.C. Caudill, D. Joosten, T. Clabough, and E.L. Johnson, 2013. Using the Juvenile Salmon Acoustic Telemetry (JSATS) system to evaluate adult Pacific lamprey movements and fate in Columbia
River reservoirs. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Zobott, H.*, C.C. Caudill, R. Budwig, M.L. Keefer, and M. Moser. 2013. Lamprey passage at migration barriers: Fishway design criteria and biological insights. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Kirk, M.A.*, C.C. Caudill, E.L. Johnson, P. Johnson, M.L. Keefer, T. Clabough, M.A. Jepson, and W. Nagy.
2013. Evaluation of Pacific lamprey behavior in fishway environments of two Columbia River dams
using Dual-Frequency Identification Sonar (DIDSON) acoustic imaging. Annual meeting of the Western Division of the American Fisheries Society, Boise, ID.

Caudill, C.C., M. Jepson, T. Clabough, S. Lee, T. Dick, M. Knoff, M. Morasch, M. Keefer, and T. Friesen. 2013. Migration behavior and distribution of adult spring Chinook salmon radio-tagged at Willamette Falls in 2012. USACE Willamette Basin Fisheries Science Review, Corvallis, OR.

Caudill, C.C., M. Jepson, T. Clabough, S. Lee, T. Dick, M. Knoff, M. Morasch, J. Uber, M. Keefer, B. Clemens, and C. Sharpe. 2013. Migration behavior and distribution of adult winter and summer steelhead radiotagged at Willamette Falls in 2012. USACE Willamette Basin Fisheries Science Review, Corvallis, OR.

Roumasset, A.*, and C. Caudill (presenter). 2013. Prespawn mortality of Upper Willamette River spring Chinook salmon: Associations with stream temperature, watershed attributes and environmental conditions on the spawning grounds. USACE Willamette Basin Fisheries Science Review, Corvallis, OR.

Keefer , M.L., C. Caudill, G. Naughton, T. Clabough, G. Taylor, M. Knoff, A. Roumasset, C. Schreck, and M. Kent. 2013. Spawning success of spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River, 2008-2012. USACE Willamette Basin Fisheries Science Review, Corvallis, OR.

Bourret, S.*, B.P. Kennedy, C.C. Caudill, and L. Borgerson. 2013. Characterizing life history patterns in UWR Chinook salmon (*Oncorhynchus tshawytscha*) reared above WVP reservoirs. USACE Willamette Basin Fisheries Science Review, Corvallis, OR.

Schreck, C., M. Kent, M. E. Colvin, S. Benda*, C. Sharpe, J. T. Peterson, B. Dolan, R. Chitwood, J. Unrein, C. C. Caudill, and G. Naughton. 2013. Evaluating potential causes and management of pre-spawning mortality in adult upper Willamette River Chinook salmon. USACE Willamette Basin Fisheries Science Review, Corvallis, OR.

Colvin, M.E., J. T. Peterson, C. Sharpe, S. Benda*, C. Schreck, M. Kent, B. Dolan, and C.C. Caudill. 2013. Upper Willamette River spring Chinook prespawn mortality synthesis and modeling. 2013 Oregon Division of the American Fisheries Society, Bend, OR.

2012

Keefer, M.L., and C.C. Caudill. 2012. A review of adult salmon and steelhead straying with an emphasis on Columbia River populations. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR. http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Corbett, S., M. Moser, and C.C. Caudill. 2012. Improving adult Pacific lamprey passage at Bonneville Dam using lamprey passage structures (LSPS) and refuges. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR. http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Caudill, C.C., H. Zobott*, M.L. Keefer, and R. Budwig. 2012. Development of 3-D modeling tools to document fish passage information and prioritize improvements at lower Columbia River Dams, 2012. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR. http://www.nwdwc.usace.army.mil/tmt/documents/AFEP/

Keefer, M.L., C.C. Caudill, E.L. Johnson, T.S. Clabough, M.A. Jepson, S. Corbett, and M.L. Moser. 2012.

General migration and upstream passage patterns in HD PIT-tagged adult Pacific lamprey. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR. http://www.nwdwc.usace.army.mil/tmt/documents/AFEP/

Caudill, C.C., E.L. Johnson, P. Johnson, M.L. Keefer, T.S. Clabough, M.A. Jepson, and W. Nagy. 2012.
Evaluation of lamprey behavior at lower fishway sections of Bonneville and John Day dams using DIDSON, 2012. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR.
http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Noyes, C.J., C.C. Caudill, D. Joosten, T.S. Clabough, and E.L. Johnson. 2012.
Using the Juvenile Salmon Acoustic Telemetry (JSATS) system to evaluate adult Pacific lamprey movements and fate in Columbia River reservoirs. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR.
http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Loge, F., C. Negrea, C.C. Caudill, and D. Thompson. 2012. Enumeration and evaluation of adult Pacific lamprey escapement and behavior in underwater video at McNary and Ice Harbor dams with the application of computerized imaging software (AVEDac). USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR. http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Loge, F., C.C. Caudill, and D. Thompson. 2012.Application of DIDSON and underwater video to evaluate adult Pacific lamprey behavior and passage performance at the McNary Dam south fishway entrance.
2012. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR.
http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Keefer, M.L., T.S. Clabough, M.A. Jepson, E.L. Johnson, C.T. Boggs, and C.C. Caudill. 2012. Passage bottlenecks and prioritization planning: Highlights from the adult lamprey data synthesis. USACE 2012 Anadromous Fish Evaluation Program Research Review, Portland, OR.
http://www.nwdwc.usace.army.mil/tmt/documents/AFEP/

Caudill, C.C., M.L. Keefer, H. Zobbot*, and R. Budwig. 2012. Lamprey synthesis Studies Review Work Group Meeting Workshop for USACE, Portland District, 30 October 2012. Day-long seminar on adult Pacific lamprey passage issues presented to fisheries manager representatives from the USACE, NWPPC ISRB, tribes, and NOAA-Fisheries. http://www.nwd-wc.usace.army.mil/tmt/documents/AFEP/

Caudill, C.C. 2012. Migratory behavior of adult Pacific lamprey in the Columbia Basin. 2012. Native American Fish and Wildlife Society Pacific Region Conference, Pendleton, OR (invited).

Caudill, C.C., C. Noyes *, G.P. Naughton, T. Clabough, S.R. Lee, T. Castro-Santos, J. Beeman, and M. Parsley. Spawning migrations of American shad in the Columbia River. 2nd Annual National Conference on Engineering and Ecohydrology for Fish Passage, Amherst, MA.

Caudill, C.C., M.A. Jepson, T.S. Clabough, S.R. Lee, G.P. Naughton, M.R. Morasch, M.J. Knoff, D.C. Joosten, T.L. Dick, and M.L. Keefer. 2012. Migration behavior, timing, and distribution of spring Chinook salmon radio-tagged at Willamette Falls Dam, 2011. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

Caudill, C.C., G. Naughton, G.A. Taylor, M.L. Keefer, M.J. Knoff, A. Roumasset*, C.B. Schreck, and M. Kent.
2012. Migration behavior and spawning success in spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: relationships among fate, fish condition, and environmental factors, 2008-2011. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

Roumasset, A*. and C.C. Caudill. 2012. Associations between Chinook salmon prespawn mortality rates, environmental factors, and watershed features in sub-basins of the Willamette River Valley. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

Bourret, S*., B.P. Kennedy, C.C. Caudill, and L. Borgerson. 2012. Characterizing juvenile Chinook salmon life history variability in the Willamette Valley using otoliths and scales. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

Schreck, C.B., M. Kent, S. Benda*, J. Unrein, R. Chitwood, C.C. Caudill, and G. Naughton. 2012. Prespawn mortality in spring Chinook salmon in the upper Willamette River: potential causes. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

Schreck, C.B., M. Kent, S. Benda*, J. Unrein, R. Chitwood, C.C. Caudill, and G. Naughton. 2012. Prespawn mortality in spring Chinook salmon in the upper Willamette River: potential management options. USACE 2011 Willamette Basin Fisheries Science Review, Corvallis, OR.

2011

Caudill, C.C., M. Keefer, and M. Moser. 2011. Estimating upstream passage metrics and performance in Pacific lamprey from the Columbia River Hydrosystem. USACE 2011 Anadromous Fish Evaluation Program, Walla Walla, WA.

Keefer, M. C. C. Caudill, T. Clabough, M. Jepson, E. Johnson, and M. Moser. 2011. Identifying passage bottlenecks for adult Pacific lamprey at Bonneville and The

Dalles dams: meta-analysis results. USACE 2011 Anadromous Fish Evaluation Program, Walla Walla, WA.

Caudill, C.C., E. Johnson, P. Johnson, W. Nagy, M. Keefer, T. Clabough, and M. Jepson. 2011. Pacific lamprey monitoring with DIDSON (Dual-Frequency Identification Sonar) at Bonneville Dam. USACE 2011 Anadromous Fish Evaluation Program, Walla Walla, WA.

Caudill, C.C., C. Noyes*, G. Naughton, D. Joosten, T. Clabough, E. Johnson, and S. Lee. 2011. Using the Juvenile Salmon Acoustic Telemetry (JSATS) system to evaluate adult Pacific lamprey movements and fate in Columbia River reservoirs. USACE 2011 Anadromous Fish Evaluation Program, Walla Walla, WA.

M. Keefer, C.C. Caudill, and M. Moser. 2011. Adult lamprey data mining: using models to prioritize sites for fishway passage improvements and to predict lamprey run timing and size. USACE 2011 Anadromous Fish Evaluation Program, Walla Walla, WA.

Loge, F., C.C. Caudill, D. Thompson, and C. Boggs. 2011. Video Monitoring to Determine Pacific Lamprey Ladder Escapement and Behavior at McNary and Ice Harbor dams. USACE 2011 Anadromous Fish Evaluation Program, Walla Walla, WA.

Caudill, C.C. 2011. Assessing migration success in altered river corridors. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Moser, M., M. Keefer, and C.C. Caudill. 2011. Impediments to lamprey spawning migration and development of lamprey-specific fishways. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Keefer, M. C.C. Caudill, and C.A. Peery. 2011. Adult Pacific salmonids in hot water: behavior and survival studies from the Columbia River basin. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Mann, R. C.A. Peery, C.C. Caudill, and M. Keefer. 2011. An approach to estimating the effects of high temperature exposure during maternal upstream migration on embryo development and survival in Chinook salmon. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Crozier, L., B.J. Burke, C.C. Caudill, and M. Keefer. 2011. Seasonal variation in the bioenergetic cost of migration in Snake River spring/summer Chinook salmon and potential selection for earlier migration in response to climate change. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Peery, C.A., M. Keefer, C.T. Boggs, and C.C. Caudill. 2011. Developing a PIT-tag detection system for Pacific lamprey in the Columbia River. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Bourret, S.*, C.C. Caudill, B.P. Kennedy, and L. Borgerson. 2011. Feasibility of using otolith and scale techniques to characterize life history variation of spring Chinook salmon in the Willamette Valley. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Roumasset, A.*, C.C. Caudill, R. Mann, M. Keefer, C. Schreck, and M. Kent. 2011. Effects of watershed characteristics, stream temperature, condition and disease on prespawn survival in Upper Willamette River Chinook salmon. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Noyes, C.*, T. Clabough, C.C. Caudill, T. Castro-Santos, J. Beeman, and M.J. Parsley. 2011. Spawning migrations of American shad in the Columbia River. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Benda, S.*, C.S. Schreck, M. Kent, R. Chitwood, V. Watral, C.C. Caudill, and R. Mann. 2011. Prespawn mortality in spring Chinook salmon in the Upper Willamette River: potential causes and management strategies. 141st Annual Meeting of the American Fisheries Society, Seattle, WA.

Caudill, C.C. 2011. Migration syndromes and "success" in migratory fishes. National Conference on Engineering and Ecohydrology for Fish Passage, Amherst, MA.

Beeman, J., C.C. Caudill, M.A. Jepson, E.L. Johnson, and M.L. Keefer. 2011. Look out below: juvenile passage operations at Columbia and Snake river dams can slow adult upstream passage. 2011 Oregon Chapter of the American Fisheries Society.

Beeman, J., S. Juhnke, T. Castro-Santos, C.C. Caudill, and M. Parsley. 2011.Upstream passage of radio-tagged American shad at the lower four Columbia River dams in 2010: not what you might think. 2011 Oregon Chapter of the American Fisheries Society.

McIlraith, B.J.*, C. C. Caudill, and B.P. Kennedy. 2011. Distribution, timing, behavior, and habitat of spawning adult Pacific lamprey (*Lampetra tridentata*) translocated into tributaries of the Snake and Clearwater Rivers. 2011 Idaho Chapter of the American Fisheries Society

Baker, G., G.J.M. Moret, C.C. Caudill, and N. Tallent-Halsell. 2011. Year-round hydrologic monitoring of subalpine lakes in Great Basin National Park. 2011 George Wright Society Biennial Meeting on Parks, Protected Areas, and Cultural Sites, New Orleans, LA.

Keefer, M.L., G.A. Taylor, D.F. Garletts, C. Helms, G.A. Gauthier, T.M. Pierce, and C.C. Caudill. 2011. Downstream fish passage above and below dams in the middle fork Willamette River: a multi-year summary. USACE 2010 Willamette Basin Fisheries Science Review, Grand Ronde, OR.

Caudill, C.C., B.P. Kennedy, S. Bourret, and L. Borgerson. 2011. Feasibility of using otolith and scale analyses to characterize life history variation in spring Chinook salmon in three Willamette Valley Project reservoirs and tributaries. USACE 2010 Willamette Basin Fisheries Science Review, Grand Ronde, OR.

Caudill, C.C., R. Mann, G.A. Taylor, M.L. Keefer, A. Roumasset, C.B. Schreck, and M. Kent. 2011. Migration behavior and spawning success in spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: relationships among fate, fish condition, and environmental factors, 2008-2010.

Schreck, C.C., M. Kent, S. Benda, K. Berkenkamp, R. Chitwood, V. Watral, L. Lindsay, C.C. Caudill, and R. Mann. 2011. Pathological chances associated with prespawning mortality in Chinook salmon in the Willamette River and management options.

Caudill, C.C., M. Keefer, and M. Moser. 2010. Estimating upstream passage metrics and performance in Pacific lamprey: overview and patterns from the Columbia River Hydrosystem. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Keefer, M., C. Boggs, E. Johnson, C.C. Caudill, T. Clabough, B. Ho., and M. Moser. 2010. Adult lamprey passage success and behavior in the lower Columbia River, 2010. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Caudill, C.C., E. Johnson, B. Ho, M. Keefer, T. Clabough, and M. Moser. 2010. Fishway use and passage success of adult Pacific lamprey at Bonneville Dam including the modified Cascades Island Entrance, 2010. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Caudill, C.C., M. Jepson, T. Clabough, M. Keefer, and B.J. Burke. 2010. Evaluation of Adult Spring–Summer Chinook Salmon Passage at Lower Columbia River Dams, 2010. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Boggs, C., C.C. Caudill, M. Keefer, M. Moser. 2010. Evaluation of adult Pacific lamprey passage and behavior at McNary Dam, 2010 and multi-year summary of passage metrics. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Caudill, C.C., G. Naughton, D. Joosten, T. Clabough, E. Johnson, S. Lee, and C. Noyes. 2010. Evaluation of adult Pacific lamprey behavior in Columbia River reservoirs using the Juvenile Salmon Acoustic Telemetry (JSATS) system, 2010. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Eder, K., D.T. Thompson, C. Boggs, C. C. Caudill, D. Cline, and F. Loge. 2010. Video monitoring of fish ladder modifications to improve Pacific lamprey passage at the McNary Dam Oregon-shore Fishway, 2010. 2010 USACE Anadromous Fish Evaluation Program Annual Review, Portland, OR.

Moret, G.J.M., and C.C. Caudill. 2010. A long-term monitoring plan for springs in the Mojave Desert based on aquifer type. 2010 National Park Service Aquatic Professionals Meeting, Fort Collins, Colorado.

Caudill, C.C. 2010. Migration in the modern world: Tales of concrete, free rides, hot water, blood-sucking natives and delicious exotics. (Invited). Department of Fisheries Biology, Humboldt State University, Arcata, CA.

Keefer, M.L, G.A. Taylor, D. Gartletts, G.A. Gauthier, T. Pierce, and C.C. Caudill. 2010. Prespawn mortality in spring Chinook salmon outplanted above dams in the Middle Fork Willamette River. U.S. Army Corps of Engineers Annual Research Review, Willamette Basin Anadromous Fish Evaluation Program, Grand Ronde, OR.

Caudill, C.C., R. Mann, G.A. Taylor, M.L. Keefer, D. Calvert, C.B. Schreck, and M. Kent. 2010. Migration behavior and spawning success in spring Chinook salmon in Fall Creek and the North Fork Middle Fork Willamette River: Relationships among fate, fish condition, and environmental factors. U.S. Army Corps of Engineers Annual Research Review, Willamette Basin Anadromous Fish Evaluation Program, Grand Ronde, OR.

Schreck, C.B., M. Kent, K. Berkenkamp, V. Watral, R. Mann, and C.C. Caudill. 2010. Pathological changes associated with prespawning mortality in Chinook salmon in the Willamette River. U.S. Army Corps of Engineers Annual Research Review, Willamette Basin Anadromous Fish Evaluation Program, Grand Ronde, OR.

Keefer, M.L., and C.C. Caudill. 2010. Research needs for Willamette River adult salmon and steelhead: results from a literature review. U.S. Army Corps of Engineers Annual Research Review, Willamette Basin Anadromous Fish Evaluation Program, Grand Ronde, OR.

Keefer, M.A., C.T. Boggs, E.L. Johnson, C. C. Caudill, T.S. Clabough, B. Ho, and M.A. Moser. Adult lamprey passage success and behavior in the lower Columbia River, 2009. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Walla Walla, WA.

Johnson, E.L., C.C. Caudill, M.L. Keefer, T.S. Clabough, and M.A. Moser. Effects of water velocity on fishway entrance success by adult Pacific lamprey and fishway use summaries at Bonneville Dam, 2009. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Walla Walla, WA.

Caudill, C.C., E.L. Johnson, C.T. Boggs, M.L., Keefer, M.A. Jepson, and B.J. Burke. Evaluation of adult spring-summer Chinook salmon and adult Pacific lamprey passage at the Cascade Island fishway after entrance modifications, 2009. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Walla Walla, WA.

Boggs, C.T., C.C. Caudill, and M.A. Moser. Evaluation of adult Pacific lamprey passage and behavior at McNary Dams including preliminary evaluation of a reduced nighttime flow velocity operation, 2009. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Walla Walla, WA.

Caudill, C.C., T.S. Clabough, E.L. Johnson, D.C. Joosten, and C.A. Peery. 2009. Use of video to quantify adult lamprey passage at night at Bonneville and The Dalles dams on the Columbia River. American Fisheries Society Western Division Annual Meeting, Albuquerque, New Mexico.

Keefer, M.L., M. Moser, C.A. Peery, C. Boggs, E.L. Johnson, and C.C. Caudill. 2009. Size Matters: adult Pacific lamprey migration in the Columbia River. American Fisheries Society Western Division Annual Meeting, Albuquerque, New Mexico.

Mann, R., G.A. Taylor, C.A. Peery, and C.C. Caudill. 2008. An assessment of energetic condition for two populations of adult summer Chinook salmon in the Willamette Valley of central Oregon. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Keefer, M.A., C.T. Boggs, E. Johnson, C.A. Peery, C. C. Caudill, and M.A. Moser. 2008. Adult lamprey passage success and behavior in the lower Columbia River, 2008. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Ho, B., C.A. Peery, E. Johnson, and C.C. Caudill. Relationship between energetic status and migratory behavior and success in Pacific Lamprey: Preliminary results. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Johnson, E., C.A. Peery, C.C. Caudill, and M. Moser. 2008. Effects of water velocity on fishway entrance success by Pacific lamprey and fishway use summaries at Bonneville Dam, 2008. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Boggs, C.T., C.A. Peery, C.C. Caudill, and M. Moser. 2008. Evaluation of adult Pacific lamprey passage and behavior at McNary and Ice Harbor Dams. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Clabough, T.S. E. Johnson, D.C. Joosten, C.C. Caudill, and C.A. Peery. 2008. Use of night video to quantify adult lamprey passage at Bonneville and the Dalles dams, 2007 and preliminary 2008 results. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Jepson, M.A., C.A. Peery, and C.C. Caudill. 2008. Adult Chinook salmon passage at Little Goose Dam in relation to spill operations, 2008. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.

Clabough, T.S., G.P. Naughton, C.C. Caudill, M.A. Jepson, C.A. Peery, and B.J. Burke. 2008. Adult salmon and steelhead passage at Lower Granite Dam with a modified transition pool and in relation to ladder temperature. Meeting of the U.S. Army Corps of Engineers Anadromous Fish Evaluation Program, Portland, OR.
Caudill, C.C., C.A. Peery, C.T. Boggs, M.L. Keefer, and M.L. Moser. 2008. Down the river and back up again: toward conservation of Pacific lamprey in the Columbia Basin, USA. Society for Conservation Biology, Chattanooga, Tennessee.

Caudill, C.C., and M. Parsley (symposium co-organizers). 2008. Overview of shad in the Columbia Basin: history and current status. American Fisheries Society Western Division Annual Meeting, Portland Oregon.

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

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

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

Caudill, C.C., L. Garrett, E. Starkey, T. Rodhouse, R. K. Steinhorst, and K.M. Irvine. 2008. Integrated water quality monitoring plan for the Upper Columbia Basin

Network (poster). 2008 National Park Service Aquatic Professionals Meeting, Fort Collins, Colorado.

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

29.1 FUNDING & AWARDS (amounts are direct award to CCC)

Current:

Caudill, C.C., J.R. Bellmore, and M. Dunkle. 2017. Investigating the influence of hydrologic variability on food web dynamics and resource stability in southeast Alaskan streams. Joint Venture Agreement with US Forest Service PNW Research Station. $ 5,000.

Caudill, C.C., S. Narum, J. Nagler, and C.S. Sharpe. 2017. USACE Portland District-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation, 2017. Multi-component research grant investigating fish migration passage and survival in the Columbia and Willamette rivers with five major tasks: Task 1: Adult Pacific Lamprey passage modifications at Bonneville Dam: DIDSON Monitoring and PIT Telemetry Monitoring, 2017-2018; Task 2: Evaluation of adult Pacific Lamprey passage behavior and performance at lower Columbia River dams using PIT- and radiotelemetry, 2017-2019; Task 3: Evaluation of reintroduction strategies for winter steelhead above Foster Dam on the S. Santiam River, 2017; Task 4: Evaluation of the Foster Dam Adult Fish Trap, 2017; Task 5: Evaluation of reintroduction strategies for Chinook salmon above Foster Dam on the S. Santiam River, 2017: Release of adult Chinook Salmon to Foster Reservoir. $ 2,537,123 awarded to UI; $2,221,813 direct to CCC.

Caudill, C.C. 2016, J. Nagler, S.R. Narum, F. Loge, M.L. Keefer, and C. Sharpe (ODFW). 2016. USACE
Portland District-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation, 2016. Multi-component research grant investigating fish migration passage and survival in the Columbia and Willamette rivers with four major tasks: Task 1: Evaluation of salmon passage at an adult collection facility, 2016; Task 2: Characterization and return rates of UWR Chinook salmon life history types; Task 3: Evaluation of reintroduction strategies using genetic pedigree analysis, 2016; Task 4: Synthesis of status and trends in adult salmon and steelhead passage behavior and success in the lower Federal Columbia River Hydrosystem, 1996-2014. 2016 Total: $522,480

Caudill, C.C. 2015-2018. The role of Pacific lamprey marine-derived nutrients in freshwater food webs.

$143,385 awarded from Columbia River Intertribal Fisheries Commission and Yakama Fisheries.

Previous Awards:

Caudill, C.C., and M.L. Keefer. 2016. Assembly and analysis of radiotelemetry and temperature logger data from adult Chinook salmon and steelhead migrating through the Columbia River basin. $8,796 awarded from US EPA via subcontract from TetraTech.

Caudill, C.C. 2015-2017. Evaluation of upper Columbia River steelhead adult migration and overwintering behavior. $144,884 awarded from Washington Division of Fish and Wildlife.

Evans, A., C.C. Caudill, and M. Keefer. 2015. Summary of adult steelhead passage and conversion in the Federal Columbia River Power System. Subcontract through Blue Leaf Environmental/Real Time
Research for USACE Walla Walla IDIQ Prime Contract W912EF-14-D-0004. $69,885 awarded to UI.

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

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

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

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

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

Caudill, C.C (Lead PI), K. Frick (NOAA-Fisheries), B. Burke (NOAA-Fisheries), R. Budwig, D. Tonina, T. Friesen (ODFW), and C. Sharpe (ODFW). 2014. USACE-Univ. Idaho Cooperative Ecosystems Study Unit (CESU) Agreement: Columbia River Fish Mitigation, 2014. Multi-component research grant investigating fish migration passage and survival in the Columbia and Willamette rivers with seven major tasks: Task 1: Evaluation of Adult Lamprey Passage Behavior in Relation to Lower Columbia River Dam Modifications – 2014; Task 2: Evaluation of adult Pacific lamprey behavior and fate in the lower Columbia River

using acoustic telemetry, 2014; Task 3: Development of Adult Lamprey Passage Structures at Lower Columbia and Snake River Dams – 2014; Task 4: Evaluation of Adult Salmon and
Steelhead Passage Behavior and Success in the lower Federal Columbia River Hydrosystem – 2014; Task 5: Migration and Passage Behavior of Overwintering Summer Steelhead in the Lower Columbia and Snake Rivers – 2014; Task 6: Evaluation of adult UWR winter steelhead and summer steelhead upstream migration, distribution, survival, and life history, 2014; Task 7: Characterization and return rates of different juvenile UWR Chinook life history types; Task 8: Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, 2014 total: $1,995,743.

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

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

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

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

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

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

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

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

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

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

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

Caudill, C.C., C. Schreck, and M. Kent. 2011. Monitoring upstream migration and potential causes of prespawn mortality in adult UWR Chinook, Middle fork Basin of the Willamette River, 2011. $334,322. U.S. Army Corps of Engineers, Portland District.

Fremier, A.F., B.P. Kennedy, and C.C. Caudill. 2011-2015. Integrated data-driven spatial analysis to support life cycle modeling for effectiveness monitoring in the Columbia Basin 2011. $499,808 awarded from Bureau of Reclamation to A. Fremier.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2007 and earlier:

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

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

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

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

Research and travel grants during Ph.D. training, 1996-2000. Fifteen awards totaling $6,856. Sources: Sigma

Xi Grants-in-Aid of Research (National and Cornell Chapters), North American Benthological Society Student Travel Award, Cornell University Rawlins Endowment, Cornell University Griswold Endowment, Cornell Graduate School, RMBL Lee R.G. Synder Fund.

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

29.2 AWARDS

2016

2013 American Fisheries Society Fisheries Engineering Committee Distinguished Project in Fisheries

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

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

29.3 PROFESSIONAL SERVICE, DEVELOPMENT AND OUTREACH

University Service:

2017-present Department of Fish and Wildlife Annual Film Festival Organizing and Selection Committee 2016-present Department of Fish and Wildlife Sciences Assessment Committee 2016-present University of Idaho Common Read selection committee.

2013-present University of Idaho Research Council, Faculty Representative for College of Natural Resources.
2016 Department of Fish and Wildlife Tenure and Promotion Committee
2015 Faculty search committee (Wildlife Ecology Management), Department of Fish and Wildlife Sciences.
2015 Search committee, CNR Director Graduate Studies
2014 Faculty search committee, Department of Fish and Wildlife Sciences.
2014 Faculty search committee, Department of Fish and Wildlife Sciences.
2014 College of Natural Resources ad hoc committee reviewing service performance of CNR Fiscal Services.
2014 Promotion and Tenure review committee, Department of Forestry, Rangeland, and Fire Sciences.
2013-2014 University-wide committee to review compensation time policy, Faculty Representative for College of Natural Resources.
2013 College of Natural Resources ad hoc committee faculty representative on CNR internal accounting policy

Scientific outreach:

Caudill, C.C. 2016 & 2017. Connections between salmon, the Columbia River and endangered orca whales of Puget Sound. Lecture and separate ½ field trip to Lower Granite Dam for 20 middle school children, Palouse Prairie Charter School, Moscow, ID.

Caudill, C.C. 2016. Thermal ecology of Upper Willamette River Spring Chinook Salmon. Invited seminar, 12 April 2016, Salem, OR for Willamette Instream Flow Science Review Workshop.

Caudill, C.C. 2016. The long way home: a very short history of fish migration in the Columbia Basin. Invited seminar 7 March 2016, Moscow, ID for UI Environmental Law Society, Native American Law Students Association, and Friends of the Clearwater.

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

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

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

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

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

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

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

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

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

Manuscript reviewer for *2017: PLOS One; Journal of Applied Ecology; Ecology of Freshwater Fish; Ecological Engineering; 2016: BioScience (2); Hydrobiologia (2); Journal of Fish and Wildlife Management; Water Resources Research; Canadian Journal of Fisheries and Aquatic Sciences; 2015: River Research and Applications; Journal of Applied Ecology; Fisheries; Hydrobiologia; Springer (Edited Volume Book Proposal); Book chapter for* Jawless Fishes of the World*; Ecological Engineering; Environmental*
Biology of Fishes; 2014: Freshwater Science (review recognized as Excellent by Editor);
Environmental Science and Policy; Ecological Engineering; 2013: PLOS One, Fisheries, River
Research and Applications, Transactions of the American Fisheries Society (2), Canadian Journal of
Fisheries and Aquatic Sciences; 2012: Conservation Letters, North American Journal of Fisheries
Management (2); 2011: Animal Behaviour, Physiological and Biochemical Zoology, North American
Journal of Fisheries Management, American Fisheries Society Books. 2008-2010: Ecology, Ecological
Applications, Hydrobiologia, Journal of Animal Ecology, Journal of Applied Ecology, Journal of the North American Benthological Society, North American Journal of Fisheries Management, Oikos, Transactions of the American Fisheries Society, USFWS, and USGS.

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

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

Participant in UI PNW NSF COSMOS Indigenous Knowledge Field Camp 2016, 8-11 August. Workshop with

nine native students from U. Idaho, U. Montana, and Montana State University, their graduate mentors, and Nez Perce elders exploring native history, culture and barriers and opportunities to native STEM graduate education on Nez Perce tribal lands.

CURRICULUM VITAE

University of Idaho

NAME: Cain, Kenneth D. **DATE:** March 29, 2018

RANK OR TITLE: Professor, Department of Fish and Wildlife (Aquaculture and Fish Health)
Associate Director, Aquaculture Research Institute (Campus Facilities)

DEPARTMENT: Fish and Wildlife Resources

OFFICE LOCATION AND CAMPUS ZIP: 105D, 1136

OFFICE PHONE: (208) 885-7608
FAX: (208) 885-9080
EMAIL: kcain@uidaho.edu

DATE OF FIRST EMPLOYMENT AT UI: November 29, 1999

DATE OF TENURE: July 1, 2005

DATE OF PRESENT RANK OR TITLE: July 1, 2011

EDUCATION BEYOND HIGH SCHOOL:

Degrees:

Ph.D., Washington State University, Pullman, Washington, 1997, Animal Sciences (Fish Immunology)
M.S., Michigan State University, East Lansing, Michigan, 1993, Fish and Wildlife (Fish Nutrition)
B.S., Michigan State University, East Lansing, Michigan, 1990, Fish and Wildlife

EXPERIENCE:

Teaching, Extension and Research Appointments:

2015 - Present, Adjunct Faculty, Center for Reproductive Biology, Washington State University
2011 - Present, Professor (Aquaculture and Fish Health), University of Idaho
2011 Honorary Research Associate, Australian Maritime College, University of Tasmania
2002 - Present, Associate Director, Aquaculture Research Institute, University of Idaho
2005 - 2011, Associate Professor (Aquaculture and Fish Health), University of Idaho
1999-2005, Assistant Professor (Aquaculture and Fish Health), Fish and Wildlife Resources, University of Idaho
1998-99, Research Scientist (Postdoctoral Research Fellow), University of Technology, Sydney, Australia
1994-97, Graduate Research/Teaching Assistant, Animal Sciences Department, Washington State University
1991-93, Graduate Research Assistant, Department of Fish and Wildlife, Michigan State University

Academic Administrative Appointment:

2002 - Present, Associate Director (Aquaculture Research Institute), Campus facilities, University of Idaho

Non-Academic Employment including Armed Forces:

1993-94, Fish Health Technician/Fish Culturist, Clear Springs Foods, Inc., Buhl, Idaho
1989-90, Fish Culturist, Bay Port Aquaculture Systems, Inc., West Olive, Michigan
1988, Biologist's Aide, Idaho Department of Fish and Game, McCall, Idaho

Areas of Specialization:

Aquaculture vaccine development
Fish Health/Diseases
Fish Immunology/Pathology
Molecular diagnostics
Proteomics
Aquaculture development (new species)

TEACHING ACCOMPLISHMENTS:

Courses Taught (UI courses in bold):

Hatchery/Wild Fish Interactions, Fish 504, **(now Fish 525),** Fall Alt yrs (Co-teach with Dr. Dennis Scarnecchia)
Coldwater Aquaculture Workshop, Fish 503, Summer 2017 (Co-taught with Dr. Brian Small)
Fish Nutrition/Disease Workshop (Mt. Lassen trout farms) 2017
Coldwater Fish Culture Workshop, 2011
Fish Immunology Workshop, 2011
Biosecurity workshop, shortcourse/workshop presented to Idaho trout industry, Hagerman, Idaho, Summer 2009
Biosecurity workshop, shortcourse/workshop presented to Idaho trout industry, Hagerman, Idaho, Summer 2009
Salmon Disease Workshop, Corvalis, OR, July, 2009; July 2013 (Participating instructor): Intensive 2 wk disease course for fish health professionals
Current and Emerging Pathogens of Fishes in the Pacific Northwest (Workshop presented at annual Idaho Chapter AFS meeting), Boise, ID. Feb. 2007
Coldwater Disease Workshop, Annual extension shortcourse/workshop presented to Idaho trout industry, Hagerman, Idaho, Summer 2004, 2005
Fish Disease/Health Management, Annual extension shortcourse presented to Idaho trout industry, Hagerman, Idaho, September 2000, August 2001, August 2002
Aquaculture and Fish Health, Fish 419, Spring 2000
Fish Health Management, Fish 424, Spring semesters (alt/yrs as of 2015)
Concepts in Aquaculture, Fish 422, Fall semesters through 2007; Spring semesters 2007-2014; Spring alt/yrs as of 2016
Current Topics in Fish Health, Fish 494, Fall alt/yrs (no longer taught)
Fish Disease Diagnostics and Control, Fish 524, Fall alt/yrs (no longer taught)
Sustainable Aquaculture, Fish 504, Fall 2004 (Co-taught with Dr. Christine Moffitt)
Directed studies, Fish 499, Spring/Fall semesters as appropriate
Fish 398 Aquaculture Internship, every semester as arranged
Guest presentations annually in **Fish 102**
Served as poster judge and participate in course projects annually for the CNR college capstone course "**NR 470**"

Students Advised:

Undergraduate Students:

Approximately 45 to completion
Advised during the 2016-2017 academic year: 12 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students
Advised during the 2015-2016 academic year: 15 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2014-2015 academic year: 15 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2012-2013 academic year: 13 major/program advisees, interacted with 10-25

on-campus students, interacted with 10 or more former students.
Advised during the 2011-2012 academic year: 11 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2010-2011 academic year: 12 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2009-2010 academic year: 12 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2008-2009 academic year: 12 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2007-2008 academic year: 15 major/program advisees, interacted with 10-25 on-campus students, interacted with 10 or more former students.
Advised during the 2006-2007 academic year: 20 major/program advisees, interacted with 10-25 on-campus students, interacted with 10-25 off-campus students.
Advised during the 2005-2006 academic year: 10 major/program advisees, interacted with 10-25 on-campus students, interacted with 10-25 off-campus students.
Aquaculture Club. (2000-2013) – Faculty advisor
Numerous directed study (DS: 299 or 499) students advised

Undergraduate Research Mentor:

Anthony Cianciotto, REU student, 2012
Marcy Swain, REU student, 2011
David Burbank, McNair Scholarship, 2008

Graduate Students advised to completion of degree-major professor:

Neil Ashton, PhD., in progress
Moureen Matuha, PhD., in progress
Sinem Gulen, M.S., in progress
Marc Terrazas, M.S., 2016
Bikram Ghosh, PhD (University of Tasmania co-advisor), 2015
Tyson Fehringer, M.S., 2013
Neil Ashton, M.S., 2013
Amy Long, Ph.D., 2012
James Barron, M.S., 2011
David Burbank, M.S., 2011
Tarah Johnson, M.S., 2010
Mark Polinski, M.S., 2009
Ben LaFrentz, Ph.D., 2007
Nicole Lindstrom, M.S., 2007
John Drennan, Ph.D., 2006
Christine Swan, M.S., 2006
Nathan Jensen, M.S., 2006
Leslie Grabowski, M.S., 2004
Wade Cavender, M.S., 2003
Ben LaFrentz, M.S., 2002

Served on graduate committee:

Tracy Kennedy, (FWS), PhD, in progress
Tucker A. Brauer, (FWS), M.S., in progress
Andreas Brezas, (Animal and Vet Sciences), Ph.D., in progress
Jake Bledsoe, (FWS), PhD, in progress
Alf Seljenes Dalum (Norwegian School of Veterinary Sciences), 2017
Alejandro Villasante, (Animal and Vet Sciences), Ph.D., 2015
Carla Schubiger, Ph.D., (WSU vet med), 2014

Guro Løkka (Norwegian School of Veterinary Sciences), 2014
Carson Watkins, M.S., (Fish and Wildlife), 2014
Christopher Smith, M.S., (Fish and Wildlife), 2013
Karol Gliniewicz, Ph.D., (WSU vet med), 2012
Tom Loch, Ph.D., (Michigan State University), 2012
Scott Snyder (Animal and Vet Sciences), Ph.D., 2011
Heidi Henuguin (Biology), M.S., 2009
Derek Fryer, M.S., 2008
John Cheng (WSU), M.S., 2008
Shannon Amberg (CSS), Ph.D., 2008
Shannon Miller, M.S., 2007
Ryan Mann, M.S., 2007
Dustene Cummings, M.S., 2007
Johnathan Stodard (Biology), M.S., 2005
Luis Mazuera, M.S., 2005
Peggy Simpson, Ph.D., 2003
Darin Jones, M.S., 2002
Joel Green, Ph.D., 2001
Brian Peterson, Ph.D., 2001
Bill Johnson, M.S., 2000
Cameron Heuser, M.S. 2000
Tim Welker, Ph.D., 2000

Postdoctoral Researchers:

Jia Ma, 2017-present
Tim Bruce, 2017-present
Sudheesh Ponnerassey, 2003-2008, 2013-2017
Karen Plant, 2006-2011
Tanuja Upadhyaya, 2006

Research Technicians/Lab Managers:

Luke Oliver 2017-present
Joe Evavold, 2013-present
Scott Williams, 2006-present
Dan Korbel, 2017-present
Pat Blaufuss, 2012-2015
Neil Ashton, 2011-2012
Nate Jensen, 2006-2011
Najeeb Parvez, 2008-2010

Visiting Scholars:

Francis Baleta (Professor and Director, Isabela State University, Philippines) Jan.- June 2017
Jingfeng Sun (Faculty - Tianjin Agricultural University, China), Jan. 2013 –Jan. 2014
Bikram Ghosh (PhD student – University of Tasmania, Australia), Jan. 2013 – Sept. 2013)
Makesh Marappan (Central Inst. of Fisheries Education, India), October 2013-Feb. 2014)

Materials Developed:

Fish Nutrition/Disease Workshop (Mt. Lassen trout farms) 2017
Salmon disease workshop (adaptive immunity and Flavobacterial diseases), 2009, 2013
Coldwater Fish Culture Workshop/shortcourse, 2011, 2017
Fish Immunology Workshop/shortcourse, 2011
Biosecurity workshop (notebook/manual and CD), 2009

Current and Emerging Pathogens of Fishes in the Pacific Northwest (notebook/manual and CD), 2007
Coldwater disease extension bulletin (published through Western Regional Aquaculture Center), 2004
Manual for Coldwater disease workshop, 2004
Manual for Fish Health shortcourse, 2000, 2001
Website development for Fish 422 and 424, Fall 2003 (www.cnr.uidaho.edu/fish422and424/)
Website development for Fish 422 and 424 (Blackboard)

Courses Developed:

Coldwater Aquaculture Workshop, Fish 503, Summer 2017 (Co-taught with Dr. Brian Small)
Aquaculture in relation to wild fishes, Fish 525, Fall 2012 (Co-taught with Dr. Dennis Scarnecchia)
Hatchery/Wild Fish Interactions, Fish 504, Fall 2010 (Co-taught with Dr. Dennis Scarnecchia)
Concepts in Aquaculture, Fish 422, Fall 2001 (now taught every Spring)
Fish Health Management, Fish 424, Spring 2001 (now taught every Spring)
Current Topics in Fish Health, Fish 404/504 (now 494), Fall 2001, 2003, 2005
Sustainable Aquaculture, Fish 504, Fall 2004 (Co-taught with Dr. Chris Moffitt)
Fish Disease Diagnostics and Control, Fish 524, Fall 2002
Developed and implemented an Aquaculture Minor for undergraduate students, 2006
Aquaculture and Fish Health Management, Fish 419, Spring 2000

Non-credit Classes, Workshops, Seminars, Invited Lectures, etc.:

Coldwater Aquaculture Workshop, (Hagerman, ID) 2017
Fish Nutrition/Disease Workshop (Mt. Lassen trout farms) 2017
Governor Butch Otter's IGEM promotional tour - University of Idaho. (Invitation to highlight fish health products developed in my lab). Jan. 2012.
Fish diseases caused by select *Flavobacterium spp*. (Invited Lecture). Online Fish Health Course offered to USFWS professionals. Aug. 2012.
Coldwater Fish Culture Workshop (Participating instructor), 2 week shortcourse for aquaculture professionals, attended by fish culturists from IDFG and Nez Perce tribe, Moscow and Hagerman, ID. June/July, 2011
Fish Immunology Workshop (Participating/Invited instructor), 1 week course with laboratory, National Institute of Water and Atmosphere, Wellington, New Zealand, March 2011
JFA304 Aquatic Animal Physiology and Behavior, Guest speaker, University of Tasmania, March 2011
Fish 102, Guest speaker, November 2011, March 2017
Animal and Veterinary Sciences (AVS 471 – Domestic animal diseases), Guest Lecture, Oct 2010
University Core course **CORS 224**, Guest lecture, May 2010
Salmon Disease Workshop, Corvalis, OR, July, 2009, 2013 (Participating instructor): Intensive 2 wk disease course for fish health professionals
Biosecurity workshop, (instructor), August 14, 2009, Hagerman, ID
Nucleospora Workshop, (participant), August 19, 2009, Boise, ID
Current and Emerging Pathogens of Fishes in the Pacific Northwest, (instructor) February 20, 2007, Idaho Chapter AFS, continuing education (one day workshop)
CNR Outreach Workshop (invited participant/contributor), July 12, 2007
Northwest Reproductive Sciences Symposium (Invited speaker) Reproductive aspects associated with the development of a conservation aquaculture program for burbot (*Lota lota maculosa*), March 23, 2007
Lower Snake River Compensation Plan Office Annual Meeting (Invited Presenter), March 12-16, 2007
Palouse Unit AFS meeting (Invited Seminar) Research overview, November 28, 2007
Flavobacterium 2007 workshop (Invited participant/organizer), International meeting bringing over 80 researchers together from all over the world, May 2-4, 2007
Fish Immunology Workshop, (invited workshop/seminar), Oct 5, 2006, Benchmark Biolabs, Lincoln, NE
Coldwater Disease Workshop, Annual extension shortcourse presented to Idaho trout industry, Hagerman, Idaho, June 10, 2004, June 2005, August 2005
Aquaculture short course for Native Americans, (invited instructor) June 15-July 23, 2004, Hagerman,

Idaho
WSU Vancouver (invited seminar), WSU Seminar Series, October 4, 2004
46th Western Fish Disease Workshop, (organizer, speaker and session chair) AFS/Fish Health Section, June 27-29, Boise, ID. 2005.
Coldwater disease workgroup meeting, (invited participation with Federal, State, and Tribal agencies to address coldwater disease problems), Seattle, Washington, February 5, 2004
Workshop for the Center for Reproductive Biology, (invited seminar) Stimulating protective immunity in rainbow trout to the fish pathogen *Flavobacterium psychrophilum*, Washington State University, Pullman, Washington, June 11, 2003
Fish Disease/Health Management workshop/shortcourse, Annual extension shortcourse presented to Idaho trout industry, Hagerman, Idaho, September 2000, August 2001, August 2002
Fish Immunology Workshop, Annual American Fisheries Society/Fish Health Section meeting, Gig Harbor, Washington, June 2000
Oregon State University, Fish Disease Laboratory (invited seminar), March 2001
FISH 102 (invited presentation), September 2000, 2008, 2009, 2011
8th Congress of the International Society of Developmental and Comparative Immunology (invited presentation) Cairns, Australia, July 2000
Idaho Aquaculture Association, annual meeting (invited presentation) June 2000
FISH 501 (invited presentation) April 2000

SCHOLARSHIP ACCOMPLISHMENTS:

Publications:

Refereed:

Nguyen P, Sudheesh, P.S. Sinnesael, M., Thomas, A. Haman, K., and Cain, K.D. Rapid Detection and Monitoring of *Flavobacterium psychrophilum* in Water by Using a Handheld Field-Portable qPCR System. *North American Journal of Aquatic Animal Health* (in revision)

Terrazas, M.M., Anderson, C.L. and Cain, K.D. Determining juvenile Burbot *Lota lota maculosa* susceptibility to stress-mediated pathogens. *North American Journal of Aquatic Animal Health* (Accepted - In Revision)

Jaing, M.N, Fan, Yuding, Cain, K., Zeng, L. 2018. Development of cross-priming amplification coupled with vertical flow visualization for rapid detection of infectious spleen and kidney necrosis virus (ISKNV) in mandarin fish, *Siniperca chuatsi*. *Journal of Virological Methods* 253, 38-42

Terrazas, M.M., Adams, J.R., Sudheesh, P. and Cain, K.D. 2017. Effects of Diel Temperature Fluctuation on Growth, Stress Response, and Immune Function of Burbot. *Transactions of the American Fisheries Society*, Volume 146, 996 – 1007

Hudson, K.S. and Cain, K.D. Pathogens and Parasites. 2017. In: *Aquaculture: Farming Aquatic Animals and Plants*. Volume 3, (ed) Southgate, P.C.) Wiley-Blackwell publishing. (In Press)

Sudheesh, P.S. and Cain, K.D. 2017. Prospects and challenges of developing and commercializing immersion vaccines for aquaculture. *International Biology Review* 1(1): 1-20

Villasantea, A.,Powell, M.S., Murdoch, G.K., Overturf, K., Cain, K., Wacyke, J., Hardy, R.W. 2016. Effect of anthocyanidins on myogenic differentiation 1 in induced and non-induced primary myoblasts from rainbow trout (*Oncorhynchus mykiss*). *Comparative Biochemistry and Physiology Part B* 196–197: 102–108

Sudheesh, P.S. and Cain, K.D. 2016. Optimization of efficacy of a live attenuated *Flavobacterium psychrophilum* immersion vaccine. *Fish & Shellfish Immunology* 56: 169-180

Ashton, N.K., Campbell, M.R., Anders, P.J., Powell, M.S. and Cain, K.D. 2016. Evaluating Microsatellite Markers for Parentage-Based Tagging of Hatchery Burbot. *Northwest Science*, 90(3):249-259

Sudheesh, P.S., Zimmerman, J.K. and Cain, K.D. 2016. Dietary effects on immunity, stress, and efficacy of two live attenuated *Flavobacterium psychrophilum* vaccine formulations. *Aquaculture* 454 35-43

Ghosh, B., Cain, K.D., Nowak, B.F. and Bridle, A.R. 2016. Microencapsulation of a putative probiotic Enterobacter species, C6-6, to protect rainbow trout, *Oncorhynchus mykiss* (Walbaum), against bacterial coldwater disease. *Journal of Fish Diseases* 39(1):1-11

Karol Gliniewicz, Mark Wildung, Lisa H. Orfe, Gregory D. Wiens, Kenneth D. Cain, Kevin K. Lahmers, Kevin R. Snekvik and Douglas R. Call. 2015. Potential mechanisms of attenuation for rifampicin-passaged strains of *Flavobacterium psychrophilum*. *BMC Microbiology* 15:179

Long, A., Call, D.R. and Cain, K.D. 2015. Comparison of quantitative PCR and ELISA for detection and quantification of *Flavobacterium psychrophilum* in salmonid broodstock. *Diseases of Aquatic Organism* 115: 139–146

Ghosh, B., Bridle, A.R., Nowak, B.F. and Cain, K.D. 2015. Assessment of immune response and protection against bacterial coldwater disease induced by a live-attenuated vaccine delivered orally or intraperitoneally to rainbow trout, Oncorhynchus mykiss (Walbaum). *Aquaculture* 446: 242–249

Makesh, M., Sudheesh, S.S. and Cain, K.D. 2015. Systemic and mucosal immune response of rainbow trout to immunization with an attenuated *Flavobacterium psychrophilum* vaccine strain by different routes. *Fish and Shellfish Immunology* 44: 156-163

Schubiger, C.B., Orfe, L.H., Ponnerassery, S.P., Cain, K.D., Shah, D.H. and Call, D.R. 2015. Entericidin is requisite for a probiotic treatment (Enterobacter C6-6) to protect trout from coldwater disease challenge. *Applied and Environmental Microbiology* 81:658 –665

Egan, J.P., Johnson, R.D., Anders, P.J. and Cain, K.D. 2014. Initial Characterization of Embryonic Development in North American Burbot *Lota lota maculosa*. *North American Journal of Aquaculture* 77:1, 37-42

Wiens, G.D., LaPatra, S.E., Welch, J.J., Rexroad 3rd, C., Call, D.R., Cain, K.D., LaFrentz, B.R., Vaisvil, B., Schmitt, D.P. and Kapatral, V. 2014. Complete genome of *Flavobacterium psychrophilum* strain CSF259-93 used to select rainbow trout for increased genetic resistance against bacterial cold water disease. *Genome Announcements* 2(5):e00889-14. doi:10.1128/genomeA.00889-14

Plant, K. P., LaPatra, S.E., Call, D.R., and Cain, K.D. 2014. Attempts at validating a recombinant *Flavobacterium psychrophilum* gliding motility protein N as a vaccine candidate in rainbow trout, *Oncorhynchus mykiss* (Walbaum) against bacterial cold water disease. *FEMS Microbiology Letters* 358, 14–20

Long, A., Fehringer, T.R., LaFrentz, B.R., Call, D.R. and Cain, K.D. 2014. Development of a waterborne challenge model for *Flavobacterium psychrophilum*. *FEMS Microbiology Letters*, 359, 154–160

LaPatra, S.E., Fehringer, T.R. and Cain, K.D. 2014. A probiotic Enterobacter sp. provides significant protection against *Flavobacterium psychrophilum* in rainbow trout (*Oncorhynchus mykiss*) after injection by two different routes. *Aquaculture*, 433, 361–366

Fehringer, T.R., Hardy, R.W. and Cain, K.D. 2014. Dietary inclusion of salmon testes meal from Alaskan seafood processing byproducts: Effects on growth and immune function of rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Aquaculture,* 433, 34-39

LaFrentz, B.R., LaPatra, S.E., Call, D.R., and Cain, K.D. 2014. Immunization of rainbow trout *Oncorhynchus mykiss* (Walbaum) with a crude lipopolysaccharide extract from *Flavobacterium psychrophilum*. *Journal of Fish Diseases,* 45, 476–483

Ashton, N.K., Anders, P.J., Young, S.P. and Cain, K.D.. 2014. Coded Wire and Passive Integrated Transponder Implantations in Juvenile Burbot. *North American Journal of Fisheries Management,* 34:2, 391-400

Long, A., Call, D.R. and Cain, K.D. 2014. Investigation of the link between broodstock infection, vertical transmission, and prevalence of *Flavobacterium psychrophilum* in eggs and progeny of rainbow trout and coho salmon. *Journal of Aquatic Animal Health,* 26(2):66-77.

Cain, K.D. and Polinski, M.P. 2014. Infectious Diseases of Coldwater Fish in Fresh Water. Chapter 3. In: *Diseases and Disorders of Finfish in Cage Culture.* Volume 2, (eds) Woo, P.T.K., and Bruno, D.W. CABI publishing, New York, NY. pp.60-113

Ashton, N.K., Ireland, S.C. and Cain K.D. 2013. Artificial Marker Selection and Subsequent Tagging Evaluations with Juvenile Burbot. *Transactions of the American Fisheries Society*, 142:6, 1688-1698

Barren, J.M. Jensen, N.R., Anders, P.J., Egan, J.P Ireland, S.C. and Cain K.D. 2013. Effects of stocking density on survival and yield of North American burbot reared under semi-intensive conditions. *Transactions of the American Fisheries Society*, 142:6, 1680-1687

Holt, R.A., Bertolini, J., Cain, K. and Long, A. 2013. Coldwater Disease. *In: Fish Health Section Blue Book; Suggested procedures for the detection and identification of certain finfish and shellfish pathogens*. Chapter 2.2, American Fisheries Society (Invited book chapter)

Woo, P.T.K. and Cain K.D. 2013. *Editors.* Current and Emerging Diseases/Disorders of Fish in Aquaculture. Special Issue: *Journal of Aquaculture Research and Development,* (International Open Access) ISSN:2155-9546

Barren, J.M., Jensen, N.R., Anders, P.J., Egan, J.P., Ireland, S.C. and Cain, K.D. 2013. Suppression of cannibalism during larviculture of burbot (*Lota lota maculosa*) through size grading. *North American Journal of Aquaculture* 75:4, 556-561

Valdenegro-Vega, V.A., Crosbie, P., Vincent, B., Cain, K.D., and Nowak· B.F. 2013. Effect of immunization route on mucosal and systemic immune response in Atlantic salmon (*Salmo salar*). *Veterinary Immunology and Immunopathology* 151(1-2):113-23

Long, A., Fehringer, T.R, Swain, M.A., LaFrentz, B.R., Call, D.R. and Cain K.D. 2013. Enhanced efficacy of an attenuated *Flavobacterium psychrophilum* strain cultured under iron- limited conditions. *Fish and Shellfish Immunology,* 35: 1477-1482

Polinski, M., Jensen, N., Foltz, J., Ireland, S. and Cain, K.D. 2013. Hydrogen peroxide treatments administered to hatchery reared burbot (Lota lota): assessing treatment regimes from embryonic development through juvenile rearing. *North American Journal of Aquaculture*, 75:1 50-56

Burbank, D.R., LaPatra, S.E., Fornshell, G. and Cain, K.D. 2012. Isolation of bacterial probiotics candidates from the gastrointestinal (GI) tract of rainbow trout and screening for *in vitro* inhibitory activity to *Flavobacterium psychrophilum*. *Journal of Fish Diseases*, 35:11 809-816

Gliniewicz, K, KP Plant, SE LaPatra, BR LaFrentz, K Cain, KR Snekvik and DR Call. 2012. Comparative proteomic analysis of virulent and rifampicin attenuated *Flavobacterium psychrophilum*. *Journal of Fish Diseases,* 35(7):529-39

Snyder, S, Barrows, R., Hill, R., Gaylord, G., Overturf, K. Cain, K.D., and Hardy, R. 2012. Effects of carnosine supplementation to an all-plant protein diet for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* 338-341, 72-81

Foltz, J.R., Jensen, N.R., Polinski, M.P., Ireland, S.C. and Cain, K.D. 2012. Characterization of egg development by catheterization and consequences for delaying egg fertilization in hatchery reared burbot (*Lota lota*) *North American Journal of Aquaculture*, 74:3 408-412

Long, A., Polinski, M.P., Call, D.R., and Cain, K.D. 2012. Validation of Diagnostic Assays to Screen Broodstock for *Flavobacterium psychrophilum* infections. *Journal of Fish Diseases*, 35, 407-419

Barren, J.M., Jensen, M.R., Anders, P.J., Egan, J.P., Ireland, S.C. and Cain, K.D. 2012. Effects of temperature on the intensive culture performance of larval and juvenile North American burbot (*Lota lota maculosa*). *Aquaculture*, 364-365, 67-73

Burbank, D.R., Shah, D.H., LaPatra, S.E., Fornshell, G. and Cain, K.D. 2011. Enhanced resistance to coldwater disease following feeding of probiotic bacterial strains to rainbow trout (*Oncorhynchus mykiss*). *Aquaculture,* 321, 185-190

LaFrentz, B.R., LaPatra, S.E., Call, D.R., Wiens, G.D., and Cain, K.D. 2011. Identification of Immunogenic proteins within distinct molecular mass fractions of *Flavobacterium psychrophilum*. *Journal of Fish Diseases,* 34, 823-830

Lloyd, S.J., LaPatra, S.E., Snekvik, K.R., Cain, K.D., and Call, D.R. 2011. Quantitative PCR demonstrates a positive correlation between a *Rickettsia*-like organism and severity of strawberry disease lesions in rainbow trout (*Oncorhynchus mykiss*). *Journal of Fish Diseases,* 34, 701-709

Jensen, N.R., Anders, P.J., Hoffman, C.A., Porter, L.S., Ireland, S.C., and Cain, K.D. 2011. Performance and macronutrient composition of Age-0 burbot fed four diet treatments. *North American Journal of Aquaculture*, 73:3, 360-368

Paragamian, V.L, Laude, C., Cain, K.D., Barron, J.M., and Jensen,N. 2011. A novel experiment of rearing burbot larvae in cages. Journal of Applied Ichthyology. 27 (1), 16–21

Neufeld, M.D., Cain, K., Jensen, N., Ireland, S.C., and Paragamian, V.L. 2011. Movement of Lake Origin Burbot Reared in a Hatchery Environment and Released into a Large River. *North American Journal of Fisheries Management* 31, 56-62

Plant, K.P., LaPatra, S.E., Call, D.R., and Cain, K.D. 2011. Immunization of rainbow trout (*Oncorhynchus mykiss*) with *Flavobacterium psychrophilum* proteins elongation factor-Tu, SufB Fe-S assembly protein and ATP synthaseβ. *Journal of Fish Diseases* 34, 247-250

Cain, K.D and Swan, C.M. 2010. Barrier Function and Immunology. "The Multifunctional Gut of Fish" Elsevier Inc., (Invited book chapter), *Fish physiology* vol: 30, 112-134.

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Polinski, M.P., Fehringer, T.R., Johnson, K.A., Snekvik, K.R., LaPatra, S.E., LaFrentz, B.R., Ireland, S.C., Cain, K.D. 2010. Characterization of susceptibility and carrier status of burbot to IHNV, IPNV, *Flavobacterium psychrophilum*, *Aeromonas salmonicida*, and *Renibacterium salmoninarum*. *Journal of Fish diseases* 33, 559-570

Polinski, M.P., Johnson, K.A., Ireland, S.C., Jensen, N.R., and Cain, K.D. 2010. Assessment of formalin and hydrogen peroxide use during egg incubation of burbot (*Lota lota maculosa*). *North American Journal of Aquaculture* 72, 111-117

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LaFrentz, B.R., LaPatra, S.E., Call, D.R.., and Cain, K.D. 2008. Development and characterization of rifampicin resistant *Flavobacterium psychrophilum* strains and their potential as live attenuated vaccine candidates. *Vaccine* 26 (2008) 5582–5589

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Peer Reviewed/Evaluated:

Cain, K.D. 2017. Challenges to the development of new disease management tools/products for a growing aquaculture industry. 8th International Conference on Fisheries & Aquaculture. *Journal of Aquaculture Research and Development.8 (Suppl) DOI: 10.4172/2155-9546-C1-016*

Makesh, M., Sudheesh, S.S. and Cain, K.D. 2014 Systemic and mucosal immune response of rainbow trout to immunization by different routes. *Livestock diseases affecting livelihood options and global trade-strategies and solutions, At Madras Veterinary College, Chennai, India* (Conference paper)

Plant, K. P., LaPatra, S.E., Call, D.R., and Cain, K.D. 2014. Attempts at validating a recombinant *Flavobacterium psychrophilum* gliding motility protein N as a vaccine candidate in rainbow trout, *Oncorhynchus mykiss* (Walbaum) against bacterial cold water disease. *FEMS Microbiology Letters* 358(1):14-20. doi: 10.1111/1574-6968.12543. Featured supplement in: *World Biomedical Frontiers*

Neufeld, M.D., Davis, C.A., Cain, K.D., Jensen, N.R., Ireland, S.C. and Lewandowski, C. Evaluation of Methods for Collection and Fertilization of Burbot Eggs from a Wild Stock for Conservation Aquaculture Operations. 2011. *Proceedings of the Third International Burbot Symposium, Journal of Applied Ichthyology* 27 (Suppl. 1), 9-15

Paragamian, V.L., Laude, C., Cain, K.D. and Jensen, N. A Novel Experiment of Rearing Burbot Larvae in Pens. 2011. *Proceedings of the Third International Burbot Symposium, Journal of Applied Ichthyology* 27 (Suppl. 1), 16-27

Jensen, N. R., Williams, S. R., Ireland, S. C., Siple, J. T., Neufeld, M. D., Cain, K. D. 2008. Spawning and behavior observations of captive wild burbot *(Lota lota maculosa)*. *Proceedings of the Second International Burbot Symposium* 59, 155-165

LaFrentz, B.R., and Cain, K.D., Coldwater Disease, Extension Bulletin, 2004. Western Regional Aquaculture Consortium (WRAC) 9 pgs.

Simpson, P.R., B.C. Peterson, K.D. Cain, R.W. Hardy, K. Overturf, and T.L. Ott. 2002. Physiological effects of recombinant bovine somatotropin (rbST) in rainbow trout (*Oncorhynchus mykiss*). Growth Hormone and IGF Research. 12(4):234.

Cain, K.D., Grabowski, L. and LaPatra, S.E. 2001. Separation and comparison of proteins from virulent and nonvirulent strains of the fish pathogen *Flavobacterium psychrophilum*, using a 2-D electrophoretic approach. BioRadiations 107 19-21.

Cain, K.D., Grabowski, L. and LaPatra, S.E. 2001. Separation and comparison of proteins from virulent and nonvirulent strains of the fish pathogen *Flavobacterium psychrophilum*, using a 2-D electrophoretic approach. Bio-Rad Tech Note # 2670.

Cain, K.D., Jones, D.R. and Raison, R.L. 2000. Analysis of antibody-antigen kinetics following immunization of rainbow trout (*Oncorhynchus mykiss*) with a T-cell dependent antigen. Developmental and Comparative Immunology 24 (1) S15.

Cain, K.D., LaPatra, S.E., Shewmaker, B., Jones, J. and Ristow, S.S. 1997. Does chum salmon virus (CSV) conferred resistance to IHNV in rainbow trout occur at mucosal sites? American Fisheries Society/Fish Health Section Newsletter: 25 (2): 2-4.

Ristow, S.S., Cain, K.D. and LaPatra, S.E. 1997. Innate antiviral properties identified in the mucus of rainbow trout (*Onccorhynchus mykiss*) challenged with infectious hematopoietic necrosis virus (IHNV). *9th International Congress of Mucosal Immunology,* Immunology and Cell Biology 75 (1): A59.

Cain, K.D. and Garling, D. 1993. Trout Culture in the North Central Region. Extension Bulletin. North Central Regional Aquaculture Center, U.S.D.A. Fact Sheet Series #108. 8 pages.

Other:

Cain, K.D. and Call, D.R. Probiotics and vaccine treatments fight coldwater disease in rainbow trout. Aquaculture North America. August 2016.

Ashton, N., P. Blaufuss, and K. Cain. 2013. Kootenai Tribal Burbot Project Report 2012. Submitted to Kootenai Tribe of Idaho. 11pp.

Cain, K.D. 2011. Researchers tackle top trout killer, *Capital Press Article*, August, 2011

Call, D.R., Schubiger, C., Cain, K.D. 2011. What causes Strawberry Disease in rainbow trout? US Trout Farmers, *Trout Talk Newsletter*, Fall 2011

Jensen, N., Ireland, S., Neufeld, M., Anders, P., Jones, R., Paragamian, V., and Cain, K.D. 2010. Hatchery reared burbot released for the first time in British Columbia Canada and Idaho USA. *AFS Fish Culture Section Newsletter*, Winter, Pgs 10-11

Jensen, N., Ireland, S., Neufeld, M., Anders, P., Jones, R., Paragamian, V., and Cain, K.D. 2010. Hatchery reared burbot released for the first time in British Columbia Canada and Idaho USA. *University of Idaho Aquaculture Research Institute Newsletter,* spring, Pgs 1-2

Cain, K.D. and Call, D.R. 2010. Coldwater Disease Research, *Waterlines newsletter,* 16, Pg 10

Call, D.R., Snekvik, K.R., and Cain, K.D. 2010. Strawberry Disease Research. *Waterlines newsletter,* 16, Pg 11

Jensen, N.R. and Cain, K.D. 2009. Burbot: Not just another cod. *Hatchery International Magazine*, 10(3) May/June

Cain, K.D. 2009. Strategies for Control and Prevention of Coldwater Disease, *Waterlines newsletter,* 15(1), Pgs 18-20

Cavender, W.P., Wood, J.S., Powell, M.S., Overturf, K., and Cain, K.D. 2003. A real-time quantitative PCR (QPCR) approach for identifying *Myxobolus cerebralis* and determining infection severity in rainbow trout. Final Technical Report. Montana Water Center (Whirling Disease Foundation), Bozeman, Montana.

Cain, K.D., Grabowski, L., and Reilly, J.J. 2001. Immunomodulatory effects of β-1,3, glucan administered to tilapia (*Oreochromis nilotocus*) in a Spirulina based diet. Internal report. Hartz Mountain Corporation, Bloomfield, New Jersey.

Cavender, W.P., Johnson, K.A., and Cain, K.D. 2001 Distribution of *Myxobolus cerebralis* during the migration period for juvenile anadromous salmonids in the Snake and Salmon Rivers of Idaho. Final Technical Report. Montana Water Center (Whirling Disease Foundation), Bozeman, Montana.

Refereed/Adjudicated (currently scheduled or submitted):

Peer Reviewed/Evaluated (currently scheduled or submitted):

Presentations and Other Creative Activities:

Community presentation:

Cain, K.D. (Clearwater Flycasters presentation). Burbot conservation aquaculture and species recovery, December, 11th 2013.

Workshop/manual development (since 1999):

Salinas, I., Nowak, B., and Cain, K.D., Fish Immunology Workshop (Notebook/manual), 2011

Hardy, R., Cain, K.D., Powell, M., Fornshell, G., and Patterson, T. Coldwater Fish Culture Workshop (notebook/manual and materials), 2011

Fornshell, G., and Cain, K.D. Biosecurity workshop (notebook/manual and CD), 2009

Cain, K.D., Johnson, K., Heindel, J., Emerging Pathogens of Fishes in the Pacific Northwest, Workshop manual and CD, February 20, 2007

Cain, K.D. and LaFrentz, B.R. Coldwater Disease Workshop and Shortcourse. UI Cooperative Extension System. June 10, 2004.

Cain, K. Overview of the Fish Immune System. Fish Immunology Workshop Manual. AFS/FHS continuing education, June 27, 2000.

Cain, K. Stress and the Immune Response. Fish Immunology Workshop Manual. AFS/FHS continuing education, June 27, 2000.

Cain, K. Bacterial and Viral Diseases in Aquaculture. Trout Disease/Health Management Short Course Manual. UI Cooperative Extension System and Hagerman Fish Culture Experiment Station. September 12-13, 2000, August 2001.

Professional Meeting Papers, Workshops, Showings, Recitals:

Presentations and Posters (since 1999)

Cain, K.D. 2017. Challenges to the development of new disease management tools/products for aquaculture. Aquaculture America Conference, Las Vegas, NV. (Invited talk) February 19-22, 2018

Ashton, N., Ross, T.J., Hardy, R., Young, S., Nemeth, D. and Cain, K. Identification of thermal bottlenecks affecting burbot embryo development: Implications for restoring the lower Kootenai River population. Idaho Chapter American Fisheries Society. March 2018

Cain, K.D. 2017. Challenges to the development of new disease management tools/products for a growing aquaculture industry. 8th International Conference on Fisheries & Aquaculture. Toronto, Canada, October 2017 (**Keynote Speech**)

Cain, K.D. and P.S. Sudheesh. Cross-protection to emerging flavobacterial pathogens following

vaccination with a live attenuated *Flavobacterium psychrophilum* vaccine (Fp-B.17-ILM). World Aquaculture Society Conference. Cape Town, South Africa. June 2017

Baleta, F.N., Sudheesh, P.S. and Cain, K.D.Utilization of *Sargassum* extracts as immunostimulant for raibow trout: effects of route administration on growth and immune response. 58th Western Fish Disease Workshop, Suquamish, WA June 20-22, 2017

Burbank, D.R. and Cain, K.D. Probiotics in aquaculture; development of a probiotic to reduce coldwater disease associated mortality. 58th Western Fish Disease Workshop, Suquamish, WA June 20-22, 2017

Cain, K.D. and P.S. Sudheesh. Cross-Protection To Emerging Flavobacterial Pathogens and Divergent Flavobacterium psychrophilum strains following Vaccination with a Live Attenuated Vaccine (Fp-B.17-ILM). Eastern Fish Health Workshop. (Invited talk) East Lansing, MI. April 3rd – 6th, 2017

Cain, K.D., Schubiger, C.B., Burbank, D.R., Ghosh, B. and D.R. Call. Characterization of a putative probiotic enterobacter strain (C6-6) and potential mechanisms associated with protection of rainbow trout challenged with *Flavobacterium psychrophilum.* Aquaculture America Conference, San Antonio, Texas. February 20-23, 2017.

Cain, K.D. Emerging and Re-emerging Flavobacterial diseases. Special session of the US Trout Farmers Association (Invited talk), Aquaculture America Conference, San Antonio, Texas. February 20-23, 2017.

Cain, K.D. Overview of Aquaculture and Fish Health Research at the University of Idaho. Norwegian School of Veterinary Medicine. (Invited Seminar) Oslo, Norway. February 9th, 2017.

Cain, K.D., Schubiger, C.B., Burbank, D.R., Ghosh, B. and D.R. Call. Characterization of a putative probiotic Enterobacter strain (c6-6) and potential mechanisms associated with protection of rainbow trout challenged with *Flavobacterium psychrophilum*, the causative agent of coldwater disease/rainbow trout fry syndrome. 17th International Symposium on Fish Nutrition and Feeding (ISFNF), (Invited) Sun Valley, Idaho. June 5-10, 2016.

Cain, K.D. and Terazzas, M. Stress and disease susceptibility of burbot. Kootenai Tribe of Idaho Annual Planning Meeting. (Invited) July 2016.

Cain, K.D. and Wilson, M. Can "freshwater cod" be produced in Southern Idaho: overview of pilot trials at the University of Idaho (UI) and the College of Southern Idaho (CSI). Idaho Aquaculture Association annual meeting. (Invited) Twin Falls, ID June 11th, 2016.

Cain, K.D. 2016. Developing "freshwater cod" or burbot (*Lota lota*) into a viable commercial aquaculture species in the United States. Western Regional Aquaculture Center Annual meeting. Proposal presentation. Oct. 12th.

Cain, K.D. 2016. Emerging and Re-emerging Flavobacterial Pathogens of Salmonids. Proposal presentation. Oct. 12th.

P.S. Sudheesh, and KD Cain. Efficacy of an improved live attenuated *Flavobacterium psychrophilum* immersion vaccine. FLAVOBACTERIUM 2015. 4th International Conference on Flavobacterium, October 27-29, 2015, Auburn University, Auburn, AL, USA

P.S. Sudheesh, Katherine H., and KD Cain. A Novel *Flavobacterium sp.* Causes Bacterial Cold Water Disease-like Symptoms in Steelhead and Rainbow Trout. American Fisheries Society, 145th Annual Meeting, Portland, August 16 - 20, 2015

Cain, K.D. and Sudheesh, P. 2015. Optimizing the efficacy of a live attenuated *Flavobacterium psychrophilum* vaccine for coldwater disease. World Aquaculture Society (Aquaculture America conference). New Orleans, LA. February 19-22nd.

Cain, K.D. 2015. Idaho Department of Commerce (IGEM council). Licensing and Commercialization of a Live Attenuated Aquaculture Vaccine (proposal finalist – invited presentation). Boise, ID. September 30th.

Cain, K.D. 2015. Lower Snake River Compensation Program (Annual Meeting). Coldwater Disease – Working toward a Vaccine (Invited). Clarkston, WA. March 10th.

Cain, K.D. 2014. Research overview presentation (Invited). Skretting ARC – Stavanger, Norway October, 29th.

Cain, K.D. 2014. Conservation aquaculture as a critical tool for recovery of native fish Populations. (Invited seminar) Iowa State University. October 10th.

Cain, K.D. 2014. Developing "freshwater cod" or burbot (*Lota lota*) into a viable commercial aquaculture species in the United States. Western Regional Aquaculture Center Annual meeting. Oct. 8th.

Cain, K.D. 2014. Defining the relationship between stress, immune function and disease resistance in rainbow trout fed immunostimulants and functional feed additives. Western Regional Aquaculture Center Annual meeting. Oct. 8th.

Terazzas, M. and Cain, K.D. 2014. Determining Juvenile Burbot Susceptibility to Stress Mediated Pathogens. 65th Annual Northwest Fish Culture Conference. Pendleton, OR. Dec 2-4.

Blaufuss, P. and Cain, K.D. 2014. Aquaculture developments for Burbot *Lota lota* intended for population restoration in the Kootenai River. 65th Annual Northwest Fish Culture Conference. Pendleton, OR. Dec 2-4.

Cain, K.D. 2014. Coldwater Disease (CWD) Vaccine. Pacific Northwest Fish Health Protection Committee Meeting. (Invited) Lewiston, ID. September 27th.

Cain, K.D. Sudheesh, P. and Zinn, J. 2014. Coldwater Disease (CWD) Vaccine: Myth or Reality? (Invited) US Trout Farmers Annual Meeting Twin Falls, ID. September 22nd-23rd.

Sudheesh, P. and Cain, K.D. 2014. Optimizing the efficacy of a live attenuated *Flavobacterium psychrophilum* vaccine for coldwater disease. International Symposium of Aquatic Animal Health. Portland OR. August 31st – September 4th.

LaPatra, S., Feringer, T. and Cain, K.D. 2014. Probiotic Provides Significant Protection Against *Flavobacterium psychophilum* in Rainbow Trout After Injection by Two Different Routes. International Symposium of Aquatic Animal Health. Portland OR. August 31st – September 4th.

Cain, K.D. and Sudheesh, P. 2014. Dietary Effects on Immunity, Stress, and Efficacy of a Live Attenuated *Flavobacterium Psychrophilum* Vaccine. International Symposium of Aquatic Animal Health. Portland OR. August 31st – September 4th.

Ghosh, B., Cain, K.D., Nowak, B.F. and Bridle, A.R. 2014. Oral immunoprophylaxis of finfish using alginate microencapsulation. International Symposium of Aquatic Animal Health. Portland OR. August 31st – September 4th.

Blaufuss, P.C., Cain, K.D., Evavold, J. and Young, S. 2014. Aquaculture development for burbot *Lota lota*. Aquaculture America. February 9th-12th.

Cain, K.D., Call, D.R., Long, A. and LaFrentz. 2013. New Tools and Potential Management Strategies For Coldwater Disease. (Invited special session talk) 38th Annual Eastern Fish Health Workshop, Gettysburg, PA. April 29th – May 3rd.

Long, A., Call, D.R. and Cain, K.D. 2013. Use Of Diagnostic Assays For Identification Of *Flavobacterium psychrophilum* Isolates. (Invited special session talk) 38th Annual Eastern Fish Health Workshop, Gettysburg, PA. April 29th – May 3rd.

Ashton, N. Young, S., Anders, P., Campbell, M., Powell, M. and Cain, K.D. 2013. Evaluations of Artificial and Natural Markers for Monitoring Hatchery Releases of Juvenile Burbot (*Lota lota*). Idaho Chapter/Western Division American Fisheries Society Annual Meeting, April 15-18.

Ashton, N. Young, S. and Cain, K.D. 2013. Advancements in Aquaculture and Supplementation of Imperiled Burbot in the Kootenai River. Idaho Chapter/Western Division American Fisheries Society Annual Meeting, April 15-18.

Cain, K.D. 2013. Commercializing specific naturally occurring probiotic bacterial strains to aid in fish disease management for aquaculture. Idaho State Board of Education, Legislative lunch (Invited presentation to Idaho legislature), Feb. 4th.

Cain, K.D. 2013. Burbot production and research update. Kootenai Tribe of Idaho annual program review and planning meeting. Bonner's Ferry. Jan. 17th.

Cain, K.D., Long, A., Ownbey, R., and Zinn, J. 2012. Coldwater Disease Research: Update on Vaccine Licensing and Commercialization Status. (Invited) Northwest Fish Culture Conference, Portland, OR. December 10-13.

Ashton, N., Young, S. and Cain, K.D. 2012. Advancements in Aquaculture and Supplementation of Imperiled Burbot in the Kootenai River. Northwest Fish Culture Conference, Portland, OR. December 10-13.

LaFrentz, B.R., Cain, K.D., Shoemaker, C. and Klesius, P.H. 2012. Vaccination of fish against *Flavobacterium columnare* and *F. psychrophilum.* Joint meeting with USGS Western Fisheries Center and Russian Fisheries Scientists. Seattle. WA. Nov.

Cain, K.D. 2012. Update on coldwater disease vaccine development. (Invited) Western Regional Aquaculture Center annual meeting, Oct. 10-12.

Long, A., Fehringer, T.R., Swain, M.A., LaFrentz, B.R., Call, D.R. Zinn, J. and Cain, K.D. 2012, Culturing a Live Attenuated Flavobacterium psychrophilum Vaccine in Iron Limited Media Enhances Efficacy. Annual AFS/Fish Health Section meeting. Lacross, WI. Aug.

Barron, J.M., Jensen, N.R., Anders, P.J., Egan, J.P., Ireland, S.C., and Cain, K.D. 2012. Effects of Stocking Density on Survival and Yield of North American Burbot Reared Under Semi-intensive Conditions. International Congress on Fish Biology (Burbot Symposium). Madison, WI. July.

Fehringer, T.R., Hardy, R.W. and Cain, K.D. 2012. Assessing the ability of gonad meal to act as a nucleotide immunostimulant in rainbow trout *(Oncorhynchus mykiss*). 53rd Annual Western Fish Disease Workshop. Boise, ID. June.

Long, A., Fehringer, T.R., Swain, M.A., LaFrentz, B.R., Call, D.R. and Cain, K.D. 2012. Culturing of a live attenuated *Flavobacterium psychrophilum* strain vaccine by culturing in iron limited media enhances efficacy. 53rd Annual Western Fish Disease Workshop. Boise, ID. June.

Cain, K.D. 2012. Conservation aquaculture as a critical tool for recovery of native fish populations. (Invited) James Cook University. Queensland, Australia. March 27th.

Cain, K.D. 2012. Thinking outside the box: new and innovative ways to prevent or control disease in aquaculture. (Invited) James Cook University. Queensland, Australia. March 28th.

Gliniewicz, K., Plant, K., LaPatra, S.E., Cain, K.D., Snekvik, K.R., LaFrentz, B.R. and Call, D.R. 2012. Comparative Proteomic Analysis of Virulent and Rifampicin Attenuated Strains of *Flavobacterium psychrophilum.* Idaho Chapter of American Fisheries Society Meeting. Coure d Alene, ID. Feb.

Long, A., Fehringer, T.R., Swain, M.A., LaFrentz, B.R., Call, D.R. and Cain, K.D. 2012. Culturing of a live attenuated *Flavobacterium psychrophilum* strain vaccine by culturing in iron limited media enhances efficacy. Idaho Chapter of American Fisheries Society Meeting. Coure d Alene, ID. Feb.

Cain, K.D. 2012. Identification of specific probiotics capable of enhancing resistance to bacterial coldwater disease (CWD) in rainbow trout. (Invited) Rocky Plains Fish Pathology Meeting. Boise, ID. Jan. 25-26.

Cain, K.D. 2012. A potential vaccine to control bacterial coldwater disease (CWD). (Invited) Rocky Plains Fish Pathology Meeting. Boise, ID. Jan. 25-26.

Cain et al. 2011. Identification of specific Autochthonous probiotics capable of enhancing resistance to bacterial coldwater disease. (Invited) Northwest Fish Culture Conference, Victoria, BC Canada. December 6-8.

Cain et al. 2011. A potential vaccine for coldwater disease. (Invited) Northwest Fish Culture Conference, Victoria, BC Canada. December 6-8.

Cain et al. 2011 Conservation aquaculture as a critical tool to recover burbot populations in Idaho's Kootenai River. (Invited) Northwest Fish Culture Conference, Victoria, BC Canada, December 6-8

Cain et al. 2011. Identification of specific Autochthonous probiotics capable of enhancing resistance to bacterial coldwater disease. AADAP meeting Bozeman, MT August 1-4.

Cain et al. 2011. Identification of specific Autochthonous probiotics capable of enhancing resistance to bacterial coldwater disease. (Invited) Pacific Northwest Fish Health Protection Committee (PNFHPC) meeting, Portland OR. September 21-22.

Cain et al. 2011. A potential vaccine for coldwater disease. (Invited) Pacific Northwest Fish Health Protection Committee (PNFHPC) meeting, Portland OR. September 21-22.

Cain et al. 2011. Identification of specific Autochthonous probiotics capable of enhancing

resistance to bacterial coldwater disease. (Invited) US Trout Farmers and Idaho Aquaculture Association annual conference, Twin Falls, ID September 29-Oct 1.

Cain et al. 2011 A potential vaccine for coldwater disease. (Invited) US Trout Farmers and Idaho Aquaculture Association annual conference, Twin Falls, ID September 29-Oct 1.

Cain, K.D. 2011. Research overview and update. (Invited) University of Tasmania. February 10th, Launceston, Tas, Australia

Cain, K.D. 2011. Fish Health Research and Development. CSIRO laboratories. March, Hobart, Tas, Australia (invited presentation to Salmon industry)

Cain, K.D., 2011. Aquaculture in Idaho and the Pacific Northwest of the US: Research at the University of Idaho. (Invited) Department of Primary Industries, Mount Pleasant Laboratories, May 7th, Launceston, Tas, Australia

Cain et al. 2011 Conservation aquaculture as a critical tool to recover native fish species. May 18th, University of Tasmania, Launceston, Tas, Australia (invited seminar speaker)

Gliniewicz, K, KP Plant, SE LaPatra, KD Cain, KR Snekvik, BR LaFrentz, and DR Call. Comparative proteomic analysis of virulent and rifampicin attenuated strains of *Flavobacterium psychrophilum*. *American Fisheries Society Annual Meeting*, Seattle, WA, 5-7 September 2011.

Swain, MA, A Long, TR Fehringer, BR LaFrentz, DR Call, and KD Cain. Vaccine efficiency in Coho salmon against *Flavobacterium psychrophilum*. Talk presented at the Center for Research on Invasive Species and Small Populations end of summer presentations. Moscow, Idaho, August 4, 2011.

Cain et al., 2011. Assessing probiotic use for the control of *Flavobacterium psychrophilum* in rainbow trout (*Oncorhyncus mykiss*). 1st Australasion Scientific conference on Aquatic Animal Health. (Invited talk), July 5-8

Burbank, D.R., LaPatra, S.E., Fornshell, G. and Cain, K.D., 2011. Assessing probiotic use for the control of *Flavobacterium psychrophilum* in rainbow trout (*Oncorhyncus mykiss*). Eastern Fish Health Workshop. (Invited talk) March.

Long, A, MP Polinski, DR Call, and KD Cain. Validation of Diagnostic Assays to Screen Broodstock for *Flavobacterium psychrophilum* Infection. Talk presented at the *Idaho Chapter of the American Fisheries Society Annual Meeting.* Boise, Idaho, March 2-4, 2011.

Long, A, J Bertolini, C Olson, DR Call, and KD Cain. 2011. Use of Diagnostic Assays to Evaluate Transmission of Bacterial Coldwater Disease. Presented at American Fisheries Society 141st Annual Meeting. Seattle, Washington.

Gliniewicz, K., Plant, K., LaPatra, S.E., Cain, K.D., Snekvik, K.R., LaFrentz, B.R., and Call, D.R. 2011. Comparative Proteomic Analysis of Virulent and Rifampicin Attenuated Strains of *Flavobacterium psychrophilum*. American Fisheries Society Annual meeting, Seattle, WA September.

Burbank, D.R, S.E. Lapatra, G. Fornshell, and K.D. Cain. 2010. Assessing Candidate Probiotic Use for the Possible Control of Flavobacterium psychrophilum in Rainbow Trout Oncorhynchus mykiss. Aquaculture America 2010, San Diego, CA, Book of Abstracts, p. 150.

Johnson, T.J., Parvez, N., Call, D.R., LaFrentz, B.R., Miura, T., and Cain, K.D. (2010) Confirmation of Safety and Efficacy for a Live Attenuated *Flavobacterium psychrophila* Vaccine. Sixth International Symposium of Aquatic Animal Health, September 5-9th, Tampa, FL

Long, A., Call, D.R., and Cain, K.D. (2010) Use of Diagnostic Assays to Screen Rainbow Trout (*Oncorhynchus mykiss*) Broodstock for *Flavobacterium psychrophilum.* Sixth International Symposium of Aquatic Animal Health, September 5-9th, Tampa, FL

Cain, K.D., Burbank, D.R., Cavender, W.P., Swan, C.M., Wilson, C. and LaPatra, S.E. (2010) Assessing candidate probiotic use for the possible control of *Flavobacterium psychrophilum* in rainbow trout. American Fisheries Society (Fish Health Section) 51st Annual Western Fish Disease Workshop, Corvallis, OR June 22-24

Plant, K.P., LaPatra, S.E., Call, D.R. and Cain, K.D. (2010) Is vaccination with *Flavobacterium psychrophilum* gliding motility protein N (GldN) effective? American Fisheries Society (Fish Health Section) 51st Annual Western Fish Disease Workshop, Corvallis, OR June 22-24

Cain, K.D., Burbank, D.R., Wilson, C. and LaPatra, S.E. (2010) Assessing candidate probiotic use for the possible control of *Flavobacterium psychrophilum* in rainbow trout. Idaho Aquaculture Association annual meeting, Twin Falls, ID June

Johnson, TJ, BR. LaFrentz, DR. Call, and KD Cain (2010). Characterization of an attenuated *Flavobacterium psychrophilum* vaccine. Idaho Chapter of the American Fisheries Society Annual Meeting, Pocatello, ID March 2-5

Gliniewicz, Snekvik, Cain, LaPatra and Call, "Assessing the immune-protective potential of FP1493 against coldwater disease in rainbow trout Washington State University Showcase, March 2010.

Lanier, Shah, Kumar, LaPatra, Gliniewicz, Snekvik, Cain, and Call, "Production of recombinant *in vivo* induced proteins of *Flavobacterium psychrophilum* for development of a coldwater disease vaccine in rainbow trout. Washington State University Showcase, March 2010.

Gliniewicz, Snekvik, Cain, LaPatra, and Call, "Assessing the immune-protective potential of FP1493 against coldwater disease in rainbow trout. American Society for Microbiology, San Diego, CA, 23-27 May 2010.

Gliniewicz, Cain, Snekvik, and Call. "The role of *rpoB* gene in rifampicin attenuation of *Flavobacterium psychrophilum.* 11th Annual College of Veterinary Medicine Research Symposium, October 27, 2010.

Cain, K.D. (2010) Conservation aquaculture as a critical tool to recover burbot populations in Idaho's Kootenai River. Idaho Chapter of the American Fisheries Society Annual Meeting, Pocatello, ID March 2-5

Cain, K.D. (2010) Conservation aquaculture as a critical tool for recovery of burbot populations in the Kootenai River. Kootenai Valley Resource Initiative annual Burbot subcommittee meeting. May 25th, Bonner's Ferry, ID.

Lloyd, S.J., LaPatra, S.E., Snekvik, K.R., Cain, K.D., and Call, D.R. (2010) Quantitative PCR demonstrates a positive correlation between a *Rickettsia*-like organism and severity of strawberry disease lesions in rainbow trout (*Oncorhynchus mykiss*). American Society of Microbiology annual meeting, Mach, San Diego, CA.

LaFrentz BR, Peterson MP, Jensen NR, Cain KD (2010) Conservation aquaculture: a tool for recovering declining fish populations. 2010 USDA-ARS Auburn Location Earth Day Celebration and Annual Environmental Management System Awareness Training, April 22, Auburn, AL, USA

Gliniewicz, KS, KD Cain, KR Snekvik, and DR Call. The role of *rpoB* in the attenuation of *Flavobacterium psychrophilum* after passage with rifampicin. Poster presented at the *10th Annual College of Veterinary Medicine Research Symposium*, Pullman, WA, October 14, 2009.

Cain, K.D. (2009) Coldwater disease research update. Idaho Aquaculture Association annual meeting, Twin Falls, ID June

Cain, K.D., Jensen, N., Ireland, S., Siple, J. and Neufeld, M. (2009) Development of aquaculture methods for burbot *lota lota*. Idaho Chapter of the American Fisheries Society Annual Meeting, Boise, ID March 4-6

Cain, K.D., LaFrentz, B.R., LaPatra, S.E. and Call, D.R. (2009) Development and characterization of rifampicin resistant *Flavobacterium psychrophilum* strains and their potential as live attenuated vaccine candidates. Aquaculture America, Seattle, WA Feb.15-18

Cain, K.D., Jensen, N., Ireland, S., Siple, J. and Neufeld, M. (2009) Development of intensive culture methods for burbot *lota lota*. Aquaculture America, Seattle, WA Feb.15-18

Barron JM, Jensen NJ, Jones RN, Ireland SC, Siple JT, Neufeld MD, Paragamian VL, Cain KD (2009). Development and Optimization of Culture Techniques for the North American Burbot (*Lota lota maculosa*) US Fish and Wildlife Service Pacific Region Hatchery Management Workshop, November 3-5, Richland, WA

Johnson, TJ., BR. LaFrentz, and KD Cain (2009). Development and optimization of a potential vaccine for *Flavobacterium psychrophilum*, the bacterial agent of cold water disease. Fish Health Section of the American Fisheries Society annual meeting, June 8-10th, Park City, Utah

Johnson, TJ, BR. LaFrentz, DR. Call, and KD Cain (2009). Characterization of an attenuated *Flavobacterium psychrophilum* vaccine. American Fisheries Society annual meeting, Aug 30th-Sept 3rd, Nashville, Tennessee

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Cain, K. D. (Presenter & Author), Western Regional Aquaculter Center Meeting, "Coldwater disease prevention and control through vaccine development and diagnostic improvements", Reno, NV. (October 5, 2006).

Cain, K. D. (Author Only), LaFrentz, B. (Presenter & Author), Lindstrom, N. (Author Only), LaPatra, S. (Author Only), Call, D. (Author Only), International Symposium on Aquatic Animal Health, "Analysis of *Flavobacterium psychrophilum* carbohydrate antigens and their potential role in protective immunity", San Francisco, CA. (September 4, 2006).

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Cain, K. D. (Presenter & Author), Call, D. (Presenter & Author), Aquaculture Initiative annual review, "CWD vaccine development", WSU/UI, Pullman, WA. (March 8, 2006).

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LaFrentz, B.R., LaPatra, S.E., Jones, G.R., Congleton, J.L., Sun, B. and Cain, K.D. 2002. Characterization of serum and mucosal antibody responses and relative percent survival in rainbow trout (*Oncorhynchus mykiss*) following immunization and challenge with *Flavobacterium psychrophilum*. 4th International Symposium on Aquatic Animal Health, New Orleans, Louisiana, September 1-5.

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Cain, K.D. 2002. Broodstock immunization: A potential strategy to reduce disease related mortality in ESA listed stocks. Salmon Recovery Symposium: Issues on Pacific Salmon

Recovery in the Northwest: Reproduction and Conservation, Moscow, Idaho, March 28-29 (invited presentation)

Cavender, W.P., Johnson, K.A., and Cain, K.D. 2002. Distribution of *Myxobolus cerebralis* during the migration period for juvenile anadromous salmonids in the Snake and Salmon rivers of Idaho. 8th Annual Whirling Disease Symposium, Denver, Colorado, February 13-15.

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Cain, K.D., Jones, D.R. and Raison, R.L., 2000. Antibody-antigen kinetics following immunization of rainbow trout (*Oncorhynchus mykiss*) with a T-cell dependent antigen. 8th Congress of the International Society of Developmental and Comparative Immunology, Cairns, Australia (invited presentation)

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Patents:

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Cain, K.D. An antibody for screening salmon and trout broodstock for the aquatic pathogen *Flavobacterium psychrophilum*, which causes bacterial coldwater disease and rainbow trout fry syndrome. Technology licensed to ImmunoPrecise Antibodies, Ltd. (2009)

Cain, K.D., Probiotic bacterial strain C6-6 (*Enterobacter sp.*) for use in fish disease control. Invention disclosure (OTT case number 09-002; filed: 2009)

Cain, K.D., LaFrentz, B.R., and LaPatra, S.E. Vaccines for diseases of fish. Non-provisional patent filed 6/2/08; patent application number 12/156,509

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Cain, K.D. and Cavender, W. QPCR diagnostic probe for detecting the whirling disease parasite in fish: Real-time quantitative polymerase chain reaction (QPCR) technique composed of a forward and reverse primer and a TazMan® Minor Groove Binding (MGB) probe specific for the genetic sequence that encodes the Heat shock protein 70 (Hsp 70) gene of *Myxobolus cerebralis*. Invention Disclosure, (Filed: October 2003).

Grants and Contracts Awarded:

Funded:

Small, Brian (PI), Cain, Ken (CO-PI), Hardy, Ron (Co-PI), Overturf, Ken (Co-PI) Developing critical knowledge of intestinal microbiota and mucosal immune system influence on early fish health using a unique trout model. USDA-NIFA **$149,949.00** (1/1/18 – 12/31/19)

Salinas, Irene (PI), Cain, Ken (Co-PI) Understanding the duration and mechanisms of long-lasting protection of nasal vaccines in rainbow trout. USDA-NIFA **$50,000 (UI)** (8/1/17-7/31/21)

Cain, Ken (PI), Myrick, Chris (CoPI), Fornshell, Gary (Co-PI). Developing "freshwater cod" or burbot (Lota lota) into a viable commercial aquaculture species in the United States. USDA-Western Regional Aquaculture Center (WRAC), **($444, 783**) (Oct. 2017-Oct. 2021)

Loch, T. (PI), Faisal, M. (PI), Cain, Kenneth (PI), and Call, D. (PI), Flavobacterial diversity and its effect on disease in aquaculture. $360,428 (**$79,526 UI)** (Jan. 2016-Jan 2019)

Cain, Kenneth (Principal), Thermal bottlenecks affecting reproductive success of burbot. Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, (**$106,194**) (Feb. 2017-Jan. 2018)

Cain, Kenneth (Principal), Coldwater vaccine optimization for licensing and commercialization. Private Animal Health Company. ($93,735 + 34,695+$36,600 + $187,298 = **$352,328**) (Jan. 2015 – March 2018)

Cain, Kenneth (Principal), "Kootenai River Burbot egg/embryo/larval Temperature dependent survival study. USFWS. (**$45,000+$55,000 + $55,000)** (July 2015 – June 2018)

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Cain, Kenneth (Principal)," Commercializing newly developed aquatic animal health products to benefit aquaculture through disease reduction" (Idaho Department of Commerce – Idaho Global Entrepreneurial Mission), State funding, (**$124,021**) (July 2013 – November 2014)

Cain, Kenneth (Principal), "Performance Analysis of Algae Meal as a Feed Ingredient in Salmonids", Research and Development Contract, Algal Scientific (Private Company) (**$13,753**) February 2013 – July 2013)

Cain, Kenneth (Principal), "Development of Burbot (Lota lota) conservation aquaculture and evaluation of disease susceptibility", Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, (**$170,889**) (January 2013 – January 2014)

Cain, Kenneth (Principal), Ashton, Neil (student), Measuring the effectiveness of coded wire tagging as a potential tool for mass marking juvenile burbot (*Lota lota*) for population recovery efforts in the Kootenai river of Idaho and British Columbia, Northwest Marine Technologies (Private Company), ($**15,000**) (September 2012-January 2013)

Cain, Kenneth (Principal), Finalizing Critical Needs for Commercialization and Licensing of a Coldwater Disease Vaccine, Research and Development Contract, Aquatic Life Sciences (Private Company), **($20,000**) (November 2012-February 2013)

Cain, Kenneth (Principal), "Development of Burbot (*Lota lota*) conservation aquaculture and evaluation of disease susceptibility", Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, **$172,295** (January 2012 – January 2013)

Cain, Kenneth (Principal), "Development of Burbot (*Lota lota*) conservation aquaculture and evaluation of disease susceptibility", Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, **$167,930** (January 2011 – January 2012)

Cain, Kenneth (Principal), "Development of Burbot (*Lota lota*) conservation aquaculture and evaluation of disease susceptibility", Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, **$161,741** (January 2010 – January 2011)

Cain, Kenneth D (Principal), "Commercializing autochthonous probiotics to control fish diseases in aquaculture", Idaho State Board of Education, Incubation fund grant, **$34,848** (April 2011 – July 2012)

Cain, Kenneth (Principal), "Pilot testing of potential phyto-therapeutics for inhibition of bacterial pathogens important to aquaculture", Research service agreement, Private company (Liveleaf Biosciences), **$5,489** (October 2010 – April 2011)

Gilman, Vladimir (Prinicpal) Cain, Kenneth (Co-Principal) Development of a High Sensitivity and Specificity Quantitative Aptamer Assay for Coldwater Disease Management Applications. Sponsored by Infoscitex Corporation as a USDA/SBIR phase I subcontract, Federal, $100,000 **($27,000 UI),** (July 2010 – Jan 2011)

Cain, Kenneth D (Principal), "Comparative genomics and proteomics of *Flavobacterium psychrophilum*: moving toward vaccine development", Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, $96,000 (**$43,000 UI**). (October 2010 - October 2011).

Cain, Kenneth D (Principal), "Comparative genomics and proteomics of *Flavobacterium psychrophilum*: moving toward vaccine development", Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, $100000 (**$50,000 UI**). (October 2009 - October 2012).

Cain, Kenneth D (Principal), "Development of autochthonous probiotics to control fish diseases in aquaculture", Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, **$30,000** (October 2009 - October 2012).

Hardy, McIver, Cain, Murdock, Powell, Rodnick. Transforming environmental and physiological assessments using fish erythrocyte gene expression to measure responses. *National Science Foundation.* **$600,000** (12/09-12/11).

Hardy, Ron (Principal); Cain, Kenneth (Co-Principal), "Converting Alaska fish byproducts into value added ingredients and products" Sponsored by USDA, ARS (University of Alaska), Federal, $**234,956** (September 2009 – September 2012)

Cain, Kenneth (Principal); Plant, Karen (Co-Principal), "Understanding innate defense mechanisms to enhance control strategies for infectious hematopoietic necrosis virus in rainbow trout." Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, **28,000** (October 2009 - October 2010)

Cain, Kenneth (Principal), "Development of Burbot (*Lota lota*) conservation aquaculture and evaluation of disease susceptibility", Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, **$154,151** (November 2008 – January 2010)

Cain, Kenneth D (Principal), "Comparative genomics and proteomics of *Flavobacterium psychrophilum*: moving toward vaccine development", Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, $100000 ($**40,000 UI**). (October 2008 - October 2009).

Cain, Kenneth D (Supporting), Douglas Call (Co-Principal - WSU), "Identifying the etiologic agent of Strawberry Disease in rainbow trout",Sponsored by WSU/UI Aquaculture Initiative, Federal, $**25,000 UI**. (October 2008- October 2009).

Cain, Kenneth D (Principal), Douglas Call (Co-Principal - WSU), Fornshell, Gary CG (Supporting), "Coldwater disease prevention and control through vaccine development and diagnostic improvements", Sponsored by Western Regional Aquaculture Center (USDA/CSREES), Federal, **$324,874: $158,230 to UI**. (October 2007 - October 2011).

Cain, Kenneth D (Principal), "Comparative genomics and proteomics of *Flavobacterium psychrophilum*: moving toward vaccine development", Sponsored by WSU/UI Aquaculture Intiative (USDA/CSREES), Federal, **$100,000: $50,000 to UI**. (October 2007 - October 2008).

Cain, Kenneth (Principal), "Development and Evaluation of Extensive Larval and Juvenile Rearing Techniques and Systems for Burbot (*Lota Lota maculosa*) to meet Conservation Aquaculture Needs", Sponsored by USFWS, Federal, **$66,000** (October 2007 – September 2011).

Cain, Kenneth (Principal), "Development of Burbot (*Lota lota*) conservation aquaculture and evaluation of disease susceptibility", Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, **$143,362** (November 2007 – November 2008)

Cain, Kenneth (Principal), Tim Alefantis (Co-Principal) "Bacterial Ghosts as a Vaccine for the Prevention of Cold Water Disease Affecting the Salmonid Aquaculture Industry", Sponsored by Vital Probes, Inc. as a USDA/SBIR phase I subcontract, Federal**, $75,000: $22,624** to UI, (July 2007 – Jan 2009)

St. Hilaire, Sophie (Principal – ISU), Cain, Kenneth (Co-investigator with many others), "The development of an oral delivery system for DNA vaccines in aquatic species", Idaho State Board of Education (SBOE) One-time grant, **$550,000: $24,150** to UI. (January 2008 – January 2010)

Strom, Mark (Principal-NOAA), Cain, Kenneth (Co-Principal), "Genomic and proteomic expression profiling of *Renibacterium salmoninarum* during the infection of Chinook salmon", NOAA Fisheries, Federal**, $90,088** (September 2007 – September 2009)

Cain, Kenneth D (Supporting), "Identifying the etiologic agent of Strawberry Disease in rainbow trout", Sponsored by WSU/UI Aquaculture Initiative, Federal, $35000. (October 2007 - October 2009).

Cain, Kenneth D (Principal), "Development of Burbot (Lota lota) conservation aquaculture and evaluation of disease susceptibility", Sponsored by Kootenai Tribe of Idaho (BPA), Federal, $126963. (December 2006 - December 2008).

Cain, Kenneth D (Principal), "Comparative genomics and proteomics of *Flavobacterium psychrophilum*: moving toward vaccine development", Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, $100000. (October 2006 - October 2007).

Cain, Kenneth D (Principal), "Development of autochthonous probiotics to control fish diseases in aquaculture", Sponsored by WSU/UI Aquaculture Initiative (USDA/CSREES), Federal, $34987. (October 2006 - October 2009).

Cain, Kenneth D (Supporting), "Identifying the etiologic agent of Strawberry Disease in rainbow trout", Sponsored by WSI/UI Aquaculture Initiative, Federal, $35000. (October 2006 - October 2007).

Cain, Kenneth D (Co-Principal), "Control of BKD by Inactivation of the *Renibacterium salmoninarum* Sortase as an Alternative to Antibiotics", Sponsored by NOAA/NMFS, Federal, $79720. (September 2006 - September 2007).

Cain, Kenneth D (Principal), "ELISA detection of antibody response in fish", IDFG, $700. (September 2006 - November 2006).

Cain, Kenneth D (Co-Principal), "Genomic and proteomic expression profiling of Renibacterium salmoninarum during the infection of Chinook salmon", Sponsored by NOAA/NMFS, Federal, $24600. (May 2006 - September 2006).

PI: Dr. Ken Cain, Co-PI: Dr. Keith Johnson (IDFG), Distribution of *Mxyobolus cerebralis* during the Migration Period for Juvenile Anadromous Salmonids in the Snake and Salmon Rivers of Idaho, Whirling Disease Foundation, 9/00-12/01, $29,954.

PI: Dr. Scott LaPatra Co-PI: Dr. Ken Cain, Immunological Responses of Rainbow Trout to Coldwater Disease, USDA/SBIR phase I proposal with Clear Springs Foods, 5/01-11/01, $75,000 (subcontract: $22,212).

PI: Dr. Charles Hatch, Co-investigators: Brannon, Hardy, Powell, Cain, Overturf. Innovative Seafood Production: Customizing Feeds/Fish in Sustainable Aquaculture, NSF, 1/01-12/04, $564,709.

Support (to date) under this funding:

PI: Dr. Ken Cain, Immune response to *Flavobacterium columnare* in tilapia *(Oreochromis niloticus):* implications for an ornamental fish vaccine, approx.: $100,000.

PI: Dr. Ken Cain, Effects of Density on Manifestation of WSIV in White Sturgeon, Kootenai Tribe of Idaho, 4/01-12/01, $10,000.

PI: Dr. Ken Cain, Co-PI: Dr. Keith Johnson (IDFG), Distribution of *Mxyobolus cerebralis* during the Migration Period for Juvenile Anadromous Salmonids in the Snake and Salmon Rivers of Idaho, continued funding through LSRCP and Idaho Power, 1/01-12/01, $16,092.

PI: Dr. Ken Cain, Beneficial Use Reconnaissance Program (BURP), Idaho DEQ, 8/01- 11/01, $164,080.

Co-PI: Dr. Ken Cain, USDA/CSREES: Aquaculture Idaho and Washington: Congressional initiative in support of aquaculture research at UI and WSU: FY02 $600,000: FY03 $750,000: FY04 $650,000. Funding supports small individual and larger WSU/UI collaborative projects.

Support (to date) under this funding:

PI: Dr. Ken Cain, Mucosal Immunity in Fish: Triggering the First Line of Defense, 9/02- 9/05, FY02 $30,000: FY03 $35,000: FY04 $35,000.

PI: Dr. Ken Cain, Co-PI: Dr. Doug Call, Collaborators: Scott LaPatra, Gary Thorgaard, Ken Overturf. Comparative genomics and proteomics of *Flavobacterium psychrophilum* and regulation of host genes during a protective immune response, 9/02-9/04, FY02 $100,000{$50,000 (UI)}: FY03 $100,000 {$50,000 (UI)}: FY04 $100,000 {$50,000 (UI)}.

PI: Dr. Ken Cain, Separation and comparison of proteins from virulent and nonvirulent strains of the fish pathogen *Flavobacterium psychrophilum,* using a 2-D electrophoretic approach, Bio-Rad company, 3/01, $500.

PI: Dr. Ken Cain, (Service contract), Histology and data analysis, Clear Springs Foods, Inc., 9/00-1/01, $7,000.

PI: Dr. Ken Cain, (Service contract), Data analysis for Tilapia diet study, Hartz Mountain Corporation, 1/01-5/01, $4,500.

PI: Dr. Ken Cain, (Service contract), Analysis of fish T-cell antibodies, Immuno-Precise Antibodies Ltd., 1/02-10/02, $3,800.

PI's: Dr. Ken Cain, Dr. Douglas R. Call, Dr. Rollin Hotchkiss, Dr. Frank J. Loge, Development of a Comprehensive Monitoring Protocol to Characterize the Concentration and Associated Health Risks of Salmonid Pathogens Suspended in Water, Washington Water Resources, December 2001, $19,997.

PI's: Cain, Cloud, Nagler, Thorgaard, Ingermann, Byrne, McElwain, Passavant, Phillips, WSU/UI Center for Reproductive Biology, WSU and UI Salmon Restoration Program – "Broodstock Vaccination Strategies for Enhanced Reproductive Efficiency Through Disease Resistance" and 8 other projects, USFWS ($500,000 FY02; $375,000 FY03)

Support (to date) under this funding:

PI: Dr. Ken Cain, Reduction of disease-related impacts on important salmonid stocks through broodstock immunization against key pathogens, 7/02-10/05, $101,947.

PI: Dr. Ken Cain, Identifying and evaluating immunogenic components of the fish pathogen *Flavobacterium psychrophilum.* UI seed grant program, 7/02-10/03, $10,000.

PI: Dr. Ken Cain, A Quantitative PCR (QPCR) Approach to Rapidly Distinguish Between *Myxobolus* Species and Assess Infection Severity in Fish. Whirling Disease Foundation, 7/02-12/03, $35,167.

PI: Dr. Scott LaPatra Co-PI: Dr. Ken Cain, Immunity to *Flavobacterium psychrophilum* antigens and development of a coldwater disease (CWD) vaccine. USDA/SBIR 9/03-9/05, $299,907 (Subcontract $148,000 to UI).

PI: Dr. Ken Cain, Feasibility assessment and development of Burbot *(Lota lota)* conservation aquaculture. Kootenai Tribe of Idaho, 9/03-9/04, $46,545.

PI: Dr. Ken Cain, Primitive mechanisms of immunity in white sturgeon *(Acipenser transmontanus)* to the viral pathogen, white sturgeon iridovirs (WSIV). UI seed grant program, 7/03-7/04, $9,909.

PI: Dr. Ken Cain, Gary Fornshell, Bacterial disease workshop, UI/WSU Aquaculture Initiative Extension Products, Support for hosting annual disease workshop in Hagerman, Idaho, 04-05, $4,142.

PI: Dr. Fran Wagner, Dr. Ken Cain, Dr. George Newcombe, Dr. Armando MacDonnell, Under the microscope. USDA Equipment grant for teaching microscope, 03 $25,000.

PI: Dr. Ken Cain and John Drennan, Direct DNA amplification of the *ribonucleotide reductase* gene from white sturgeon *iridovirus.* Laboratory for Ecological and Conservation genetics – DeVlieg Small Grants Project, $683.

PIs: Dr. Lisette Waits, Dr. Steve Brunsfeld, Dr. Cort Anderson Co-PIs: Cain and others. Research Center Grant submitted to establish the Center for Research on Invasive Species and Small Populations Cain, Ken (PI), Sato, Esteban (Co-PI), Fornshell, Gary (Co-PI). Emerging and Re-emerging Flavobacterial Pathogens of Salmonids. USDA-Western Regional Aquaculture Center (WRAC), ($328,775)

Langdon, Chris (PI), Hawkward, Matt (Co-PI), Cain, Ken (Co-PI), Sudheesh, Ponnerassery (Co-PI). Development of more effective delivery methods for vaccines for prevention of disease in finfish culture. USDA-Western Regional Aquaculture Center (WRAC), ($471,335)

Cain, Ken (PI), Linley, Tim (Co-PI). Lake Roosevelt Burbot Maturation Study. Colville Tribe, ($341,177) (CRISSP). State Board of Education (SBOE), 04-07 $1,000,000.

PI: Dr. Ken Cain, Burbot *(Lota lota)* Development of Conservation Aquaculture Techniques for Burbot *(Lota lota).* Kootenai Tribe of Idaho, 9/04-9/06, $97,357: funding tentatively agreed on (start date 9/04)

PI: Dr. Ken Cain, Improved Methods to Limit Vertical Transmission of WSIV in Progeny of White Sturgeon, Kootenai Tribe of Idaho, 3/02-12/05, $126,373: ($53,209 – yr 1, $35,068 – yr 2, $38,096 – yr 3)

Submitted:

2017:

Small, Brian (PI), Cain, Ken (CO-PI), Hardy, Ron (Co-PI), Overturf, Ken (Co-PI) Developing critical knowledge of intestinal microbiota and mucosal immune system influence on early fish health using a unique trout model. USDA-NIFA **$149,949.00** (1/1/18 – 12/31/19)

Salinas, Irene (PI), Cain, Ken (Co-PI) Understanding the duration and mechanisms of long-lasting protection of nasal vaccines in rainbow trout. USDA-NIFA **$50,000 (UI)** (8/1/17-7/31/21)

Cain, Kenneth (Principal), Coldwater vaccine optimization for licensing and commercialization. Private Animal Health Company. **$187,298** (Feb. 2017 – March 2018)

2016:

Small, Brian (PI), Cain, Ken (CO-PI), Hardy, Ron (Co-PI), Overturf, Ken (Co-PI). Using a Model Trout Strain to Explore the Roles of Genotype and/or Gut Microbiota in Non-Specific Disease Resistance for Farmed Fish. USDA-NIFA, **($499,958**)

Call, Doug (PI), Cain, Ken (Co-PI). Determining the mechanism by which entericidin B, from the probiotic Enterobacter C6-6, protects trout from coldwater disease. USDA-NIFA, Animal Health and Production, (**$500,000**)

Cain, Ken (PI), Myrick, Chris (CoPI), Fornshell, Gary (Co-PI). Developing "freshwater cod" or burbot (Lota lota) into a viable commercial aquaculture species in the United States. USDA-Western Regional Aquaculture Center (WRAC), (**$444, 783**)

Cain, Ken (PI), Sato, Esteban (Co-PI), Fornshell, Gary (Co-PI). Emerging and Re-emerging Flavobacterial Pathogens of Salmonids. USDA-Western Regional Aquaculture Center (WRAC), (**$328,775**)

Langdon, Chris (PI), Hawkward, Matt (Co-PI), Cain, Ken (Co-PI), Sudheesh, Ponnerassery (Co-PI). Development of more effective delivery methods for vaccines for prevention of disease in finfish culture. USDA-Western Regional Aquaculture Center (WRAC), (**$471,335**)

Cain, Ken (PI), Linley, Tim (Co-PI). Lake Roosevelt Burbot Maturation Study. Colville Tribe, (**$341,177**)

Cain, Kenneth (Principal), "Identification of critical thermal bottlenecks affecting embryo and early life-stage development for Burbot Lota lota: Implications for Kootenai River hydro-management" (Idaho Department of Fish and Game. (**$104,371 – yr 2 portion**)

Cain, Kenneth (Principal), "Kootenai River Burbot egg/embryo/larval Temperature dependent survival study. USFWS. FONs project: (**$45,000 year 2 portion**)

Cain, Kenneth (Principal), Thermal bottlenecks affecting reproductive success of burbot. Sponsored by the Kootenai Tribe of Idaho (BPA), Federal, (**$106,194**)

Cain, Kenneth (Principal), Coldwater vaccine optimization for licensing and commercialization. Private Animal Health Company. (**$34,695**)

Unfunded:

Small, Brian (PI), Cain, Ken (CO-PI), Hardy, Ron (Co-PI), Overturf, Ken (Co-PI). Using a Model Trout Strain to Explore the Roles of Genotype and/or Gut Microbiota in Non-Specific Disease Resistance for Farmed Fish. USDA-NIFA, ($499,958)

Call, Doug (PI), Cain, Ken (Co-PI). Determining the mechanism by which entericidin B, from the probiotic Enterobacter C6-6, protects trout from coldwater disease. USDA-NIFA, Animal Health and Production, ($500,000)

Cain, Ken (PI), Sato, Esteban (Co-PI), Fornshell, Gary (Co-PI). Emerging and Re-emerging Flavobacterial Pathogens of Salmonids. USDA-Western Regional Aquaculture Center (WRAC), ($328,775)

Langdon, Chris (PI), Hawkward, Matt (Co-PI), Cain, Ken (Co-PI), Sudheesh, Ponnerassery (Co-PI). Development of more effective delivery methods for vaccines for prevention of disease in finfish culture. USDA-Western Regional Aquaculture Center (WRAC), ($471,335)

Cain, Ken (PI), Linley, Tim (Co-PI). Lake Roosevelt Burbot Maturation Study. Colville Tribe, ($341,177)

Loch, Tom (Co-PI), Faisal, Mohammed (Co-PI), Cain, Ken (Co-PI), Evolution and emergence of fish-pathogenic flavobacteria as a consequence of Chinook salmon introductions into the Great Lakes. NSF - **$441,361**

Hardy, Ron (Principal), Rodnick, Ken (Co-principal - ISU), Schreck, Carl (Co-principal OSU), Cain, Ken (Co-principal) Genomic identity of thermal adaptation: evolutionary and ecological trade-offs. NSF – preproposal

Cain, Kenneth (Principal), Call, Doug (Co-principal - WSU), 2014. US-UK Collaborative: Novel strategies to control coldwater disease and rainbow trout fry syndrome (CWD/RTFS) in rainbow trout and Atlantic salmon aquaculture. USDA AFRI program (**$499,980**)

Loch, Tom (Principal – MSU); Cain, Kenneth (Co-Principal). 2014. Flavobacterial diversity and its effect on disease in aquaculture. USDA AFRI program (**$109,414 – UI portion**)

Cain, Kenneth (Principal) 2014. Develop practical strategies for controlling coldwater disease in salmonids at all life stages. NIFA (USDA Special Grants Program) (**$300,000**)

Hardy, Ron (Principal); Cain, Kenneth (Co-principal) 2014. Exploring the genetic mechanisms and the gut microbiota of a selected trout strains resistant to diseases as a model to develop preventive tools for disease resistance in farmed fish. USDA AFRI program (**$500,000**)

Cain, Kenneth (Principal) 2014. Developing "freshwater cod" or burbot (Lota lota) into a viable commercial aquaculture species in the United States. Western Regional Aquaculture Center (USDA) (**$460,235**)

Cain, Kenneth (Principal) 2014. Defining the relationship between stress, immune function and disease resistance in rainbow trout fed immunostimulants and functional feed additives. Western Regional Aquaculture Center (USDA) (**$480,000**)

Loch, Tom (Principal); Cain, Kenneth (Co-Principal). 2013. Evolution and emergence of fish-pathogenic flavobacteria as a consequence of Chinook salmon introductions into the Great Lakes. NSF **($500,000)**

Cain, Kenneth (Principal), Call, Doug (Co-principal - WSU), LaFrentz, Ben (Co-principal - USDA), 2013. Controlling warmwater and coldwater aquaculture diseases using probiotics with pathogen specific antimicrobial properties. USDA AFRI program (**$499,988**)

Cain, Kenneth (Principal) 2012. Algae-Derived Feed Supplements Containing Beta-1,3-Glucan for Reduced Disease Impact and Improved Aquaculture Productivity. Subcontract – USDA/SBIR phase I proposal submission with the company Algal Scientific ($150,000 - **28,955** to UI)

Cain, Kenneth (Principal), 2012. Development of Techniques to Culture Pacific Lamprey in the Snake River Basin. USFWS, ($89,630)

Cain, Kenneth (Principal), 2012. Finalizing Critical Needs for Commercialization and Licensing of a ColdwaterDisease Vaccine, Research and Development Contract, Aquatic Life Sciences (Private Company), ($127,764) – partially funded

Cain, Kenneth (Principal) Development of a High Sensitivity and Specificity Quantitative Aptamer Assay for Coldwater Disease Management Applications. Subcontract – USDA/SBIR phase II proposal submission with the company InfoScitech ($400,000 – **$177,000** to UI)

Cain, Kenneth (Principal), Understanding *Nucleospora salmonis* infections in wild and hatchery fish to develop strategies to limit transmission and spread, Lower Snake River Compensation Program/USFWS, ($70,404)

1. Cain, Kenneth (Principal), Call, Douglas (Co-Principal – WSU), "Characterization and delivery of Flavobacterium psychrophilum 259.93B.17, an attenuated vaccine candidate for coldwater disease" USDA/CSREES AFRI program, Federal, **$374,998** (Submitted – 3/31/09)

Cain, Kenneth (Principal), Call, Douglas (Co-Principal – WSU), "Development of vaccines for *Flavobacterium psychrophilum* through enhanced expression of recombinant protein antigens and improved delivery of an attenuated vaccine strain", Sponsored by USDA/CSREES NRI program, Federal, **$372,002** (October 2008 – October 2011)

Walsh (Principal), Cain and 5 others (Co-PIs), "Characterization of a novel fungus infecting burbot in the pacific northwest", Sponsored by Smithsonian Institution, Federal, $43,500 (March 2008 – March 2009)

Cain, Kenneth D (Supporting), "Identification and characterization of immunodominant antigens in the

catfish pathogen *Flavobacterium columnare*", Sponsored by USDA/NRI, Federal, $60000. (October 2007 - October 2010).

PI: Dr. Joe Cloud Co-PIs: Cain and others. IGERT for the Impacts of Global Change on Conservation Biology: A Union of Biology and Geography, National Science Foundation (NSF), 2,000,000.

PIs: Dr. Gary Thorgaard, Dr. Chris Bayne, Dr. Ken Cain. "Dissecting a Natural Killer Cell Complex in Trout" National Institute for Health (NIH), 1,702,174.

PI: Dr. Ken Cain, Adaptation of Larval Burbot *(Lota lota)* to Commercially Available diets. UI seed grant program, February 2004, $10,000.

PI: Dr. Ken Cain, Dr. Gary Thorgaard, Dr. Chris Bayne, Dissecting a candidate natural killer complex in trout National Institute of Health (NIH), 7/04-7/08, $1,702,174.

PI: Dr. Cort Anderson, Co-PI: Dr. Ken Cain, Isolation and sequencing of the myxozoan mitochondrial genome, and validation of PCR-based diagnostic tools McIntire-Stennis, 2003, $67,200.

PI: Dr. Ken Cain; Co-PI: Dr. Doug Call, Identification and characterization of vaccine target antigens for the fish pathogen *Flavobacterium psychrophilum.* USDA/NRI Animal Health and Well-Being program, New Investigator/Standard Strengthening, January 2002, $247,640.

PI: Dr. Ken Cain, A quantitative PCR (QPCR) approach to rapidly diagnose *Myxobolus cerebralis* and assess infection severity in fish, Whirling Disease Foundation, February 2001, $43,136.

PI: Dr. Ken Cain, Aquaculture Vaccine Development: Eliciting Immunity to *Flavobacterium psychrophilum*, UI seed grant program, February 2001, $10,000.

PI: Dr. Ken Cain, Mucosal Immunity in Fish: Triggering the First Line of Defense, USDA/NRIP Animal Health and Well-Being program, New Investigator/Standard Strengthening, January 2001, $362,166.

PI: Dr. Ken Cain, Virulence-Associated proteins of *Flavobacterium psychrophilum*, USDA/NRI seed grant program, October 2000, $75,000.

PI: Dr. Sandra Ristow, Co-PI's: Dr. Ken Cain and 7 others, Developmental and Comparative Immunobiology of Finfish, Western Regional Aquaculture Consortium (WRAC), May 2000, $400,000.

PI: Dr. Ken Cain, Immunological Characterization of White Sturgeon, UI seed grant program, February 2000, $10,000.

PI: Dr. Ken Cain, Identification of Unique Cell Surface Markers on Fish Lymphocytes, Washington Sea Grant Program, January 2000, $160,000.

Honors and Awards:

Nominated (by Research Office) as Fellow for National Academy of Inventors
Mid-Career Presidential Award 2013-2014
Innovation Award for licensed technology, 2012
Innovation Award for Issued Patent "Vaccines for Diseases of Fish", 2010
Innovation Award for Technology Licensed (Cain/ImmunoPrecise Antibodies, Ltd), 2009
Best Professional Poster presentation (Idaho Chapter AFS meeting), 2009
UI Alumni Award for Excellence, 2008
Certificate of Appreciation, UI Tech Transfer, Invention disclosure, coldwater disease vaccine
Certificate of Appreciation, UI Tech Transfer, Invention disclosure, C6-6 probiotic candidate
Outstanding Alumni Award (Alumni Hall of Fame), Swartz Creek High School, 2008
Certificate of Appreciation: As faculty mentor for UI McNair Scholarship program, 2008

Certificate of Appreciation: for Burbot conservation efforts, Kootenai Valley Resource Initiative, 2005
UI Award for Excellence in Teaching (Nominated, 2005)
UI alumni award for excellence in mentoring, 2001
Outstanding graduate student award, (Department of Animal Sciences), 1997
Best paper award nomination, (Progressive Fish Culturist), 1995
Snieszko Student Travel Award, AFS (fish health section), 1995

SERVICE:

2011-2013, Co-editor, Special Issue (New and Emerging Diseases in Aquaculture), JARD
2010-2013, Executive Editor, *The Journal of Aquaculture Research and Development (JARD)*
2007-present, Co-Director (Aquaculture Core Laboratories), WSU/UI Center for Reproductive Biology
2005-present, Editorial Board, *Aquaculture Research*
2005-present, Editor, Aquaculture Research Institute Newsletter

Major Committee Assignments:

Board of Director, US Aquaculture Society, (Nominated 2017)
CNR Promotion and Tenure Committee, 2017-present
CNR Awards Committee, 2017-present
CNR Wet lab steering committee (Chair), 2017-present
3rd year review committee, Chris Caudill, 2015.
ARI new building design and planning committee, 2014-present
Student Programs Committee (FWS), 2015-present
Search Committee, Fish Physiologist (ARI/FWS), 2014-2015
CNR committee on committees, 2015-present
UI Dismissal Hearing Committee, 2015-present
UI Scientific Misconduct Committee, 2013-present; Chair, 2015-2016
Promotion and Tenure committee, AVS, 2014
Search Committee, Department Head (FWS), 2013-2014
Search Committee, College of Business, 2012
CNR curriculum committee, served for Dr. Rachlow while she was on sabbatical, Fall 2012
Chair, Promotion and Tenure committee, Department of Fish and Wildlife Sciences (Quist), 2012
Promotion and Tenure committee, Department of Animal and Veterinary Sciences, 2011
UI Intellectual Properties Committee, 2010-2013
Chair, 2009-2010, Dismissal Hearings Committee, University of Idaho, 2007- 2010
Ted Bjorn Scholarship Committee, 2009-present
Idaho Fish Health Policy Committee, 2007-present
National Science Foundation, Marine Biotechnology and other SBIR Review Panels, 2004-present
USDA Aquaculture SBIR review panel, 2006-present
Western Regional Aquaculture Center (WRAC), Technical advisory board – Research subcommittee, 2004-present
Chair, Rankings committee, USGS, Fish Physiologist Co-op position, 2009
Promotion and Tenure committee, Department of Animal and Veterinary Sciences, 2007
Chair, Search Committee, Riparian Ecologist, Department of Fish and Wildlife, 2007-2008
Chair, 2005 – 2007 Animal Care and Use Committee, University of Idaho, served since 2001
Search Committee, Department of Fish and Wildlife, Limnologist, 2006-2007
Search Committee, College of Natural Resources, Developmental Director, 2007
Chair, Fisheries Curriculum Review Committee, 2005
Chair, 3rd year review committee, Department of Fish and Wildlife, 2007
Burbot Recovery Team, Aquaculture Subcommittee, 2004-present
Burbot Aquaculture Facility Design Team, 2007-present
Organizing committee, 46th Western Fish Disease Workshop, AFS/Fish Health Section, June 27-29, Boise, ID. 2005.
Bacteriology Subcommittee, AFS/FHS Technical standards committee, 2003-2005
EXCOM Secretary/Treasurer, Fish Health Section of AFS, 2002-2005

CNR Scientific Equipment Committee, 2004-present
White Sturgeon Recovery Team, 2002-present
Chair, Graduate student/postdoc selection committee, Center for Research on Invasive Species and Small Populations (CRISSP), 2004
Search Committee, Department of Fish and Wildlife Resources, Fish Ecologist, 2004
DeVleig Scholarship Committee, 2002
Idaho Fish Health Protection Committee, 2001-present
Promotion and Tenure committee, Biology department, October 2001
Program review committee, Department of Fish and Wildlife Resources, 2000-01
Search Committee, Department of Fish and Wildlife Resources, Riparian Ecology, 2000-01
3rd and 5th year Review Committee, Department of Fish and Wildlife Resources, 2000
Aquaculture Wet Lab Steering Committee, Department of Fish and Wildlife Resources, 2000-present
Graduate Selection Committee, Department of Animal Science, Washington State University, 1995-96

Professional and Scholarly Organizations:

European Association of Fish Pathologists
American Fisheries Society (Fish Health Section)
International Society of Developmental and Comparative Immunology (former member)
International Society of Aquatic Animal Epidemiology
World Aquaculture Society
US Aquaculture Society
Idaho Aquaculture Association
WSU/UI Center for Reproductive Biology
Member of Center for Fish Disease Research (Oregon State University)
Center for Research on Invasive Species and Small Populations (CRISSP)

Manuscripts reviewed for following journals: (only partial list)

Journal of Aquaculture Research and Development (former Editor)
Fisheries
Vaccine
Microbiology
Journal of Aquatic Animal Health
North American Journal of Fish Management
Transactions of the American Fisheries Society
Aquaculture Research (Editorial board member)
Archives in Virology
Journal of Veterinary Medicine
Diseases of Aquatic Organisms
Fish and Shellfish Immunology
Journal of Fish Diseases
Journal of the World Aquaculture Society
Journal of Fish Biology

Grant proposals reviewed for the following funding agencies: (only partial list)

Kuwait Foundation for the Advancement of Sciences (KFAS)
Norwegian Research Council
American Academy for the Advancement of Sciences
Polish Foundation for Sciences
Technology grant program (Greece)
Mississippi State University (Center for Veterinary Medicine)
Minnesota Sea Grant
Maryland Sea Grant
National Research Council (Canada)

Canadian Foundation for Innovation (CFI)
National Science Foundation (SBIR)
USDA (SBIR)
Western Regional Aquaculture Center
Great Lakes Trust Foundation

Outreach Service:

Press release, Aquaculture North America, 2016
SBOE Legislative lunch, 2013
Moscow/Pullman daily news, 2012
Spokesman review, 2012
Columbia Basin Bulletin, 2012
Argonat interview, 2012
NPR interview, 2012
TV highlights, channel 7 Boise, 2012
Article for *Capital Press*, 2011
Article for *Trout Talk*, 2011
Coldwater Fish Culture Workshop, 2011
Fish Immunology Workshop, 2011
Invited presentation (5) related to Sabbatical in Australia, 2011
Editor for Aquaculture Research Institute bi-annual newsletter, 2005-present
Article for *Hatchery International Magazine*, 2009
Articles for *Waterlines* (published by the Western Regional Aquaculture Center), 2009
Biosecurity Workshop (instructor), presented to trout industry
Salmon Disease Workshop, Corvalis, OR, July, 2009 (Participating instructor): Intensive 2 wk disease course for fish health professionals
Presented research overview at Idaho Aquaculture Association annual meeting, 2008
Spokesman Review, Article on Coldwater Disease Vaccine development, October, 2006
Idaho Science and Technology newsletter, October, 2006
Columbia Basin Bulletin, October, 2006
Spokesman Review, Article on Burbot Aquaculture, December, 2006
CNR magazine, research highlights, 2006
CNR alumni news, research highlights, 2005, 2006, 2007
UI Research Webpage (Today at UI), Press release describing Burbot aquaculture project, 2004
Twin Falls Times (Ag weekly), Article on research presentation given by Ben LaFrentz at IAA meeting, 2004
Coldwater Disease workshop presented to Aquaculture Industry, CSI Hatchery, Twin Falls, Idaho, 2004
Fish Immunology Workshop, AFS/Fish Health Section, Continuing education, 2000
Twin Falls Times (Ag Weekly), Highlighted Fish Health Class tour of Aquaculture Industry
Trout Disease Workshop, Idaho trout industry, provide shortcourse for industry employees
Totally Wild Television program, Sydney, Australia, segment on Fish Vaccination
Twin Falls Times (Ag Weekly), article highlighting invited seminar for Idaho Aquaculture Association

Community Service:

Annual contribution (fishing trip), Palouse Unit, American Fisheries Society
Taught beginning whitewater kayaking course, University of Idaho Outdoor Program, August 2000

PROFESSIONAL DEVELOPMENT:

Teaching:

Participant in McNair Scholar Program, 2004, 2007-2008
Writing across curriculum (WAC) workshop, January 2000

Scholarship:

Sabbatical – Jan. 2011-June 2011. University of Tasmania, Australia
Sabbatical application, (accepted 2008) Building international collaborations in aquaculture and fish health through research, teaching, and outreach. (Spring semester 2011)
Continuing education, AFS/FHS (80+credit hrs – Fish Virology, Histology, Hematology, Immunology, and Neoplasia in Fishes New Molecular Diagnostic Techniques, Early Fish Development, Fish Nutrition, Toxicology, Application of bacterial genomics to fish diagnostics, etc.)
Grant writing workshop, April 2000

Administration/Management:

Associate Director, Aquaculture Research Institute, July 2002-present

APPENDIX B: INDIVIDUAL REVIEWER COMMENTS

REVIEWER 1

Peer Review of:
Bureau of Reclamation Measures to Reduce *Ceratanova shasta* Infection of Klamath River Salmonids: A Guidance Document
An External Scientific Peer Review
July 13, 2018

Scientific Review of Documents to Address Fish Disease Concerns in the Klamath River

June 18, 2018
Revised July 13, 2018

Project Name: Klamath River Fish Disease 380
Atkins Project #: 100060380

Prepared by:
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Summary:

The Guidance Document provided for this review outlines measures aimed at reducing the impact of the myxozoan parasite, *Ceratonova shasta*, in the Klamath River. My review centers on my expertise in fish health, genetics, and parasitology (particularly myxozoan parasites); however, other areas (flow and sediment mobilization) are well described in the document and I have provided comments as the data, and my understanding of them, allow. The recommended management measures are well founded in a fundamental principle of parasite control, which is to know the target parasite's life cycle, and attack it at its weakest points. Because *C. shasta* is not directly transmitted from fish to fish, but requires a polychaete alternate host, this allows managers to target the parasite in at least four places: the vertebrate host, the myxospores released from the vertebrate host, the invertebrate host, and the actinospores released from the invertebrate host. Another possible approach to control would be to focus on reservoir hosts, but although *C. shasta* infects multiple species, there are largely host specific lineages of this parasite which suggests that if they occur, reservoirs play a minor role in this system. The management guidance (MG) measures focus primarily on reducing exposure of the fish host to the actinospore stages, either through directly flushing these spores from the system or by reducing polychaete habitat so that there are fewer infected worms, and therefore fewer actinospores released into the system. Four measures propose modifying flows to achieve this end. Another measure also uses modified river flows, but to mobilize salmon carcasses and flush out myxospores from the system in the fall. Thus reducing the risk of exposure for polychaetes. The sixth measure aims at reducing exposure of juvenile hatchery fish to the actinospore stage, but timing releases for when the parasite is at acceptably low levels in the river water. The 4 eliminated measures were removed justifiably because they were either impractical, lacked support from empirical data, or would be unnecessary with pending dam removal.

All proposed MG measures were reasonable and based on scientific data with some more likely to have an impact on the transmission of the parasite than others. I have focused on the control of the parasite, but acknowledge that there may be practical limitations and conflicting interests of other stakeholders in some cases. For example, the geomorphic flows proposed in MG3 are very likely to flush spores from the system and disrupt polychaete habitat, so I rank it high for controlling the parasite. However, such large flows may be impractical on an annual basis and are not likely representative of natural annual flows. More moderate flows may accomplish the same goals and satisfy multiple interests. It is worthwhile noting that water temperature is important because fish are less likely to become infected or succumb to infection at cooler water temperatures. Temperature could be an important variable in a trigger-based measure like MG4.

Not included in the Guidance Document are responses to flow data from 2017 and 2018, but a draft 2017 report and preliminary data from 2018 were provided as supplements for the purposes of review. The 2017 data strongly support the idea that increasing flow serves to reduce parasite burden in the system. As any measures are implemented and dam removal is considered, the continued monitoring efforts will be critical to evaluate responses and natural changes of *C. shasta* in the Klamath River system.

What follows is a response to each question provided by Atkins North America Inc. (in italics). The topics of some questions overlap, but I have tried to answer each completely.

Management measures within the Guidance Document intended to reduce the prevalence of C. shasta infection in coho and Chinook salmon will be the focus of the review. When answering each question below, the effectiveness of the management measures for coho and Chinook salmon need to be addressed separately. Additionally, for questions 1-4, please address both the six management measures, and the four control measures considered, but eliminated. The review will address the following questions:

Question 1: Effectiveness of Measures

2. *Of the management measures contained within the Guidance Document, which measures can be expected to have the greatest influence on reducing the prevalence and severity of C. shasta infections within Klamath River salmonids?*
    a. *Conversely, which management measures can be expected to have the least influence on reducing the prevalence and severity of C. shasta infections within Klamath River salmonids?*

All of the Management Guidance (MG) measures are reasonable and a clear argument is made for their inclusion. Based on the data available, I have ranked the flows that would disrupt polychaete habitat and flush actinospores (MG1, 2, 3, 4) as most likely to have an impact on *C. shasta* infections. The rationale being that these can be associated to past flows and the resulting impacts of *C. shasta* in previous years. The other measures (MG5 & 6) could also have an impact, but there is greater uncertainty around these because there are fewer years of data to evaluate the impacts. The effectiveness of emergency flows as suggested in MG4 is not clear, but the idea behind it is sound. Similarly, modifying hatchery practices (MG6) is conceptually sound, but there is greater complexity and less data to determine the degree to which it would be effective. The measures that involve flow would potentially benefit both Chinook and coho (MG1-5). MG6 would more greatly impact parasitism in Chinook salmon as the hatchery Chinook, if they have a significant influence on *C. shasta* in the system, would be more likely to be infected with type I *C. shasta*.

The first three measures (MG1-3) propose flows of increasing magnitude. The deep flushing (MG2) and geomohically effective flows (MG3) would likely have the greatest impact on the parasite by decreasing usable habitat for polychaete, thus driving down the abundance of this alternate host for *C. shasta*. Past years with higher flows have seen lower prevalence of *C. shasta*. Following a higher flow event (>12000 cfs) in 2016, the usable polychaete habitat decreased relative to prior years, and visual inspection of polychaete habitats showed fewer worms relative to earlier years. In 2017, flows consistent with a deep flushing event coincided with low parasite prevalence in water samples and in sentinel fish. Furthermore, modeling of polychaete presence showed a dramatically lower probability of occurrence with flows at 7950 cfs as compared to 1200 cfs.

The geomorphic flows from MG3 would likely have the greatest impact on the prevalence of *C. shasta* simply because the flows are the highest of all the proposed measures. However, this method also has a lot of uncertainty surrounding it. There is no set timing for these events except "whenever possible", which might be multiple times in a year, or years apart. There may be flows at lower rates that accomplish the same ends (e.g., MG2). The report also cites concerns about public safety, infrastructure capacity, and future weather considerations. So although these

high disruptive flows would likely have the greatest impact on the parasite, other measures may be better suited to accomplish the same goals and better balance the interests of many stakeholders.

The deep flushing flows proposed in MG2 would be next most likely to have an impact on the prevalence of *C. shasta*. There is direct evidence that such flows decrease polychaete habitat with the 2016 survey data showing less usable habitat and fewer polychaetes. Lower parasite prevalence in fish (sentinel and river survey) was also observed that year relative to 2015. Spore concentrations at Beaver Creek did climb again in 2016 to 40 spores/L in April and 70 spores/L in June, but it is important to note that the previous year (2015), spore concentrations exceeded 1000 spores/L. The difference represents at least a 90% drop in spore concentration between years likely due to the direct disruption of polychaete habitat. Given such high numbers in the previous year, which likely reflects abundant polychaetes and relatively high prevalence in these hosts, the increased flow greatly decreased the parasite, but did not drop the spore concentrations in 2016 below 5 spores/L. Similar drops between 2015 and 2016 were seen in other measures with sentinel mortality of Chinook at Beaver Creek reached approximately 30% in June 2016, but was lower than 2015 which saw 60% from May and 50% in June. Furthermore, the juvenile salmon survey saw a drop in prevalence between 2015 and 2016 at K4, going from 72% to 27% respectively. A deep flushing event occurred in 2017 as well, and here spore concentrations were relatively low (reached 10 spores/L at Beaver Creek in June), sentinel mortality was low (<20% in all months at Beaver Creek), and juvenile fish prevalence low (17% at K4). This suggests that the deep flushing regimes are effective at controlling the parasite. Although the greater flows in MG3 would likely have a significant impact on the parasite when they occur, the flows proposed for MG2 have a more specific plan for implementation, and there is direct evidence that they can be effective. This measure (MG2) is most likely strike a balance between being effective, and occurring in a predictable manner that balances needs of stakeholders and can be evaluated more effectively than MG3.

Next most likely to decrease prevalence of *C. shasta* are the surface flushing flows proposed in MG1. The goal of this measure is to mobilize fine sediments and flush dead and dying algae resulting from algal blooms. The effect is to reduce the amount of fine sediment which would be prime polychaete habitat, and reduce a food source (algae) that supports the polychaete populations. Depending on the timing of the event this may also help to flush actinospores out of the system in early spring (proposed annual window to implement is Nov 1 - Apr 30). In 2005, there was a short flow in the surface flushing range, followed by a decrease in prevalence in fish. The spore concentrations in water increased following this event suggesting that this flow acted to dilute spores, but the effect on polychaete habitat is less clear. In 2011, there was a flow approaching 6000 cfs in the spring (there are 2 short spikes that exceed 5000 cfs, a few above 4000 cfs, and the majority of the increased flow around 3000 cfs). The OSU 2011 report on 2011 their 2011 data indicated that polychaete abundance was lowest in the 5 year span of 2007-11. Prevalence in sentinel fish and trapped fish was also low that year. In 2018, a surface flushing flow was used (and an emergency dilution flow), and spore concentrations did not exceed 5 spores/L so far this year (data up to June 18, 2018). The duration proposed in MG1 is for at least 3 days (72 hrs) at 6030 cfs. Including the downramping time, the heightened flows are expected to mobilize fine sediment but as recommended by the guidance document, the actual effects should be carefully monitored.

The emergency flows and trigger points are discussed extensively below in response to direct questions about MG4. The idea of flushing spores is supported at higher flows and observations in other years. What is less clear is whether the proposed flows would be sufficient. When similar flows have occurred in the past, they have not been for as long as these proposed flows might be, so it is difficult compare. On the other hand, if surface and deep flushing flows are performed on a regular basis the need for an emergency dilution of spores may not come up, or it would be later in the season when most outmigrants have passed the survey point. Also uncertain with this measure are the trigger points. Looking at previous years, the 5 spore/L trigger appears sensible because when annual prevalence is high, action should be taken at this point because subsequent weeks increase dramatically. On the other hand, there are years where concentrations reach this threshold, but then do not dramatically increase. Furthermore, the 5 spores/L is not conservative, given this is a 40% mortality level for coho, but the type II spores may not be present, or they are present at low levels in the system. In years where the trajectory of spore concentrations is increasing, many fish will already be exposed to the parasite, so prevalence might appear to increase before it begins to decline in response to an emergency flow. Water temperature may also be important to consider with this measure because lower water temperatures are associated with decreased mortality in infected fish, and slower development of infectious actinospores in the polychaete host. Although the exact degree to which MG4 would be effective is uncertain, an emergency flow was conducted in May 2018 and this should be evaluated carefully. Spore concentrations decreased following this flow, but were always relatively low (<5 spores/L), but the prevalence in juvenile salmon decreased greatly following the implementation of this flow (from 47% to 10%) at K4.

Providing increased flows in the Fall to flush myxospores and redistribute carcasses is next most likely to impact the parasite. In this measure (MG5), the myxospore stages are targeted, with the intent of decreasing polychaete exposure and subsequent prevalence of polychaete infections the following spring. Like with the actinospore flushing measures, the underlying concept is sound, but with this measure there is little data to show it works. As suggested in the Guidance Document, if implemented, carcass surveys could be done to evaluate their movement, and water samples should be collected during these times to evaluate concentrations in response to the increased flows. The PCR test does not specifically detect myxospores, so live and dead actinospores may contribute to the abundance of DNA in these samples.

The last measure (MG6) proposes that modifying hatchery practices could decrease prevalence of *C. shasta* in the Klamath system. Because these are hatchery Chinook, this measure pertains more to this species and the type I *C. shasta* specific to Chinook. It is not so much that this method is least likely to work, but more that there is a lot of uncertainty about the role of hatchery fish in propagating the parasite, and whether changing when fish are released would have an effect on prevalence if so. It is difficult to interpret observations of high prevalence in hatchery fish captured in the river, because they are often released at high, or peak, actinospore concentrations in the water. If many succumb to ceratomyxosis, then they would be a potential source of myxospores. In a somewhat vicious cycle, these then immediately contribute to infecting polychaetes, which then produce more actinospores. The magnitude of this effect is not known. Hatchery fish are small but many, and the relative myxospore contribution of these compared to adult or wild fish is not known. Prevalence in the hatchery itself is reasonably low

(0-18% in 2011-15), so the direct infusion of the parasite from hatchery fish is probably small, particularly in high prevalence years. Releasing yearlings would very likely decrease their contribution of parasite to the system because they are less likely to become infected in the river. However, holding the fish takes additional infrastructure and cost, and opens up the possibility of other infections in the hatchery during this prolonged holding.

a. How might the effectiveness of the management measures vary year-to-year based on hydrologic conditions, size and health of salmon runs, or other factors?

The year to year variation in the management measures likely will depend on the effectiveness of the measures themselves. For example, if polychaete habitat is greatly reduced (and therefore prevalence in polychaetes reduced) with measures such as MG1-3, then the size of the run and overall health of the fish should not matter for a particular year. Exposures will be low for all fish. The prevalence in the next year may depend on the size of the run because more infected carcasses in the river increases the risk of exposure to the polychaetes. Still, if polychaete habitat is limited, then this effect may be negligible. If prevalence in adults the previous year was also low, then even with large runs, the relative contribution of spores, compared to high prevalence years, would be lower. Redistribution of carcasses in MG5 would still potentially be effective regardless of run size. The emergency flows in MG4, if effective, would immediately benefit the fish in the season in which they occur. If this successful at driving down prevalence, the biomass of the parasite in the system could be decreased so that the next year also benefits.

Rainy and cool years would likely make the proposed measures more effective because of increased natural flows along the river, and the association of temperature with parasite development in both hosts. Related to temperature are stress and health in general. Salmon experiencing stress or an infection with another pathogen may be more likely to succumb to an infection with *C. shasta*. This may be important in MG6 if hatchery fish are known to have another pathogen prior to release. The degree to which these factors influence, or are influenced, by the different measures should be evaluated through continued monitoring.

<u>Question 2: Support for Measures</u>

3. *Are the management measures contained within the Guidance Document supported by the best available science and monitoring data?*

The Guidance Document incorporates data from multiple sources: peer reviewed scientific papers, USFWS annual reports, and OSU research annual reports. Some components of the data start over a decade ago. In the course of this review, I did not encounter another crucial scientific source that was overlooked. As with any scientific study there may be cases where more data would be desirable (e.g., specific responses to the suggested flow regimes), but the measures are well based on the data that are available. In general, more data are available for Chinook salmon from the USFWS migrating fish surveys, but data from both sentinel coho and Chinook help fill this gap.

The Guidance Document is dated January 17, 2017, so doesn't include the most recent years. However, additional reports were provided to this reviewer for 2017, and preliminary data from 2018, so these were considered in this report.

Question 3: Eliminated Measures

4. *What are the assumptions and uncertainties associated with the management measures and the four control measures that were "considered but eliminated from further consideration," and have they been adequately characterized?*

Four control measures were eliminated from final consideration. These were: 1) dewatering, 2) manual carcass removal, 3) direct sediment introduction, and 4) channel restoration. For each of these measures, the assumptions, uncertainties, and level of characterization are as follows:

1) Dewatering
Assumptions: That reducing the flow would desiccate and kill polychaetes. Enough polychaetes would be killed that this would result in a drop in actinospore levels in water, thus decreasing exposure to fish.
Uncertainties: Impacts to other species and components of the system unknown but likely negative. Length of time to desiccation not known. Even if effective, may not kill enough polychaetes because infected polychaetes known to occur at deeper water levels.
Level of Characterization: Dewatering is well characterized as an approach that may kill some polychaetes, but is unlikely to interrupt the life cycle of *Ceratonova shasta*, and would likely have greater impacts of other components on the system.

2) Manual carcass removal
Assumptions: That a sufficient number of carcasses could be removed manually that would decrease the shedding of *C. shasta* myxospores to the point where the burden in the system is decreased or the life cycle is interrupted. That the number of myxospores in the system is directly related to polychaete infections and subsequent actinospore loads later in the season.
Uncertainties: The geographic scope, access to many carcasses, and person hours are impractical to allow implementation. Effectiveness of carcass removal, unless absolute, may not decrease load sufficiently in the system (i.e., a small proportion of carcasses, <13%, contribute ~89% of the spores to the system).
Level of Characterization: Carcass removal is well characterized as a method unlikely to be effective or practical for reducing myxospore load in the system. A small proportion of carcasses contribute the greatest amount of myxospores to the system, so unless this could be done very thoroughly, which is impractical, it is unlikely this would noticeably disrupt the *C. shasta* life cycle.

3) Direct sediment introduction
Assumptions: Changes in sediment/substrate can disrupt polychaete habitat and therefore lessen the number of alternate hosts for *C. shasta* in the system.
Uncertainties: The document does not appear to provide evidence of when this has occurred naturally or intentionally, and whether it would disrupt polychaete habitat.
Level of Characterization: It is not clear how this would be implemented. I.e., this measure suggests sediment be introduced directly, but not where that would come from, or at what

location, or whether this has been done previously. The increasing flows (particularly the deep flushing) suggested in the specific disease control measures, have the same goal which is to disrupt polychaete habitat, and are much better characterized. Furthermore, the pending removal of the dams on this river suggest that developing and monitoring this poorly characterized measure would not be warranted.

4) Channel restoration
Assumptions: Modifying the river channel would reduce *C. shasta* prevalence likely through reduction of polychaete habitat.
Uncertainties: Channel restoration would likely reduce polychaete habitat, but no empirical data are provided to support this. Additional research is needed here.
Level of Characterization: Excluding this measure is appropriate because of the lack of data showing the effectiveness. More importantly, the potential removal of dams in the near future would make these efforts pointless because the channels may be restored naturally, or the post-dam restoration efforts would need to focus on that river form, not the current one. If dam removal is delayed, this may warrant revisiting this measure in a broader context of restoration, and not just parasite control.

Question 4: Support for Eliminating Measures

5. *What is the level of scientific support for eliminating the four control measures that were "considered but eliminated from further consideration"?*

The rationale for elimination of these four measures is clear and sensible. In each instance, the case for elimination was not strictly based on a scientific evaluation (i.e., ideally each method would be scientifically tested and found to be effective or ineffective for controlling the parasite).

Dewatering can be eliminated because of the potential negative impacts on many species in the river, not just the polychaetes. The document also cites the occurrence of polychaetes at lower depths that would not be subject to desiccation. Even exposed communities may not dry out sufficiently depending on weather, shade, and duration. With other feasible control options available, and the high likelihood of negative impacts on the entire river community, dewatering can be reasonably eliminated. Manual carcass removal can be justifiably eliminated because of the enormous logistical effort required for it to be successful. The scientific data show that a small proportion of carcasses contribute the majority of myxospores to the system. Unless all of these were removed (which is impractical), even a relatively small number of heavily infected fish could seed the entire system for the next year. Both sediment introduction and channel restoration have similar rationales for their elimination. The removal of the dams on the Klamath River in the near future would make these efforts temporary because the subsequent sediment introduction and restoration efforts would alter the system greatly and new restoration efforts would need to be developed. Furthermore, there are no empirical studies provided to demonstrate that these would be effective measures for controlling *C. shasta*.

Question 5: Specific Questions about Measures

6. *Specific to management measures within the Guidance Document:*

a. *Are the flow magnitudes identified within management measures 1 and 2 (6,030 cfs and 11,250 cfs, respectively) better supported than any other value within the range of surface flushing flows (5,000 - 8,700 cfs) and deep flushing/armor disturbance flows (8,700 - 11,250 cfs)?*

On this question, I will defer to the Hydrology experts, but have provided some observations. The surface flushing flow of 6030 cfs was chosen because it is consistent with the 2-year flood occurrence level. In 2005, there were flows within this range in early May, and an associated decrease in prevalence in Chinook sampled from the river. Flows in 2018 appear to have reached approximately the target value (USGS website, Klamath flows at IGD), so as the system is evaluated this year, these may provide critical data to evaluate this flow level.

The deep flushing level of 11250 cfs was selected at the upper end of deep flushing and lower end of armor disturbing flow. Thus lower values may not achieve the same goals. The deep flushing event of 2016 reduced polychaete usable habitat ("weighted usable area" = WUA) at the three sites examined, providing empirical data that this is an effective flow (see previous comments on 2016 relative to 2015). The 2017 flows were similar to this, and prevalence of the parasite was lower than other recent years.

b. *What scientific support exists for implementing surface and deep flushing flows at a frequency other than the natural recurrence interval based on geomorphic assessments of the Klamath River? Please consider that flows of this magnitude have not occurred at the natural recurrence interval in the recent past.*
    i. *If there is scientific support for implementing these flows at a frequency other than the natural recurrence interval, at what point is a return to the natural recurrence interval appropriate?*

In the last 15 years (or more) are where the most data exist for evaluating the influence of flows on the parasite. Yet in these same years, there have been severe drought conditions in the region. Thus, understanding exactly how certain flows might impact the parasite over multiple years is difficult because these drought years differ as compared to the previous decades. It may be that drought conditions are more common in the future with the uncertainty of the climate. It must also be acknowledged that the natural flows do not occur on a clockwork cycle.

The suggested flows in MG1 and MG2 are recommended to occur each year or every other year, respectively. The geomorphic memo suggests that such events would occur naturally every 2 years (for 6030 cfs flows in MG1), and every 5 years (for MG2). Thus both proposed flows of MG1&2 occur with greater frequency than the estimated natural occurrence interval. In a sense, and depending on the timing, the surface flushing flows (6030 cfs) could end up occurring every 2 years because in alternate years the deep flows (11250 cfs) would satisfy both goals in those years. This still leaves the deep flows occurring at a more intense frequency than every 5 years.

Looking at flow data from 2004-2018, there was a flow event in 2006 that reached 10000 cfs. That year, the prevalence of *C. shasta* was lower relative to other years (Nichols and True, 2007), with prevalence lower earlier in the season and increasing to around 60% later in the season. Based on prevalence in captured juveniles (USFWS reports) prevalence did increase to

around 80% in 2007, but only later in the season. In 2008, prevalence had a higher starting point in fish captured in April (~55%) and increased to around 80%. If this is an indicator of the effectiveness of a deep flow, it appears that in the subsequent year, the parasite may be delayed in becoming established at high levels. However, after 2 years, the effects of the deep flow seem to have faded, supporting the idea of conducting these every other year. Adding to this complexity were modest flows of around 4000 cfs and 3000 cfs flows in 2007 and 2008 respectively. Of course, a single example does not capture the repeatability of such an event or the complexity within the system.

In 2011, there was a flow approaching 6000 cfs, and prevalence of *C. shasta* at K4 was lower than other years (low in April, and approaching 60% in June). The following year (2012), prevalence remained low at K4, around 20% at its height in June and July. There was also a spring flow in 2012 around 4000 cfs, so this likely complicates these observations. In 2013, there was a modest flow in April (~2000 cfs), and prevalence at K4 is similar to 2012 (USFWS), but sentinel fish data from OSU saw higher mortality in Chinook and coho as compared to 2012. These data are suggestive of the parasite recovering from the flow event in 2011. In 2014 and 15, flows are generally lower and the parasite impact is great.

In MG5, flushing flows are recommended for moving myxospores out of the system and redistribute carcasses. This is recommended to occur every year in winter, but there is overlap in the timeline with the surface flushing flows of MG1. The magnitude of the events are different, but there may be an opportunity to combine these measures. The most obvious downside to moving the surface flushing to the late fall instead of the spring is that the potential benefit of flushing actinospores out in the spring (March or April) is lost. If there are fewer infected polychaetes in the system in general, that secondary benefit may not be necessary.

Thus, there is some scientific evidence for having flows at greater frequency that the natural occurrence because there are years when the parasite appears to recover quickly in some years. In 2017, a deep flow occurred, so the data from 2018 and 2019 will be critical in evaluating the effectiveness of such flows, and the longevity of their influence.

c. To what degree do hatchery management practices contribute to the transmission of C. shasta between salmonids and polychaetes? Please consider both inter- and intra-annual effects.

There is uncertainty in determining the degree of influence hatchery practices have on *C. shasta* transmission in the Klamath system. Prevalence in hatchery fish tends to be low (0-18%), so the direct impact of adding infected fish to the system is likely low. Within a given year, the Guidance document suggests that adult carcasses contribute the majority of myxospores to the system, although a thesis by Benson (2014) suggests that juveniles could contribute greatly as well. It is not possible to identify the source of myxospores in a water sample (or even myxospores from actinospores), so spore shedding from fish must be evaluated and extrapolated to the larger system. Year to year differences in timings of release, size of release, flow regimes, prevalence in the system, and polychaete populations, make determining the impacts of hatchery fish difficult.

For hatchery fish released in June, risk of infection is high many years because the levels of *C. shasta* are often very high at this same time. Prevalence in sentinel fish later in the season is often higher, supporting this. If these June releases are being sent to their demise, then lower survival means that goals for outmigrating juveniles are not really met, and these dead fish will now contribute to the myxospore load in the system. In this case, the effect may have a larger impact inter-annually; increasing prevalence in the polychaete population, which may then start at a higher level the subsequent year. Releases from 2013-16 presented in MG6 show a shift to more June releases which may be hitting the higher peaks of prevalence in the system. Moving to earlier releases (May) could avoid these peaks. In low prevalence years this may be less of a problem, so survey, sentinel, and spore concentration data should be considered in these actions. Balancing this is the concern that earlier releases may interfere with the migrations of naturally-spawned juveniles. This should also be considered in the timing and annual variability in the hatchery releases.

d. What is the level of scientific support for using spore dilution as a mechanism to minimize and/or reduce the prevalence of infection in out-migrating salmonids?

There is some support for this from the 2005 data that saw a decrease in prevalence following a flow event. The spore concentrations in water were also low during the flow event (suggesting dilution), but because there are no concentration values prior to the event it is difficult to say whether the spores were dilute, or they were just low to start with. Given the high prevalence in Chinook, it is very unlikely that the spore concentrations were starting low. Instead it is more likely they were diluted. Thus, this is the most direct evidence of the effectiveness of diluting spores from an (likely) existing high concentration and a subsequent decrease in prevalence in fish.

There are also data to support the idea that spores are diluted by flows earlier in the season, thus delaying increases and mortalities. The caveat with these is that they don't show a change from a high to low concentration or prevalence in direct response to an increase in flow. Instead they may be diluting spores before the flows drop, and a subsequent increase in spore concentration occurs. In 2008, there were flows at IGD reaching 3000 cfs in April and dropping down to 2000 in May and June. Here, the spore concentrations did not exceed 1 spore per liter approximately until the end of April and appears to co-occur with the decreasing flow from 3000 cfs to 2000 cfs. However, the higher flows precede the spore increase, so this is not direct evidence of dilution. In a similar example, in 2012, there was a flow at IGD of approximately 4000 cfs in April which tapered in May to 3000 and 2000. The spore concentrations do not increase above 1 spore/L until almost June. Prevalence in sentinel fish is low for April and May as well.

In 2011, there were flows that exceeded 3000 cfs from mid-March to late May, better spanning the time when the parasite tends to increase in the system. Here, spore concentrations stayed below 1 spore/L until the flows decrease in June. Prevalence in sentinel fish in April and May that year was low, only increasing in June.

The concept of spore dilution makes sense, and there is no direct evidence against it. Neither is there strong evidence to show it would certainly be effective. The 2005 data with a flow May is the best evidence for the effectiveness of this measure. The delay in spore concentrations in other

years that have sufficient flows also add weight of evidence that spores can be diluted. There are uncertainties with this measure as pointed out above and elsewhere in this review. If implemented, the response should be evaluated thoroughly.

In 2018, an emergency flow was conducted in May, and following the initiation of this flow, prevalence in juvenile salmon decreased over the subsequent weeks (47% on April 30 to 10% on May 21). The May 31 and June 4 samples have too small a sample size to accurately determine prevalence, but the June 13th prevalence was 3%. This suggests an emergency flow may be effective, but it should be noted this followed a flushing flow (6000 cfs) earlier in 2018.

If support exists:

i. *How is the effectiveness of management measure 4 expected to change longitudinally along the Klamath River?*

The relative contribution of the increased flow from IGD, longitudinally along the Klamath is likely best addressed by a hydrologist. As tributaries contribute more to the Klamath, the relative contribution from IGD would decrease. However, if the main hot spot of infection for *C. shasta* is below IGD then both the increased flows and the tributaries would act to dilute the parasite. It is worth considering some observations on spore concentrations from previous years. The biggest potential confounding factor with these observation is that PCR test for water does not distinguish shedding myxospores, dead actinospores, or infectious actinospores. This may be a bigger problem downstream where all of these stages may be flushed, particularly later in the season as myxospores and dead actinospores might be more common.

There are spore concentration data at different river sites for the last several years (Oregon State University annual reports). In 2014 and 2015 flows are less than 3000 cfs (except one time in the winter of 2015 which doesn't coincide with high spore numbers), and provide a sense of the spore distribution in low flow years such as these. In both years, spore concentrations increase sharply early in the season (April), and as the season goes on some upriver sites (e.g., Beaver Creek in 2015) possess the highest spore concentrations.

In both 2011 and 2012 [graphs presented in 2013 OSU report], flows reached 4000 cfs and spore concentrations were below 1 spore/L at all sites until mid to late May. Into July and August (and beyond), the downriver sites tended to see the higher spore concentrations relative to upriver sites (all sites were around or below 10 spores/L these years). This suggests that the higher flows flush the spores to the downriver sites. Tied into these observations is that the sentinel Chinook at the KOR downstream site in June for these same years shows mortality less than 10%. Here, dead spores may explain higher downstream values.

In 2016, there were flows that exceeded 2000 cfs in late April, and there is a drop in spore numbers at Beaver Creek in early May, suggestive of dilution, and the downriver sites have the highest spore concentrations later in the season. Suggestive of flushing downstream, but also possibly redistributing spores at downstream sites rather than flushing completely out of the system. This year (2016), sentinel Chinook at the downstream KOR site had relatively high mortality (~80%).

Flows were higher in 2017, with spring levels reaching 10000 cfs and tapering down below 3000 cfs in mid-May. Spore concentrations did not exceed 12 spores/L at any site, and downriver sites did not have higher concentrations relative to upriver sites which was seen in other years. The higher initial flows may have disrupted polychaete habitat sufficiently to drive down numbers, or completely flush spores from the system.

In the years with flows most similar to the proposed emergency flow, the higher spore concentrations at downriver sites could be explained by dilution upstream and the redistribution of spores downstream. The influence of dilution at downstream sites is difficult to determine because further downriver there may be more chances for infected polychaetes to contribute spores to the system, and dead actinospores and myxospores may have a greater relative contribution to the concentrations at these sites. Sentinel fish at these sites will be important for evaluating the influence of the proposed flows on the dilution and flushing of spores.

ii. *Would the inclusion of temperature and/or specific monitoring location as additional triggers for implementation of management measure 4 better predict salmonid prevalence of infection (POI)?*

As discussed in response to question 6 below, there are prior years where the MG4 triggers would be a good indicator of an imminent increase in the parasite in water and by weekly prevalence in fish. However, there are examples of other years where these thresholds are crossed, but then drop the next week and do not increase dramatically. The apparent link in most years is the flow (and likely connected to this is temperature). Higher flows may prevent spore concentrations from increasing much beyond the trigger point, and when actinospores are low, the prevalence in fish is also low. Temperature further plays a role because development of the parasites in their hosts depends on temperature, with lower temperatures generally equating to slower development and pathogenesis. Higher temperatures may mean earlier increases in actinospore shedding in a given season, and a more rapid progression of disease and mortality in exposed fish. Thus, it seems that including flow or temperature, or both, are worth further investigation if this measure is considered.

The document did not make a specific case for including other sampling sites. The existing sites are distributed along the river, and have a wealth of historical data, so monitoring effects of any measures should include these so year-to-year comparisons can be made.

iii. *How does a non-genotypic-specific spore concentration and trigger relate to POI within Chinook and coho salmon?*
AND
iv. *Is a non-genotypic spore concentration greater than 5 spores/L an accurate indicator of increasing POI in both Chinook and coho salmon?*

The current qPCR test to determine levels of *C. shasta* DNA in water samples detects any genotype. However, type I is typically associated with Chinook salmon, and type II with coho. In experimental studies, Hallett et al. (2012) found that a 40% mortality threshold was reached with 5 spores per liter with type II, and 10 spores per liter with type I (in sentinel fish at 15C). Thus, the management measure take the conservative approach with the assumption that the 5 spores

per liter could all be type II. Empirical data presented in the Oregon State University (OSU) annual reports tend to show that type I is dominant in water samples collected Beaver Creek, with types II and 0 occurring at lower levels (and often at later time points).

The OSU annual reports provide data on sentinel Chinook and coho, and in the most recent years, the numbers of spores in water at the beginning and end of each sentinel exposure. Generally, as spore concentrations increase, the mortality in sentinels increases, but there are exceptions. For example, in April 2015, the spore concentrations at the start and end of the Beaver Creek exposure were 75 and 206, respectively. However, the mortality in Chinook was less than 10% and none in coho. The weekly water sampling data show type I as dominant until May 2015 when type II exceeds the 5 spore threshold, and mortality is observed in May and June sentinels.

In 2014, higher coho mortality was observed in the sentinel fish, and the OSU report provides weekly spore concentration data by genotype. Spore concentrations exceed the trigger point in almost every week, and type II remains at lower concentrations relative to type I. However, the estimated numbers of type II do exceed 5 spores/L most weeks and high coho mortality was observed. Even in years where any genotype was relatively low compared to other years (2011, 2012, & 2013) mortality was noted in sentinel coho. It suggests coho are particularly sensitive to this parasite.

In the last 2 years (2016 and 2017), no mortality was reported in coho sentinels. In 2016, the weekly water sampling reports a spore concentration exceeding 5 spores per liter in April, but genotyping analysis only finds trace levels of type II until mid-June. Thus, the general 5 spore limit was exceeded early in the season, but the impact on sentinel fish was moderate that year (at Beaver Creek: <5% in April, 0% in May, ~30% in June). In 2017, spore levels did not exceed 5 spores/L until June.

Thus, a 5 spore/L trigger using a test that is not specific to any single genotype presents many uncertainties. In retrospect, there are years when the threshold is crossed and the spore concentrations increase rapidly suggesting a small time window to take action. Other years, the levels do cross the trigger point, but only increase to moderate levels (e.g., 2016). Ideally, a specific type II test could be developed because of the apparent severe impacts on coho, and the low dose associated with mortality.

<u>Question 6: Triggers for Emergency Flow</u>

7. *Are the triggers included in Management Guidance 4 for implementing an emergency dilution flow indicative of imminent increases in salmonid POI?*
    a. *Referencing the spore and fish infection technical memos and the associated actinospore and Klamath River flow data (2005-2017), how would the emergency dilution flows have influenced spore concentrations in the Klamath River below Iron Gate Dam? Given the varying distribution of the 'infectious zone' and river flows at which the triggers have been exceeded in the period of record (2005-2017), can emergency dilution flows be reasonably expected to measurably*

decrease the prevalence of C. shasta in outmigrating salmon? If so, what is the minimum Iron Gate Dam flow that would be beneficial?

The triggers for an emergency flow are: 1) if spore concentrations exceed 5 spores per liter, OR 2) if prevalence in fish exceeds 20% at the Kinsman Trap. These measures would be limited to a window of April 1 to June 15 (or when 80% of Chinook outmigration has occurred).

The spore concentration trigger is well based in the scientific literature. Hallett et al. (2012) evaluated spore concentrations and observations of mortality in chinook and coho salmon, identifying a 40% mortality threshold, at >15C, when concentrations reached 10 or 5 spores per liter for Chinook and coho respectively. It is important to note that these were sentinel fish with exposures of 3 days. This does provide a known exposure which is critical for quantifying the impact on fish. However, the duration of exposure in Klamath River fish would be longer. Hallett et al. (2012) also used parasite induced mortality rather than prevalence of infection for their comparison, but this is a very relevant endpoint because infection doesn't always equate to mortality. Nonetheless, this is reasonably consistent when evaluating prevalence in both sentinel and non-sentinel fish. Taking the Beaver Creek peak spore data from the Spore Memo and the Bartholomew (2017) report, and looking at sentinel fish mortality (Bartholomew 2017 report), and the prevalence data from the USFWS annual reports (various authors: True, Nichols, Foote, Bolick), there is an association of spore concentration and occurrence of infection and disease. In years of lower spore concentrations (e.g., 2012), trap prevalence is lower than other years, and sentinel fish mortality relatively lower than other years. When spore concentrations exceed 100 spores/L prevalence and mortality are much higher (generally exceeding 50%). Moderate spore concentrations tend to show intermediate levels of prevalence and mortality. The Klamath does warm to >15C with timing dependent on the year. If earlier in the season, more fish are 'caught in these less optimal conditions and greater mortality may be seen. Exposure to the parasite may occur before this, but the infected fish may still be exposed to >15C water. Thus, 5 spores per liter appears to be well support both by experimental data and field observations.

The 20% prevalence of *C. shasta* at the Kinsman trap as a cut off is not clearly explained in the guidance document. The True et al. (2016) report is cited, but doesn't provide an explanation of this trigger point. Looking at the data in Appendix A, Table 2 of True et al. (2016), there is clearly a trend where prevalence is low at each collection site, but then increases quickly. In USFWS reports from 2014 -16, once prevalence hits 20%, it continues to increase precipitously in the following week. In 2017, prevalence hits 20% on the week of May 14th, but drops the following week. Similarly, looking at the 2011 USFWS report by Bolick, prevalence spikes to 40% on the week of May 16th, then drops to 0%, and subsequently climbs back up to 20% by May 30th. These years (2011 and 2017) also saw higher flows (>5000 cfs at times), so this may be an important factor to consider for this trigger point. On low flow years (e.g., 2013-2015 saw flows less than 2000 cfs with a few short spikes exceeding this), it is likely very important to act once prevalence reaches 20%. On higher flow years (as described above), an additional week of sampling may be necessary. This is important because in these example years, the emergency flow would have likely been triggered prior to the 80% outmigration endpoint. When in reality, there were a couple more low prevalence weeks that would likely have then passed the 80% outmigration endpoint, thus the emergency flow would not have been implemented. It is also important to note that estimates of prevalence are heavily influenced by sample size. For

example, in the Bolick et al. (2011) report, the 16-May prevalence was based on 10 fish (4/10 = 40%) but the confidence intervals around this are approximately (17%-69%). Even with zero fish infected, the confidence interval around a sample size of 10 is approximately 0%-28%. In the more recent reports of True et al. for years 2015-17, sample sizes have increased to 20 (2015&16) and 30 (2017). These will provide much more accurate estimates of prevalence. Taking the zero values at 20 or 30, the confidence intervals are 0-16% and 0-11%, which fall below the 20% trigger. Generally this trigger point appears to be indicative of an imminent prevalence increase in several years that are characterized by low river flow (e.g., at or around peak 2000 cfs in 2013-15). An exception to this was 2010, where K4 prevalence did reach 26% in May but then decreased for a few weeks before rising again at the end of June. In 2018, an emergency flow was conducted in May, and following the initiation of this flow, prevalence in juvenile salmon decreased over the subsequent weeks (47% on April 30 to 10% on May 21). The May 31 and June 4 samples have too small a sample size to accurately determine prevalence, but the June 13th prevalence was 3%. This suggests an emergency flow may be effective, but it should be noted this followed a flushing flow earlier in 2018.

See responses to other questions above (question 5.d.) for other considerations on the potential effectiveness of these flows.

Question 7: Management Measures after Dam Removal

8. *What level of scientific support exists for the need to implement the management measures in the absence of the four hydroelectric dams (i.e., after Klamath River dam decommissioning)?*

All of the management measures except MG6 (changing hatchery practices) involve regulating water flow at the Iron Gate Dam. Because this dam would be one of those removed, continuing these measures exactly as described would not to be possible. Indeed the document indicates that these measures are to cover the period before dam removal. If water flow can be regulated at remaining dams further upriver, then the effectiveness of these measures would need to be evaluated again in the context of the changed river system. However, the underlying scientific concept of increasing flow (if possible) is still sound, because reducing spore levels below 5 spores per liter or disrupting polychaete habitat would help to reduce exposures whether the dams are present or not.

Another way to look at this is to ask whether any flushing or management would be necessary after dam removal. There would certainly be substantial changes in the areas below removed dams, mobilizing sediments and likely altering polychaete habitat in infection hot spots. This might mean new foci of polychaete habitat form, but it is not clear whether this would create large hot spots as are currently observed, or these would be small pockets. The parasite would not likely be eliminated but subject to the unregulated (or less regulated) "natural" flows of the Klamath. During years with periodic higher natural flows, the scientific data suggest that this would help to flush out spores and disrupt polychaete habitat, and thus the natural flows would likely have the effect of decreasing parasite numbers without management. In drought years, however, the lower flows may give rise to higher prevalence as have been seen in previous years of low flow (such as 2013-15). Here, if flow can be regulated at remaining dams, increased flows should have the same effects

as would be expected from the IGD in the current management measures (dilute actinospores, disrupt polychaete habitat).

Dam removal restores natural flows and channels, and also opens stretches of river previously not reached by *C. shasta* or certain genotypes of *C. shasta*. Thus, removal of dams creates connectivity for spread of the parasite, but potentially spreads it out, reducing areas like those found below the Iron Gate Dam, for the parasite to deposited in great abundance and act as a 'hot spot' for spore release. A return to more 'natural' flows may reduce polychaete habitat as well as flush out spores from the system. Furthermore, the removal of dams may also decrease an important food source for polychaetes, by reducing the amount and intensity of algal blooms that currently occur behind the dams.

Hurst et al. (2012) evaluated *C. shasta* in the Williamson River as a risk assessment for dam removal, and made some of these same points. Hurst et al. (2012) also provides an example of another river system (Cowlitz River) where *C. shasta* occurs and dam has been removed, and cites increased prevalence following dam removal, but this is based on a personal communication regarding hatchery fish rather than a scientific study of wild fish, so it is difficult to apply broadly. On the Klamath River, the sampling strategies are already in place and years of data are in hand, so continued monitoring after dam removal will be able to detect important changes and place the observations into a historical context.

If *C. shasta* remains a problem following dam removal, and if measure MG6 (change hatchery release practices) is found to be effective, it would potentially remain unchanged in this new system. Avoiding the peak spore concentrations by releasing in the early spring or later fall would likely still be a sound practice.

Continued monitoring for the existing measures is recommend by the Guidance Document, and continued, consistent monitoring would be warranted following dam removal to evaluate this changing system.

REVIEWER 2

Peer Review of:
Bureau of Reclamation Measures to Reduce *Ceratanova shasta* Infection of Klamath River Salmonids: A Guidance Document
An External Scientific Peer Review
July 13, 2018

Review of "Measures to Reduce *Ceratanova shasta* Infection of Klamath River Salmonids: A Guidance Document."

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13 July, 2018

The primary aim of the Guidance Document is to identify management actions which may be undertaken to reduce mortality in Klamath River Coho and Chinook Salmon caused by infections by *Ceratonova shasta*, a myxozoan parasite with a complex life cycle. *C. shasta* produces myxospores in salmonid hosts (live and dead), which infect a freshwater polychaete worm (*Manayunkia speciosa*). All species in the interaction are native. The Southern Oregon/Northern California Coast (SOCCN) Coho Salmon ESU is listed under the ESA and both Coho and Chinook Salmon have wild and hatchery components in the basin.

The Document was developed in response to recent disease outbreaks in 2014 and 2015 and calls on four recent Technical Memos produced by the USFW Arcata Field Office (AFO) and relevant literature. I also reviewed other materials provided by Atkins, including the draft report by Bartholomew et al. (2018) and available 2017 and 2018 disease memos, and several referenced peerreviewed papers, and preliminary POI and *C. shasta* spore concentration data for spring 2018 received in July 2018. Below I address each specific question identified in the SOW after offering some preliminary comments.

Overall, I found the Guidance Document to be well-written, that the recommendations were well supported by available data, and that the authors clearly identified areas of uncertainty and potential for negative effects of a given action. I did not identify any critical errors or flaws in logic.

The SOW states that "When answering each question below, the effectiveness of the management measures for coho and Chinook salmon need to be addressed separately." In general, the approach taken by the region has been to use Chinook Salmon as a surrogate for Coho Salmon because the population abundance of the latter has limited the ability to obtain sufficient sample sizes in some years. Notably, Coho Salmon are more susceptible to infection and mortality from *C. shasta* (Hallett et al. 2012): "Also, a 40% mortality threshold is reached for coho with Type II at 5

spores/L and for Chinook with Type I at 10 spores/L (Hallett et al. 2012)." (Bartholomew et al. 2018).

1. **Of the management measures contained within the Guidance Document, which measures can be expected to have the greatest influence on reducing the prevalence and severity of *C. shasta* infections within Klamath River salmonids?**
    a. **Conversely, which management measures can be expected to have the least influence on reducing the prevalence and severity of *C. shasta* infections within Klamath River salmonids?**
    b. **How might the effectiveness of the management measures vary year-to-year based on hydrologic conditions, size and health of salmon runs, or other factors?**

Broadly, I rank the six measures into three groups on their likely effectiveness to reduce *C. shasta* prevalence and severity based on the information available. The ranking closely follows how the actions are presented in the Guidance Document. The groups are: Highest (1-3; Flow actions); Midrange (4 Spring dilution & 6 Hatchery) and Lower (5 Fall flow variability).

In my view, the low uncertainty that polychaete population densities have increased because of reduced mean flow magnitude, loss of geomorphically relevant flushing flows, cultural eutrophication upstream, and increases in thermal loading during spring that likely accelerate polychaete growth and increase actinospore concentration and transmission rate during spring migration all support prioritizing actions directly targeting polychaetes.

With respect to 1b., the probability that the effectiveness of actions will vary year-to-year is high, in part because temperature affects spore production, disease transmission, mortality rate and possibly the timing of juvenile outmigration. Mortality for a given spore concentration increases non-linearly above temperatures of ~15°C (Hallet et al. 2012) and thus threshold effects related to temperature are likely. While the technical memos and Guidance Document incorporate known information on infection rate, spore concentration, and water temperature, the effects of temperature on outmigration timing may (or may not) ameliorate disease expression in the wild populations if outmigration is advanced in relatively warm or low flow years. The Guidance Document could explicitly address the relationship of temperate on outmigration timing (e.g., is there a relationship between April temperature and the date of 80% passage at Kinsman trap?). Thus, metrics of in-season temperature regime may be useful to incorporate into implementation triggers.

<u>High: Flow Actions</u>

The actions with highest likely effectiveness are the three flow actions. The likely effectiveness is expected to increase initially with the magnitude of the flow event and duration within year for all three flow actions given the recent flow regime. There is little uncertainty that 1) the flow regime of the lower Klamath River has experienced unusually low winter flows since ~2000; 2) that the population dynamics of *M. speciosa* is affected by flow regime via a combination of food web effects, transport processes, and disturbance regime as described in Technical Memos and key references (e.g., Jordan 2012; Malakauskas et al. 2013; Alexander et al. 2016); and 3) winter flushing flows reduce polychaete abundance on soft-sediment habitats (e.g., Alexander et al.

2016). Notably, this action is also supported by the postulation that polychaetes are at much higher densities under current nutrient and flow regimes relative to the historical state. In contrast, the other host of *C. shasta* (post-spawn salmon carcasses) are presumably at lower densities than the historical condition, with perhaps the exception of unnaturally high densities at hatchery planting sites and collection locations.

The remaining uncertainty with respect to how the three flow actions will affect polychaete populations and *C. shasta* actinospore production are related to: 1) the spatial (meta)population dynamics of polychaetes within the river; 2) the degree to which flushing flows reduce fine benthic and fine particulate organic matter (FBOM/FPOM) levels and inputs, particularly in soft sediments; 3) whether there is a density dependent relationship between polychaete densities and prevalence of *C. shasta* in polychaetes, and between worm density and actinospore production rate; 4) how the frequency and sequencing of annual flow events affect polychaetes to what degree interannual carryover effects drive polychaete abundance; and 5) how flow magnitude and duration affect downstream flux/removal of polychaetes from upstream reaches.

Based on the available evidence, it is clear the polychaete is a disturbance adapted species, with morphological and behavioral specializations for living in lotic systems. Consequently, under historical flow regimes, "source" populations in hydrologic refuges (large boulders and other locations with low shear during high flow; e.g., see Vannote, R., and GW Minshall. 1982. Fluvial processes and local lithology controlling abundance, structure, and composition of mussel beds. Proc. Natl. Acad. Sci. USA **79**:4103-4107 for an analogous case) likely annually recolonized depositional areas. The high densities and large spatial extents of polychaetes observed in recent years almost certainly require multiple years of immobile or stable bed flows to develop. Irrespective of the dispersal and metapopulation dynamics within the river, surface flushing and higher flows undoubtedly reduce habitat quality for polychaetes by reducing FBOM abundance, which likely accumulates within the infectious reach in this system faster than historically because of reservoir production.

Interestingly, the observational data presented in the Guidance Document and Technical Memos suggest that infection dynamics within the polychaete may be related to polychaete condition, whereby high densities of polychaetes decrease individual worm condition and increase susceptibility to infection by and POI of *C. shasta* (note, this effect would not be the result of higher horizontal transfer at higher densities given the life cycle). Notably, such density dependence in polychaetes are consistent with the 2014-2015 increase in POI and reduced POI and polychaete densities following the 2016 high flow event.

The net displacement and mortality of polychaetes downstream during flow events is a final area of uncertainty that I identified and one that was largely unaddressed in the material reviewed. The uncertainty likely stems from the logistical challenges of studying long-distance movement of such a small organism, but implicit in the actions is population reductions via direct mortality or downstream removal. The relative effectiveness of the three flow actions will depend in part on such transport processes.

As the authors note, the effects of the proposed flow actions are hierarchical. I have identified the areas of uncertainty above because the incremental benefit of deep flushing over surface flushing

and geomorphically effective flows over lower flows will depend on the interactions outlined above. For instance, flushing flows may have relatively little direct effect on polychaete density via mortality (Malakauskas, et al. 2013), but could have dramatic effects via food web effects or net downstream transport if polychaetes are transported long distances. Regardless, it is clear that effectiveness will increase with both flow magnitude and frequency. I concur with the author's statement "Implementation of the geomorphically oriented management guidance actions may significantly reduce the need for the other management guidance actions such as spring dilution, fall variability, and hatchery changes" (Pg. 8). I also concur with the authors statement "Of all the management action prescriptions, this [the March 2016 deep flushing flow event] appears to have the most demonstrated success at significantly reducing polychaete density" (Pg. 11). Consequently, I conclude that Actions 3 then 2 then 1 are most likely to have the highest effectiveness in the short term.

Interannual effects: With respect to question 1b, there is considerable support for the effects of past annual flow conditions to affect disease dynamics within a year, with risk increasing with duration since flushing (or higher) flows. It is also plausible that the beneficial effect of a given winter flow condition will increase in years following high salmon runs by removing carcasses, infected polychaetes and myxospores. Similarly, there may be an interaction between winter flow level and conditions the following year, with a greater benefit to increased winter flows prior to years with low spring flow, early spring phenology, and/or warm early summer periods because all three factors are expected to accelerate polychaete population growth and spore concentrations.

Expected species-specific responses: None identified.

Other minor notes regarding flow Actions:

Action 3: The short-term peak of 11,250 could be accompanied by recommendations for the desirable maximum flow and duration. Also, while outside the scope of the document, is there a decision pathway for deciding when and how such flows could be implemented? This could be helpful given the short response times involved (i.e., response to specific weather events).

Mid-Range:

Action 4. Spring dilution flows to address high spore concentrations.

There is strong evidence, both empirical and from first principles, that increasing flow will decrease actinospore concentrations and reduce infection rate for any given temperature regime. Less certain are how flow timing, flow magnitude and water temperature interact to reduce transmission rate, but the interactions appear to be complex and non-linear (e.g., Figure 3 Technical Memo 4). Non-linear interactions between flow and temperature may be important for driving interannual variability in disease expression. Specifically, mortality increases non-linearly at temperatures above ~15°C and thus, the dilution effects of increased flows may have minimum effects in cool years and greater than expected effects in warm years. However, such effects may also be complicated by shifting outmigration, e.g., earlier outmigration in years with early spring warming. With respect to temperature, the interannual effect of temperature may be larger than the effect of dilution flows on temperature within year because emergency flows are proposed to originate primarily from main stem sources. Nonetheless, increased flow may reduce the *rate* of spring warming within year by reducing water residence time and increasing thermal mass in downstream reaches.

The current guidance is focused on proximate triggers and the connection to disease targets (the ultimate goal) were not explicit. The trigger framework could include a temperature or DD component, since the highest risk (and effectiveness) presumably would be in a low-flow, early-warming year. This would be especially useful if there is evidence that either flow or temperature (or both) predict the timing of juvenile outmigration.

The current triggers are plausibly expected to reduce spore concentrations during periods and conditions leading to past outbreaks. The triggers can be refined as more information becomes available about the effectiveness of dilution flows, if implemented. The thresholds currently use a non-specific spore concentration of 5 spores/liter. Development of a Coho specific assay (Bartholomew et al. 2018) should help elucidate the relationships between genotype composition of spores during the migration season, species-specific disease dynamics, and help in the refinement of future trigger levels.

The primary uncertainty related to Action 4 is that the biological effectiveness of a given flow level is difficult to predict with available information, as noted in the Guidance Document.

Action 6. Changes in Iron Gate Hatchery practices to reduce infection rates.

The guidance outlined in this Action has potential to reduce mortality by *C. shasta* through two pathways: reducing exposure to juvenile hatchery fish during outmigration and by reducing myxospore production in juvenile carcasses. There is little uncertainty that earlier releases when POI and temperatures are lower will reduce POI in hatchery smolts, particularly in warm and/or high actinospore concentration years. To what degree juvenile carcasses contribute to myxospore production is largely unknown, but potentially important because juvenile carcasses become available as temperatures are rising and flows are decreasing. Thus juvenile carcasses may produce more myxospores / gram of tissue than adult carcasses, because many if not most, juvenile carcasses are expected to be infected, and the potential inputs of carcasses are non-trivial given the numbers released. For instance, 5.1M fingerlings / 90 ffp = 56,666 pounds of fingerlings = 5,666 pounds of tissue at 10% mortality rate. However, such calculations are speculative and several factors may counter such effects, including the assumption that juvenile mortality occurs in the infectious zone and that carcasses are retained in the zone during myxospore production and that myxospore development is similar during fall/winter and spring.

Interannual effects: As stated in the Guidance, the effect of Action 6 will be greatest under conditions favoring outbreaks (low water years, warm spring, etc.).

Expected species-specific responses: None identified.

Lowest:

5. Fall flow variability to disrupt transmission of myxospores from salmon carcasses to polychaete$_3$ worms.

This recommendation is intuitive, but is relatively poorly supported in my view for the following reasons, some of which repeat statements above. From the broadest perspective, all three species in the disease dynamic are native and the historical condition had much higher salmon spawning abundances and densities. Consequently, the potential for myxospore production in carcasses has been higher in the past and thus is not likely the key shift causing disease outbreaks under recent conditions. This fact may have been considered by the authors and the region, but I didn't not find reference to it in the materials I reviewed.

A key weakness of the current guidance is the lack of connection between the selected flow targets and carcass transport. While the recommended flows would undoubtedly have some effect on the redistribution of carcasses, few data are available to evaluate what proportion of carcasses would move, what habitats would receive them and what distances they would move. Future research and monitoring should address the following: If a carcass is resuspended, what microhabitat(s) receives it and what is the polychaete density in that habitat? What is the relationship between the proportion of carcasses redistributed and discharge? What is the desired proportion of carcasses to be moved? What is the dispersal distribution of carcasses downstream at a given discharge and duration of flow (and the desired median carcass movement distance?). What is the relative myxspore production between an adult carcass deposited in fall/winter vs. a smolt carcass deposited in the spring? What is the relationship between adult carcass density and myxspore production?

A second weakness (that is well acknowledged) is lack of information on how myxozoans infect polychaetes.

Interannual effects: Infection rates vary among years, and thus fall/winter flow pulses could be targeted to years when adult POI is high and/or adult spawning densities are highest.

Expected species-specific responses: None identified.

Overall, I will note that the rationale and logic used for proposing fall flow variability is sound and unlikely to do harm assuming flow magnitude, timing, frequency and ramping rates remain within the bounds of the historical flow regime. Thus, uncertainties aside, this management action could have large effect in years with known high burdens in adults/carcasses, e.g., high POI in adults.

Minor comment: Based on experience with low carcass recovery rates (5-20%) in much smaller systems, I would recommend an active tag study of carcass movement (i.e., radio tags with fixed site receivers & mobile tracking).

2. Are the management measures contained within the Guidance Document supported by the best available science and monitoring data?

As noted above, yes. The recent report by Bartholomew et al (2018) provides data summaries and recent data that are largely consistent with the patterns and conclusions forwarded in the Technical Memos with respect to disease dynamics.

3. What are the assumptions and uncertainties associated with the management measures and the four control measures that were "considered but eliminated from further consideration," and have they been adequately characterized?

4. What is the level of scientific support for eliminating the four control measures that were "considered but eliminated from further consideration"?

The Guidance Document states "The DTAT considered physical possibility, safety and a reasonable timeline for implementation in its review of possible guidance actions. In other words, guidance provided by the DTAT must be physically possible and achievable". (pg. 2).

My evaluation of Questions 3 and 4 above presumes only "physically possible" except where noted.

Dewatering:
An assumption of dewatering is dewatering will kill large number of *M. speciosa*. The elimination of dewatering is well-supported scientifically because dewatering would have strong negative effects on other components of the ecosystem, and as noted by the authors, may not be as effective as expected because the distribution of infected polychaetes is deeper than average for the population (Polychaete Memo, Figure 4).

Manual Carcass Removal:

Carcass removal would be unlikely to be effective because polychaetes could still be infected by juvenile smolt mortality. Additionally, physical removal would likely only remove a minority of carcasses, based on direct experience in smaller rivers where carcasses are more accessible. See also:

J. S. Foott, R. Stone, R. Fogerty, K. True, A. Bolick, J. L. Bartholomew, S. L. Hallett, G. R. Buckles & J. D. Alexander (2016) Production of *Ceratonova shasta* Myxospores from Salmon Carcasses: Carcass Removal Is Not a Viable Management Option, Journal of Aquatic Animal Health, 28:2, 75-84, DOI: 10.1080/08997659.2015.1103803

Direct Sediment Introduction:

Given the dynamics of the polychaete populations, particularly use of a wide variety of softsediment, hard-sediment, and algal habitats (Malakauskus et al. 2013; Polychaete Memo), it is unlikely direct introduction of sediment would have a long-term (more than 1 year) effect on *M. speciosa* abundance in the absence of other actions.

Channel Restoration:

Again, given the diversity of habitats and potential for polychaete populations to be elevated by reservoir FPOM/FBOM inputs irrespective of flow regime, altering channel morphology alone would not likely be sufficient to control *M. speciosa*. An assumption is that channel restoration would not improve habitat conditions sufficiently for juvenile salmon that they would be less susceptible to infection. Finally, there is strong support from other large dam removal projects for the assumption that the effects of dam removal would overwhelm effects of channel restoration.

5. Specific to management measures within the Guidance Document:

a. Are the flow magnitudes identified within management measures 1 and 2 (6,030 cfs and 11,250 cfs, respectively) better supported than any other value within the range of surface flushing flows (5,000 - 8,700 cfs) and deep flushing/armor disturbance flows (8,700 - 11,250 cfs)?

Surface flushing flows: The selected magnitude (6,030) represents the BOR estimated 2-year return interval. The 5,000 cfs value represents the lower limit for surface flushing flows estimated by Holmquist-Johnson and Milhouse (2010; as summarized in Technical Memo 1 Table 4). That study estimated the upper limit of surface flushing flows at 8,700. The 6,030 cfs value is very near the average value (6,000 cfs) estimated by Ayres Associates (1999). Reclamation (2011) estimated a minimum median flow for surface flushing flows (a.k.a. Slight Bed Material Mobilization Flow) of 5,800 cfs, with other estimates ranging much higher than this value for other reaches. Noting the selection of a precise discharge value will be inexact, the value of 6,020 is well supported based on the summary information in the Technical Memo because the reviewed studies using alternative approaches converged on values near 6,000 as either a lower limit to the initiation of surface flushing flows or the value was near the mid-point of the range of estimates for surface flushing flows.

Deep flushing/armor disturbance flows: Similarly, the 11,250 cfs recommendation for deep flushing/armor disturbance flows represents a value very near the minimum value from two studies (Holmquist-Johnson and Milhous 2010 & Reclamation 2011) and on the lower end of the range from a third (Ayres and Associates 1999; as summarized in Technical Memo 1 Table 7)

b. What scientific support exists for implementing surface and deep flushing flows at a frequency other than the natural recurrence interval based on geomorphic assessments of the Klamath River? Please consider that flows of this magnitude have not occurred at the natural recurrence interval in the recent past.

i. If there is scientific support for implementing these flows at a frequency other than the natural recurrence interval, at what point is a return to the natural recurrence interval appropriate?

Noting this question falls outside my direct area of expertise, flushing flows may need to be implemented more frequently than the natural recurrence interval given the decades-long alteration of the flow regime and sediment budgets. Specifically, substantial reductions in polychaetes may require alteration of the sediment particle size distribution given the ability of the worms to survive dislodging flows (Malakauskus et al. 2013) and development of high densities on shallow soft substrates.

c. To what degree do hatchery management practices contribute to the transmission of *C. shasta* between salmonids and polychaetes? Please consider both inter- and intra-annual effects.

Limited information was provided to assess the effects of specific hatchery management practices beyond those discussed in Action 6 above.

d. What is the level of scientific support for using spore dilution as a mechanism to minimize and/or reduce the prevalence of infection in out-migrating salmonids?

As noted above, spore dilution is well supported. Preliminary data from 2018 provided in July are consistent with a beneficial effect of spore dilution (http://microbiology.science.oregonstate.edu/content/monitoring-studies)

If support exists:

i. How is the effectiveness of management measure 4 expected to change longitudinally along the Klamath River?

I would expect the magnitude of the effect to remain relatively constant longitudinally, given the consistent longitudinal pattern in infection rates, peaking near Beaver Creek and declining both up- and downstream. Note this pattern occurs despite the fact that the relative dilution from Iron Gate releases will decline below the confluences of major tributaries. Figure 1.2.2 in Bartholomew et al. (2018) also suggests relative spore concentrations between locations is relatively constant through the year. Comparison of the time-series of infection among sites (e.g., KBR vs. KOR) in the recently released 2018 data (http://microbiology.science.oregonstate.edu/content/monitoring-studies) is also consistent with a relatively consistent longitudinal effect because relative spore concentration declined to an equal or greater degree at KOR, though alternative mechanisms (such as seasonal effects independent of the emergency flows) could produce a similar pattern.

ii. Would the inclusion of temperature and/or specific monitoring location as additional triggers for implementation of management measure 4 better predict salmonid prevalence of infection (POI)?

As noted above, it is plausible that inclusion of a degree day threshold or at least monitoring degree day accumulation annually may provide insights into the progression of POI. Specifically, measure 4 may be more effective in years with early/rapid DD accumulation.

iii. How does a non-genotypic-specific spore concentration and trigger relate to POI within Chinook and coho salmon?

While the virulence of *C. shasta* on Coho and Chinook Salmon differs among C. shasta genotypes, and patterns of mortality retrospectively correlated to shifts in genotype composition of spores in the Klamath River (Hallet et al. 2012), in the absence of suitable in-season monitoring tools and rigorous data to understand how genotypes fluctuate within and across years, the non-genotypic-specific spore concentration trigger provides a conservative and likely effective trigger. The on-going development of high-throughput assays described in Objective 4 of Bartholomew et al. (2018) should provide a pathway to development of triggers specific to Coho/Chinook and/or *C. shasta* genotypes.

iv. Is a non-genotypic spore concentration greater than 5 spores/L an accurate indicator of increasing POI in both Chinook and coho salmon?

Yes, for spring (i.e., before 80% of wild fish have passed Kinsman trap), based on summary information presented in Bartholomew et al. (2018), which summarizes previous data and substantiates previous results. Results presented for 2017 are also supportive because concentrations were below 5 spores/L prior to the 80% wild fish passing Kinsman trap and mortality of sentinel Chinook Salmon was low (<7.6%).

6. Are the triggers included in Management Guidance 4 for implementing an emergency dilution flow indicative of imminent increases in salmonid POI?

a. Referencing the spore and fish infection technical memos and the associated actinospore and Klamath River flow data (2005-2017), how would the emergency dilution flows have influenced spore concentrations in the Klamath River below Iron Gate Dam?

Emergency dilution flows would have reduced spore concentrations. For example, see Figures 5 & 6 Spore Technical Memo.

Given the varying distribution of the 'infectious zone' and river flows at which the triggers have been exceeded in the period of record (2005-2017), can emergency dilution flows be reasonably expected to measurably decrease the prevalence of *C. shasta* in outmigrating salmon? If so, what is the minimum Iron Gate Dam flow that would be beneficial?

Yes, with caveats. While the effect of flow augmentation almost certainly will result in dilution, the specific answer will be context-dependent because the degree to which prevalence will be reduced will depend (non-linearly) on both the spore concentration and water temperature based on Fish Infection Technical Memo Figure 3. Notably, the relationships provided in Figure 3 imply that dilution at higher spore concentrations will provide greater reduction in infection rate than lower concentrations, and that dilution will have a greater effect at higher temperatures. Comparison of Figures 5 and 6 in the Spore Concentration Memo suggest that an approximate doubling of discharge reduced spore concentrations 2-5 fold. As stated above, this question is also challenging to fully address because "measurable" and "beneficial" are not specified. To draw an analogy with statistical power analyses, were the variance, effect size and desired power are needed to estimate adequate sample size, "measurable" depends on sample size and variance whereas "beneficial" depends on the effect size deemed useful toward the management goal (i.e., is a reduction of 10% in POI beneficial?). Finally, dilution flows are a function of relative increase in volume, not a minimum flow at IG. My apologies for not being able to more directly address the question.

7. What level of scientific support exists for the need to implement the management measures in the absence of the four hydroelectric dams (i.e., after Klamath River dam decommissioning)?

As noted in the Guidance Document, dam removal would fundamentally alter physio-chemical conditions in the river. Thus, it is challenging to predict whether specific actions would be needed in the absence of the dams. The flow management and nutrient inputs from the upper basin would continue to affect the lower Klamath River ecosystem. Consequently, actions aimed at mimicking key elements of the flow regime would likely be needed given the eutrophication present in the upper system if those elements were not restored with dam removal. Following dam removal, flow management may be especially important to manage fine sediments released from behind dams that would affect the distribution, abundance and quality of polychaete habitat in downstream reaches, including the infectious zone. Other actions could be necessary, depending on the responses of salmon, *M. speciosa*, and *C. shasta* populations to dam removals.

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REVIEWER 3
Peer Review of:
Bureau of Reclamation Measures to Reduce *Ceratanova shasta* Infection of Klamath River Salmonids: A Guidance Document
An External Scientific Peer Review
June 22, 2018
Revised July 2018

Project Name: Klamath River Fish Disease 380

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Document Reviewed: Measures to Reduce Infection of Klamath River Salmonids: A Guidance Document
Submitted: 6/22/2018

Independent Science Review of Documents to Address Fish Disease Concerns in the Mainstem Klamath River.

The following review addresses the management and control measures put forth by the Disease Technical Advisory Team (DTAT) in the "Measures to Reduce *Ceratanova shasta* Infection of Klamath River Salmonids: A Guidance Document". As requested, I have and analyzed the level of support for the six management measures put forth in the Guidance Document and reviewed the four control measures that were "Considered but Eliminated from Further Consideration". My specific area of expertise is associated with fish health and disease management and my review primarily reflects my interpretation of the scientific support and issues associated with the management measures presented and how they may impact parasite dynamics and infection risks to Coho and Chinook salmon. For context purposes, I have provided brief background and an overview of the problem and important considerations associated with assessing parasite and disease management recommendations. I have also incorporated findings from recent technical documents provided by Atkins on June 5th, 2018 (i.e. Bartholomew et al., 2017 – Klamath River Fish Health Studies: Salmon Disease Monitoring and Research *Draft*) as well as other related literature.

Background and Overview:

The underlying goal of the management measures presented in the Guidance Document is to reduce parasite associated disease impact to both Chinook and Coho Salmon within the Klamath River. The document lays out criteria and proposes management measures that are to be considered and potentially implemented for control of infection from the parasite *Ceratonova shasta* (formerly known as *Ceratomyxa Shasta*). Understanding the complex life cycle of *C. shasta* is critical when considering and formulating management actions. Those proposed in the Guidance document do take into consideration key aspects of the *C. shasta* life cycle (Figure 1).

As with most myxosporean parasites, the life cycle of *C. Shasta* involves an intermediate host, the polychaete worm *Manayunkia speciosa*. Interestingly, and not mentioned in the Guidance Document, there is another parasite (*Parvicapsula minibicornis*) that also shares the same life cycle as *C. Shasta* (Figure 1), and this parasite is commonly monitored in conjunction with *C. shasta*. True et al. (2017) provides data that shows *P. minibicornis* commonly infects fish in the Klamath River at high rates, but apparently fish can recover from *P. minibicornis* infection. The Guidance Document only considers *C. shasta* and the assumption appears to be that *C. shasta* is the primary parasite impacting fish in the system. However, *P. minibicornis* is being monitored in current sampling (True et al., 2017) and infection levels in fish are typically higher than for *C. shasta*. The potential impact co-infection has on fish health in the Klamath may not be understood, but it is important to keep in mind that many factors may affect fish health in a natural system. Clearly, implementing management measures that target one of these parasites should reduce the prevalence and infection rates of both parasites.

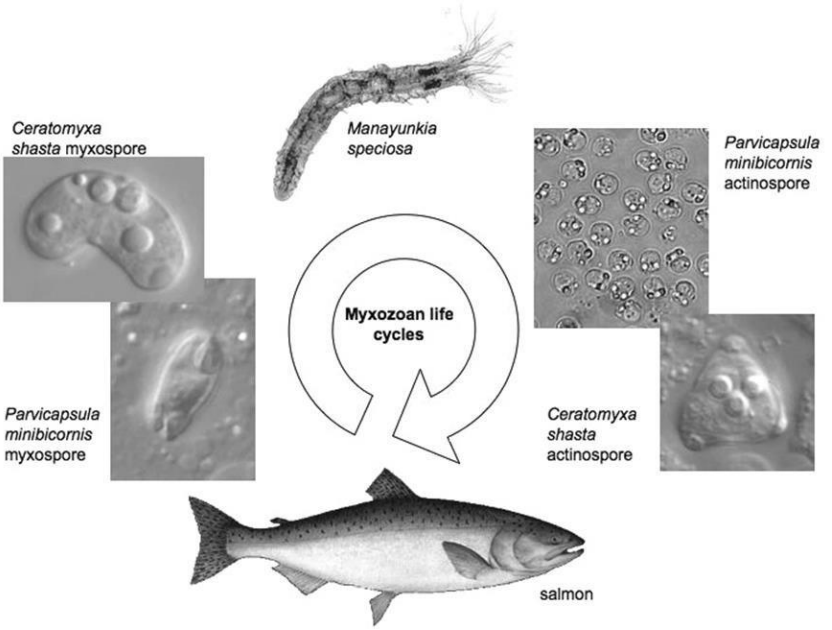

Figure 1. The life cycle of *Ceratomyxa shasta* and *Parvicapsula minibicornis*. *Manayunkia speciosa* is a small freshwater polychaete worm (3-5 mm in length) and the intermediate host of both parasites. Graphic incorporated from DTAT Guidance Document (originally provided with permission from J. Bartholomew, Oregon State University).

Another factor that appears clear is that overall disease prevalence and impact in the Klamath River may be influenced by more than just *C. shasta* prevalence. There are other pathogens (bacterial and viral) that could play a role and contribute to population level impacts during times when fish experience stressful environmental conditions associated with low flow or high temperatures. It has been noted that the bacterium *Flavobacterium columnare* causes significant problems during warm water periods. This can causes the disease Columnaris and it would be reasonable to assume that parasite burden in Coho and Chinook salmon (even at low levels) could increase susceptibility of fish to other pathogesn such as *F. columnare*. This information is provided only as background and to provide a "big picture" look at disease ecology in a natural system. The key to developing a successful strategy to disease management in such a natural (or semi-natural) system is to provide the optimum conditions (environment) for fish and to minimize stress during key life stages (i.e. juvenile out-migration and adult return). This basic concept of fish health management is key to implementing any management measures, and given that the fish host and pathogen are endemic (naturally occurring) in this system the primary measures that can be implemented would target environmental manipulation in a way that minimizes either host or reduces the concentration of infectious spores in the Klamath River.

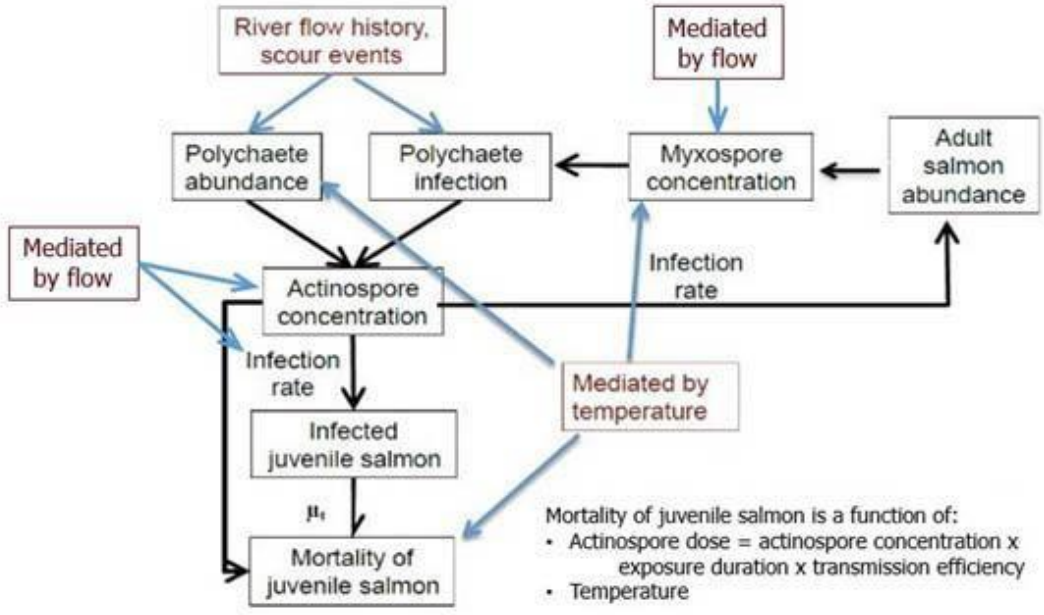

Figure 2. Factors that influence infection and disease (mortality) of salmon. Graphic incorporated from guidance document (originally taken from USFWS Memoranda and modified in guidance document).

Proposed Management Approach:

Disease management strategies for parasites can be effective and typically attempt to disrupt an intermediate host in a way to break the life cycle of the pathogen. This has proven effective for *Myxobolus cerebralis*, another myxosporean parasite that causes whirling disease in salmonids. *M. cerebralis* has been successfully controlled in fish hatcheries when affected hatcheries shifted from earthen ponds to concrete ponds/raceways to eliminate the intermediate oligochaete host (*Tubifex tubifex*). This has been successful in situations where incoming water sources are free of the infectious actinospore stage. Such examples are encouraging, but control of a parasite or pathogen in the natural environment provides many more challenges due to the limited level of control typically available. The intermediate host for *C. shasta* involves a polychaete worm (*M. speciose*), and abundance of this worm and reduction of myxospore concentration are the main criteria that the proposed management actions in the Guidance Document are aimed at manipulating. The objectives are based on the general understanding that if myxospore concentration (either the infectious stage for fish or for polychaetes) can be manipulated then there will be an overall reduction in clinical disease and ultimately in population level impacts for Chinook and Coho salmon in the Klamath River. This approach is theoretically sound and is supported by the scientific literature and the materials provided for this review. Such approaches will not eliminate this parasite from this system and infection of fish by *C. shasta* will still occur. The key measure of success will be based on the level of reduction of the prevalence of infection (POI) and overall "disease" impact for Coho and Chinook salmon in the system. There are many factors that play into the dynamics of infection and disease for this parasite (Fig. 2), and the measures presented in the Guidance Document take much of this into account.

The ability to manipulate the environment and potentially influence disease prevalence rates will rely primarily on flow management actions to be implemented at Iron Gate Dam (IGD). The ability to change hydraulic conditions at IGD should provide a means of monitoring the effects of

different flow regimes on *C. shasta*; however, it must be recognized that many seasonal variables may influence the anticipated outcomes. Such variables include: temperature, snow pack, annual carcass abundance, hatchery juvenile numbers, and infection rates of fish in the system. The ability to keep variables constant over multiple years will influence short term evaluation of different management actions, but in general the scientific support in the provided documents, the literature, and the technical memorandums, suggest that some management measures will be beneficial if successfully implemented.

Specific review of management measures:

Criteria to be considered by reviewers (from Statement of Work):

The reviewers are asked to analyze the level of support for six management measures, and four control measures that were considered but eliminated from further consideration, contained within the Guidance Document.

Questions posed (and responses):

Management measures within the Guidance Document intended to reduce the prevalence of C. shasta infection in coho and Chinook salmon will be the focus of the review. When answering each question below, the effectiveness of the management measures for coho and Chinook salmon need to be addressed separately. Additionally, for questions 1-4, please address both the six management measures, and the four control measures considered, but eliminated. The review will address the following questions:

1. **Of the management measures contained within the Guidance Document, which measures can be expected to have the greatest influence on reducing the prevalence and severity of *C. shasta* infections within Klamath River salmonids?**

   Of the six disease control measures put forth in the Guidance Document and based on review of the *C. shasta* literature, management measures 2, 3, and 4 are likely to provide the greatest influence on reducing the prevalence and severity of *C. shasta* infection. Guidance measure 1 (surface flushing flows) may be beneficial if implemented at the appropriate time (late spring) annually, but may have less benefit if implemented during other times of the year. Effects of flow timing would need to be evaluated in conjunction with other variables to be sure such flows were effective.

   Based on the technical memos and scientific findings there is evidence that flow has direct effects on polychaete distribution and abundance and that diluting spore concentrations will reduce POI for fish as well as polychaetes. It is clear that deep flushing and other high magnitude flows may provide the greatest benefit and have occurred rarely in the past 15-20 years. If high flows can be achieved regularly to mobilize sediment and flush polychaetes downstream this would result in a reduction in the numbers of polychaetes in key river sections. This should reduce the concentration of infectious infections actinospores in the water column and in turn lower infection rates (POI) of Coho and Chinook salmon.

Guidance measure 2. Provide deep flushing flows and armor disturbing flows to the mainstem Klamath River below Iron Gate Dam.

Flows of this magnitude have the potential to provide benefits as suggested in the techncal memos. It was noted in the Polychaete Memo that in 2016 a deep flushing event (11,000 cfs) appeared to significantly reduce polychaete density. This is further supported in relation to recent high flows in 2017, where Bartholomew et al. (2018), and True et al. (2017) showed lower polychaete populations, *C. shasta*, and POI downstream from Iron Gate Dam (IGD). Field exposures of Coho and Chinook in 2017 showed limited mortality due to *C. shasta* (Bartholomew et al., 2017).

A portion of the high flow events occurring after March 2017 were court mandated; however, the majority of the high flows experienced were due to natural hydrologic events. As noted in recent reports, "polychaete densities and prevalence of *C. shasta* infection were lower than in previous years at all index sites". This provides substantial support that deep flows and high magnitude geomorphically effective flows (as recommended in measure 3) impact polychaete populations and POI for *C. shasta*. The continual monitoring by the various groups is important and will provide long-term data on the effectiveness of such flow alterations, the time for recolonization of polychaetes, and the changes in POI over time and in relation to alterations in the flow regime.

Given the flows experienced in 2016 and the moderate infection year and the recent high flows in 2017 corresponding to marked reductions in POI and polychaete densities, it can be reasonably concluded that high flows (likely combined with lower temperature) resulted in reduced parasite concentrations in the Klamath River as predicted.

Such actions should provide benefit for both Coho and Chinook salmon. However, the majority of monitoring has involved Chinook salmon and less information is available for Coho in the Guidance Document, technical memos, or other literature. The primary key to understanding risk for Coho salmon specifically would be the finding that Coho are more susceptible to the Type 2 genotype *C. shasta* and Chinook are susceptible to a Type 1 genotype parasite.

Guidance measure 3. Provide Geomorphically Effective flows on an Opportunity Basis.

New reports provide the most recent parasite prevalence data following sample collection in 2017 (Bartholomew et al., 2018; True et al., 2017). This analysis provides insight on flow effects as 2017 represents the wettest year since 1998 for the Klamath basin. (NOAA, 2017). Flows from February to June of 2017 ranged from 10,500 cfs below IGD to as high as 40,000 cfs at the Seiad Valley downstream of IGD and at the lower end of the "infectious zone" (Figure 3 and 4). The short duration flow of 11,000 cfs in 2016 may have also provided benefit, but the 2017 peaks and continued higher flows appear to have produced added benefit. Although these flow levels below IGD were not above the 11,250 cfs set for the geomorphic flow, they were close and the indication is that such flows are indeed beneficial and should be implemented when possible.

Such actions or events would provide benefit for both Coho and Chinook salmon.

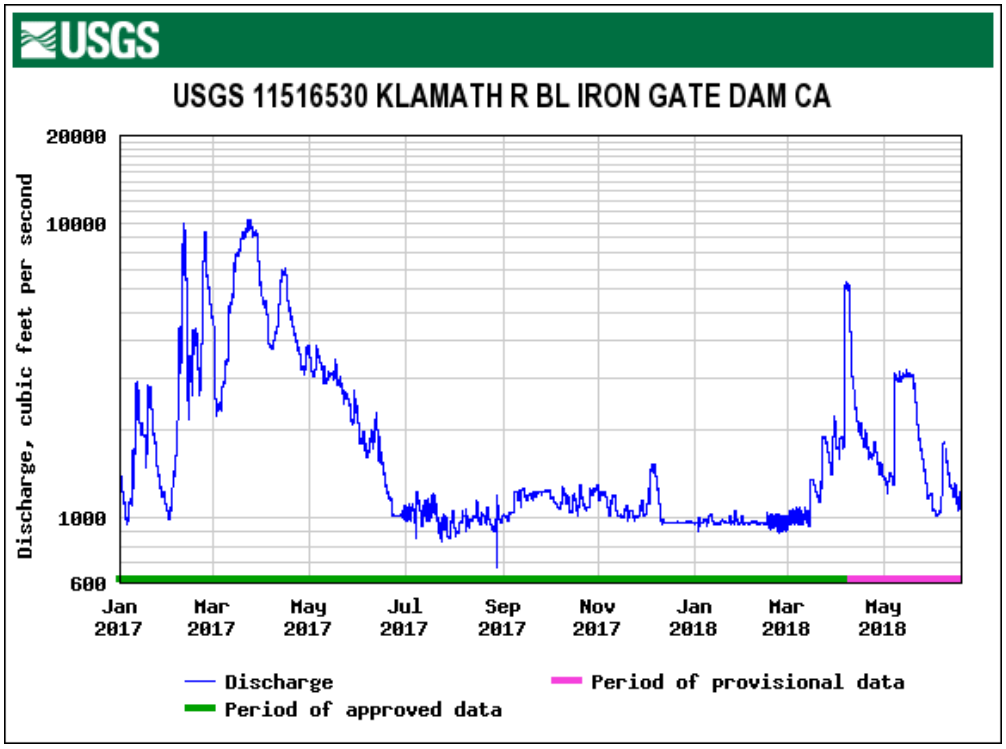

Figure 3. Water flow data and discharge (cfs) levels recorded below Iron Gate Dam from January 2017 to June 2018. Source: USGS https://waterdata.usgs.gov/

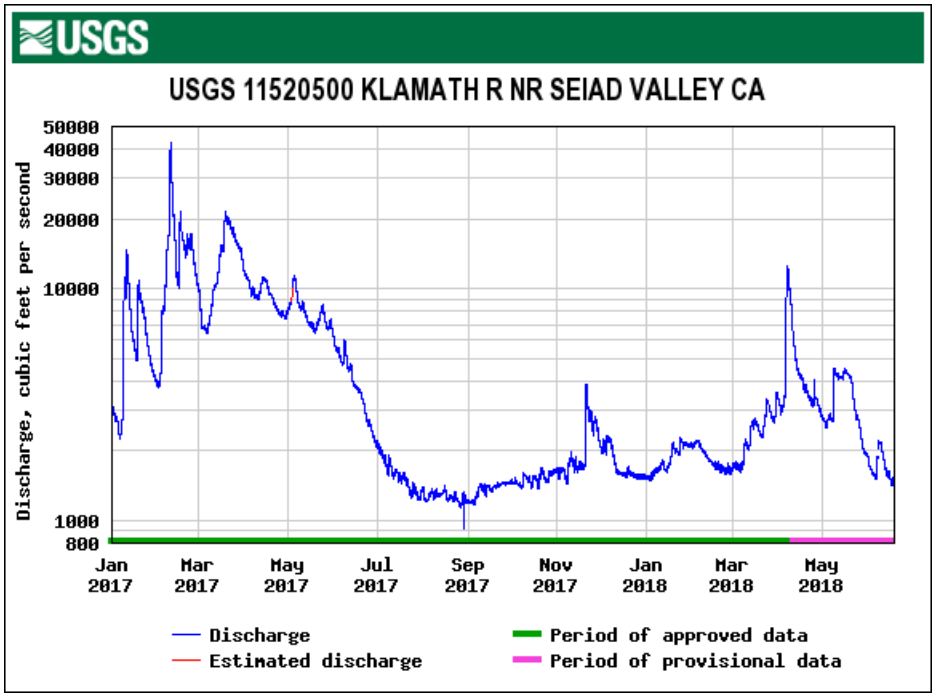

Figure 4. USGS water flow data and discharge (cfs) near Seiad Valley from January 2017 to June 2018.

Guidance measure 4. Emergency Provision of Flow in the Spring to Dilute Spore Concentrations of C. shasta.

This measure should have benefits based on the studies completed to date. There is a need to minimize potential for infection of out-migrating salmon during this time of year and higher flows (in combination with lower temperature) can reduce the infection rate. Evidence shows that this action, either in combination with other high flow events or implemented alone during years with minimal spring runoff, would provide benefit when compared to doing nothing. One key aspect needed clarification is the role of temperature during such releases and the need to keep temperature from increasing due to shallow water releases from IGD. This could subsequently increase the risk of infection rather than lower it.

This management measure should provide benefit for both Coho and Chinook salmon. However, the key to success of this guidance measure will be to implement it effectively and during the period when the majority (80%) of migrating salmon are in the system. However, there are uncertainties in relation to the potential of fish to become infected further downriver if polychaetes are not flushed out and just settle out and become more abundant as they are transported downstream. It is unclear if such "reestablishment " of polychaetes in other locations as a result of flow augmentation has been evaluated. The long term impact could be that there would be a shift in the "infectious zone" to sites further downriver.

Of the **four control measures considered but eliminated from further consideration**, number 1 (dewatering) and 2 (manual carcass removal) would be suspected to have the greatest impact on POI for *C. shasta.* Dewatering would dry up areas where polychaetes are present resulting in desiccation and elimination of worms. Carcasses have been identified as a major source of myxospores that infect polychaetes and reduction or elimination of this source of myxospores would reduce infection levels in polychaetes and ultimately fish. Each of these control measures would be challenging to implement and have critical uncertainties.

Control measures 3 (sediment introduction) and 4 (channel restoration) were considered but eliminated due to the potential of dam removal. In theory such measures may influence infection prevalence, but specific criteria for how such measures would be implemented would be required to better understand what potential impacts (if any) they may have over the short or long term.

1. *Dewatering*

    - Dewatering could have a significant impact, but was not considered further because it was determined that flows would need to be reduced to very low levels. Such low water levels were deemed to have other potential ecological impacts, and because infected polychaetes inhabit deeper portions of the river they may not be eliminated from those areas. These are important considerations and could limit the effectiveness of implementing such a control measure. However, if desiccation could occur and polychaetes are eliminated or substantially reduced one could conclude that parasite levels would be affected dramatically. If such a

reduction or near elimination of the polychaete intermediate host were achieved over consecutive years then the parasite life cycle could be broken. Removal of the fish host has recently been found to break the life cycle of *M. cerebralis* in specific systems in Colorado (Nehring 2014) and demonstrates the potential of eliminating myxospores by host removal for a period of time.

In theory, this control measure could reduce or eliminate the polychaete host from specific sections of the river; however, as pointed out in the Guidance Document, implementation would be difficult at best and the effects of such actions on other aspects in the system may have significant negative impact overall. Therefore, such a control option is unlikely to be successful if applied on a broad scale. If specific sections where high concentrations of polychaetes could be dewatered for short periods (through diversion or other means) then this approach may be possible on a more targeted basis.

2. Carcass removal

Although (Foote et al., 2016) concluded that this approach was not a viable management option for the Klamath River, it can be argued that if indeed the resources were available to remove the majority of salmon carcasses annually it would clearly reduce the number of myxospores released to the system. Because of the high load of myxospores released from decaying carcasses they are a major source of polychaete infection. The conclusions from the Foote et al. (2016) study show that carcass removal in the study was inefficient, labor intensive, and had many logistical limitations. Additional arguments put forth in the Guidance Document against carcass removal relate to the importance of nutrient inputs into the system that are provided by these carcasses. For these reasons, carcass removal was eliminated for further consideration. If the objective is to reduce myxospore release in the fall, and substantial carcass removal was possible then parasite loads into the system would be reduced.

a. Conversely, which management measures can be expected to have the least influence on reducing the prevalence and severity of *C. shasta* infections within Klamath River salmonids?

Based on the materials provided and information available, management guidance measures 1, 5, and 6 will most likely have the least effect on reducing parasite impacts.

Guidance measure 1. Provide Surface Flushing Flows to the Mainstem Klamath River Below Iron Gate Dam.

This management measure certainly may have benefits and is designed to induce movement of fine sediment below IGD. Its goal is similar to other flow manipulations suggested and focusses on reducing polychaete populations by moving sediment. The flow levels suggested are 6,030 cfs based on work showing

that such a flow can mobilize sediment. This could have benefit if conducted on a relatively frequent basis during times just prior to or coinciding with high POI risks and in conjunction with the other higher flow measures (guidance measures 2, 3, and possibly 4). However, surface flushing flows implemented alone and as proposed in this measure without other flow manipulations are not likely to have dramatic results or produce significant changes in POI of Coho or Chinook salmon in the system. The results of implementing this type of a flow measure should be further defined in the context of seasonal timing (later winter/spring likely providing greatest benefit) and duration.

Guidance measure 5. Provide flow in the late fall and early winter to redistribute salmon carcasses and myxospores.

This measure somewhat overlaps in timeframe with the surface flushing flow recommendation #3, but would be at a lower magnitude. Implemented alone this may have limited impact due to practical uncertainties and limited knowledge of the effectiveness of carcasses redistribution through such flow increases. Scientific justification shows that spore dilution would reduce host infection (for polychaetes and fish); however, there appears to be limited information on the effects of timing and duration of flow manipulation on actual carcass movement and redistribution. The magnitude of the flows proposed seems low (1500 to 2500 cfs), and may be ineffective at redistributing salmon carcasses. Most carcasses were noted to settle into deeper areas that coincide with primary polychaete habitat. Therefore, such flows may not have a substantial effect on carcass movement in these areas. However, given the settling rate of myxospores is 0.35 to .045m/day (Waterborne spore memo), flow increase (especially if sustained throughout the period of pre- and post-spawn mortality) may be effective at distributing already suspended myxospores downstream. Again, this action could have benefit but there is uncertainty, and it seems likely that many myxospores may remain in the sediment following decomposition of adult carcasses.

The flow levels proposed may not produce the desired result, and it is possible that any redistributed carcasses or myxospores would just settle out further downstream and be available for polychaete infection within other river segments. Without removing myxospores from the system or flushing them out entirely, the long term result may be minimal and just shift the “infectious zone” further downstream of current locations. This not result in lower POI of out-migrating juvenile fish, but may shift where they become infected (i.e. lower in the system). Obviously, any increase in flow during the fall may influence carcasses, polychaetes, and myxospore distribution, but little evidence exists to suggest such low flows would have meaningful results. Given that Foote et al. (2016) found that carcass removal was not efficient enough to have significant impact on spore levels, this measure may be ineffective.

When considering the impacts on Coho and Chinook, it should be recognized that they spawn at different times in the fall and it is possible that flow alterations would have differential effects. The scientific evidence shows that each species is infected by a different parasite genotype. Given this, one could speculate that flow changes that target redistribution of Chinook carcasses and not Coho carcasses (presumed to be present later in the year) could result in a greater presence of Type 2 genotype myxospores available for polychaete infection within specific river reaches. This would in turn result in a higher proportion of polychaetes releasing the Type 2 actinospores, which are infective for Coho salmon.

Guidance measure 6. Iron Gate Hatchery Release Strategy.

This management measure should have positive effects but there may be inherent difficulties in meeting the criteria put forth and ensuring that release times and strategies are consistent annually. The primary recommended actions suggested are to:

1. Release more yearlings in the fall (mid-Nov) and fewer fingerlings in the spring.
    - It appears that the idea behind this measure is that more fish released at larger sizes in the fall would be beneficial as they would be less susceptible to infectious actinospores in the system and that fewer actinospores are released during this period than in the late spring. The challenges to this would be primarily related to altering hatchery production to produce greater numbers of yearling fish especially given the high target numbers for Chinook (6,000,000 fish annually). The impacts of releasing more yearling fish in the fall on subsequent adult return would need to be evaluated.
2. Continue to increase fingerling releases in May and minimize releases in June.
    - As described in the Guidance Document, some facility alterations may be needed to produce larger fish and/or meet early release timing. The primary requirement may be to increase water temps in order to maximize growth. This would be especially true for eggs taken later during spawning as mentioned in the document. The potential effects of altering rearing strategies on out-migration and adult return timing should be considered and monitored over time. One question and uncertainty that needs to be clarified is; if juveniles are released earlier do they remain in-river longer during the out-migration period? The residence time for out-migration may impact POI. If fish released earlier remain in-river longer than fish released in June, their parasite exposure time may be extended. Although infectious actinospore levels (exposing dose) may be lower the increased exposure time could result in

similar POI to later released fish by the time they reach the estuary.

3. Consider reduction of fingerling release numbers in relation to natural run size.
    - This action is vague and no specifics are provided. The concept would of course provide less fish in the river for the parasite to infect; however, it would ultimately lower the numbers of returning fish unless somehow this strategy resulted in higher numbers of fish emigrating from the system. There is the potential that natural fish would be less impacted due to lower competition with hatchery fish (if high numbers are released in parallel with natural fish migration timing), but this has not been demonstrated.

There are scientific uncertainties with the above recommendations. An extension to the release strategy measure that did not appear to be considered would be to **release fish further downriver** below the "infectious zone" where infection risks are lower. If there are concerns over interaction with natural fish this may be mitigated if hatchery fish are released lower in the system and they may emigrate over a shorter period of time. The records show that infections in hatchery fish are typically low at time of release and if fish were transported to lower river sections there may be less risk of substantial contact with high concentrations of actinospores. This may also mitigate issues if physiological changes in juveniles associated with smoltification are not complete by May releases by ensuring that longer in-river migrations is not through river sections with the highest spore loads. Again, smoltification timing and out-migration timing for early released fish was not defined in the documents.

This management measure appears to focus primarily on Chinook produced at the hatchery. It was not clear what alterations would be made for Coho and how this would fit into Coho production plans at Iron Gate Hatchery. Given that different parasite genotypes impact Chinook and Coho, this action may have minimal benefit for Coho salmon due to their susceptibility to the Type 2 genotype of *C. shasta.*

b. How might the effectiveness of the management measures vary year-to-year based on hydrologic conditions, size and health of salmon runs, or other factors?

Clearly the effectiveness will be widely influenced annually due to many of the variables that have been outlined in the memos and document.

For example:

Impact of the management measures listed would have less impact if:

1. Drought conditions are present and limit the ability to implement suggested flow related management measures or result in high temperatures over a greater timeframe.
2. Unidentified refuge areas for polychaetes are present where flow increases do not mobilize sediment in a way needed to flush polychaetes downstream.
3. Large numbers of infected salmon return and the resulting carcasses contribute an excessive load of myxospores to the system.
4. Excessive juvenile out-migrants become infected during some years, which could result in high juvenile mortality (and spore contribution) or high spore loads once adults return.

2. Are the management measures contained within the Guidance Document supported by the best available science and monitoring data?

Yes, the measures that have been proposed are supported by the best available science. Monitoring data continues to be collected and is critical to applying an adaptive management approach. For example, this past year provided an opportunity to evaluate parasite, polychaete, and POI in relation to hydrologic and other variables that were atypical in 2017. It was noted that 2017 was a unique fish health monitoring year (True et al., 2017). There were low adult returns, there were geomorphic flushing flow events, and lower than average numbers of juvenile Chinook were released from Iron Gate Hatchery. This combination of changes appears to have disrupted the *C. shasta* parasite life cycle due to reducing fish host numbers combined with high flows that reduced polychate host numbers. As a result, low *C. shasta* infection levels were observed and clinical disease did not occur in any fish sampled during the out-migration period of March to August, 2017. From the data it is clear that 2017 was different than most years and although many variables exist, the take home message is that alterations in hydrologic and host levels do appear to impact infection prevalence. These observations provide further evidence that at least some flow related management measures in the Guidance Document are on track and if implemented should have an effect on parasite prevalence.

3. What are the assumptions and uncertainties associated with the management measures and the four control measures that were "considered but eliminated from further consideration," and have they been adequately characterized?

Management measure 1 (Surface flushing flows):

The support (or assumptions) for this measure comes from information in the Geomophic flow memo showing a range of flows from 5,000 to 8,000 cfs would mobilize fine sediment. The flow of 6,030 was recommended to provide an increase in the number of days that the river (below IGD) is in a mobile surface substrate state. The primary assumption is that the low frequency of discharge at such flows and time period since 2000 has resulted in greater numbers of polychaetes present. By requiring flows of this magnitude annually it will provide the necessary surface flushing to move sediment and affect polychaete numbers.

The question remains as to what the best timing is for implementation of such flows. The range of November 1 to April 30 in the guidance document is quite large. Based on seasonal fluctuations associated with infection risks, it would seem that implanting flushing flows in the spring would be most beneficial.

The uncertainties noted regarding exactly what sediments and what habitats will be mobilized was accurately characterized. One uncertainty is if this measure is implemented in the absence of other measures, will it be beneficial? Until such flows are implemented at the interval and level selected it is not completely certain what the effects will be on sediment. It is noted that duration is important but overall the response of such flushing flows on the polychaete populations during the period described is not completely certain.

The assumptions and uncertainties were adequately characterized in the Guidance Document.

Management measure 2 (Deep flushing flows and Armor disturbing flows):

The support and assumptions for increasing deep flushing and disturbance flows relate to the rarity of such events over the past 16 years. There has been evidence that such flows (such as the documented short event in 2016) likely had an effect on polychaete density. Recent reports (Bartholomew et al. 2018 *draft*) and True et al. (2017) provide further evidence that such assumptions are correct and that large flow events do impact polychaete density. However, recent natural high flows in 2017 downriver from IGD may have been higher than can be achieved through IGD flow manipulations and therefore it may be difficult to tease out what level of specific effect would be expected.

The uncertainties presented in the Guidance Document relate primarily to implementation (i.e. infrastructure capacity, safety, and hydrologic support), but there is little uncertainty that such flows will impact polychaete abundance.

The assumptions and uncertainties were adequately characterized in the Guidance Document.

Management measure 3 (Geomorphically effective flows):

The assumptions and support for this measure follows on from those presented under measure 2 and essentially state that flows above 11,250 cfs have declined in frequency and duration. This has contributed to a proliferation of polychaetes and research has clearly suggested that mobilizing sediments would dislodge polychaete worms.

The uncertainties stated under this measure only relate to the potential difficulties in implementing these types of flows, and not in any uncertainty that such flows would reduce polychaete abundance.

The assumptions and uncertainties were adequately characterized in the Guidance Document, and given the 2017 events (and minor events in 2016) it appears that flows approaching the recommended 11,250 cfs are beneficial and provide support for the assumptions.

Management measure 4 (Emergency provision of flow in the spring):

The assumptions and support for this management measure are that by increasing flows in the spring it will result in higher spore dilutions and a reduction in POI. The need to implement emergency releases would be dependent upon constant monitoring and the detection of spore concentrations above 5 spores per liter at any sampling station or a POI of > 20% in all fish tested (hatchery and wild) at the Kinsman screw trap the preceding week. It was not clear why POI at only the Kinsman site (and not others) was chosen as the criteria for implementing emergency flows. This may just be due to logistics or lack of sampling at other locations, but this could be further expanded upon for clarity. Also, the relation between temperature and actinospore release is described and relatively clear, but it was not clear why temperature was not a considered as specific criteria for release. It has been well documented that increasing flow from IGD can be a potential mechanism to mitigate high temperatures and lower risk of infection to Coho or Chinook salmon.

Uncertainties were described and focus on the unknown relationship between flow effect and temperature effect. Another uncertainty would be in determining when 80% of the juvenile run had passed the Kinsman screw trap. It is assumed that the uncertainty would relate primarily to determining the 80% of the wild run, but this was not well characterized. It was also not clear why implementation of this action would not occur if 80% of the wild run had been documented at the Kinsman trap? Why not set this at 80% of all fish? One could imagine a scenario where 80% of the wild run may be caught early in the spring period and therefore nothing would trigger a flow increase. This may not coincide with the majority of hatchery fish out-migration and it would be possible for spore concentrations and POI to exceed the thresholds listed. This would seem to be counter to the overall goals and objectives of lowering the annual incidence of infection and limiting parasite load in the system.

Although the assumptions and uncertainties were presented, there are still questions as to why other factors (such as temperature) would not be considered in the decision plan for implementing an emergency release? Why is only the one site considered as the trigger for emergency flow decisions? Further characterization would be beneficial.

Management measure 5 (Provide flow in the fall/winter to redistribute salmon carcasses and myxospores):

The support for this management measure is built upon the assumption that salmon carcasses will be redistributed by implementing fall/winter flushing flows. The assumption that a 3-5 day flow increase (1500 – 2500 cfs) between November 15th and January 15th will redistribute carcasses seems to have minimal documented support. Yes, decaying carcasses can emit and contribute a large number of myxospores to the system; however, significant redistribution is questionable. First of all, criteria for when to implement peak flow targets are vague and many questions as to how monitoring will be implemented to determine the benefits of such measures are unanswered. This, combined with recent studies that indicate that even manual carcass removal may not be beneficial (Foote et al., 2016) call into question the use of this as a management measure.

The uncertainty noted under this measure is that little is known about the actual method of infection of polychaetes. Regardless of the mechanism, it is clear that myxospore presence is required for them to become infected. The greatest uncertainty seems to be that there is a lack of information on how effective such a measure would be at distributing carcasses and myxospores. Because Coho and Chinook salmon spawn at different times, carcass abundance may peak at different times and would accumulate into early winter. This and the lack of information on decomposition rates and how this may associate with carcass spore concentration and release rates would represent further uncertainties. The need to continually monitor the effectiveness of this measure and possibly sample gut tissues from carcasses to determine spore concentrations are apparent, but much uncertainty exists on how this may be implemented.

Management measure 6 (Iron Gate Hatchery Release Strategy):

Support and assumptions for this measure suggest that there is a need to shift the majority of juvenile salmon releases to May and release more yearlings in November. This is based on the current criteria for release and that infection risk during spring out-migration is lowest in May and increases in June. Infection risk for yearling in fall would be lower, but this is not well characterized in the Guidance Document. Other support for this measure is based on the potential for infected juveniles to contribute large numbers of myxospores to the system if mortality levels are high during out-migration. Another aspect of this management measure is to "consider reduction of fingerling releases relative to natural run size", but support for this was not well characterized. It is speculated that the assumption would be that a substantial reduction from the current high production goals would lower the number of susceptible fish hosts in the system. The support for lowering release numbers as a management measure was not clear.

The uncertainty section was not well characterized as there are more potential uncertainties than just the two that were listed (adult infection risk due to myxospores released from juvenile carcasses and the number of hatchery fish to

be released in May and not impacting wild/natural fish). Additional uncertainties seem to be many. For example: what mortality rates would be expected from fish released in May/June at given POI; what river sections would juvenile carcasses most likely settle out, Would juvenile mortality be primarily consumed by predators (fish, birds, etc.) and how would that related to myxospore release?; how many myxospores would be released on average from decomposing juveniles and how does this correspond to the temporal release of actinospores from polychaetes? Another uncertainty would be the challenges associated with producing greater numbers of yearly fish in the hatchery. There is the potential that fish health problems (other diseases) may be encountered in the hatchery in fish that are kept to larger sizes and not released during typical juvenile out-migration periods.

Control Measures Considered but Eliminated from Further Consideration:

1. *Dewatering.*
2. *Manual carcass removal*
3. *Direct sediment introduction*
4. *Channel restoration*

The assumptions and uncertainties characterized for eliminating the above control measures from further consideration were minimal. In most cases the action was not considered feasible from an implementation standpoint or was not considered further due to the "imminent prospect of dam removal".

4. What is the level of scientific support for eliminating the four control measures that were "considered but eliminated from further consideration"?

The measures that were eliminated from further consideration do not appear to have been thoroughly evaluated, but there were clear uncertainties with each of these measures and in most cases a lack of scientific data to support the options one way or the other. An example would be dewatering to allow for desiccation of polychaetes. The scientific support for this would be that substantial removal of the intermediate host for *C. shasta* would result in overall disease reduction. However, this control measure was assumed to damage other important ecological functions of the river, and that polychaetes reside in deeper portions of the river and may not be impacted by the low flows. These points may have merit but further evaluation of short term dewatering during specific times of the year may warrant further investigation.

The primary reasons for not further considering most of these control measures related to the feasibility of implementation due to perceived difficulties (and cost) of such actions (e.g. dewatering and carcass removal). Other reasons for not considering further relate to the potential of dam removal in the system (e.g. measures 3 and 4). The two measures that are most supported by the scientific data would be dewatering and carcass removal; however, the challenges and uncertainties for either option are many.

5. Specific to management measures within the Guidance Document:

a. Are the flow magnitudes identified within management measures 1 and 2 (6,030 cfs and 11,250 cfs, respectively) better supported than any other value within the range of surface flushing flows (5,000 - 8,700 cfs) and deep flushing/armor disturbance flows (8,700 - 11,250 cfs)?

It is difficult to know the impacts of such flows and the duration and timing with polychaete abundance infection prevalence plays such a critical role. Given what there is to go on, the most supported flow numbers relate to the deep flushing/armor disturbance flows of up to 11,250 cfs or higher geomorphic flows when possible.

b. What scientific support exists for implementing surface and deep flushing flows at a frequency other than the natural recurrence interval based on geomorphic assessments of the Klamath River? Please consider that flows of this magnitude have not occurred at the natural recurrence interval in the recent past.

As described earlier, 2017 data provides insight on flow effects and formulation of conclusions related to implementing such flows. High magnitude flows did occur and there was an effect. The question of the frequency outside of when they would naturally occur would be based on the scientific information showing parasite levels that are historically high, presumably due to the unnatural hydrologic regime of the system over the past 2 decades. In the short term, the scientific support would suggest that implementing high flows during critical times is most important (these may or may not coincide with traditional intervals). Additionally, there is support for providing such flows at any time possible to move polychaetes and reduce their preferred habitat.

i. If there is scientific support for implementing these flows at a frequency other than the natural recurrence interval, at what point is a return to the natural recurrence interval appropriate?

Yes, the scientific support for flow increases outside of the natural recurrence interval relates the fact that high flows reduce polychaete abundance and infection risks. This scientific finding and the "objectives" outlined in the Guidance Document relate to the requirement of limiting infection risks through flow alterations. Any increase in flow would be beneficial from a number of different standpoints (e.g. sediment mobilization, spore dilution, carcass redistribution, etc.).

c. To what degree do hatchery management practices contribute to the transmission of *C. shasta* between salmonids and polychaetes? Please consider both inter- and intra-annual effects.

Hatchery practices at Iron Gate Hatchery may contribute to transmission of myxospores between salmonids and polychaetes. This should be qualified in that any contribution would be based on the level of infection in hatchery fish once they emigrate from (or die during migration) the system. As suggested, hatchery contribution may be minimized by releasing during low actinospore periods (earlier in May rather than later in June). Review of infection levels between years provides evidence that in some years fish (hatchery and wild – most likely) can have high POI. There is potential to minimize this annually and scientific evidence was presented (Fish infection memo) and suggests that if spore concentrations are low and fish are released when temperatures are low (10ºC) and flows are at high velocities (>.2 to .3 m/s) infection rates would be minimized. If spring flushing flows could coincide with hatchery release strategies it is likely this would have the greatest benefit for reducing *C.shasta* impact on juvenile fish.

d. What is the level of scientific support for using spore dilution as a mechanism to minimize and/or reduce the prevalence of infection in out-migrating salmonids? If support exists:

Reducing the infective dose of the infections actinospore stage for *C. shasta* is scientifically justified as a mechanism to lower the POI of out-migrating salmonids. This would be important for Coho and Chinook salmon as well as other susceptible species in the system. As exposure dose corresponds to infection and disease state for fish, even if fish become infected the risk to population level disease impact would be lowered by this approach. Another important factor is that for this endemic parasite, many species co-evolve with it and develop some level of immunity. Although this is the case in the Klamath and those salmonids native to the system have partial resistance, they are still impacted when the parasite is present at high levels in the river. This is simply because they are overwhelmed by the high infective dose resulting in clinical disease and mortality.

Ideally, the parasite life cycle should be broken and one of the two hosts eliminated; however, this is unlikely given the dynamics of such a natural system. The only option would be to limit spore exposure during the stage that the *C. shasta* is infective for fish. Given the complex life cycle of this parasite and the ecological constraints to the Klamath system, other more drastic measures are impractical for the most part.

i. How is the effectiveness of management measure 4 expected to change longitudinally along the Klamath River?

The effectiveness of this management measure will depend upon rapid monitoring and implementation. If emergency flows are implemented in an attempt to dilute spore concentrations, the longitudinal effectiveness may be influenced by actinospore production and release throughout the

system and any additional natural flow increases. Benefit would be greatest if flow increase result in reduced out-migration timing and dilution of spore per liter concentrations. From a monitoring standpoint it may be important to collect samples further downstream as the duration of exposure would increase longitudinally and this could result in a higher POI at collection points downstream from the Kinsman trap.

ii. Would the inclusion of temperature and/or specific monitoring location as additional triggers for implementation of management measure 4 better predict salmonid prevalence of infection (POI)?

The specific location for monitoring is set at the Kinsman screw trap. Yes, another measure based on temperature may be important as an additional trigger to release water if it can be predicted that such a release would lower water temperature to levels that would reduce actinospore release from polychaetes. Addition of other monitoring sites would also be beneficial and provide a broader picture of what is happening in relation to spore concentration and POI. It should be realized that the real time nature of the monitoring proposed may limit consideration of criteria at multiple sites and such consideration could delay implementation of the emergency release due to sample analysis constraints.

iii. How does a non-genotypic-specific spore concentration and trigger relate to POI within Chinook and coho salmon?

Clearly it would be ideal to define spore genotype from water samples; however, if the threshold is set at 5 spores per liter for *C. shasta* then this should provide a conservative target beneficial to both Coho and Chinook. Theoretically, if 5 spores per liter were all type 2 then Coho may be impacted the most, but given the likely mix of spore types in the samples it seems unlikely that all spores would be of type 2 genotype.

iv. Is a non-genotypic spore concentration greater than 5 spores/L an accurate indicator of increasing POI in both Chinook and coho salmon?

As stated above, it would be a good indicator of risk and potential POI of both Chinook and Coho, but conservative in nature. If all spores are type 1 then it would indicate that only Chinook are at risk of increasing POI (although infection risk for Chinook is at 10 spores per liter). If all spores are type 2 and the concentration is greater than 5 spores per liter then indeed Coho would be at risk of increasing POI. It is important to determine spore genotype, but given the importance of a rapid turnaround, this could be followed up on post initial analysis of samples.

6. Are the triggers included in Management Guidance 4 for implementing an emergency dilution flow indicative of imminent increases in salmonid POI?

Yes they appear to be, but other triggers such as those described above (e.g. temperature, spore concentration at other monitoring sites, etc.) may provide a further indication of the imminent risk of increasing POI in out-migrating fish.

a. Referencing the spore and fish infection technical memos and the associated actinospore and Klamath River flow data (2005-2017), how would the emergency dilution flows have influenced spore concentrations in the Klamath River below Iron Gate Dam? Given the varying distribution of the 'infectious zone' and river flows at which the triggers have been exceeded in the period of record (2005-2017), can emergency dilution flows be reasonably expected to measurably decrease the prevalence of *C. shasta* in outmigrating salmon? If so, what is the minimum Iron Gate Dam flow that would be beneficial?

Given the past information, the emergency dilution flows (measure 4) would have most likely influenced spore concentration (reduced) in years listed where flows never reached a 6,030 cfs minimum (measure 1). Other than stating the obvious that spore concentration (i.e. spores per liter) would have been lower below IGD, it is difficult to know the magnitude or spatial effects downstream. The ability of emergency dilution flows to measurably decrease the POI in out-migrating salmon would clearly depend on many factors. However, if other measures (such as hatchery release timing, temperature, etc.) reflect recommendations in the Guidance document then it would be reasonable to assume that measurable decreases in POI would be observed in out-migrating salmon. Based on the Fish Infection Memo and information in the guidance document, discharges of 1900 cfs did not appear to have an effect; however, releases of 3000 and 4000 cfs in 2012 coincided with low disease occurrence.

The question of what is the minimum IGD flow that would be beneficial is difficult due to all the factors described. The 3000 cfs may indeed reflect a minimum. If higher levels could be achieved then more benefit would be expected, and vice versa. The recommendation to increase flows to 4000 cfs if spore loads do not decrease after 7 days is good, but there is still uncertainty on how effective this will be. In years where flows are low and spore concentrations in the water are high, the likelihood of an emergency dilution flow affecting POI would be greater than on a year where triggers are hit during periods of higher flows. The effect of this flow on temperature is also important and if such releases result in an increase in temperature, the measure may be counterproductive.

7. What level of scientific support exists for the need to implement the management measures in the absence of the four hydroelectric dams (i.e., after Klamath River dam decommissioning)?

The historic pre-dam incidence of *C. shasta* prevalence within the Klamath River is not well documented, but there are potential risks associated with dam removal. *Ceratonova shasta* and the polychaete host (*Manayunkia sp.)* are present in the upper basin and high parasite densities have been noted in some areas, especially the Williamson River, a tributary of the Klamath River. Hurst et al. (2012) looked at the risk of infection in Coho and Chinook salmon in this tributary by conducting sentinel exposures. Pathology associated with infections was minimal and it was concluded that parasite genotype differences existed in upper basin locations, although the type 2 genotype seems to persisted above the dam. Dam removal may impact parasite populations in the upper basin if lower basin genotypes are transported and distributed widely by anadromous fish moving into these sections. Scientific support for the need to implement the described management measures in the absence of the four hydroelectric dams is minimal at this time. If (when) the dams are fully decommissioned, it is assumed that the Klamath River would have seasonal high and low flows characteristic of historic natural river conditions. As such, the occurrence of disease caused by *C. shasta* would be expected to be cyclic and follow a similar patter based on flow and temperature and be exacerbated during drought conditions. If the upper basin is characterized by parasite genotypes with minimal risk to Coho and Chinook, the immediate risk to increases in POI would be minimal as fish begin utilizing the upper basin. If genotypes infectious for Coho and Chinook become further established in the upper basin then increases in POI in out-migrating juveniles in those sections may increase over time. It is unclear how or what flow based management measures would be feasible to implement in the absence of the target hydroelectric dams. It may be possible to implement measures that were eliminated from consideration in the Guidance Document such as carcass removal, sediment introduction, or channel restoration. However, these and any potential flow alterations would need to be further evaluated in the context of the new river habitat. Overall, disease incidence is unlikely to be eliminated in the absence of dams.

It will be important to continue to monitor impacts on Fish Health and *C. shasta* populations in the Klamath River post dam removal or decommissioning. Clearly, there will initially be dramatic changes in sediment loads and sediment transport. This could result in unforeseen changes in polychaete habitat and the resulting spore concentrations and POI may be influenced for an unknown period of time. Changes in the environmental conditions of the river and a return to more historic hydrographs would be expected to be beneficial; however, there is the possibility that newly opened upstream habitats harbor other bacterial and viral pathogens in addition to *C. shasta* that could impact Coho and Chinook salmon populations. The key for long term health of the system will relate to that ability of these important salmonid species to adapt and evolve with endemic pathogens. Even so, it is expected that natural cyclic impacts will be observed, especially in the context of impending climate change.

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