David – thanks for sharing your thoughts on the letter and regional responses. It's getting ample regional exposure. BPA supports Kintama's desire to secure necessary data. That said, I want to ensure we achieve success while also maintaining constructive relationships with regional partners. Based on points in Tim Copeland's email and Aswea's response below, could you provide BPA with a modified and specific request for FPC and other possible data sources (i.e. tagging agencies). We will have an internal discussion of how best to assist once we have a specific list.

Thanks very much and have a nice weekend

Jody B. Lando, Ph.D.
Research, Monitoring and Evaluation Lead | EWP-4

Bonneville Power Administration
jblando@bpa.gov | P 503-230-5809 | C [redacted]

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-

From: David Welch [mailto:David.Welch@kintama.com]
Sent: Friday, October 04, 2019 11:31 AM
To: Petersen,Christine H (BPA) - EWP-4; Lando,Jody B (BPA) - EWP-4
Cc: Erin Rechisky
Subject: [EXTERNAL] FW: Kintama Letter

Christine and Jody—

Not to belabor this point any further, but Aswea has documented that the FPC folks really do already generate the smolt survival above the topmost dam, at least for the Snake River populations. Just read the text highlighted in yellow, below.

No need to respond here, it is just that the FPC is claiming to us that this is hard to do (which it isn't), and already doing it for their own purposes in the 2018 CSS report.

From: Aswea Porter
Sent: Friday, October 04, 2019 11:20 AM
To: David Welch
Cc: Erin Rechisky
Subject: RE: Kintama Letter

Tim's comments do have merit but he is talking about wild fish while Christine interpreted hatchery. Most of the [redacted]

Although Tim's email does address survivals from release to the top dam, there was room in our letter for the FPC to misconstrue that we would accept the S1 survivals (release to top dam).

The CSS should have S1 survivals release to the top dam based on their methods.

Where:

From: David Welch
Sent: October-04-19 15:14
To: Petersen,Christine H (BPA) - EWP-4
Cc: Lando,Jody B (BPA) - EWP-4; Erin Rechisky; Aswea Porter
Subject: RE: Kintama Letter

Hi Christine—

Thanks for these emails. They fit the common pattern, which is that when someone says something contrary to the conventional dogma in the Columbia River basin (and simple!!) the response nearly always seems to be along the lines of *"…well, wait a minute… here are all these possible complexities!!*". The critic then provides a list of things that *might* affect the answer/conclusions… and then stop. I don't think I can recall a case yet where the critic actually rolls up their sleeves and digs into whether or not the possible issues means that the contradictory findings would really be undermined by the issues raised. It seems that no one actually wants to actually move things forward, just defend the status quo.

I have a call planned with Greg Ruggerone to ask him his perspective on a few things today. I am just waiting on our preparation of a summary graph to guide that discussion.

Could we set up a call with you very late this afternoon or (perhaps preferable) on Monday?

David

From: Petersen,Christine H (BPA) - EWP-4 [mailto:chpetersen@bpa.gov]
Sent: Friday, October 04, 2019 9:49 AM
To: David Welch
Cc: Lando,Jody B (BPA) - EWP-4
Subject: FW: Kintama Letter

Hi David,

I am copying a response to the mass email from two days ago (just noticed they misspelled the address of Ritchey Graves). Anyhow, some of what Tim Copeland is saying is fairly valuable as far as actually being able to track down hatchery-to-hatchery SARs.

That we or you should have tried to approach groups operating hatcheries and wild traps at IDFG and other entities was not obvious. I will also admit to being somewhat surprised when Josh Murauskas suggested it would be not particularly time consuming to get the data from PTAGIS (would take him less than a week?). In 2017, my memory of the verbal conversation over at the FPC office (following an emailed request for data – which was to be used for our BA – (it's not quite fair to act like we were misleading them by saying it was for the BA)) was that Gabe Scheer said that it would take him months and months to get the Hatchery-to-hatchery SARs. This was primarily because there are some many year X site combinations. But they said that they could start working on it in the background. But because this was a verbal conversation, there is no record and people can walk away remembering something different. Carrying out the correspondence via written letter and then email is a bit more bold but it does get your and their position there on the record.

However, you will want to consider your next steps. What Tim is saying backs up the idea that CWT hatchery-to-hatchery SARs and PIT based SARs have many differences. In his response, I don't think that Tim understands that you are not trying to group the hatcheries together, but are requesting the data so that you can avoid doing that. Are these PIT based hatchery or trap SARs actually available from other entities?

By the way, Charlie Paulsen and a few others in the NOAA modeling circles have looked into the patterns of movement and survival upstream of Lower Granite. Size at tagging, by itself, could confound the rate of movement downstream from both traps and hatcheries (in the CSS study, it is assumed that the multiple tagging groups randomly enter into the Co (undetected) and C1 (detected) groups at Lower Granite, Little Goose). But size at tagging is just one factor for what is happening upstream – you have traps in warm tributaries like the Lemhi, traps in cold tributaries, hatcheries at varying distances to Lower Granite that raise their juveniles to different sizes at release. It is messy, just as Tim Copeland is saying.

I am going to talk to Jody later today. Perhaps we could arrange for a check in or update with you soon?

Christine Petersen

From: Copeland,Tim [mailto:tim.copeland@idfg.idaho.gov]
Sent: Wednesday, October 02, 2019 2:37 PM
To: Michele Dehart; Adam Storch (adam.j.storch@state.or.us); Erick VanDyke (Erick.S.VanDyke@coho2.dfw.state.or.us); Tucker Jones (tucker.a.jones@state.or.us); 'Tom Lorz (lort@critfc.org)'; 'Rob Lothrop (lotr@critfc.org)'; Robert Lessard (LESR@critfc.org); 'Christine Golightly'; 'ED.Bowles@state.or.us'; Hebdon,Lance; Rawding, Daniel J (DFW) (Daniel.Rawding@dfw.wa.gov); 'Bill Tweit (tweitwmt@dfw.wa.gov)'; Garrity, Michael D (DFW) (Michael.Garrity@dfw.wa.gov); Steve_Haeseker@fws.gov; David Swank; ritche.graves@noaa.gov; Jay Hesse (jayh@nezperce.org); zpenney@critfc.org
Cc: Jerry McCann; Brandon Chockley; Erin Cooper; Gabriel Scheer; Bobby Hsu; Petersen,Christine H (BPA) - EWP-4; Schrader,Bill; Bowersox,Brett
Subject: [EXTERNAL] RE: Kintama Letter

Hi Michele,

I'd like to make two points relevant to this letter.

Survival from release to Lower Granite Dam has always been the responsibility of the tagging agencies, not CSS. Much of the tagging in the Snake basin has been in cooperation with and assisted by CSS (in the form of extra PIT tags), but the traps where this tagging occurs were usually established for other reasons. In essence, CSS has been leveraging work done by other entities to generate more tags into the hydrosystem. This is an effective and efficient way for CSS to facilitate its analyses of events downstream of Lower Granite Dam. To come to my first point, Dr Welch was asking the wrong people.

Second, for wild salmon and steelhead in the Snake basin, we tend to define a smolt as a fish that has passed Lower Granite Dam. We treat the geographic location of the dam as our evaluation point for the life stage. That is because a majority of the juveniles exiting natal streams do so in the fall (see Copeland et al 2014 TAFS 143:1460-1475). There are literally hundreds of miles of river below some tagging sites with suitable habitat for little salmon and steelhead. Steelhead in particular may make extensive use of this habitat, residing several years before smolting in some cases. Hence mortality from initiation of smoltification is confounded with winter mortality (and more for steelhead). Further, fish that use downstream habitats often have a different SAR (LGR-BON) than those that remain in their natal stream until smolting. Again, Dr Welch was not asking the right people. I do not believe simplifying this diversity into a single number for easy comparison is justifiable.

Sincerely, Tim

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Timothy Copeland, PhD

Coordinator

Wild Salmon & Steelhead Monitoring Program

Idaho Department of Fish & Game

(208)287-2782

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Tim:

I agree with all of your points. Welch is doing this under contract with BPA. Although we have asked for the contract deliverables, BPA has not provided them. The Welch article submitted for publication in PLOS, illuminates the purpose/reason that Welch is asking for this data. Welch has already circulated this article to the region by submitting it to the NPCC Fish and Wildlife amendment process. Let me know if you do not have a copy of this article. The Welch request is for CSS tag data. We will provide the data to Welch. We will review whatever analyses Kintama does for BPA and make our comments available to the region.

Michele

From: Lando,Jody B (BPA) - EWP-4

Sent: Wed Oct 09 17:43:01 2019

To: David Welch; Petersen,Christine H (BPA) - EWP-4

Cc: Erin Rechisky

Subject: RE: Kintama Letter to FPC

Importance: Normal

It would be good to talk, but next week would be much better than this week.

Christine – please use my calendar to find a time that works.

Jody B. Lando, Ph.D.
Research, Monitoring and Evaluation Lead | EWP-4

Bonneville Power Administration
jblando@bpa.gov | P 503-230-5809 | C [redacted]

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From: David Welch [mailto:David.Welch@kintama.com]

Sent: Wednesday, October 09, 2019 4:11 PM
To: Petersen,Christine H (BPA) - EWP-4; Lando,Jody B (BPA) - EWP-4
Cc: Erin Rechisky
Subject: [EXTERNAL] RE: Kintama Letter to FPC

Erin is away on Thursday at another meeting, and [redacted]

My schedule is wide open on Friday, but it looks from [redacted] **otherwise, she seems to be free.**

I suggest that we let you & Jody set a time that works for you on Friday, and one or both of us will make sure we are able to cal in. Attached is an updated version of the harvest rate multiplier graph.

If Friday won't work both of our schedules look pretty open next week.

David

From: Petersen,Christine H (BPA) - EWP-4 [mailto:chpetersen@bpa.gov]
Sent: Wednesday, October 09, 2019 4:04 PM
To: David Welch; Lando,Jody B (BPA) - EWP-4

Cc: Erin Rechisky
Subject: RE: Kintama Letter to FPC

Jody, David, Erin,

Would 1-2pm tomorrow (Thursday) be a good time for a phone call? We could check in on this particular subject, and also how things are going in general.

I know Jody is juggling multiple things. Please let me know if Friday or next week would be better (we have a federal holiday on Monday). It would be nice to go over this, especially if it was a burning issue to inquire with Tim Copeland as to how to get hatchery or trap-to Bonneville SARs from any particular groups. However, I know that you have been discussing how to proceed on multiple elements of your revision.

Christine

From: David Welch [mailto:David.Welch@kintama.com]
Sent: Monday, October 07, 2019 11:49 AM
To: Lando,Jody B (BPA) - EWP-4; Petersen,Christine H (BPA) - EWP-4
Cc: Erin Rechisky
Subject: [EXTERNAL] RE: Kintama Letter to FPC

Hi Jody—

I agree with the desire to try to keep some level of civility in the proceedings. However, before we engage in yet another fishing expedition for more data, I think we should caucus by phone to go over what we have already established: I don't think that getting even more data at this point will be productive. We have already vastly exceeded what my original time budget was for getting the data sorted out—I had naively thought that most of our time would be spent analyzing the published SAR data and asking what it all meant, not in trying to "prove" the data was perfect (which is where the FPC is trying to push the debate).

I have what I wanted to achieve simply by sending the letter. The original criticism by the FPC to our prior analysis was in part that their published data wasn't the "right" data to use because it excludes upstream survival. If they now make that argument to the editor of the journal again, we will be able to stand firm and say that we tried to get "more correct" data, but were rebuffed. As we said in the original manuscript, if it had worked out that the SARs for Puget Sound or British Columbia were in the 2-6% recovery target range that the Columbia wants to achieve there seems little doubt that those currently hostile to our analysis would have embraced it without question and used it as proof that the recovery targets were in fact achievable because river systems.

That being said, we do need to caucus and have a discussion soon. The points to discuss are:

(b)(5) [redacted]

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[redacted]

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[redacted]

(b)(5)
[redacted]

(b)(5)

[redacted]

(b)(5)

[redacted]

(b)(5) [redacted]

Lots of detail here—apologies in advance. We will walk you through this one step at a time in a phone call when it is convenient for you. Please consider everything we have outlined as preliminary until we can fully nail things down.

David Welch

From: Lando,Jody B (BPA) - EWP-4 [mailto:jblando@bpa.gov]
Sent: Friday, October 04, 2019 2:48 PM
To: David Welch; Petersen,Christine H (BPA) - EWP-4
Cc: Erin Rechisky
Subject: RE: Kintama Letter

David – thanks for sharing your thoughts on the letter and regional responses. It's getting ample regional exposure. BPA supports Kintama's desire to secure necessary data. That said, I want to ensure we achieve success while also maintaining constructive relationships with regional partners. Based on points in Tim Copeland's email and Aswea's response below, could you provide BPA with a modified and specific request for FPC and other possible data sources (i.e. tagging agencies). We will have an internal discussion of how best to assist once we have a specific list.

Thanks very much and have a nice weekend

Jody B. Lando, Ph.D.
Research, Monitoring and Evaluation Lead | EWP-4

Bonneville Power Administration
jblando@bpa.gov | P 503-230-5809 | C (b)(6) [redacted]

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From: David Welch [mailto:David.Welch@kintama.com]
Sent: Friday, October 04, 2019 11:31 AM
To: Petersen,Christine H (BPA) - EWP-4; Lando,Jody B (BPA) - EWP-4
Cc: Erin Rechisky
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Christine and Jody—

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generate the smolt survival above the topmost dam, at least for the Snake River populations. Just read the text highlighted in yellow, below.

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Sent: Friday, October 04, 2019 11:20 AM
To: David Welch
Cc: Erin Rechisky
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Tim's comments do have merit but he is talking about wild fish while Christine interpreted hatchery. Most of the [redacted]

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The CSS should have S1 survivals release to the top dam based on their methods.

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From: David Welch
Sent: October-04-19 15:14
To: Petersen,Christine H (BPA) - EWP-4
Cc: Lando,Jody B (BPA) - EWP-4; Erin Rechisky; Aswea Porter
Subject: RE: Kintama Letter

Hi Christine—

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I have a call planned with Greg Ruggerone to ask him his perspective on a few things today. I am just waiting on our preparation of a summary graph to guide that discussion.

Could we set up a call with you very late this afternoon or (perhaps preferable) on Monday?

David

From: Petersen,Christine H (BPA) - EWP-4 [mailto:chpetersen@bpa.gov]
Sent: Friday, October 04, 2019 9:49 AM
To: David Welch
Cc: Lando,Jody B (BPA) - EWP-4
Subject: FW: Kintama Letter

Hi David,

I am copying a response to the mass email from two days ago (just noticed they misspelled the address of Ritchey Graves). Anyhow, some of what Tim Copeland is saying is fairly valuable as far as actually being able to track down hatchery-to-hatchery SARs.

That we or you should have tried to approach groups operating hatcheries and wild traps at IDFG and other entities was not obvious. I will also admit to being somewhat surprised when Josh Murauskas suggested it would be not particularly time consuming to get the data from PTAGIS (would take him less than a week?). In 2017, my memory of the verbal conversation over at the FPC office (following an emailed request for data – which was to be used for our BA – (it's not quite fair to act like we were misleading them by saying it was for the BA)) was that Gabe Scheer said that it would take him months and months to get the Hatchery-to-hatchery SARs. This was primarily because there are some many year X site combinations. But they said that they could start working on it in the background. But because this was a verbal conversation, there is no record and people can walk away remembering something different. Carrying out the correspondence via written letter and then email is a bit more bold but it does get your and their position there on the record.

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I am going to talk to Jody later today. Perhaps we could arrange for a check in or update with you soon?

Christine Petersen

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Sent: Wednesday, October 02, 2019 2:37 PM
To: Michele Dehart; Adam Storch (adam.j.storch@state.or.us); Erick VanDyke (Erick.S.VanDyke@coho2.dfw.state.or.us); Tucker Jones (tucker.a.jones@state.or.us); 'Tom Lorz (lort@critfc.org)'; 'Rob Lothrop (lotr@critfc.org)'; Robert Lessard (LESR@critfc.org); 'Christine Golightly'; 'ED.Bowles@state.or.us'; Hebdon,Lance; Rawding, Daniel J (DFW) (Daniel.Rawding@dfw.wa.gov); 'Bill Tweit (tweitwmt@dfw.wa.gov)'; Garrity, Michael D (DFW) (Michael.Garrity@dfw.wa.gov); Steve_Haeseker@fws.gov; David Swank; ritche.graves@noaa.gov; Jay Hesse (jayh@nezperce.org); zpenney@critfc.org
Cc: Jerry McCann; Brandon Chockley; Erin Cooper; Gabriel Scheer; Bobby Hsu; Petersen,Christine H (BPA) - EWP-4; Schrader,Bill; Bowersox,Brett
Subject: [EXTERNAL] RE: Kintama Letter

Hi Michele,

I'd like to make two points relevant to this letter.

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Sincerely, Tim

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Timothy Copeland, PhD

Coordinator

Wild Salmon & Steelhead Monitoring Program

Idaho Department of Fish & Game

(208)287-2782

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Tim:

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Michele

From: Petersen,Christine H (BPA) - EWP-4
Sent: Fri May 22 14:35:04 2020
To: 'David Welch'; Erin Rechisky; Aswea Porter
Subject: RE: 18th
Importance: Normal
Attachments: IWR W912HQ20F0011 CRSO Ecological Models Final Model Report_May 4 2020.pdf

Hi David,
Sorry for the slow response. Things really have been quite busy with the two Biological Opinions, and (b)(5) [redacted]ey are public, so I could possibly share it later. It was interesting to see what people brought up, and we were able to cite your papers in a few cases. There were a few people outside the agencies who showed good understanding of what is going on, and there were a lot who were emphasizing the killer whale themes and other talking points.

Regarding the proposal – I will talk to Jody again when she emerges from the USFWS Biological Opinion review. She primarily asked if you could circulate a '1 pager' for any proposal ideas rather than try to fit it all into a one hour presentation. It was not necessarily a call for doing a large amount of extra work.

Discussing a telemetry proposal would be fairly complex, so that might be something we would have to set up as a follow up phone call. I could remind everyone that we have this second data analysis in the contract that was halted while we asked you to focus on this revision, and I could also let everyone know that you do have additional concepts including field work.

We should all have a sort of renewed perspective on the next few years, with a variety of new research objectives expressed in the Biological Opinions from NOAA and USFWS. I will also share a public review that the IEPR panel made based on the set of models used in the CRS environmental impact statement which included CSS, Compass, the NOAA lifecycle model framework, and UW's TDG models. They spent a lot of time making a series of recommendations regarding TDG, including using 3-d computational fluid dynamics models, using advanced telemetry to get depth and time distribution data in the tailraces, and also integrate all the results into population exposure and survival models. In helping the Corps write the response to these recommendations, I was a little unsure about what we would be committing the Corps to doing, if I wrote "yes, we agree with your recommendation, we should include these objectives in future monitoring plans".

I could hunt for the Columbia treaty modeling results, but I know that some of the official final reports have been embargoed, and they aren't being distributed for some reason.

Christine

From: David Welch <David.Welch@Kintama.com>
Sent: Thursday, May 7, 2020 4:39 PM
To: Petersen,Christine H (BPA) - EWP-4 <chpetersen@bpa.gov>; Erin Rechisky <

Erin.Rechisky@Kintama.com>; Aswea Porter <Aswea.Porter@Kintama.com>
Subject: [EXTERNAL] RE: 18th

Thanks—

1) You wrote "there are papers describing at least 3-5 different potential mechanisms of 'carryover effect', some of which appear to be more realistic than others"**. Are these papers available for us to read?**

(b)(5) [redacted]

3) We will focus on presenting the findings of the revised paper on May 29th. Your colleagues in principle should be somewhat aware of them, but our last check in was November 1st, as I recall. It will be good timing to review the substance again in light of the EIS, which we will read in the interim.

(b)(5) [redacted]

5) Do you have an idea of where the original Haeseker analysis is? I would like to take a look at it, starting from first principles. However, there seem to be various iterations of it around (or at least varying citations), so I wanted to read the original analysis that underlays the whole higher spill/TDG argument.

From: Petersen,Christine H (BPA) - EWP-4 < chpetersen@bpa.gov>
Sent: Thursday, May 07, 2020 12:27 PM
To: David Welch < David.Welch@Kintama.com>; Erin Rechisky < Erin.Rechisky@Kintama.com>; Aswea Porter < Aswea.Porter@Kintama.com>
Subject: RE: 18th

Hi,
Sorry for the slow response.

We moved the day of the presentation because many of us are really stretched for time what with the review of two Biological Opinions, and Leah Sullivan and John Skidmore potentially couldn't attend.

I spoke with Jody Lando. We are very much interested in your new ideas. This month is a challenging time to review a proposal under our technical services procedure but June could be a much better period. Plus we would approach this with a lot of new perspective based on the new 'Conservation Measures' list that NOAA is requiring (this replaces the RPA table from the 2008 Biological opinion). I wish I could copy and paste this for you to scan, but the document says it is in draft form so I cannot.

(b)(5) [redacted]

(b)(5) [redacted]

(b)(5) [redacted]

https://grok.newsdata.com/cgi-bin/viewpdf.cgi?iss=cup1951&cid=IFJrjXxjxeiQ

Talk to you soon,
Christine Petersen

From: David Welch < David.Welch@Kintama.com>
Sent: Friday, May 1, 2020 12:53 PM
To: Erin Rechisky < Erin.Rechisky@Kintama.com>; Petersen,Christine H (BPA) - EWP-4 < chpetersen@bpa.gov>; Aswea Porter < Aswea.Porter@Kintama.com>
Subject: [EXTERNAL] RE: 18th

Yes, reaching a bigger audience and getting broader feedback is probably wise. With the self-isolation likely to go on in a very substantive way for a long while, I am sure we can accommodate whatever works for you; I certainly have nothing planned in the way of travel!

A question—does a discussion on starting the next contract need to come after the presentation? Obviously, I would prefer to nail that contract down asap. I would

(b)(5) [redacted]

Your thoughts?

David

From: Erin Rechisky < Erin.Rechisky@Kintama.com>
Sent: Friday, May 01, 2020 12:08 PM
To: Petersen,Christine H (BPA) - EWP-4 < chpetersen@bpa.gov>; Aswea Porter < Aswea.Porter@Kintama.com>; David Welch < David.Welch@Kintama.com>
Subject: RE: 18th

(b)(6) [redacted]

Erin

From: Petersen,Christine H (BPA) - EWP-4 < chpetersen@bpa.gov>
Sent: May 1, 2020 10:56 AM
To: Aswea Porter < Aswea.Porter@Kintama.com>; Erin Rechisky < Erin.Rechisky@Kintama.com>;

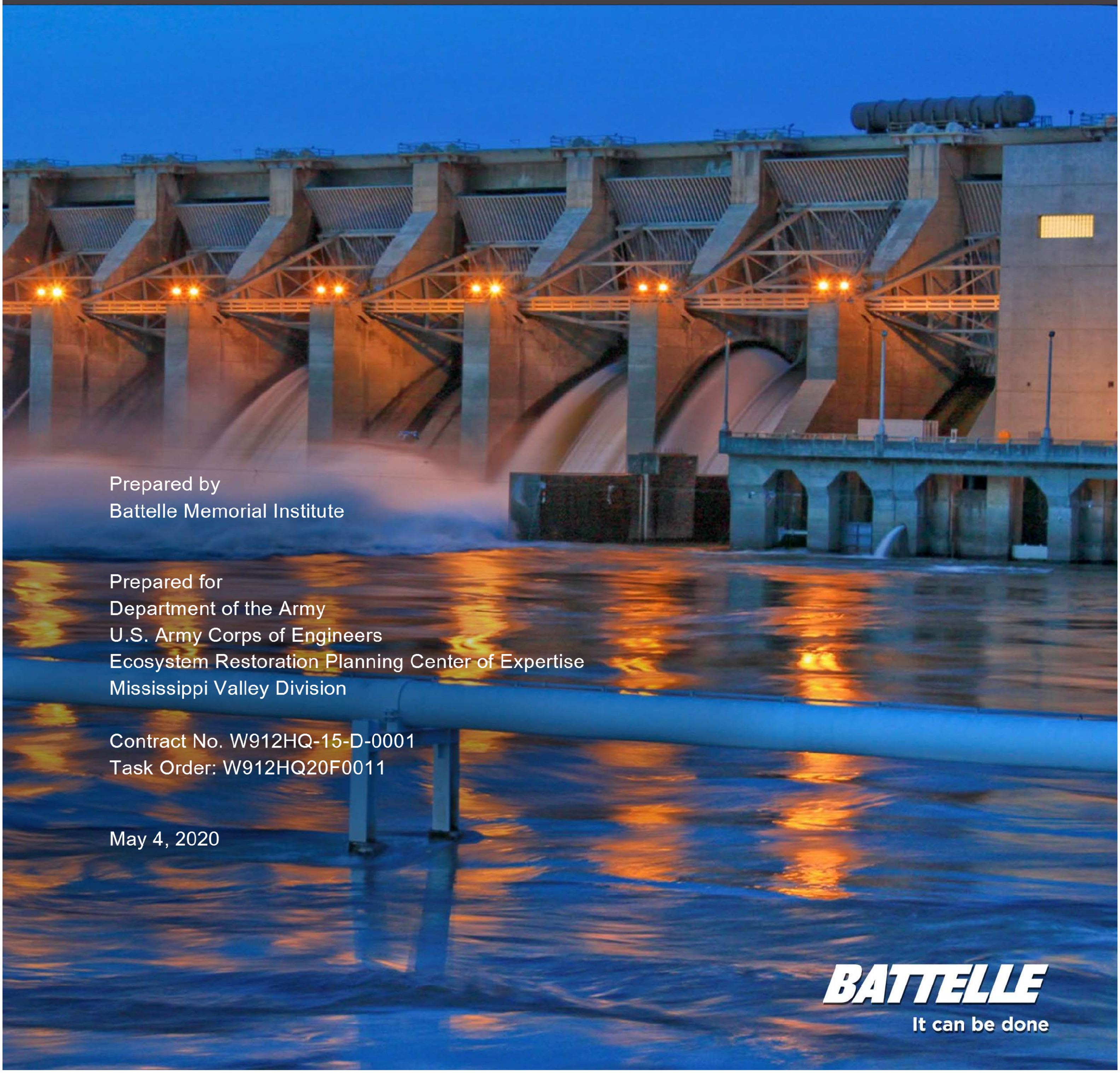
David Welch < David.Welch@Kintama.com>
Subject: 18th

Hi,
I got some feedback that a few people feel really time crunched for the whole month because we will receive two Biological Opinion documents to quickly review so they have already signed up to do overtime and have no time to spare at all, plus we have the added situation of people having kids at home and being less efficient. They were recommending a day May 27th or later.

I will take a look for a different day that we could potentially move this to. Maybe the afternoon of the 29th? I would like to give you the opportunity to talk to a fairly large audience.

Christine

Final Report for the Model Independent External Peer Review Columbia River System Operations (CRSO) Ecological Models



Prepared by
Battelle Memorial Institute

Prepared for
Department of the Army
U.S. Army Corps of Engineers
Ecosystem Restoration Planning Center of Expertise
Mississippi Valley Division

Contract No. W912HQ-15-D-0001
Task Order: W912HQ20F0011

May 4, 2020

BATTELLE
It can be done

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CONTRACT NO. W912HQ-15-D-0001
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Final Report for the Model Independent External Peer Review Columbia River System Operations (CRSO) Ecological Models

Prepared by

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Final Report for the Model Independent External Peer Review Columbia River System Operations (CRSO) Ecological Models

Executive Summary

Project Background and Purpose

The U.S. Army Corps of Engineers (USACE), Bonneville Power Administration (BPA), and Bureau of Reclamation (Co-lead Agencies) are jointly developing a comprehensive Environmental Impact Statement (EIS), referred to as the Columbia River System Operations (CRSO) EIS, to evaluate long-term system operations and configurations of 14 multiple-purpose projects that are operated as a coordinated system within the interior Columbia River Basin in Idaho, Montana, Oregon, and Washington. USACE was authorized by Congress to construct, operate, and maintain 12 of these projects for flood risk management, navigation, power generation, fish and wildlife conservation, recreation, and municipal and industrial water supply purposes. USACE projects that are included in the Draft EIS (DEIS) are Libby, Albeni Falls, Dworshak, Chief Joseph, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville. The Bureau of Reclamation was authorized to construct, operate, and maintain the other two projects—Hungry Horse and Grand Coulee—for the purposes of irrigation, flood risk management, navigation, power generation, recreation, and other beneficial uses. The BPA is responsible for marketing and transmitting the power generated by these dams. Together, these Co-lead Agencies are responsible for managing the system for these various purposes, while meeting their other statutory and regulatory obligations.

The Co-lead Agencies will use the DEIS to assess and update their approach for long-term system operations and configurations through the analysis of alternatives and evaluation of potential effects to the human and natural environments. The scope and scale of this project; its potential to impact human life safety; interest on the part of the Governors of Montana, Idaho, Washington, and Oregon and 19 Federally recognized tribes; connection to ongoing litigation on the Federal Columbia River Power System (FCRPS); and the likelihood for the project to result in public dispute drive a requirement for a heightened level of review and meet the criteria of a highly influential scientific assessment in Office of Management and Budget (OMB) and Bureau of Reclamation peer review policies.

The primary goal of ecological model review and approval is to establish that models, analyses, results, and conclusions are theoretically sound, computationally accurate, based on reasonable assumptions, well-documented, and in compliance with the requirements of the OMB Peer Review Bulletin (OMB, 2004). The primary criterion identified for model approval is technical soundness. Technical soundness reflects the ability of the model to represent or simulate the processes and/or functions it is intended to represent. The performance metrics for this criterion are related to theory and computational correctness. In terms of the theory, a quality ecological model should 1) be based on validated and accepted "state of the art" theory; 2) properly incorporate the conceptual theory into the software code; and 3) clearly define the assumptions inherent in the model. In terms of computational correctness, a quality ecological model should 1) employ proper functions and mathematics to estimate functions and processes represented;

and 2) properly estimate and forecast the actual parameters it is intended to estimate and forecast. Other criteria for quality ecological models are efficiency, effectiveness, usability, and clarity in presentation of results. A well-documented quality ecological model will stand the tests of technical soundness based on theory and computational correctness, efficiency, effectiveness, usability, and clarity in presentation of results.

The ecological models reviewed as part of the CRSO Ecological Models Independent External Peer Review (IEPR) include the National Oceanic and Atmospheric Administration (NOAA) Fisheries Comprehensive Passage (COMPASS) Model, the NOAA Fisheries Interior Columbia Basin Life-Cycle Models (LCM), the Fish Passage Center's Comparative Survival Study (CSS) Model, and the University of Washington (UW) Columbia Basin Research Total Dissolved Gas (TDG) Model.

Model Independent External Peer Review Process

Independent, objective peer review is regarded as a critical element in ensuring the reliability of scientific analysis. USACE is conducting an IEPR of the CRSO Ecological Models. As a 501(c)(3) non-profit science and technology organization, Battelle is independent, is free from conflicts of interest (COIs), and meets the requirements for an Outside Eligible Organization (OEO) per guidance described in USACE (2018). Battelle has experience in establishing and administering peer review panels for USACE and was engaged to coordinate this IEPR. The IEPR was external to the agency and conducted following USACE and OMB guidance described in USACE (2018) and OMB (2004). This final report presents the Final Panel Comments of the IEPR Panel (the Panel). Details regarding the IEPR (including the process for selecting panel members, the panel members' biographical information and expertise, the charge submitted to the Panel to guide its review, and additional findings provided by the Panel for further consideration) are presented in appendices.

Based on the technical content of the documentation for the models and the objective of the models, Battelle identified potential candidates for the Panel in the following key technical areas: quantitative ecology (two panel members), integrated ecological modeling, fish passage biology, and mathematical statistics. Battelle screened the candidates to identify those most closely meeting the selection criteria and evaluated them for COIs and availability. USACE was given the list of all the final candidates to independently confirm that they had no COIs, and Battelle made the final selection of the five-person Panel from this list.

The Panel received electronic versions of the model review documents and software along with a charge that solicited comments on specific sections of the documents to be reviewed. Following guidance provided in USACE (2018) and OMB (2004), USACE prepared the charge questions, which were included in the draft and final Work Plans.

The USACE Project Delivery Team (PDT) briefed the Panel and Battelle on the development of the models and their intended application during a teleconference at the start of the review. The purpose of this teleconference was to familiarize the panel members with the models being reviewed. Other than Battelle-facilitated teleconferences, there was no direct communication between the Panel and USACE during the model peer review process.

IEPR panel members reviewed the model documents individually and produced individual comments in response to the charge questions. The panel members then met via teleconference with Battelle to review key technical comments and reach agreement on the Final Panel Comments to be provided to USACE.

Each Final Panel Comment was documented using a five-part format consisting of (1) a comment statement; (2) relevant model assessment criteria; (3) the basis for the comment; (4) the significance of the comment (high, medium/high, medium, medium/low, or low); and (5) recommendations on how to resolve the comment.

Results, Recommendations, and Conclusions of the Model Independent External Peer Review

The panel members agreed on their assessment of the technical quality, system quality, and usability of the CRSO Ecological Models reviewed. The models are very comprehensive and provide a detailed comparison of alternatives under very flexible input specifications. However, the Panel has identified a number of concerns and has provided specific recommendations to improve the models in the Final Panel Comments. Overall, 13 Final Panel Comments were identified and documented. Of these, two were identified as having high significance, four have medium/high significance, six have medium significance, and one has medium/low significance. Table ES-1 lists the Final Panel Comment statements by level of significance. The full text of the Final Panel Comments is presented in Section 5 of this report.

The Panel commends USACE and its modeling teams for developing an integrative modeling approach, incorporating statistical, data-driven, and physics-based models into a framework for forecasting population dynamics of Columbia River System salmonids. Both sets of models, the COMPASS/LCM and the CSS sets, are sensible and credible, and they allow for flexibility over a range of inputs that will be helpful for modeling future conditions.

In building such a modeling framework, USACE and the modeling teams have sought to assemble the best available information to guide decision-making in the future, including alternative selection. However, the Panel further seeks to ensure that these models are useful as a part of a decision-making process and also are not looked upon as the ultimate solution to the understanding of the CRSO ecological system. The ecological modeling program should be thought of as an evolving, adaptive process with both current utility/value and a continual need for improvement. The Panel suggests that the individual modeling teams (LCM, COMPASS, CSS, TDG) each prepare a model status and development plan, including clear statements about knowns, unknowns, and future needs for additional data, additional model formulation, additional controlled laboratory experiments, and additional field testing. The Panel believes that the current models have value in the current EIS process, but that the current models can be improved by incorporating some of the suggestions provided herein, in the near term and in the future, as more data become available and ecological understanding of the system improves.

Based on the documents the Panel was asked to review, the Panel has a number of specific concerns about the technical quality, system quality, and usability of the models and has provided specific recommendations to improve the models in the Final Panel Comments. Recommendations include the following:

- Develop documentation specific to each model used for evaluating alternatives for operating/altering the CRSO project, detailing the exact state of the model at the time it was run; which subcomponents of the models were used and why; the assumptions applied; limitations that remain; outcomes of calibrations conducted; evidence of the model's fit and validation to the environment being assessed; and uncertainties and risks that remain within the outputs and conclusions.

- Reassess the limitations and validity of using large sets of predictor variables to make inferences from relatively small response datasets.
- Assess the impact of using different assumptions with regard to adult migration in the CSS and COMPASS/LCM models.
- Reassess the assumptions regarding TDG and gas bubble disease (GBD) throughout the models, especially regarding fish behavior.
- Revise the model documentation to include complete explanations of model parameters and associated assumptions, procedures for model use, data input needs, and clear illustrations of output metrics.

These issues are important for the effective application of the models by experienced users and USACE staff. The Panel recommends that USACE and the modeling teams address these issues prior to finalizing the decisions made for the models' use.

Table ES-1. Overview of 13 Final Panel Comments Identified by the CRSO Ecological Models IEPR Panel

No.	Final Panel Comment
Significance – High	
1	Differences in the attribution of salmon survival rates to the ocean environment versus Columbia River dam/reservoir operations used in the COMPASS/LCM and CSS models result in increased uncertainty of the actual benefits attained by future changes.
2	The results of testing performed to determine the CSS model's sensitivity to spill and the TDG upper limit may not accurately represent TDG exposures that lead to GBD.
Significance – Medium/High	
3	The use of large sets of predictor variables in the LCM, COMPASS, and CSS models increases the probability of either finding false relationships or exaggerating the effects of any real relationships that end up in each predictive model.
4	The COMPASS/LCM and CSS models are being used to extrapolate beyond the range of conditions to which they have been calibrated.
5	The model documentation often does not report the results of the assessment of model assumptions, fit, or validation.
6	The methodology for use of the powerhouse passage variable (PITPH) in the CSS model is not clear and may be statistically problematic.

Table ES-1. Overview of 13 Final Panel Comments Identified by the CRSO Ecological Models IEPR Panel (continued)

No.	Final Panel Comment
Significance – Medium	
7	The TDG model lacks information on model formulation, data inputs, and sensitivity and uncertainty analyses conducted on the model.
8	The model documentation does not assess impacts of model uncertainty on the prospective results.
9	The scaling of data and models from one timeframe to another is confusing and has the potential to affect inference of certain variables.
10	Simplifying assumptions applied to the adult migration portion of the life cycle decrease the accuracy and interpretability of the LCM and CSS models.
11	The biological effect of TDG supersaturation would be more accurately modeled if the Fish Individual-based Numerical Simulator (FINS) and/or Politano et al. models were used for the TDG analysis.
12	An accurate TDG model requires data, or at least informed assumptions, regarding fish behavior to accurately assess the real TDG exposure migrants encounter and subsequent biological effects.
Significance – Medium/Low	
13	The model documentation does not provide the appropriate high-level descriptions of model assumptions, formulations, calibration, results, discussion, and conclusions or the materials to allow an independent modeler to use the models.

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LIST OF ACRONYMS

AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
BPA	Bonneville Power Administration
CJS	Cormack-Jolly-Seber
COI	Conflict of Interest
COMPASS	Comprehensive Passage
CRSO	Columbia River System Operations
CSS	Comparative Survival Study
CSSOC	CSS Oversight Committee
DEIS	Draft Environmental Impact Statement
DIC	Deviance Information Criterion
DrChecks	Design Review and Checking System
EC	Engineer Circular
EIS	Environmental Impact Statement
ELAM	Eularian-Lagrangian-Agent Method
ERDC	Engineer Research and Development Center
FCRPS	Federal Columbia River Power System
FERC	Federal Energy Regulatory Commission
FGE	Fish Guidance Efficiency
FINS	Fish Individual-based Numerical Simulator
GBD	Gas Bubble Disease
IEPR	Independent External Peer Review
ISAB	Independent Scientific Advisory Board
IWR	Institute for Water Resources
LCM	Life-Cycle Modeling
LGD	Little Goose Dam
LGR	Lower Granite Dam
MARSS	Multivariate Auto-Regressive State-Space
MIC	Maximum Information Coefficient
MLE	Maximum Likelihood Estimate (or Estimation)

MPG	Major Population Group
NOAA	National Oceanic and Atmospheric Administration
O&M	Operation and Maintenance
OEO	Outside Eligible Organization
OMB	Office of Management and Budget
OPSEC	Operations Security
PCX	Planning Center of Expertise
PDT	Project Delivery Team
PITPH	Powerhouse Passage Variable
QRF	Quantile Regression Forest
SAR	Smolt-to-Adult Return
TDG	Total Dissolved Gas
TIR	Transported to In-river Return Ratio
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
UW	University of Washington
WTT	Water Travel Time

1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Bonneville Power Administration (BPA), and Bureau of Reclamation (Co-lead Agencies) are jointly developing a comprehensive Environmental Impact Statement (EIS), referred to as the Columbia River System Operations (CRSO) EIS, to evaluate long-term system operations and configurations of 14 multiple-purpose projects that are operated as a coordinated system within the interior Columbia River Basin in Idaho, Montana, Oregon, and Washington. USACE was authorized by Congress to construct, operate, and maintain 12 of these projects for flood risk management, navigation, power generation, fish and wildlife conservation, recreation, and municipal and industrial water supply purposes. USACE projects that are included in the Draft EIS (DEIS) are Libby, Albeni Falls, Dworshak, Chief Joseph, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville. The Bureau of Reclamation was authorized to construct, operate, and maintain the other two projects—Hungry Horse and Grand Coulee—for the purposes of irrigation, flood risk management, navigation, power generation, recreation, and other beneficial uses. The BPA is responsible for marketing and transmitting the power generated by these dams. Together, these Co-lead Agencies are responsible for managing the system for these various purposes, while meeting their other statutory and regulatory obligations.

The Co-lead Agencies will use the DEIS to assess and update their approach for long-term system operations and configurations through the analysis of alternatives and evaluation of potential effects to the human and natural environments. The scope and scale of this project; its potential to impact human life safety; interest on the part of the Governors of Montana, Idaho, Washington, and Oregon and 19 Federally recognized tribes; connection to ongoing litigation on the Federal Columbia River Power System; and the likelihood for the project to result in public dispute drive a requirement for a heightened level of review and meet the criteria of a highly influential scientific assessment in Office of Management and Budget (OMB) and Bureau of Reclamation peer review policies.

The primary goal of ecological model review and approval is to establish that models, analyses, results, and conclusions are theoretically sound, computationally accurate, based on reasonable assumptions, well-documented, and in compliance with the requirements of the OMB Peer Review Bulletin (OMB, 2004). The primary criterion identified for model approval is technical soundness. Technical soundness reflects the ability of the model to represent or simulate the processes and/or functions it is intended to represent. The performance metrics for this criterion are related to theory and computational correctness. In terms of the theory, a quality ecological model should 1) be based on validated and accepted "state of the art" theory; 2) properly incorporate the conceptual theory into the software code; and 3) clearly define the assumptions inherent in the model. In terms of computational correctness, a quality ecological model should 1) employ proper functions and mathematics to estimate functions and processes represented; and 2) properly estimate and forecast the actual parameters it is intended to estimate and forecast. Other criteria for quality ecological models are efficiency, effectiveness, usability, and clarity in presentation of results. A well-documented quality ecological model will stand the tests of technical soundness based on theory and computational correctness, efficiency, effectiveness, usability, and clarity in presentation of results.

The ecological models reviewed as part of the CRSO Ecological Models Independent External Peer Review (IEPR) include the National Oceanic and Atmospheric Administration (NOAA) Fisheries Comprehensive Passage (COMPASS) Model, the NOAA Fisheries Interior Columbia Basin Life-Cycle

Models (LCM), the Fish Passage Center's Comparative Survival Study (CSS) Model, and the University of Washington (UW) Columbia Basin Research Total Dissolved Gas (TDG) Model.

Report Organization

This report presents the approach and the results of the review of the CRSO Ecological Models. It is organized into the following sections:

Section 1 - Model Purpose, IEPR Evaluation Assessment Criteria and Approach, and Summary of Panel Findings – Describes the overall purpose of each model; explains the IEPR review approach, including the review process and the criteria used to assess technical quality, system quality, and usability; and provides a high level summary of the Panel's findings.

Section 2 - Technical Quality Assessment – Summarizes the key issues identified from the model technical quality assessment.

Section 3 - System Quality Assessment – Summarizes the key issues identified from the model system quality assessment.

Section 4 - Usability Assessment – Summarizes the key issues identified from the usability assessment.

Section 5 - Model Assessment Summary – Presents the full five-part Final Panel Comments prepared by the Panel.

Section 6 - Conclusions – Summarizes the Panel's conclusions and overarching recommendations to resolve the key issues identified during the model review.

Section 7 - References – Lists the references used for this model assessment and referenced from the model documentation.

Appendix A - Information on the dates and steps followed to conduct the Model IEPR.

Appendix B - Biographical information on the expert Panel selected to perform the review.

Appendix C - The final charge guidance and questions to the Panel to guide its review of the CRSO Ecological Models.

Appendix D - The Conflict of Interest form that was provided with Battelle's original proposal.

Appendix E - Additional findings provided by the Panel for consideration.

1.1 Model Purpose and Summary

The purpose of each model reviewed as part of the CRSO Ecological Models IEPR and a summary of the model's functions are provided here.

- *NOAA Fisheries Comprehensive Passage (COMPASS) Model.* This model was developed by scientists from throughout the Pacific Northwest. The purpose of the model is to predict the effects of alternative operations of Snake and Columbia River dams on salmon survival rates, expressed both within the hydrosystem and potentially (due to latent effects) outside the hydrosystem. Accordingly, the model has the following capabilities: 1) realistically simulate survival and travel time through the hydrosystem under variable river conditions; 2) produce results in agreement with available data, particularly PIT-tag data; 3) allow users to simulate the effects of alternative management actions; 4) operate on sub-seasonal time steps; 5) produce an estimate of uncertainty associated with model results; and 6) estimate hydrosystem-related effects that may occur outside of the hydrosystem.

- *NOAA Fisheries Interior Columbia Basin Life-Cycle Models (LCM).* The LCM incorporates COMPASS outputs for evaluating alternative recovery actions in the Columbia River Basin. Specifically, the LCM allows evaluation of the numerous factors affecting salmon and steelhead returns in the Columbia River Basin. The LCM report builds from previous efforts that modeled hydrosystem and climate effects on salmonid population viability, and expands those efforts to cover more populations and habitat actions and to improve representation of climate effects, hatchery spawners, spatial interactions, and effects of toxins.

- *Fish Passage Center Comparative Survival Study (CSS) Model.* The CSS model was developed to estimate survival probability of salmon and steelhead from their outmigration as smolts to their return to freshwater as adults—referred to as smolt-to-adult return rate (SAR).

- *University of Washington (UW) Columbia Basin Research Total Dissolved Gas (TDG).* This model assesses the relative impacts of the hydrosystem operations on TDG generation and its effects on juvenile fish passing through the hydrosystem. The information also provides a relative measure of the potential impacts of TDG exposure in the hydrosystem on survival of fish in the estuary and Columbia River plume. The TDG model uses the COMPASS smolt passage model (Zabel et al., 2008) to simulate the fish movement and TDG exposure based on flow, spill, and TDG provided from models developed by other groups involved in the CRSO analysis. The model characterizes the effect of TDG on juvenile fish passage with three metrics:

    1. Mortality due to gas bubble disease (GBD)
    2. Reach average TDG exposure
    3. Cumulative passage TDG exposure

    These models must be technically sound, represent the system being modeled, and have been reviewed for theoretical soundness and compliance with USACE planning policy and procedures.

1.2 Model Evaluation Assessment Criteria and Approach

Independent, objective peer review is regarded as a critical element in ensuring the reliability of scientific analysis. The objective of the work described here was to conduct an IEPR of the CRSO Ecological Models in accordance with procedures described in the Department of the Army, USACE, Engineer Circular (EC) *Review Policy for Civil Works* (EC 1165-2-217) (USACE, 2018) and the OMB *Final Information Quality Bulletin for Peer Review* (OMB, 2004). Supplemental guidance on evaluation for conflicts of interest (COIs) was obtained from the *Policy on Committee Composition and Balance and Conflicts of Interest for Committees Used in the Development of Reports* (The National Academies, 2003).

USACE requires that all planning models be reviewed to ensure that they are technically sound. In this case, the IEPR of the CRSO Ecological Models was conducted and managed using contract support from

Battelle, which is an Outside Eligible Organization (OEO) (as defined by EC 1165-2-217). Battelle, a 501(c)(3) organization under the U.S. Internal Revenue Code, has experience conducting IEPRs for USACE.

This final report presents the findings of the IEPR Panel (the Panel) on the technical soundness and computational accuracy of the models and establishes whether the models' assumptions, analyses, results, and conclusions are well documented. Appendix A describes in detail how the IEPR was planned and conducted, including the schedule followed in executing the IEPR. Appendix B provides biographical information on the IEPR panel members and describes the method Battelle followed to select them. Appendix C presents the final charge to the IEPR panel members for their use during the review; the final charge was submitted to USACE in the final Work Plan according to the schedule listed in Table A-1. Appendix D presents the organizational COI form that Battelle completed and submitted to the Institute for Water Resources (IWR) prior to the award of the CRSO Ecological Models IEPR. Appendix E presents additional findings by the Panel that, in the Panel's opinion, did not require a Final Panel Comment but nevertheless warrant consideration and resolution.

The methods used to conduct the IEPR are briefly described in this section. The IEPR was completed in accordance with established due dates for milestones and deliverables as part of the final Work Plan; the due dates are based on the award/effective date and the receipt of review documents.

The Panel received electronic versions of the model review documents and software along with a charge that solicited comments on the quality of the model documentation, scientific theories, and usability. Following guidance provided in USACE (2018) and OMB (2004), USACE prepared the charge questions, which were included in the draft and final Work Plans.

The Panel reviewed the CRSO Ecological Models documents and produced 13 Final Panel Comments in response to 23 charge questions provided by USACE for the review. This charge also included two overview questions added by Battelle, for a total of 25 questions. Battelle instructed the Panel to develop the Final Panel Comments using a five-part structure:

1. Comment Statement (succinct summary statement of concern)
2. Relevant Model Assessment Criteria
3. Basis for Comment (details regarding the concern)
4. Significance (high, medium/high, medium, medium/low, or low; in accordance with specific criteria for determining level of significance)
5. Recommendation(s) for Resolution (at least one implementable action that could be taken to address the Final Panel Comment).

Battelle reviewed all Final Panel Comments for accuracy, adherence to USACE guidance (EC 1165-2-217), and completeness prior to determining that they were final and suitable for inclusion in the Final Model Report. There was no direct communication between the Panel and USACE during the preparation of the Final Panel Comments. The Panel's overall findings are summarized in Section 1.3. The Panel's findings as they relate specifically to technical quality, system quality, and usability are discussed in greater detail in Sections 2, 3, and 4. Table 1 lists the Final Panel Comment statements by level of significance; the full Final Panel Comments are presented in Section 5.

Table 1. Overview of 13 Final Panel Comments Identified by the CRSO Ecological Models IEPR Panel

No.	Final Panel Comment
Significance – High	
1	Differences in the attribution of salmon survival rates to the ocean environment versus Columbia River dam/reservoir operations used in the COMPASS/LCM and CSS models result in increased uncertainty of the actual benefits attained by future changes.
2	The results of testing performed to determine the CSS model's sensitivity to spill and the TDG upper limit may not accurately represent TDG exposures that lead to GBD.
Significance – Medium/High	
3	The use of large sets of predictor variables in the LCM, COMPASS, and CSS models increases the probability of either finding false relationships or exaggerating the effects of any real relationships that end up in each predictive model.
4	The COMPASS/LCM and CSS models are being used to extrapolate beyond the range of conditions to which they have been calibrated.
5	The model documentation often does not report the results of the assessment of model assumptions, fit, or validation.
6	The methodology for use of the powerhouse passage variable (PITPH) in the CSS model is not clear and may be statistically problematic.
Significance – Medium	
7	The TDG model lacks information on model formulation, data inputs, and sensitivity and uncertainty analyses conducted on the model.
8	The model documentation does not assess impacts of model uncertainty on the prospective results.
9	The scaling of data and models from one timeframe to another is confusing and has the potential to affect inference of certain variables.
10	Simplifying assumptions applied to the adult migration portion of the life cycle decrease the accuracy and interpretability of the LCM and CSS models.
11	The biological effect of TDG supersaturation would be more accurately modeled if the Fish Individual-based Numerical Simulator (FINS) and/or Politano et al. models were used for the TDG analysis.

Table 1. Overview of 13 Final Panel Comments Identified by the CRSO Ecological Models IEPR Panel (continued)

No.	Final Panel Comment
12	An accurate TDG model requires data, or at least informed assumptions, regarding fish behavior to accurately assess the real TDG exposure migrants encounter and subsequent biological effects.
Significance – Medium/Low	
13	The model documentation does not provide the appropriate high-level descriptions of model assumptions, formulations, calibration, results, discussion, and conclusions or the materials to allow an independent modeler to use the models.

1.3 Summary of Findings

The panel members agreed on their assessment of the technical quality, system quality, and usability of the CRSO Ecological Models reviewed. The models are very comprehensive and provide a detailed comparison of alternatives under very flexible input specifications. However, based on the documents the Panel was asked to review, the Panel has identified a number of concerns and has provided specific recommendations to improve the models in the Final Panel Comments. Recommendations include the following:

- Develop documentation specific to each model used for evaluating alternatives for operating/altering the CRSO project, detailing the exact state of the model at the time it was run; which subcomponents of the models were used and why; the assumptions applied; limitations that remain; outcomes of calibrations conducted; evidence of the model's fit and validation to the environment being assessed; and uncertainties and risks that remain within the outputs and conclusions.

- Reassess the limitations and validity of using large sets of predictor variables to make inferences from relatively small response datasets.

- Assess the impact of using different assumptions with regard to adult migration in the CSS and COMPASS/LCM models.

- Reassess the assumptions regarding TDG and GBD throughout the models, especially regarding fish behavior.

- Revise the model documentation to include complete explanations of model parameters and associated assumptions, procedures for model use, data input needs, and clear illustrations of output metrics.

These issues are important for the effective application of the models by experienced users and USACE staff. The Panel recommends that USACE and the modeling teams address these issues prior to finalizing the decisions made for the models' use.

2.0 TECHNICAL QUALITY ASSESSMENT

Analytical tools, including models, used for planning purposes need to be technically sound and based on widely accepted contemporary scientific theory. The CRSO and the Columbia River Basin Ecosystems must be reasonably represented by the model variables selected, and the correlation of responses of salmonids with the variables selected must be supported by sound scientific studies. The model calculations must reflect how the ecosystem is expected to change with changes in project actions based on the application of scientific theory. Formulas and calculations that form the mechanics of the model must be accurate and correctly applied, with sound relationships among variables. The model should be able to reflect natural changes as well as the influence of anthropogenic laws, policies, and practices. All model assumptions must be reasonable and should be well-documented. The analytical requirements of the model must be identified, and the model must address these requirements. The model should also produce robust, reproducible results that stand up to rigorous scrutiny in later stages of the plan formulation process. The results of the Panel's assessment of these criteria are summarized in the following sections.

2.1 Model Documentation Quality

The model documentation provided to the Panel for review of the four ecological models consisted of a conglomeration of documents developed for a variety of reasons at different times in the life of each model, rather than a cohesive document that reported on the specific model used to conduct the CRSO modeling of the alternatives. Throughout the remainder of this report, the Panel will outline how the lack of coherent and accurate documentation of the specific model and parameters used impacted the Panel's ability to establish that the models, analyses, results, and conclusions are theoretically sound, computationally accurate, based on reasonable assumptions, well-documented, and in compliance with the requirements of the OMB Peer Review Bulletin (OMB, 2004).

Although listed as a medium/low significance comment because of the definitions of each significance level (medium/low is a documentation issue), Final Panel Comment 13 outlines how the lack of accurate high-level descriptions and thorough documentation adversely affected the Panel's review. First, it hindered the Panel's ability to understand the assumptions, formulations, calibration, results, discussion, and conclusions of the models used for the CRSO analysis. Second, it prevented the Panel from using the models. Final Panel Comments 5, 7, and 8 further outline specific issues related to the lack of information on model formulation, data inputs, assumptions, and sensitivity and uncertainty analyses conducted on the model.

The lack of cohesive documentation also led to incomplete information being initially provided to the Panel for review. During the Mid-Review Teleconference, with the Panel, Battelle, and the USACE PDT and modelers convened, it was discovered that several documents were supplied that should not have been or were missing from the review. Although this information was ultimately provided, it became clear to the Panel that the haphazard organization of the model documentation facilitated the dissemination of incomplete information and hindered the Panel's ability to obtain the correct information associated with the specific setup of each model for the CRSO-related runs. No central repository appears to be in place to document how the models were to be set up and run, with all assumptions and limitations outlined. Furthermore, these models continue to be modified, which means that without the specific information used to implement the model runs used in the CRSO, it may not be possible to replicate the models and their outputs if needed.

2.2 Theory and External Model Components

The Panel commends USACE and its modeling teams for developing an integrative modeling approach, incorporating statistical, data-driven, and physics-based models into a framework for forecasting population dynamics of Columbia River System salmonids. Both sets of models, the COMPASS/LCM and the CSS sets, are sensible and credible, and they allow for flexibility over a range of inputs that will be helpful for modeling future conditions. However, there were concerns about the use of the powerhouse passage variable (PITPH) in the CSS model (Final Panel Comment 6). In addition, the TDG model did not take into account fish behavior and depth/spatial variability of TDG and GBD (Final Panel Comments 11 and 12).

For CSS, the powerhouse passage variable PITPH is a central focus of the CSS modeling effort, as the main link between project operations and impacts to salmonids. The PITPH variable is estimated or predicted on multiple scales, and in turn, is used as a predictor variable in multiple models. The different estimation methods and assumptions required to form the estimate on these different scales are not clearly described. For prospective use, PITPH is a model prediction with multiple sources of uncertainty, including daily environmental stochasticity, measurement error of flow and % spill, and error related to model fit (parameter uncertainty). The models with PITPH as a predictor of salmonid life cycle parameters include water travel time (WTT), which is also a function of flow. In this case, measurement error and stochasticity are impacting these models multiple times. The Panel is concerned about the impact of variance inflation and multi-collinearity on these model predictions.

For TDG, the Panel believes that the modelers should reconsider incorporating the Fish Individual-based Numerical Simulator (FINS) and/or Politano models to more accurately model the biological effect of TDG supersaturation on juvenile salmonids. Juvenile salmonids commonly occupy a range of depths during their migrations that result in varying exposure to TDG levels. This varying exposure to supersaturation both limits the development of GBD and provides recovery from GBD when fish occupy depths at TDG levels lower than 100% saturation. Knowledge of the depths that fish occupy during exposure to supersaturation is necessary to accurately predict the occurrence and severity of GBD and thus fish mortality. In addition, the use of mean TDG levels perpetuates a misconception that mean TDG levels predict biological effects, namely GBD. Fish exposed to mean TDG levels in shallow water (e.g., hatchery troughs, raceways, or shallow tributaries) will have biological effects reasonably modeled by mean TDG levels, whereas fish exposed to mean TDG levels in conditions of substantial stream depth are not likely to be accurately assessed by mean TDG levels.

2.3 Representation of the System

The Panel believes that the current ecological models have value in the current EIS process, but that there are changes that could improve the models in their present form, and that they will continue to improve over time. From a conceptual standpoint, the Panel agrees that, in general, most of the model components used in the four ecological models do a reasonable job of characterizing and projecting the various ecosystems and processes that are being modeled. However, insufficient model documentation including model validation, descriptions of how various components were used in the different timeframes, and justification of assumptions made it hard for the Panel to verify that the models accurately represent the CRSO system based on the information provided. The Panel's main concerns in that regard include the need for model documentation that 1) reports the results of an assessment of model assumptions, fit, and validation (Final Panel Comment 5), and 2) assesses the impacts of model uncertainty on the prospective results (Final Panel Comments 1 and 8).

When different models are combined into full life cycle models, the Panel is concerned that ecological inferences may change when relationships between variables are summarized at different time steps. When variables are scaled from one time step to another within individual models like CSS and LCM, and then when these variables are summarized or compiled, it is not clear how their interpretation might change because neither the CSS nor LCM documentation explains how the different timeframes were handled (Final Panel Comment 9).

Additional justification is needed for using simplified survival relationships during adult upstream migration and the pre-spawning period in both the CSS and COMPASS/LCM population projections, as simplifying assumptions are unlikely to account for the complex set of factors that can influence survival. A substantial body of research indicates that multiple factors influence adult survival rates, including harvest quotas (fisheries), pinniped predation rates, water temperature, fish travel time, and the timing of freshwater entry, all of which are part of the CRSO project. Without accounting for variability related to these known processes, it is unclear how management actions within the CRSO are expected to influence adult survival (Final Panel Comment 10).

2.4 Analytical Requirements

The Panel agreed that the analytical requirements of the four ecological models are well-developed. No issues were identified during the review of the analytical requirements behind the model. However, the Panel did note that some of the data sets, such as the salmon tagging and monitoring, may not be available in other systems.

2.5 Model Assumptions and Limitations

As noted under Sections 2.1 and 2.3, the Panel believes that the documentation of and reasoning behind the various model assumptions and limitations is weak. At a minimum, the model documentation should contain a standard section listing assumptions and limitations relevant to the version of each model being used for the CRSO assessment.

The Panel is also concerned about the use of large sets of predictor variables in LCM, COMPASS, and CSS models (Final Panel Comment 3). The Panel believes that using large sets of predictor variables for small sets of data increases the probability of either finding false relationships or exaggerating the effects of any real relationships that end up in each predictive model. For example, the most extreme case is the LCM ocean survival model, where 59 predictors are applied to only 14 years of data.

Another concern raised by the Panel is the fact that the COMPASS/LCM and CSS models are being used to extrapolate beyond the range of conditions to which they have been calibrated, including major changes to the structure and operation of the system including the removal of four major dams, and potential changes to future ocean conditions (Final Panel Comment 4). While this is clearly necessary when predicting a system response to future conditions, it is important to note that projecting outside the range of observations reduces the confidence in critical model outputs such as salmon survival at various life stages, potential changes in latent mortality, etc.

3.0 SYSTEM QUALITY ASSESSMENT

System quality refers to the quality of the entire system used to develop, use, and support the model. In general, the Panel's evaluation of system quality included assessing whether the model's calculations and formulas were correct and whether the models had been tested and validated. The results of the Panel's assessment of system quality are summarized in the following sections.

3.1 Model Calculations/Formulas

The Panel brought up two main concerns regarding the model's calculations and formulas. First, the use of large sets of predictor variables in LCM, COMPASS, and CSS could increase the probability of either finding false relationships or exaggerating the effects of any real relationships that end up in each predictive model (Final Panel Comment 3). This problem, also known as "data dredging," has been known to occur in ecological models when researchers incorporate a large number of variables from data sets that are short in length and limited in the amount of contrast. The drawback to data dredging is the use of spurious relationships or an exaggeration of the effects of any real relationships that may end up in the predictive model (Myers, 1998).

Second, the scaling of data and models from one timeframe to another is of concern (Final Panel Comment 9). Both CSS and LCM use datasets with varying timeframes, but the model documentation does not explain how it handles or adjusts each to be compatible. For example, LCM uses COMPASS model results produced on a daily time step and integrates the results with climate change scenarios that use annual predictors. The documentation was insufficient for the Panel to evaluate the validity of inference made on certain variables, especially when mixed with other models making different assumptions at other states within the complete life cycle.

3.2 Testing/Evaluation Process

The Panel found limited information (COMPASS), and in some instance no information (CSS, LCM, and TDG) on the testing and evaluation performed on these models. As already suggested, to ensure that these models represent the system, the model documentation should report the results of an assessment of model assumptions, fit, and validation (Final Panel Comment 5).

4.0 USABILITY ASSESSMENT

Usability refers to how easily model users can access and run the models, interpret model output, and use the model output to support planning decisions. An assessment of model usability includes evaluating the availability of data required to run the models and the ability of the user to learn how to use the model properly and effectively. Model outputs should be easy to interpret, useful for supporting the purpose of the model, easy to export to project reports, and sufficiently transparent to allow for easy verification of calculations and outputs. The results of the Panel's usability assessment are summarized in the following sections.

4.1 Operating Requirements of the Model

Although the Panel was given code and limited documentation for some of the models, panel members experienced some difficulties in installation owing to a lack of adequate documentation (Final Panel Comment 13). The full COMPASS model can only run with Linux or Unix operating systems, which was unfamiliar to some panel members, and thus required a substantial time commitment to implement even prior to attempting to run models with limited documentation. For future applications, the Panel suggests including a user's manual and a vignette with examples of model application. The Panel was also told that the desktop version of COMPASS has very limited capabilities and were not used for the CRSO runs. For the CSS model, computer code was provided for cohort simulations, but ancillary data and documentation were not provided, so the Panel was unable to run the simulations. In the end, although the Panel attempted to run some of the models, the only model that they could actually run was the limited online version of the TDG model.

4.2 Input Availability and Output Understandability

The Panel agreed that the input availability and output understandability of the four ecological models is satisfactory. No issues were identified during the review of these parts of the model. However, the Panel did note that some of the data sets, such as the salmon tagging and monitoring, may not be available in other systems; therefore, if USACE were to consider using these models for other locations, the model inputs may be limited.

4.3 Condition Characterization Usefulness

The Panel agreed that the condition characterization usefulness of the four ecological models is well-developed. No issues were identified during the review of these parts of the model.

4.4 Model Usefulness in Selecting Alternatives

The Panel raised four concerns related to the use of the models for selecting the alternatives. Two have previously been mentioned: 1) the COMPASS/LCM and CSS models are being used to extrapolate beyond the range of conditions to which they have been calibrated (Final Panel Comment 4), and 2) the model documentation does not assess impacts of model uncertainty on the prospective results (Final Panel Comment 8).

With regard to two additional concerns, the first focused on the differences in the attribution of salmon survival rates to the ocean environment versus Columbia River dam/reservoir operations used in the COMPASS/LCM and CSS models. The Panel is concerned that the difference in modeling frameworks results in increased uncertainty of the actual benefits attained by future changes (Final Panel Comment 1). As explained in the DEIS, the critical difference is in what in-river factors are assumed to affect ocean mortality—i.e., “latent” mortality. In the COMPASS/LCM approach, date of arrival at Bonneville and river temperature affect ocean survival. In the CSS approach, a variable representing the expected number of powerhouse passages is the critical driver. Unfortunately, the current data may not be sufficient to resolve questions about how much variability in ocean survival can be attributed to these different factors.

The last concern with regard to the models’ usefulness in selecting alternatives is that the results of testing performed to determine the CSS model’s sensitivity to spill and the TDG upper limit may not accurately represent TDG exposures that lead to GBD (Final Panel Comment 2). The Panel believes that, as currently modeled, CSS does not explicitly consider increases in gas bubble mortality with increased spills, especially during involuntary spillage. Until the model is more fully validated, especially for elevated TDG levels, support for high spill-level alternatives may result, which may prove detrimental to juvenile fish survival and ultimately adversely affect SAR.

5.0 MODEL ASSESSMENT SUMMARY

This section presents the full text of the Final Panel Comments prepared by the IEPR panel members. The Panel also offers additional findings that did not rise to the level of a Final Panel Comment but need specific resolution (Appendix E). These additional findings are offered to help further clarify information in the documentation and offer some other suggestions that the USACE and modelers may find useful.

Final Panel Comment 1

Differences in the attribution of salmon survival rates to the ocean environment versus Columbia River dam/reservoir operations used in the COMPASS/LCM and CSS models result in increased uncertainty of the actual benefits attained by future changes.

Relevant Model Assessment Criteria

Model Usefulness in Selecting Alternatives

Basis for Comment

There are two contrasting modeling approaches: the COMPASS/LCM and the CSS efforts. These two modeling frameworks differ greatly in how much of the variation in salmon survival rates is assigned to the ocean environment and how much to operations of the Columbia River dam/reservoir system. Consequently, they often differ drastically in their predictions of the effect of changes in operations on salmon survival. As both models are credible efforts from competent scientists, the implication is that the effects of changes contemplated in the DEIS are highly uncertain.

As explained in the DEIS (Chapter 3, pages 3-360 to 3-362), the critical difference is in what in-river factors are assumed to affect ocean mortality—i.e., "latent" mortality. In the COMPASS/LCM approach, date of arrival at Bonneville and river temperature affect ocean survival. In the CSS approach, a variable representing the expected number of powerhouse passages is the critical driver.

Unfortunately, the current data may not be sufficient to resolve questions about how much variability in ocean survival can be attributed to these different factors. Although large quantities of high-quality observations exist, they do not stem from an experimental design to address these differences. Climate variations likely simultaneously affect in-river flow and temperatures, dam/reservoir operations, and at least the estuarine oceanic environment, making it difficult to parse out the effects of each on salmon survival. The best and most detailed survival data, from PIT tags, is restricted to the last two decades, when the configuration of the dam/reservoir system has been largely static (although some significant operational changes and some structural changes have occurred).

Independent reviews (e.g., Independent Scientific Advisory Board [ISAB]) emphasized resolving the question through tests of the mechanisms (e.g., looking at the condition of fish exiting the powerhouse) and adaptive management approaches (e.g., monitoring the effects of increased spills on future SARs). However, because of large inherent variability, learning through adaptive management is likely to be a slow process.

Significance – High

Large differences in the predicted effects of changes to the dam system's configuration and operation from two credible models imply that the data are not informative, and that the outcome of changes is highly uncertain.

Recommendations for Resolution

1. Prepare a comprehensive model development, calibration, and validation plan for both modeling frameworks that outlines the modeling assumptions, knowns, unknowns, current

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limitations, additional data (field, laboratory) needs, and future laboratory and field-based experimentation.

2. Perform additional studies to resolve the relative roles of the dam/reservoir system and the estuary/ocean environment in determining salmon survival, focusing on identifying and quantifying latent effects of a fish's experience in the dam/reservoir system on later survival. This will likely take significant time and effort.

3. In the short term, develop methods to quantify the level of uncertainty in projections of the effects of any proposed structural or operational changes to the dam/reservoir system, synthesizing the predictions of both modeling approaches.

Final Panel Comment 2

The results of testing performed to determine the CSS model's sensitivity to spill and the TDG upper limit may not accurately represent TDG exposures that lead to GBD.

Relevant Model Assessment Criteria

Model Usefulness in Selecting Alternatives

Basis for Comment

The CSS model sensitivity to spill and the TDG upper limit should be further tested, especially given the following statement: "We found that the most significant benefits to in-river survival rates and SARs occurred at the highest TDG limit spill levels, and that benefits under breached conditions at BiOp spill levels were higher than under impounded conditions at 125% spill levels" (McCann et al. 2017 CSS Annual Report, Chapter 2). The CSS model predicts that by increasing the spill levels to 125%, returning adults roughly double.

The increase in gas bubble mortality with increased spill is not considered explicitly, although it may be incorporated in the statistical relationships between spill and survival. In the juvenile survival model, the examination of the TDG effects is ad hoc and statistically suspect. If TDG is to be examined, it should be as another predictor in the Bayesian Cormack-Jolly-Seber (CJS) analysis. However, the analysis is probably sufficient to cast doubt on the importance of these effects. Since TDG is a function of spill, some TDG effects may also be indirectly incorporated through other predictors.

Questions arise: Is there an upper limit to TDG where mortality increases? What if the TDG cap were raised to 130%, 140%, etc.? Does the CSS model accurately represent TDG exposures that lead to GBD? Is the model falsifiable?

Field data analyzed do not indicate an effect of TDG percentage on survival, including data for involuntary spills of TDG up to 135% of saturation. One concern to this last point is that with high river flows resulting in 135% TDG during involuntary spill, the overall passage percentages and mixing conditions downstream may be different than during lower flow conditions with an elevated gas cap.

Significance – High

The implementation of the TDG component within the CSS model appears to be entirely insensitive to levels of TDG saturation. Until the model is more fully validated, especially for elevated TDG levels, support for high spill-level alternatives may result, which may prove detrimental to juvenile fish survival and ultimately adversely affect SAR.

Recommendation for Resolution

1. Develop a field-based experimental plan to assess the impact of high levels of TDG saturation, in particular under voluntary spill conditions. This approach should include multiple dams within the system to explore local configurations.

Final Panel Comment 3

The use of large sets of predictor variables in the LCM, COMPASS, and CSS models increases the probability of either finding false relationships or exaggerating the effects of any real relationships that end up in each predictive model.

Relevant Model Assessment Criteria

Model Assumptions and Limitations
Calculations and Formulas

Basis for Comment

Several models that sought to incorporate environmental influences suffer from “data dredging” (the term for investigating a large set of predictor variables relative to the length and amount of contrast in a data series). The effect of data dredging is a high probability of finding spurious relationships or of exaggerating the effects of any real relationships that end up in the predictive model (Myers, 1998).

All models that incorporate oceanographic indices have this issue; the most extreme case is the LCM ocean survival model, where 59 predictors are applied to only 14 years of data. Another example is the COMPASS model of smolt arrival at Lower Granite Dam, where two nominal variables, flow and temperature, are expanded to 31 potential predictors by subsetting by month and by using means and ranges and maximums for each month. In this analysis, each quantile regression involved fitting 31 predictors to 26 years of data.

Model averaging is only a partial solution. The guidance from the ecological modeling literature, including guidance by the leading proponents of a model averaging approach, is to minimize the number of potential predictors to avoid this issue. Pre-screening the variables by only formally estimating the effects of some does not solve this problem, if the pre-screening is to select those with the strongest relationships with the response variable. Spurious and exaggerated effects that would have been found by examining all predictors will be retained by this method of screening. Instead, a limited set of potential predictors to examine should be chosen *a priori*, based on the plausibility of the mechanisms by which they might affect the response variable (Anderson, 2008).

One of the CSS ocean survival models (McCann et al. 2017 CSS Annual Report, Chapter 2) has the same issue, with subsetting of predictors leading to 49 candidate predictors examined. In contrast, the CSS ocean survival/SAR model used in Chapter 3 of the 2017 Experimental Spill Management document is based on Haeseker et al. (2012), which only considered three oceanographic variables, avoiding this data dredging issue.

Additionally, sometimes the relationships found between predictors and response variables are poorly described, suggesting definitive cause-effect relationships when only correlative ones have been demonstrated, or overemphasizing statistically significant relationships that have small biological effects.

Example: The discussion of SAR and transported to in-river return ratio (TIR) models in the CSS documentation (CSS Oversight Committee [CSSOC] 2017 Documentation of Experimental Spill Management Report, page 33) covers a suite of predictors that are correlated with each other and are estimated in similar ways. PITPH is correlated with flow, WTT is correlated with flow, ocean survival is correlated with arrival time below Bonneville, run timing is correlated with flow. Inferring causality to

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any relationships with these variables is problematic without additional data supporting their mechanism of action. Example: In Chapter 2 of the Zabel and Jordan 2019 Life Cycle Models of Interior Columbia River Basin Spring and Summer Chinook Populations technical memorandum (henceforth Zabel and Jordan 2019 LCM Report, which discusses COMPASS modeling results, Figures 1 and 2 show extremely small survival differences among groups (less than one percentage) and large overlap in the range of survival rates among these groups. In part of the Discussion section, the authors do characterize these differences as small and try to explain this result. In another part, however, they state "…the results for the upper Columbia COMPASS runs showed that both the 120-Perf and 125-Perf scenarios had consistently higher survival…", which the Panel feels is unwarranted. Example: The McCann et al. 2017 CSS Annual Report (page 41) states that "…lower early ocean survival of transported fish may be attributable to the [Pacific Decadal Oscillation]." The Pacific Decadal Oscillation is merely a pattern of climatic variability, not by itself a mechanism that would lead to mortality in the ocean.
Significance – Medium/High
Application of the LCM, COMPASS, and CSS models would be enhanced by 1) using fewer variables and outlining clear linkages between the variables used and biological processes, and 2) presenting hypotheses that explain why these factors would result in observed patterns (e.g., differentially affect transported fish more than those that migrated in-river).
Recommendations for Resolution
1. Rebuild the LCM and CSS ocean survival models, following the example of Haeseker et al. (2012) in using fewer and broader-scale predictors, based on a plausible mechanism for an effect and support for this effect in the literature. 2. Rebuild the dam arrival timing model(s), again using fewer predictors. Consider whether the spline-smoothing issues could be avoided with simpler models, such as a beta shape with parameters dependent on these predictors. Possibly, capturing the mean and spread of the arrival timing distribution would be sufficient for the purposes of comparing alternative system structural/operational modes. 3. Systematically quantify the effect sizes of statistically supported predictive relationships, and describe their magnitude as well as their significance. Revise text where a causal explanation might be simply correlative. Describe clear connections between predictor variables and the ecological processes they represent based on hypotheses supported by literature.

Literature Cited

Anderson, D.R. (2008). Model based inference in the life sciences: a primer on evidence. Springer, New York.

Haeseker, S.L. et al. (2012). Transactions of the American Fisheries Society 141:121–138.

Myers, R.A.M. (1998). Reviews in Fish Biology and Fisheries 8:285-305.

Final Panel Comment 4

The COMPASS/LCM and CSS models are being used to extrapolate beyond the range of conditions to which they have been calibrated.

Relevant Model Assessment Criteria

Model Assumptions and Limitations
Model Usefulness in Selecting Alternatives

Basis for Comment

Both sets of models are used to extrapolate beyond the range of conditions to which they have been calibrated, including major changes to the structure and operation of the system up to the removal of four major dams, and potential changes to future ocean conditions. This reduces the confidence in critical model outputs such as salmon life-cycle survival, potential changes in latent mortality, etc.

In some cases, there appear to be insufficient data for crucial aspects of forecasting. Both COMPASS and CCS have used approximate assumptions for fish passage efficiencies at projects, stating that the COMPASS team chose Powerhouse Surface Passage efficiencies of 30% and 40% for sub-yearling and yearling Chinook, respectively, and 50% for Steelhead while CSS tried values of 10%, 20%, and 30% for all juvenile salmon. For comparison, at Wanapum Dam the Attraction Flow prototype collected less than 3% of the downstream migrants, whereas at the same dam, the Future Units Fish Bypass collected over 75% of the juvenile migrants, indicative of the wide-ranging effectiveness of surface passage devices. Similar, widely variable, data exists at Federal Columbia River Power System dams (e.g., Lower Granite). The use of such widely variable project- and passage-specific data raises concerns with regard to forecasting with models calibrated to historical data.

For the CSS model, the conclusion was drawn that TDG was not impacting survival. However, the data used to form this conclusion do not include larger TDG values expected in some prospective scenario analyses. No impact will be modeled because there is no modeled detriment to increased spill, although it is certain that there are impacts at some TDG levels. Also, the treatment of TDG as a predictor variable is separate from the other variables (CSSOC 2017 Documentation of Experimental Spill Management Report, page 28) and done in an exploratory/post-hoc way. Results may have been different if TDG had been included in the main model.

Significance – Medium/High

Although extensive work has been performed to calibrate the models to historical data, concerns remain about model assumptions and inherent predictability for future Columbia River System conditions, which extend beyond the calibration conditions.

Recommendations for Resolution

1. Describe the assumptions and limitations of the models for forecast mode, and note and discuss the implications when projecting to conditions beyond the calibration datasets.

Final Panel Comment 4
2. Prepare an adaptive research and development plan that will continue to improve the model approaches and predictability as the CRSO program moves into future years.

Final Panel Comment 5

The model documentation often does not report the results of the assessment of model assumptions, fit, or validation.

Relevant Model Assessment Criteria

Model Documentation Quality
Representation of the System
Testing/Evaluation Processes

Basis for Comment

Ecological models are simplifications of reality that can aid understanding of the natural world but require simplifying assumptions that are not always valid. The usefulness of a model for predicting the consequences of management decisions depends upon the ability of the model to match observations (fit), and more importantly, the predictive capabilities of the model (validity). When a model performs poorly, it is often because the broad assumptions necessary to form the model have not been met. Conflicting results among models can often be explained based on model fit, validation, and assumptions.

The CRSO ecological model documentation does not contain sufficient information on model fit, validation, and assumptions for individual model components to be fully evaluated. For any model fitted to data, it is important to check model fit to ensure that model behavior is reasonable and to evaluate whether the fitted parameter values can be used with confidence (thus, measures of uncertainty should be presented alongside fitted parameter estimates). This transparency is important in a complex system with a web of interacting models that are constantly being updated and calibrated in new ways.

Because the models are being used by USACE to compare future operations, model validation is critical in understanding potential weaknesses in the modeling process. Model validation differs from model fit in that it is an assessment of how well the model performs against data not used in the calibration. It provides the most relevant indication of how well predictions of the future are likely to match reality.

COMPASS/LCM

Both applications of the COMPASS model (i.e., to generate both cohort-specific estimates for Snake River Chinook and steelhead and full life cycle estimates) generally seem to capture overall trends in the observed data. However, neither approach specifically quantifies model fit or uncertainty associated with specific parameters or with overall model components in the results. The COMPASS model documentation provides little to no discussion of the many model assumptions inherent within each component model, and the level of detail provided on important modeling decisions varies. Decisions to use fixed values for some model inputs are not defended at all. Decisions to exclude data because of poor precision in Appendix 1 (PIT Tag Data) should include quantitative evidence and commentary on the implications of excluding data. There is a model diagnostics appendix (Appendix 3), but it needs expansion, more explanation, and additional assessment of assumptions and model validation. The fit of the survival models appears to be poor (specifically the McNary-to-

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Bonneville portion and the Lower Granite Pool), which conflicts with statements in the Zabel and Jordan 2019 LCM Report that models fit the observed data well. The CJS models are part of this model set but are not discussed in any detail. In the COMPASS documentation Appendix 7, validation methods for the models predicting arrival time at Lower Granite Dam model are included, but these do not appear to be based on standard validation methodology using predictive accuracy. The two years nominally reserved for “cross-validation” are instead used to select a model form that provides smooth shapes to the arrival distribution.

For the LCM (Zabel and Jordan 2019 LCM Report, Chapter 4), there needs to be a more thorough explanation of how models were assessed and selected. It is unclear which models were included in the complete set, which is relevant for Akaike Information Criteria (AIC) comparison. Statements that ocean survival is independent of downstream and upstream survival estimates (page 4-1) and the exploratory nature of the ocean survival models (58 potential covariates; page 4-4) need to be discussed in detail.

Cross-validation is an excellent validation technique but should be applied to capture the dominant sources of variability. In the life-cycle modeling, K(10)-fold cross-validation of PIT tag data was run, but the validation was based on subsampling fish, rather than years. This was not the best approach, as the major source of variation to explain is the yearly effect of a single value of an environmental index on the ensemble survival of all fish. Therefore, the validation methodology likely substantially underestimates the prediction uncertainty. A more realistic estimate of uncertainty would be a leave-one-out cross-validation, removing an entire year’s worth of data each time.

TDG

The TDG model assumptions should be stated and the implications of violations discussed. This documentation has inconsistent and imprecise language for listed steps in the process (bottom of page 5). The details on data used to calibrate the model for mortality as a function of TDG should be described in the model documentation (i.e., what are the “x” values used for calibration; are they independent replicates?), and standard summary fit values should be provided (e.g., sample size, R^2, standard errors). Detail is needed on the methodology for selecting depth distribution shape and parameters, along with the potential impacts of different shapes. No model validation is provided.

CSS

For all component models, important assumptions are made without discussion of the potential influence of those assumptions on model results. Specific examples include the following:

1) The level of tagging effort varies among populations or subbasins, so some areas may be overrepresented by the models.

2) In many locations, hatchery fish dominate the samples, but these fish may exhibit vital rates and behaviors that differ from those of wild individuals.

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3) Size and mortality are explicitly linked ecologically, but this linkage is not considered in the life cycle.

In Chapter 3 of the CSSOC 2017 Documentation of Experimental Spill Management Report (pages 34-35), model results are presented with no assessment of model fit (beyond simple plots) or best model selection. Although mixed models produce both marginal (averaged across random effects) and conditional (specific to individual group) predictions, it is unclear which predictions are plotted for comparison to observed values. Post-hoc consideration of TDG effects are based on t-values and may be inadequate. Random effects were used in various models to account for lack of independence among observations, but the implications of removing random effects based on Deviance Information Criteria (DIC) are not discussed. There was no documentation of model validation.

In Chapter 2 of the McCann et al. 2017 CSS Annual Report, AIC was apparently used to select the best model; however, the standard practice of reporting AIC comparisons is not followed, and no quantitative assessment of model fit is provided. The basis for selecting three representative years for prospective models (page 34) is not supported. The life cycle model is referred to as “statistically validated” (page 56), but no evidence of such validation is presented.

Significance – Medium/High

Validation is a fundamental part of the technical soundness and quality of a model. It is likely to reveal weaknesses in models, which leads to better understanding of the system being modeled as well as differences in model results in the CRSO. If the models do not fit or predict well, a review of assumptions can reveal important caveats for interpretation and targets for research improvements.

Recommendations for Resolution

1. Include an assessment of assumptions, model fit, and validation for each model component that is consistent with standard practices and justified by literature. It is likely that most of this assessment and possibly corresponding documentation of the assessment is currently available, but it should become part of standard documentation.
2. Include all model assumptions and potential consequences of departure from assumptions in the model documentation. Assumptions include the form of the model (e.g., linear, piecewise linear, quadratic); distribution of residuals (normal, binomial, beta); all relevant independence assumptions; appropriate range of inference; all variables considered; the strength and representativeness of the underlying datasets; and more.
3. List model fitting processes and decisions with justification and provide detailed final model fit statistics and graphics, following standard practices.
4. Assess the validity of all model components through prediction of observations not included in model calibration, and discuss the impacts of bias and lack of precision on decision-making.

Final Panel Comment 6

The methodology for use of the powerhouse passage variable (PITPH) in the CSS model is not clear and may be statistically problematic.

Relevant Model Assessment Criteria

Theory and External Model Components

Basis for Comment

Throughout the CSS documentation, PITPH is used with very little description, and reference for more information is given as the 2015 CSS Report, Appendix J. However, the term PITPH is not used in Appendix J, and there is not enough detail in that appendix to clarify exactly how this parameter was used retrospectively and prospectively at various spatial and temporal scales.

Both retrospectively and prospectively, the PITPH metric estimates the expected number of powerhouse passages within a major segment (e.g., Lower Granite to McNary Dam) by summing powerhouse passage probabilities across projects. This estimator relies on the assumption that passage through each powerhouse is independent, and that fish guidance efficiency (FGE) is constant across all conditions within projects. These are important assumptions, and they should be discussed and defended within the model documentation, including the likelihood and implications of assumption violations. For example, if the likelihood of powerhouse passage decreases with fish length at certain spills (Harnish et al., 2020), then this sum would not adequately capture the expectation across the range of fish sizes and spill levels. The assumption that FGE is constant for each project (i.e., the proportion of fish that enter the bypass facility given that they have entered the powerhouse is invariant under different environmental conditions) is justified via citation, but more detail on the strength of the assumption and implications of assumption violation is needed.

When PITPH is used prospectively, it is predicted from a statistical model as a function of total flow, % spill, and the presence or absence of a spillway weir. The model is calibrated using PIT tag counts through the collection facility and constant estimated FGE for each powerhouse. Note that flow and % spill are not independent variables (i.e., if spill were held constant, % spill would be completely determined by flow). When multi-collinearity is present, predictions can be badly biased if the relationships between the correlated predictors change, which could be the case under changed operations. There may be a better way to formulate this regression rather than including flow and % spill as independent variables (for example, by using flow as an offset variable). The approach used to formulate the model should be reviewed and defended.

The PITPH dependent variable is estimated on multiple scales for use as an independent variable in multiple models (CSSOC 2017 Documentation of Experimental Spill Management Report, Chapter 3):

1) for individual release cohorts within a year (fish travel time model, juvenile survival model, ocean survival model, smolt-to-adult returns);

2) for population groups within release cohorts (Lower Granite Reservoir survival model, also known as detection probability model); and

3) annually (TIR).

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The different estimation efforts and assumptions required to form the estimate on these different scales are confusing and should be supported by much more detailed descriptions.

For prospective use, PITPH is a model prediction with multiple sources of uncertainty, including daily environmental stochasticity, measurement error of flow and percent spill, and uncertainty associated with model fit (parameter uncertainty) (see CSS Annual Report 2015, Figures J3 and J4). The models using PITPH as a predictor of salmonid life cycle parameters include WTT, which is also a function of flow. In this case, measurement error and stochasticity are impacting these models multiple times. For example, if juvenile survival in the year 2040 is predicted as a function of WTT and PITPH, the model equation includes 1) a weighted average of reservoir volume divided by flow (WTT) over the selected time period (average across dams within the large reach); and 2) a separate sum or average of flow and spill percent (average across dams within the large reach). The Panel is concerned about the impact of variance inflation and multi-collinearity on these model predictions.

The discussion surrounding PITPH in the ocean survival model (McCann et al. 2017 CSS Annual Report) also warrants careful review, as it is used as a predictor of ocean survival and discussed as though it is an observed variable, which it is not. If it is to be used as a predictor of ocean survival, the model predicting PITPH should be presented with coefficient values and detailed explanation of specific model calibration for this purpose. The explanation should include the exact flow rates and spill rates that were used to predict PITPH. The validity of using this layered modeling approach and the statistical implications should be carefully reviewed and described.

Significance – Medium/High

The powerhouse passage variable PITPH is a central focus of the CSS modeling effort, as the main link between project operations and impacts to salmonids. This variable has not been sufficiently defended and documented, and the Panel is concerned that inferences drawn from the variable may be improper or misleading.

Recommendations for Resolution

1. Assemble and clarify documentation of PITPH to include methods for estimation at all spatial and temporal scales, assumptions, and uncertainties.
2. Assess fit of retrospective models, and report standard errors and model limitations.
3. Assess predictive capability using standard validation techniques and report prediction error and potential biases.
4. Assess the implications of using a model prediction as a predictor in a statistical regression model, including potential bias and inflation of parameter uncertainty.
5. Properly caveat conclusions based on the findings of the above analysis.

Literature Cited

Harnish, R.A., K.D. Ham, T. Fun, X. Li, J.R. Skalski, R.L. Townsend, and J. Lady (2020). Juvenile salmon and steelhead passage and survival through the Snake and Columbia River hydrosystem during spring gas cap spill, 2018. Presentation at the Upper Columbia Science Conference, January 2020, Wenatchee, Washington.

Final Panel Comment 7

The TDG model lacks information on model formulation, data inputs, and sensitivity and uncertainty analyses conducted on the model.

Relevant Model Assessment Criteria

Model Documentation Quality

Basis for Comment

It does not appear that spillway-specific populations are modeled to experience any additional TDG exposure beyond the reservoir exposure after the populations are reassembled downstream of the dam. Increasing the TDG cap at the dams will allow increases in the percentage of total river flow passing through the spillway, thereby increasing both the percentage of juveniles using the spillway as a passage route and the percentage of fish exposed to high local levels of TDG within the spillway tailrace region. While these exposure durations would be short, these spillway-passed fish will have a different exposure history than other populations passing the powerhouse, sluiceways, or elevated spillway weir structures. Specifically, while all fish will be exposed to TDG levels consistent with the downstream compliance monitoring location (~120% at most dams), only spillway-passed fish are likely to briefly experience the high local TDG levels (~140% to 160% at many dams) in the spillway vicinity.

Additionally, the documentation of the TDG model lacks specificity on a number of input parameters and processes. In particular, the process for estimated tailrace TDG is unclear. Assuming variable TDG is assigned based on spillway discharge-tailwater elevation combinations, how are TDG rating curves established? As part of RESSIM or as part of SYSTDG?

Sensitivity to TDG production would benefit from a more thorough sensitivity analysis. In general, the models are constructed to facilitate sensitivity, uncertainty, and risk analyses, but the TDG model team has not fully completed these studies. Given the complexity and intermodal dependencies of these models, the potential for errors is not insignificant.

The data for calibrating the model components is very sparse and could potentially be expanded. The mortality model is based on a single, limited laboratory study, and the use of the data from the study is not described well or justified. For the depth distribution, a table of numbers from literature is given, but justification for the model selected is omitted.

Significance – Medium

Because increased TDG exposures in the spillway region are not taken into account and model documentation is incomplete, the TDG model may be used improperly or yield incomplete or inaccurate results with respect to alternative selection.

Recommendations for Resolution

1. Consider developing an additional TDG exposure relationship applied to spillway-passed juveniles that are exposed to local elevated levels of TDG saturation.

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2. Complete a thorough sensitivity and uncertainty analysis of the TDG model.
3. Revise the model document report to include input forcing data (TDG rating curves); the basis of data used for calibration and the limitations of available data; a discussion on model assumptions and limitations; and a more thorough sensitivity and uncertainty analysis.

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The model documentation does not assess impacts of model uncertainty on the prospective results.

Relevant Model Assessment Criteria

Model Documentation Quality
Representation of the System
Review of Model Usefulness in Selecting Alternatives

Basis for Comment

Documentation of the source and magnitude of uncertainty is especially important when models are used for predictions that influence management decisions, so decision makers can understand the implications of imperfect deterministic estimates. Decision makers will benefit from an evaluation of uncertainty that allows them to ask questions such as: How confident can I be that this estimate falls between these two values? How likely is a result that would change our interpretation of a management scenario?

Most of the documentation for the various models reviewed by the Panel acknowledged potential sources of uncertainty but lacked an analysis or appropriate discussion of the potential for uncertainty to influence results. Important assumptions were made with little or no discussion about the potential influence of those assumptions on model results. Additionally, in many cases model outputs were provided as deterministic estimates, without an explicit acknowledgment of potential uncertainty (e.g., confidence intervals). Interpretation of all results would benefit from a discussion of major areas of uncertainty and the scale of uncertainty in projections. Acknowledgment of specific parts of the model with lower certainty or consistent bias would provide more transparency.

COMPASS

No uncertainty was included for “fixed” estimates, such as dam survival, which were treated deterministically. Annual uncertainty was not discussed. Monte Carlo simulation mode allows users to incorporate uncertainty in survival predictions and to partition variance components. This approach is valuable, and the resulting graphs demonstrated uncertainty surrounding estimates. The Panel feels it would also be helpful to provide numerical estimates of uncertainty around mean survival estimates in results (e.g., simulations run for the CRSO EIS), so managers understand the magnitude of uncertainty associated with model output. Additionally, it would be helpful if results were presented to the number of decimal places to which the model is accurate; results with a large number of decimal places imply high precision. For the prospective modeling, the researchers looked at variability across years and populations in terms of arrival time to Lower Granite Reservoir, in-river survival, and proportion of juvenile fish transported. The analysis shows substantial variability across years and across some populations. This information could be used to inform sensitivity, uncertainty, and risk analyses for the survival estimates produced by COMPASS.

LCM

There is some uncertainty included in the COMPASS outputs and the LCM outputs, including confidence intervals for most estimates and projections. Additionally, some important potential sources

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of variability and uncertainty are described in the discussions. However, there is no comprehensive discussion of uncertainty, and the results are not clearly described in terms of what types of uncertainty are included or ignored. Within the full life cycle model, environmental variability/uncertainty is incorporated by drawing model parameters from a distribution or modeling them as stochastic, and model output is presented as a range of values, which is helpful. However, these inputs represent process variation, and there is no assessment or discussion of the potential for input data errors and modeling uncertainties.

TDG

No sensitivity or uncertainty information is provided. Because model output is dependent on values input for the variable TDG_C, uncertainty should be quantified. For this modeling approach, it would be valuable to partition uncertainty into environmental stochasticity, sampling error, and model error, and to discuss the implications of each error component.

CSS

Both applications of the model (i.e., to generate cohort-specific estimates, as well as full life-cycle estimates) generally seem to capture overall trends in the observed data. However, the model appears to underestimate variability observed in the PIT tag data for both in-river survival and ocean survival estimates, but no estimates of associated uncertainty are provided. Additional information on uncertainty associated with specific parameters, as well as the overall model and potential biases in each model component, would help readers understand how reliable model outputs are. Projections from prospective modeling are shown in result figures as "sensitivity analyses" used to illustrate predicted survival, abundance, and productivity under various management scenarios, but no accompanying discussion of uncertainty associated with specific assumptions used for these projections, such as dam breaching, is presented. There is no assessment or discussion of the potential for input data errors and modeling uncertainties.

Significance – Medium

When ecological models are used for decision making, underestimating uncertainty can lead to poor decisions.

Recommendations for Resolution

1. Within model documentation, identify areas of uncertainty and the scale of uncertainty in model projections. Discuss primary underlying assumptions and associated sources of uncertainty, identify potential sources of bias or error, and provide estimates of uncertainty for model output.

2. Perform quantitative uncertainty analyses or sensitivity analyses to evaluate the degree of confidence that can be placed on model output (or model components in the full life cycle models). This can help readers assess underlying differences between the modeling approaches.

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3. Include some measure of uncertainty when evaluating the differences between modeled scenarios and how these uncertainties influence rank order of alternatives. A conceptual diagram illustrating uncertainty in each component of the LCM and the relative magnitude of each could prove useful for comparing relative sources of uncertainty within and among models.

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The scaling of data and models from one timeframe to another is confusing and has the potential to affect inference of certain variables.

Relevant Model Assessment Criteria

Representation of the System
Model Calculations/Formulas

Basis for Comment

Data used in the combined life-cycle models are collected at different time scales, including daily, in two-week cohorts, annually, and possibly others (the temporal scales of some predictor variables were ambiguous). Evaluating the relationship between predictive factors and response variables of interest over a daily or weekly timeframe provides important insights into these processes—for example, that smolt travel time decreases over the migration period (CSS) and smolt migration date is a significant predictor of first-year ocean survival (LCM). When combined into full life-cycle models, which are run at an annual time step, some variables calculated at shorter time steps are scaled up to an annual metric. In both the CSS and LCM, it is unclear exactly how this is done due to limited or confusing documentation. Ecological inference may change when relationships between variables are summarized at a coarser time step than that at which data were originally collected.

LCM

Chapter 4, Ocean Survival: It is not clear how COMPASS model results produced on a daily time step were integrated into climate change scenarios that necessarily use annual predictor variables. Specifically, the description of matching the annual Multivariate Auto-Regressive State-Space (MARSS) scenario data to predicted daily COMPASS output was confusing, and thus it was difficult to evaluate the effectiveness of this approach (Zabel and Jordan 2019 LCM Report, pages 4-14 and 4-15). It is also unclear how individual adult survival was calculated using average run timing distributions (since adult upstream survival decreases above a temperature threshold, one would expect the probability of individual adult survival to have a strong seasonal effect) and how this calculation was aggregated into an annual population survival estimate, which was then evaluated relative to average June temperatures (Zabel and Jordan 2019 LCM Report, page 4-15). Better documentation would help readers understand the potential implications of moving from short timeframes to annual time steps, and from individual-level metrics to annual, population-level responses.

CSS

In the CSSOC 2017 Documentation of Experimental Spill Management Report, observed and predicted values of in-river smolt survival, ocean survival, and SARs are estimated for outmigrant cohorts grouped at two-week intervals. These same parameters are estimated and modeled on an annual time step in Chapter 2 of the McCann et al. 2017 CSS Annual Report. The documentation does not specify how observed in-river survival, SARs, and ocean survival were calculated annually. It is unclear whether these annual values represent an average value, or if cohort estimates were used and somehow weighted by the proportion of the run represented by each cohort, or some other

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approach. Each of these different approaches comes with potential pitfalls and assumptions, so it is important to include enough methodological documentation that readers can understand potential implications of the methods employed. The predictor variables WTT and PITPH are also estimated on a two-week time step for individual release cohorts within a year in the CSSOC 2017 Documentation of Experimental Spill Management Report, and as an annual variable in the McCann et al. 2017 CSS Annual Report, but there is no clarification regarding how estimation methods vary between the time steps. It is unclear whether the annual values are somehow weighted by proportion of the migration at certain times/flows or if they are simply measures of average conditions across the entire migration period. When considered at these different temporal scales, predictor variables can take on different meanings, and as an annual measure may have considerably different inference than when measured by individual dam or for a discrete cohort of fish. For example, as an annual metric that statistically represents flow and spill, PITPH may be more representative of annual hydrography than a specific measurement of powerhouse passage, since powerhouse passage varies seasonally, with fish size, and among individual dam sites.

Significance – Medium

Because ecological inference may change when relationships between variables are summarized at different time steps, it is important to understand how variables are scaled from one time step to another, and when these variables are summarized or compiled, how their interpretation might change.

Recommendations for Resolution

1. Clarify methods used to scale up from smaller time steps to annual time steps and use diagrams and equations when possible. Describe methods used to estimate key parameters. Define predictors used in models within the model documentation. If a variable is used at multiple temporal scales, specify the scale each time the variable is used in the variable name (e.g., $PITPH_{cohort}$ vs $PITPH_{annual}$) or define a different metric with a different name altogether.

2. Provide enough information about variables and relationships in the documentation in the form of equations, figures, estimates, etc., for readers to understand and validate the major ecological inferences and conclusions.

Final Panel Comment 10

Simplifying assumptions applied to the adult migration portion of the life cycle decrease the accuracy and interpretability of the LCM and CSS models.

Relevant Model Assessment Criteria

Representation of the System

Basis for Comment

The adult freshwater portion of the salmon-steelhead life cycle encompasses freshwater migration through the hydrosystem and up to natal tributaries, a pre-spawn holding period, and spawning itself. A substantial body of research indicates that multiple factors influence survival during this period, including harvest quotas (fisheries), pinniped predation rates, water temperature, fish travel time, and the timing of freshwater entry. Both the CSS and LCM full life cycle models include simplified adult salmonid survival relationships that are unlikely to account for the complex set of factors that can influence survival during adult upstream migration and the pre-spawning period. Both models focus considerable effort on juvenile survival across short time steps (daily or for two-week cohorts) relative to multiple predictor variables. In contrast, adult survival is modeled as an averages for each year, without accounting for variability related to known processes, thus making unsupported assumptions about how management actions within the CRSO are expected to influence adult survival. Specifically, temperature, transportation history, and spill have been shown to influence adult survival (or at least "conversion rate", a metric used to approximate adult survival), all of which have management implications within the CRSO. For example, higher spill at Columbia River dams has been linked to increased juvenile survival but decreased adult survival. The ability to evaluate such trade-offs is a particular strength of complete life cycle models, but to the Panel's knowledge was not explicitly included in the current application of these models.

LCM

Documentation for the LCM states that adult survival includes all adult migration mortalities from arrival at the Columbia River mouth to spawning grounds, including estimated marine mammal predation in the Lower Columbia, harvest in the mainstem, upstream mortalities, and pre-spawn mortality above Lower Granite Dam. However, not all components are defined in each chapter or scenario, and it is not always clear how the various estimates were combined into a complete adult survival estimate. Complete model documentation should include equations with coefficient estimates and sources of input data for each different use of every model.

It is also unclear how harvest was accounted for in the model(s). The upstream survival component and the prediction of this component for prospective modeling is not well-described (Zabel and Jordan 2019 LCM Report, page 4-15). Specifically, this predicted relationship between annual survival rate and mean June temperature may not adequately capture important within-year variations in adult survival.

Inclusion of additional predictors of migration survival such as spill (Crozier et al., 2017) and fish transportation history (Keefer et al., 2008), as well as a separate component for pre-spawning mortality modeled relative to holding temperatures, could improve accuracy of the model. Some of these variables might have been included in predictions of individual fish survival but were not

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described in the documentation provided. Additionally, modeling adult survival on a shorter time step (daily or weekly) would allow evaluation of seasonal trade-offs, such as higher pinniped predation rates at the start of migration for early-season migrants (Keefer et al., 2012) vs. higher migration mortality related to high stream temperatures for late-season migrants (Crozier et al., 2017).

CSS

In the CSS model, the number of spawners was defined as the sum of the run of each age class of fish not harvested that survive migration passage for a given population and year. This definition would seem to account only for survival through the migration corridor (as suggested by the equations for predicted SAR), defined as returns to Lower Granite Dam (or the current location of Lower Granite Dam under breach scenarios). By this definition, the current CSS model would not account for pre-spawning mortality that occurs above Lower Granite Dam, which would lead to underestimates in the number of adult spawners since pre-spawning mortality has been observed in the populations of interest.

In addition, the migration conversion rates were not defined, and no values were given for this derived estimate (lambda). Additionally, it was not clear where these values were located in the reference provided, (the reference was listed as “US vs. OR Biological Assessment Tables” in Table 2.1, McCann et al. 2017 CSS Annual Report), or whether this reference was for adult conversion rates or harvest schedules. For prospective analyses, harvest was modeled relative to abundance, but no equation was provided showing how this was calculated.

Conversion rate values (not provided) were drawn at random from the most recent 20 years of conversion rates. The assumption that adult migration survival (known as conversion rate in the model) is random is overly simplistic, and the theoretical underpinning for this assumption should be supported with data or literature. Inclusion of predictor variables, such as those evaluated in McCann et al. 2017 CSS Annual Report, Chapter 8, may provide more insight into the ecological function of the system and will explicitly acknowledge that adult survival is not completely random (e.g., there are multiple lines of evidence suggesting that adult upstream survival is lower in years with elevated water temperatures).

In the prospective analysis, the conversion rate represents survival rate after “adult losses net of harvest,” and those losses include predation, pre-spawn mortality, and passage-related mortality, which implies consideration of the adult life stage from freshwater entry to spawning (a slightly different definition than the one provided for lambda in the life-cycle equations). As such, the subsequent assumption—that under a scenario in which the four Snake River dams are breached, there would be a 50% reduction in upstream mortality throughout that entire life stage—should be backed up with data and/or literature. The supporting data should demonstrate the relative contribution of mortality related to hydrosystem passage vs. pinniped predation and pre-spawning conditions, and the effect of this assumption on overall results should be discussed.

In Chapter 8 of the McCann et al. 2017 CSS Annual Report, the authors modeled adult survival relative to variables such as water temperature and juvenile transport, although it did not appear that these relationships were included in the overall life-cycle modeling. This approach seemed somewhat exploratory, as several different approaches were tested. The authors chose models based on what

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was the most biologically plausible to them and/or the lowest AIC value. The recommended approach for model selection using AIC is to first choose models that are biologically relevant, and then compare models using AIC (Burnham and Anderson, 2002), rather than to combine the two approaches. In this assessment, too many predictors and interactions were selected to be plausible for a 14-year time series. Although year was included as a random effect (so that each year would have an intercept offset), it is likely that within-year pseudo-replication was not adequately accounted for by this term. Possibly a random year/predictor interaction with temperature or arrival date would give better results. These issues aside, there appeared to be a negative effect of temperature on adult migration survival and a potential negative effect of transport. As these results become further developed, inclusion of these relationships in the complete life cycle model could improve accuracy of prospective models.
Significance – Medium
Although survival during the adult life stage is typically higher than for other life stages, failure to account for factors that influence survival during all components of the adult life stage, including freshwater entry, upstream migration, and holding prior to spawning, could lead to inaccurate estimates of spawner abundance. Failure to evaluate the relationship between environmental conditions and adult survival in models could lead to management decisions that benefit one life stage without adequate consideration of the cost to other life stages.
Recommendations for Resolution
1. Evaluate the importance of including additional environmental predictor variables and selecting appropriate time steps in the adult survival component of life cycle models to improve predictive accuracy. 2. Provide adequate documentation of each model use, including equations with parameter estimates and source of input data.

Literature Cited

Burnham, K.P., and D.R. Anderson (2002). Model selection and multimodel inference: A practical information-theoretic approach. Springer-Verlag, New York.

Crozier, L., L. Wiesebron, E. Dorfmeier, and B. Burke (2017). River conditions, fisheries and fish history drive variation in upstream survival and fallback for Upper Columbia River spring and Snake River spring/summer Chinook salmon. Report of research by Fish Ecology Division, Northwest Fisheries Science Center.

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

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

Final Panel Comment 11

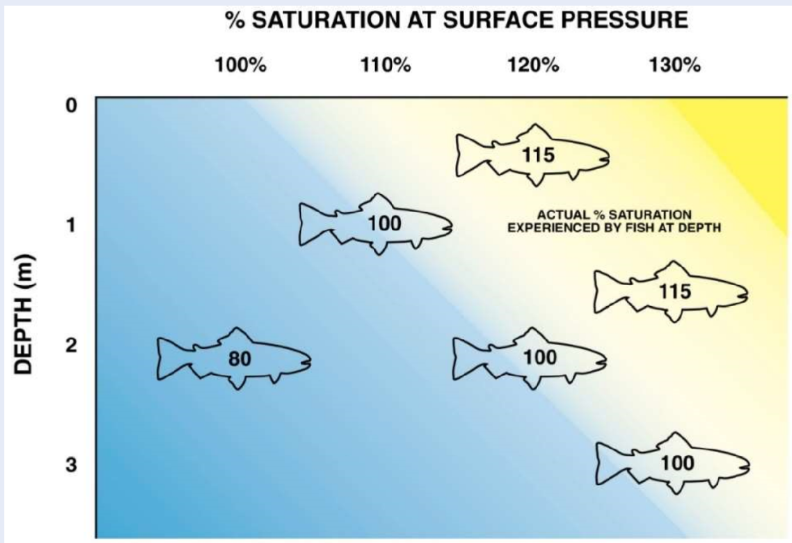
The biological effect of TDG supersaturation would be more accurately modeled if the Fish Individual-based Numerical Simulator (FINS) and/or Politano et al. models were used for the TDG analysis.

Relevant Model Assessment Criteria

Review Theory and External Model Components

Basis for Comment

Juvenile salmonids commonly occupy a range of depths during their migrations that result in varying exposure to TDG levels, as presented in the figure below. This varying exposure to supersaturation both limits the development of GBD and provides recovery from GBD when fish occupy depths at TDG levels lower than 100% saturation.



Relationship of measured and actual TDG levels experienced by fish at various depths.

The FINS (Scheibe and Richmond, 2002; Scheibe et al., 2002) and/or Politano (Politano et al., 2009, 2012, 2017) models could be used in a decoupled mode to run numerical experiments to better understand the relationship between fish behavior, depth distribution of juvenile salmonids, and their supersaturation exposure history. The results of these numerical experiments could be used to improve the simplified TDG exposure relations used in the larger system-scale population models.

The TDG model documentation provides several objections to using the FINS model that the Panel suggests be reconsidered. We recommend that the TDG modeling team explore ways to overcome these objections. The FINS and/or Politano models can be used to better understand the depth distribution, and duration at various depths, of juvenile salmonid migrants under different behavioral

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assumptions. The depth distribution / duration of exposure is the most important combination in determining the biological effects of TDG supersaturation.

Stated objections to the FINS model are as follows:

1. A three-dimensional (3-D) hydraulic model is required.
2. Information on the radio-tracked movement of fish is required.
3. FINS does not compute the mortality resulting from gas exposure.
4. Only a single reservoir is modeled.
5. FINS cannot be integrated with the other models used in the CRSO modeling system.

In response to these stated objections, the Panel offers the following counter-arguments for consideration:

1. FINS and/or the Politano model could be used as stand-alone models as they exist to explore the exposure history of radio-tracked fish, in particular, at projects with varying spill operations, subsequent levels of downstream TDG, and recorded biological data of gas bubble trauma. This has been done at a few select locations where associated model results exist. The Panel was unable to find reference to these data being reviewed or used by the TDG team in its development of the overall TDG model assumptions. Given the level of physics captured by FINS, and in particular the Politano model, a greater understanding of the driving physical mechanisms for elevated TDG can be explored, including the entrainment and entrapment of air at the plunge point of the spillway jet, the break-up and coalescence of bubbles, and the subsequent dissolution of gas into fluid (Wang et al., 2019).

2. In the absence of radio-tagged data, 3-D computational fluid dynamics models of a tailrace region along with numerical particle tracking data is a good surrogate for fish pathways and associated exposure history, as the energy and flow velocities in the spillway region far exceed the fish's swimming strength and ability for volitional movement.

3. True, neither FINS nor the Politano models directly compute mortality resulting from TDG gas exposure, but using these models along with field data should increase understanding of fish mortality and would potentially lead to more simplified causal relationships that may be later incorporated into CSS or COMPASS. However, the absence of any significant mortality and low incidence of GBD in monitored juveniles migrating within the study area indicates that an accurate model would not predict mortality.

4. True, both the FINS and Politano models only simulate a single reservoir—hence the need to run the models decoupled from CSS or COMPASS and use the results to improve understanding as stated above. As an example, the Politano model has been used at Wanapum and Well Dams (mid-Columbia), Brownlee and Hells Canyon Dams (Hells Canyon Reach) and McNary Dam (lower Columbia), providing a wide range of dam configurations, flow conditions, and reach-specific attributes.

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5. As previously stated, the Panel suggests using the models as decoupled, numerical tools to increase understanding of underlying processes and to advance more simplified relations that could be integrated into the populations dynamics models.

Incorporation of behavior (depths occupied by fish) is necessary for an accurate modeling of the supersaturation exposure fish actually receive.

Significance – Medium

Knowledge of the depths fish occupy during exposure to supersaturation is necessary to accurately predict the occurrence and severity of GBD and thus fish mortality. However, the absence of GBD observations in the fish sampled from the study area indicates that the migrants are spending sufficient time at depths adequate to compensate for up to 130% of saturation. Therefore, a more accurate model is not likely to alter conclusions or decisions.

Recommendation for Resolution

1. Develop a research plan to include these advanced technologies (FINS and/or Politano model) to improve the current TDG model and its implementation into the larger system-scale population models.

Literature Cited

Politano M., P.M. Carrica, and L. Weber (2009). A multiphase model for the hydrodynamics and total dissolved gas in tailraces. Int. J. Multiphase Flow, 35(11), 1036.

Politano M., A. Arenas Amado, S. Bickford, J. Murauskas, and D. Hay (2012). Evaluation of operational strategies to minimize gas saturation downstream of a dam. Computer and Fluids, 68, 168.

Politano, M., A. Castro, and B. Hadjerioua (2017). Modeling total dissolved gas for optimal operation of multireservoir systems. J. Hyd. Eng., 143(6), 04017007.

Scheibe, T.D., and M.C. Richmond (2002). Fish individual-based numerical simulator (FINS): a particle-based model of juvenile salmonid movement and dissolved gas exposure history in the Columbia River basin. Ecological Modelling 147:233-252.

Scheibe, T.D., M.C. Richmond, and L.E. Fidler. (2002). Impacts of individual fish movement patterns on estimates of mortality due to dissolved gas supersaturation in the Columbia River Basin. Pacific Northwest National Lab. 12 pp. https://www.researchgate.net/profile/Marshall_Richmond/publication/255243601_Impacts_of_individual_fish_movement_patterns_on_estimates_of_mortality_due_to_dissolved_gas_supersaturation_in_the_Columbia_River_Basin/links/55873c7308aeb0cdade0b53f.pdf

Wang Y., M. Politano, and L. Weber (2019). Spillway jet regime and total dissolved gas prediction with a multiphase flow model. J. Hyd. Res., 57(1), 26.

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An accurate TDG model requires data, or at least informed assumptions, regarding fish behavior to accurately assess the real TDG exposure migrants encounter and subsequent biological effects.

Relevant Model Assessment Criteria

Theory and External Model Components

Basis for Comment

Using a TDG model that relies on mean TDG levels perpetuates a misconception that mean TDG levels predict biological effects, namely GBD. Both fish populations and TDG levels vary with depth and spatial position in the tailrace region, resulting in unique incidence of exposure and subsequent renormalization for fish that remain at depth as they migrate downstream into areas of lower TDG levels.

Fish exposed to mean TDG levels in shallow water (e.g., hatchery troughs, raceways, or shallow tributaries) will have biological effects reasonably modeled by mean TDG levels, whereas fish exposed to mean TDG levels in conditions of substantial stream depth are not likely to be accurately assessed by mean TDG levels.

Additional research into the depth-exposure-biological response is needed to improve the TDG model. The use of coupled field/laboratory–numerical experiments, applying controlled environmental conditions and higher-order, physics-based models such as FINS (Scheibe and Richmond, 2002; Scheibe et al., 2002) or the Politano et al. and the Wang et al. (Politano et al., 2009, 2012, 2017; Wang et al., 2019) models, would result in a better understanding of actual GBD and the latent mortality from high TDG exposures.

Significance – Medium

The TDG model does not accurately model fish exposure to the TDG levels experienced by migrating juvenile salmonids. However, monitoring indicates that the levels of GBD and juvenile fish mortality occurring within the study area are sufficiently low therefore increasing the TDG model accuracy may not alter conclusions or alternative selection.

Recommendation for Resolution

1. Develop a research plan to better understand the impact of TDG exposure and depth on fish injury and mortality.

Literature Cited

Politano M., P.M. Carrica, and L. Weber (2009). A multiphase model for the hydrodynamics and total dissolved gas in tailraces. Int. J. Multiphase Flow, 35(11), 1036.

Politano M., A. Arenas Amado, S. Bickford, J. Murauskas, and D. Hay (2012). Evaluation of operational strategies to minimize gas saturation downstream of a dam. Computer and Fluids, 68, 168.

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The model documentation does not provide the appropriate high-level descriptions of model assumptions, formulations, calibration, results, discussion, and conclusions or the materials to allow an independent modeler to use the models.

Relevant Model Assessment Criteria

Model Documentation Quality
Review of Operating Requirements of the Model

Basis for Comment

Many of the models have a long history that includes numerous modifications, some internally motivated and some suggested by external review such as the ISAB process. These improvements are ongoing, such that there have been many versions of a model. The documents provided to the Panel consisted of a mix of 1) documenting the equations, justifying the structure, and describing the parameterization ("fitting") of a model, not necessarily for the most recent version (e.g., COMPASS Model – Main Documentation), 2) presenting analyses focused on modifying or extending the scope of a model (e.g., incorporating a new fish stock [McCann et al. 2017 CSS Annual Report, Chapter 6]), 3) presenting analyses potentially relevant to future model modifications (e.g., Zabel and Jordan 2019 LCM Report, Chapter 2), and 4) using models to predict the effects of a CRSO structural/operational scenario akin to, but not exactly corresponding to, a DEIS alternative (CSSOC 2017 Documentation of Experimental Spill Management Report, Chapter 3).

Although the Panel was given code and user manuals for some of the models, panel members experienced some difficulties in installation owing to a lack of adequate documentation. Panel members agreed not to use their limited time on attempting to run the software themselves. Thus, the Panel's comments on these aspects of the charge are fairly limited. If, in the future, these models are to be made available for use by a more general audience beyond the modelers themselves, the Panel recommends more detailed instructions for installation and application, accompanied by a vignette that illustrates the basic uses.

The Panel's charge was to establish that models, analyses, results, and conclusions are theoretically sound, computationally accurate, based on reasonable assumptions, well-documented, and in compliance with the requirements of the OMB Peer Review Bulletin (OMB, 2004). Due to the large number of models and variety of model usages contained in the documents for review, the panel members prioritized their reviews, focusing on models relevant to the DEIS. This focus required some searching through the documents provided, reviewing some material that was not originally provided, and obtaining some clarification and guidance from the modelers themselves. In particular, it was difficult to understand which models were used and which were not; which versions were used; and the interface between submodels, such as between the USACE HydSim model and the COMPASS juvenile migration and survival model, or between the COMPASS model and the LCM ocean survival or SAR models.

The documentation of many of the models was incomplete. The standard for such documentation is that a competent modeler should be able to recreate the model. The Panel found a range of clarity, from the quite good documentation of the COMPASS model (although not necessarily as good for the

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inputs), to the short and confusing documentation of the LCM adult upstream survival model, to the CSS documentation in which the only information about critical methods and variables was a reference to an outside document that was not provided. Terminology was sometimes confusing. The definition of PITPH seemed inconsistent in different documents or document sections, and SAR could mean survival from an upstream dam to return to Bonneville, upstream dam to the same upstream dam, or Bonneville to an upstream dam. Sometimes the exact usage was not clear.
Significance – Medium/Low
A lack of adequate model documentation inhibits understanding; other modelers would not be able to replicate the models. A lack of accurate installation procedures means that interested parties would not be able to run or use the models.
Recommendations for Resolution
1. Document every component model thoroughly, including assumptions, limitations, validation, sensitivities, uncertainties, and areas of potential improvement. 2. Include alternative methodologies that could have been used and list pros and cons. 3. Create an overview of the documentation that addresses the technical aspects of the specific models used in the DEIS—in particular, the aspects not documented elsewhere (such as how submodels were integrated), with the goal of enabling a competent outside modeler to replicate the analyses. 4. Create an accurate installation guide, including minimum software needs, necessary to run the models.

6.0 CONCLUSIONS

The Panel commends USACE and the modeling teams for developing an integrative modeling approach, incorporating statistical models, data-driven models, and physics-based models into a framework for forecasting population dynamics of Columbia River System salmonids. Both sets of models, the COMPASS/LCM and the CSS sets, are sensible and credible and allow for flexibility over a range of inputs that will be helpful for modeling future conditions.

In building such a modeling framework, USACE and the modeling teams have sought to assemble the best available information to guide decision-making in the future, including alternative selection. However, the Panel further seeks to ensure that these models are useful as a part of a decision-making process and also are not looked upon as the ultimate solution to the understanding of the CRSO ecological system. The ecological modeling program should be thought of as an evolving, adaptive process with both current utility/value and a continual need for improvement. The Panel suggests that the individual modeling teams (LCM, COMPASS, CSS, TDG) each prepare a model status and development plan, including clear statements about knowns, unknowns, and future needs for additional data, additional model formulation, additional controlled laboratory experiments, and additional field testing. The Panel believes that the current models have value in the current EIS process, but that the current models can be improved by incorporating some of the suggestions provided herein, in the near term and in the future, as more data become available and ecological understanding of the system improves.

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APPENDIX A

IEPR Process for the CRSO Ecological Models Project

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A.1 Planning and Conduct of the Independent External Peer Review (IEPR)

Table A-1 presents the major milestones and deliverables of the Independent External Peer Review (IEPR) of the Columbia River System Operations (CRSO) Ecological Models (hereinafter: CRSO Ecological Models IEPR). Due dates for milestones and deliverables are based on the award/effective date listed in Table A-1. The review documents were provided by U.S. Army Corps of Engineers (USACE) on December 20, 2019. Note that the actions listed under Task 6 occur after the submission of this report. Battelle anticipates submitting the pdf printout of the USACE's Design Review and Checking System (DrChecks) project file (the final deliverable) on July 2, 2020. The actual date for contract end will depend on the date that all activities for this IEPR are conducted and subsequently completed.

Table A-1. Major Milestones and Deliverables of the CRSO Ecological Models IEPR

Task	Action	Due Date
1	Award/Effective Date	12/20/2019
	Review documents available	12/20/2019
	Battelle submits draft Work Plan[a]	1/3/2020
	USACE provides comments on draft Work Plan	1/10/2020
	Battelle submits final Work Plan[a]	1/15/2020
2	Battelle submits list of selected panel members[a]	1/13/2020
	Battelle submits revised list of selected panel members[a]	2/6/2020
	USACE confirms the panel members have no COI	2/7/2020
3	Battelle convenes kick-off meeting with USACE	1/14/2020
	Battelle convenes kick-off meeting with panel members	3/3/2020
	Battelle convenes kick-off meeting with USACE and panel members	3/3/2020
4	Panel members complete their individual reviews	4/1/2020
	Panel members provide draft Final Panel Comments to Battelle	4/14/2020
	Panel finalizes Final Panel Comments	4/16/2020
5	Battelle submits Final Model Report to USACE[a]	5/4/2020
6[b]	Battelle convenes Comment Response Teleconference with panel members and USACE	6/17/2020
	Battelle submits pdf printout of DrChecks project file[a]	7/2/2020
	Contract End/Delivery Date	1/31/2021

[a] *Deliverable.*

[b] *Task 6 occurs after the submission of this report.*

At the beginning of the Period of Performance for the CRSO Ecological Models IEPR, Battelle held a kick-off meeting with USACE to review the preliminary/suggested schedule, discuss the IEPR process, and address any questions regarding the scope (e.g., terminology to use, access to DrChecks, etc.). Any revisions to the schedule were submitted as part of the final Work Plan. The final charge consisted of

23 charge questions provided by USACE, two overview questions added by Battelle (all questions were included in the draft and final Work Plans), and general guidance for the Panel on the conduct of the peer review (provided in Appendix C of this final report).

Prior to beginning their review and after their subcontracts were finalized, all the members of the Panel attended a kick-off meeting via teleconference planned and facilitated by Battelle in order to review the IEPR process, the schedule, communication procedures, and other pertinent information for the Panel. Battelle planned and facilitated a second kick-off meeting via teleconference during which USACE presented project details to the Panel. Before the meetings, the IEPR Panel received an electronic version of the final charge, as well as the review documents and reference/supplemental materials listed in Table A-2.

Table A-2. Documents to Be Reviewed and Provided as Reference/Supplemental Information

Review Documents	Number of Pages
NOAA COMPASS Documentation	
COMPASS Model - Main Documentation	30
COMPASS Model – Application Software (BASH or another modern Linux/Unix shell with the awk and sed utility languages and a correct version of the “R” programming language included)	--
COMPASS Model – Appendix 1. PIT-tag data	13
COMPASS Model – Appendix 2. Calibration of Survival and Migration Models	20
COMPASS Model – Appendix 3. Model Diagnostics	57
COMPASS Model – Appendix 4. Dam Passage Algorithms	15
COMPASS Model – Appendix 5. Dam Survival Parameters	65
COMPASS Model – Appendix 6. Hydrology	19
COMPASS Model – Appendix 7. Arrival Timing at Lower Granite Dam	30
COMPASS Model – Appendix 8. Sensitivity Analysis	12
NOAA Life-Cycle Modeling Documentation	
LCM Model Documentation	772
LCM Model Application Software	--
Fish Passage Center Comparative Survival Study Model Documentation	
Letter Overview of CSS Model Documentation	4
Introduction to CSS PowerPoint Presentation. 2018. Background and Overview of Modeling	241
CSS Model Documentation – 2018 Annual Report	248
CSS Model Documentation – Experimental Spill Management: Models, Hypotheses, Study Design, and Response to ISAB	139
CSS Model Application Software (includes code for CSS cohort models and CSS-LifeCycle.tpl file)	--
University of Washington Total Dissolved Gas Modeling Documentation	
TDG Model Documentation	17
TDG Model Application Software (PERL must be installed. R must be installed. COMPASS must be installed with executable in the working directory)	--
Total Number of Review Pages	**1,682**

Table A-2. Documents to Be Reviewed and Provided as Reference/Supplemental Information (continued)

Supplemental Documents[a]	Number of Pages
Zabel et al. 2008. Comprehensive passage (COMPASS) model: a model of downstream migration and survival of juvenile salmonids through a hydropower system. Hydrobiologia, 609: 289-300	11
Northwest Power and Conservation Council. ISAB 2006-2. Review of NOAA Fisheries' COMPASS Model.	16
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Northwest Power and Conservation Council. ISAB 2010-5. Review of the Comparative Survival Study (CSS) 2010 Annual Report.	13
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Northwest Power and Conservation Council. ISAB 2013-4. Review of the Comparative Survival Study (CSS) 2013 Annual Report.	30
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Northwest Power and Conservation Council. ISAB 2017-1. Review of the Comparative Survival Study (CSS) 2018 Annual Report.	152
Northwest Power and Conservation Council. ISAB 2018. Review of the Comparative Survival Study (CSS) Draft 2018 Annual Report.	29
Total Number of Reference Pages	**424**

[a] *Supporting documentation only. These documents are not for Panel review and should be used as information sources only. They are not included in the total page count.*

In addition to the materials provided in Table A-2, the panel members were provided the following USACE guidance documents.

- Review Policy for Civil Works (EC 1165-2-217, February 20, 2018)
- Office of Management and Budget's Final Information Quality Bulletin for Peer Review (December 16, 2004)

About halfway through the review, a teleconference was held with USACE, Battelle, and the Panel so that USACE could answer any questions the Panel had concerning either the review documents or the project. Prior to this teleconference, Battelle submitted 34 panel member questions to USACE. USACE was able to provide responses to all the questions during the teleconference, or was able to provide written responses to all the questions prior to the end of the review.

In addition, throughout the review period, USACE provided documents at the request of panel members. These documents were provided to Battelle and then sent to the Panel as additional information only and were not part of the official review. A list of these additional documents requested by the Panel is provided below.

- 2015 CSS Annual Report.pdf
- 2017 CSS Annual Report.pdf
- Tech.Memo.Outline.docx
- CRSO-32.pdf
- 30-17rev1.pdf
- All CRSO Draft EIS Files from the Public Review.

A.2 Review of Individual Comments

The Panel was instructed to address the charge questions/discussion points within a charge question response form provided by Battelle. At the end of the review period, the Panel produced individual comments in response to the charge questions/discussion points. Battelle reviewed the comments to identify overall recurring themes, areas of potential conflict, and other overall impressions. At the end of the review, Battelle summarized the individual comments into a preliminary list of overall comments and discussion points. Each panel member's individual comments were shared with the full Panel.

A.3 IEPR Panel Teleconference

Battelle facilitated a teleconference with the Panel so that the panel members could exchange technical information. The main goal of the teleconference was to identify which issues should be carried forward as Final Panel Comments in the Final Model Report and decide which panel member should serve as the lead author for the development of each Final Panel Comment. This information exchange ensured that the Final Model Report would accurately represent the Panel's assessment of the project, including any conflicting opinions. The Panel engaged in a thorough discussion of the overall positive and negative comments, added any missing issues of significant importance to the findings, and merged any related individual comments. At the conclusion of the teleconference, Battelle reviewed each Final Panel Comment with the Panel, including the associated level of significance, and confirmed the lead author for each comment.

A.4 Preparation of Final Panel Comments

Following the teleconference, Battelle distributed a summary memorandum for the Panel documenting each Final Panel Comment (organized by level of significance). The memorandum provided the following detailed guidance on the approach and format to be used to develop the Final Panel Comments for the CRSO Ecological Models IEPR:

- Lead Responsibility: For each Final Panel Comment, one panel member was identified as the lead author responsible for coordinating the development of the Final Panel Comment and submitting it to Battelle. Battelle modified lead assignments at the direction of the Panel. To assist each lead in the development of the Final Panel Comments, Battelle distributed a summary email detailing each draft final comment statement, an example Final Panel Comment following the five-part structure described below, and templates for the preparation of each Final Panel Comment.

- Directive to the Lead: Each lead was encouraged to communicate directly with the other panel members as needed and to contribute to a particular Final Panel Comment. If a significant comment was identified that was not covered by one of the original Final Panel Comments, the appropriate lead was instructed to draft a new Final Panel Comment.

- Format for Final Panel Comments: Each Final Panel Comment was presented as part of a five-part structure:

  1. Comment Statement (succinct summary statement of concern)
  2. Relevant Model Assessment Criteria
  3. Basis for Comment (details regarding the concern)
  4. Significance (high, medium/high, medium, medium/low, and low; see description below)
  5. Recommendation(s) for Resolution (see description below).

- Criteria for Significance: The following were used as criteria for assigning a significance level to each Final Panel Comment:

  1. **High:** There is a fundamental issue within study documents or data that will influence the ecological model's technical soundness, system quality, or usability.
  2. **Medium/High:** There is a fundamental issue within study documents or data that has a strong probability of influencing the ecological model's technical soundness, system quality, or usability.
  3. **Medium:** There is a fundamental issue within study documents or data that has a low probability of influencing the ecological model's technical soundness, system quality, or usability.
  4. **Medium/Low:** There is missing, incomplete, or inconsistent technical or scientific information that affects clarity, understanding, or completeness of study documents, and there is uncertainty regarding whether the missing information will affect the ecological model's technical soundness, system quality, or usability.
  5. **Low:** There is a minor technical or scientific discrepancy or inconsistency that affects the clarity, understanding, or completeness of study documents, but does not influence the ecological model's technical soundness, system quality, or usability.

- Guidelines for Developing Recommendations: The recommendation section was to include specific actions that USACE should consider to resolve the Final Panel Comment (e.g., suggestions on how and where to incorporate data into the analysis, how and where to address insufficiencies, areas where additional documentation is needed).

Battelle reviewed and edited the Final Panel Comments for clarity, consistency with the comment statement, and adherence to guidance on the Panel's overall charge, which included ensuring that there were no comments regarding USACE policy. At the end of this process, 13 Final Panel Comments were prepared and assembled. There was no direct communication between the Panel and USACE during the preparation of the Final Panel Comments. The full text of the Final Panel Comments is presented in Section 5.0 of the main report.

A.5 Final Model Report

After concluding the review and preparation of the Final Panel Comments, Battelle prepared a Final Model Report (this document) on the overall IEPR process and the IEPR panel members' findings. Each panel member and Battelle technical and editorial reviewers reviewed the Final Model Report prior to submission to USACE for acceptance.

A.6 Comment Response Process

As part of Task 6, Battelle will enter the 13 Final Panel Comments developed by the Panel into USACE's DrChecks, a Web-based software system for documenting and sharing comments on reports and design documents, so that USACE can review and respond to them. USACE will provide responses (Evaluator Responses) to the Final Panel Comments, and the Panel will respond (BackCheck Responses) to the Evaluator Responses. All USACE and Panel responses will be documented by Battelle. Battelle will provide USACE and the Panel a pdf printout of all DrChecks entries, through comment closeout, as a final deliverable and record of the IEPR results.

APPENDIX B

Identification and Selection of IEPR Panel Members for the CRSO Ecological Models Project

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B.1 Panel Identification

The candidates for the Independent External Peer Review (IEPR) of the Columbia River System Operations (CRSO) Ecological Models (hereinafter: CRSO Ecological Models IEPR) Panel were evaluated based on their technical expertise in the following key areas: quantitative ecology (two panel members), integrated ecological modeling, fish passage biology, and mathematical statistics. These areas correspond to the technical content of the review documents and overall scope of the CRSO Ecological Models project.

To identify candidate panel members, Battelle reviewed the credentials of the experts in Battelle's Peer Reviewer Database, sought recommendations from colleagues, contacted former panel members, and conducted targeted Internet searches. Battelle evaluated these candidate panel members in terms of their technical expertise and potential conflicts of interest (COIs). Of these candidates, Battelle chose the most qualified individuals, confirmed their interest and availability, and ultimately selected five experts for the final Panel. The remaining candidates were not proposed for a variety of reasons, including lack of availability, disclosed COIs, or lack of the precise technical expertise required.

Candidates were screened for the following potential exclusion criteria or COIs. These COI questions were intended to serve as a means of disclosure in order to better characterize a candidate's employment history and background. Battelle evaluated whether scientists in universities and consulting firms that are receiving U.S. Army Corps of Engineers (USACE) funding have sufficient independence from USACE to be appropriate peer reviewers. Office of Management and Budget (OMB) guidance (2004, p. 18) states:

> "…when a scientist is awarded a government research grant through an investigator-initiated, peer-reviewed competition, there generally should be no question as to that scientist's ability to offer independent scientific advice to the agency on other projects. This contrasts, for example, to a situation in which a scientist has a consulting or contractual arrangement with the agency or office sponsoring a peer review. Likewise, when the agency and a researcher work together (e.g., through a cooperative agreement) to design or implement a study, there is less independence from the agency. Furthermore, if a scientist has repeatedly served as a reviewer for the same agency, some may question whether that scientist is sufficiently independent from the agency to be employed as a peer reviewer on agency-sponsored projects."

The term "firm" in a screening question referred to any joint venture in which a firm was involved. It applied to any firm that serves in a joint venture, either as a prime or as a subcontractor to a prime. Candidates were asked to clarify the relationship in the screening questions.

Panel Conflict of Interest (COI) Screening Questionnaire for the IEPR of the Columbia River System Operations (CRSO) Ecological Models
1. Previous and/or current involvement by you or your firm in the Columbia River System Operations (CRSO) Environmental Impact Statement (EIS) (hereinafter: CRSO), and related projects including the Comprehensive Passage Model (COMPASS), Interior Columbus Basin Lifecycle Model (LCM), Comparative Survival Study (CSS) Model, Total Dissolved Gas (TDG) – University of Washington Model.

Panel Conflict of Interest (COI) Screening Questionnaire for the IEPR of the Columbia River System Operations (CRSO) Ecological Models
2. Previous and/or current involvement by you or your firm in salmonid projects in the Columbia River Basin.
3. Previous and/or current involvement by you or your firm in the conceptual or actual design, construction, or operation and maintenance (O&M) of any projects in the Columbia River Basin.
4. Current employment by the USACE, Bonneville Power Administration, or Bureau of Reclamation.
5. Previous and/or current involvement with paid or unpaid expert testimony related to Columbia River Basin projects.
6. Previous and/or current employment or affiliation with members of the following Federal, State, County, local and regional agencies, environmental organizations, and interested groups *(for pay or pro bono)*: • Governor of Washington State • Governor of Oregon • Governor of Idaho • Governor of Montana • Burns Paiute Tribe • Confederated Salish and Kootenai Tribes • Confederated Tribes and Bands of the Yakama Nation • Confederated Tribes of the Colville Reservation • Confederated Tribes of Grand Ronde • Confederated Tribes of the Chehalis Reservation • Confederated Tribes of Siletz • Confederated Tribes of the Umatilla Indian Reservation • Confederated Tribes of the Warm Springs Reservation of OR • Coeur D'Alene Tribe • Cowlitz Indian Tribe • Fort McDermitt Paiute-Shoshone Tribe • Kalispel Tribe of Indians • Kootenai Tribe of Idaho • Nez Perce Tribe • Shoalwater Bay Tribe • Shoshone Bannock Tribes of the Fort Hall Reservation • Shoshone-Paiute Tribes of the Duck Valley Reservation • Spokane Tribe of Indians • Upper Columbia United Tribes • Center for Whale Research • Save Our Wild Salmon • National Resources Defense Council • Sierra Club

Panel Conflict of Interest (COI) Screening Questionnaire for the IEPR of the Columbia River System Operations (CRSO) Ecological Models
• Earth Justice • Dam Sense • Defenders of Wildlife • Trout Unlimited • Wild Orca Center • Earth Economics • Bluefish.org • Columbia Riverkeepers • Northwest River Partners • Audubon Society • American Rivers • Oceana.
7. Past, current, or future interests or involvements (financial or otherwise) by you, your spouse, or your children related to Columbia River Basin.
8. Current personal involvement with other USACE projects, including whether involvement was to author any manuals or guidance documents for USACE. If yes, provide titles of documents or description of project, dates, and location (USACE district, division, Headquarters, Engineer Research and Development Center [ERDC], etc.), and position/role. Please highlight and discuss in greater detail any projects that are specifically with the USACE Northwest Division, Bonneville Power Administration, or Bureau of Reclamation.
9. Previous or current involvement with the development or testing of models that will be used for, or in support of the CRSO project projects including the Comprehensive Passage Model (COMPASS), Interior Columbus Basin Lifecycle Model (LCM), Comparative Survival Study (CSS) Model, Total Dissolved Gas (TDG) – University of Washington Model.
10. Current firm involvement with other projects, specifically those projects/contracts that are with the USACE Northwest Division, Bonneville Power Administration, or Bureau of Reclamation. If yes, provide title/description, dates, and location (USACE district, division, Headquarters, ERDC, etc.), and position/role. Please also clearly delineate the percentage of work you personally are currently conducting for the USACE Northwest Division, Bonneville Power Administration, or Bureau of Reclamation. Please explain.
11. Any previous employment by USACE as a direct employee, notably if employment was with the USACE Northwest Division, Bonneville Power Administration, or Bureau of Reclamation. If yes, provide title/description, dates employed, and place of employment (district, division, Headquarters, ERDC, etc.), and position/role.
12. Any previous employment by USACE, Bonneville Power Administration, or Bureau of Reclamation as a contractor (either as an individual or through your firm) within the last 10 years, notably if those projects/contracts are with the USACE Northwest Division, and Bonneville Power Administration, or Bureau of Reclamation associated with the Columbia River Basin. If yes,

Panel Conflict of Interest (COI) Screening Questionnaire for the IEPR of the Columbia River System Operations (CRSO) Ecological Models
provide title/description, dates employed, and place of employment (district, division, Headquarters, ERDC, etc.), and position/role.
13. Previous experience conducting technical peer reviews. If yes, please highlight and discuss any technical reviews concerning salmonids and include the client/agency and duration of review (approximate dates).
14. Pending, current, or future financial interests in contracts/awards from USACE, Bonneville Power Administration, or Bureau of Reclamation related to the CRSO project.
15. Significant portion of your personal or office's revenues within the last three years came from USACE Bonneville Power Administration, or Bureau of Reclamation contracts.
16. Significant portion of your personal or office's revenues within the last three years came from contracts with any of the organizations listed in Screening Question 6.
17. Any publicly documented statement (including, for example, advocating for or discouraging against) related to the CRSO project.
18. Participation in relevant prior and/or current Federal studies related to the CRSO project.
19. Previous and/or current participation in prior non-Federal studies related to the CRSO project.
20. Has your research or analysis been used or evaluated as part of the CRSO project including development of the models noted in Screening Question 1?
21. Is there any past, present, or future activity, relationship, or interest (financial or otherwise) that could make it appear that you would be unable to provide unbiased services on this project? If so, please describe.

Providing a positive response to a COI screening question did not automatically preclude a candidate from serving on the Panel. For example, participation in previous USACE technical peer review committees and other technical review panel experience was included as a COI screening question. A positive response to this question could be considered a benefit.

B.2 Panel Selection

In selecting the final members of the Panel, Battelle chose experts who best fit the expertise areas and had no COIs. Table B-1 provides information on each panel member's affiliation, location, education, and overall years of experience. Battelle established subcontracts with the panel members when they indicated their willingness to participate and confirmed the absence of COIs through a signed COI form. USACE was given the list of candidate panel members, but Battelle selected the final Panel.

Table B-1. CRSO Ecological Models IEPR Panel: Summary of Panel Members

Name	Affiliation	Location	Education	P.E.	Exp. (yrs)
Quantitative Ecologist #1					
Tracy Bowerman	Independent consultant	Leavenworth, WA	Ph.D., Aquatic Ecology	No	15
Quantitative Ecologist #2					
Milo Adkison	Independent consultant	Juneau, AK	Ph.D., Fisheries	No	26+
Integrated Ecological Modeling Specialist					
Larry Weber	Independent consultant	Iowa City, IA	Ph.D., Civil Engineering	Yes	30+
Fish Passage Biologist					
Don Weitkamp	LEON Environmental, LLC	Seattle, WA	Ph.D., Fisheries Biology	No	45+
Mathematical Statistician					
Alice Shelly	R2 Resource Consultants, Inc.	Redmond, WA	M.S., Quantitative Ecology and Resource Management	No	25+

Table B-2 presents an overview of the credentials of the final five members of the Panel and their qualifications in relation to the technical evaluation criteria. More detailed biographical information on the panel members and their areas of technical expertise is given in Section B.3.

Table B-2. CRSO Ecological Models IEPR Panel: Technical Criteria and Areas of Expertise

Technical Criterion	Bowerman	Adkison	Weber	Weitkamp	Shelly
Quantitative Ecologist #1					
At least 10 years of experience in their area of expertise	X				
M.S. degree or higher	X				
Extensive work within the Pacific Northwest (direct experience with salmonid ecology, restoration, or ecological modeling is preferred)	X				

Table B-2. CRSO Ecological Models IEPR Panel: Technical Criteria and Areas of Expertise (continued).

Technical Criterion	Bowerman	Adkison	Weber	Weitkamp	Shelly
Familiar with large, complex water resources projects with high public and interagency interests	X				
Demonstrated experience in numerical ecological modeling for salmonids, impact assessment methodologies, and assessing and informing planning and management decisions associated with salmonid resources	X				
Demonstrable understanding and experience in researching and analyzing observed behavior in the context of life history variability, both within and among population and species	X				
Focus on salmon mortality processes and behavioral ecology of salmon populations	X				
Focus on ecological simulation modeling or organismal migrations	X				
Research, analysis, and publication of salmon ecology and evaluating habitat quality	X				
Quantitative Ecologist #2					
At least 10 years of experience in their area of expertise		X			
M.S. degree or higher		X			
Extensive work within the Pacific Northwest (direct experience with salmonid ecology, restoration, or ecological modeling is preferred)		X			
Familiar with large, complex water resources projects with high public and interagency interests		X			
Demonstrated experience in numerical ecological modeling for salmonids, impact assessment methodologies, and assessing and informing planning and management decisions associated with salmonid resources		X			
Developing models of population dynamics, spatial and temporal movement patterns.		X			
Development and use of ecological models to suppose habitat evaluations assessments for the purposes of informing management, planning, and restoration decisions		X			
Integrated Ecological Modeling Specialist					
At least 10 years of experience in their area of expertise			X		
M.S. degree or higher			X		

Table B-2. CRSO Ecological Models IEPR Panel: Technical Criteria and Areas of Expertise (continued).

Technical Criterion	Bowerman	Adkison	Weber	Weitkamp	Shelly
Extensive work within the Pacific Northwest (direct experience with salmonid ecology, restoration, or ecological modeling is preferred)			X		
Familiar with large, complex water resources projects with high public and interagency interests			X		
Demonstrated experience in numerical ecological modeling for salmonids, impact assessment methodologies, and assessing and informing planning and management decisions associated with salmonid resources			X		
Applies a wide range of techniques including theoretical modeling, numerical simulations, lab experiments, and field work to understand the role of decision making spatially and temporally in fish migration			X		
Explore and apply coupled ecological and engineering models			X		
Researches and explores the roles of coupling ecological and physical process to predict environmental responses to fish passage projects			X		
Familiarity with R, PERL, BASH (or another modern Linux/Unix shell with the awk and sed utility languages) software/programming language			X		
Fish Passage Biologist					
At least 10 years of experience in their area of expertise				X	
M.S degree or higher				X	
Extensive work within the Pacific Northwest (direct experience with salmonid ecology, restoration, or ecological modeling is preferred)				X	
Familiar with large, complex water resources projects with high public and interagency interests				X	
Demonstrated experience in numerical ecological modeling for salmonids, impact assessment methodologies, and assessing and informing planning and management decisions associated with salmonid resources				X	
Study, analysis, and modeling of fish movement, fish passage barriers, design and effects in large riverine settings				X	
Computational fluid dynamics in aquatic ecosystems combined with principles of engineering hydraulics (i.e., ecohydraulics)			X		
Mathematical Statistician					
At least 10 years of experience in their area of expertise					X
M.S. degree or higher					X

Table B-2. CRSO Ecological Models IEPR Panel: Technical Criteria and Areas of Expertise (continued).

Technical Criterion	Bowerman	Adkison	Weber	Weitkamp	Shelly
Extensive work within the Pacific Northwest (direct experience with salmonid ecology, restoration, or ecological modeling is preferred)					X
Familiar with large, complex water resources projects with high public and interagency interests					X
Demonstrated experience in numerical ecological modeling for salmonids, impact assessment methodologies, and assessing and informing planning and management decisions associated with salmonid resources					X
Use of statistical methods and mathematical modeling to describe ecological processes and inform management decisions and environmental impact studies					X
Survival estimation of juvenile and adult fish species using capture-recapture methods, and on developing models to describe fish passage					X
Research, analysis and publication of salmon ecology and evaluating habitat quality					X
Familiarity with R, PERL, BASH (or another modern Linus/Unix shell with the awk and sed utility languages) software/programming language					X

B.3 Panel Member Qualifications

Detailed biographical information on each panel members' credentials, qualifications and areas of technical expertise is provided in the following paragraphs.

Name	Tracy Bowerman, Ph.D.
Role	Quantitative Ecologist #1
Affiliation	Independent Consultant

Dr. Bowerman is an independent consultant with 15 years of experience as an ecologist specializing in fish biology, population dynamics, fisheries science, and aquatic ecosystems and hydrology. She has broad experience with Pacific Northwest salmonid ecology and migration ranging from field-based mark-recapture studies to fish passage analyses to predictive modeling. She earned her Ph.D. in aquatic ecology from Utah State University in 2013 and her B.S. in biology from the University of Montana in 1999. She has more than 10 years of experience with ecological modeling and is familiar with large complex water resource projects with high public and interagency interests. Dr. Bowerman has co-authored numerous peer-reviewed journal articles focused on salmonid movement ecology and population dynamics, migration modeling, salmon morphology, impacts of river temperature on migration behavior within and among species, and salmon mortality processes.

Dr. Bowerman worked as a post-doctoral researcher for the University of Idaho from 2013 to 2016 and as a doctoral research assistant at Utah State University, U.S. Geological Survey Utah Cooperative Fish and Wildlife Research Unit from 2007 to 2013. She has collected and analyzed large mark-recapture datasets from throughout the Columbia River Basin to assess salmonid migration behavior and ecology in the context of life-history variability within and among populations and species. She has researched salmonid survival, prespawn mortality, bioenergetics, habitat use, and migration patterns.

Dr. Bowerman was a co-author on the development of an individual-based model to predict individual adult salmon travel times through diverse segments of the Columbia and Snake River migration corridors. She has experience with a wide range of analytical approaches, including capture-recapture maximum likelihood and Bayesian techniques, univariate and multivariate analysis, generalized linear models, mixed effects models, and matrix population models. She has consulted with Native American Tribes, Universities, and non-profit organizations on topics ranging from aquatic invasive species monitoring to fish habitat improvement projects. Dr. Bowerman also teaches introductory courses for natural resource professionals on the R programming language.

From 2005 to 2007, Dr. Bowerman worked as a Wild Salmon Coordinator for the Oregon Natural Desert Association, designing and implementing ecological restoration activities on public and private lands. In 2016, Dr. Bowerman was invited to speak to the Upper Columbia United Tribes and Affiliated Tribes of Northwest Indians Climate Change Resilience Program for the Upper Columbia River Workshop, where she presented on anticipated and observed effects of climate change on salmonid populations throughout the Columbia River Basin.

Name	Milo Adkison, Ph.D.
Role	Quantitative Ecologist #2
Affiliation	Independent Consultant

Dr. Adkison is an independent consultant but also works as a professor in the Department of Fisheries, College of Fisheries and Ocean Sciences at the University of Alaska, Fairbanks. He has a Ph.D. in fisheries from the University of Washington and a master's in biological sciences with a minor in statistics from Montana State University. Dr. Adkison has more than 26 years of experience in resource and environmental management with a primary focus on the development and application of quantitative methodologies for salmon biology and management. He specializes in Pacific salmon management, especially development and evaluation of quantitative management methodologies, hatchery program impacts on wild stocks, implications of climate fluctuations, early marine growth and survival, and the economic viability of rural fishing communities.

Dr. Adkison has studied the application of decision analysis and Bayesian statistics to decision-making in natural resource management, stock assessment and management strategies with imperfect data, and long-term challenges to salmon and salmon-dependent communities. Habitat and movement-related work studies include separating the influence of freshwater vs. nearshore and offshore oceanic environmental fluctuations on fluctuations in abundance, impacts of oil spills and invasive species, the importance of marine-derived nutrients for maintaining productivity, and the use of habitat characteristics to inform setting escapement goals. He has worked with and reviewed science, management, and sustainability of stocks from Japan, Russia, Alaska, Canada, and the Pacific Northwest.

Name	Larry Weber, Ph.D., PE
Role	Integrated Ecological Modeling Specialist
Affiliation	Independent Consultant

Dr. Weber earned a Ph.D. from the University of Iowa in civil and environmental engineering in 1993. He is an independent consultant but also currently is the Edwin B. Green Chair in Hydraulics and a full professor in the Department of Civil and Environmental Engineering at the University of Iowa. His current area of focus includes coupling computational fluid dynamics models to community and individual-based behavioral models to further understand fish behavioral decisions in the immediate vicinity of passage facilities. These models have been applied to natural river reaches and hydraulic structures both for fundamental advancement of scientific understanding of fish swim path selection and for practical application to the design of successful fish passage facilities.

From 2004 to 2017, Dr. Weber served as the Director of the Iowa IIHR – Hydroscience & Engineering, the nation's oldest academic research program focused on hydraulics, hydrology, and fluid mechanics. He has extensive knowledge in community resilience and planning; flooding; flood mapping; flood mitigation; river hydraulics; fate and transport of nutrients; hydropower; coupling individual-based ecological and fluid mechanics models; fish passage facilities; environmental hydraulics; hydraulic structures; and river restoration and sustainability. Through these research programs, Dr. Weber's impact has ranged from theoretical numerical model development and scientific discovery (as demonstrated in over 60 peer-reviewed scholarly publications) to the broad application of numerical models and systems-level design approaches to solve complex large-river ecological challenges (as demonstrated in over 200 conference papers and engineering research reports for contracted projects).

In particular, Dr. Weber led the computational fluid dynamics model development for the first fully coupled Eularian-Lagrangian-Agent Method (ELAM) model to fully predict the swim path of downstream migrating juvenile salmonids on the Columbia-Snake River system. This ELAM model, developed in partnership with scientists at the USACE Engineer Research and Development Center (ERDC), was successfully applied to develop downstream fish passage structures at several USACE projects (Walla Walla District, Seattle District), public power utilities (Grant Public Utility District, Chelan Public Utility District) and private power utilities (Idaho Power). From 2000 to present, Dr. Weber and his team have developed the most physically accurate, computational fluid dynamics model coupled with air entrainment and gas transfer modules to predict the fully three-dimensional total dissolved gas (TDG) distribution downstream of hydropower dams. This TDG model has been used extensively throughout the Pacific Northwest, Asia, and South America and has led to spillway deflector designs in the Mid-Columbia, Lower Snake, and Hells Canyon reaches in the Columbia River system.

Through these integrated model development and application projects, Dr Weber has gained a deep understanding of numerical methods and algorithms, a visionary approach to systems-level integrated design and development, and a genuine understanding of the complexities of both engineering physics and ecological behavior and ecosystem response.

Name	Don Weitkamp, Ph.D.
Role	Fish Passage Biologist
Affiliation	LEON Environmental, LLC

Dr. Weitkamp is a fisheries biologist with more than 45 years of experience dealing with fish, invertebrate, and associated aquatic resource issues. He earned his Ph.D. in fisheries biology from the University of Washington in 1977 with a dissertation developing a detailed understanding of TDG supersaturation resulting from hydroelectric projects. He has worked on various water quality (temperature, dissolved oxygen, total dissolved gas supersaturation) and juvenile salmonid passage issues at most of the larger dams (50- to 300-foot head) in the Columbia River basin from Bonneville Dam to Noxon Dam on the Clark Fork River, and Brownlee Dam on the Snake River. He conducted a 15-year study of fall Chinook spawning in the Columbia River to evaluate effects of dam operations.

Dr. Weitkamp has directed studies of juvenile and adult passage survival at Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids Dams for passage through spillways and turbines. Using biological information together with physical modeling, he directed the development of appropriate criteria to provide to engineers for the design of successful screens and surface-collector bypass systems. As a member of an engineering team working on a surface collection device for a Rocky Reach Dam project, Dr. Weitkamp led efforts to incorporate biological criteria in the design of a unique collector for juvenile salmon. This system incorporated hydraulic characteristics with fish behavior tendencies to provide a practical bypass solution that avoids expensive installation of intake diversion screens. His role was to help develop and evaluate alternative designs by incorporating fish behavior characteristics with hydraulic evaluations.

For the Wanapum and Priest Rapids Dams Evaluations project, Dr. Weitkamp again provided biological expertise to help develop a unique intake screen and bypass system for these dams to meet Federal Energy Regulatory Commission (FERC) requirements. Prototype testing showed favorable results of very high survival and very low stress in screened fish. He was responsible for biological evaluation of orifice collection bypass gallery tests. He evaluated engineering alternatives for moving diverted fish efficiently from dam gate wells to downstream outfalls. Models were assessed using both hydraulic parameters and small fish.

As a member of an interdisciplinary team, Dr. Weitkamp helped develop an outfall design and location constructed at Wanapum Dam. This effort involved field evaluations; construction of a 1:100 scale model of the dam and three miles of the river; and videotaping of both the real site and the model to identify a location that would minimize predation. A 1:10 scale model of the outfall was constructed to evaluate the best means for discharging young salmon. Dr. Weitkamp also directed investigations to assess the current conditions of dissolved gas supersaturation downstream from Wanapum and Priest Rapids Dams. This included biological monitoring, a routine dissolved gas monitoring program, and a program to assess the reduction in dissolved gas provided by spillway deflectors. He worked with hydraulic engineers to evaluate options and conduct field evaluations of deflector prototypes. Dr. Weitkamp has worked with experts in computational fluid dynamics in aquatic ecosystems combined with principles of engineering hydraulics, but he is not an expert in these fields.

Dr. Weitkamp has directed studies of genetics and migration survival of hatchery populations of salmonids in the mid-Columbia. He helped to evaluate the potential effects of reservoir drawdown in the Snake and Columbia rivers. He has provided biological expertise to interpret physical and computational hydrodynamic model results to deal with fisheries passage concerns. He also helped a multi-agency workgroup develop and conduct aquatic resource investigations for water quality issues on the Clark Fork and Spokane River Projects (five hydroelectric dams), including work with the U.S. Fish and Wildlife Service (USFWS) to develop a supplemental biological assessment that met license requirements. Dr. Weitkamp worked with Battelle on the Mount St. Helens Sediment Control Facility Independent External Peer Review.

Name	Alice Shelly
Role	Mathematical Statistician
Affiliation	R2 Resource Consultants, Inc

Ms. Shelly is an environmental statistician with R2 Resources Consultants, Inc. with over 25 years of experience as a consulting statistician to fisheries and ecology projects throughout the Pacific Northwest. She received her master's degree in quantitative ecology and resource management from the University of Washington in 1994. Ms. Shelly has designed sampling for studies of fish relative abundance, fish growth and survival, fish habitat preference, stream physical habitat variables, riparian vegetation cover and survival, seed dispersal studies, instream flow studies, water quality studies, benthic invertebrate community analyses, and bird and mammal population studies. She is proficient in the R programming language and has designed and conducted univariate and multivariate statistical analyses using R in widespread ecological disciplines.

Ms. Shelly has used statistical models to study short- and long-term changes to important salmonid habitat variables as streams recover from tree harvest in the riparian zone, and to study the impacts of turbidity on Coho salmon growth after considering the effects of stream temperature using bioenergetics modeling. Both studies resulted in peer-reviewed publications. She has consulted with the Washington State Department of Natural Resources; the Cooperative Monitoring, Evaluation, and Research Committee; and the Washington State Salmon Recovery Funding Board to provide statistical analysis and review for evaluations of road effectiveness monitoring, forest practices compliance monitoring, and restoration effectiveness monitoring. Ms. Shelly has conducted Monte Carlo simulation studies and jackknife cross-validation studies to assess model uncertainty and validity, statistical power analysis, and sampling design alternatives for multiple ecological studies. Ms. Shelly conducted a comprehensive study on available data relating large-scale environmental and atmospheric variables to Chinook salmon escapement and run timing in Alaska and reviewed a study of Mid-Columbia sturgeon hatchery success using mark-recapture methods. She used statistical models to estimate salmonid habitat area as a function of pre- and post-project flow conditions for FERC licensing studies in the Susitna River. Ms. Shelly also designed the decision support system for model integration across all Susitna River instream flow projects and was a participant in stakeholder consultation and Technical Workgroup Meetings.

Ms. Shelly assisted with an ecological model describing adult and juvenile steelhead passage through a diversion dam, a critical riffle downstream of the diversion, and a sand bar at the mouth of the Santa Clara River. She used a Bayesian belief network to evaluate uncertainties in flow conditions, groundwater conditions, and modeling assumptions (including passage requirements, run timing, and changes due to climate change), which was used to study impacts of different management decisions for diversion operations. Ms. Shelly also developed a linked statistical model to evaluate the probability of passage of passive, active, and hitchhiking aquatic invasive species through the Erie Canal System. The model was built to estimate the relative effectiveness of different barrier technologies and network locations in preventing the spread of invasive fish and invertebrates.

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APPENDIX C

Final Charge for the CRSO Ecological Models IEPR

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Charge Questions and Guidance to the Panel Members for the Independent External Peer Review (IEPR) of the Columbia River System Operations (CRSO) Ecological Models

This is the final Charge to the Panel for the CRSO Ecological Models IEPR. This final Charge was submitted to USACE as part of the final Work Plan, originally submitted on January 15, 2020. The dates and page counts in this document have not been updated to match actual changes made throughout the project.

BACKGROUND

The U.S. Army Corps of Engineers (USACE), Bonneville Power Administration (BPA), and Bureau of Reclamation (Co-lead Agencies) are jointly developing a comprehensive Environmental Impact Statement (EIS), referred to as the Columbia River System Operation (CRSO) EIS, to evaluate long-term system operations and configurations of 14 multiple-purpose projects that are operated as a coordinated system within the interior Columbia River Basin in Idaho, Montana, Oregon, and Washington. USACE was authorized by Congress to construct, operate, and maintain 12 of these projects for flood risk management, navigation, power generation, fish and wildlife conservation, recreation, and municipal and industrial water supply purposes. USACE projects that will be included in the EIS are Libby, Albeni Falls, Dworshak, Chief Joseph, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville. The Bureau of Reclamation was authorized to construct, operate, and maintain the other two projects—Hungry Horse and Grand Coulee—for the purposes of irrigation, flood risk management, navigation, power generation, recreation, and other beneficial uses. The BPA is responsible for marketing and transmitting the power generated by these dams. Together, these Co-lead Agencies are responsible for managing the system for these various purposes, while meeting their other statutory and regulatory obligations.

The Co-lead Agencies will use this EIS to assess and update their approach for long-term system operations and configurations through the analysis of alternatives and evaluation of potential effects to the human and natural environments. The scope and scale of this project, its potential to impact human life safety, interest on the part of the Governors of Montana, Idaho, Washington, and Oregon, 19 Federally recognized tribes, connection to ongoing litigation on the Federal Columbia River Power System, as well as the likelihood for the project to result in public dispute, drive a requirement for a heightened level of review and meet the criteria of a highly influential scientific assessment in OMB and Bureau of Reclamation peer review policies.

OBJECTIVES

The objective of this work is to conduct an independent external peer review (IEPR) of the CRSO Ecological Models (hereinafter: CRSO Ecological Models IEPR) in accordance with the Department of the Army, USACE, Water Resources Policies and Authorities' *Review Policy for Civil Works* (Engineer Circular [EC] 1165-2-217, dated February 20, 2018), and the Office of Management and Budget's (OMB's) *Final Information Quality Bulletin for Peer Review* (December 16, 2004). Peer review is one of the important procedures used to ensure that the quality of published information meets the standards of the scientific and technical community. Peer review typically evaluates the clarity of hypotheses, validity of the research design, quality of data collection procedures, robustness of the methods employed, appropriateness of the methods for the hypotheses being tested, extent to which the conclusions follow from the analysis, and strengths and limitations of the overall product.

The primary goal of ecological model review and approval is to establish that models, analyses, results, and conclusions are theoretically sound, computationally accurate, based on reasonable assumptions, well-documented, and in compliance with the requirements of OMB Peer Review Bulletin. The use of a reviewed model does not constitute technical review of the planning product. Independent technical review of the selection and application of the model and the input data is still the responsibility of the users.

The primary criterion identified for model approval is technical soundness. Technical soundness reflects the ability of the model to represent or simulate the processes and/or functions it is intended to represent. The performance metrics for this criterion are related to theory and computational correctness. In terms of theory, a quality ecological model should 1) be based on validated and accepted "state of the art" theory, 2) properly incorporate the conceptual theory into the software code, and 3) clearly define the assumptions inherent in the model. In terms of computational correctness, a quality ecological model should 1) employ proper functions and mathematics to estimate functions and processes represented, and 2) properly estimate and forecast the actual parameters it is intended to estimate and forecast. Other criteria for quality ecological models are efficiency, effectiveness, usability, and clarity in presentation of results. A well-documented quality ecological model will stand the tests of technical soundness based on theory and computational correctness, efficiency, effectiveness, usability and clarity in presentation of results. The IEPR will be limited to technical review and will not involve policy review. The IEPR will be conducted by subject matter experts (i.e., IEPR panel members) who meet the technical criteria and areas of expertise required for and relevant to the project and are free of conflicts of interest (COIs).

The Panel will be "charged" with responding to specific technical questions as well as providing a broad technical evaluation of the overall models' technical soundness, system quality, or usability.

DOCUMENTS PROVIDED

The following is a list of documents, supporting information, and reference materials that will be provided for the review. The review assignments for the panel members may vary slightly according to discipline.

Review Documents	No. of Review Pages
NOAA COMPASS Documentation	
COMPASS Model - Main Documentation	30
COMPASS Model – Application Software (BASH or another modern Linux/Unix shell with the awk and sed utility languages and a correct version of the "R" programming language included)	--
COMPASS Model – Appendix 1. PIT-tag data	13
COMPASS Model – Appendix 2. Calibration of Survival and Migration Models	20
COMPASS Model – Appendix 3. Model Diagnostics	57
COMPASS Model – Appendix 4. Dam Passage Algorithms	15
COMPASS Model – Appendix 5. Dam Survival Parameters	65
COMPASS Model – Appendix 6. Hydrology	19
COMPASS Model – Appendix 7. Arrival Timing at Lower Granite Dam	30
COMPASS Model – Appendix 8. Sensitivity Analysis	12
NOAA Life-Cycle Modeling Documentation	
LCM Model Documentation	772
LCM Model Application Software	--

Review Documents	No. of Review Pages
Fish Passage Center Comparative Survival Study Model Documentation	
Letter Overview of CSS Model Documentation	4
Introduction to CSS PowerPoint Presentation. 2018. Background and Overview of Modeling	241
CSS Model Documentation – 2018 Annual Report	248
CSS Model Documentation – Experimental Spill Management: Models, Hypotheses, Study Design, and Response to ISAB	139
CSS Model Application Software (includes code for CSS cohort models and CSS-LifeCycle.tpl file)	--
University of Washington Total Dissolved Gas Modeling Documentation	
TDG Model Documentation	17
TDG Model Application Software (PERL must be installed. R must be installed. COMPASS must be installed with executable in the working directory)	--
Total Number of Review Pages	**1,682[1]**
Supplemental Documents[2]	
Zabel et al. 2008. Comprehensive passage (COMPASS) model: a model of downstream migration and survival of juvenile salmonids through a hydropower system. Hydrobiologia, 609: 289-300	11
Northwest Power and Conservation Council. ISAB 2006-2. Review of NOAA Fisheries' COMPASS Model.	16
Northwest Power and Conservation Council. ISAB 2006-6. Review of NOAA Fisheries' COMPASS Model.	6
Northwest Power and Conservation Council. ISAB 2006-7. Review of NOAA Fisheries' COMPASS Model.	14
Northwest Power and Conservation Council. ISAB 2008-3. Review of NOAA Fisheries' COMPASS Model.	20
Northwest Power and Conservation Council. ISAB 2013-5. Review of NOAA Fisheries' Interior Columbia Basin Life-Cycle Modeling.	30
Northwest Power and Conservation Council. ISAB 2010-5. Review of the Comparative Survival Study (CSS) 2010 Annual Report.	13
Northwest Power and Conservation Council. ISAB 2011-5. Review of the Comparative Survival Study (CSS) 2011 Annual Report.	13
Northwest Power and Conservation Council. ISAB 2012-7. Review of the Comparative Survival Study (CSS) 2012 Annual Report.	24
Northwest Power and Conservation Council. ISAB 2013-4. Review of the Comparative Survival Study (CSS) 2013 Annual Report.	30
Northwest Power and Conservation Council. ISAB 2014-5. Review of the Comparative Survival Study (CSS) 2014 Annual Report.	21
Northwest Power and Conservation Council. ISAB 2015-2. Review of the Comparative Survival Study (CSS) 2015 Annual Report.	20
Northwest Power and Conservation Council. ISAB 2016-2. Review of the Comparative Survival Study (CSS) 2016 Annual Report.	25
Northwest Power and Conservation Council. ISAB 2017-1. Review of the Comparative Survival Study (CSS) 2018 Annual Report.	152
Northwest Power and Conservation Council. ISAB 2018. Review of the Comparative Survival Study (CSS) Draft 2018 Annual Report.	29
Total Number of Reference Pages	**424[1]**

1. The actual number of pages provided to the Panel for review may differ from this estimate by plus or minus 20%.
2. Supplemental documents are provided for context only. Panel members are not asked or expected to directly comment on these documents.

Policy Documents for Reference

- Review Policy for Civil Works (EC 1165-2-217, February 20, 2018)
- OMB's Final Information Quality Bulletin for Peer Review (December 16, 2004)

SCHEDULE & DELIVERABLES

This schedule is based on the receipt date of the final review documents and may change due to circumstances out of Battelle's control such as changes to USACE's project schedule and unforeseen changes to panel member and USACE availability. As part of each task, the panel member will prepare deliverables by the dates indicated in the table (or as directed by Battelle). All deliverables will be submitted in an electronic format compatible with MS Word (Office 2003).

Task	Action	Due Date
Meetings	Subcontractors complete mandatory Operations Security (OPSEC) training	2/27/2020
	Battelle sends review documents to panel members	1/29/2020
	Battelle convenes kick-off meeting with panel members	1/30/2020
	Battelle convenes kick-off meeting with USACE and panel members	1/31/2020
	Battelle convenes mid-review teleconference for panel members to ask clarifying questions of USACE	2/13/2020
Review	Panel members complete their individual reviews	3/3/2020
	Battelle provides talking points for Panel Review Teleconference to panel members	3/5/2020
	Battelle convenes Panel Review Teleconference	3/6/2020
	Battelle provides Final Panel Comment templates and instructions to panel members	3/9/2020
	Panel members provide draft Final Panel Comments to Battelle	3/13/2020
	Battelle provides feedback to panel members on draft Final Panel Comments; panel members revise Final Panel Comments	3/14/2020 - 3/22/2020
	Panel finalizes Final Panel Comments	3/23/2020
Final Report	Battelle provides Model Review Report to panel members for review	3/25/2020
	Panel members provide comments on Model Review Report	3/31/2020
	*Battelle submits Model Review Report to USACE	4/2/2020
	USACE Planning Center of Expertise (PCX) provides decision on Model Review Report acceptance	4/9/2020
Comment Response Process	Battelle inputs Final Panel Comments to Design Review and Checking System (DrChecks) and provides Final Panel Comment response template to USACE	4/13/2020
	Battelle convenes teleconference with Panel to review the Comment Response process	4/13/2020

Task	Action	Due Date
	USACE Project Delivery Team (PDT) provides draft Evaluator Responses to USACE PCX for review	4/29/2020
	USACE PCX reviews draft Evaluator Responses and works with USACE PDT regarding clarifications to responses, if needed	5/5/2020
	USACE PCX provides draft PDT Evaluator Responses to Battelle	5/6/2020
	Battelle provides draft PDT Evaluator Responses to panel members	5/8/2020
	Panel members provide draft BackCheck Responses to Battelle	5/13/2020
	Battelle convenes teleconference with panel members to discuss draft BackCheck Responses	5/14/2020
	Battelle convenes Comment Response Teleconference with panel members and USACE	5/15/2020
	USACE inputs final PDT Evaluator Responses to DrChecks	5/22/2020
	Battelle provides final PDT Evaluator Responses to panel members	5/26/2020
	Panel members provide final BackCheck Responses to Battelle	5/29/2020
	Battelle inputs panel members' final BackCheck Responses to DrChecks	6/1/2020
	*Battelle submits pdf printout of DrChecks project file	6/2/2020
	Contract End/Delivery Date	1/31/2021

* Deliverables

CHARGE FOR PEER REVIEW

Members of this IEPR Panel are asked to determine whether the CRSO Ecological Models are technically sound relative to the design objectives. In addition to the underlying theory, conceptualization, and computational aspects of the methods, reviewers are asked to comment on aspects of the model that potentially affect its usability and reliability as a potential producer of information to be used to influence planning decisions. Specific questions for the Panel are included in the general charge guidance below. The intent of these questions is to focus your review on the assessment criteria that need to be evaluated.

General Charge Guidance

Please answer the scientific and technical questions listed below and conduct a broad overview of the materials provided for the CRSO Ecological Models. Please focus your review on your discipline/area of expertise and technical knowledge. However, please feel free to answer any questions that you feel able to. In addition, please note the following guidance.

1. Your response to the charge questions should not be limited to a "yes" or "no." Please provide complete answers to fully explain your response.
2. Answer the scientific and technical questions listed below and conduct a broad overview assessment of the planning tools. **Use the Charge Response Form provided when answering the questions.**
3. Evaluate the soundness of the models and comment on whether the models effectively represent the systems being modeled and how the models can be validated.
4. Focus the review on scientific information, including factual inputs, data, the use and soundness of model calculations, assumptions, and results that inform decision makers.
5. Offer opinions as to whether the model parameters and formulas are sufficient to quantify ecosystem function.
6. Offer suggestions for future improvements that could be considered by USACE but are not necessary for model use at this time.
7. If desired, panel members can contact one another. However, panel members **should not** contact anyone who is or was involved in the project, prepared the subject documents, or was part of the model development team.
8. Please contact the Battelle Program Manager, Lynn McLeod; mcleod@battelle.org for requests or additional information.
9. In case of media contact, notify the Battelle Program Manager, Lynn McLeod (mcleod@battelle.org) immediately.
10. Your name will appear as one of the panel members in the peer review. Your comments will be included in the Model Review Report but will remain anonymous.

Please submit your comments in electronic form to the Program Manager, no later than 10 pm ET by the date listed in the schedule above.

Independent External Peer Review of the Columbia River System Operations (CRSO) Ecological Models

Charge Questions as Supplied by USACE

The following Review Charge to Reviewers outlines the objectives of the independent external peer review (IEPR) for the subject ecological models and identifies specific items for consideration for the IEPR Panel.

The objective of the IEPR is to establish that models, analyses, results, and conclusions are theoretically sound, computationally accurate, based on reasonable assumptions, well-documented and in compliance with the requirements of Office of Management and Budget (OMB) Peer Review Bulletin. The IEPR Panel is requested to offer a broad evaluation of the overall model documentation in addition to addressing the specific technical and scientific questions included in the Review Charge. The Panel has the flexibility to bring important issues to the attention of decision makers, including positive feedback or issues outside those specific areas outlined in the Review Charge. The Panel can use all available information to determine what scientific and technical issues related to the model or its documentation may be important to raise to decision makers.

Panel review comments are to be structured to fully communicate the Panel's intent by including the comment, why it is important, any potential consequences of failure to address, and suggestions on how to address the comment.

The Panel is asked to consider the following items as part of its review of the model documentation and supporting materials.

Technical Quality

1. Does the model documentation clearly and precisely describe the focus of the model? Discussion may include, but is not limited to, geographic range, applicability limits, model domain, or boundary conditions.
2. Did the model development process clearly follow a general structure of conceptualization, quantification, and evaluation?
3. Are the intended uses of the model defined, clear, and appropriate?
4. Are the spatial and temporal resolutions of the model described appropriately?
5. Are interpretations and conclusions sound, justified by the data, and consistent with the objectives?
6. Are the assumptions and limitations of the model clearly communicated and supported?
7. Comment on the degree to which the model can be used to evaluate existing conditions of the evaluation area and to forecast conditions anticipated to occur during the period of analysis (50 years).

8. Does the model documentation sufficiently include a question or hypothesis and an appropriate underlying theoretical framework?
9. Are the most sensitive parameters or factors of the model identified and supported with sensitivity analyses?
10. Are the model variables, functions, and parameters clearly defined and dimensionalized, preferably in table format?
11. Is the organization of the model documentation satisfactory (e.g., no discussion in results)?
12. Is the model documentation sufficiently detailed such that it could be replicated, reproduced, or used independent of the model development team (i.e., black box vs open source)?
13. Comment on the degree to which the model facilitates sensitivity, uncertainty, and risk analyses.

System Quality

14. Are model computations presented in sufficient detail, and are they ecologically relevant?
15. Does the model documentation sufficiently describe testing steps utilized during model development (i.e., consistency check, sensitivity analyses, calibration, validation)?
16. Has the model programming system been tested for errors? If not, what is the potential for errors to occur?
17. Does the model inform users of erroneous or inappropriate inputs or outputs?

Usability

18. What are the hardware, software, and operating system requirements of the model? To what degree can the hardware, software, and operating system requirements complicate use of the model?
19. Is user documentation user-friendly and complete? Comment on the model's ease of use.
20. Are the input requirements evident to the user? Is the data readily available?
21. Is the required level of precision and accuracy of inputs documented?
22. Comment on the understandability of model output(s).
23. Comment on the level of difficulty likely to be encountered when attempting to assess the model's sensitivities to alternative inputs.

Battelle Summary Charge Questions to the Panel Members[1]

Summary Questions

24. Please identify the most critical concerns (up to five) you have with the project and/or review documents. These concerns can be (but do not need to be) new ideas or issues that have not been raised previously.

25. Please provide positive feedback on the project and/or review documents.

[1] Questions 24 and 25 are Battelle-supplied questions and should not be construed or considered to be part of the list of USACE-supplied questions. These questions were delineated in a separate appendix in the final Work Plan submitted to USACE.

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APPENDIX D

Conflict of Interest Form

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David Kaplan
USACE, Institute for Water Resources
December 12, 2019
C-2

Conflicts of Interest Questionnaire

Independent External Peer Review

Columbia River System Operations (CRSO) Ecological Model Review

The purpose of this document is to help the U.S. Army Corps of Engineers identify potential organizational conflicts of interest on a task order basis as early in the acquisition process as possible. Complete the questionnaire with background information and fully disclose relevant potential conflicts of interest. Substantial details are not necessary; USACE will examine additional information if appropriate. Affirmative answers will not disqualify your firm from this or future procurements.

NAME OF FIRM: **Battelle Memorial Institute Corporate Operations**
REPRESENTATIVE'S NAME: **Courtney Brooks**
TELEPHONE: **614-424-5623**
ADDRESS: **505 King Avenue, Columbus, Ohio 43201**
EMAIL ADDRESS: **brooksc1@battelle.org**

I. INDEPENDENCE FROM WORK PRODUCT. Has your firm been involved in any aspect of the preparation of the subject study report and associated analyses (field studies, report writing, supporting research etc.) No **Yes** (if yes, briefly describe): Battelle managed Pacific Northwest National Laboratories (PNNL). PNNL assisted with the scoping for the Ecological Model Review. However, due to contractual requirements, Battelle Corporate staff do not work with PNNL staff and are firewalled from PNNL work, therefore the Battelle staff conducting the Model Review have not had and will not have any involvement with the PNNL work and PNNL will not have any involvement with the Model Review.

II. INTEREST IN STUDY AREA OR OUTCOME. Does your firm have any interests or holdings in the study area, or any stake in the outcome or recommendations of the study, or any affiliation with the local sponsor? **No** Yes (if yes, briefly describe):

III. REVIEWERS. Do you anticipate that all expert reviewers on this task order will be selected from outside your firm? No **Yes** (if no, briefly describe the difficulty in identifying outside reviewers):

IV. AFFILIATION WITH PARTIES THAT MAY BE INVOLVED WITH PROJECT IMPLEMENTATION. Do you anticipate that your firm will have any association with parties that may be involved with or benefit from future activities associated with this study, such as project construction? **No** Yes (if yes, briefly describe):

V. ADDITIONAL INFORMATION. Report relevant aspects of your firm's background or present circumstances not addressed above that might reasonably be construed by others as affecting your firm's judgment. Please include any information that may reasonably: impair your firm's objectivity; skew the competition in favor of your firm; or allow your firm unequal access to nonpublic information.

No additional information to report.

Courtney M. Brooks
Courtney Brooks

12/12/2019
Date

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APPENDIX E

Additional Findings Provided by the Panel for Consideration

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IEPR PANEL ADDITIONAL FINDINGS ON THE NOAA FISHERIES COMPREHENSIVE PASSAGE (COMPASS) MODEL

General

1. The main report should begin with a clear division between model development/calibration (sometimes called historical?) and model use ("prospective" modeling). As it stands, there is a confusing juxtaposition of these two processes that the reader is constantly forced to tease apart. A schematic of the whole calibration process, more detailed than that provided in Appendix 2, Figure A2.1-1, would be helpful.

2. The interplay between the Main Report and the appendices is inconsistent and confusing. The most straightforward approach would be to include a complete outline of model calibration in the Main Report, with justification for each step and a final resulting model with parameters. Then each appendix could include technical considerations and details. Detailed results could be given in an appendix, but they should be summarized and discussed in the Main Report. For example, calibration of the survival model is partially discussed in multiple places (Main Report, Appendix 1, Appendix 2), but these discussions are not clear or comprehensive, nor are they consistent with each other. Future model refinements and modifications should be discussed in one section of one document, rather than scattered haphazardly throughout the documents.

3. Because there are multiple survival domains, the word "survival" requires qualification every time it is used (e.g., "reservoir survival," "downstream dam passage survival").

4. The formulation of full potential models is important to discuss as part of model development, but it needs to be better segregated from the final model selection. The Main Report provides detail on the most complex models that were considered without context of full versus final model formulations. Something as simple as a statement like: "these are potential variables that were attempted" would be helpful. Then there should be a matching list in the Results section of the main report stating which variables were abandoned and why (for example, some were abandoned because they could not be parameterized, some because they just did not make the AICc cut). As it is, the discussion caused the Panel much unnecessary confusion.

5. Clear linkages should be made between chosen predictors and observed biological triggers. Also, consider the predictive future capability of chosen factors. For example, Julian day of maximum daily change in LGP is difficult to predict in the future, whereas mean monthly water temperatures should be fairly predictable.

6. When there are not enough data to parameterize a model, some predictors have been assumed to be fixed and are estimated as best as possible. This does not mean that the fixed value plugged into the model is without uncertainty. If the value itself can be based on professional opinion, then surely the range of potential values also can be applied. There is no good excuse for excluding uncertainty in these "fixed" parameters from the sensitivity or the uncertainty analyses.

7. The researchers provided some analysis of model uncertainty and sensitivity for the calibration of this model and discussed plans for improvements. For the prospective modeling and how uncertainty in this model impacts COMPASS results, the researchers looked at variability across years and across populations in terms of arrival time to Lower Granite Reservoir, in-river survival,

and proportion transported. The analysis shows substantial variability across years, and across some populations. This information could be used to inform sensitivity, uncertainty, and risk analyses for the survival estimates produced by COMPASS. However, in the COMPASS model discussion of uncertainties, this model is not considered. For example, the Panel must assume that a weighted mean of estimated arrival distributions (how is this done? weighted mean quantiles?) for populations for which data were available is representative of all populations. One way to think about how good this estimation might be would be to do a leave-one-out cross validation, where the weighted average is calculated multiple times, each time leaving out one (or more) of the populations.

8. It would be helpful to explain in more detail why the iterative MLE process is required for fitting the parameters of the migration rate model, including an example of one complete cycle of model fitting.
9. In the example in LCM 2019 Chapter 2, a constant arrival distribution at Wells Dam was assumed for Columbia River stocks. For projections assuming the environment is not undergoing systematic change, perhaps resampling the empirical timing at Rock Island Dam with the estimated offset would be sufficient and would incorporate interannual variability as well.
10. If projection under changed future environmental conditions is desired, a simpler model (beta shape?) should be used with a few carefully selected candidate predictors to consider. It is unlikely that details of the shape beyond the mean date and spread in dates will have a significant effect on any of the COMPASS survival and migration modeling that the simulated arrival distributions will be used for.
11. For many interior Idaho spring/summer Chinook populations, a greater proportion of juveniles out migrate as age-0 parr in the fall than do smolts in the spring. Some rear in the mainstem areas of the Salmon and Snake Rivers, while others pass Lower Granite in late summer and fall and migrate to the ocean. Survival of parr through the hydrosystem is much lower than smolts, but SARs are higher. It does not appear that the parr life history component has been included in juvenile survival or SAR estimates. What is the potential effect of ignoring this life history diversity on results?
12. Has any consideration been given to the age/size structure of smolts, particularly steelhead? Juvenile Salmon Acoustic Telemetry System data suggest that larger smolts are less likely to enter powerhouses.
13. The terminology for migration rate throughout the main report and all appendices is inconsistent and confusing: fish velocity, migration rate, travel time, migration time.

Specific Points

Comprehensive Passage (COMPASS) Model – version 2.0 Review Draft April 2019 - Main Documentation

14. **Page 10** – On page 10, distance-based mortality is discussed as part of the survival model formulation, and it was set to be a constant. But no estimates or results were provided, and modeler's response was that it was not used. Obviously, this is confusing.

15. **Page 18** – Starting at the bottom of page 18, equations/formulations of the full model are not discussed in enough detail. There is a quadratic effect of Julian day, but why would this be? There is also an interaction term between Julian day and velocity; again, why would this be? Why were other interactions not considered? It is general practice to discuss these issues in the presentation of statistical models.

16. **Page 18** – Starting at the bottom of page 18, the value of the "day" parameter is not obvious and should be more succinctly defined everywhere it is used. On page 18, "d" is defined as "the day the cohort enters the top of the reservoir." So here it should have an *i* subscript, and it should be better explained. What is d? The use of the migration rate model for the upper cohort arriving at Lower Granite is not explicit.

17. **Page 19** – The second migration rate model (top of page 19) uses different parameter subscripts (beta) for the same model coefficients, which is unnecessarily confusing and complicated.

18. **Page 20** – There is no description of how temperature was modeled, either for calibration or prospective use of COMPASS. The main documentation only states that "A temperature flow relationship was developed to generate daily temperatures."

Appendix 1 – PIT Tag Data

19. **Page 1** – In the middle of page 1, it states that wild and hatchery fish data were combined for survival and migration rate estimation to Lower Granite Dam. Appendix 7, Arrival Timing at Lower Granite Dam (bottom of page 3), states that only wild or unknown origin fish were used.

Appendix 2 – Calibration of Models for Migration Rate and Survival

20. **Page 5** – The Panel did not find a discussion explaining how dam survival is applied in prospective models. Survival estimates through each route at each dam are fixed estimates based on limited data. The "efficiencies" or proportions through each route are modeled, with parameters estimated for individual logistic regressions using AIC. The uncertainty in these models is not a part of the COMPASS Monte Carlo option. On page 5 of Appendix 2, modelers say they "fix" the dam survival parameters. But dam survival is a function of efficiencies, which vary based on flow, temperature, timing, etc.

21. **Page 6** – The discussion of intercept terms is confusing; note that there was discussion on this topic in previous reviews. The middle paragraph on page 6 of Appendix 2, which mentions different intercept terms, has no context and could not be deciphered, as these parameters are not discussed anywhere else. The formula on the top of page 7 of Appendix 2 implies there are models with no intercepts.

22. **Page 7** – The calibration results in Appendix 2 are presented without discussion.

23. **Page 8** – The results presented in Appendix 2, Table A2.2-1, need clarification. First, the beta subscripts do not match variable names in the Main Report's page 11 equation. So what equation is this? Second, the text states that results for the "full model" are given, which might pertain to the R^2 and AICc result at the top of each group, but coefficients are obviously for final model only. It is standard practice to provide the AIC differences, and these should be provided. The Panel thinks that there are multiple AIC results because of the iterative MLE methods used, but an

explanation is required. AIC weights were promised in the methods discussion on Appendix 2 page 7, but were not provided here.

24. **Pages 8 and 12** – Calibration parameters are provided Tables A2.2-1 and A2.2-2, but results for the estimated rate of spread parameter for the inverse gaussian and uncertainty for this parameter are not provided.

25. **Page 12** – One consideration for future efforts, if not already done, might be to consider a single model form across projects for migration timing and/or reservoir survival with random effects parameters for projects. How much would the environmental variables driving migration rates be expected to differ among projects for the same cohort heading downstream? It seems there could be some benefit in combining data for all projects into one model. However, results in Appendix 2, Table A2.2-2, show differences across projects. Why would that be, other than random error? Some discussion on this topic would be informative.

26. **General** – The outline/structure of Appendix 2 is particularly hard to follow.

Appendix 3 – Model Diagnostics

27. **Page 1** – This appendix states that model fits for the Lower Columbia River and Lower Granite pool were relatively poor and that "Because of high uncertainty in the observed survival estimates in these reaches, it is difficult to detect a signal." This uncertainty should somehow be carried over into the LCM discussion.

Appendix 4 – Dam Passage Algorithms

28. **General** – Dam survival is estimated based on survival through each potential passageway at each dam and the probability of fish passing through each potential passageway. This model for dam survival should be contained in one appendix concluding with a total model estimating total dam survival for each project (as a function of variables). The poor organization of Appendix 4 (Dam Passage Algorithms), with bad sequencing and differing levels of detail from apparently different writers, is frustrating and very difficult to follow. This is essentially a multinomial modeling approach; it does not have to be so complicated in its presentation. Notations and terminology for the same variable are inconsistent (e.g., fish spill proportions, flow spill proportions, flow), which causes difficulty for interpretation. The models are fine, but they seem inconsistent because they are so poorly described.

Appendix 7 – Arrival Timing at Lower Granite Dam

29. The arrival timings may be barely affected by changes to the operation of the hydropower system, as the smolts encounter a single project before being recorded. For projections not involving climate change, it might suffice to simply resample historical data years and use the observed arrival timings from those years.

30. In the presentation of the arrival time distribution model, survival estimates are produced by population, and there is some discussion of a weighted average arrival time distribution, but no detail is given, and the distribution is not presented. Even if it were, a distribution of arrival times at the dam or forebay of the dam would appear to be inconsistent with application of the reservoir survival model, which is based on travel time. In general, the arrival time distribution model is not well-explained.

DEIS Appendix E - Fish, Aquatic Macroinvertebrates, and Aquatic Habitat

1. It is unclear if McNary-Bonneville estimates that combined Upper Columbia and Snake River stocks were applied to both, or if Snake River stocks in that reach used values from analysis of their data only. The text suggests the latter but is not definitive.
2. The description of temperature inputs from USACE is short. Did they depend on flow? Were they daily values?
3. Where did the assumptions about passage efficiency and reduction of mortality from improved turbines come from?
4. MO3 modifications refer to survival and travel time models above Lower Granite Dam, one from the Snake River trap and one from the Imnaha/Grande Ronde traps. What models are these? The LGR arrival timing model in the LCM or a different model?

IEPR PANEL ADDITIONAL FINDINGS ON THE LIFE CYCLE MODELING (LCM)

Specific Points

Life Cycle Models of Interior Columbia River Basin Spring and Summer Chinook Populations (March 27, 2019)

Chapter 1 – Introduction

1. **Page 1-9** – The document states that: "Having an analytical tool as the consumer of monitoring data allows direct assessments of the consequence of variation in data quality since the impact of data quality can be immediately translated into the quality of decision-making in terms of risk of making an incorrect decision." This is an important point, but in the current form, there does not appear to be an assessment of the consequence of variation in data quality. Such an assessment would likely provide important insights into differences between the LCM and CSS approaches.

Chapter 2 – The COMPASS Model for Assessing Juvenile Salmon Passage through the Hydropower Systems on the Snake and Columbia Rivers

2. **Page 2-1** – No parameter estimates for the COMPASS model runs are provided in the LCM documentation, so it would not be possible to reproduce or replicate the results. In general, the descriptions given in the LCM documentation for the component models are very brief.

3. **Page 2-5** – For extrapolating to future environments, such as modeling the effects of trends caused by climate change, the prospective modeling using the estimated correlation structure of the environmental drivers makes sense. However, this is, in effect, extrapolation, and there is a possibility that the relationships with survival and the correlations among environmental variables might break down at levels the Panel has not yet observed. For projections that assume the existing environment applies, projections might not need to model environmental drivers at all; resampling survival residuals from the historical record, possibly maintaining any time series structure, would produce realistic levels of variability.

4. **Page 2-8** (and similar statement on page 2-17) – Under Results it states, "The average arrival timing at Bonneville Dam showed more change among the scenarios than survival (Table 1)." This statement is not supported and does not appear to be valid. Days and percentages are not directly comparable. This statement needs to be justified in quantitative terms; is it a greater relative change?

5. **Page 2-8** – It would make more sense to compare average arrival time at BON (averaged across transported and in-river fish) among scenarios, since the transported proportions and the timing of fish coming into these groups is impacting the results (this issue is discussed later, but it is confusing in the results.)

6. **Page 2-8** – There is some uncertainty included in the COMPASS outputs and the LCM outputs. Unfortunately, there is no comprehensive discussion of uncertainty, and the results are not clearly described in terms of what types of uncertainty are included or ignored. Stochasticity in environmental conditions is included through the consideration of the flow/temperature period of record (e.g., 1929-2018). Sampling or measurement error and another form of environmental stochasticity are included in the distributions of estimated parameters for the reservoir survival model and are used to form a sort of confidence interval on juvenile survival (Figure 3, page 2-13). But the COMPASS model is a very complex combination of mechanistic and statistical models containing many types and levels of uncertainties, and they are not fully considered. The

modelers are making inroads into this issue by using Monte Carlo simulations from parameter distributions, but it is only some parameters in some models that are treated this way. Other parameters are assumed to be fixed (e.g., release group timing, dam survival). The panel recommends that the methodologies for accounting for uncertainties (or not) across the entire model should be documented and updated as the models are revised and improved over time.

7. **Page 2-9** – The statement that there are differences but that they are very small is an improper interpretation of statistical results and is not supported. There are no differences; rather, this interpretation refers to the statement that the differences among years are greater than the differences among scenarios. It would be much better to look at the differences among scenarios on an annual basis (a sort of paired analysis). The magnitude of the change is then the average difference (across years) in juvenile survival if the 120% spill or 125% spill scenario is adopted. The methods for showing and discussing results in Chapter 2, discussing tiny shifts in the mean or median with completely overlapping boxplots as though they are actual changes, are not appropriate.

8. **Page 2-16** – Please elaborate on the transport prediction component of the model and how it changes under the 120-Perf and /125-perf scenarios (e.g., increased spill reduces the proportion of fish entering bypass system at collector dams leading to lower transportation rates). Where does this model component come from, and how was it validated? Could you illustrate this in the results to more effectively show these differences.

9. **Page 2-17** – The term “consistently higher survival” is used. If this is the case, it should be supported with the graphs and tables presented in the results section, and it is not.

10. **Pages 2-10 and 2-11** – Results in Table 1 and 2 are not described. Are they arithmetic means of 80 years of COMPASS runs (without uncertainty)? There should be some indication of the range of results, not just the mean. The same is true for Figure 1; the discussion of this figure should state that the boxplots represent the range of observed model results over the 80-year period of record, and that no other source of uncertainty other than flow and temperature (and maybe run timing for the Snake River?) stochasticity are included.

11. **Page 2-16** – Many interesting points are raised in the discussion, but they are not supported by evidence (graphs, tables, citations?).

Chapter 4 – Smolt to Adult Returns

12. **Page 4-1** – A more thorough explanation of how models were assessed and selected is needed. There are many potential models, and it is unclear which models were included in the AIC comparison, which is relevant information.

13. **Page 4-1** – The upstream survival component and the prediction of this component from monthly temperatures is not well described. In some of the life cycle models (e.g., Chapter 7), it is stated that the upstream survival is randomly selected from a normal distribution, which does not match this use for SARs.

14. **Page 4-3** – Given research suggesting that congeneric density (pink and chum abundance) affect coho and Chinook growth and survival, consider including some metric of competition in ocean survival analyses.

15. **Page 4-3** – Page 4-3 states that the top two models were used, but AIC comparison is not referenced. AICc (corrected for sample size) is apparently shown in the table, but again, it is not described in the text. It is also unclear what the full suite of models compared was.

16. **Pages 4-3 and 4-4** – Pages 4-3 and 4-4 describe estimating SAR survival for each migration day (d), but Figure 4.1 shows annual estimates. How were daily estimates collated to form annual?
17. **Page 4-4** – Since Figure 4.1 shows model fit, it might be helpful to show model predictions from the complete top model rather than individual predictor variables.
18. **Page 4-5** – The Panel understands that detrending may make sense for creating a covariance structure for projections, although the modeler might be removing the main part of the covariation. What if one series trends down and the other trends up, but after detrending the residuals are somewhat positively correlated? Should the modeler project a positive relationship into the future? The Panel thinks that in the retrospective analysis, the variables were not detrended before model fitting. If they were, the Panel would have similar concerns.
19. **Pages 4-5 and 4-6** – Pages 4-5 and 4-6 consist of a detailed discussion that has no unifying description. It appears to be a description of the MARSS modeling, but that term is not used here and there is no context to the discussion. The Panel's impression is that some text has been accidentally deleted.
20. **Page 4-6** – In Figure 4-3, the time series of ocean survivals for wild in-river fish and wild transported fish do in fact appear to have a strong correlation, contrary to what the text says. Peaks and troughs show reasonable correspondence.
21. **Pages 4-7 and 4-8,** Figures 4.4/4.5 – It is unclear which of these variables were used in which analyses. Were T_{stream} in Marsh Creek and South Fork Salmon River (rearing areas) used as predictors in the ocean survival models?
22. **Page 4-8** – The Panel did not understand Figure 4.5. Why fit a model of the effect of temperature on upriver survival for simulated data that incorporates an effect of temperature on upstream survival? Why is this relationship much less pronounced than the one found for real data in Crozier et al. (2017)? Is this a result of averaging across fish experiencing different temperature regimes?
23. **Page 4-8** – The SARS prospective analysis under "future climate scenarios" needs much more explanation.
24. **Page 4-9** – The description of using a MARSS approach to marry ocean survival projections to COMPASS needs much more detail. The Panel did not understand what was meant by "COMPASS time series," specifically whether this was a simulation of a hypothetical simulated year or a year drawn from the historical record. A more complete description of the year-matching process starts at the bottom of page 4-14. The Panel did not understand the last sentence of the paragraph ending on page 4-15. These two sections need to be married and placed in the Methods section of the projection analysis.
25. **Page 4-10,** Figure 4.6 – It would be nice to compare the observed SAR series to the projected SAR series assuming current conditions. Do they look similar? Are their properties (mean, variance, time series character) similar? The observed SAR series could even be added to the Figure 4.6 graph for visual comparison.
26. **Pages 4-11 to 4-13** – Much of the material on pages 4-11 to 4-13 shows results from the retrospective analysis or methodological descriptions. These results should be moved from their current position in the description of the prospective analysis to the section on retrospective analysis. The 2017 document has much of this material under the appropriate discussion section, which is a better fit.

27. **Page 4-13** – Model results coefficients are presented in a table labeled 5-2, which is never referenced in the text.

28. **Pages 4-14 and 4-15** – The description of the matching of COMPASS to the MARSS model to estimate SAR does not provide enough information to be understood.

29. **Page 4-15** – Three climate scenarios that generate contrasting flow and temperature regimes are mentioned in the description of upstream adult survival, along with reconstructed flow and temperatures from 1929 to 1998. Two of these scenarios are specified as being warm/wet and hot/dry; the third appears to be the 70 reconstructed years. It is unclear whether the first two scenarios also incorporated interannual variability. It is also unclear how any of these scenarios are used—for example, whether they are applied in the in-river COMPASS modeling. Both flow and temperature are supposedly outputs of these scenarios, but upstream survival is modeled solely as a function of temperature.

30. **General** – The tables and equations are all mis-numbered in Chapter 4.

Chapter 7 – A life cycle modeling framework for estimating impacts to Wenatchee springrun Chinook salmon from hydropower operations, habitat restoration, and pinniped predation effects

31. For Wenatchee populations, were differences in life history expression in abundance and survival estimates accounted for? The Panel assumes that fish that out migrate as parr in the summer and fall likely have lower survival rates through the hydrosystem than those that out migrate as smolts. However, there is some evidence that parr have higher survival rates through the estuary, and in Idaho populations, SARs are higher for fish that out migrate as parr. These seem like important trade-offs to consider within the framework of a complete life cycle model.

Chapter 8 – Middle Fork and South Fork Salmon River MPGs of the Snake River Spring/Summer-Run Chinook Salmon ESU

32. **General** – For most of the Snake River spring/summer Chinook populations considered in this chapter, a greater proportion of juveniles out migrate as age-0 parr in the fall than do smolts in the spring. Some rear in the mainstem areas of the Salmon and Snake Rivers; others pass Lower Granite and migrate to the ocean. Survival of parr through the hydrosystem is much lower than smolts, but SARs are higher. It does not appear that the parr life history component has been included in juvenile survival or SAR estimates. What is the potential effect of ignoring this life history diversity on results? (Source: every presentation by Tim Copeland over the last 5 years).

33. **Pages 8-4 and 8-5** – Clarify how freshwater environmental covariates were used in components of the model, and include equations.

34. **Page 8-7** – Our characterization of historical population distributions visually matched that observed at most quantiles. Please quantify if possible. Visual comparison suggests that the model has a tendency to overestimate spawner abundance in the right tail. What are the implications?

35. **Pages 7-18 and 8-8** – It is very difficult to see the differences in the boxplots between Figure 3A of Chapter 8 and Figure 3 of Chapter 7. Either describe quantiles and maybe add a reference line at the median environmental baseline, or make the boxplots larger.

36. **Page 8-10,** Figure 8-3 – Descriptions state that median spawner abundance declined in spill scenarios, but it does not look like they declined by very much. Please provide estimates and measures of uncertainty along with these statements.

37. **General** – The figures are mis-numbered in Chapter 8. For example, there is a Figure 3A (page 8-8), Figure 3B (page 8-9), and then a Figure 3 (page 8-10).

Chapter 9 – Estimating population level outcomes of restoration alternatives – An example from the Upper Salmons River focusing on Spring/Summer Chinook Salmon populations

38. **General** – It is unclear which populations were used for what parts of the modeling process. Initial descriptions stated that parr and redd capacity estimates were generated by the Quantile Regression Forest (QRF) modeling approach for the Upper Salmon MPG, which are predominantly composed of wild fish. But spawner density estimates included populations from the Entiat, South Fork Salmon, Upper Grande Ronde, and Wenatchee, which include large proportions of hatchery spawners. Define populations of interest in targeted restorations. Evaluation of spawning density combined for hatchery and wild fish might be misleading because of the propensity for hatchery fish spawning in the wild to spawn in poorer/downstream habitats, often closer to release sites (e.g., Murdoch et al. 2010 and Dittman et al. 2010), and often at higher densities.

39. **General** – Recent Juvenile Salmon Acoustic Telemetry System data indicate that powerhouse passage decreases with length, so larger fish may have higher survival rates through the FCRPS. Given that as smolt abundance (density, production) increases, average fork length may decrease (Tattam et al. 2015, Transactions of the American Fisheries Society), what is the potential for changes in abundance to indirectly influence downstream survival? It might be important to look at the relative effects of these two relationships in the context of life cycle dynamics and habitat restoration.

40. **Page 9-6** – Two functions of user-specified stochasticity: It is commendable that both sources of variance are allowed as inputs.

41. **Pages 9-13 and 9-14** – Parr capacity QRF model: It appears that several of the variables included are somewhat redundant (e.g., fish cover and large woody debris—while not all cover is composed of large wood, it typically makes up a substantial portion) and some of these partial dependence plots show the reverse of what is borne out by other literature (e.g., density decreases with cover). These observations suggest that the scale used to evaluate the variables may be inappropriate for the biological response, or that the partial dependence plots are skewed It seems that, given the large number of predictor variables, there is the potential for overfitting models. Additionally, data upstream of typical spawning areas should be included so that bounds on the upper and lower limits of relationships are established: otherwise, predictions will suggest that restoration should occur in habitat that will never be suitable for fish because it is limited by stream size and gradient, or will truncate predictions/partial dependence plots where data are sparse.

42. **Page 9-15** – Even though random forest maximum information coefficient (MIC) addresses correlation, it is still important to identify biological drivers of predictor variables and choose those that best represent important observations borne out by understanding of ecology.

IEPR PANEL ADDITIONAL FINDINGS ON THE CSS MODELING

Specific Points

CSS 2017 Annual Report – Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye

Chapter 2 - CSS Life Cycle Modeling Evaluation of Alternative Spill and Breach Scenarios

1. **Page 26** – PTRANS is introduced here (not seen in other documents previously reviewed). It is not described here, and the Panel had to go to McCann et al. (2016), Appendix E, to find the definition. In that appendix, the Panel only found information on retrospective estimates. It is unclear how this variable is used prospectively.
2. **Page 27** – In the Methods section, describe how spawner and smolt abundances were estimated for observed data and potential bias/uncertainty related to those estimates. How do changes in those numbers link to habitat and management changes that have already been implemented over the time period shown? Discuss other factors potentially affecting spawner-to-smolt relationships during this timeframe.
3. **Page 27** – It is unclear how (or whether) the Beverton-Holt parameters are estimated for the two stocks with no juvenile data. The Beverton-Holt relationships for these two are not shown in the Results section. It is also unclear how data for the two populations lacking smolt data are treated in the likelihood process.
4. **Page 27** – The modeled changes in the Beverton-Holt parameters would be the consequence of concrete habitat improvement actions. These analyses require additional modeling, specifically to calculate the effect of a particular habitat improvement on the two parameters, before a comparison could be made between the benefits of such an action versus the benefits of a comparably costly change in dam operations.
5. **Page 31** – It is unclear how the combined SAR used in the likelihood equation is calculated. Is it the average of the two values, or are all fish lumped so that the numerically dominant downriver pathway dominates?
6. **Pages 31 and 32** – Using SAR, C_0 SAR, and T_X SAR values together in the likelihood seems statistically somewhat dubious, as they are not independent of each other. This is probably a minor issue, but removing SAR from the likelihood would solve the problem.
7. **Page 32** – It is unclear what “C_0 returns” and “T_X returns” mean. The Panel assumed that they were adult returns of untransported and transported juveniles, respectively.
8. **Pages 32 and 33** – There are five disparate data types that are simultaneously fit. The weighting of multiple data sets is a tricky decision; weights affect the parameter values (and the calculated values of the MLEs of the sigmas). Not assigning weights implicitly assigns each likelihood component a weight of one; it does not circumvent the fact that a choice was made that affected the results. Log-transforming all of the response variables effectively weights each data set by its number of observations, all other factors being equal. The data-weighting question should not be avoided. Rather, the sensitivity of the results to different weights should be examined, and the choice of weights should be based on an assessment of the reliability of each type of data.
9. **Page 34** – For prospective models, three representative years are selected, three years in a row (2009-2011). No evidence to support the appropriateness of this selection and potential uncertainties is supplied.

10. **Pages 35 to 37** – PITPH and WTT were fixed in prospective “simulations,” while Pacific Decadal Oscillation and upwelling were random simulations, and harvest rate was increasing over time with some complicated formula. The “conversion rate” is drawn at random from the most recent 20 years of conversion rates, then breaching was assumed to cut the rates in half. To the Panel, this approach seems capricious and the results unreliable. A much more robust theoretical underpinning/verification/defense for these decisions is needed.
11. **Page 37** – The relationship between harvest rate and abundance is not clearly specified. An equation would help. It is also unclear whether this harvest rate is total harvest or just harvest above Bonneville Dam.
12. **Page 39** – Summarizing each simulation using a 10-year average of returns is probably too short and may slightly inflate the variance of the results distribution. However, the ISAB (2017 review, page 50) believes these distributions are probably too narrow to start with.
13. **Pages 39 and 40** – It is unclear why changes in Beverton-Holt parameters were only evaluated under average flow. If habitat is improved, flow will still vary.
14. **Pages 39 and 40** – The simulation modeling of the effect of changes to Beverton-Holt parameters on Req is almost unnecessary. As the juvenile stage is, with the exception of harvest, the only compensatory process in the life cycle model, one could essentially get the same answer by using the deterministic formula for equilibrium stock size (Meq = b(a-1)/a), and taking the ratio of the equilibria using changed vs. unchanged parameter values. This approach would show that increasing capacity (b) would increase Req by the same percentage, whereas increasing productivity (a) is less effective if productivity is already high. This formula explains the results summarized at the top of page 60.
15. **Page 40** – The first paragraph of the Results section describes a model selection procedure that should probably be in the Methods section. Also, in the Methods section, it was not clear that models with subsets of predictors would be considered. An AIC table would be helpful to see the level of support for each predictor.
16. **Page 40** – AIC was apparently used to select the best model; however, it is standard practice to report AIC results, and they are not reported here. The only assessment of model fit appears to be figures (see Figure 2.6) displaying observed and fitted results on an annual basis. These plots cannot be used to evaluate the fit of the model. There are well-established graphics for doing so, but they are not used in this context.
17. **Page 41** – The Results section states that parameter values were bounded to biologically plausible values. Bounding (which variables, what bounds were, etc.) is not clearly described anywhere.
18. **Page 42** – In Figure 2.3, the labels “a” and “b” on the graphs are confusing. The caption makes it clear that these are actually “ln(a)” and “ln(b)”.
19. **Page 44** – Figure 2.5 is a confusing mix of graphs. Some show correlations among predictors, some show correlations among predictors and predicted (not observed) responses, some show correlations among predicted response variables. Also, clarify that these are annual predictors and model-predicted responses.
20. **Page 48** – Inconsistent use of terminology between text and figures makes results harder to interpret. It appears that “juvenile data” and “smolts” refer to the same values, which are denoted M in the model equations.

21. **Pages 56 to 61** – The potential implications of changes in percent hatchery origin during the observed time period should be addressed in the discussion.
22. **Page 61** – The Panel does not agree that keeping PITPH and WTT fixed somehow improves the understanding of the effects of different types of variability. There are other ways to separate these effects; the Panel assumes that time was an issue. The lack of variability through time and predictive uncertainty in the PITPH and WTT variables most likely contribute to them being strong predictors.

Chapter 3 – Effects of the In-River Environment on Juvenile Travel Time, Instantaneous Mortality Rates and Survival

23. **Page 73** – Why look at residuals of log(Z)? Log(Z) is a doubly log-transformed survival.
24. **Page 73** – Why is a logit model for survival, the equivalent of the model of instantaneous survival, in the TDG section?
25. **Page 73** – Why was TDG tested in the regular modeling framework as well as a residual analysis for instantaneous mortality, while TDG effects were only examined in the residual framework for logit survival?
26. **Page 74** – Third sentence says, "S both increased and decreased over the season, and Z increased over the season." This is not possible, as Z is a monotonic transformation of S.
27. **Pages 75 to 77** – The data clusters in Figures 3.2 through 3.4 are too crowded, and some types of results are difficult to see (the most difficult being the top right of Figure 3.4). The figures are trying to illustrate: differences among stocks, differences among years, seasonal pattern with a year, fit of model to data. All of this data cannot be represented well simultaneously; the figures should be split into more figures with fewer data objectives. The Panel suggests removing model predictions and using separate figures to illustrate model fit.
28. **Page 80** – The sentence in the section "Results" about excluding two years of sockeye data should be in the Methods section.
29. **Page 80** – Table 3.4 is ambiguous. It only lists random effects, but from the importance weights on the environmental predictors, some must be included in the best models for each stock. Are these R2 values for the models with the lowest AIC scores, or models with just the random effects shown? Table 3.4 also gives R2 for survival, but no model is listed for survival. Specify whether R2 values for survival refer to specific models and clarify whether these models refer to the logit survival model in the TDG methods or some other definition of survival.

Chapter 8 – Adult Success-Summer Chinook, Snake River Sockeye and Steelhead

30. **Page 185** – Chapter 8 seems very exploratory. There are many potential avenues for improving these retrospective models and working the improvements into prospective life cycle modeling. There also seems to be an overreliance on model fitting, rather than biological understanding.
31. **Page 186** – The term "arrival timing" should be defined.
32. **Page 188** – Consider the implications of using a hard cutoff point (e.g., 10 days or 30 days) for "short" vs "long" travel times rather than a quantile or similar interval-based cutoff point, when there is annual variability in median travel times. Also, consider what those definitions mean for steelhead in light of potential trade-offs, as steelhead seek cold-water refugia during upstream migration and will enter tributaries for weeks to months before continuing upstream migration.

CSS Documentation of Experimental Spill Management: Models, Hypotheses, Study Design, and Response to ISAB, May 8, 2017

Chapter 2 – Retrospective Analysis of Life Cycle Productivity and Smolt-to-Adult Return Rates Using Run Reconstruction Data

33. **Page 17** – Second-to-last paragraph of the section "Methods," the text "From the set of biologically plausible models (identified in Petrosky and Schaller 2010 and Schaller et al. **2104** [sic]…)" is confusing. The rest of the Methods section implies that the top models are identified in an analysis described in Chapter 2, but the quoted text implies that the top models came from analyses performed years before.
34. **Page 17** – It is unclear what "biologically plausible" means (assuming it is not simply another way of referring to the models with the best AIC/BIC/R2 values).
35. **Page 17** – From text in the section titled "Results", it appears that the survival rate index analysis may not have been redone, but that the analysis from Schaller et al. (2014) was simply reused. Similarly, it appears that the analysis of the smolt-to-adult return (SAR) data was not redone, but that the analyses of Petrosky and Schaller (2010) were reused. However, the coefficients in Table 2.2 do not match those in Table 4 of Schaller et al. (2014), nor do the coefficients in Table 2.4 match those of Petrosky and Schaller (2010), Table 2.

Chapter 3 – Retrospective Analysis of Juvenile Travel Time and Survival, Ocean Survival, and Smolt-to-Adult Return Rates Using PIT Tag Data

36. **General** – For many interior Idaho spring/summer Chinook populations, a greater proportion of juveniles out migrate as age-0 parr in the fall than do smolts in the spring. Some rear in the mainstem areas of the Salmon and Snake Rivers; others pass the Lower Granite Dam and migrate to the ocean. Survival of parr through the hydrosystem is much lower than smolts, but SARs are higher. It does not appear that the parr life history component has been included in juvenile survival or SAR estimates. What is the potential effect of ignoring this life history diversity on results?
37. **Pages 25 and 26** – The two-week cohorts defined in the juvenile fish travel time modes leave out the tails of the migration. In some years (e.g., 2011) a substantial proportion of individuals may have been excluded. Discuss the potential effect of this truncated sampling on results.
38. **Pages 25 to 34** – It is unclear how the LGR detection probability estimates were used (if at all). Were they used to adjust the detected smolt numbers upward to bias-correct the data for in-river survival and SAR? If so, this does not seem possible, as the results give a comparative value of detection by period but cannot produce an absolute value of detection probability to give estimates of the actual number of smolts.
39. **Pages 27 to 33** – The description states that data were centered to improve model convergence. Consider standardizing data so effects sizes can be compared.
40. **Page 28** – In the juvenile survival model, the examination of the TDG effects is ad hoc and statistically suspect. If TDG is to be examined, it should be as another predictor in the Bayesian CJS analysis. However, the analysis is probably sufficient to cast doubt on the importance of these effects. Since TDG is a function of spill, some TDG effects may also be indirectly incorporated through other predictors. Also, the available data do not include severe TDG values, so results for operational scenarios that cause severe TDG values would be considered extrapolation. This should be carefully noted.

41. **Page 28** – Random effects were used in the models to account for lack of independence among observations. When the random effect term did not improve the DIC, the random effect was not used. The implications of this decision should be reviewed and defended; otherwise, a lack of independence prevails.
42. **Page 29** – Provide data used to estimate ocean survival S_0 rates, including variance estimates for SAR and juvenile survival.
43. **Page 32** – Is the "detected smolts" model really reservoir survival probability upstream of LGD? It is called "detection probability on the number of smolts detected in each two-week cohort." Here, this upstream survival is predicted as a function of "cohort number" (equally spaced two-week periods inserted as integers?) and "Det_Prob," which are not well defined. The analysis only says that PITPH methods described in Appendix J of McCann et al. (2015) are used. This is unclear. Why are only 4 years used for this model (2009, 2010, 2011, 2014)?
44. **Page 33** – In the TIR model, it is unclear why oceanographic predictors were not considered in the ratio of SARS as they were for the SARS themselves. It seems possible that transportation or the stresses of in-river migration could have an effect on preparedness for entering the ocean environment.
45. **Pages 34 and 35** – Results state that the models "captured a high degree of the variability." Explain what this means and support it with numerical results.
46. **Pages 34 and 35** – Model results are not accompanied by a discussion of model fit or best model selection. The coefficients are all included in tabled model results and characterized as "significant." Figure 3.1 (and others) are not useful graphs for reviewing fit of models; in fact, it is unclear whether model fit was assessed. Are marginal or conditional predictions shown in graphics? There is no discussion of what the use of random effects means for predictive (prospective) models. This description of model results is far too simplistic, especially for mixed effects models. BIC or AIC comparisons and specific methodology for predictions from the random effects model are needed. TDG models are compared based on t-value of individual variable rather than AIC; this post hoc consideration of TDG seems inadequate. On page 36, Figure 3.7 is described as showing a "reasonable level of agreement," but the Panel finds that characterization to be questionable. On what basis is it reasonable?
47. **Pages 41 to 46** – Figures 3.1, 3.2, 3.5, 3.6: Include confidence intervals on survival estimates. These are good exploratory plots, but they do not adequately convey important information about model fit, uncertainty, and bias.

IEPR PANEL ADDITIONAL FINDINGS ON THE UW TOTAL DISSOLVED GAS (TDG) MODELING

Model Documentation for IEPR Review: Evaluating the Effects of Total Dissolved Gas (TDG) on Juvenile Salmonids for the CRSO EIS

General Comments

It would be helpful to include a schematic example of how the TDG model uses and runs with COMPASS. In general, the description of each model component is very brief and lacks detail. No interpretations or conclusions are presented for this model. The data for calibrating the model components are very sparse. The mortality model is based on very limited, very old data. The depth distribution used is not justified (only a table of numbers from literature is given, and the final selection. Results were presented in our kick-off meeting with slides, but the Panel is not sure how they can be evaluated).

The assumptions should be stated, their validity assessed, and implications of violations discussed. The following assumptions warrant further assessment:

- TDG mortality is piecewise linear.
- Change in TDG mortality with depth is constant.
- Mortality rate is normally distributed.
- When TDG is zero, mortality is zero.
- Exposure time and mortality rate in the Dawley study, which are not well explained.
- Mortality rate is a linear function of fish length.
- Fish vertical distribution function is constant.

Specific Points

1. **Quantification, page 4** – Sentences like "To compute the TDG exposure metrics, detailed book-keeping of fish exposure to water properties is computed at 21 locations" are too vague for model documentation. Specific information on how fish exposure was estimated should be documented along with the data used.

2. **Mortality Due to Gas Bubble Disease (GBD), page 5** – The language for the listed steps in the process (bottom of page 5) is confusing, inconsistent, and imprecise. Why is the modeler "adjusting TDG" rather than adjusting mortality for depth, and then adjusting mortality for fish length? This adjustment is not well explained.

3. **Mortality Rate Equation, page 6** – Mortality equation: M should say mortality PER DAY. Z is not defined at all. The definition of parameter m is ambiguous. Would it be helpful to define the m/z relationship first?

4. **Mortality Rate Equation, Table 1, page 7** – The table of parameter estimates should have basic summary fit values: sample sizes, R^2, standard errors.

5. **Mortality Rate Equation, Table 2, page 7** – The use of data to calibrate the model for mortality as a function of TDG should be described. Survival data for fish exposed for under 40 days are used. How are they used exactly? Is each listed exposure (each row in Table 2) a replicate? Is the listed mortality in units of mortality/day? Is each mortality rate an independent estimate? How are the survival and mortality rates related to each other?

6. **TDG Depth Correction Factor m, page 9** – The TDG depth correction factor (m) needs more information explaining how it is applied.

7. **Size-Mortality Rate Relationship, page 10** – The equation for fish length adjustment (M(L) = …) is not described. What is c? What is L? How is it estimated?

8. **Fish Vertical Distribution, page 12** – The selection of depth distribution is provided but not described. Depths are presented in Table 4, there is no justification for selection of 7 ft and 50 ft for the CRSO analysis?

9. **Reservoir Survival Associated with GBD, page 13** – Step 6 is not adequately explained. Simply presenting an equation is not sufficient.

BATTELLE

It can be done

From: Petersen,Christine H (BPA) - EWP-4

Sent: Wed Jun 03 15:22:55 2020

To: 'David Welch'

Subject: NOAA tech memo

Importance: Normal

Attachments: Zabel.and.Jordan.NOAA.LCM.Tech.Memo.DRAFT.20190327.pdf

This is the Zabel Jordan tech memo – I hope this actually goes through due to size.

Christine

Life Cycle Models of Interior Columbia River Basin Spring and Summer Chinook Populations.

U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC

Richard W. Zabel and Chris E. Jordan, editors

DRAFT

Suggested citation (entire document):
Zabel, R. and C. Jordan (eds.). In Press. Life Cycle Models of Interior Columbia River Basin Spring and Summer Chinook Populations. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC xxx.https://doi.org/xx.xxxx/xx/TM-NWFSC-xxx.

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Table of Contents

CHAPTER 1: INTRODUCTION

Rich Zabel (NOAA Fisheries, NWFSC, Seattle), Chris Jordan (NOAA Fisheries, NWFSC, Newport), Tom Cooney (NOAA Fisheries, NWFSC, Portland)

1.1 Overview

Life-Cycle modeling has become an invaluable tool for managing at-risk populations (Doak et al. 1994, Beissinger 2002), particularly for species that have distinct life stages. A major advantage of life cycle models is that they can translate changes in demographic rates (survival, capacity, or fecundity) in specific life stages into measures of population viability metrics (e.g., long-term abundance, productivity, or probability of extinction), which are more relevant for population management. In addition, life-cycle models allow for the examination of impacts across several life stages and in concert with other factors such as climate variability and change (Figure 1).

In the Columbia River basin, researchers have used life-cycle models to address a broad range of questions in a variety of populations (Kareiva et al. 2000, Wilson 2003, Zabel et al. 2006, Interior Columbia Technical Recovery Team and Zabel 2007, Crozier et al. 2008, Honea et al. 2009, Jorgensen et al. 2009). While early models were deterministic and density independent (Kareiva et al. 2000), later efforts were more sophisticated, including stochasticity, density dependence and climate variability and change (Zabel et al. 2006, Interior Columbia Technical Recovery Team and Zabel 2007, Crozier et al. 2008).

Here we present Life-Cycle models in support of the 2018 Federal Columbia River Power System (FCRPS) Biological Opinion. We focus on models of Spring and Summer Chinook salmon. We present models and results for several Major Population Groups (MPGs) in the Interior Snake and Columbia River basin: Grande Ronde River basin, Upper Salmon River, Middle and South Fork Salmon River, and Wenatchee. In addition, we present supporting modules for all of the models: Survival through the hydrosytem, survival through the estuary and ocean life stages, mortality due to pinniped predation, and the effects of climate change.

Much of the focus for these models is on the benefits of habitat restoration. We have produced a companion NOAA Technical Memorandum (Pess and Jordan in press) that describes the methodology for converting habitat actions into benefits that can be incorporated into Life Cycle models.

Buhle et al. (2018) present results for an Integrated Population model of 27 Interior Columbia River populations that is relatively simple in structure compared to the models presented here. These results serve as a comparison to the more complex models presented here.

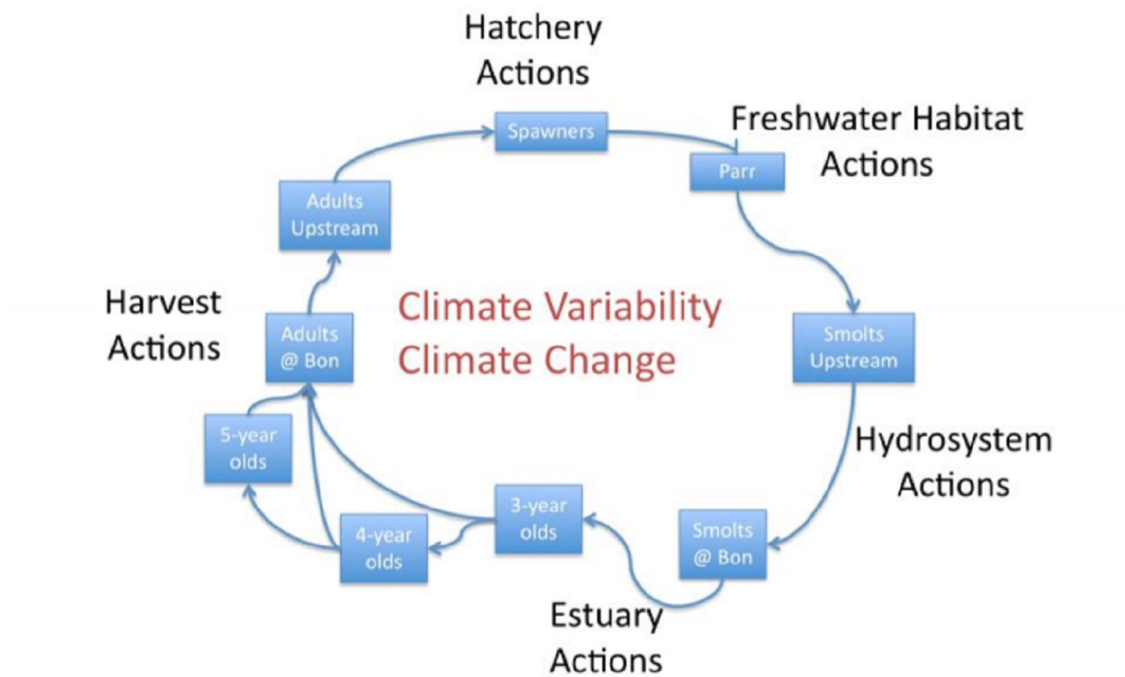

Figure 1. Typical Interior Columbia River basin spring and summer Chinook salmon life cycle, with mitigation actions occurring at several life stages. In addition, climate variability and change can interact with actions to influence population performance.

1.2 Population Models

Grande Ronde Basin

The Grande Ronde River basin in northeastern Oregon offers a good system for contrasts. Some of the tributaries have been heavily modified (Catherine Creek and Upper Grande Ronde River) and have been the focus of habitat restoration actions, and some of the tributaries are relatively pristine (Lostine/Wallowa, Minam, and Wenaha). In addition, some of the tributaries have supplementation, while others rely on natural production. These models are described in Chapter 6.

Wenatchee

The Wenatchee River is a complex system that is supported by five production areas: Chiwawa River, Nason Creek, White River, Little Wenatchee River, and Mainsten Wenatchee River. We modeled the contributions of these areas separately, but combined the results from the production areas to produce population-level metrics. The area has also suffered from habitat degradation, and is the focus of many habitat actions. In addition, the population is heavily supplemented. We present the Wenatchee model in Chapter 7.

Middle Fork/South Fork/Upper Salmon

This suite of models covers three MPGs. In the Middle Fork Salmon River, we developed models for Bear Valley Creak, Big Creek, Camas Creek, Loon Creek, Marsh Creek and Sulphur Creek. For the South Fork Salmon River MPG we developed models for Secesh River and South Fork Salmon River. For the Upper Salmon River MPG we developed a model for Valley Creek. Most of the populations lie within wilderness areas. In addition, these models are supported by a lengthy time series of PIT tag parr-to-smolt survival data, and we explored relationships between survival and tributary flow and temperature. Population models for these MPGs are presented in Chapter 8.

Upper Salmon River

We developed models for several populations in the Upper Salmon MPG: Lemhi River, Pahsimeroi River, Panther Creek, East Fork Salmon River, Salmon River mainstem, North Fork Salmon River, and Valley Creek. These populations are impacted by water withdrawals and habitat degradation. Many of the habitat actions are focused on reconnecting habitat to make it accessible to salmon populations. We describe these models on Chapter 9.

1.3 Common Modules

Our strategy for developing the Life-Cycle models was to produce two modules: one that was specific to the freshwater phase of specific populations, and another that was common at the ESU level. In these chapters, we describe modules that are common to ESUs.

Survival through the Hydrosystem

Survival through the hydrosystem is handled by the COMPASS model. The description of the model and the alternative produced for the Biological Opinion are contained in Chapter 2.

Pinniped Predation

Pinniped predation, primarily by California Sea Lions, on adult salmon occurs in the Estuary. We modeled population-specific mortality due to pinnipeds based seasonally varying estimates of survival and on population-specific arrival timing. Pinniped predation has increased dramatically over the past few years, particularly for early arriving populations. We describe our methods in Chapter 3.

Smolt to Adult Returns

We model survival from passage as juveniles at the uppermost dam in the migration route (Lower Granite Dam or Rock Island Dam) to return as adults to the same location. We split this stage into: 1) survival as juveniles through the hydrosystem to detection at Bonneville Dam; 2) Estuary/Ocean survival from detection at Bonneville Dam to return as adults to Bonneville Dam; and 3) upstream survival through the hydrosystem as adults. This module is described in Chapter 4.

1.4 Other Sections

Climate Change

We did not explicitly account for climate change in our modeling for the 2019 FCRPS Biological Opinion. This is a supplemental Biological Opinion that only covers 2-3 years. However, in Chapter 5 we describe the approach that we are taking to model climate change in the next Biological Opinion, due in 2 years.

Population Prioritization

The objective of Chapter 10 is to develop a standardized, quantitative method for identifying focal populations for near term emphasis in habitat restoration. The basis for evaluation of populations is meant to be consistent with avoiding immediate (e.g. 24 year) losses in DPS/ESU capabilities to withstand demographic and localized catastrophic risk factors and for making progress towards longer term goals for ESA and broad-sense recovery. The focal population concept will integrate into ongoing ESA recovery implementation and related activities (e.g. ESA consultations involving tributary habitat) in the Columbia River basin. The focal population identification will provide strategic guidance for sequencing of future habitat restoration and protection at the population or MPG level. The focal population analysis is intended to be a tool for use in strategic planning initiatives such as the Grande Ronde ATLAS and the Upper Salmon MPG regional restoration planning effort involving Idaho Office of Species Conservation & IDFG), federal agencies and tribal fisheries staff). The framework described in this chapter was initially developed for application to the Snake River Spring/Summer Chinook ESU major population groups and their component populations; however, we have also developed a version for application to steelhead DPSs.

1.5 Scenarios Evaluated

For all of the populations modeled in this exercise, we developed a standard set of scenarios to compare a range of management actions that capture the Propose Actions considered in the 2019 FCRPS Biological Opinion. The scenarios are referenced to an environmental baseline that acts as the starting physical and biological setting of impacts on Columbia River basin salmonid populations. The baseline is then further developed to represent the range of management options in the Proposed Action. To facilitate comparing across scenarios and population modeling frameworks, we also established a standard analytical approach and a corresponding suite of output graphics.

Environmental Baseline
The Environmental Baseline The first series of graphics (population specific) focuses on building up the environmental baseline to represent the populations in their current state.

1. Base Hydro Operation – Represents how the hydrosystem is currently operated.
2. + Past Habitat Actions – Represents the positive effects of habitat actions already implemented.

3. + Continued Hatchery Operations – Represents supplementation as it is currently implemented. Note that some populations do not have supplementation.
4. + Increased Marine Mammal Predation. Represents the effect of current marine mammal predation. Particularly important for early migrating populations.

Together, these sequential graphics should, capture, to the extent practicable, our ability to quantitatively assess how these factors combine to affect productivity and abundance. NOTE: If these actions don't apply (for example past hatchery actions, or hatchery practices) then they will not be presented.

Proposed Action
The second series of graphics focuses on assessment of the proposed action in relation to the environmental baseline.

1. Env. Baseline – This is represented by all of the actions in the environmental baseline above.
2. + Future Habitat – This represents the effect of habitat actions over the near-term (next 3-6 years)
3. + Proposed Hydro Operation – Based on COMPASS model output for the Proposed Action; only survival through the hydrosystem. Does not contain latent mortality effects.
4. + Latent Mortality 10% -- Adds a latent mortality scalar of 10%. Multiplies ocean survival by 10%.
5. + Latent Mortality 25% -- Adds a latent mortality scalar of 25%.
6. + Latent Mortality 50% -- Adds a latent mortality scalar of 50%.

Standard Model Outputs

Figures for each population, grouped by MPG, include the following components. In each case, the plots show the outcome of many (e.g., 1000) replicate simulations; each run being a single instance of the specified scenario and the aggregate output reflecting the uncertainty bounding the parameterization of the underlying demographic processes.

We produced a series of boxplots to represent model outputs. For each boxplot, the solid bar in the middle of the plot represents the median of the metric across all replicate simulations. The box represents middle 50% of the replicates, with the lower extreme of the box representing the 25^{th} percentile and the upper extreme of the box representing the 75^{th} percentile. The horizontal bars terminating the vertical dashed lines bound the middle 95% of the replicates, with the lower bar representing the 2.5^{th} percentile, and the upper bar representing the 97.5^{th} percentile.

For each replicate simulation, we produced three metrics after 24 years of projection into the future: mean abundance, probability of falling below the Quasi-Extinction Threshold (QET) of 30 spawners, and probability of falling below QET of 50 spawners.

We represented abundance of spawners as the geomean of spawner abundance calculated over the 24-year simulation time period. To calculate the probability of falling below QET, we used a several step process. First, we assessed whether a single simulation represented a population that fell below the quasi-extinction threshold. This was defined as the 4-year mean of spawners (on the spawning ground) falling below the specified QET. If a population fell below this threshold, it was assigned a value of 0. If it persisted, if was assigned a value of 1. The probability of falling below QET was calculated across all simulations.

Note that this approach assigns a single probability per alternative. We describe how we calculated the uncertainty in this probability below (Section 1.9).

1.6 Modeling Habitat relationships

The 2008 FCRPS BiOp places emphasis on increasing population performance by improving habitat conditions in freshwater. Accordingly, we have focused on developing relationships between juvenile productivity and habitat conditions. The goal of freshwater mitigation actions is to change the state of freshwater ecosystems in such a way to improve the conditions for juvenile rearing and adult spawning. The mitigation actions take on many forms, including moderating water temperature by increasing riparian vegetation, restoring stream structure, or allowing better access to or increasing the amount of productive habitat. In addition, other anthropogenic impacts, such as climate change, can also alter freshwater ecosystems, and can consequently change population performance, either positively or negatively.

A major challenge of developing fish/habitat relationships is understanding the mitigation actions – change in ecosystem – fish response pathway (Figure 2). Establishing these linkages requires detailed field data, both in terms of fish response and habitat conditions. We have developed five example analyses to demonstrate how we can use existing data to develop these types of relationships and incorporate them into life-cycle models. In addition, we present 3 more examples where we are in the process of developing these types of models. Here is a summary of these models:

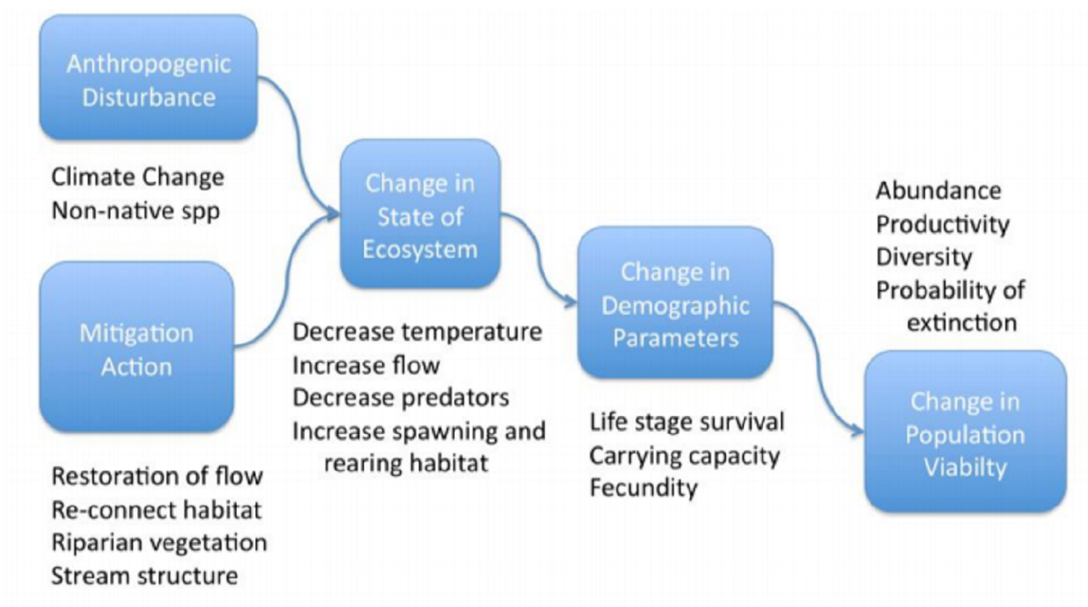

Figure 2. Representation of the pathway of actions and anthropogenic disturbance through changes in the state of ecosystems, demographic parameters, and population viability.

1.7 Spatial Modeling

It is quite clear that salmon populations are not independent units; however, it is not always clear when and where demographic isolation occurs. It is also clear that basic fish-habitat relationships exist by species; but again, it is not always clear the degree to which these relationships can be applied broadly within and across populations and ESUs. These constraints may imply that to apply life cycle based management tools, every salmonid population requires a complete and locally specific parameterization effort. We take, however, a somewhat moderated view, by assuming that there are broad commonalities to salmonid biology, watershed processes, and their interactions, across populations within the interior Columbia River Basin. As such, "borrowing" data within and among populations is a reasonable approach to allow the development of complex life cycle models in what may appear to be data "poor" population areas.

Also, note that spatial structure in populations was incorporated into the ICTRT's viability and recovery criteria (ICTRT 2007). We use these expectations, plus the results of metapopulation assessments of Chinook populations in the Salmon River ESU as part of the prioritization scheme presented in Chapter 10.

1.8 Adaptive Management

Portfolio of life-stage specific actions

One of the advantages of Life-Cycle modeling is the ability to assess impacts at multiple life stages by translating changes in life-stage demographic rates to changes in viability metrics. In this way, we can put together a portfolio of actions to compare across different portfolios. We are proposing an adaptive management strategy where we use life-cycle models to design and assess alternative suites of actions. Prospective life-cycle models are used to develop alternative portfolios of actions. Alternative portfolios can be compared with a variety of performance metrics, such as in a cost-benefit or extinction risk framework. The life cycle models also play a critical role in an adaptive management context as they make testable, quantitative predictions. These predictions are treated as hypotheses, and an appropriately designed monitoring program can assess the predicted outcome and can be used to evaluate and improve the analytical framework when the outcomes differ from expected.

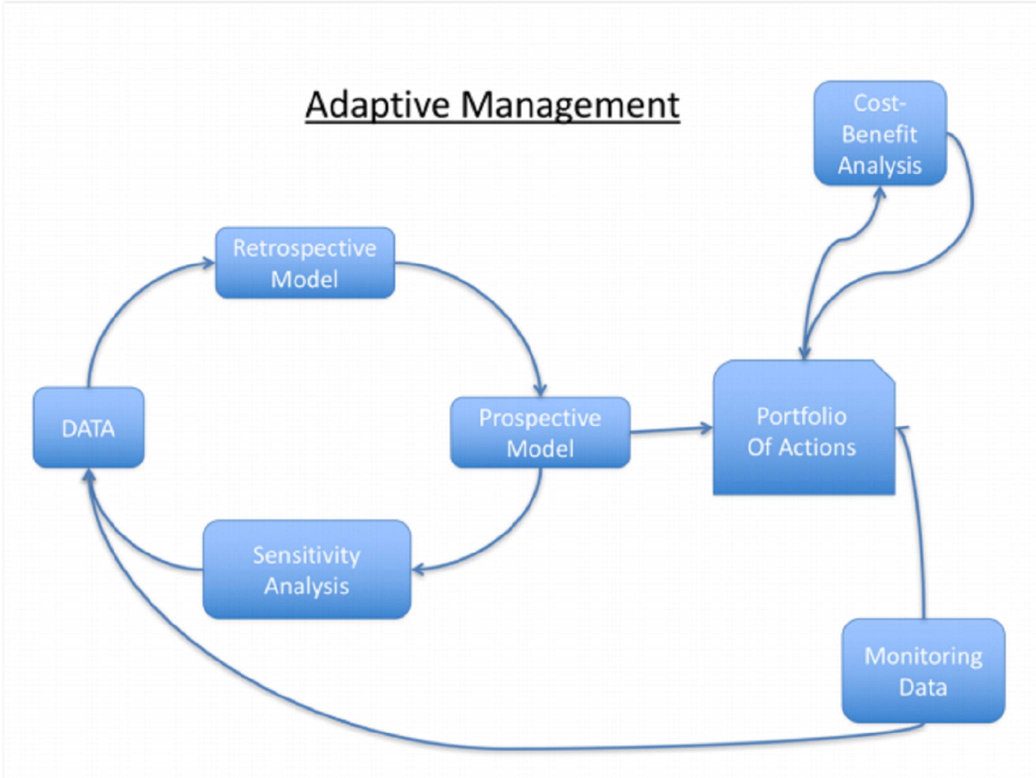

Figure 3. Adaptive Management scheme. Prospective life-cycle models are used to develop alternative portfolios of actions. Alternative portfolios can be compared in a cost-benefit analysis. Once a portfolio is chosen, we will use monitoring data to assess whether actions were effective.

Promote consistent use if available info & assumptions

Developing a suite of analytical tools to support decision-making around salmonid recovery actions in the Columbia River basin is critical given the scale of the region (3 species, 6 ESUs, more than 100 populations) and diversity of potential management actions (Hydro, Hatchery, Habitat….). Life cycle models are the obvious choice in this situation because they enforce consistent use of population and habitat data and constrain how management actions impacts are evaluated. As such, life cycle models represent a template that explicitly accounts for the diversity of population settings and management actions.

Applications (inform status assessments, strategic planning etc)

All assessments of salmon population management in an ESA (and MSFMA) context can be supported by life cycle modeling. Simple life cycle models are currently used in stock forecasting for most ocean salmon harvest. More complex life cycle models that are spatially explicit or have finer temporal resolution are used to support water management in the

Sacrament River delta system. All ESA listing and status decisions are supported with full life cycle evaluations of extinction risk or population persistence. Consultations on reach-scale single habitat alterations may appear to be too small and too isolated to be applicable to a life cycle modeling based evaluation; however, the methods could be applied in a regional context if consultations were bundled spatially to a larger-scale.

Systematic framework for setting RME priorities

In the context of Adaptive Management, life cycle models both form the analytical framework for making quantitative, testable predictions of management action outcomes, but also form the basis for the data or monitoring needs. The data needs of a life cycle model based decision support system are both to parameterize the population processes represented in the model (e.g., stage specific abundance, survival and capacity), and to test the population response to management actions (e.g., fish-habitat relationships, mainstem project survival, hatchery-wild interactions). In either case, the life cycle model is the use-case for the monitoring data and as such should be used to set the spatial and temporal resolution of sampling, choice of monitoring metrics, and ultimately the data quality in terms of sampling and measurement uncertainty. Having an analytical tool as the consumer of monitoring data allows direct assessments of the consequence of variation in data quality since the impact of data quality can be immediately translated into the quality of decision-making in terms of risk of making an incorrect decision.

1.9 Representing the uncertainty in falling below QET

Here we present the idea of "risk plots", which characterize the risk and uncertainty of populations. The plots can represent current risk (measured as probability of falling below QET), as well as risk under a variety of alternatives. Because the plots essentially summarize model outputs (abundance and recruits per spawner), they can be applied to any class of model, from simple to complex. They allow for comparison across alternatives, models and populations.

Before we describe our approach, we provide some definitions:

Run: A single iteration of the model with a given set of parameters for a set number of years (usually fifty or a hundred years). For each run we keep track of the population trajectory so we can calculate a suite of model metrics. To capture uncertainty in model outputs, we conduct a large number of runs per scenario.

Scenario: A specific set of parameters that represent a particular management scenario. The "Baseline" alternative represents current conditions. All other alternatives represent a proposed future management scenario.

To represent productivity and abundance, we produce the following outputs:

Productivity: In keeping with previous analyses (e.g., Interior Columbia Technical Recovery Team and Zabel, 2007), we calculate productivity as recruits (R, measured as returning spawners referenced to a brood year) per spawner (S) measured at relatively low abundance. This represents the ability of a population to rebound from low abundance. At higher abundances, populations tend to hover about an equilibrium level, so recruits per spawner approaches unity, and does not distinguish among alternatives. We measured productivity for each run as R/S at 50 spawners. We determined this by fitting a Gompertz model to each model run. The Gompertz equation is:

$$\log\left(\frac{R}{S}\right) = a + b \cdot \log\,(S)$$

where a and b are parameters. We chose this equation (over a Beverton Holt equation) because it is linear (and does not have convergence issues), and it strongly resembles a Beverton-Holt equation, particularly at low abundance. Figure 4 demonstrates this for nine runs of for the Wenatchee Spring Chinook population.

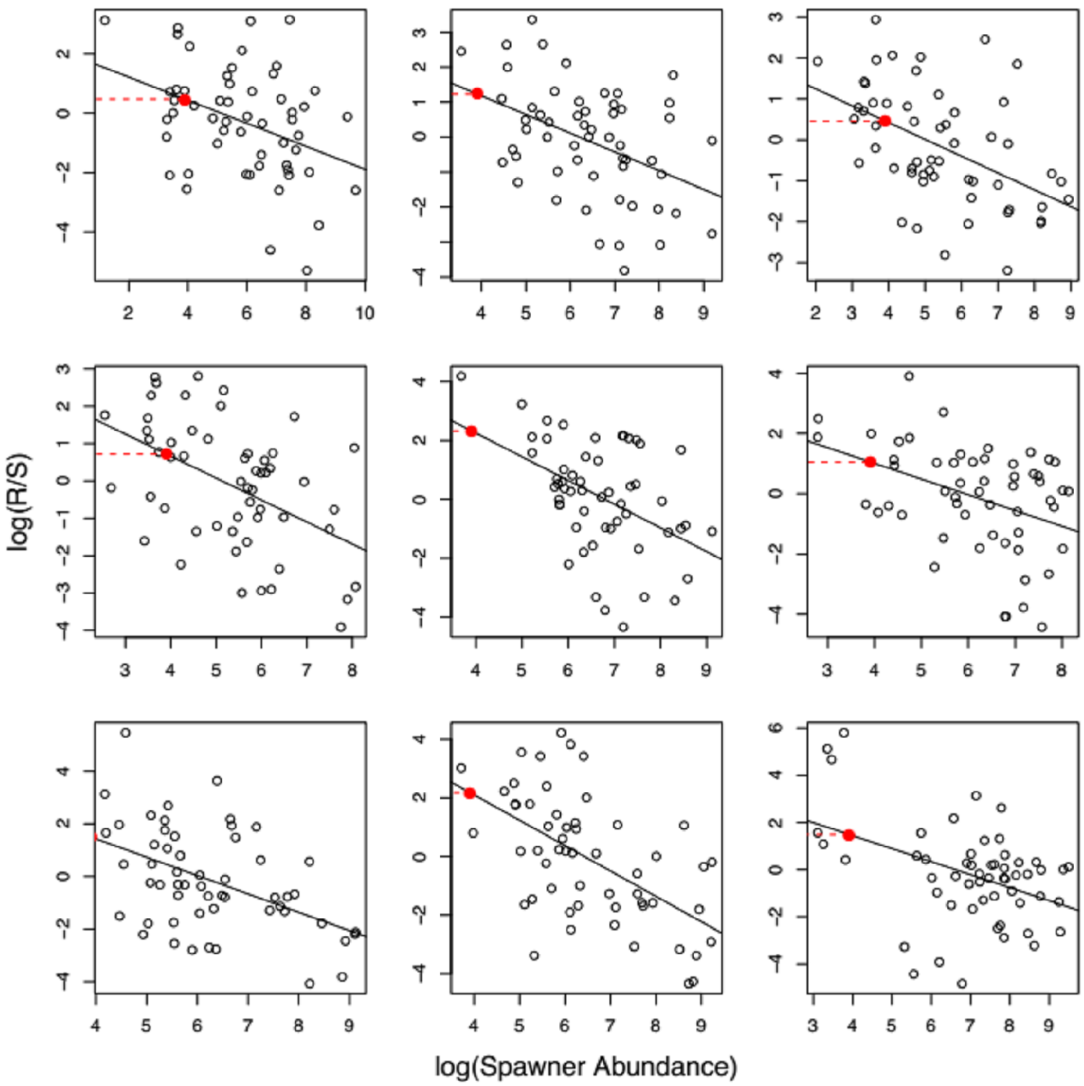

Figure 4. Gompertz model (solid line) fit to nine different runs of the baseline model for Wenatchee River Chinook. Each point represents the relationship between log(R/S) versus log(Spawner Abundance). The red point represents log (R/S) for 50 spawners for each model run.

Abundance: With this measure, we are capturing population abundance at equilibrium. Accordingly, we measured abundance for years 26-50. In keeping with precedent (e.g., Interior Columbia Technical Recovery Team and Zabel, 2007), we calculated the geometric mean of abundance across each run. Geometric mean was used because population abundances tend to have a logarithmic distribution, characterized by peaks in abundance, and the geometric mean down-weights the peaks.

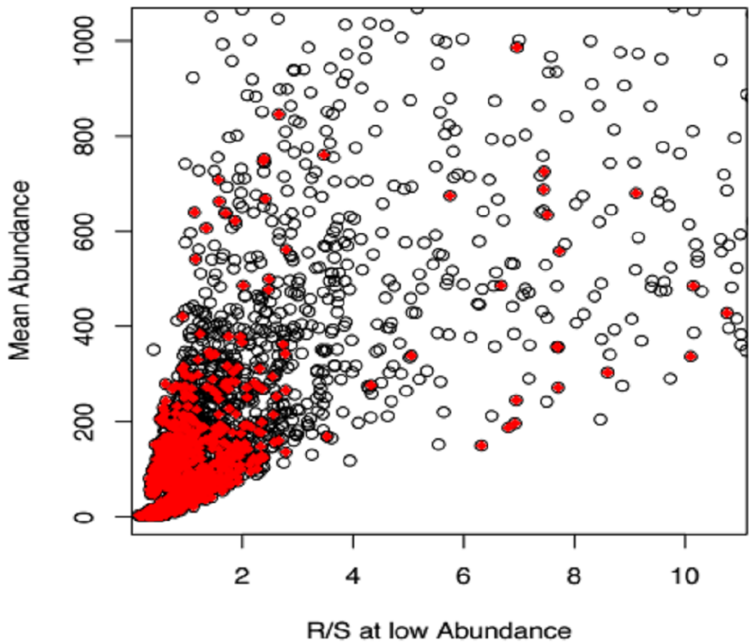

Figure 5. Mean Abundance versus R/S at low Abundance for Wenatchee Spring Chinook. Each point represents results for a single model run, and a range of scenarios are represented in the plot. Red points represent runs where the population fell below the quasi-extinction threshold.

We ran the model across several scenarios (Figure 5) and plotted Mean Abundance versus Productivity.

Consistent with the TRT, we calculated the abundance and productivity VSP score as measure of risk, as defined as probability of following below extinction thresholds. Below we describe the methods to do this.

Probability extinction: We adopted the definition of quasi-extinction that was established by the TRT. P(QET) is the probability of falling below the quasi-extinction threshold (QET) within T years, where $T = 24$. A population is considered to have fallen below the threshold if it drops below the QET threshold, on average per year, over a four-year period. We computed P(QET) for each alternative by compiling the proportion of 1000 runs that fell below the QET threshold. We chose 1000 runs because our estimates of P(QET) stabilized after that number of runs. The quasi-extinction threshold is determined for a population based on its historical size and complexity of subpopulations. We set a QET of 30 or 50 spawners per year.

To generate a response surface, we used logistic regression to relate P(QET) to the Productivity and Abundance metrics, described above. For each of the 500 runs within an alternative, we determined whether the individual run fell below QET. If it did, we designated it as 0 (red points in Figure 5); otherwise it was designated as 1. We did this across all alternatives to create a data file with each line indicting whether the run fell below QET or not, and also the mean Productivity and Abundance for the run. We then performed a logistic regression to develop a response surface for probability of extinction versus Productivity and Abundance using the following equation:

$$logit(Prob(QET)) = P + N$$

where *P* is Productivity and *N* is abundance. Figure 6 demonstrates a response surface based on Wenatchee River spring Chinook.

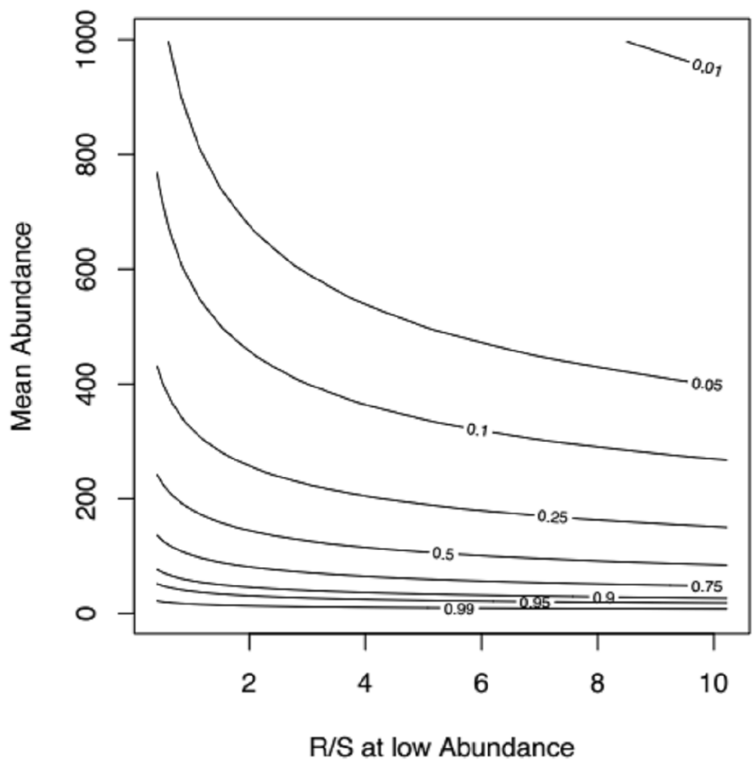

Figure 6. Isoclines of extinction probability on a plot of mean abundance versus mean productivity for the Wenatchee River spring Chinook population.

After we calculated the response surface, we could estimate P(QET) for a single simulation, instead of calculating P(QET) across all simulations. In this way, we could compute the uncertainty around our estimates of P(QET).

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Chapter 2: The COMPASS Model for Assessing Juvenile Salmon Passage through the Hydropower Systems on the Snake and Columbia Rivers

James R. Faulkner, Daniel L. Widener, and Richard W. Zabel

Introduction

The Comprehensive Passage (COMPASS) Model was developed as a tool for investigating the passage experience of migrating juvenile salmon and steelhead under various environmental conditions and management scenarios (Zabel et al. 2008, COMPASS 2008). COMPASS was reviewed by the ISAB in 2008 and has been used to inform a variety of management decisions concerning juvenile salmon since then.

COMPASS contains physical descriptions of the Snake and Columbia Rivers and their main tributaries, which include spatial representations with widths, depths, and elevations to allow volume and velocity calculations. The hydroelectric dams in the system are also represented and algorithms are used to route flow through the set of passage routes unique to the configurations at each dam. This allows dam operations such as spill and surface collector operation to be accounted for on daily or finer time steps.

Flow is input at the river headwaters or at the dams, either as measured observations or as predictions from hydrological models. Other possible environmental inputs include temperature, turbidity, and dissolved gas. COMPASS can also take spill proportions and reservoir elevations as inputs and can take surface weir volumes and operation schedules. Schedules and rates of smolt transportation on barges are also taken as inputs for operation of collector dams.

COMPASS contains a set of biological models we developed for arrival timing at the head of the hydropower system, reservoir migration rate, reservoir survival, dam survival, and dam passage routing for various species. These models were all fitted to observed data and are functions of the set of variables describing environmental conditions and dam operations that are available to COMPASS- including flow, velocity, temperature, and spill. When combined together, these sub-models allow predictions of the passage experience of population releases through the system to Bonneville Dam tailrace.

The model runs on a sub-daily timestep, and uses environmental inputs on a daily level to update the predictions of the sub-models for each timestep. Fish are added at the top segment of the system (head of Lower Granite reservoir for Snake River stocks) according to the arrival timing sub-model. The model then advances sequentially via timesteps, moving the fish downstream using the migration rate sub-model and applying mortality in each timestep according to the reservoir survival sub-model or dam passage sub-models. The final results returned at the completion of a COMPASS model run include the total proportion of fish that survived to Bonneville Dam tailrace and the daily proportion of survivors reaching Bonneville Dam tailrace.

COMPASS also models the smolt transportation program. COMPASS takes the collection start date and separation probability as inputs for each of the three collector dams- Lower Granite, Little Goose, and Lower Monumental dams. After the collection start date, all fish predicted by the dam routing sub-model to enter the juvenile bypass system are potentially subject to transportation. The proportion of fish specified by the separation probability will be returned to the river, but all remaining fish will be transported to the tailrace of Bonneville Dam. COMPASS assumes a uniform travel time of 2 days from the collection date and survival of 0.98 during transportation for all transported fish. For a COMPASS model run with transportation enabled, the results returned by the model include the overall proportion of fish surviving to Bonneville Dam tailrace as well as separate estimates for in-river migrants and transported fish, separate vectors of the daily proportion of surviving in-river migrants and transported fish reaching Bonneville Tailrace, and the overall proportion of fish that were transported. These results are returned to the overarching Lifecycle model and serve as inputs to the smolt-to-adult return rate model and other models.

Here we describe the application of the model to a set of simulated data representing three different management scenarios, and present the results of the COMPASS runs. These scenarios represent different sets of rules for the operation of hydroelectric dams. The first scenario describes a baseline operation that models a continuation of the operational rules used from 2014 through 2017. The second and third scenarios represent two different management rulesets, both of which are part of one overall management program meant to improve conditions for fish passage via increased spill. Because these two scenarios are part of the same program, we also present the averaged results of the two scenarios. We also briefly describe some of the updates that have been done to COMPASS since the publication of the 2008 documentation; a full update of the COMPASS documentation containing detailed descriptions of these changes is planned for completion in 2019.

Methods

Model Updates

Since the most recent documentation of COMPASS (Zabel et al. 2008; COMPASS 2008), we have made several updates to the sub-models and to the general functionality of the COMPASS. The following is a brief list of changes:

- Updated the data used to calibrate the travel time and reservoir survival components of the model to 1998-2017.

- Updated the data for the dam passage routing models (spill efficiency and fish guidance efficiency) to 1998-2017. Also made changes to passage models to better account for observation uncertainty.

- Updated estimates of route-specific survival for dams on the Snake and lower Columbia Rivers. These estimates come from experiments on fish implanted with radio tags or acoustic tags.

- Changed the structure of the reservoir survival models. We use a hierarchical modeling format where random effects for the true unknown survival probabilities follow beta distributions, and the observed survival (Cormack-Jolly-Seber estimates) follow log-normal distributions conditional on the latent random survival effects. This structure allows a more accurate decomposition of the uncertainty.

- Added component to the reservoir survival models that allows predator density and smolt density to affect survival through a functional response. These parameters are still experimental, and the survival models used for the BiOp COMPASS scenarios did not use either of these terms.

- Updated models that predict dissolved gas supersaturation based on flow and spill. This allows us to produce estimates of exposure to supersaturation and even related mortality.

- Updated models that predict water temperature. We expanded previous models to include more explanatory variables (snow pack, air temperature, precipitation, flow from Dworshak Dam), created more complex and flexible model forms, and expanded the range of data used to fit the models (1997-2015).

- Added models for dam passage for the dams on the Upper Columbia River. These models include route specific survival and functions for passage route probabilities. We also have travel time and survival models for fish originating in the Upper Columbia.

- Implemented the ability to use finer time step length in the reservoir passage model (up to 16 per day) to allow more accurate travel time calculations.

- Added new models to predict arrival distributions of smolts at Lower Granite Dam based on quantile regression of observed arrivals for various populations of Snake River-basin Chinook salmon and steelhead.

- Implemented a Monte Carlo sampling process that produces estimates of uncertainty in model outputs for reservoir survival. The process draws new sets of model parameters from their probability distributions based on the estimated model parameters and variance components and their estimated covariance matrices. COMPASS is run once for each set of parameter draws, and this is repeated hundreds to thousands of times, producing distributions of outcomes of interest.

Prospective Modeling

Three management scenarios were investigated. The first scenario, labeled as the Base scenario, represents the configurations and operations of the dams used from 2014 through 2017, including timing of transportation. Two scenarios, labeled Perf-120 and Perf-125, represent adjustments to the spill operations of the Base scenario, where a "flex spill" spill pattern is enabled that varies spill throughout the day. In design, both the Perf-120 and Perf-125 scenarios are planned to have two four-hour blocks of time per day of "Performance Standard" spill, one block in the morning and one block in the evening. This "Performance Standard" spill is roughly equal to the levels of spill in the Base scenario. The remainder of the day outside of these blocks of time will have higher levels of spill, targeting either a 120% TDG (Total Dissolved Gas) gas cap or a 125% TDG gas cap respectively for Perf-120 and Perf-125.

Due to constraints on the length of timesteps used in the COMPASS model (which are 90 minutes long in the current calibrated version), we were unable to exactly reproduce this timing of planned daily spill operations in the Perf-120 and Perf-125 scenarios. Instead of having two 4-hour blocks per day of "Performance Standard" spill, the COMPASS implementation has one 4.5-hour block in the morning and one 3-hour block in the evening, for a total of 7.5 hours per day of spill at the "Performance Standard" level. The other aspects of the management scenarios- flow, temperature, and reservoir elevation- are identical between the three scenarios in all years.

The Bonneville Power Administration (BPA) generated the scenarios using their hydrological model, HYDSIM. This model accurately accounts for power generation and spill and associated hydrology in the hydropower system and outputs daily predictions of flow, spill, and reservoir elevation associated with each dam. This was done for a set of 80 water years representing headwater inputs for the years 1929-2008. These water inputs are applied to the operation rules determined by each scenario by HYDSIM.

We used the daily flow, spill, and reservoir elevation values predicted by the HYDSIM model for the 80 water years for each scenario as inputs to COMPASS.

We constructed models of the arrival distribution at Lower Granite Dam for various populations of wild Snake River Chinook salmon and steelhead. These models are based on data for PIT-tagged wild smolts, and use quantile regression to predict the probability distribution of fish arrival using flow and temperature in Lower Granite reservoir. Separate arrival models were fitted for multiple populations of fish originating in the Grande Ronde River, Imnaha River, and South Fork, Middle Fork, and upper Salmon River. We applied these models to the 80 water years for each scenario, and then combined the predicted arrival distributions for the individual populations into an overall distribution based on the average number of spawners for each population. These predicted population distributions were used as release profiles in COMPASS, where each water year had the same number of fish released.

For upper Columbia River stocks, we constructed an arrival distribution at Rock Island Dam based on observed passage of smolts (hatchery and wild, tagged and untagged). We created a multi-year average of daily proportion of smolts passing Rock Island Dam using data from 1998-2013. We then shifted this arrival distribution earlier based on the average observed travel time of smolts between Wells Dam and Rock Island Dam, and changed the release location to Wells Pool. This predicted distribution was held constant and used as the release distribution for all 80 water years in all scenarios for COMPASS runs with upper Columbia River fish.

We ran the COMPASS model for each of the 80 water years for each scenario. We produced separate results for Snake River spring-summer Chinook and upper Columbia River spring Chinook. We collected several summary measures of passage experience for each year, including in-river survival from Lower

Granite Dam to Bonneville Dam for both in-river migrants, proportion of fish transported, and daily arrival distributions at Bonneville Dam tailrace for both in-river and transported fish. Since there are no collector dams on the Columbia River, no fish from upper Columbia River stocks were transported, and we did not produce any outputs related to transportation for those runs.

We also ran the Monte Carlo version of COMPASS for each scenario to estimate uncertainty in predicted in-river survival. We drew 500 random parameter sets for the reservoir survival sub-model and predicted in-river survival for each scenario with each parameter draw. The full results of all 500 survival estimates were provided to the lifecycle modeling group for use with Monte Carlo runs of the overall lifecycle model.

Results

Here we present results from prospective model runs for all three scenarios (Tables 1, 2). In general, differences between scenarios for the various COMPASS output statistics were smaller than the year-to-year variability within scenarios.

For Snake River spring-summer Chinook salmon, both of the flex spill scenarios had slightly higher in-river survival than the Base scenario, with the 125-Perf scenario having less benefit (Table 1, Figure 1). The average arrival timing at Bonneville Dam showed more change among the scenarios than survival (Table 1). For in-river migrants, the 120-Perf scenario had slightly later arrival timing than the Base scenario, while the 125-Perf scenario averaged more than a full day later average arrival timing than the Base scenario. For transported fish, average arrival timing at Bonneville Dam for both scenarios was more than a full day later than in the Base scenario. For transportation rates, both flex spill scenarios resulted in significant reductions in transportation rates compared to the Base scenario, but the 125-Perf scenario had a significantly lower transportation rate than either the Base or 120-Perf scenarios (Table 1).

For upper Columbia River spring Chinook salmon, there were very small differences in in-river survival between the three scenarios (Table 2, Figure 2). Both the 120-Perf and 125-Perf scenarios had slightly higher in-river survival than the Base scenario, but the difference was very small (Table 2). Mean arrival day at Bonneville Dam showed more differences among the three scenarios. The 120-Perf scenario had the earliest mean arrival timing and was about half a day earlier than the Base scenario. The 125-Perf scenario also had earlier arrival timing than the Base scenario, but the difference was smaller than that for the 120-Perf scenario (Table 2).

We produced 500 Monte Carlo estimates of survival for each of the 80 water years in each of the three scenarios (Figures 3-5). Uncertainty in COMPASS survival varied by year, but generally the 95% confidence band extended around ten percentage points in survival about the deterministic estimate.

Table 1. Mean COMPASS statistics predicted for Snake River spring Chinook salmon for the three management scenarios.

Scenario	Mean Inriver Survival	Mean Day at BON (inriver)	Mean Day at BON (transport)	Proportion Transported
Base	0.5754	132.40	134.80	0.3244
120-Perf	0.5824	132.72	135.80	0.2432
125-Perf	0.5816	133.48	136.21	0.1697

Table 2. Mean COMPASS statistics predicted for upper Columbia River spring Chinook for the three management scenarios.

Scenario	Mean Inriver Survival	Mean Day at BON (inriver)
Base	0.5127	150.19
BlockA	0.5191	149.73
Spillblocks	0.5165	149.90

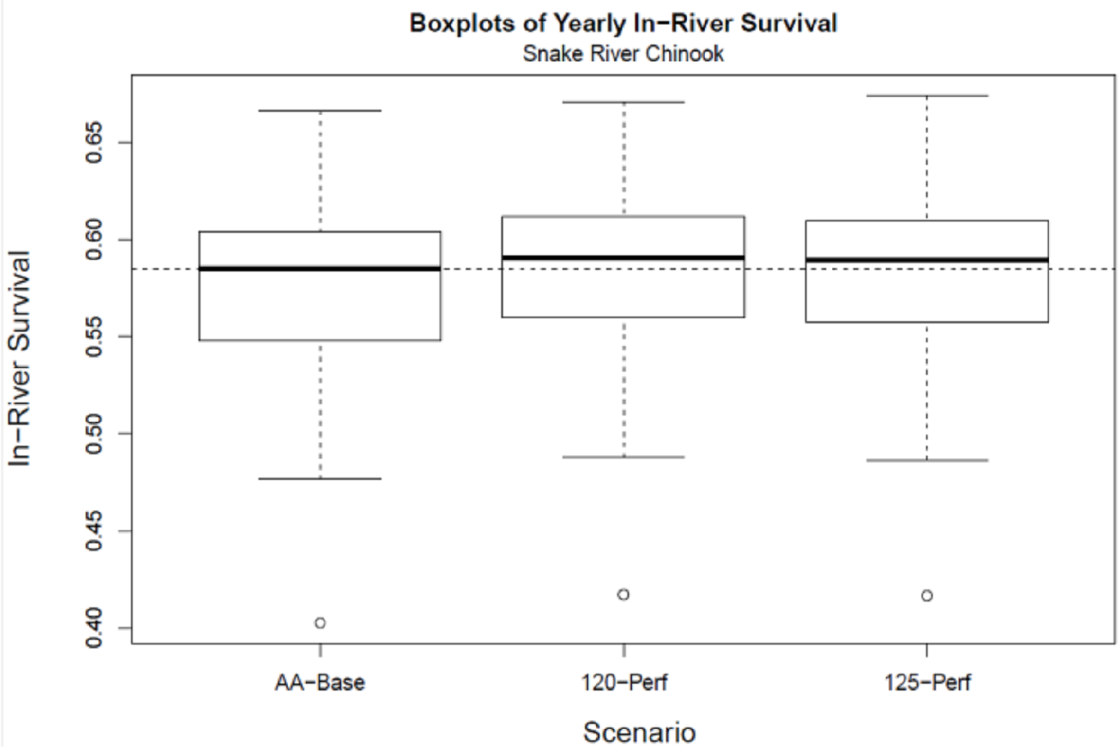

Figure 1. Boxplots of COMPASS predicted in-river survival for Snake River spring Chinook salmon by management scenario.

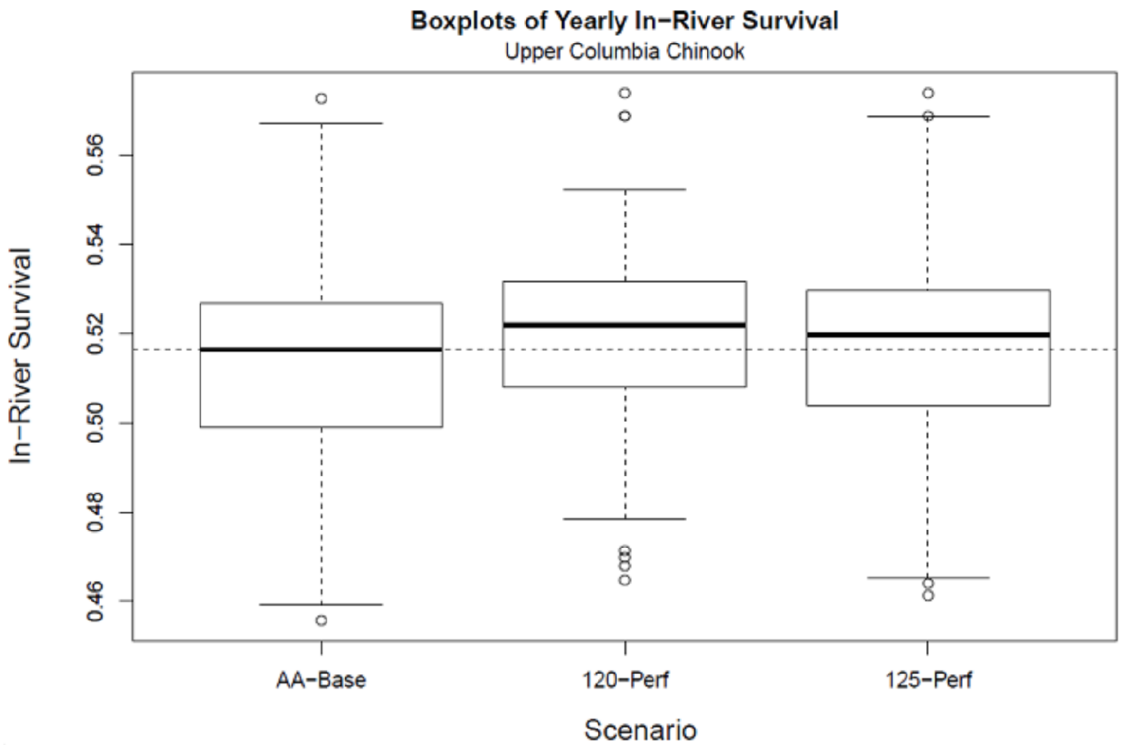

Figure 2. Boxplots of COMPASS predicted in-river survival for upper Columbia River spring Chinook salmon by management scenario.

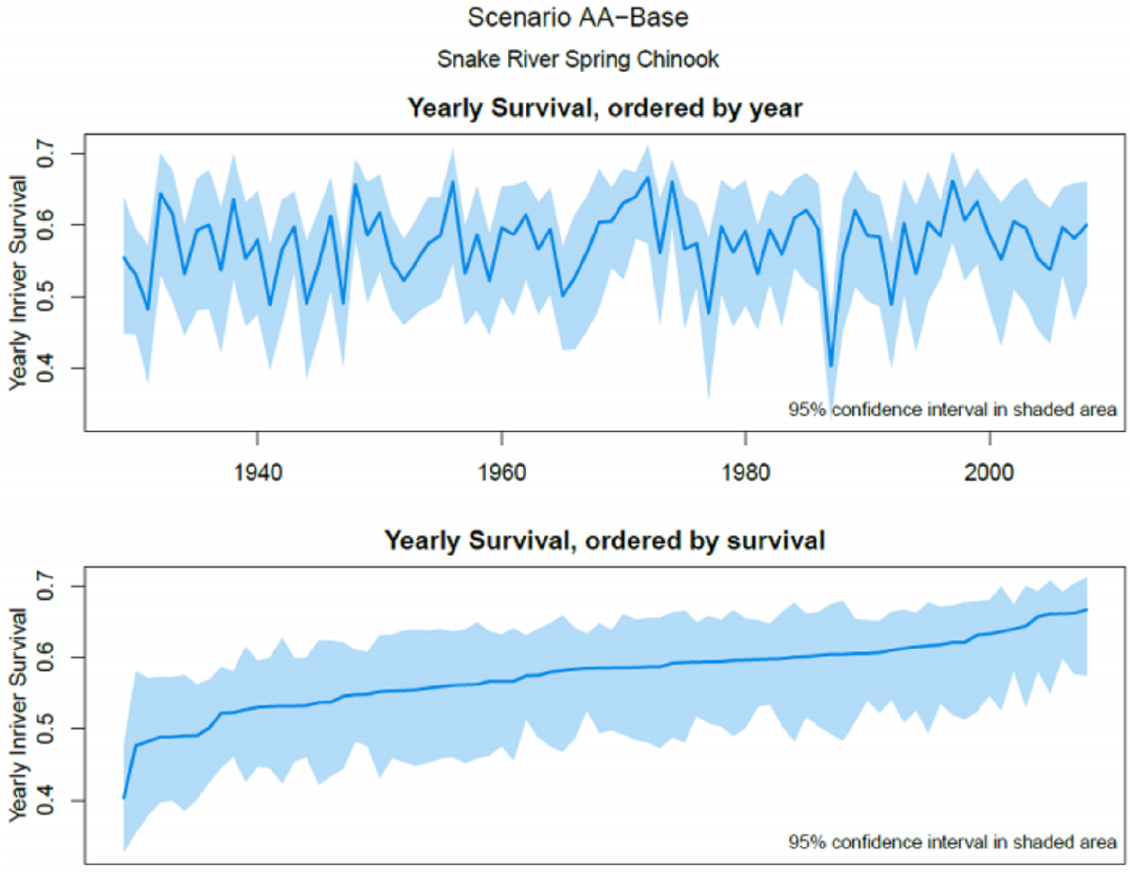

Figure 3. Results of the 500 Monte Carlo runs for the Base scenario for Snake River spring Chinook salmon. The top panel shows predicted survival across the 80 water years, with the dark blue line in the center the deterministic survival estimate for that year and the shaded band containing 95% of the resulting Monte Carlo survival estimates using random survival parameter draws for that year. The bottom panel shows the same data, but with the years re-ordered by the deterministic survival estimate.

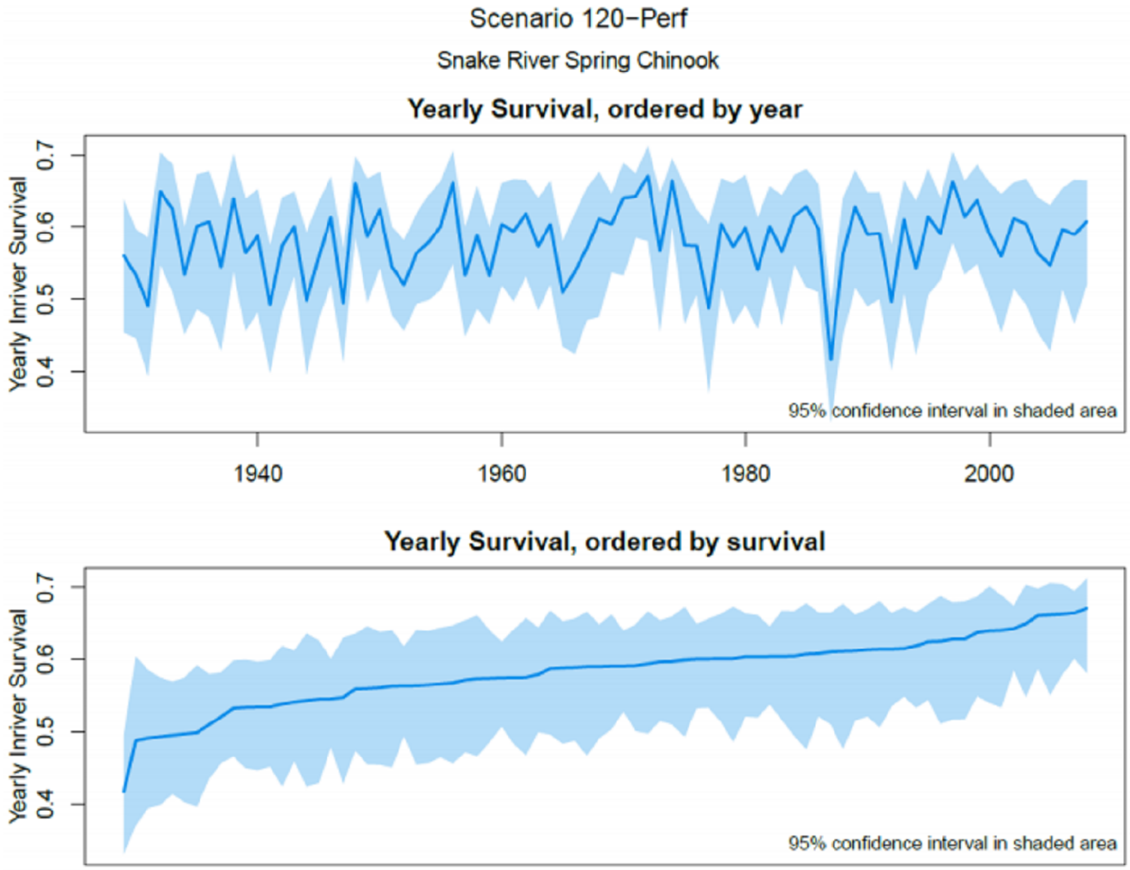

Figure 4. Results of the 500 Monte Carlo runs for the 120-Perf scenario for Snake River spring Chinook salmon. The top panel shows predicted survival across the 80 water years, with the dark blue line in the center the deterministic survival estimate for that year and the shaded band containing 95% of the resulting Monte Carlo survival estimates using random survival parameter draws for that year. The bottom panel shows the same data, but with the years re-ordered by the deterministic survival estimate.

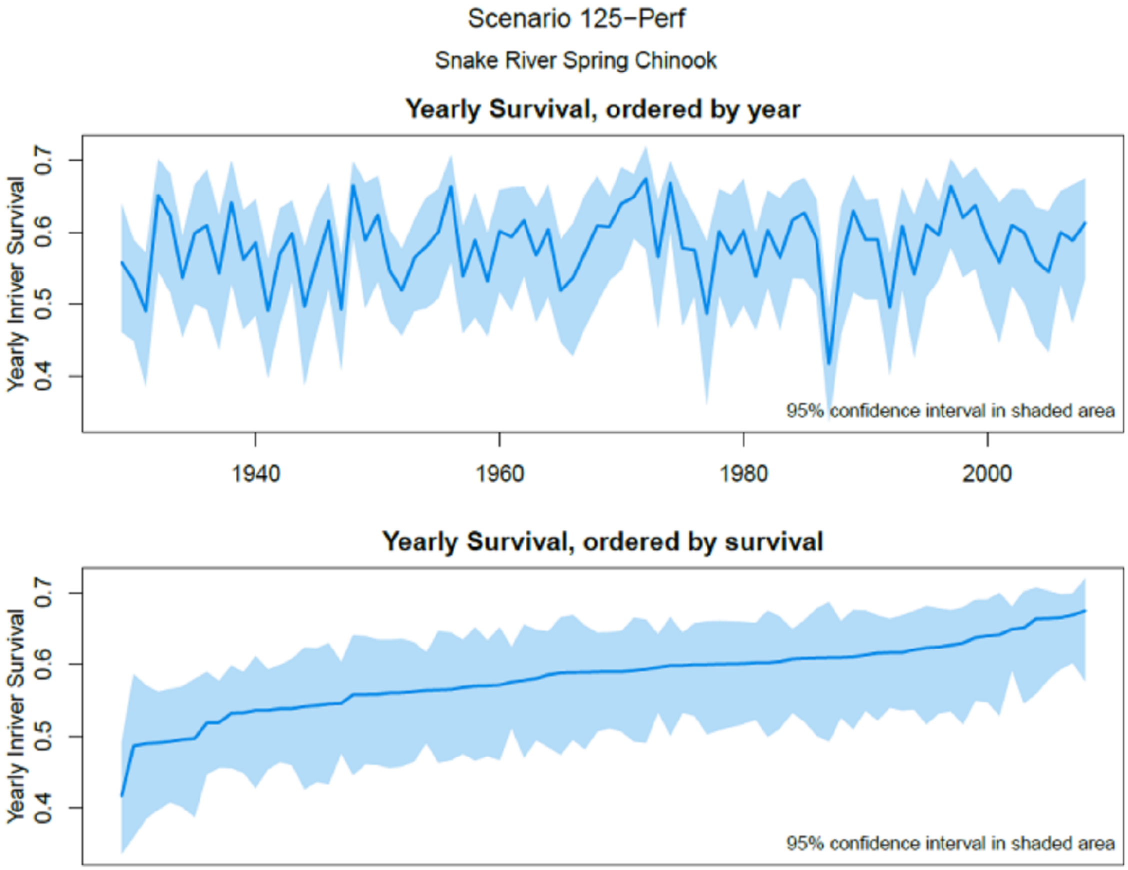

Figure 5. Results of the 500 Monte Carlo runs for the 125-Perf scenario for Snake River spring Chinook salmon. The top panel shows predicted survival across the 80 water years, with the dark blue line in the center the deterministic survival estimate for that year and the shaded band containing 95% of the resulting Monte Carlo survival estimates using random survival parameter draws for that year. The bottom panel shows the same data, but with the years re-ordered by the deterministic survival estimate.

Discussion

The results from the COMPASS runs show that the 120-Perf and 125-Perf scenarios, which had increased spill over the Base case, had increases in in-river survival, but the differences were small. The reason for the small size of the impact on survival is primarily because the only difference between the various scenarios is in spill, and spill is not a predictor in any of the calibrated reservoir survival sub-models. Spill does affect survival at dams by changing passage route proportions, but the impact will generally be small because most routes have comparable survival, and the proportional change in fish passage is not large between the high spill rates in the Base scenario and the higher rates in the 120-Perf and 125-Perf scenarios. Most of the predicted differences in in-river survival are a secondary effect of differences in predicted reservoir migration rates. The reservoir migration rate sub-model does respond directly to changes in spill, with higher spill resulting in faster predicted migration rates. Thus, the higher levels of spill in the 120-Perf and 125-Perf scenarios lead to increased migration rates, which in turn reduced exposure in the reservoir mortality sub-model and increased survival relative to the Base scenario.

However, it is not obvious that the 120-Perf and 125-Perf scenarios had higher migration rates on average than the Base scenario by examining the average arrival timing at Bonneville Dam. In fact, in both flex spill scenarios mean arrival day at Bonneville Dam is later than in the Base scenario (Table 1). This unintuitive result is produced by changes in the transportation rate. The increased levels of spill in the 120-Perf and 125-Perf scenarios substantially reduce the proportion of fish entering the bypass system at collector dams when transportation is active, and both scenarios are predicted to have much lower transportation rates than the Base scenario. This results in more late-season fish passing the hydrosystem in-river rather than by barge. These additional late-season migrants cause the average in-river arrival timing to be later in the season, despite the fact that the average migration rate is faster than in the Base scenario.

The end result is that changes in arrival timing at Bonnevile Dam are more pronounced between these scenarios than changes in survival. The arrival distributions predicted by COMPASS are inputs to the smolt-to-adult return rate model in the lifecycle model where earlier arrival results in higher predicted return rate. The resulting changes in smolt-to-adult return rate stemming from changes in arrival timing will certainly be more consequential to the overall lifecycle than the changes in hydrosystem survival predicted by COMPASS.

For upper Columbia River Chinook salmon, the complicated relationship between transportation and arrival timing does not apply, since none of these fish are transported. Instead, the results for the upper Columbia COMPASS runs showed that both the 120-Perf and 125-Perf scenarios had consistently higher survival and earlier arrival timing than the Base scenario. However, the differences were very small. This is mostly because the bulk of the migration pathway for these fish passes through dams on the mid-Columbia River; because these dams are not federally owned, they were not part of the prospective management program in the scenarios tested and operations at these dams remained fixed at the same values for all scenarios. Instead, upper Columbia origin fish only experienced the changes on increased spill in the 120-Perf and 125-Perf scenarios in the reach of the Columbia River from McNary Dam to Bonneville Dam.

It is also interesting to note that, for Upper Columbia fish, the improvement in survival and the change in arrival timing are smaller relative to the base for the 125-Perf scenario than for the 120-Perf scenario, despite the fact that the 125-Perf scenario is targeting a higher gas cap and thus ostensibly has higher overall levels of spill. This result occurred because the 125-Perf scenario allocates spill between dams differently than the 120-Perf scenario. The 125-Perf scenario has much higher levels of spill at all Snake River dams than the 120-Perf scenario, but it actually has lower levels of spill than the 120-Perf scenario does at John Day Dam and The Dalles Dam. Because Upper Columbia fish pass only the lower Columbia River dams, the lack of increases to spill at those two dams results in less overall benefit under the 125-Perf scenario than under the 120-Perf scenario.

We did not attempt to account for the negative effects of increased spill related to increased production of saturated gas and possible trauma induced by passage through highly turbulent spillways. Spill level and pattern can also create eddies in the tailraces of some dams depending on flow and turbine operations. Fish trapped in eddies are more vulnerable to predation and are subject to longer travel times. Such conditions are not modeled in COMPASS and effects on survival are not explicitly accounted for.

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Chapter 3: Effect of population-specific migration timing on salmon survival through an estuary with increasing pinniped abundance

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Abstract

The recovery and range expansion of predators is causing increased conflicts with conservation efforts for at-risk prey, requiring new tools to incorporate species interactions in recovery plans. As a tool to assess the effect of predator recovery on population viability, we estimated the proportional decrease in survival of populations of adult Chinook salmon (*Oncorhynchus tshawytscha*) through the lower Columbia River migration corridor in 2013–2015, years with higher pinniped abundance, relative to years with baseline pinniped abundance (2010–2012). Population-specific timing of when salmon return to the mouth of the river was needed to estimate survival because it can influence exposure to pinniped predation and other sources of mortality that vary seasonally. The earliest migrating populations experienced a 16.8% reduction in en route survival on average in 2013–2015 relative to the 2010–2012 period, whereas intermediate-migrating populations averaged an 8.3% reduction, and survival of late-migrating populations decreased by 1.2 % between these periods. These results highlight that migration timing was a significant factor in determining decreased en route mortality of distinct populations that was associated with increased pinniped abundance. The decrease in survival that coincided with increased pinniped abundance has been incorporated into life-cycle models to assess the effect on extinction risk and inform management.

Introduction

While the recovery of top predators can help restore balance in ecosystems and has cultural benefits, it can also lead to conservation and legal challenges when predation rates on depleted or protected prey populations increase (Marshall et al. 2016). Assessing and managing conflicts between threatened prey and recovering and expanding predators, which are often afforded legal protections of their own, is challenging because their interactions are often complex ecologically and their management is socio-politically charged (Berger 2006; Roman et al. 2015). Climate change and anthropogenic disturbances are likely to accelerate the frequency and impacts of these conflicts by altering the distribution of predators and the resiliency of prey populations (Baum and Worm 2009; Rahel et al. 2008). Information about complex and dynamic predator-prey interactions will therefore be needed to inform conservation decision-making and management (Carey et al. 2012; Schneider 2001).

Pinniped abundance and their consumption of Chinook salmon have increased over the past 40 years in the eastern Pacific Ocean (Chasco et al. 2017). Within the lower Columbia River (LCR) specifically, harbor seals (*Phoca vitulina*), Steller sea lions (*Eumatopias jubatus*), and California sea lions (*Zalophus californianus*) consume returning adult Chinook salmon. Following the passage of the Marine Mammal Protection Act in 1972, the abundance of harbor seals and Stellar sea lions have steadily increased in the LCR (Brown et al. 2005; Jeffries et al. 2003; Pitcher et al. 2007). California sea lions were rare in the LCR prior to the 1980's, but have been seasonal occupants in spring and fall since then (Maniscalco et al. 2004; Service 1997). In spring 2013, the abundance of California sea lions hauled out in the LCR near Astoria (Figure 1) increased four fold relative to levels observed during the previous decade and continued to increase through 2015. Additionally, the abundance of Harbor Seals in the LCR increased roughly three fold in 2015 (Chasco et al. 2017).

Survival rates of adult Chinook salmon en route between Astoria (rKm 44) and Bonneville Dam (rKm 234) between 2010 and 2015 were found to be negatively associated with counts of sea lions in the LCR and to be greater for later migrating fish (Rub et al. 2019). Earlier migrating fish overlap with more pinnipeds, because California sea lions depart from the river mouth during the end of the spring-summer Chinook salmon migration to breed in June–July. Other factors contributing to greater survival later in the season may include the availability of alternative prey for pinnipeds and shorter travel times of salmon.

Because different populations of Chinook salmon arrive in the river at different times, we deduced that they had different survival rates to Bonneville Dam (Keefer et al. 2004; Keefer et al. 2012). We expected that the decrease in survival associated with increased pinniped abundance in 2013–2015 likely affected earlier-migrating populations to a greater degree.

Our objective was to estimate the degree to which population-specific Chinook salmon survival rates through the LCR declined in 2013–2015 as a function of migration timing and pinniped abundance. We estimated the percent decline in survival rates of populations between the 2010–2012 period when sea lion abundance was like that observed during the decade prior, and the 2013–2015 period of heightened sea lion abundance.

Methods

Study Area

We analyzed observation of survival and migration timing of spring-summer Chinook salmon through the LCR between Astoria and Bonneville Dam (Figure 1). The LCR is tidally influenced with brackish waters at Astoria and nearly fresh water at Bonneville Dam.

Our analysis focused on evaluating pinniped predation on populations of spring Chinook from the Upper Columbia River Evolutionarily Significant Unit (ESU) listed as Endangered under the Endangered Species Act (ESA) and populations of spring-summer Chinook salmon from the Snake River ESU, which are Threatened (Figure 1). The spring run of adult Chinook salmon begins to enter the LCR in late winter. By June, the spring run has concluded and the adult Chinook passing Astoria belong to summer-run populations.

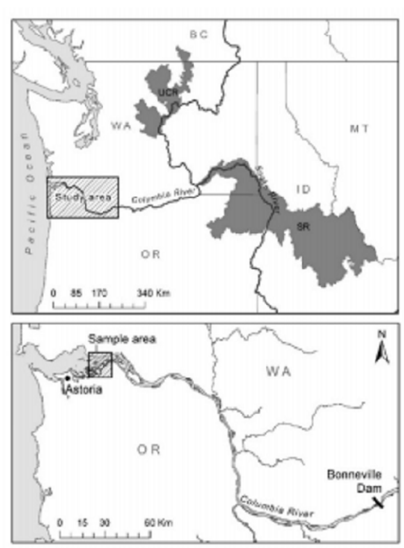

Figure 1. Study area in the lower Columbia River where survival and migration timing were estimated and shaded boundaries of the spawning and natal rearing areas for the Upper Columbia River (UCR) and Snake River (SR) Evolutionarily Significant Units of Chinook Salmon.

Data

This analysis integrated two previously-developed data sets to estimate the percent change in population-specific mortality between years with high pinniped abundance and baseline abundance. The first dataset came from adult spring-summer Chinook from unknown populations captured near the city of Astoria and implanted with passive integrated transponder (PIT) tags (Figure 1). We used detections of those fish that survived to ascend fish ladders at Bonneville Dam to estimate survival and transit time through the study area (Rub et al. 2019). The fish in this study were identified by genetic analysis as belonging to one of three Evolutionarily Significant Units of Chinook salmon that spawn upstream of Bonneville Dam, but could not be identified to individual populations of origin. The second data set was of detections of fish PIT-tagged as juveniles in their natal basin that survived to return from the ocean to pass Bonneville Dam as adults. These fish could be identified to individual populations of origin based on where they were tagged as juveniles, and we used this dataset to characterize the distinct migration timing of different populations. We conducted all analysis and created all figures using the statistical software program R version 3.4.3 (R Core Team 2017).

Models

We used these datasets to construct the following three linear models. 1) Survival probability of fish from unknown populations between Astoria and Bonneville Dam as a function of ecological variables corresponding with date of release. 2) Travel time between Astoria and Bonneville Dam of fish from unknown populations based on ecological variables corresponding with date passing Bonneville Dam, and 3) population- and year-specific passage timing at Bonneville Dam.

Survival probability.– The numbers of adult chinook z with adipose-fin clip status c that were released near Astoria on day a and year y that were also detected passing Bonneville Dam were assumed to be binomially distributed,

$$z_{a,y,c} \sim Binomial(\eta_{a,y,c}, s_{a,y,c}), \qquad (1)$$

where η is the number of fish released and s is the joint probability of survival and detection at Bonneville Dam. Detection efficiency of fish passing Bonneville Dam is near 100%, so all undetected fish were assumed to have died between Astoria and Bonneville Dam (Rub et al. 2019). The probability of surviving to pass Bonneville was modeled on the logit scale,

$$logit\ (s_{a,y,c}) = \alpha + \beta_1 CSL_{a,y} + \beta_2 temp_{a,y} + \ \beta_3 c \qquad (2)$$

as a function of the log-transformed 7-day average count of California sea lions in Astoria *CSL* beginning on the day that a fish was released, and the log-transformed 7-day mean river temperature *temp* beginning on the day that a fish was released. We included a categorical variable c indicating whether a fish was marked with an adipose-fin clip to identify it as hatchery origin and therefore eligible for harvest in the recreational fishery. Sea lion abundance was negatively associated with survival, and water temperature was positively associated with survival. Being marked with an adipose fin clip was negatively associated with survival.

Travel time.– The number of days between when a fish was released near Astoria and detected at Bonneville Dam (*tt*; travel time) for fish that survived (n = 899) was modeled on the log scale

$$\log(tt_{b,y}) = \alpha + \ \beta_1 temp_{b,y} + \beta_2 spill_{b,y} + \ \beta_3 b + \ \varepsilon\ ; \ \ \varepsilon \sim N(0,\sigma^2) \qquad (3)$$

as a function of the mean water temperature (°C) *temp* over 40 days prior to when a fish passed Bonneville Dam; mean spill (kcfs) *spill* over 30 days prior to the date that a fish passed Bonneville Dam (Columbia Basin Research 2016); and the day of year that a fish passed Bonneville Dam *b*. Higher spill volumes were associated with longer travel times, while higher temperatures were associated with shorter travel times. Julian date of Bonneville Dam passage had a relatively weak positive relationship with travel times.

Population-specific Bonneville Dam passage timing. – The day *b* that a fish from a population *p* passed Bonneville Dam in a particular year *y* was assumed to be normally distributed on the log scale. We fit a year-invariant mean and variance parameter for each population's day of passage to capture migration-timing behavior evolved to conditions in a population's distinct migration and spawning habitats. We fit population-invariant year effects to capture the effect of environmental conditions on passage timing that are experienced by all populations in the ocean and Lower Columbia River.

$$\log(\boldsymbol{b}_{p,y}) = \boldsymbol{\beta}_p \boldsymbol{P} + \boldsymbol{\beta}_y \boldsymbol{Y} + \varepsilon_p;\ \varepsilon_p \sim N(0, \boldsymbol{\sigma_p}^2), \qquad (4)$$

where $\boldsymbol{\beta}_p$ and $\boldsymbol{\beta}_y$ are vectors of population- and year-specific regression coefficient, $\boldsymbol{P}$ and $\boldsymbol{Y}$ are design matrices of dummy variables for population and year, and $\boldsymbol{\sigma_p}^2$ is a vector of population-specific residual variances. The model was fit using generalized least squares with the *gls* function in the 'nmle' package (Pinheiro et al. 2015) because it allows estimation of heterogeneous variances among populations.

Population-specific survival. – We needed to estimate the timing of individual populations passing Astoria each year to align with the estimates of survival as a function of Astoria-release date. To do so, we calculated the joint probability of each combination of Astoria-arrival date and Bonneville-passage date,

$$\begin{array}{cc} & \textit{Bonneville Day} \\ \textit{Astoria Day} & \begin{bmatrix} b_1 tt_{0,1} & b_2 tt_{1,2} & b_3 tt_{2,3} & \cdots & b_n tt_{n-1,n} \\ 0 & b_2 tt_{0,2} & b_3 tt_{1,2} & \cdots & b_n tt_{n-2,n} \\ 0 & 0 & b_3 tt_{0,3} & \cdots & b_n tt_{n-3,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & b_n tt_{0,n} \end{bmatrix}, \end{array}$$

where b_i is the probability of a fish passing Bonneville Dam on the day i of the study (based on equation 4), and $tt_{i,j}$ is the probability of a fish having a travel time of i days given that it passed Bonneville Dam on day j of the study. n is the number of possible Bonnevile-passage days . The proportion of the population that passed Astoria on each day of the year a was calculated by marginalizing the day passing Bonneville (summing each row) and normalizing the resulting vector to sum to 1.

The survival s for each population by year combination was calculated as the average across all days passing Astoria (restricted to 20 March – 14 June) weighted by the proportion of fish that passed Astoria on each day,

$$s_{p,y} = \sum_a s_{a,y} * p(a_{p,y}) \qquad (5)$$

To represent pinniped-associated mortality, we calculated the average survival over the years prior to the increase in California sea lions (2010–2012) and years with greater sea lion abundance (2013–2015) and calculated the percent change in survival between the two groups of years.

We characterized model parameter uncertainty and generated distributions of pinniped-associated mortality by bootstrapping the data sets and refitting each of the three models 5,000 times. For each iteration, the models were refit to random samples of the original data sets, drawn with replacement, of the same size of the original data sets, and population-and year-specific survival probabilities and pinniped-associated mortality were recalculated for each iteration.

Results

Average survival rates of early-migrating populations declined substantially in 2013–2015 relative to 2010–2012, coincident with the increase in sea lion abundance, whereas survival of intermediate-migrating populations declined less, and late-migrating populations experienced similar survival (Figure 2). Survival of the earliest arriving of the populations examined—Yankee Fork, Lemhi River, Sulphur Creek, Marsh Creek, Upper Grande Ronde, Catherine Creek, Tucannon River, and Methow River—was on average 16.8% lower in 2013–2015 than in 2010–2012. The Upper Salmon River, East Fork Salmon River, Valley Creek, Big Creek, Camas Creek, Loon Creek, Bear Valley Creek, Minam River, Entiat River, and Wenatchee River populations, which had intermediate run timing, experienced survival rates that were 8.3% lower on average in 2013–2015. The late-arriving populations—Pahsimeroi River, Chamberlain Creek, Upper South Fork Salmon River, East Fork South Fork Salmon River, Secesh River, Imnaha River, and Lostine River—most of which are considered summer-run, averaged 1.2% lower survival in 2013–2015 than 2010–2012.

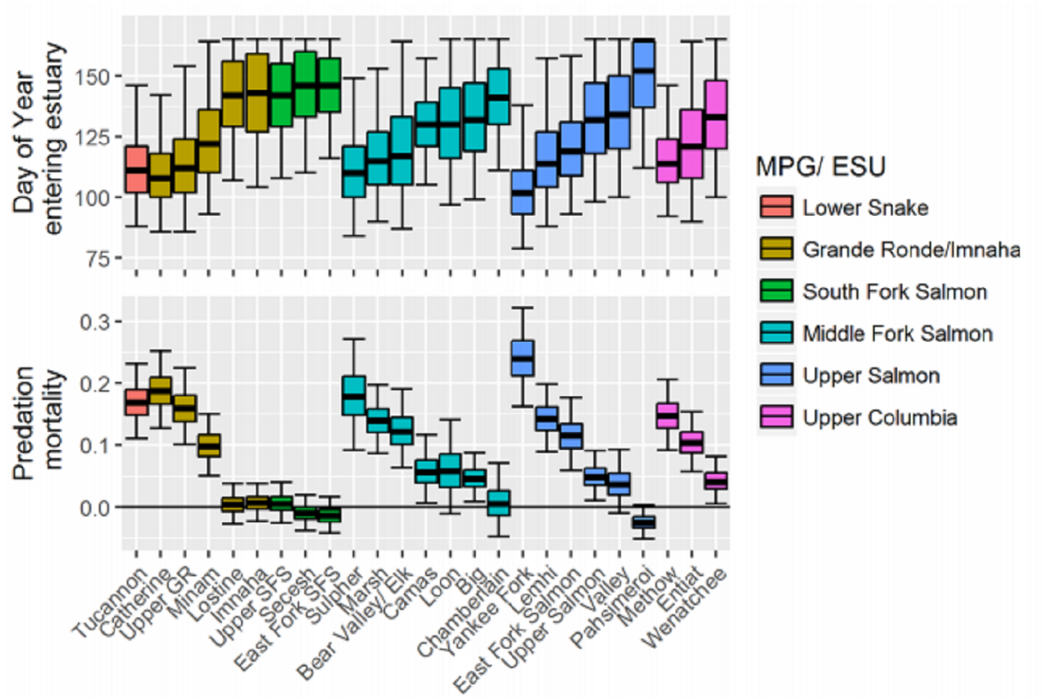

Figure 2. *Top panel*: Population-specific timing arriving at Astoria, where boxes represent the range when 50% of a population passed and the whiskers span when 95% of the population passed Astoria. *Bottom panel*: The proportional decline in population-specific average survival between years with baseline pinniped abundance (2010–2012) and high pinniped abundance (2013–2015), assumed to represent the increase in pinniped-predation mortality between the groups of years. Boxes span interquartile range and whiskers span 95% confidence interval.

There was considerable variability among populations in estuary-entry timing, including within individual MPGs (Figure 2). For example, within the Grande Ronde MPG, the Upper Grande Ronde and Catherine Creek populations migrated earlier than the Lostine River population. Furthermore, some spring-run populations, such as the Lostine River, had relatively late migration timing that was closer to summer-run populations.

However, summer-run populations did have considerably later migration timings on average than spring-run populations.

Discussion

En route survival between arriving in the estuary and passing Bonneville Dam declined considerably for early-migrating populations of spring Chinook salmon in 2013–2015, relative to a baseline period of 2010–2012. The primary change between 2010–2012 and 2013–2015 in the LCR, that explained the decrease in survival between year groups, was the number of pinnipeds present. Counts of California sea lions at their primary haul out were relatively constant from 2000 to 2012 but were four to ten times greater from 2013 through 2015, and harbor seal abundance increased by a factor of three in 2015 (Chasco et al 2017). High returns of Eulachon (*Thaleichthys pacificus*) in 2013–2015 may have caused more pinnipeds to forage in the LCR. Anomalously warm sea surface temperatures in the Northeast Pacific Ocean in 2013–2015 could have effected both the condition of salmon returning to the river, and the distribution and diet composition of pinnipeds in the California Current (Cavole et al. 2016).

California sea lions are generally more abundant earlier in the season which explained some of the trend of increasing survival as the run progressed (Rub et al. 2019). There was an additional positive relationship between water temperature and survival in our model, which was supported by the data, but has no obvious mechanistic explanation. Temperature increased steadily with the day of the year in all years, so several seasonal factors that affected survival may have been correlated with temperature. Chinook salmon that passed Astoria later and experienced warmer temperatures exhibited faster swimming speeds and shorter travel times, which reduced their overall time of exposure to predators and other mortality mechanisms. Per capita predation rates of sea lions on Chinook salmon may have declined as the season progressed if the predators began consuming more American shad *(Aloso sapidissima)*, which arrive during the tail end of the spring Chinook run. Additionally, more of the sea lions counted in Astoria later in the season may have been simply passing through en route to their breeding grounds as opposed to feeding within the river.

Our quantitative estimates of estuarine mortality are being used in population models to evaluate the effects of increasing pinniped abundance on the viability of at-risk prey populations and evaluate management actions to offset or reduce the effects. The life-cycle models can be used to assess and compare the benefits of restoring estuarine survival to baseline levels as opposed to or in combination with other actions that restore rearing habitat, increase migration survival, reduce predation on juvenile salmon by non-native fish, and reduce harvest (Kareiva et al. 2000). These modeling approaches can simulate all such alternatives within a common framework to find the optimal solution for all the species involved.

We were able to quantify the percent change in estuarine survival for individual populations coinciding with an increase in pinniped abundance in the LCR, however, our understanding of the predator-prey interaction is limited. Investigation of the seasonal diet composition of pinnipeds residing within the Columbia River are still needed to better understand their relative reliance on adult salmonids and alternative prey. Scat analysis and bioenergetics modeling is currently underway for California sea lions in the LCR. There is virtually no information on the seasonal abundance and distribution of harbor seals and Steller sea lions in the LCR, which would help to determine the degree to which they are affecting salmon survival rates. These types of data, combined with information on prey abundance and distribution, can help characterize the functional and numerical response of pinnipeds to the abundance of salmon and other prey within the Columbia River and the coastal ocean (e.g.

Middlemas et al. 2006). Additionally, injuries and stress from pinniped attacks may have affected subsequent survival of fish that successfully passed upstream of Bonneville Dam, which could be evaluated and considered in conservation planning (Naughton et al. 2011).

The recovery and range expansion of predators are causing conflicts between environmental laws, and dilemmas for managers with increasing frequency (Marshall et al. 2016; Roman et al. 2015). It will require new tools to navigate these troubled waters, and enact policy that leads to functioning ecosystems where both predator and prey populations are viable (Ritchie et al. 2012; Soulé et al. 2003). These tools will be more effective if they incorporate information on the many aspects of predator-prey interactions and population models (Lovari et al. 2009). Accounting for major factors such as the variable spatiotemporal overlap between migrating predators and prey populations, as we have done here, is an example of how modeling can improve estimates of predation rates to inform recovery plans.

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Chapter 4. Smolt to Adult Returns

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Using PIT-tag data

Relative to the freshwater life stage, the ocean life stage has been modeled at a much coarser resolution in many salmon life cycle models. This chapter describes an ongoing effort to utilize new data from passive integrated transponder (PIT) tags to apply more statistical rigor to characterizations of this life stage. We revised the analytical approach to take advantage of these data, to account for correlations in the factors that affect survival in different life stages, and to better account for uncertainty in the modeling process.

In previous efforts (Zabel et al. 2006), the ocean component of the life cycle was evaluated using S_3 (third-year survival or first year in the ocean) data as the response variable. This value was back-calculated from SAR (smolt to adult survival), which was based on juvenile and adult counts at Lower Granite Dam. Using this approach, SAR had to be adjusted to account for downstream and upstream in-river survival, age composition, harvest and 2nd and 3rd year survival in the ocean. Adjustments also had to be made to account for the proportion of the run at Lower Granite Dam that were transported and between hatchery and wild fish. This approach was taken out of necessity, as no other data were available to directly represent the ocean component of salmon life cycle.

More recently, the time series of ocean survival based on PIT tag data is long enough that we can more directly and more accurately model this component of the salmonid life cycle. We explicitly model each migration component separately (downstream, estuary/ocean, and upstream). Therefore, no in-river survival adjustments are necessary and resulting estimates of ocean survival are independent of estimates of downstream and upstream in-river survival.

Data sources

PIT-tag data were assembled by Columbia Basin Research (CBR) via PTAGIS for outmigration years 2000 through 2014. These data went through a rigorous set of algorithms to determine whether data were from juveniles or adults and from transported or in-river migrants. Additionally, data files include 1) last detection date at Bonneville Dam as juveniles, 2) rear type (hatchery or wild), and 3) whether fish survived back to the river. For survivors, the file also included the number of years fish spent in the ocean and the date and location of the first adult detection at one of the mainstem Columbia River dams. Updates to these files will be posted each year on the CBR website (http://www.cbr.washington.edu/).

Given that over 90% of the PIT tagged juveniles detected at Bonneville Dam are hatchery fish, it would be worth including them in survival analyses – if they survive at similar rates and respond to the environment similarly to wild fish. Unfortunately, a simple comparison between hatchery and wild fish survival (for in-river fish only) shows that wild fish can survive at rates anywhere from 0.5 to 2.5 times those of hatchery fish. The interannual variability in this relationship makes it difficult to account for it in models without adding a lot of model complexity. Therefore, all results included here are for wild fish only.

Similarly, if transported fish had a constant survival relationship with in-river fish, we could include them in the analysis, accounting for them with a model offset. The ratio of transport to in-river survival has been studied extensively (Anderson et al. 2012). As found in other analyses, this ratio is not constant in these data and complicates the addition of transported fish into ocean survival models. We included all transported fish in these analyses, but modeled them separately from the in-river fish, allowing covariate effects for both groups to be evaluated independently.

General modeling approach

We divide the ocean/estuary component of the SAR estimation into retrospective and prospective analyses. With a mixed-effect model, the retrospective analysis disaggregates the sources of annual variation in SAR associated with random year effects and fixed environmental forces. With the parameters of the retrospective model, the prospective analysis estimates SAR under future climate scenarios. Using AIC (Akaike 1975), the future climate scenarios only include environmental forces from the retrospective analysis that provide statistically better fits to the observed SAR data. The estuary/ocean component of this tech memo maintains the logical differences between the retrospective and prospective analyses in separate sections.

Retrospective analysis

We used a mixed-effects logistic regression model to quantify the effect of the date of ocean entry and environmental covariates on the probability that an individual fish would return as an adult to Bonneville Dam, which was a binomial response. We explored both linear and quadratic effects of migration start date based on previous work (Scheuerell et al. 2009, Holsman et al. 2012) and initial data exploration. Moreover, the importance of timing can shift from year to year. We therefore allowed the effect of Julian date in the model to vary among years by treating it as a random effect (each year's coefficient is assumed to come from a common normal distribution of potential coefficient values). As the random component of mixed-effects models must be specified prior to model selection on the fixed effects (Zuur et al. 2009), we initially compared models with a linear random effect of date to models with a quadratic random effect. Over several model designs, the linear random effect of Julian date was better supported by the data. However, during initial model selection exercises, the squared term for Julian date was supported in the fixed-effects component of the model. Therefore, we chose a null model with a quadratic effect in the fixed-effects term and a linear effect in the random effects term. This model structure allowed the effect of Julian date to be quadratic, with each year having a slightly different impact, similar to that described empirically in (Scheuerell et al. 2009).

Historical SAR

To this base model, we added environmental covariates to try and describe the remaining interannual variability. We obtained covariate data from a variety of sources, including variables representing large-scale oceanographic patterns as well as regional and local physical and biological metrics (Fig. 5.1). Although not all variables will have a direct mechanistic relationship with salmon survival, these variables occupy many locations along the continuum of being easily accessible vs. being mechanistic.

We use a logistic model to describe the historical relationship between SAR, migration timing, and environmental covariates,

$$s_{retro}(i,d,t) = \frac{1}{1+\exp(\eta(i,d,t))},$$

$$\eta(i,d,t) = \boldsymbol{\beta}^{env}(i)\mathbf{x}^{env}_{retro}(t) + \beta^{day}(i) \times d + \beta^{day^2}(i) \times d^2 + \alpha(i,t)$$

Where, $s_{retro}(i,d,t)$, is the predicted survival for smolts migrating on day *d* during year *t* and *i* is an index defining whether the smolts migrated in-river or were transported by barge, $\boldsymbol{\beta}^{env}(i)$ is a vector of parameters relating survival of migration type *i* in year *t* to the vector of environmental covariates year *t* ($\mathbf{x}^{env}_{retro}(t)$), $\alpha(i,t)$ is the random effect for year *t*, and $\beta^{day}(i)$ and $\beta^{day^2}(i)$ are the parameters relating the migration of the *i*th individuals on day *d*. We use the generalized linear mixed effect model package in R (**glmer**), with a binomial link to estimate the parameters of the model,

$$L\left(s_{retro}(i,d,t)\middle|n(i,d,t),k(i,d,t)\right)$$
$$= \int_{\alpha} Binomial\left(s_{retro}(i,d,t)|n(i,d,t),k(i,d,t)\right) \times Normal\left(\alpha(i,t),\sigma_{\alpha}(i)\right)d\alpha$$

Where, $n(i,d,t)$ is the observed SAR for smolts of migration type *i* on day *d* in year *t*, *n*(i,*d*,*t*) is the number of PIT tagged smolts of migration type *i* on day *d* during year *t*, and $k(i,d,t)$ is the number of smolts of migration type *i* on day *d* in year *t* that survived in the ocean and were detected in the hydrosystem. The random effect for migration type *i* in year *t*, $\alpha(i,t)$, is normally distributed with mean zero and a standard deviation of $\sigma_{\alpha}(i)$.

The top two models, as determined by AIC, include combinations of three variables, two of which are measures of sea surface temperature (SST): SST along a broad arc of coastline from the equator to Alaska in winter (referred to as SSTarc.win) and SST along the Washington and Oregon coasts in summer (SST.sum). The first model included SST.sum and ersstArc.win and the second model included SST.sum and coastal upwelling index in the spring (cui.spr) (Fig. 4-1).

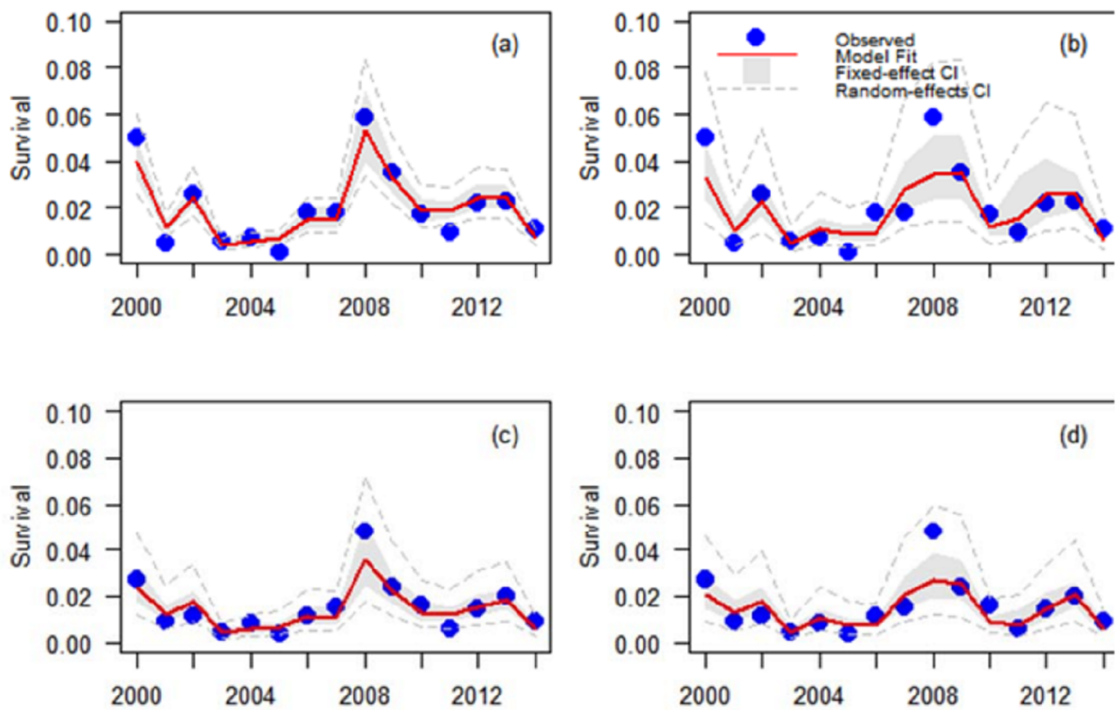

Figure 4.1. Model fits (solid red lines) to the observed PIT tag survival data (blue dots) for the in-river (top row) and transport fish (bottom row) with summer sea-surface temperature (left column) and coastal upwelling index (right column) as predictor variables. Models for survival of both the in-river and transport fish include an intercept, julian, julian2, year as a random effect, and the winter sea-surface temperature (ersstArc.win) for a region of the North Pacific where Chinook salmon are known to rear.

Historical covariance of environmental forces

We initially considered 58 potential environmental covariates for marine survival, based on previous work (Table 1; Burke et al. 2013). Although a principal component of all environmental variation is the strongest single predictor, such a variable is not useful in scenario projections because it makes too strong an assumption about the future correlation structure of the environment. Many of these environmental factors are strongly correlated with each other, so we compared the AIC of all univariate models to eliminate all covariates that did not improve the AIC by at least 1 unit. We then compared all two covariate models that had a pairwise correlation between the two correlates of less than 0.7.

When simulating environmental scenarios for prospective modeling (see next section), we aimed to maintain the statistical properties (i.e., variance, autoregression) of the ecological data driving survival in the various life stages. However, another critical aspect of these data is the covariance across environmental drivers. Large-scale oceanic and atmospheric drivers impact both the marine and the freshwater environments, such that a good or bad year in one environment correlates with a good or bad year in other environments.

Computationally, it is easier to analyze the covariance of the environmental data if it is all on the same scale. Even if we rescale the variables, there still may be a trend in the environmental data that we do not want to use when projecting the SAR. Figure 4.2 demonstrates time-series for each variable. While the environmental variable ersst.Arc has a mean of zero, other variables such as the summertime temperatures for parr is between 10 and 16 degrees C, or Snake River flow at Lower Granite Dam has a mean of 90,000 cubic meters per second. Additionally, the short time-series for many of the variables results in a positive or negative trend. Detrending and scaling all of the environmental variables, as shown in Figure 4.3, improves the estimability of the covariance matrix for the time-series of observations.

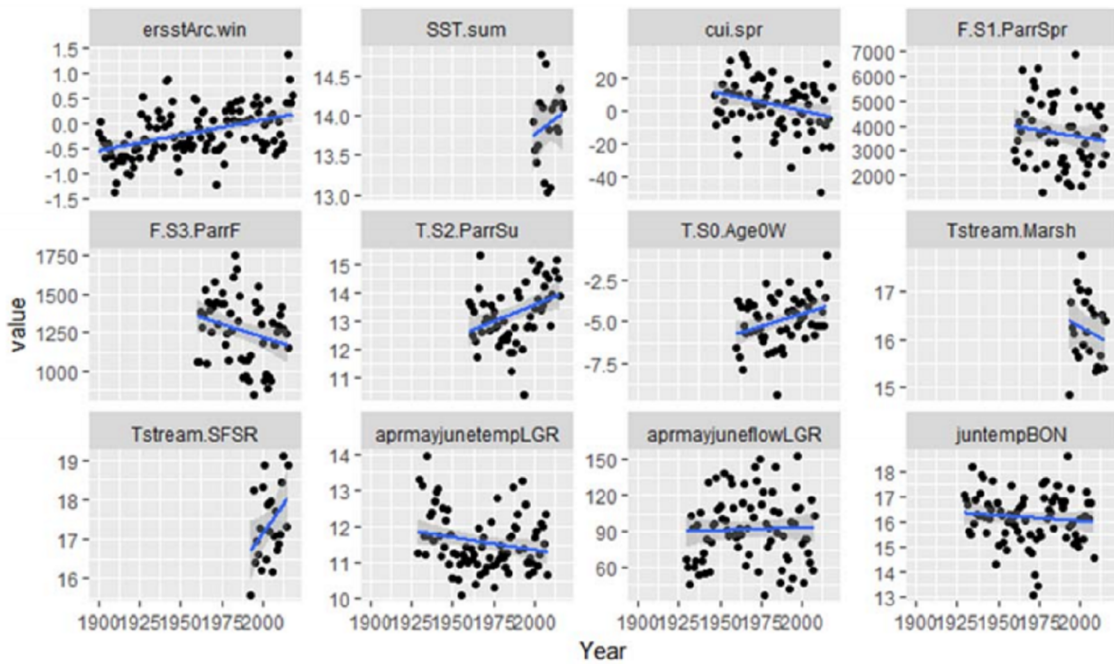

Figure 4.2. The 'raw' data for each freshwater and marine time-series. Notice the differences in the y-axis scales.

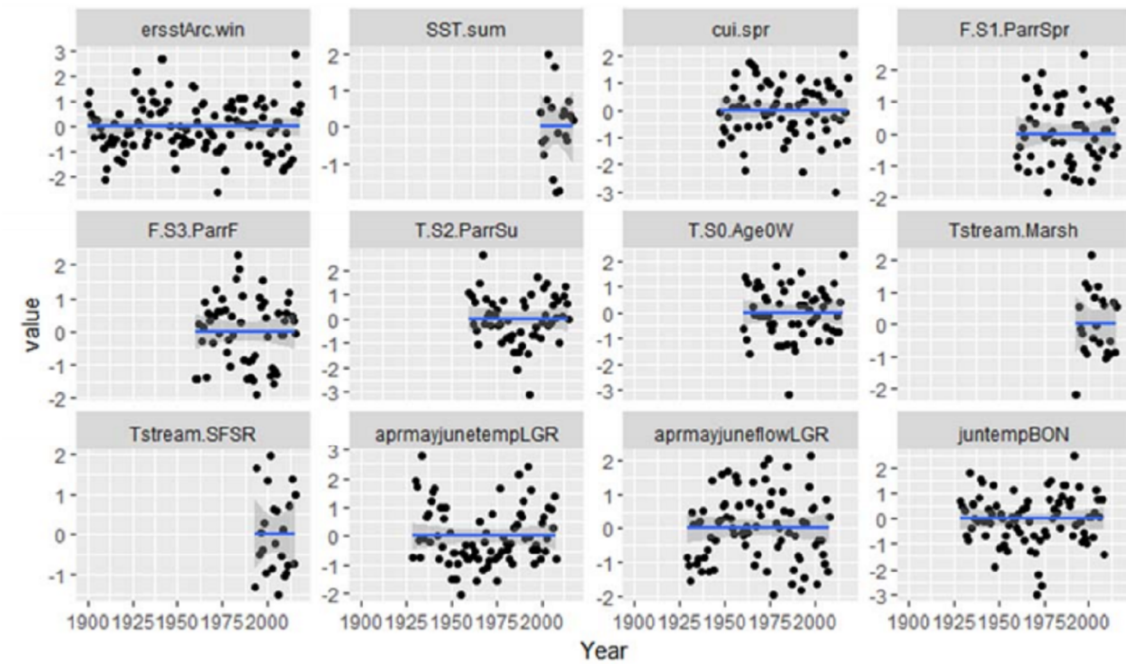

Figure 4.3. Detrended and scaled variables environmental variables.

We estimated variances and covariances of the freshwater covariates (air temperature, summer stream temperature at Marsh Creek and the South Fork Salmon River, Columbia River temperature at Bonneville Dam, fall and spring flow at Salmon, Idaho) and ocean covariates (upwelling, cui.spr; summer sea surface temperature, SST.sum; and sea surface temperature in the arc of the North Pacific, ersstArc.win, Figure 4.4). Using just the process equation, this is the same as estimating an autoregressive process (AR1) with mean reversion.

$$x_t = b \cdot x_{t-1} + w \qquad [5.1]$$

where x_t is a vector of the environmental data at time t, b is a vector that represents the strength of the mean reversion for each covariate, and w is multivariate normal (0, Q). Here, the diagonal elements of Q are the estimated variances of the individual time series and the off-diagonal elements are the covariances among environmental time series (Figure 4.5).

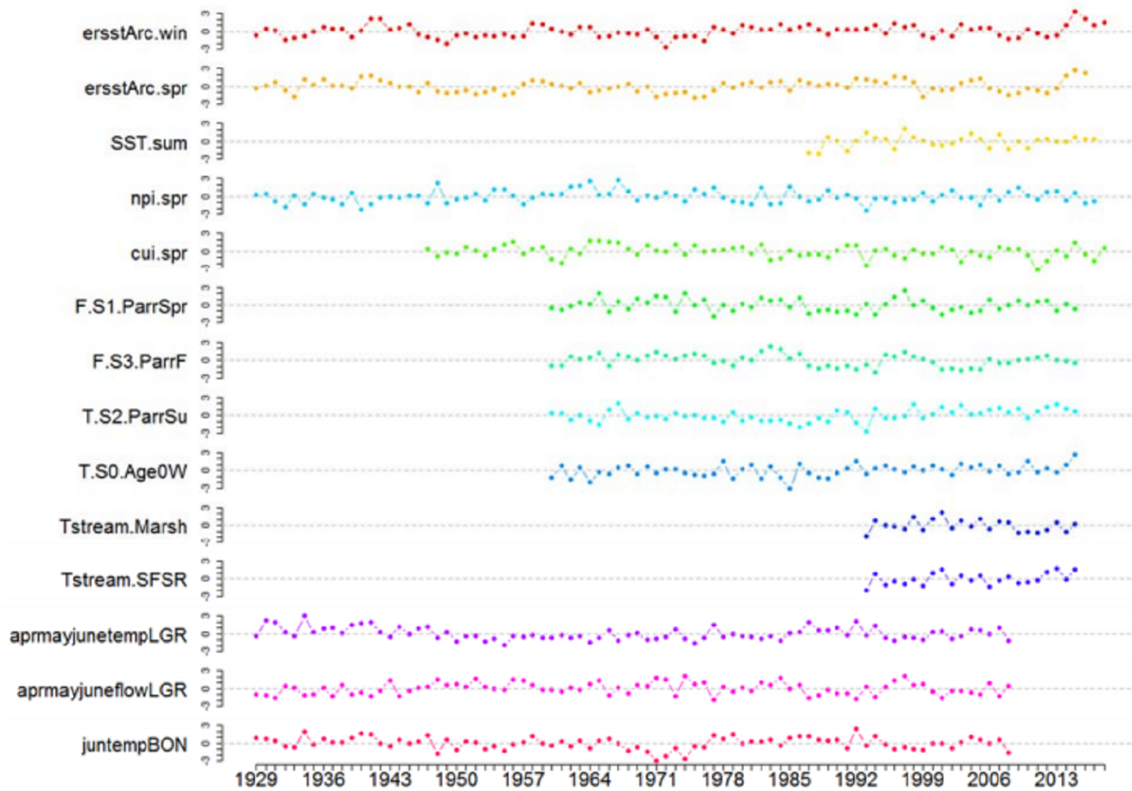

Figure 4.4 Detrended and scaled (Z score) time series of environmental data for both freshwater and marine habitats.

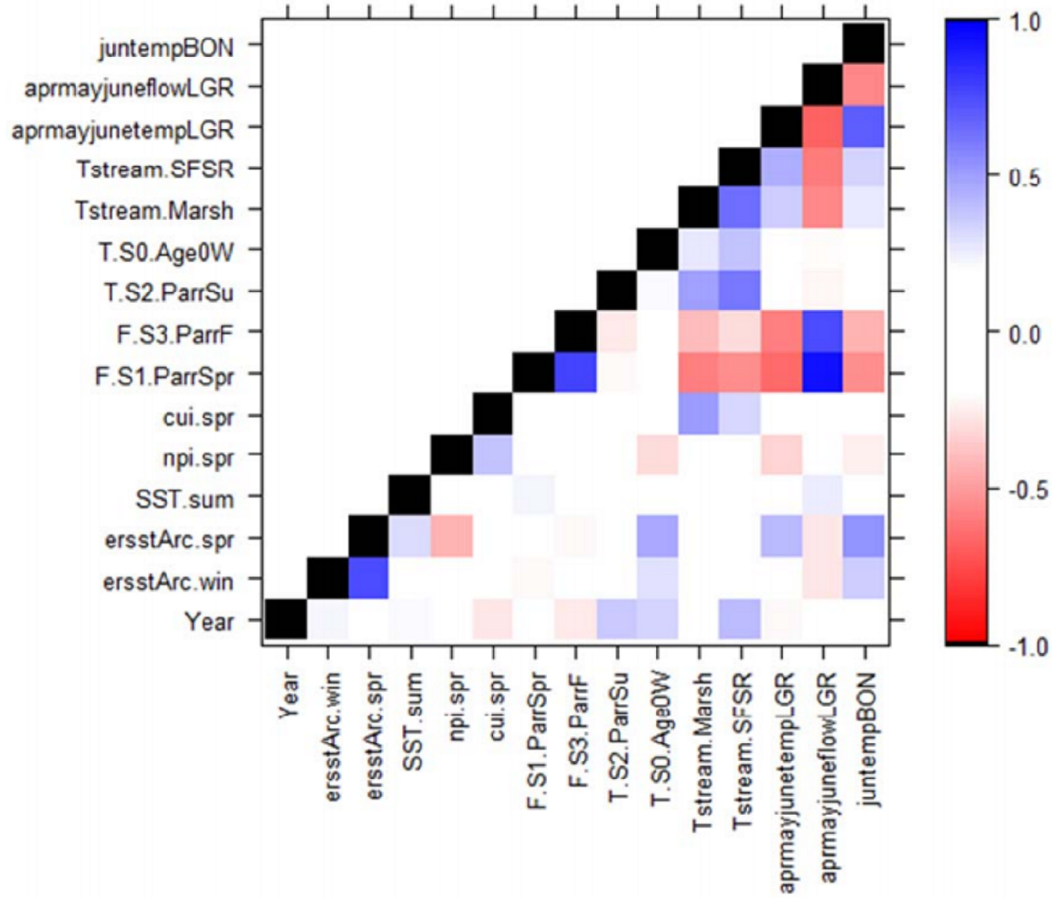

Figure 4.5 Cross-correlation among marine and freshwater environmental variables.

Prospective analysis

Future climate scenarios

Based on preliminary analyses, we found that annual deviations of specific environmental conditions and the time of ocean entry can significantly affect ocean survival. To project future SAR or estimate SAR under various management scenarios, we must account for these temporal effects that occur at two different scales - between years and within a year. Our initial analysis projected 500 future climate scenarios for 100 years and assumed no change in the environmental conditions - SST.sum, cui.spr, and ersstArc.win - that were found to affect SAR. That is, the mean for deviates of the ecological conditions is zero, and the covariance of the environmental variables was equal to Q based on the retrospective analysis.

Projected migration timing

Arrival timing was modeled using COMPASS, as described in Chapter 2. The number of fish that arrived each day were input into the SAR model. We used MARSS to simulate the order in which COMPASS years would be input into the simulation by including the temperature and flow at Lower Granite Dam, which maps onto the COMPASS time series. Then the MARSS simulations for these variables were associated with the most similar conditions modeled in COMPASS using quantile mapping.

Projected SAR

The projected SAR for any given simulation *j* during projection year *t* for migration type *i* is a product of the linear mixed-effects model using the estimated parameters for the observed PIT tag data ($\boldsymbol{\beta}^{env}(i), \beta^{day}(i), \beta^{day^2}(i)$), the observed environmental data, and the probability of migration on day *d*. The projected environmental conditions, $\mathbf{x}^{env}_{projected}(t)$ are 500 simulations of environmental variables using the estimated covariance matrix from the variance/covariance AR1 analysis. Estimated SAR for each day of the year were averaged, weighting by the number of juvenile salmon passing Bonneville Dam each day (output from the COMPASS model),

$$s_{projected}(i,j,t) = \sum_d \frac{1}{1+\exp(\eta(i,d,t))} w_d,$$

$$\eta(i,d,t) = \boldsymbol{\beta}^{env}(i)\mathbf{x}^{env}_{projected}(t) + \beta^{day}(i) \times d + \beta^{day^2}(i) \times d^2 + \alpha(i,t)$$

This analysis was applied separately for in-river and transported fish. However, both put the majority of model weight into a model based on two measures of sea surface temperature: SSTarc.win and SST.sum. Additional variables that were important in the top models were biological indices such as ichthyoplankton biomass and the northern copepod index, and other physical indices (SSTarc in spring, the North Pacific Index, and upwelling in spring). For this effort, we focused on the subset of top models for which we could reasonably forecast conditions several decades into the future, eliminating all of the biological models, which would be too difficult to project that far into the future. This limited the analyses to two models, one with SSTarc.win and SST.sum and one with SSTarc.win and CUI.spr (Table 5.2). A summary of the weighted SAR for a given migration type and projection year is shown in Figure 4.6. The uncertainty in the SAR estimates for a single hydro scenario assuming stable climate conditions and historical arrival timing through the dams for in-river migrants is considerable. The wide confidence intervals for the 500 simulations is reflective of the high variance of individual realizations (Figure 4.6, green line).

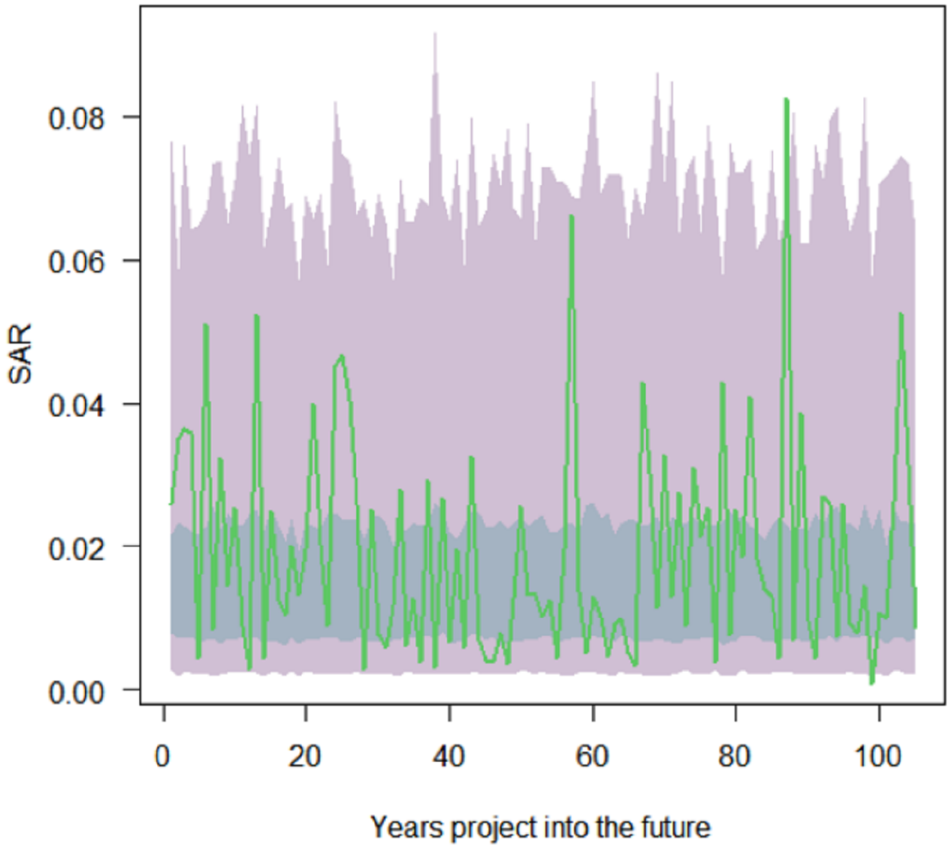

Figure 4.6. The 50% (blue) and 95% (purple) simulation intervals for the 500 SAR projections based on stationary climate and average smolt migration timing. The green line is a single realization for a projection. The output reflects projections for in-river migrants based on ersstArc.win and SST.sum environmental conditions.

Table 5.1. Potential environmental covariate data and sources tested in the marine survival model.

Variable	Description	Years Available	URL / Source
CRflow.spr **CRflow.sum**	[A]Seasonal Columbia River flow as measured near Bonneville Dam	1978-present	http://waterservices.usgs.gov/rest/DV-Service.html
CRtemp.spr **CRtemp.sum**	[A]Seasonal Columbia River temperatures at Bonneville Dam	1997-present	http://waterservices.usgs.gov/rest/DV-Service.html
cui.win **cui.spr** **cui.sum** **cui.aut**	[B]Seasonal coastal upwelling index	1946-present	http://www.pfeg.noaa.gov/products/PFELData/upwell/monthly/upanoms.mon
mei.win **mei.spr** **mei.sum** **mei.aut**	[B]Seasonal Multivariate ENSO Index	1950-present	http://www.esrl.noaa.gov/psd/enso/mei/table.html
npgo.win **npgo.spr** **npgo.sum** **npgo.aut**	[B]Seasonal North Pacific Gyre Oscillation	1950-present	http://www.o3d.org/npgo/npgo.php
npi.win **npi.spr** **npi.sum** **npi.aut**	[B]Seasonal North Pacific Index (index of Aleutian Low Pressure)	1899-present	https://climatedataguide.ucar.edu/sites/default/files/npindex_monthly.txt
oni.win **oni.spr** **oni.sum** **oni.aut**	[B]Seasonal Oceanic Niño Index	1950-present	http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml
pdo.win **pdo.spr** **pdo.sum** **pdo.aut**	[B]Seasonal Pacific Decadal Oscillation	1900-present	http://jisao.washington.edu/pdo/PDO.latest
sst.win **sst.spr** **sst.sum** **sst.aut**	[B]Seasonal coastal sea surface temperature, averaged over buoys (LAPW1, 46211, 46041, 46029, 46050)	1991-present	https://www.ndbc.noaa.gov/
sstarc.win **sstarc.spr** **sstarc.sum** **sstarc.aut**	[B]Seasonal sea surface temperature from Johnstone and Mantua (2014)	1900-2016	https://www1.ncdc.noaa.gov/pub/data/cmb/ersst/v5/netcdf/

UppTempWin[C]	Mean temperature in the upper 20m at station NH05 from Nov-May	1998-present	www.nwfsc.noaa.gov/oceanconditions
UppTempSum[C]	Mean temperature in the upper 20m at station NH05 from May-Sep	1998-present	www.nwfsc.noaa.gov/oceanconditions
DeepTemp[C]	Mean temperature at 50m at station NH05 from May-Sep	1998-present	www.nwfsc.noaa.gov/oceanconditions
DeepSalinity[C]	Mean salinity at 50m at station NH05 from May-Sep	1998-present	www.nwfsc.noaa.gov/oceanconditions
CopRichness[C]	Copepod species richness at station NH05	1998-present	www.nwfsc.noaa.gov/oceanconditions
NCopBiomass[C]	Biomass of northern species of copepods at station NH05	1998-present	www.nwfsc.noaa.gov/oceanconditions
SCopBiomass[C]	Biomass of southern species of copepods at station NH05	1998-present	www.nwfsc.noaa.gov/oceanconditions
BioTrans[C]	Biomass of southern species of copepods at station NH05	1998-present	www.nwfsc.noaa.gov/oceanconditions
IchthyoBio[C]	Biomass of ichthyoplankton collected across the Newport Hydrographic Line (Jan-Mar)	1998-present	www.nwfsc.noaa.gov/oceanconditions
IchthyoComp[C]	Species composition of ichthyoplankton collected across the Newport Hydrographic Line (Jan-Mar)	1998-present	www.nwfsc.noaa.gov/oceanconditions

A Seasonal Indices represent the average of daily values, spr=Mar-May, sum=Jun-Aug

B Seasonal Indices represent the average of daily values, win=Dec-Feb, spr=Mar-May, sum=Jun-Aug, aut=Sep-Nov

C NWFSC sampling

Table 5.2 Top seven models of marine survival for in-river fish (top) and transported fish (bottom).

	(Intercept)	julian	julian2	ersstArc.win	ersstWAcoast.spr	ersstWAcoast.sum	IchthyoBio	IchthyoComp	npi.spr	SST.sum	df	AICc	delta	weight
Mod1	-3.88	-0.24	-0.05	-0.61						-0.31	6	5669.16	0	0.69
Mod2	-3.91	-0.22	-0.05	-0.53				-0.26			6	5673.6	4.44	0.07
Mod3	-3.89	-0.23	-0.05	-0.52		-0.25					6	5674.01	4.86	0.06
Mod4	-3.87	-0.24	-0.05		-0.43		0.41				6	5674.16	5.01	0.06
Mod5	-3.88	-0.23	-0.05	-0.48			0.24				6	5674.35	5.19	0.05
Mod6	-3.91	-0.22	-0.05	-0.55					0.19		6	5675.23	6.07	0.03
Mod7	-3.91	-0.22	-0.05	-0.63							5	5675.28	6.12	0.03

	(Intercept)	julian	julian2	cui.spr	ersstArc.spr	ersstArc.win	ersstWAcoast.spr	IchthyoBio	npi.spr	pdo.spr	SST.sum	df	AICc	delta	weight
Mod1	-4.35	-0.08	-0.04			-0.56					-0.29	6	10479.45	0	0.23
Mod2	-4.32	-0.08	-0.04		-0.39			0.36				6	10479.79	0.35	0.19
Mod3	-4.33	-0.08	-0.04					0.43		-0.36		6	10479.96	0.51	0.17
Mod4	-4.31	-0.08	-0.04				-0.34	0.46				6	10480.4	0.95	0.14
Mod5	-4.34	-0.08	-0.04			-0.4		0.34				6	10480.93	1.48	0.11
Mod6	-4.34	-0.08	-0.04	0.29	-0.5							6	10481.19	1.74	0.09
Mod7	-4.31	-0.08	-0.04					0.5	0.3			6	10481.8	2.35	0.07

Interestingly, a disproportionate share of the model support went to models that contained both a winter variable (before salmon out-migrated) and a spring or summer variable. There were 66 models that had both a winter variable and a spring/summer variable, making up slightly less than 19% of the models. However, these models held over 31% of the AICc weight, suggesting that salmon survival is a complex result of environmental conditions across multiple seasons.

Age structure

Faster-growing fish tend to return at younger ages, which is evident in these PIT tag data. Smaller fish may spend more time in the ocean to increase size and gain mass for spawning, which can influence their survival. Therefore, age structure and ocean survival are explicitly intertwined. A model structure that either predicts age structure as well as survival, or accounts for age structure while predicting survival (see Chapter 7) would be a large improvement over the current method, which does not account for interannual changes in age structure. However, due to their inter-dependent nature, it is very difficult to model age structure and survival together. Although age structure varies among years, fish spending two years in the ocean dominate in almost every year. For the current analysis, we therefore made the simplifying assumption that all Chinook mature after two winters in the ocean and lagged all environmental variables appropriately.

Complications

Switching to PIT tag data comes with some complexities and new limitations. First, we can only use data from populations that have been PIT tagged in sufficient numbers. Many populations in the Snake River Basin have been PIT tagged since the late 1990s, but this is less true for the Upper Columbia River. Additionally, the various subbasins will have different amount of tagging effort, so distinct populations may be suboptimally weighted in the data set. Second, the length of the time series is much shorter for

PIT tag data than it is for fish count estimates. The main adult PIT tag detectors at Bonneville Dam were installed in 1998 and did not cover all adult routes until 2002 (http://www.ptagis.org/sites/mrr-site-metadata). For analyses here, we started all time series of PIT tag data in outmigration year 2000 (most Chinook return after 2 ocean years, which would be 2002). Using only cohorts that have completely returned to the river by 2018, this leaves 2000 to 2015, or 16 years of data. This is a relatively short period compared to the 35 years used in the previous analysis for Snake River Chinook (Zabel et al. 2013).

Downstream survival

We estimated downstream survival through the hydrosystem (from Lower Granite Dam to Bonneville Dam) and arrival day at Bonneville Dam using the pre-existing COMPASS model (Zabel et al. 2008). The COMPASS model is a deterministic model of the downstream travel time, passage success, and survival of juvenile salmonid smolts. The model comprises eight dams and eleven riverine reaches, from Lower Granite Pool on the Snake River to Bonneville Dam Tailrace on the Columbia River. Each dam and riverine reach has associated algorithmic equations that use environmental covariates including flow, temperature, and spill to predict fish survival and migration rate in riverine reaches and passage route proportions at dams. Survival at dams is not computed algorithmically, and is instead set at fixed values for each passage route based on estimates of survival from dam passage studies (see Hydro Chapter). The model runs on a sub-daily timestep, and uses environmental inputs on a daily level to update its equations for each timestep. Fish are added at the top segment of the COMPASS model (Lower Granite Pool) according to a release distribution, and then the model advances sequentially via timesteps, moving the fish downstream using the migration rate equation and applying mortality in each timestep according to the mortality rate equation or dam equations.

The version of the COMPASS model used for this analysis was calibrated for Snake River stocks of Chinook salmon, using Passive Integrated Transponder (PIT) tag data from 1998 through 2017 (Faulkner et al. 2018). The calibration has separate survival and migration rate equations for the riverine reaches of the Snake River versus those in the Columbia River. The release distribution used for these runs was based on a multi-year average of the proportion of smolts arriving per day at Lower Granite Dam. These runs used a universal transportation start date of May 1st at all three transporter dams: Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam. After this date, all fish predicted to enter the bypass system at these dams are instead transported by the COMPASS model; they are removed from the river at the transport dam, and added to the tailrace of Bonneville Dam 2 days later. COMPASS assumes uniform 0.98 survival during transportation. Dam operations including reservoir elevation and spill were set based on a current conditions scenario reflecting operational rules used at Federal dams on the Snake and Columbia Rivers from 2014 through 2017. We also ran a version of the model without any juvenile transportation for comparison.

The variance/covariance AR1 simulation used to generate individual years in the climate change scenarios produces prospective temperature and flow conditions on an annual level, not the daily level required by the COMPASS model. In order to generate prospective COMPASS estimates of juvenile survival and travel time for these conditions, we created a grid of annual flow and temperature values that covered the parameter space seen under the climate change scenarios. For each grid point, we took empirical daily flow and temperature trajectories from 1929 through 2008 and proportionally scaled the daily trajectories until the annual mean for that water year matched the flow and temperature for that grid point. For each year in the prospective climate change scenarios produced by the MARSS scenario, we randomly drew a daily flow and temperature trajectory from the closest matching grid point and predicted COMPASS survival and travel time using those daily trajectories.

Upstream survival

We developed a model of upstream survival using a two-step process. Previous work established a strong relationship between individual fish survival and the temperature encountered at Bonneville Dam (Crozier et al. 2017). Using the average run timing distributions of spring- and summer-run Chinook from 2004-2016, we modeled individual survival under the three climate scenarios for which we had modeled daily temperatures of the entire Columbia River. These climate scenarios and modeled flows were produced by the River Management Joint Operating Committee- Phase I process (Brekke et al. 2010). Temperatures were modeled using methods described in Yearsley (2009, 2012). The scenarios included a historical reconstruction of mainstem temperatures from 1929 to 1998, a hot/wet climate scenario and a warm/dry scenario. We then aggregated individual survival into an annual population survival, and regressed the annual survival as a function of mean June temperature at Bonneville Dam. Models with a quadratic temperature term had significantly better fits than alternate shapes. We produced separate regression fits for spring- and summer-run populations (Figure 4-5).

We simulated mean June temperature at Bonneville Dam in MARSS, then estimated annual upstream survival based on that temperature using the coefficients in Table 4-3.

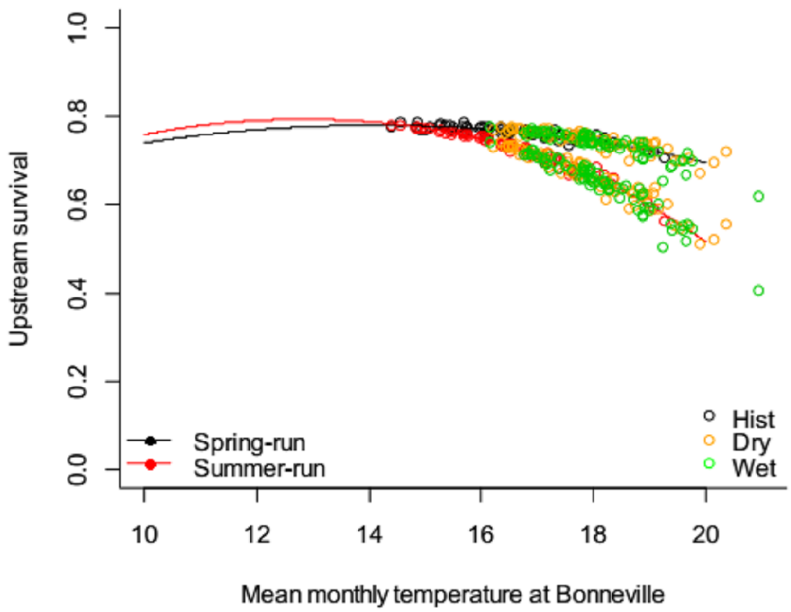

Figure 4-5. Regression fit for spring-run (black line) and summer-run (red line) Chinook salmon annual survival as a function of mean June temperature at Bonneville Dam. The data points are simulated annual survival results from a daily arrival timing model fit to modeled river temperatures.

Table 4-3. Coefficients for upstream survival as a 2-degree polynomial function of mean June temperature at Bonneville Dam. T2 is the squared term, and T is the linear term.

	Intercept	T2	T
Spring	-1.27166	-0.01269	0.358411
Summer	-2.74438	-0.02481	0.636643

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Chapter 5. Climate change

Lisa Crozier

Approach

Climate affects every life stage and therefore has cumulative effects that are important to consider in a life cycle modeling framework. Our approach is to focus on climate effects that help explain interannual variation in stage survival and total recruitment in the historical observation period, and can therefore be directly tied to a measurable population response. The possible climate effects that we explore are based on well-documented mechanistic relationships and extensive literature support.

The strength of this approach is that it is tied closely to the data. Its main limitation is that it is conservative in predicting the emergence of new limiting factors. We believe the approach is valid as long as the projected conditions are within the realm of historical observations, or can be justified based on well-established mechanistic relationships. We acknowledge, however, that additional factors may become important when we enter novel climatic conditions. Thus we consider these analyses conservative in most respects. On the other hand, we have not predicted any evolutionary adaptations or major shifts in behavior that could alter the correlational relationships described here, and may or may not improve salmon viability.

Because of the potential for cumulative effects over the full life cycle, retaining the correlation structure of environmental forcing is a high priority. To do this, we used a multivariate autoregressive state space (MARSS) model to fit and then simulate the variance/covariance structure of environmental factors, as described in Chapter 4.

Climate scenarios

We plan to develop climate scenarios using the ensemble approach, as advocated by the Intergovernmental Panel on Climate Change (IPCC 2014). This approach addresses uncertainty in model assumptions by using as many different models as possible. Where we have a limited number of actual models, we will select models that are as different as possible across the spectrum of projections in temperature and flow.

We will use MARSS to simulate natural variability in a stationary climate. We will use Global Climate Models (GCMs) to extract a range of possible trends in climate that will be added to natural variability in our simulations. There are 52 GCMs available from Coupled Model Intercomparison Project CMIP5, available from NOAA's Earth Systems Research Laboratory (Alexander et al. 2018). We plan to select representative GCM projections for relatively slow warming, relatively fast warming, and the ensemble mean.

Scientists at the University of Washington downscaled output from 10 of those GCMs using multiple downscaling methods, and processed the output through four different hydrological models to project 80 different time series for naturalized flow (RMJOC 2018, Chegwidden et al.

in prep). Although natural variability dominates much of the signal in annual time series in flow, we intend to capture the range of uncertainty across these 80 different projections within the representative concentration pathway (RCP) 4.5 and 8.5.

Stream temperatures have not been modeled yet for all of those hydrological time series. We will therefore use the few available time series for stream temperature, supplemented by air temperature projections that are available from the GCMs. We have found strong correlations between air temperatures and stream temperatures as well as population responses in many of our analyses.

Life cycle modeling

We will use the climate scenarios to alter stage transitions throughout the life cycle. We currently have statistical support for an important role of climate drivers in the spawner to smolt, downstream migration, smolt to adult, and upstream survival stages. For example, tributary and river basin scale metrics of temperature and flow influence parr abundance or survival (e.g., Crozier et al. 2008, Crozier et al. 2010). The impact of environmental conditions on downstream survival has been the extensive study of the COMPASS model, described in Chapter 2, and we will use this model to project migration survival under altered conditions. Upstream survival is also sensitive to environmental conditions, especially high flows for early-run populations, and high temperatures for late-run populations (Crozier et al. 2017).

Using MARSS to generate appropriately correlated time series of environmental conditions, we will input these drivers into the life cycle model runs. Each stage will have multiple models to describe the importance of the environmental driver. For example, after ranking models by the Akaike Information Criterion, we will not just use the top biological model, but will explore multiple options to characterize functional relationships. We will represent as much of the uncertainty in these scenarios as possible, emphasizing both consensus outcomes and perhaps more uncertain but also high-risk outcomes, as advocated by the National Climate Assessment Fourth Report (USGCRP 2018).

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6. Estimating population level outcomes of restoration alternatives in data-rich watersheds – An example from the Grande Ronde basin focusing on Spring Chinook Salmon populations

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The Grande Ronde River Basin included six historical populations of Spring Chinook Salmon (Figure 6.1). Since the early 1990s, the Oregon Department of Fish and Wildlife (ODFW) has conducted annual studies of juvenile Chinook salmon production in four of these populations (Upper Grande Ronde, Catherine Creek, the Minam River, and the Lostine River). These four Spring Chinook salmon populations represent a range of habitat conditions. The Minam River is relatively pristine basin, although there were historical mining impacts in some parts of the drainage. The upper sections of the Lostine River are also relatively intact; however, the lower sections are impacted by water withdrawals and other land use activities. Both Catherine Creek and the Upper Grande Ronde watersheds have been extensively modified by land use including timber harvest, overgrazing, beaver trapping, and mining. In addition, low gradient reaches in the Grande Ronde Valley that likely supported a diversity of juvenile Chinook salmon habitats and associated juvenile rearing patterns were extensively converted to agricultural use beginning in the mid to late 19th century.

The Grande Ronde is a basin with a rich set of demographic data for Chinook salmon. Redd counts have been made throughout much of the available spawning habitat for over 60 years (Tranquili et al. 2004). Similarly, there are 23 years of fall and spring juvenile emigrant estimates from screw traps on major tributaries. In addition, several years of mid-summer instream tagging with passive integrated transponders have led to size and survival estimates of multiple life stages from the Grande Ronde River tributaries to Lower Granite dam on the Snake River. These data have been used in a state-space model to estimate juvenile rearing capacity

6.1. Overview / Summary

The four Grande Ronde Spring Chinook salmon population LCMs are framed in the matrix life cycle modeling format originally described in Zabel et al. (2006). We used information generated from the spawner to smolt life-stage monitoring as the basis for incorporating detailed juvenile life stage survival and density dependent relationships into the freshwater juvenile stages of full life cycle models for each of the populations. Life cycle models were developed based on long-term data series including three main components: estimation of annual spawning escapements (mid-1950s to current); estimates of pre-smolt emigration (1992-2016 migration years), estimates of late summer parr densities at sample sites within each population; and PIT tag-based survival rates to Lower Granite Dam for summer parr, fall downstream migrants, winter parr and spring downstream migrants (e.g. Jonasson et al. 2017).

For each population, we estimated the total amount of rearing habitat in reaches designated as current use by ODFW above and below the location of the juvenile out-migrant traps. We used the results from a systematic survey of pools, fast water and run habitat units in Grande Ronde basin tributaries in combination with parr density estimates for each habitat category to generate standardized habitat estimates of the total amount of habitat above and below the juvenile sampling weirs for each population.

The basic approach for incorporating habitat change effects starts with current life stage capacities and survival estimates derived from the 20+year juvenile series for each population. Using the results of ODFW Aquatic Inventory surveys in each population, we calculate the total amount of pool equivalent habitat currently supporting spawning and/or rearing. Other than scaling the expression of juvenile life stage parameters to the total amount of pool equivalent habitat within a population, our Grande Ronde MLCMs do not directly include habitat parameters. We use multipliers on life stage specific survival and capacity terms as inputs to model the impact of habitat actions or environmental changes.

We analyzed a range of habitat restoration scenarios starting with maintaining baseline conditions and adding: the 2009-2016 actions; minimum 2018-21 actions; current projections for proposed 2019-24 actions: implementation of 20-year habitat restoration scenarios including Recovery Plan actions plus riparian restoration in high and moderate priority reaches identified in Justice et al. 2017. At this point, the last three habitat scenarios have been run only for Catherine Creek and the Upper Grande Ronde populations. For Catherine Creek and the Upper Grande Ronde populations we added another scenario to simulate the potential of additional habitat restoration downstream of current use. For that scenario we assume that the current area production has been extended downstream sufficiently after 25 years.

The habitat actions were analyzed in combination with two variations on future hydropower operations: : continuation of current operations under the FCRPS 2014 guidelines and implementation of the proposed 2018 spill program assuming a 120% gas cap. We ran the gas cap spill scenario under four different assumptions) bracketing a range of potential impacts on subsequent ocean stage mortality (no effect, or a 10%,25% or 50% improvement in ocean stage survival for in-river migrants subject to increased spill). The scenario analyses also incorporated the current sliding scale harvest schedule for Snake River Spring/Summer Chinook and projected impacts of increased marine mammal predation.

Modeling the addition of the 2009-2016 habitat actions reduced extinction risks for the Catherine Creek and Upper Grande Ronde populations relative to updated baseline habitat projections. Incorporating supplementation into the model runs resulted in reduction in the risks of gong below the 24-year quasi-extinction thresholds for both the Catherine

Creek and Upper Grande Ronde River populations. The largest decreases in projected risks were for habitat actions in combination with hydrosystem spill operations incorporating reductions in ocean latent mortality. The projected 24-year QET risk across model runs dropped to 0.4-2.4% (QET30) and 3.2-24.4% (QET-50) for Catherine Creek. 24-year QET risks remained high in this scenario for Upper Grande Ronde, while the risk of going below QET50 remained relatively unchanged, the risks of going below QET30 dropped further to range from 12.4-71.3% across 500 runs. The largest increase in short term abundance (+16%) from the 2014 Biological Opinion (BioOp) tributary habitat actions was projected for the Catherine Creek population, where the actions were directed at expanding summer rearing habitat, identified as a key limiting life stage.

Expressed as proportional changes from baseline conditions, the Catherine Creek recovery plan short and intermediate response actions would result in an 84% gain in parr habitat capacity by year 24. This increase includes the projected benefits of the 2019-24 in-stream actions described above. The initial responses to riparian restoration would increase that gain to a projected 125% improvement in parr rearing capacity by year 24. Benefits from increasing shading and restoration of natural stream channel characteristics would continue to accrue over time, reaching 165% over baseline conditions 48 years out. The benefits projected for the shading corresponding to fully mature riparian tree heights at approximately 100 years out would increase to approximately 206% of baseline. The Upper Grande Ronde River has a greater amount of current production habitat subject to high summer stream temperatures. As a result, riparian restoration actions have a higher proportional impact than for Catherine Creek. The projected increases in parr production potential from implementing the tributary habitat improvements from the Upper Grande Ronde 20-year restoration scenario at 24 and 48 years would be +99% and +140% respectively. Adding in the potential increase in survival gained by successfully addressing the high Grande Ronde Valley outmigration mortality would project to increase the cumulative improvements at 24 and 48 years to 199% and 262%.

We generated additional long-term scenarios to illustrate the potential for further expansion of natural production into reaches below current spawning and rearing that are currently precluded by loss of historical rearing habitat and extremely high summer temperatures (Upper Grande Ronde) along with reduced summer flows (Catherine Creek). In both cases restoring production to these lower reaches would almost certainly require successful restoration of the upstream reaches targeted in the 20-year scenario in order to extend spawning downstream enough to generate juveniles to use newly restored habitat below current spawning/rearing range.

Under the long term restoration scenarios, both populations showed large proportional increases in projected natural origin spawner abundance. For the Upper Grande Ronde population, the cumulative impact of the long-term habitat scenario combining expansion into reaches downstream of Fly Creek, reduced Grande Ronde Valley migration mortality and returning Lower Columbia marine mammal mortalities to pre-2013 averages resulted in a 525% projected increase. The corresponding scenario for Catherine Creek resulted in a median proportional improvement of 527%. However, in absolute terms, the projected abundance for Catherine Creek showed the highest increase relative to Interior Columbia Technical Recovery Team minimum abundance thresholds. More than 50% of 500 simulation runs for the long-term habitat plus Grande Ronde Valley survival improvements scenario for that population exceeded the minimum abundance threshold under the 25% and 50% latent mortality reduction assumptions. Adding reductions to current lower Columbia River predation mortalities, presumably by decreased marine mammal predation, resulted in greater than 70% of simulation runs exceeding the abundance threshold under all spill latent mortality assumptions modeled.

6.2. Grande Ronde LCM structure

Our four Grande Ronde Spring Chinook salmon population LCMs are framed in the matrix life cycle modeling format originally described in Zabel et al. (2006). Detailed LCMs for several Salmon River basin populations (Crozier et al. 2016) and the Wenatchee River (Jorgensen et al. 2017) use the same basic framework, although each set is adapted to use the different levels of information available to 'populate' freshwater life stages. We expanded the tributary habitat life stage components using the detailed information on juvenile life-stages for each of the Grande Ronde populations (Figure 6.2). We also replaced the fixed harvest rate feature of the 2007 model with an abundance driven functional relationship mimicking current harvest management practices. The matrix has the form:

$$
A(t) = \begin{matrix}
0 & 0 & 0 & b_4 \cdot s_A \cdot F_4(t) & s_A \cdot F_5(t) \\
s_2(t) & 0 & 0 & 0 & 0 \\
0 & s_3(t) & 0 & 0 & 0 \\
0 & 0 & (1-b_3)\cdot s_o & 0 & 0 \\
0 & 0 & 0 & (1-b_4)\cdot s_o & 0
\end{matrix}
$$

The s terms represent the survivals between life stages, the b_t and F(t) terms represent the rates of maturity at age(t) and relative female fecundity by age. In our Grande Ronde models, the term $S_2(t)$ is a composite representing the production of smolts as a function of parent spawners and the downstream survival of those smolts to entry in the estuary. It includes both density dependent components (summer parr per spawner, spring outmigrants per parr) and density independent elements (spring outmigrant to Lower Granite Dam smolt, smolt to below Bonneville Dam). The spawner to Lower Granite smolt elements within this stage are directly linked to tributary habitat conditions as described in detail below. Survival through the mainstem Snake and Columbia Rivers are estimated based on PIT tag data representative of the aggregate natural origin Snake River spring-summer Chinook run (Crozier 2019). The $S_3(t)$ term represents estuarine/early ocean survival through age 3. S_A represents adult migration mortalities from arrival at the Columbia River mouth to the spawning grounds. It includes estimated marine mammal predation in the Lower Columbia River, mainstem Columbia River harvest, upstream passage mortalities and prespawn mortality above Lower Granite Dam.

A detailed description of the freshwater tributary life stage elements of the models follows (Table 6.1). Descriptions of the remaining components are available in Cooney et al. 2017. Briefly, the models incorporate estimated survivals derived from data on annual aggregate Snake River spring Chinook salmon production in subsequent life history stages - downstream migration to the estuary, estuary/ocean, Columbia River entry and upstream migration (Burke et al 2017b, Crozier et al. 2017, ISAB 2017 Chap. 9c). Snake River spring/summer Chinook are subject to in-river harvest that is managed according to a sliding scale (WDFW 2017). We incorporated the sliding scale with estimates of management uncertainty derived from 1995-2014 post-season run reconstructions. Three of the four Grande Ronde populations have active local broodstock supplementation programs. Broodstocking for each of those programs is managed with population specific schedules. We include modules in the Grande Ronde population models that mimic the schedules and recent performances of the supplementation programs (including survivals to release and smolt to adult return rates).

The Grande Ronde models are calibrated to the 1993-2016 adult data series prior to being used in prospective simulations. We compare estimated adult brood year returns for the 1993-2011 brood years with model generated estimates using the inputs described above. We include the year specific estimates of upstream and downstream passage survivals and estimated brood year ocean smolt to adult return rates (SARs). Observed brood year returns have consistently been higher than modeled estimates for each population. We calculate a brood year adjustment factor (the slope of a zero intercept regression between logit transformed estimated and observed SARs) and apply it in prospective analyses.

6.2.1. Estimating life stage capacities using population specific fish and habitat data

The combination of longer-term estimates of fish data (adult and juvenile life stages) and habitat survey information at the population level allows us to address steps 1 and 2 in the generalized process simultaneously. Those data sets allowed for extrapolating annual estimates of summer parr abundance for each population. Parr production relationships were then generated for each population using the corresponding parent spawner abundance estimates. We also developed survival relationships for two additional juvenile life stages: summer parr to spring outmigrant and spring outmigrant to Lower Granite Dam.

We use the Northwest Stream Temperature (NorWeST) estimate database as a starting point for temperature indices for each population. NorWeST modeled annual temperatures are expressed as August averages for 1 km segments of the stream network. We compared NorWeST modeled temperature estimates to empirical data sets available for a subset of reaches in the populations (Isaak et al. 2016). Average NorWeST temperatures for those locations were also highly correlated with empirically based estimates of maximum weekly maximum stream temperatures, and index that has been used in studies relating adult and juvenile Chinook densities and survival rates (e.g., Justice et al. 2017).

Stream flow data for the four populations were downloaded from the Oregon Water Resources Dept website: HUhttp://apps.wrd.state.or.us/apps/sw/hydro_report/UH. Stations were Catherine Creek (13320300), Minam River (1332000), Upper Grande Ronde River (13317850) and Lostine River (1333000). Stream flow estimates were available for all years of the juvenile study for the Lostine River. There were gaps (one to three years duration) in the annual flow records for the other three populations. Annual stream flows in Grande Ronde tributaries generally peak in May or June and decrease to relatively low levels by early August. We calculated two indices of summer flow conditions for use in the statistical analyses of the population-specific stage survival relationships: September flows during the spawning and initial incubation stage and the average August and September flows one year after spawning, corresponding to the conditions encountered during the initial year of freshwater rearing. In each case we compared annual fluctuations in the population specific data series, dividing the individual year estimates by the average flow for the series.

Juvenile spring/summer Chinook salmon prefer low gradient reaches with deep pools for summer rearing (e.g., Bjornn & Reiser 1992). In addition, adult spring/summer Chinook salmon redds are generally concentrated in gravels associated with pool habitats. For each population, we estimated the total amount of rearing habitat in reaches designated as current use by ODFW above and below the location of the juvenile out-migrant traps. We used the results from a systematic survey of pools, fast water and run habitat units in Grande Ronde basin tributaries in combination with parr density estimates for each habitat category to generate standardized habitat estimates of the total amount of habitat above and below the juvenile sampling weirs for each population. The estimates were calculated by summing the habitat above and below weirs by stream reach category (pool, riffle, and fastwater) and multiplying the sums by the average relative density for each of those habitat categories. Two of the four populations had potential AQI rearing habitat with summer MWMT stream temperatures above 18 deg. C. We used a relationship between relative parr density and MWMT temperature reported in Justice et al. 2017 to discount the estimated AQI habitat in those reaches where temperatures exceeded 18 deg. C. We also standardized juvenile abundance data for each population to a common unit of habitat (10,000 m2 of AQI pool equivalent habitat) to explore general relationships between habitat conditions and juvenile production that might be common across one or more populations.

Parent spawner estimates were generated by ODFW for stream reaches upstream of the rotary screw trap sites in each population. Based on the ODFW survey results, we assumed negligible spawning below the juvenile screw trap. We developed production relationships for the reaches above the weir site standardized to a common unit of habitat (10,000 m2 of equivalent pool area) using the habitat data sets described above. We compared summer parr per spawner ratios (per 10,000 m2 AQI habitat) to flow and temperature indices representative of averages across spawning and summer rearing locations as well as against parent spawning densities. There were no significant trend relationships in the annual parr per spawner estimates for the environmental indices. However, the parr per spawner estimates did group at relatively distinct temperature levels for each population. There were significant relationships between spawner densities and parr densities for each population.

6.2.1.1. *Spawner to summer parr stage*

We fit linear and Beverton-Holt (BH) relationships to AQI standardized annual estimates of spawner escapement and summer parr production using the nls package in R. We assumed a lognormal error structure and weighted age 5 parent spawners by 1.26 (ICRT, 2007) to account for higher fecundity of the age 5 females. The Beverton-Holt model with its density dependent term was a better fit to the data series for each population (AICc criteria).

$$ln\, ln\left(\frac{Parr_{p,y+1}}{Spawners_{p,y}}\right) = a - ln(abs(1 + \left(\frac{exp\, exp\,(a)}{b}\right) * (Spawners_{p,y})$$

Where the spawner estimates are age weighted using the following formula:

$$AWSpawners_{p,y} = \left((1 - age5prop_{p,y}) + 1.26 * age5prop_{p,y}\right) * Spawners_{p,y}$$

We addressed parameter uncertainty in the fitted model parameters by generating a set of 1000 replicate paired estimates of the Beverton-Holt a (natural log parr per spawner) and b (asymptotic parr capacity) using the nlsboot bootstrap estimation routine in R. The approach we used to estimate a production relationship for this stage assumed that the spawner estimates were measured without error. Future iterations of this model are under development that use a hierarchical framework that includes accounting for potential measurement error. Initial results indicate that the stage specific relationships derived from that approach are similar.

6.2.1.2. *Summer parr to spring tributary outmigrant stage*

The combination of life stage PIT tag groups available for the four Grande Ronde populations represent a unique opportunity to evaluate survivals within the two predominant parr to oceanward migration pathways (natal area and downstream overwintering). We made a simplifying assumption, that annual early spring to Lower Granite Dam survival for the downstream overwintering components of each population was the same as the estimated survival to Lower Granite Dam for the natal overwintering group passing the smolt trap in the spring. This allowed us to estimate the total number of smolts leaving the tributary from both pathways. We considered framing juvenile life stages in more detail, using the estimates of fall migrant and winter natal area parr survival. Incorporating that level of detail requires making some assumptions about monthly mortality rates that are not directly informed by the available data for these systems. Summer parr estimates are generated based on sampling in August, fall downstream migrants passing the smolt traps generally peak in mid-October. Parr remaining above the smolt traps to overwinter pass downstream the following spring. The proportion of juveniles overwintering downstream of the trap varies across the four populations is not significantly related to annual variations in density or environmental indices. Survival from summer parr to either of these stages is not directly estimated. We calculate an aggregate overwintering mortality from summer parr to spring tributary outmigration by assuming that the estimated spring outmigrant to Lower Granite Dam survival applies to the fish surviving overwintering below the weir site (the fall downstream migrants). That assumption is generally supported by patterns in survivals across tag groups in the Grande Ronde including survival estimates derived from winter tagging above the smolt traps after fall emigration. We are exploring alternative approaches to estimating pathway specific overwintering mortalities for future iterations of the Grande Ronde detailed LCMs.

We compared annual estimates of survival from summer parr to spring outmigrant against summer parr density, summer temperatures and relative flow levels after transforming the annual survival series for each population as logits. There was a significant negative relationship of the summer parr to spring presmolt survivals and summer parr abundance for each population. Summer maximum stream temperatures and flow levels were not significant in the analyses and were not included in generating the fitted estimates.

$$Logit\left(Sow_{p,yr}\right) = Sow_{p,yr}/(1 - Sow_{p,yr})$$

$$Est[\ Logit\left(Sow_{p,yr}\right)] \ = \ A_{Sow\ ,p} * \ Parr_{p,yr} + \ B_{Sow,p} + \ \varepsilon_{0,sd}$$

$$(Sow_{p,yr}) = \left[\ Logit\left(\widehat{Sow_{p,yr}}\right)\right] /\{\ 1 + \left[\ Logit(\widehat{Sow_{p,yr}})\right]\}$$

6.2.1.3. Spring outmigrant to Lower Granite Dam stage

Population specific estimates of survival for the spring outmigrant to Lower Granite Dam were also evaluated as logistic regressions on parr density. The density dependent terms were not significant, the relationships incorporated into the life cycle were expressed as a constant multiplier with a randomly drawn error term reflecting the variability in each population series.

$$[\ Logit\left(Sl\widehat{gr}_{p,yr}\right)] \ = \ B_{Slgr\ ,p} + \ \varepsilon_{0,sd}$$

Survivals during the spring migration from the smolt traps to Lower Granite Dam are consistently lower for Catherine Creek and Upper Grande Ronde smolts in comparison to Lostine and Minam River spring migrants. In some years ODFW has also tagged spring outmigranting smolts at Elgin on the mainstem Grande Ronde River below the upper two populations and above Minam and Lostine Rivers. Survival rates to Lower Granite Dam from Elgin are comparable or higher than those estimated for smolts entering downstream from the Minam and Lostine Rivers, indicating that considerable mortality is being incurred in the upper Grande Ronde Valley during the spring outmigration.

6.2.1.4. Catherine Creek summer rearing downstream of trap

In recent years, parr sampling at Catherine Creek CHaMP sites below the weir and smolt trap determined that parr were rearing in the reach extending downstream to the Davis Dam irrigation diversions (e.g. Jonasson et al 2016). As a result, we incorporated a second tributary habitat summer rearing area into the Catherine Creek model. Given the relatively low rates of observed downstream passage from initial trap operations in the early spring to the fall, it is likely that these juveniles were produced from spawning upstream of the weir, likely migrating downstream as fry or after a short period of initial rearing. That early redistribution would be prior to the initiation of large-scale irrigation withdrawals that drastically reduce summer/fall flows in the reaches below the trap site. For the Catherine Creek model, we estimated the number of summer parr rearing below the weir site using the same combination of ODFW Aquatic Inventory data (reflecting the impacts of irrigation withdrawals) and CHaMP parr densities by reach type. We assume that the average proportion of parr production observed in the recent years (~30%) applied to the earlier study years before systematic sampling was initiated in the downstream reaches. ODFW has expanded their ongoing summer parr tagging program to include groups in the downstream area. Initial results indicate substantially lower survivals from late summer to detection at Lower Granite Dam the following spring.

6.3. Develop restoration scenarios – Habitat change analyses

White et al. (2017) used contemporary estimates of channel width based on Oregon Department of Fish and Wildlife's Aquatic Inventories Project (AIP) (Moore et al., 2008) to evaluate the impact of channel widening on the distribution of Chinook summer parr. The AIP survey is a rapid assessment of common fish habitat characteristics collected in a spatially continuous fashion across the stream network. AIP data from the 1990s were used to examine channel width as a proxy of stream channel width:depth ratio—a metric strongly tied to integrity of stream channels (e.g., Beschta and Platts 1986; Myers and Swanson 1996) and commonly used in fish-habitat models (Fausch et al., 1988)—because historical estimates of water depths were not available. Data for this analysis were limited to the low flow period to provide consistency in discharge over the years that would allow change in width to be a valid surrogate for change in width:depth ratio.

Historic channel width was estimated using information from GLO notes and then compared to current conditions to get an estimate of percentage change in channel width. A direct comparison for each location typically using this method cannot always be made, thus quantifying the magnitude of change in relation to the geomorphic valley setting is important. This is where it is important to understand the geomorphic setting utilizing various classification schemes. Streams were classified into small and large using an 8-m bankfull width threshold (Beechie and Imaki 2014), and then further divided based on valley confinement (laterally unconfined, partly confined, and confined) following the methodology described in the River Styles Framework (Brierley and Fryirs, 2005). This resulted in three classes: large streams (LS), small/partly confined and confined streams

(SC), and small/laterally unconfined streams (SU). One-way ANOVA was used to test the effect of valley setting on magnitude of channel change in impacted watersheds.

One key finding of White et al. (2017) was that these streams have yet to recover from severe anthropogenic disturbance such as cattle grazing, logging, and mining (Figure 6.3). This channel widening analysis was then coupled with other factors such as examination of stream temperature to examine how changes in one variable affects changes in another variable that could lead to alterations in fish utilization – both positive and negative. A mechanistic water temperature model demonstrated that channel widening resulted in warmer water temperatures through increased surface area exposed to solar radiation. This resulted in a drastic loss of suitable habitat meeting minimum thresholds for salmonids. Based on projections, stream restoration in the impacted watersheds could notably decrease average water temperatures—especially when channel narrowing is coupled with riparian restoration—up to a 6.6°C reduction in the upper Grande Ronde River and 3.0°C in Catherine Creek. These reductions in water temperature would translate to substantial changes in the percentage of stream network habitable to salmon and steelhead migration (from 29% in the present condition to 79% in the fully restored scenario) and to core juvenile rearing (from 13% in the present condition to 36% in the fully restored scenario) (Figure 6.4).

Justice et al. (2017) then used a deterministic water temperature model called Heat Source (Boyd and Kasper 2003) to investigate potential thermal benefits of riparian reforestation and the channel narrowing analysis from White et al. (2017) to Chinook Salmon populations in the Upper Grande Ronde River and Catherine Creek basins in Northeast Oregon, USA. Inputs to the model included LiDAR data such as channel topography, local climate data, streamflow information from gaging station and manual flow measurements, and water temperature data from thermographs. In addition, extensive field measurements associated with each plant association group (PAG) and potential tree height estimates were used to determine historic/potential and current riparian vegetation conditions. A combination of local knowledge from experienced riparian ecologists was used, as well as detailed maps of current vegetation and potential natural vegetation (PNV) for a 100-m wide stream buffer throughout the Chinook-bearing portions of the Upper Grande Ronde and Catherine Creek watersheds that incorporated physiography, geomorphology, soils, vegetation, and disturbance (Wells et al. 2015). Potential tree height was estimated from species-specific dominant tree height growth curves from regional forestry literature. Weighted-average growth curves within each PAG were then used to estimate the average tree height under fully restored PNV conditions, which was assumed to occur at 300 years. Potential shrub heights were obtained from local sources and from species descriptions in the Fire Effects Information System.

By combining restoration scenarios with climate change projections, Justice et al. (2017) evaluated whether future climate impacts could be offset by restoration actions. A combination of riparian restoration and channel narrowing was predicted to reduce peak summer water temperatures by 6.5°C on average in the Upper Grande Ronde River and

3.0°C in Catherine Creek in the absence of other perturbations (Figure 6.5). These results translated to long term, stable increases in Chinook Salmon parr abundance of 590% and 67% respectively once the modeled actions impacted the population dynamics (Figure 6.6). Although projected climate change impacts on water temperature for the 2080s time period were substantial (i.e., median increase of 2.7°C in the Upper Grande Ronde and 1.5°C in Catherine Creek), the model predicted that basin-wide restoration of riparian vegetation and channel width could offset these impacts, reducing peak summer water temperatures by about 3.5°C in the Upper Grande Ronde and 1.8°C in Catherine Creek. This translated to potential increases in Chinook Salmon parr abundance of 67% to 590 %, respectively. These results underscore the potential for riparian and stream channel restoration to mitigate climate change impacts to threatened salmon populations in the Pacific Northwest.

The basic approach for incorporating habitat change effects starts with current life stage capacities and survival estimates derived from the 20+year juvenile series for each population. Using Catherine Creek summer parr stage as an example, we calculate the total amount of pool equivalent habitat currently supporting spawning and/or rearing. Other than scaling the expression of juvenile life stage parameters to the total amount of pool equivalent habitat within a population, our Grande Ronde MLCMs do not directly include habitat parameters. We use multipliers on life stage specific survival and capacity terms as inputs to model the impact of habitat actions or environmental changes. The basic approach for incorporating habitat change effects starts with current life stage capacities and survival estimates derived from the 20+year juvenile series for each population as described above. We translate proposed actions into changes in the amount of pool equivalent habitat in the treatment reaches and express the results as a ratio of the new total to the current estimate. That ratio is than used as a multiplier to increase the summer rearing capacity in the model. Life stage survivals can be increased by habitat actions in three ways; in cases where a direct survival impact is alleviated (e.g., irrigation diversion screening related mortality), a multiplier on survival weighted for the proportion of current rearing area benefiting from the action is used. Restoring riparian cover, reconnecting stream channels to associated groundwater sources or creating localized water storage (Wondzell et al. 2007) can directly reduce stream temperatures

Although the MLCMs can be used to model the effects of individual reach scale habitat actions, assessment of larger scale restoration strategies is a more effective use of their capabilities. In practice, larger scale restoration strategies will take time to implement. In addition, actions such as restoring riparian habitat will take additional time to result in changes to conditions affecting juvenile or adult life stages in the reach. For example, developing canopy cover providing effective shade to adjacent stream reaches can take decades to reach full maturity. Our procedures for translating proposed actions into life stage model inputs use a simple set of assumptions to address these factors. We use results from a long-term habitat study in the upper sections of the Grande Ronde basin (Justice et al. 2017, White et al. 2017) as a starting point for translating potential restoration actions into temperature effects on juvenile Chinook production.

We estimated the potential changes in juvenile rearing capacity for restoring high and medium priority reaches in Catherine Creek by applying the mixed effects model described in Justice et al. (2017) that relates late summer juvenile densities to stream temperatures. We applied the model to each 200 m segment of stream in two priority sections of Catherine Creek (the current core spawning and rearing habitat above the town of Union, and the contiguous downstream section from Union to Pyles Creek). We combined the incremental implementation schedule with the generalized riparian response time described in Justice et. al. 2017 using a polynomial equation corresponding to their estimated response times (40% of benefits after 25 years, 85% after 75 years).

6.3.1. Estimating restoration effects on habitat capacity or survival - Develop historical, current and strategy-specific restoration scenarios.

We modeled three incremental habitat action sets; 1) specific actions called for in the current draft NE Oregon Recovery Plan, 2) expanded actions targeting priority reaches identified through the Catherine Creek Atlas project, and 3) implementation of stream/riparian restoration in high and moderate priority reaches identified in Justice et al., (2017). The Grande Ronde Model Watershed project is currently compiling a 6-year strategic work plan identifying projects to be developed and implemented over the next 6 years. We are prepared to analyze the potential effects of those actions when the descriptions of the component actions become available for that action plan.

Although the MLCMs can be used to model the effects of individual reach scale habitat actions, assessment of larger scale restoration strategies is a more effective use of their capabilities. In practice, larger scale restoration strategies will take time to implement. In addition, actions such as restoring riparian habitat will take some time to fully realize potential changes to conditions affecting directly juvenile or adult life stages in the reach. For example, developing canopy cover providing effective shade to adjacent stream reaches can take decades to reach full maturity. Our procedures for translating proposed actions into life stage model inputs use a simple set of assumptions to address these factors.

The impacts of restoring 10 cfs in flows were estimated using data from CHaMP sampling in the Union to Davis Dam reach analyzed using the U.S. Forest Service River Bathymetry Toolkit (McKean et al., 2009). The effect of the action was expressed as a proportional increase in suitable pool habitat. The draft Recovery Plan also calls for restoring 3 miles of side channel or meander habitat. We assumed that reconnected or reconstructed channel habitats would be in the same low gradient reach (Union to Davis Dam), and that the resulting additional channel habitat would average 80% pool frequency. We assumed these actions would increase the juvenile Chinook summer rearing capacity for the population, but that temperatures would not be changed from current ranges.

For evaluating the impacts of habitat projects implemented in 2009-2016, we used summaries of the expected change in key habitat parameters estimated by the Upper

Grande Ronde/Catherine Creek Expert Panel (EP). The U.S. Bureau of Reclamation (BOR) compiled tables capturing the results of the EP process including their identification of the specific reach locations (length treated) and their estimates of the potential change in key factors (e.g., side channel added or activated, floodplain accessed, increase in LWD, increase in sinuosity, riparian plantings, etc.). Where appropriate, the EP included estimates of the relative effectiveness of the methods used to implement the action. We used the standard action categories and the conclusions of the EP in our modeling application.

The third increment of change was based on the high and moderate priority reach restoration scenario described in Justice et al. 2017 and White et al. 2017. This scenario focuses restoring stream structure and reducing temperatures through the combined effects of riparian shade and achieving natural channel structure and width/depth ratios (White et al., 2017). Most of the reaches identified as high priority for riparian restoration along Catherine Creek course through private lands. Implementing these large-scale restoration actions will require extensive landowner cooperation and coordination. In some circumstances restoring natural channel structure may require direct intervention given the degree of degradation (e.g. extreme channel widening due to historical splash dam activities). Given the time requirements to get agreements in place and limitations on the resources required to actually implement large scale riparian restoration, we assumed a 20-year implementation schedule.

We have emphasized habitat opportunities within and immediately (8-10 kms) downstream of current production areas in these analyses. With the possible exception of the Minam River population, extending sustained natural production into those reaches would provide a basis for further restoration in the historically productive wide valley habitats immediately below.

6.3.1.1. Grande Ronde Valley Outmigrant Survivals

As described above, out-migrating smolts from Catherine Creek (and to a lesser extent the Upper Grande Ronde River) are subject to relatively high mortalities either during active migration or just prior to beginning that phase (e.g., Favrot et al 2018). The factors contributing to this increased mortality are not well understood. Two possible contributing mechanisms have been suggested, both at least partially driven by the unique spring flow condition at the lower end of the Grande Ronde Valley. Flows from the Upper Grande Ronde bypass the old Grande Ronde channel via the State Ditch, which begins near La Grande, Oregon well upstream of the former Catherine Creek confluence and rejoins the old main stem channel approximately 22 km below that confluence. Spring flows from the Upper Grande Ronde are backed up when they encounter the relatively confined geology at the lower end of the valley. As a result, migrants from Catherine Creek encounter slack water or even an upstream flow as they pass downstream. Reasons for the documented high levels of mortality during the transition through this reach are unclear. It is possible that migrating smolts delayed in this reach are highly vulnerable to avian or piscine predation. It also is possible that the interruption in normal migration timing is a contributing factor. An ODFW study is underway to gain an understanding of the causes and to identify strategies to reduce this documented mortality (Favrot et al, 2018). To illustrate the potential benefits of reducing mortality levels during this life stage, we have run scenarios including an assumption that managers will identify and implement an approach that will reduce the mortality associated with this reach to average levels observed for migrants from the Lostine and Minam Rivers, which enter a relatively short distance downstream (~50% stage survival increase).

6.3.2. Estimate population level outcomes of each restoration alternatives - Using LCM to evaluate differences in fish production among restoration scenarios

We estimated the potential changes in juvenile rearing capacity for restoring high and medium priority reaches in Catherine Creek by applying the mixed effects model described in Justice et al. (2017) that relates late summer juvenile densities to stream temperatures. We applied the model to each 200 m segment of stream in two priority sections of Catherine Creek (the current core spawning and rearing habitat above the town of Union, and the contiguous downstream section from Union to Pyles Creek). We combined the incremental implementation schedule with the generalized riparian response time described in Justice et al. 2017 using a polynomial equation corresponding to their estimated response times (40% of benefits after 25 years, 85% after 75 years).

We run 500 simulations of 105 years each for a particular scenario, drawing randomly from parameter distributions (a single 100-year simulation) and random variability elements (annually). The results are saved in arrays, the standard set includes annual spawners (total, natural origin and hatchery origin), brood year returns (natural origin) and annual adult harvest rate. For runs invoking local supplementation, annual estimates of natural origin broodstock removals, spawning area hatchery proportions and accumulated fitness effects are also stored. These arrays can be used to generate different summary statistics and graphics, both within and across scenarios.

Outputs can be summarized in ways that directly correspond to risk and recovery metrics used in status reviews, Biological Opinion evaluations and recovery planning. For example, summarizing frequency distributions of 10-year geometric mean natural origin spawners at selected years (e.g., 25, 50 or 100 years) or reporting the proportion of runs that fall below a selected quasi-extinction threshold. The ICTRT recommended using a QET of 50 fish averaged over four years as a long-term recovery benchmark. Risk assessments used in prior FCRPS hydrosystem biological opinions also included a QET of 30.

6.3.3. Estimate population level outcomes of each restoration alternatives - Using LCM to evaluate a six-year strategy for the Upper Grande Ronde and Catherine Creek

Proposed actions and locations have been developed for Spring Chinook salmon populations in the Upper Grande Ronde River and Catherine Creek (Table 6.2, Figure 6.7). This is based upon current habitat conditions and an overall understanding of the limiting factors associated with Spring Chinook salmon in these basins (Table 6.3).

6.4. Results

Current spawning and juvenile rearing habitats for each of the four populations extend from higher elevation moderate gradient forested valleys downstream through lower gradient alluvial fan and Grande Ronde Valley habitats The Upper Grande Ronde, Catherine Creek populations along with the Wallowa and Lower Lostine River reaches in the Lostine Wallowa population have been substantially altered by human impacts – including channel straightening, diking, LWD removal, degraded riparian habitats and summer baseflow reductions (e.g. White et al 2017). In recent years the Oregon Aquatic Inventory surveys (AQI) have generated direct estimates of the relative physical conditions across reaches in each population. We used relative parr densities from snorkel surveys across the three Oregon AQI stream channel classifications (pools, runs, and fastwater) as a basis for expressing the total available habitat in each population in pool density equivalents (Table 6.4). Although absolute abundance varied across surveys by year and population, average levels in run and fastwater habitats were relatively consistent in proportion to the corresponding pool densities.

The recent CHaMP/ISEMP project compiled reach level stream temperature series for sample sites across the Grande Ronde populations (Figure 6.8). Summer peak temperatures varied from site to site, but the annual patterns across months were similar. All sites had very low winter temperatures extending into early spring, followed by a gradual increase to peak temperatures in August. Stream temperatures declined through the fall to winter lows.

Projected summer (August average) stream temperatures from the NORWEST regional model were highly correlated with average August temperatures at the sample reaches. In addition, direct estimates of maximum weekly maximum temperatures (MWMT) at sample sites were highly correlated with the corresponding empirical August average stream temperatures. We used the regression of MWMT on August average temperature to project reach scale estimates of MWMT from the NORWEST August average temperatures.

$MWMT = 1.46 * NorWest\ Aug - 3.65 \quad R^2 = .9872$

Stream temperature is an important constraint on spring Chinook spawning and juvenile rearing in the Grande Ronde basin. Current summer temperatures in the lower sections of the current use reaches in the Upper Grande Ronde, Catherine Creek and the Wallowa/Lostine populations coincide with substantial declines or absences of spawner and juvenile densities (Figure 6.9). The vast majority (95%) of current spawning in the Upper Grande Ronde population is above where average summer stream temperatures exceed 17.5 degrees C, which extrapolates to 20.5 degrees MWMT (Figure 6.10).

The Oregon AQI surveys identified the amount of accessible side channel habitat associated with mainstem reaches in each population as well as the proportions of that habitat classified as pools, runs or fastwater. Using the Beechie et al. (2015) natural potential channel pattern classification system current use reaches in each population are dominated by the meandering pattern, with sections of confined and straight channel patterns (Figure 6.11). The amount of current side channel habitat is well below historical levels based on the relative frequencies of Beechie et al. (2015) channel pattern classes and a recent land use based study of floodplain status in the Interior Columbia Basin tributaries (Bond et al. 2017).

The Oregon AQI surveys indicate that with the exception of the Minam River, LWD levels are below levels for naturally functioning habitats across reaches in all populations (e.g. White et al. 2017). At the reach level summarized in the Oregon AQI results, fine sediments are not a significant limiting factor on current spawning/rearing with one major exception, the mainstem Wallowa River.

6.4.1. Steps 1 & 2: Estimating life stage capacities using population specific fish and habitat data

The amount of habitat associated with current levels of spawning and summer rearing differed considerably across the four Grande Ronde Chinook population tributaries. We standardized each of the four data series to spawner and summer parr per 10,000 m^2 of pool habitat using estimates from the ODFW Aquatic Inventory (AQI) surveys. There were consistent patterns in relative densities (pools, runs and fastwater) across surveys, populations and years. For each population, we expressed the results as an AQI index of pool equivalent habitat by weighing the category habitat subtotals by the relative density index for each category (Table 6.4). We used the resulting population totals to standardize spawner and parr densities to a common unit of habitat. For Catherine Creek, we estimated an additional expansion factor to account for the use of habitat below the weir site for spawning and early rearing.

There were consistent differences in patterns of flow and temperature conditions across the four populations. The Catherine Creek and Upper Grande Ronde study reaches have lower summer flow and higher summer maximum temperature index values. The Lostine and Minam reaches are subject to higher flow levels and lower average maximum summer air temperatures than either the Upper Grande Ronde or Catherine Creek current natural production reaches.

In three of the four study populations the juvenile screw traps were below almost of the spawning and natal rearing habitat currently in use. The Lostine/Wallowa population is an exception, with spawning and associated rearing occurring in the mainstem Wallowa River and two tributaries in addition to the Lostine River (Bear and Hurricane Creeks). Direct estimates of juvenile production are not available for the production areas outside of the Lostine River. Since 1995, an average of 65% of the redds counted in the Lostine/Wallowa population have been above the weir and juvenile screw trap. We assumed that the juvenile production relationship per unit of pool habitat (ODFW AQI) derived from the Lostine smolt trap and parent escapement estimates applied to the other three current production areas.

6.4.1.1. Spawner to summer parr stage

We compared summer parr per spawner ratios (standardized to 10,000 m^2 AQI habitat) against the flow and temperature indices and against parent spawning densities. We used the 'nlsboot' routine in R to generate a data set of 1000 iterations of the fitted a and b parameters for each curve. We stored the resulting combinations of a and b parameters for use in the matrix model. The estimates of productivity, asymptotic parr capacity (per hectare of pool equivalent habitat) and the residual standard deviation are summarized in Table 6.5 and depicted in Figure 6.12. There were no significant trends in parr per spawner for the environmental indices tested. However, the estimates grouped by population did fall out at relatively distinct temperature levels. For each population, the relationship between parent spawner density and parr density was statistically significant. The standard errors for these estimates are relatively large. The per hectare estimates of summer parr capacity can be expanded to current population totals by multiplying by the AQI estimates from Table 6.4 . The resulting mle estimates of current total parr capacity range from a low of 88,300 for the Upper Grande Ronde to 481,800 for the Lostine section of the Wallowa/Lostine population. The estimate for the remaining populations were Catherine Creek (118,500) and Minam (351,300).

Low to moderate parent escapement levels relative to the range of escapements observed since the early 1950s have a large effect on the population data sets, with very few data pairs within the higher escapements in the range. The resulting fitted curve is representative of the production relationship with the range of recent escapements. It is uncertain how the weighting to lower escapement levels affects the projected shape of the fitted relationship at higher escapement levels.

6.4.1.2. Summer parr to spring tributary outmigrant stage

A portion of the juvenile Chinook rearing in each of the four Grande Ronde study populations emigrates downstream in the fall to overwinter before initiating seaward outmigration the following spring. The remainder stay upstream to overwinter, with the survivors emigrating in the spring. The proportion of the estimated population migrating downstream to overwinter below the migrant traps in each population area varied annually, but did not appear to be a function of summer parr density, juvenile length, summer temperature or flow. The average annual ratio of fall migrants to summer parr did vary across populations. The Upper Grande Ronde and the Minam had the lowest average ratios (0.12 and 0.19 respectively). Catherine Creek had the highest (0.37) followed by the Lostine (0.29). These ratios are influenced by several factors including placement of the migrant traps relative to habitat types utilized.

Survival between summer parr stage and the fall migration (peak in October) and winter parr in natal reaches is not directly estimated for either group. The Summer parr to spring survival estimates represent the aggregate fall and spring run components (Table 6.6, Figure 6.13). We made a simplifying assumption, that survival from spring migration from downstream overwintering areas to Lower Granite Dam was the same as the estimated survival to Lower Granite Dam for the natal overwintering group passing the smolt trap in the spring. This allowed us to estimate the total number of smolts leaving the tributary (survivors from the fall downstream re-distribution and the spring outmigration from the natal rearing areas). Both fall and spring length frequencies are strongly related to summer parr density (Figure 6.14), indicating the potential for density dependent effects at recent spawning levels.

6.4.1.3. Spring outmigrant to Lower Granite Dam stage

Population specific estimates of survival for the spring outmigrant to Lower Granite Dam were also evaluated as logistic regressions on parr density. The density dependent terms were not significant, the relationships incorporated into the life cycle were expressed as a constant multiplier with a randomly drawn error term reflecting the variability in each population series (Figure 6.15). The average estimated spring outmigration survivals averaged 0.40 and 0.42 for the Catherine Creek and Upper Grande Ronde populations respectively. The survivals for this stage were consistently higher for the two populations whose natal tributaries enter below the Grande Ronde Valley (Minam: 0.58 and Lostine 0.62). For several years in the study, ODFW operated a smolt trap and conducted pit tagging on outmigranting smolts below the two upper populations but above the Minam and Lostine. Migrating smolts intercepted and tagged at that trap survived at relatively high rates to Lower Granite Dam, indicating that the difference in survivals between the upper and lower populations resulted from factors within the Grande Ronde valley above Rhinehart Gap.

6.4.2. Step 3: Estimate habitat change inputs for the LCMs

The Grande Ronde LCMs were designed to accept estimated changes in specific life stage survivals and capacities. The primary input parameters used to model the scenarios described below are multipliers reflecting the expected changes in parr rearing capacity and outmigrant survivals. In the model, overwintering survival is linked to summer parr density reflecting the strong patterns in the empirical data sets for each population. A key working assumption of the approach is that the tributary stage production and survival relationships we derived from the 20 plus year adult spawner and juvenile data sets are related to the estimates of available habitat generated using the Oregon AQI data sets. We assume that habitat actions that would increase or decrease those levels over time would proportionally translate into changes from the derived parr capacities for each population.

6.4.2.1. Current habitat conditions

The current distribution of redds in Catherine Creek is largely restricted to reaches upstream of the ODFW weir site (Figure 6.16). Less than 5% of redds counted in annual surveys between 2009 and 2016 were below the weir site. While redd counts prior to 2009 were not georeferenced, ODFW did compile the counts by index reach. A larger proportion of redds were located in the reach extending downstream of the weir site to Union in the 1950-1970 period. Potential contributing factors include the impacts of major storm events on stream structure, increased human constraints on channel movement and side channel availability, and increasing summer temperatures.

The majority of redds in the Upper Grande Ronde population are in the upper sections above Sheep Creek (Figure 6.17). Current redd surveys do not cover the mainstem reach passing through Vey Meadows. The Vey Meadows reaches were included in surveys prior to the early 1990s. We extrapolated current estimates for the Vey Meadows reach using average proportions from ODFW surveys and Oregon AQI pool data obtained in the early 1990s. ODFW AQI surveys in Sheep Creek only covered a portion of the reach habitat designated as current spawning and rearing. We used results from historical gravel surveys in the drainage to extrapolate from the AQI survey totals within Sheep Creek to cover the remaining reaches. Both survey methods gave similar estimates of average proportion pools over the common survey reaches. The gravel survey average pool proportions above the AQI survey reach was roughly 50% of the gravel survey estimates for the AQI reaches. We assumed that the ratio of run to fastwater habitat for the remaining proportion total habitat was the same as in the AQI surveyed reach. We used the resulting estimated proportions to calculate a surrogate AQI estimate for the unsurveyed reaches. The lower reaches of Sheep Creek were also not sampled in either the 2010 or 2015 Oregon AQI survey. The NorWest temperature estimates for these reaches were relatively high, and there is evidence of local influence by hot springs flowing into the reach. We assumed that temperature conditions result in negligible use of lower Sheep Creek for Chinook spawning or summer rearing. The reach may support overwintering although this has not been confirmed.

In recent years, ODFW has included geo-referencing of individual redd count (2009-2016+) in their annual Spring Chinook redd surveys in the Grande Ronde basin. ODFW complemented their CHaMP/ISEMP summer parr snorkel surveys in 2015 by sampling contiguous reaches from near La Grande upstream to the upper reaches of the East Fork Upper Grande Ronde River. We contrasted the resulting adult spawning and parr density patterns with reach specific NORWEST derived August stream temperature and selected Oregon AQI variables (pool area, sediment constituents). In spite of the availability of pool habitat, the presence of redds dropped off rapidly with increasing stream temperature. For the Upper Grande Ronde, 95% of the geo-referenced redds were upstream of the reach where average NORWEST stream temperatures exceed 17.5 C (Figure 6.18).

In 2015 ODFW conducted extended longitudinal juvenile snorkel surveys the length of the mainstem Grande Ronde River from the town of La Grande upstream to the upper extent of use in the East Fork Upper Grande Ronde (Figure 6.19). Summer rearing and spawner distributions showed similar relationships to current stream temperatures. Summer juvenile rearing was negligible below Warm Springs Creek. Two of the four study populations (Upper Grande Ronde and Catherine Creek) exhibited relatively high temperatures at the downstream end of current use as defined by ODFW. Other variables quantified by ODFW in the Grand Ronde basin include reach level longitudinal surveys summarized by habitat type (Figure 6.20), sediment characteristics (Figure 6.21), and estimates of LWD.

Justice et al., (2017) developed a temporal model of the temperature influence of riparian canopy development and paired it with results from Heat Source model runs for the Upper Grande Ronde and Catherine Creek mainstems to generate projected temperature impacts of riparian restoration scenarios (Figure 6.22). Full benefit of restoring riparian shading on adjacent stream reach temperatures took up to 300 years of tree growth, but "..the most rapid reductions in temperature occurred within the first 25 years, with incremental reductions leveling off over time..". Using an example provided in Justice et al 2017, fully implementing the riparian restoration scenario in the upper Grande Ronde River would result in a potential reduction of 3.4 degrees C at full canopy development (~300 years). A 2.2 degree reduction is projected for the first 25 years (65% of full canopy). Temperatures would be reduced by an additional 0.7 deg. C between years 25 and 75 (reaching 85% of full potential reduction).

In addition to the effects of increased shading, restoring riparian conditions can also reduce stream temperatures through reductions in stream width towards estimated natural conditions (White et al. 2017). Reduced surface area translates into reduced solar heat flux into the stream over a given reach. We used the estimated potential for reduced stream widths projected in White et al., (2017) for large sections of the Grande Ronde and Catherine Creek as the basis evaluating restoration scenarios. The time period required for riparian restoration to result in changes in stream width is a function of both the level of departure of current riparian from natural levels and the relative degradation of the stream structure. In some cases, restoring historical widths through natural processes may not be possible or would require many decades, for example in situations where low gradient channels have been widened through a combination of historical in-channel scouring (e.g., splash dam effects) and extensive loss of natural riparian restoration. In those cases, restoring potential natural stream widths in a reasonable time period would require direct channel reconstruction. In these analyses we assume that restoration of riparian habitats in designated high/moderate priority reaches would result in stream widths returning to natural potential over a 15 year period through natural processes or through direct intervention where necessary.

6.4.3. Step 4: Develop historical, current and strategy-specific restoration scenarios.

The starting point for our analysis of tributary restoration scenarios were projections of population performance assuming that base period conditions within the tributary habitats of each population continue into the future. For Catherine Creek and the Upper Grande Ronde populations we also simulated the projected impacts of sequentially accounting for three additional levels of tributary habitat actions. This includes; inclusion of 2009-12 habitat actions, adding minimum target 2018-21 actions, including current five-year planned actions (2019-24 Table 6.7), a combination of actions to restore riparian habitats in the high/moderate priority reaches identified in Justice et. al 2017, and lastly flow and channel restoration actions called for in the 2017 NE Oregon Snake River Recovery Plan (Table 6.8). Longer-term restoration strategies for the Lostine/Wallowa population are under development through the ATLAS process and included in future LCM analysis.

We added another scenario to simulate the potential of additional habitat restoration downstream of current use to the Catherine Creek and the Upper Grande Ronde populations. The potential Chinook salmon increases from restoration in these downstream areas is currently limited due to distances from current spawning reaches and high temperatures. If the restoration scenarios described above result in a downstream expansion of current spawning and rearing, it is possible there would be a source of juveniles to utilize the relatively wide valley habitats below the area of current use. For the last scenario in the sequence, we assume that the current area production has been extended downstream sufficiently after 25 years. We assume that future restoration efforts would prioritize the areas downstream of current production.

6.4.3.1. 2009-16 tributary habitat actions

Catherine Creek habitat restoration actions implemented from 2009 to 2016 were designed to increase flows in a key rearing reaches, increase the amount of functional pool habitat through stream structure improvements, and restoration of floodplain side channel reconnections. Actions also included some riparian restoration in reaches high summer stream temperatures that currently impair or inhibit summer rearing. We reviewed and adopted the Grande Ronde Expert Panel assessments of the potential change in baseline conditions within Biologically Significant Reaches (BSRs) for incorporation into our LCM habitat effects analysis. The Expert Panel had characterized baseline conditions in each BSR using ODFW Aquatic Inventory survey data augmented by results from CHaMP studies in the basin. We used the same information to characterize current habitat conditions.

The focus of actions implemented from 2009 to 2016 was summer parr rearing capacity, which was identified as the most limiting life stage parameter. It is possible that after substantial habitat restoration efforts another factor (e.g. spawning capacity or overwintering capacity) could become limiting. Actions that improve conditions for summer parr rearing would also increase the capacity for spawning and overwintering capacity so it is not likely that benefits from improving summer parr rearing habitat would override other limitations. Baseline estimates of summer parr rearing were derived from analyzing the 20-year series of adult spawner and juvenile data sets available for Catherine Creek. We translated the impacts of actions to multipliers reflecting the proportional change from baseline habitat conditions. We assumed parr habitat capacities are a simple function of available pool habitat and prevalent stream temperatures. The actions implemented in Catherine Creek addressed five limiting factors directly related to parr rearing capacity: instream habitat complexity, bed channel and form, floodplain and side-channel access and functionality and stream temperature. The actions are projected to reduce fine sediment levels in the targeted stream reaches. The BOR maintained summaries of the results of the Grande Ronde Expert Panel review of the projected changes in those habitat factors for the collective actions in each Catherine Creek BSR. We accepted those proportional changes and accumulated them into three categories: habitat changes that would be relatively immediate (1-5 years to take full effect), intermediate (10-15 years) and long term (50-100 years). The Catherine Creek actions implemented between

2009 and 2016 primarily fell into the short-term category and included stream structure (lwd additions, pool construction), bed form enhancement (increased sinuosity), side channel/floodplain restorations and flow additions (increased pool capacity).

We expect longer-term benefits to accrue from riparian restoration that would increase shading in moderate to high temperature reaches, as well as, restore natural channel widths and depths. The benefits of restoring flows by 10 cubic feet/second (cfs) were estimated using data from CHaMP sampling in the Union to Davis Dam reach and analyzed using the CHaMP Workbench HIS model (Figure 6.23, from Horne memo). We express the effect of the action as a proportional increase in suitable pool habitat. The draft Recovery Plan also calls for restoring 3 miles of side channel or meander habitat. We assumed that reconnected or reconstructed channel habitats would occur in the same low gradient reach (Union to Davis Dam), and that the resulting additional channel habitat would average 80% pool frequency. We assumed these actions would increase the juvenile Chinook summer rearing capacity for the population, but that temperatures would not change from current ranges.

We express the proportional changes in population level parr capacity as a weighted percentage to illustrate the relative change from baseline. The actions producing relatively immediate habitat change result in an estimated 21% improvement in functional parr capacity. While the temperature reductions associated with shading would not fully occur for several decades, we expect shading levels to start contributing to temperatures reductions after 5 to 10 years. By year 25, the projected benefits of temperature reductions would further increase functional parr capacity by an additional 3% to 24% over baseline. Additional shading resulting from maturing riparian plantings are projected to further reduce temperatures at 48 years. The cumulative change in functional parr capacity would increase by 27% relative to baseline, an additional 3% increase from year 25 to year 48.

6.4.3.2. 2018-21 minimum action scenario:

The action agencies have committed to pursue additional actions within the Grande Ronde MPG, targeting the same strategic priorities as in the prior BioOp. While the action agencies are targeting higher levels of implementation, past experience indicates that several factors can result in unanticipated delays or require shifting actions among alternatives that are beyond their control. The action agencies have identified improvement targets for key habitat indicators for each major population group but have not provided specific proposed actions. For the purposes of this analysis, we assume that the targets would be achieved in the same populations that were prioritized in the 2000 Hydrosystem BioOp tributary habitat strategy. Assuming that they accomplish the minimum levels of habitat improvement they identify over the three years, the estimated short-term benefits would increase by approximately 2%. Adding in the initial benefits of longer-term actions would increase functional parr capacity at 24 and 48 years to 26 and 37% relative to the original baseline.

6.4.3.3. 2019-2024 Atlas 5-year action plan:

Participants in the Grande Ronde ATLAS project have identified a series of projects in Catherine Creek and Upper Grande Ronde for implementation in the next five years (Table 6.8). The estimated changes in LWD, total pools and large pool habitats within each project area correspond to current (30% to 70%) project designs provided by project implementers. Those estimates were generated by summarizing available GIS data layers, and digitizing features (both historical and active channels) from current LIDAR and aerial imagery (Figure 6.24). We assumed that the estimated increase in main channel pool habitat relative to the corresponding current Oregon AQI reach estimates represented proportional increases in the parr rearing capacity of the target reaches. For each Catherine Creek project, we assume that the estimates of increased pool habitat would be for the main channel and would represent a shift from current run and fastwater area for the target reach.

We made two simple assumptions to convert the linear meters of added side channel habitats projected for each project into increased juvenile rearing habitat. First, we multiplied the estimated additional side channel length by the average wetted width of mainstem habitat in the treatment reach. Second, we assumed that restored side channel habitat would contain 48 percent pool equivalent juvenile rearing habitat based on average side channel to mainstem information from other studies (Trinity River and Skagit River refs). We then applied the run, pool and fastwater proportions estimated from the 2010 and 2015 Oregon AQI surveys of side channel habitats (runs<.01, total pools = .46, fastwater = .53). We summed the post-action estimates of reach level parr densities after applying a temperature weighting factor based on the NorWeST current (1993-2011) stream temperature extrapolations as described above, assuming that side channels would have the same stream temperatures as the adjacent mainstem reaches.

Several of the proposed actions include restored floodplain linkages. Previous studies, including several within the Grande Ronde basin, suggest that restoring natural floodplain function can have important benefits to rearing and spawning habitat conditions in associated stream reaches (e.g. Torgersen et al, 2012, Ebersole et. al. 2003). It is likely that the combination of restoring floodplain connectivity, natural stream channel depths and riparian habitats envisioned by several of the actions modeled in this assessment will lead to positive improvements in localized temperature conditions. Quantified estimates of potential improvements resulting from floodplain reconnection are not included in this analysis because there are no adequate methods for quantifying those improvements based on projected conditions.

The proposed 2019-2024 Catherine Creek projects primarily target restoring or enhancing stream structure and expanding side channel habitats to support summer rearing and spawning. All of the projects are in priority restoration reaches identified through the Atlas process (Tier I either within current core spawning/rearing habitats or immediately downstream). Three of the projects are in the current core spawning and rearing reach above the current adult weir and juvenile screw trap sites upstream of the town of Union.

The most extensive of these, the Hall Ranch project, would treat approximately 3.6 km of current mainstem habitat along with associated floodplain habitats (Figure 6.24 A & B) and would notably involve shifting the highway currently limiting mainstem sinuosity and side channel formation. Based on the projected changes in pool habitat for those projects, parr rearing capacity would increase by approximately 26% over baseline conditions associated with the adult and juvenile data series used to estimate life stage parameters in the Catherine Creek LCM. The majority of the increase was projected to result from restoring 2.7 km of side channels.

The remaining two are located downstream between Union and the Pyles Creek confluence, a reach that currently supports juvenile rearing but negligible spawning. Under these actions effective pool habitat in the Union to Pyles Creek reach would project to increase by 16% due to the main channel structure and side channel restoration. Habitat in the Union to Pyles Creek reaches of Catherine Creek is currently degraded by current stream temperatures as well as by water withdrawals from May into September. The potential improvements in physical stream structure projected for this project would increase with proposed flow additions and with riparian restoration included in the 20-year habitat restoration scenario.

For the Upper Grande Ronde population, the proposed 2019-24 actions (Table 6.8) included mainstem channel and side channel restoration projects in three BSRs. Two projects in the East Fork reach (BSR 7) are intended to increase AQI pool equivalents by 17%, largely (95%) as a result of adding side channel habitat. Stream temperatures within this BSR are below the threshold of 18 deg C MWMT, resulting in no adjustment for temperature effects on parr rearing densities. Two additional BSRs support current spawning and rearing in the Upper Grande Ronde population. Sheep Creek (BSR 9) is a large tributary joining the mainstem Grande Ronde below BSR 7 in Vey Meadows. Actions to improve riparian habitats and to increase in-stream structure were implemented in 2009-2016 and are accounted for in the past action inputs described above. At this stage of its development, the new project proposal for additional work in Sheep Creek does not have enough information to quantify potential effects on habitat for input into the life cycle model.

The 2019-24 proposals include two projects in the mainstem below the Sheep Creek confluence (BSR 5). This is also a designated Tier I reach. One of the projects, the middle Grande Ronde canyon reach proposal, would treat approximately 13 km of relatively confined mainstem habitat to increase pool habitat area and restore local floodplain function. The primary objective of the project would be to use placement of LWD to promote localized accumulation of gravels which would lead to increased pool habitat and floodplain function. At this stage in its development, there is insufficient information to translate this action into projected habitat changes for model input. The other proposed project in this BSR would treat a 2.4 km reach downstream of the canyon, increasing pool habitat through mainstem structural enhancement and side channel additions. Based on the estimated improvements in pool area, the project would increase potential parr density in the BSR by 11%, most of the increase resulting from projected side channel access.

Current estimates of stream temperatures in this BSR are relatively high, reducing the potential parr capacities by 40-60% relative to the 18 degree MWMT threshold we incorporate into the modeling analysis. Neither of the proposed projects in this BSR explicitly include riparian restoration during the 2019-2024 implementation phase. Reducing stream temperatures by shading and channel effects associated with riparian restoration could substantially increase the potential parr density in this BSR over the projected increases modeled for the 2019-24 actions. The habitat in this BSR falls into the high/moderate priority reach category. As a result, the model projections under the 20-year high/moderate priority restoration scenario would include the combined effects of the proposed changes in pool availability and the potential for decreased temperatures through directed riparian restoration for this BSR.

The five-year action proposal includes two projects in the mainstem Grande Ronde downstream of current spawning and rearing. Current stream temperatures in the reaches targeted by these actions approach 25 deg. C., estimated as a lethal threshold for Chinook juveniles. In addition, the two projects are well below the downstream extent of current spawning. The current project description for the Longley Meadows project is insufficient to generate an estimated impact on habitat conditions. Projected impacts on pool and side channel availability are available for the Bird Track Springs project. While this project projects to increase available AQI pool equivalent habitat by 41% for the BSR, current temperatures result in negligible potential rearing in the reach or the BSR in general. The increased physical pool habitat would translate into increased juvenile capacity if stream temperatures can be reduced if additional riparian restoration in and above the target reach. Those reductions would also need to be sufficient to support a downstream extension of current spawning to serve as a source of juveniles. While it is unlikely that these projects would contribute to increased spawning/rearing capacities in the near future, there may be benefits to overwintering or outmigrating juveniles in the spring. At this point we do not have a sufficient understanding of the relationship of survival to local habitat conditions during those stages to quantify action effects.

6.4.3.4. 20 Year habitat restoration scenario:

It is important to put results of the habitat actions to be implemented in the relatively short time-frame of this biological opinion into the context of the effects of longer-term implementation of habitat actions. For instance, life-cycle modeling for the Grande Ronde and Catherine Creek populations shows that long-term habitat restoration can have marked effects. To illustrate the potential benefits of continued implementation of potential strategic habitat actions, we modeled a 20 year implementation strategy designed to address the structural changes called for in the Snake River Recovery Plan combined with restoring riparian conditions to those reaches identified as moderate or high priority by Justice et al. 2017. We assumed the implementation would be accomplished at a consistent pace over the 20 year period.

For this scenario we assume that the longer-term Catherine Creek actions explicitly called for in the NOAA Recovery Plan would be implemented over a fifteen year period. In addition, we assume that the high and medium priority riparian restoration reaches identified in Justice et al. 2017 will be replanted at a constant annual rate over the next 20 years. Translating the projected impacts into proportional changes from baseline conditions, the recovery plan short and intermediate response actions would result in an 84% gain in parr habitat capacity by year 24. This increase includes the projected benefits of the 2019-24 in-stream actions described above. The initial responses to riparian restoration would increase that gain to a projected 125% improvement in parr rearing capacity by year 24. Benefits from increasing shading and restoration of natural stream channel characteristics would continue to accrue over time, reaching 165% over baseline conditions 48 years out. The benefits projected for the shading corresponding to fully mature riparian tree heights at approximately 100 years out would increase to approximately 206% of baseline.

6.4.3.5. Upper Grande Ronde population:

Summer rearing habitat capacity is likely the most limiting life stage for Upper Grande Ronde population. The same habitat conditions that limit summer parr capacity (availability of large deep pool habitats, high summer temperatures) also impact adult holding/spawning usage. The primary actions implemented during the 2009-2016 period were aimed at restoring riparian habitat conditions. Based on the GR Expert Panel evaluations (link to BOR files), instream complexity across the reaches currently supporting natural production would likely increase by approximately 1% over baseline conditions due to improvements in channel structure (lwd placement). The main focus of restoration efforts during this period was bank stabilization and riparian restoration. Benefits from the actions implemented 2009-2016 were projected to contribute to increasing capacity through temperature reduction as shading levels increase. Based on the simple shade model outlined in Justice et al. 2017, functional parr capacity in the Upper Grande Ronde population would project to increase by 12% at year 24, and approximately 20% by year 48.

The 20-year continued habitat implementation scenario for the Upper Grande Ronde included a combination of active channel restoration, LWD placement and riparian restoration in reaches above Starkey identified as high or moderate priority by Justice et al. (2017). We summarized the potential changes in spawning/rearing effective capacity within BSRs. We assumed that LWD placement would address reach specific current vs. potential levels over the 20 year implementation period, expressing the results as a proportional increase in effective pool habitat. We assumed that the riparian restoration effort would be implemented at a constant rate over the 20 year implementation period. The modeled response was expressed as a change in effective pool habitat resulting from decreased temperatures and improved channel structure. Direct responses from temperature changes varied across the BSRs as a function of their respective current temperatures. The uppermost BSR (UGR 7: East Fork down to Meadowbrook confluence) exhibited current reach temperatures averaging below 18 deg. C., the level above which relative chinook density begins to decline. The next downstream reach (Meadowbrook Cr. confluence to Sheep Creek confluence) averaged 18 deg. C. We assumed that the riparian improvement benefits projected in these two reaches (Justice et al 2017) would be the result of improved channel/pool structure associated with restored natural riparian conditions. Current BSR average stream temperatures Sheep Creek and in the Sheep Creek to Warm Springs Creek confluence section of the mainstem Grande Ronde are at 20 and 21 deg. C. respectively. We assumed that riparian restoration in these two reaches would increase parr production capacity through a combination of increased shading leading to reduced stream temperatures and corresponding natural channel restoration.

The long-term restoration scenario analyzed for the Upper Grande Ronde population included two components; targeted restoration of pool and side channel habitat in sections of the Grande Ronde Mainstem downstream to Warm Springs Creek (current spawning and rearing) and riparian restoration. The stream channel restoration component of the long-term scenario targeted reaches in wider valley settings classified as meandering using the Beechie index (Beechie and Imaki 2014). We used the Oregon Aquatic Inventory survey data in a gis format to quantify the current levels of pool, run and fastwater area in 200m reach segments from the upper extent of spawning and rearing from the upper East Fork downstream to Warm Springs Creek. We estimated the median pool and riffle/run areas across the reaches classified as meandering and calculated the change in weighted AQI parr potential of doubling the proportion pools. We accounted for the reduction in fastwater habitat AQI parr potential in estimating the new total AQI parr potential (based on CHaMP sampling, fastwater habitats support approximately 20% of the potential for pool habitats). We assumed that increased pool habitat would be accomplished by combinations of LWD placement and channel manipulation appropriate for each reach. In addition to the increased parr habitat, we also assumed that restored floodplain connections would result in adding side channel habitat equivalent in area to the associated mainstem reaches for the same meander class reaches. We applied the average side channel pool proportions from the Oregon AQI survey data (Catherine Creek surveys, average proportion of 0.48).

The riparian restoration component targeted reaches classified as high/moderate priority (257% increase, Justice et al. 2017). We discounted that total by 20% assuming that the Vey Meadows reach would not be available for restoration during the 20 year implementation period. The discount level was derived from earlier Heat Source model-based sensitivity analysis that evaluated the impact on temperatures of leaving individual large contiguous sections of the Upper Grande Ronde unrestored (Justice 2014). We made some simplifying assumptions to model implementing sufficient riparian restoration to achieve the full increase as a result of actions implemented over a 20 year period. Key assumptions included: a constant rate of implementation (5% of high/moderate priority reach habitat addressed per year); riparian function for a given treated reach would increase over time consistent with the rate of shade development calculated in Justice et al. 2017; riparian habitats lost to grazing, flood scouring etc. would be replaced. The 20-year restoration strategy also included an assumption that LWD placement would continue to occur targeting the remaining high and moderate priority reaches. We used Expert Panel estimates of current vs. optimum LWD densities (they used comparable reaches in the Minam River as a reference for optimum). Average deficits across Upper Grande Ronde BSRs varied from 35-47%. We assumed LWD placement would reduce LWD deficits in target reaches by 50% in each BSR (excluding the Vey Meadows reach) and that would translate into a proportional shift from fastwater habitat to pool habitat over a 5 year period. The projected increases in parr production potential from implementing the tributary habitat improvements from the Upper Grande Ronde 20 year restoration scenario at 24 and 48 years would be +99% and +140% respectively. We generated results for a variation on the 20-year tributary habitat scenario by also including an improvement in Grande Ronde Valley migration survival of 50% under the assumption actions would be identified and implemented to reduce mortalities to the same levels as experienced by the two downstream populations (Lostine and Minam Rivers). We assumed those improvements would happen over a five year period beginning in year 15. Adding in the potential increase in survival gained by successfully addressing the high Grande Ronde Valley outmigration mortality would project to increase the cumulative improvements at 24 and 48 years to 199% and 262%.

6.4.3.6. Downstream of current use scenario:

We generated an additional scenario for both populations to illustrate the potential for further expansion of natural production into reaches below current spawning and rearing that are currently precluded by loss of historical rearing habitat and extremely high summer temperatures (Upper Grande Ronde) along with reduced summer flows (Catherine Creek). In both cases restoring production to these lower reaches would almost certainly require successful restoration of the upstream reaches targeted in the 20-year scenario in order to extend spawning downstream enough to generate juveniles to use newly restored habitat below current spawning/rearing range.

For Catherine Creek, the downstream scenario we modelled assumed that access to available deeper water habitats in Ladd Marsh that are currently isolated from the artificially redirected Catherine Creek channel could be reconnected (Figure 6.24 C). In addition, sufficient flow would need to be restored to the reach to ensure that access and egress for juvenile Chinook would be maintained.

Based on GIS analysis, the surface area of open water areas in Ladd Marsh that could potentially support juvenile rearing is approximately 49 hectares (citation). Based on reported values in the literature (citation), expected juvenile Chinook densities in moderately deep marsh habitat would be approximately 37% of mainstem pool habitats. Applying that proportion, adding Ladd Marsh would ultimately increase available juvenile rearing habitat by an additional 75% over the levels projected for the long-term restoration scenario.

For the Upper Grande Ronde, the phase II long term scenario targets riparian restoration along with channel and floodplain restoration work in the Starkey to Spring Creek reach. Current temperatures in this reach are high but potentially responsive to riparian restoration (Justice et al 2017). The floodplain widens considerably in this reach (Figure 6.24 D). There are existing pools and side channels but the habitat has been substantially degraded due to historical splash dam impacts and riparian habitat loss (White et al. 2017).

6.4.3.7. Lostine/Wallowa population:

Development of intermediate (e.g. 5 year) and long-term priority habitat restoration scenarios are underway but not sufficiently complete to incorporate into the current LCM analysis. Previous habitat assessments have highlighted substantial opportunities for restoration benefits in this population, especially in the mainstem Wallowa River. We are continuing to work with ATLAS project participants to develop restoration scenarios for future LCM assessment. We were able to model the incorporation of an approximate 3% improvement in parr rearing potential for the actions implemented as a result of the 2014 Biological Opinion mitigation actions.

6.4.3.8. Grande Ronde Valley Outmigrant Survivals

Although there is strong evidence for high mortalities associated with spring movements of smolts (both natural origin and hatchery releases) through the Grande Ronde Valley upstream of Rinehart Gap, the proximate causes are currently not understood (Favrot et al. 2018). Recent studies have suggested that one possible mechanism, floodplain and oxbow stranding, is not a significant source of mortality. Four other hypotheses identified include the following:

- excessive energetic costs resulting from high spring velocities in the bermed channels throughout the reach,
- disrupted migration cues resulting from the state ditch 'rerouting' of the main stem Grande Ronde,
- reverse flows upstream of Rinehart Gap resulting from the rerouting of the main stem that results in impacts on flow timing and accumulation,
- and some combination of delays in migration timing due to the flow changes and increased presence of northern pikeminnow.

To illustrate the potential impact of reducing mortalities in this reach we included scenarios for Catherine Creek and the Upper Grande Ronde populations that assumed that downstream survivals would be improved to levels that would be the same as the average for migrants entering from the Minam and Lostine systems. Those two systems enter the Grande Ronde below Rinehart Gap.

6.4.3.9. Habitat capacity projections:

The projected increases in juvenile rearing capacity for the range of scenarios run for the Catherine Creek and Upper Grande Ronde populations are depicted in Figure 6.25. The projections clearly illustrate some of the key assumptions behind the model inputs for habitat restoration actions. We assumed that each proposed action would be implemented proportionally over a 1 to 5-year time frame depending on the elements (LWD placement, moving a highway, etc.). Habitat responses to actions were also modeled using proportionate time frames (e.g., canopy development resulting from riparian replanting). The intent of this analysis was to generally contrast the potential magnitude of changes in habitat and associated changes in survival and production across a large range of habitat treatments. We recognize that this analysis doesn't capture the potential impacts of reach level variability in action implementation or habitat response.

For both populations the projected habitat response of implementing the proposed 2019-24 projects results in larger proportional increases than those associated with the past actions plus the minimum 2018-21 actions. The 2019-24 increases for Catherine Creek are proportionally larger, resulting in habitat capacity projections approaching the projections for full implementation of recovery plan stream structure and flow actions. The projected gain in juvenile habitat capacity for the Upper Grande Ronde for the long-term scenario (includes substantial additional riparian restoration) is large, reflecting the importance of reducing temperatures for this population (e.g. Justice et al 2017). The trend lines for the long-term scenarios also reflect the assumed development rate of canopy cover and the resultant stream surface shading. Under the implementation assumptions modeled, both the 2019-24 and the long-term tributary habitat scenarios result in increasing capacity over the initial 24 year period, potentially increasing abundance and reducing short-term quasi-extinction risks. The effect of reducing outmigrant smolt mortalities to equivalent levels estimated for the Lostine and Minam populations is also substantial.

6.4.4. Step 5: Use LCM to evaluate differences in fish production among scenarios

To evaluate short term effects, we focused on projected natural origin abundance and the risks of going below quasi-extinction thresholds over the first 24 years. We also evaluated the projected 10 year median natural origin abundance centered on simulation year 75 as a measure of response to habitat actions with longer term benefits (e.g., stream temperature benefits from riparian restoration). We summarized results over 500 iterations for each scenario to capture the impact of uncertainties in life stage parameters and annual environmental effects. The habitat scenarios were run under alternative assumptions regarding the potential impact of the increased spill hydropower regimes on latent mortality. For this summary we focused on the proportional changes in quasi-extinction risks and natural origin abundance across those latent mortality assumptions. The effects of the alternative latent mortality reduction assumptions are provided in the figures and tables.

Projected 24-year abundance and quasi-extinction risks differed across the five modeled Grande Ronde River basin spring Chinook populations (Figure 6.26 & Figure 6.27, Tables 6.10 and 6.11). The box outline in each graphic illustrates the middle 50% of modeled outcomes across the 500 runs for each scenario, the 'whiskers' capture 95% of the outcomes.

The 2014 model scenario reflects average habitat conditions prior to the effects of actions initiated after 2009 and 2014 Biological Opinion hydrosystem operations. The 2018 environmental baseline scenario incorporates three updates: changes to juvenile capacity and survival projected for tributary habitat actions implemented between 2009 and 2016; increases in adult mortality in the Lower Columbia River coincident with a large increase in the abundance of marine mammals and changes to hydropower operations resulting from implementation of the 2014 Federal hydropower system Biological Opinion. Projecting the impacts of the tributary habitat improvements forward results in a 14% improvement in natural origin spawner abundance for Catherine Creek and a negligible change for the Upper Grande Ronde population. Adding continued natural stock supplementation resulted in a small reduction in median natural origin spawners for each of the three populations. It is important to note that for the supplemented populations, adult returns from the natural origin broodstock hatchery releases also contribute to spawning. For example, the median projections for total spawners (natural origin plus hatchery supplementation returns) increased to 306, 182 and 792 for Catherine Creek, the Upper Grande Ronde and the Lostine/Wallowa River populations (Figure 6.28). From a wild stock return perspective, incorporating supplementation into the model runs resulted in reduction in the risks of gong below the 24-year quasi-extinction thresholds for both the Catherine Creek and Upper Grande Ronde River populations. Modeling the addition of the 2009-2016 habitat actions and the continuation of current natural stock supplementation programs further reduced extinction risks for the Catherine Creek and Upper Grande Ronde populations. The net impact of all three factors is projected to decrease average abundance by approximately 20% for each population. 24-year risks of going below QET dropped to 0.0-4.0% and 0.1-61% for QETs of 30 and 50 respectively. For the Upper Grande Ronde population, accounting for the effects of 2009-2016 habitat actions resulted in a modest reduction to a QET30 risk of 8.5-98.1%. The risk of going below a QET of 50 over the next 24 years remained very high (76-100%).

The 20-year habitat restoration strategies modeled for Catherine Creek and the Upper Grande Ronde River populations incorporate both an implementation and a habitat response time frame. Reducing stream temperatures is an important priority identified for habitat restoration actions in the Grande Ronde populations. Restoring riparian canopies associated with high priority reaches is a major mechanism for reducing temperatures. The benefits of increased shading will accrue over several decades as replanted riparian vegetation matures. We evaluated the longer term habitat restoration strategies over the initial 24 year period to estimate potential impacts on short-term abundance and risks of dropping below QETs. To capture the longer term benefits, we summarized the results across 500 runs for each long-term scenario at year 75 to capture the cumulative effects over time (Figure 6.29). We realize that there is considerable uncertainty about the applicability of the environmental variation assumptions when extended out 75 years, but the projects provide a means of indexing the relative effects of the alternative habitat under common sets of environmental assumptions. We summarize the projected natural origin spawners at year 75 for three of the longer-term habitat scenarios (a. 2019-24 actions; b.

20 year habitat & riparian high/moderate; c. scenario b plus restoration below current spawning/rearing) in Figure 6.29. Both Catherine Creek and Upper Grande Ronde populations are subject to recent increases in adult survival losses in the lower Columbia River attributed to increased marine mammal predation. The first three scenarios were run assuming the recent year increases are maintained into the future. The fourth scenario depicted in Figure 6.29 assumes that the survivals in the lower Columbia return to base period levels as a result of reduced marine mammal predation. Each of the four scenarios were run under the same set of hydrosystem operations assumptions as the 24 year runs to illustrate the combined impacts of habitat and hydrosystem actions and all included continuation of the current natural stock supplementation program and the sliding scale management schedule.

The general pattern of projected increases in abundance with increasing levels of habitat implementation were similar for the populations, as was the response to reduced lower Columbia River mortality. Although the full benefits of implementing the riparian area restoration strategies do not accrue for decades, the initial gains in shading associated with canopy growth did translate into increasing abundance and decreased QET risks projected for the initial 24 years. As would be expected, in each case the most substantial proportional increase was associated with going from the recent 5 year implementation to the 20 year continued habitat action scenarios (Tables 6.10 & 6.11). The range of assumptions regarding potential latent morality reductions resulting from decreased exposure to powerhouse effects in the hydrosystem varied across the scenarios, but generally ranged from 0 to 19%. The largest proportional benefits of the higher latent mortality response assumptions were for the 20 year long term tributary habitat vs. current baseline scenarios for Upper Grande Ronde (reduction to .26-06 under the range of potential change in latent mortality).

Projected natural origin abundance under the 20 year habitat restoration scenarios continued to increase past the initial 24 years in response to improving temperature and stream structure. Model projections of ten year geometric mean abundance centered on model year 75 increased incrementally across the long term habitat scenarios (Table 6.12, Figures 6.27 & 6.29). Under the 2024 habitat action plan scenario, the model runs for Catherine Creek projected a large proportional response (+63% relative to the 2018 baseline projections). Projections for the 2024 Upper Grande Ronde scenario were less than 10%. The difference can be explained by the larger emphasis in this strategy on channel restoration in reaches that currently have temperatures conducive to juvenile rearing in the Catherine Creek population. The 20 year high priority tributary habitat scenarios for both populations projected to double natural origin abundance for both populations. Addressing outmigration mortality in the Grande Ronde Valley doubled projected natural abundance again for both populations, resulting in 204% and 209% increases for Catherine Creek and Upper Grande Ronde, respectively. Improved spawning and rearing conditions in the downstream sections of current use resulting from the long term actions opens up opportunities to further extend production downstream. For the

Upper Grande Ronde population, the cumulative impact of the long term habitat scenario combining expansion into reaches downstream of Fly Creek, reduced Grande Ronde Valley migration mortality and returning Lower Columbia marine mammal mortalities to pre 2013 averages resulted in a 525% projected increase. The corresponding scenario for Catherine Creek resulted in a median proportional improvement of 527%.

Based on the distributions of projected abundance across the 500 replicates, the 75 year projected natural abundance estimates for scenarios including 20 year high priority habitat implementation, improved Grande Ronde Valley outmigration survivals and high latent mortality responses to spill resulted in exceeding a threshold of 750 spawners in 11-32% of the model projections. Adding Ladd Creek habitat restoration increased the proportions exceeding 750 to 22%-83% under alternative latent mortality reduction assumptions. Combining that habitat restoration scenario with a return to pre-2013 Lower Columbia River predation levels increased the proportions of runs exceeding 750 to 70-99%. While the increases in projected natural origin returns were substantial for the Upper Grande Ronde population, only the combination of all habitat actions with reduced predation and high latent mortality response resulted in any projected 75 year abundance estimates above 750 (7% of that scenarios replicates). 20-year restoration strategies for the Lostine Wallowa population have not been fully developed at this point. Previous studies have highlighted this population as having the highest restoration potential among Spring Chinook production areas in the Grande Ronde River basin (Mobrand & Lestelle, 1997). Extending the LCM analyses to cover specific 5 and 20-year habitat restoration strategies for the Lostine/Wallowa population would be a high near term priority.

The proportional increase in projected natural origin spawner abundance over all scenarios was the greatest for the Upper Grande Ronde population. For the Upper Grande Ronde population, the cumulative impact of the long term habitat scenario combining expansion into reaches downstream of Fly Creek, reduced Grande Ronde Valley migration mortality and returning Lower Columbia marine mammal mortalities to pre 2013 averages resulted in a 607% projected increase. The corresponding scenario for Catherine Creek resulted in a median proportional improvement of 529%. However, in absolute terms, the projected abundance for Catherine Creek showed the highest response. While none of the scenarios for either population resulted in more than a 50% chance of exceeding the core area minimum adult spawner threshold of 750, approximately 40% of the runs under the most optimistic scenario for Catherine Creek were above the target level.

Several simplifying assumptions were made in characterizing the potential effects of habitat actions within each of the restoration scenarios we analyzed. We assumed that actions within each Biologically Significant Reach (BSR) would target specific reaches where key factors (e.g., pool structure, riparian cover) were below optimal levels and that follow up efforts would be taken to restore action effects that might be negated by future events (e.g., major storm events, riparian grazing). We also assumed that riparian restoration would be implemented on a scale that would result in a change in local equilibrium stream temperatures. That requires implementing actions that would affect at least 2 contiguous kilometers of stream.

The life cycle models assume that the current life history characteristics of each population, including the proportions of juveniles moving into downstream rearing areas in the early spring and in the late fall would remain constant (i.e., would be drawn from the distributions derived from the 20+ year juvenile monitoring studies in each population area. It is possible that each population could adapt to future changes in temperature conditions by changing some or all of these basic life history features. At this time, we do not have a basis for projecting any such changes.

The results described above were all run under the assumption that future variations in climate conditions in the tributaries, the mainstem Columbia River and the ocean would have the same characteristics as the baseline timeframe. The Upper Grande Ronde population is particularly vulnerable to projected increases in summer stream temperatures given that a relatively high proportion of current rearing (Sheep Creek confluence to Warm Springs Creek confluence) is subject to summer temperatures of 17 deg. C or higher. Restoring riparian shading and natural channel form in this degraded reach would be an important hedge against potential climate change. Future climate change scenarios including alternative assumptions for ocean survivals are being developed. Running the Grande Ronde LCM models with those alternative climate scenarios incorporated will be a priority in the near future.

Table 6.1. Grand Ronde River Basin LCM input parameters summary.

Life stage	Function	Derivation	Parameter Uncertainty	Variance
Spawner to parr	Beverton-Holt	R nls package	Bootstrap	Lognormal
Fall parr to spring migrant	Logistic on density	R nls package	Maximum likelihood	Lognormal
Spring migrant to Lower Granite (LG) dam	Logistic on density	R nls package	Maximum likelihood	Lognormal
Juvenile Columbia River migration	Random draw most recent 10 years	Annual system survival estimates		
Ocean: First year	Random start to fixed series with random error component	Multiple regression	Poor ocean conditions, recent ocean conditions, long-term ocean conditions	Lognormal
Ocean: years 2 through 5	Constant	0.8	No	
Harvest	U.S. V. Oregon sliding scale		Management error	Lognormal
Broodstocking	Catherine Creek Schedule	HGMP	Management error	Lognormal

Table 6.2. Proposed restoration actions for years 2018 – 2024 within the current Spring Chinook spawning and rearing domain in the Upper Grande Ronde River and Catherine Creek populations. Segment number corresponds to segment number on map in figure 9.

Seg #	River	Reach Name	Flood-plain Acres	Stream miles	In-stream flow (CFS)	Sin-uosity	LWD pieces / 100m	Total pools / km	Larges pools / km	Side channel (meters)
1	Catherine Creek	Catherine Creek 37 LWD	0	0.7	0	-	TBD	-	-	-
2	Catherine Creek	Catherine Creek Red Mill Reach	9	2.5	0.24	TBD	TBD	TBD	TBD	TBD
3	Catherine Creek	Catherine Creek State Parks	8	0.62	0	1.1	18	17	4	625
4	Catherine Creek	Catherine Creek Hall Ranch	123	2.25	0	1.3	22	15	5	5,000
6	Catherine Creek	Catherine Creek LDS Camp	8	1.2	0	1.1	40	10	5	0
6	Sheep Creek	Sheep Creek	85	4.5	0	-	20.7	-	-	TBD
7	Upper Grande Ronde River	UGR Longley Meadows/Gun Club	75	1.6	0	TBD	TBD	TBD	TBD	TBD
8	Upper Grande Ronde River	Bird Track Springs	114	1.8	0	1.3	84	31	31	1770
9	Upper Grande Ronde River	Upper Grande Ronde Bowman Property	27	1.5	0	1.1	50	18	5	804
10	Upper Grande Ronde River	UGR River Canyon	60	8.1	0	-	36	-	-	TBD
11	Upper Grande Ronde River	Woodley Campground	30	2	0	>1.2	27	8	4	690
12	Upper Grande Ronde River	UGR Mine Tailings	50	3	0	>1.2	35	8	4	776

Table 6.3. Current habitat conditions for Large Woody Debris (LWD) and pool frequency at proposed restoration reaches. Habitat data comes from Aquatic Inventories Project reports, USFS Level 2, and Columbia Habitat Monitoring Program (CHaMP).

Segment #	River	Reach Name	LWD pieces/100m	Pools/km	Large pools/km
1	Catherine Creek	Catherine Creek 37 LWD	3.8	10	5.9
2	Catherine Creek	Catherine Creek Red Mill Reach			
3	Catherine Creek	Catherine Creek State Parks	7.6	16.1	3.3
4	Catherine Creek	Catherine Creek Hall Ranch	12.3	10.7	1.5
5	Catherine Creek	Catherine Creek LDS Camp	8.7	4.7	1.4
6	Sheep Creek	Sheep Creek	24.7	18.9	0.4
7	Upper Grande Ronde River	UGR Longley Meadows/Gun Club	1	8..8	0.4
8	Upper Grande Ronde River	Bird Track Springs	3.1	18.7	0.8
9	Upper Grande Ronde River	Bowman Property	3.7	16.3	1.0
10	Upper Grande Ronde River	UGR River Canyon	15	29.3	1.0
11	Upper Grande Ronde River	Woodley Campground	27	52.6	1.1
12	Upper Grande Ronde River	UGR Mine Tailings	15.4	46.8	2.0

Table 6.4. Amounts of tributary spawning and rearing habitat in reaches used for spawning and juvenile rearing above juvenile weirs. Based on estimated area of pool, run, and fast water habitat multiplied by relative parr density observed CHaMP/ISEMP snorkel surveys.

	Habitat area (X 10,000 m2)				
	Catherine Creek	Upper Grande Ronde River	Lostine River	Minam River	Relative Density Index
Pools	7.613	5.004	3.482	15.536	1.00
Runs	1.199	1.906	4.603	5.367	0.35
Fastwater	18.454	27.079	29.764	29.764	0.24
Total	27.266	33.989	37.849	50.667	
Weighted Total	12.44	12.13	12.21	24.53	

Table 6.5. Beverton Holt parameters fitted to ODFW 1992-2016 annual adult spawning and parr abundance estimates. Spawner and parr estimates were standardized to 10,000m2 pool equivalent habitat. Parameters generated using the R statistical package *nls* routine.

Model	BevHolt 'a' (se)	exp(a)	BevHolt 'b' (se)	sigma
Catherine Creek	6.326	558.9165	9,528	0.452
	(0.258)		(5,162)	
Upper Grande Ronde River	6.287	537.5383	7279	0.439
	(0.351)		(5,269)	
Lostine River	5.918	371.6676	28,770	0.440
Minam River	6.181	483	19,640	0.542

Table 6.6. Logistic regression results for summer parr to spring migrant stage survivals vs. summer parr density.

Population	Stage	Intercept	parr density term	signif. Level	sigma
Catherine Cr.	summer to spring	-0.575	-9.61E-05	0.0058	0.420
Upper GR	summer to spring	0.100	-1.30E-04	0.0422	0.470
Lostine R.	summer to spring	-0.856	-2.89E-05	0.0004	0.182
Minam R.	summer to spring	-0.865	-5.31E-05	0.0502	0.388

Table 6.7. Catherine Creek Recovery Plan habitat actions.

Action	Upstream of Union	Downstream of Union	Implementation time frame	Response time frame
Flow Restoration	2 cfs	10 cfs addition through reach	5 years	Immediate increase in rearing pool habitat
Channel structure	Km44 project + 2 more equivalent. reaches	Restore 3 miles of side channel & floodplain	Proportional over 15 years	0-5 years
Riparian restoration	High/moderate reaches:	High/moderate reaches	Proportional over 20 years	% of max. shading benefits 40% @ yr 25, 85% @ yr 85

Table 6.8. Proposed 2019-24 action descriptions. Catherine Creek and Upper Grande Ronde River populations.

Segment #	River	Reach Name	Floodplain Acres	Stream miles	CFS Dedicated Instream	Sinuosity	LWD pieces/100m	Total pools/km	Larges pools/km	Side channel (meters)
1	Catherine Creek	Catherine Creek 37 LWD	21	0.75	0	1.38	15	7	2	119
2	Catherine Creek	Catherine Creek Red Mill Reach	13	1.44	0.24	1.4	35	20	8	1136
3	Catherine Creek	Catherine Creek State Parks	8	0.62	0	1.1	18	17	4	625
4	Catherine Creek	Catherine Creek Hall Ranch	123	2.25	0	1.3	22	15	5	5,000
6	Catherine Creek	Catherine Creek LDS Camp	8	1.2	0	1.1	40	10	5	0
6	Sheep Creek	Sheep Creek	85	4.5	0	-	20.7	-	-	TBD
7	Upper Grande Ronde River	UGR Longley Meadows/Gun Club	75	1.6	0	TBD	TBD	TBD	TBD	TBD
8	Upper Grande Ronde River	Bird Track Springs	114	1.8	0	1.3	84	31	31	1770
9	Upper Grande Ronde River	Upper Grande Ronde Bowman Property	27	1.5	0	1.1	50	18	5	804
10	Upper Grande Ronde River	UGR River Canyon	60	8.1	0	-	36	-	-	TBD
11	Upper Grande Ronde River	Woodley Campground	30	2	0	>1.2	27	8	4	690
12	Upper Grande Ronde River	UGR Mine Tailings	50	3	0	>1.2	35	8	4	776

Table 6.9. Catherine Creek population. Projected 24 year natural abundance and quasi-extinction risks for alternative habitat restoration scenarios (5,25,50,75 and 95 percentiles over 500 simulations). 2018 Baseline scenario includes increased Lower Columbia predation rates, ongoing hatchery supplementation and current mainstem harvest schedule. Habitat action scenarios are modeled under current 2018 proposed hydrosystem spill operations constrained by 120 gas cap. Habitat scenarios: 2020 – 2018-2020 actions at minimum annual rate; 2024 – current Grande Ronde Model Watershed proposed 2019-24 actions; HabLT – 20 year implementation of high/moderate priority reaches plus recovery plan actions; HabLT+DS – HabLT plus improved valley outmigration survivals.

Catherine Creek 24 year scenarios

	Median Abundance Year 24					Quasi-Extinction Risks QET=30					Quasi-Extinction Risks QET=50				
	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%
2018 Baseline	91	118	140	165	206	0	0.002	0.004	0.011	0.044	0.013	0.058	0.139	0.269	0.609
+Spill 120	91	117	138	165	204	0	0.002	0.004	0.011	0.037	0.013	0.052	0.117	0.252	0.574
+2020 Hab	91	119	142	168	211	0	0.001	0.004	0.010	0.034	0.013	0.051	0.122	0.256	0.540
+10% Latent Mort.	99	130	151	179	224	0	0.001	0.003	0.008	0.034	0.009	0.036	0.089	0.191	0.444
+25% Latent Mort.	106	140	166	199	246	0	0.001	0.002	0.006	0.024	0.005	0.022	0.060	0.130	0.406
+50% Latent Mort.	126	162	192	231	292	0	0.000	0.001	0.004	0.018	0.002	0.010	0.028	0.064	0.185
+2024 Hab	108	140	165	199	251	0	0.001	0.002	0.004	0.016	0.005	0.019	0.051	0.112	0.328
+10% Latent Mort.	115	148	179	211	267	0	0.000	0.001	0.003	0.015	0.003	0.014	0.036	0.082	0.247
+25% Latent Mort.	125	165	196	235	293	0	0.000	0.001	0.003	0.012	0.002	0.008	0.020	0.053	0.183
+50% Latent Mort.	149	190	226	276	346	0	0.000	0.001	0.002	0.008	0.001	0.004	0.011	0.026	0.087
+LTH Hab	111	146	175	210	268	0	0.000	0.001	0.004	0.015	0.003	0.015	0.038	0.098	0.254
+10% Latent Mort.	121	155	188	227	285	0	0.000	0.001	0.003	0.017	0.002	0.011	0.029	0.066	0.234
+25% Latent Mort.	136	175	206	246	319	0	0.000	0.001	0.002	0.012	0.002	0.007	0.018	0.040	0.153
+50% Latent Mort.	154	201	241	292	370	0	0.000	0.000	0.002	0.008	0.001	0.003	0.008	0.021	0.076
+LTH&DS Hab	133	172	204	245	321	0	0.000	0.001	0.003	0.008	0.002	0.009	0.022	0.050	0.152
+10% Latent Mort.	146	188	221	266	342	0	0.000	0.001	0.003	0.012	0.001	0.006	0.015	0.036	0.106
+25% Latent Mort.	158	206	245	297	376	0	0.000	0.001	0.002	0.013	0.001	0.004	0.010	0.026	0.086
+50% Latent Mort.	184	240	288	340	440	0	0.000	0.001	0.002	0.007	0.000	0.002	0.005	0.012	0.038

Table 6.10. Upper Grande Ronde River population. Projected 24 year natural abundance and quasi-extinction risks for alternative habitat restoration scenarios (5,25,50,75 and 95 percentiles over 500 simulations). 2018 Baseline scenario includes increased Lower Columbia predation rates, ongoing hatchery supplementation and current mainstem harvest schedule. Habitat action scenarios are modeled under current 2018 proposed hydrosystem spill operations constrained by 120 gas cap. Habitat scenarios: 2020 – 2018-2020 actions at minimum annual rate; 2024 – current Grande Ronde Model Watershed proposed 2019-24 actions; HabLT – 20 year implementation of high/moderate priority reaches plus recovery plan actions; HabLT+DS – HabLT plus improved valley outmigration survivals.

Upper Grand Ronde Natural Origin

	Median Abundance Year 24					Quasi-Extinction Risks QET=30					Quasi-Extinction Risks QET=50				
	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%	5%	25%	50%	75%	95%
2018 Baseline	35	47	57	67	86	0.085	0.390	0.653	0.891	0.982	0.763	0.975	0.994	0.999	1.000
+Spill 120	35	45	57	67	85	0.097	0.412	0.684	0.902	0.985	0.774	0.976	0.995	0.999	1.000
+2020 Hab	35	47	57	67	87	0.089	0.409	0.676	0.883	0.983	0.789	0.976	0.995	0.999	1.000
+10% Latent Mort.	38	51	62	73	93	0.062	0.261	0.542	0.811	0.965	0.638	0.948	0.988	0.998	1.000
+25% Latent Mort.	43	55	67	80	102	0.032	0.154	0.382	0.689	0.930	0.422	0.881	0.971	0.995	1.000
+50% Latent Mort.	51	65	78	92	117	0.010	0.067	0.183	0.410	0.797	0.170	0.701	0.899	0.977	0.998
+2024 Hab	37	50	60	73	94	0.045	0.266	0.540	0.811	0.976	0.593	0.949	0.989	0.998	1.000
+10% Latent Mort.	40	54	65	77	99	0.031	0.188	0.413	0.705	0.943	0.435	0.908	0.979	0.996	1.000
+25% Latent Mort.	47	62	72	86	112	0.015	0.096	0.247	0.516	0.857	0.226	0.785	0.942	0.986	0.999
+50% Latent Mort.	53	71	84	99	129	0.006	0.035	0.100	0.281	0.743	0.068	0.457	0.794	0.949	0.997
+LTH Hab	44	60	75	88	117	0.009	0.075	0.192	0.502	0.913	0.125	0.747	0.920	0.988	0.999
+10% Latent Mort.	49	67	81	96	127	0.007	0.046	0.126	0.369	0.850	0.081	0.544	0.846	0.970	0.999
+25% Latent Mort.	57	75	91	105	141	0.003	0.022	0.066	0.215	0.622	0.036	0.339	0.672	0.918	0.994
+50% Latent Mort.	66	87	104	123	162	0.001	0.009	0.025	0.080	0.367	0.010	0.120	0.353	0.728	0.973
+LTH&DS Hab	50	72	87	102	139	0.004	0.029	0.080	0.241	0.786	0.040	0.406	0.735	0.942	0.998
+10% Latent Mort.	57	77	93	112	154	0.002	0.019	0.057	0.183	0.597	0.017	0.242	0.614	0.904	0.992
+25% Latent Mort.	65	88	106	125	163	0.001	0.009	0.024	0.081	0.420	0.010	0.111	0.329	0.747	0.981
+50% Latent Mort.	75	102	122	146	190	0.001	0.003	0.011	0.033	0.173	0.003	0.030	0.139	0.426	0.907

Table 6.11. Catherine Creek and Upper Grande Ronde River Projected 10 year geometric mean natural origin abundance at model year 75 for long-term habitat restoration scenarios scenarios (5,25,50,75 and 95 percentiles over 500 simulations). All scenarios include 120 gas cap spill and ongoing natural stock supplementation. Habitat action scenarios: 2024 – current Grande Ronde Model Watershed proposed 2019-24 actions; HabLT – 20 year implementation of high/moderate priority reaches plus recovery plan actions; HabLT+DS – HabLT plus improved valley outmigration survivals. LaddHab & BelowFlyHab include actions below current use areas initiated in model year 25.

Catherine Creek

	5%	25%	50%	75%	95%
2024Hab+Spill	158	195	221	253	309
+Spill+10%	175	210	238	274	338
+Spill+25%	198	236	268	309	383
+Spill+50	226	274	318	374	470
LHab+Spill	199	247	282	330	411
+Spill+10%	224	269	308	356	450
+Spill+25%	249	302	352	414	510
+Spill+50	291	368	427	488	604
+DSS+Spill	319	398	462	534	668
+spill+10%	347	443	505	583	719
+Spill+25%	412	491	562	660	811
+Spill+50	468	586	668	790	965
+LaddHab+Spill	435	540	622	733	892
+Spill+10%	476	588	678	800	985
+Spill+25%	539	672	771	907	1084
+Spill+50	652	798	920	1058	1317
+Red. Pred+Spill	579	732	838	984	1228
+Spill+10%	633	802	912	1074	1362
+Spill+25%	732	909	1038	1215	1487
+Spill+50	857	1058	1226	1416	1766

Upper Grande Ronde River

	5%	25%	50%	75%	95%
2024Hab+Spill	29	45	55	64	80
+Spill+10%	36	51	61	70	87
+Spill+25%	44	60	70	81	100
+Spill+50	59	74	84	96	118
LHab+Spill	65	90	108	125	155
+Spill+10%	74	102	121	140	176
+Spill+25%	90	120	138	160	195
+Spill+50	114	144	167	192	235
+DSS+Spill	106	143	167	194	237
+spill+10%	120	159	185	213	271
+Spill+25%	144	183	209	246	299
+Spill+50	174	219	252	294	361
+BelowFlyHab+Spill	168	219	254	296	355
+Spill+10%	190	240	277	324	397
+Spill+25%	215	272	316	360	456
+Spill+50	260	330	376	444	581
+Red. Pred+Spill	226	289	341	392	510
+Spill+10%	250	314	361	445	554
+Spill+25%	287	351	424	502	650
+Spill+50	343	436	521	630	776

Figure 6.1 From Anderson et al (2011). Location of fish traps in the Grande Ronde River Subbasin during the study period. Shaded areas delineat spring Chinook salmon spawning and upper rearing areas in each study stream. Dashed lines indicate Grande

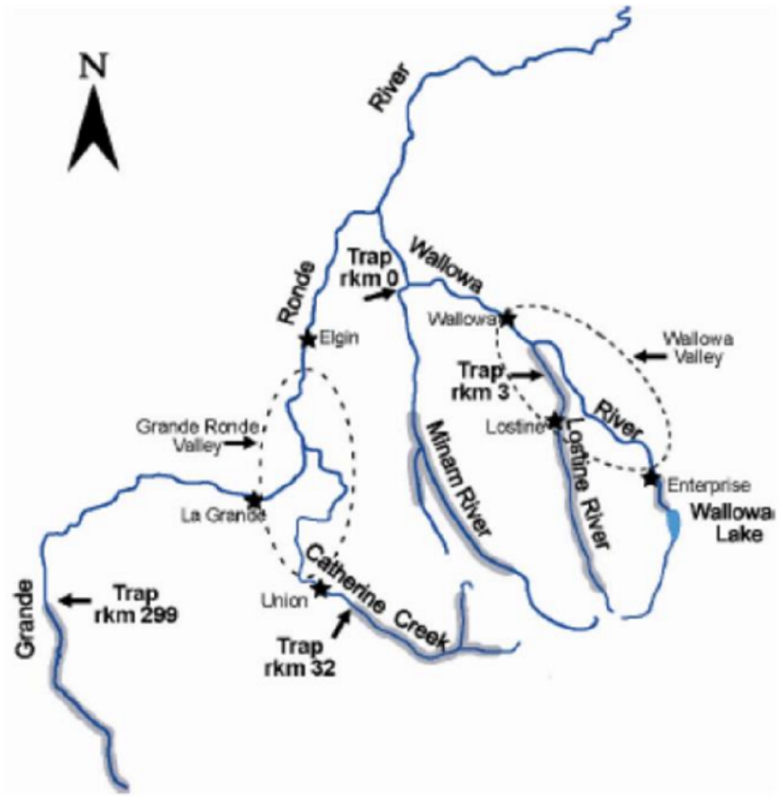


Figure 6.2. Tributary life history stage survivals and abundance estimates used to estimate current baseline model parameters.

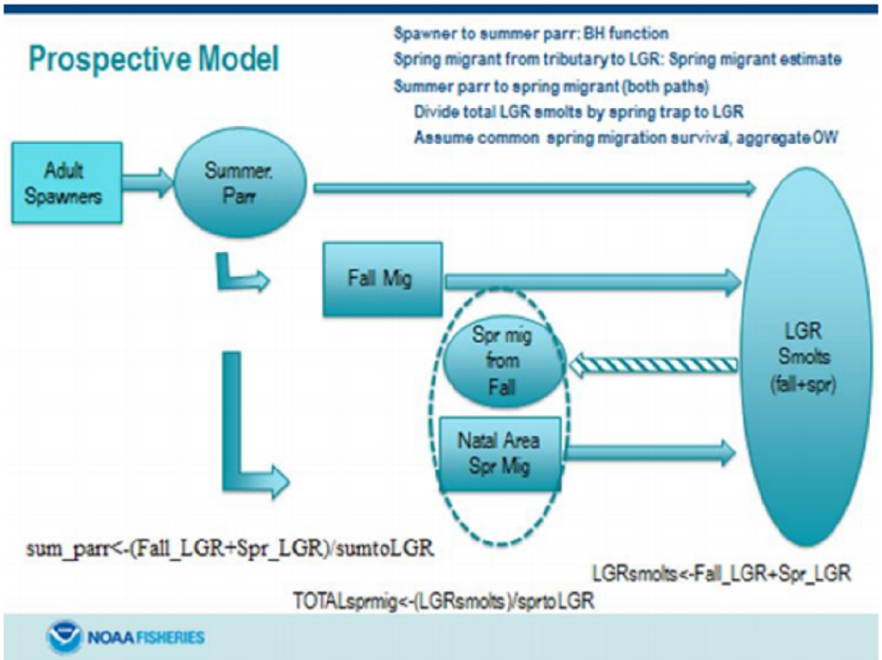


Figure 6.3. Study area, stream classification, and historical changes to channel widths in three focal watersheds. Location of study watershed in northeast Oregon including (A) major salmon-bearing tributaries and the stream classification described in the methods and (B) values of channel change estimates where historical General Land Office surveys intersected with contemporary Aquatic Inventory Program surveys. Focal watersheds include the upper Grande Ronde River, Catherine Creek, and Minam River. The upper Grande Ronde River and Catherine Creek have significantly modified stream conditions from over a century of intensive land use. The Minam River is in the Eagle Cap Wilderness area and most approximates historical reference conditions. (From White et al. 2017).

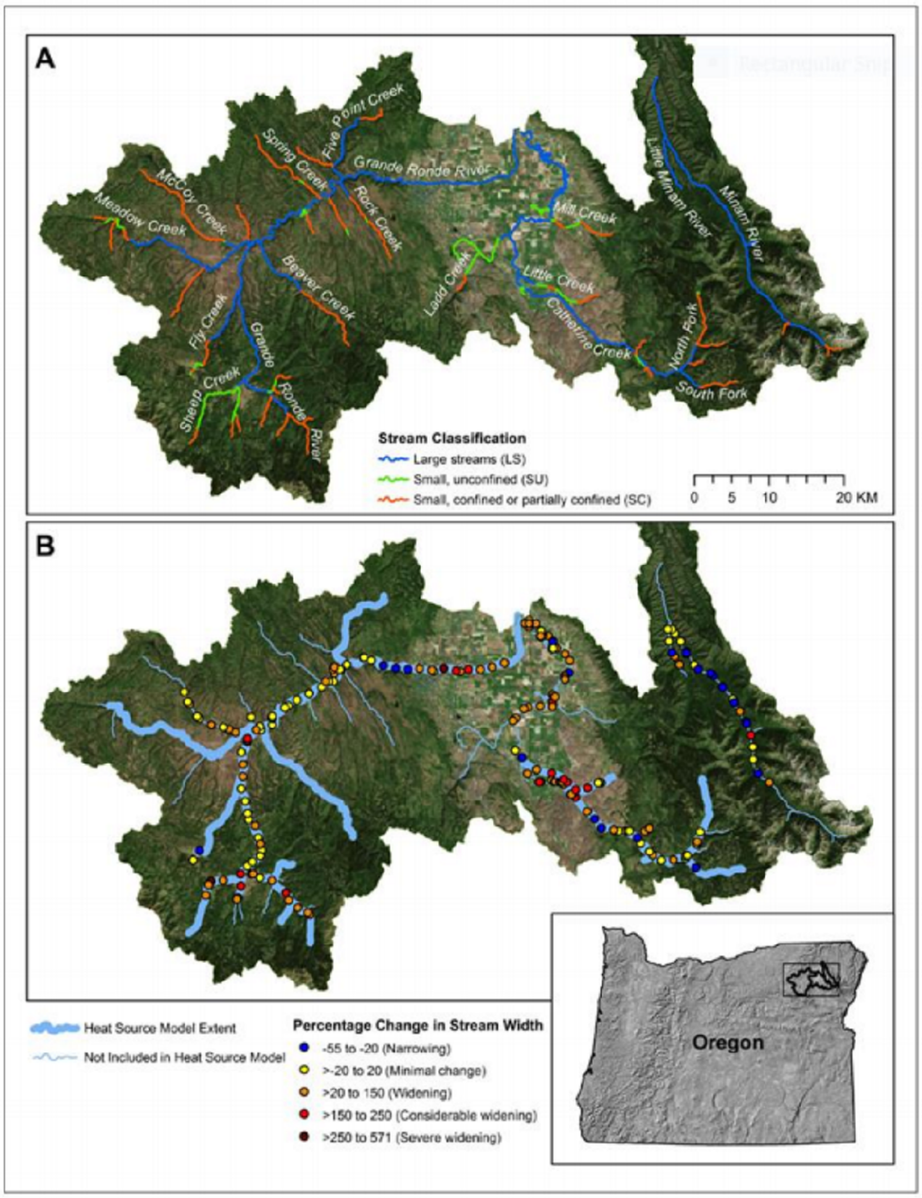


Figure 6.4 Percentage stream length below biological water temperature thresholds for model scenarios. Estimated percentage of stream length below critical salmon and steelhead thresholds for maximum weekly maximum water temperatures (MWMT) in the upper Grande Ronde River and Catherine Creek watersheds combined. Model scenarios represent current conditions (Current), restored channel width (Width), restored potential natural vegetation (PNV), and the combination of vegetation and channel width restoration (Width_PNV) (from White et al. 2017.)

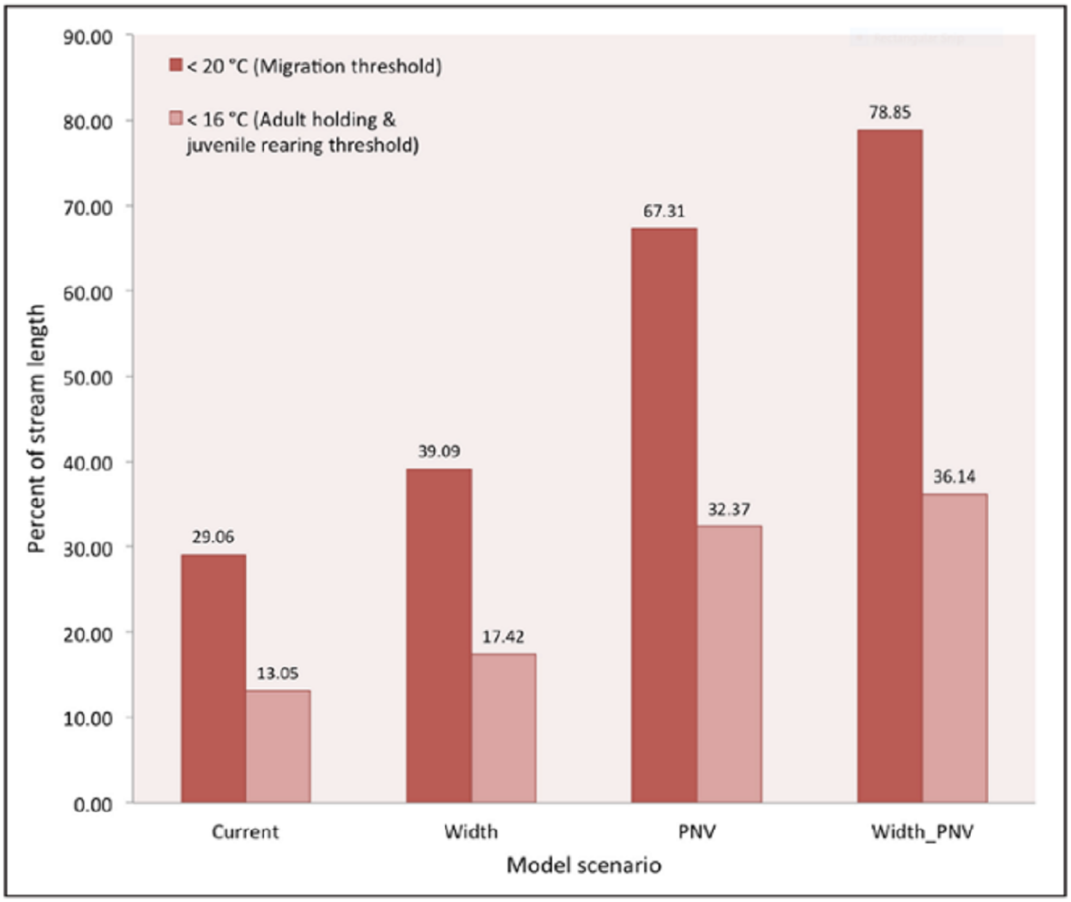


Figure 6.5. Simulated maximum weekly maximum water temperature (MWMT) in the mainstem Grande Ronde River from the headwaters to the Catherine Creek confluence for four model scenarios including current conditions, 2080s climate conditions, 2080's climate conditions plus riparian vegetation restoration, and 2080's climate conditions plus riparian and channel width restoration from Justice et al. 2017.

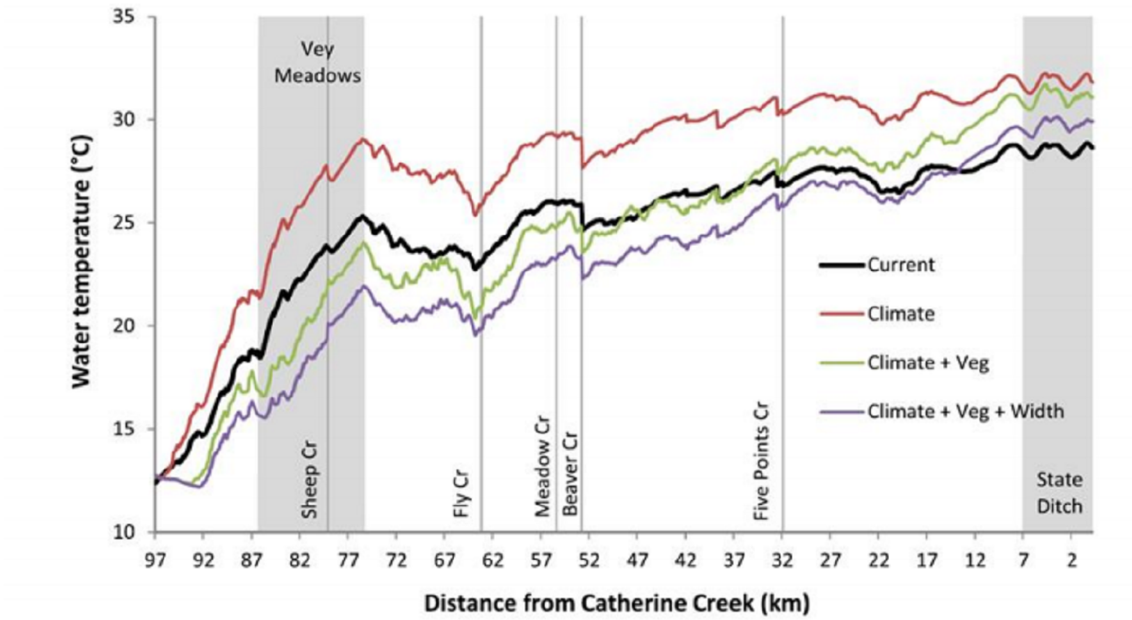


Figure 6.6. Predicted abundance of Chinook Salmon summer parr for each model scenario in (a) the Upper Grande Ronde River, and (b) Catherine Creek basins. Numbers at the top of each bar indicate the percentage change in abundance from the current condition (Justice et al. 2017).

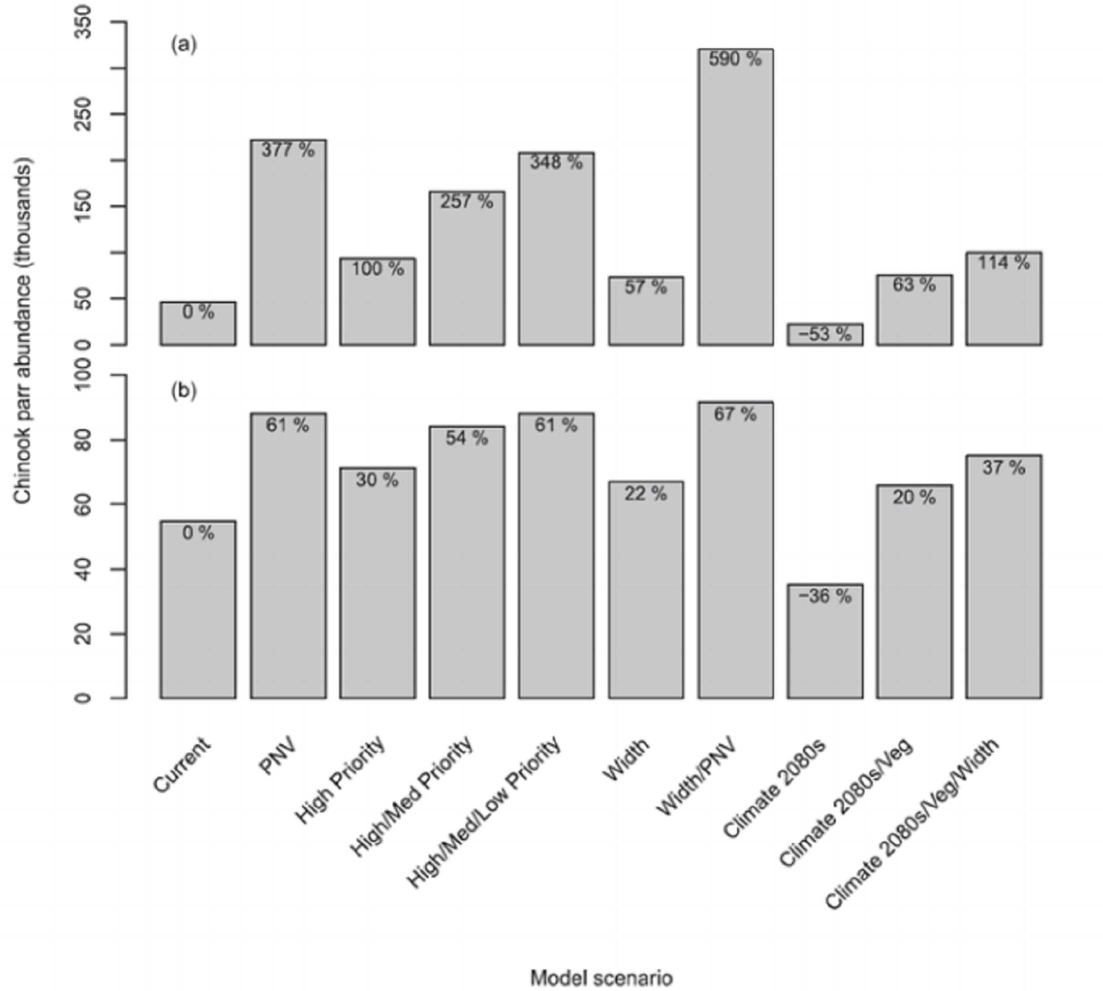
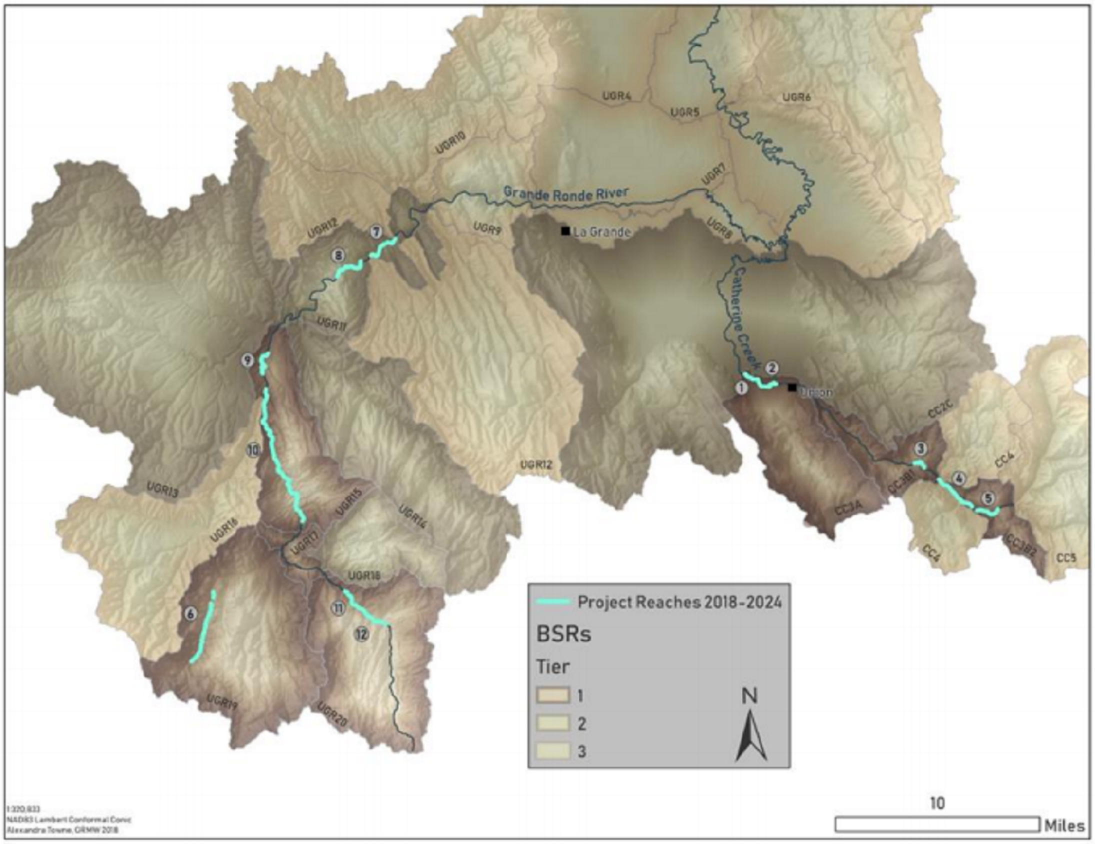


Figure 6.7. Stream restoration project areas in the Upper Grande Ronde River. Projects are slated for construction in 2018 – 2024. Numbers correspond with the segment number in tables 7 and 8.



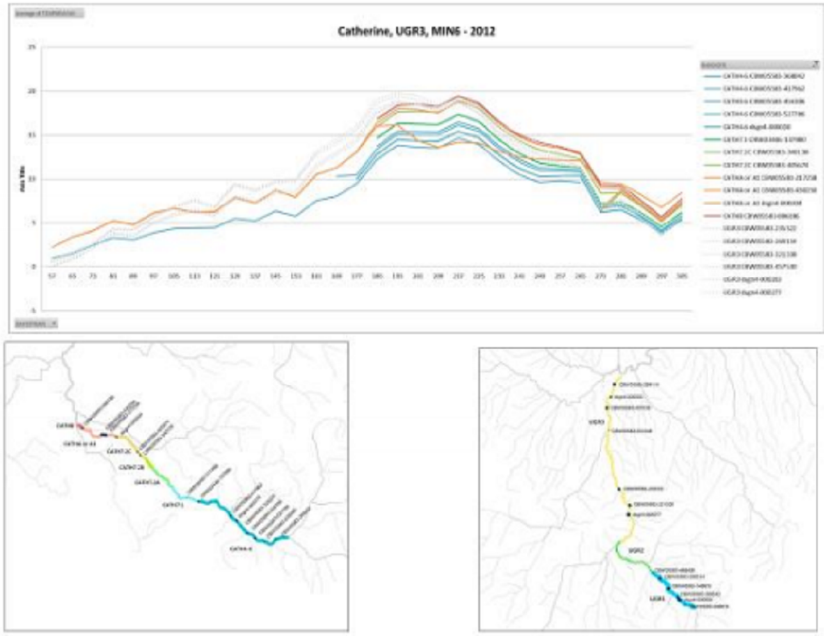


Figure 6.8. Within year instream temperature estimates from CHaMP/ISEMP sampling sites in Grande Ronde Spring Chinook populations

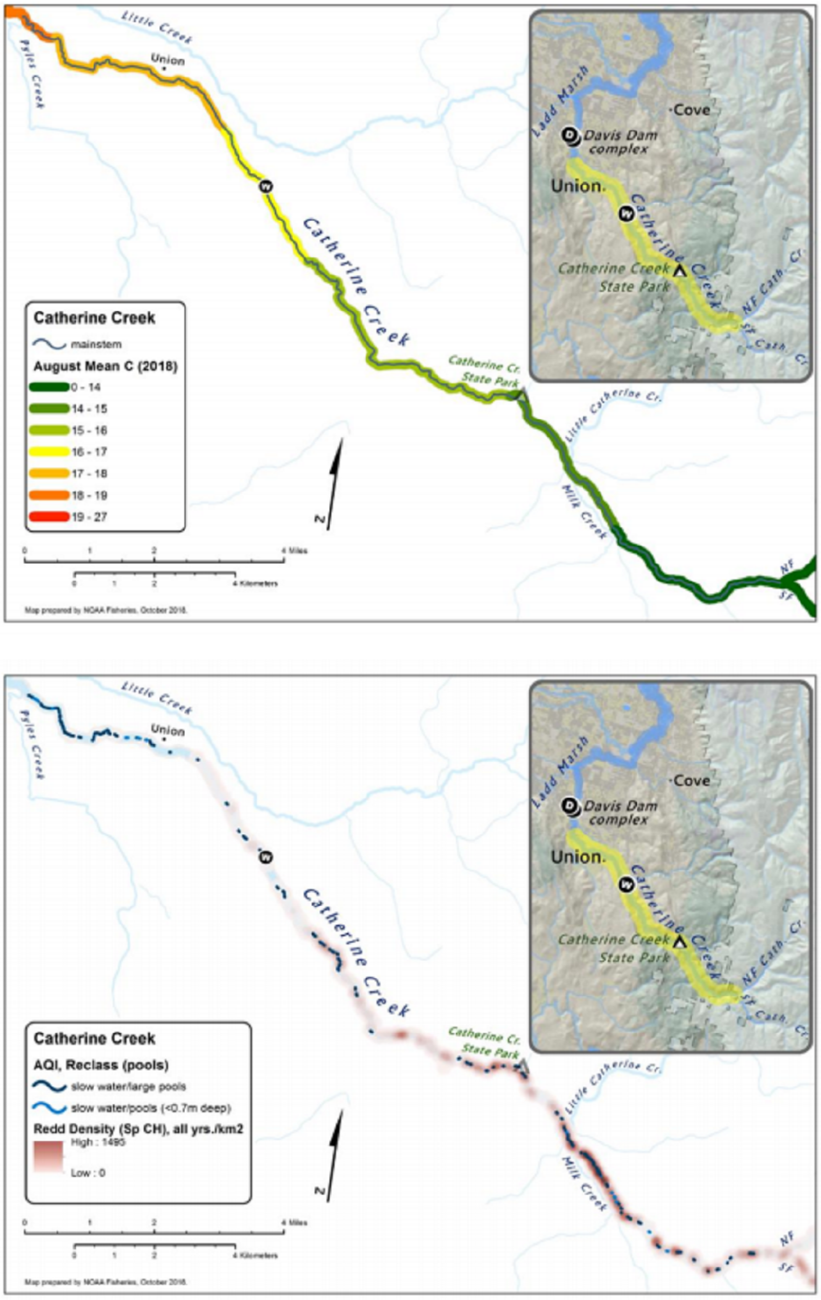


Figure 6.9. Upper panel -NORWEST August mean temperature estimates for Catherine Creek stream reaches. Lower panel - Oregon AQI reach level pools and 2009-2016 GPS redd locations within Catherine Creek.

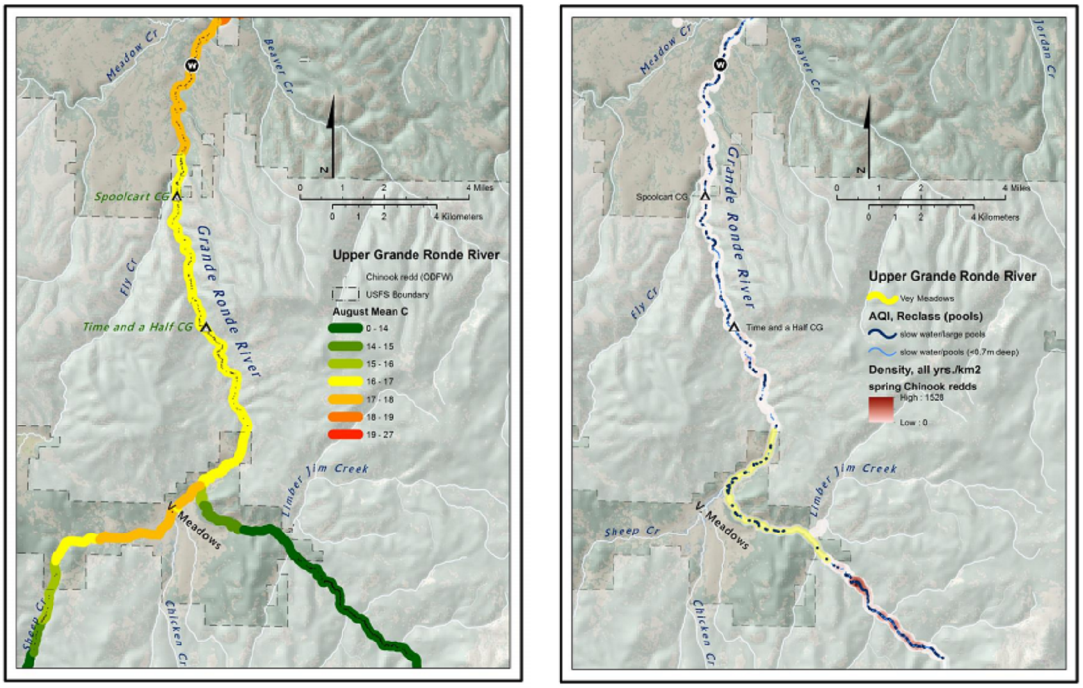


Figure 6.10. Left panel - NORWEST 1993-2011 average August stream temperatures for the Upper Grande Ronde River current spawning/rearing use reaches. Right panel - Oregon AQI reach level pools and 2009-2016 GPS redd locations within Upper Grande Rnde population current use reaches

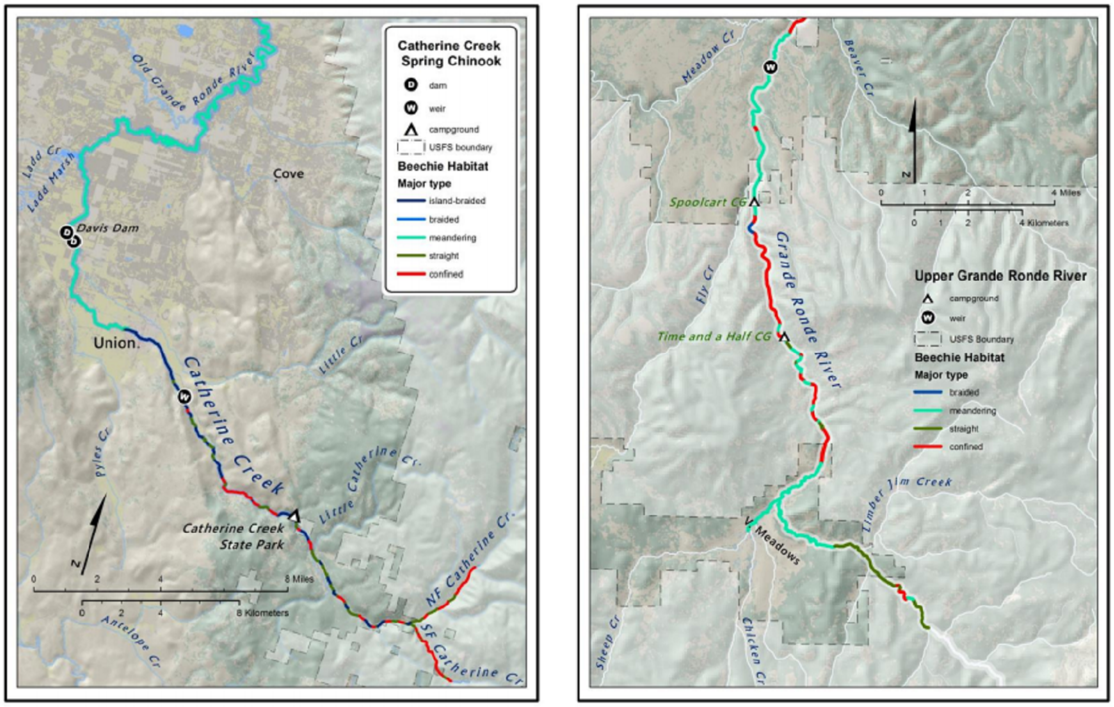


Figure 6.11. Left panel - Catherine Creek Spring Chinook population 200m reach level Beechie class ratings. Right panel - Upper Grande Ronde Spring Chinook population 200m reach Beechie stream classes.

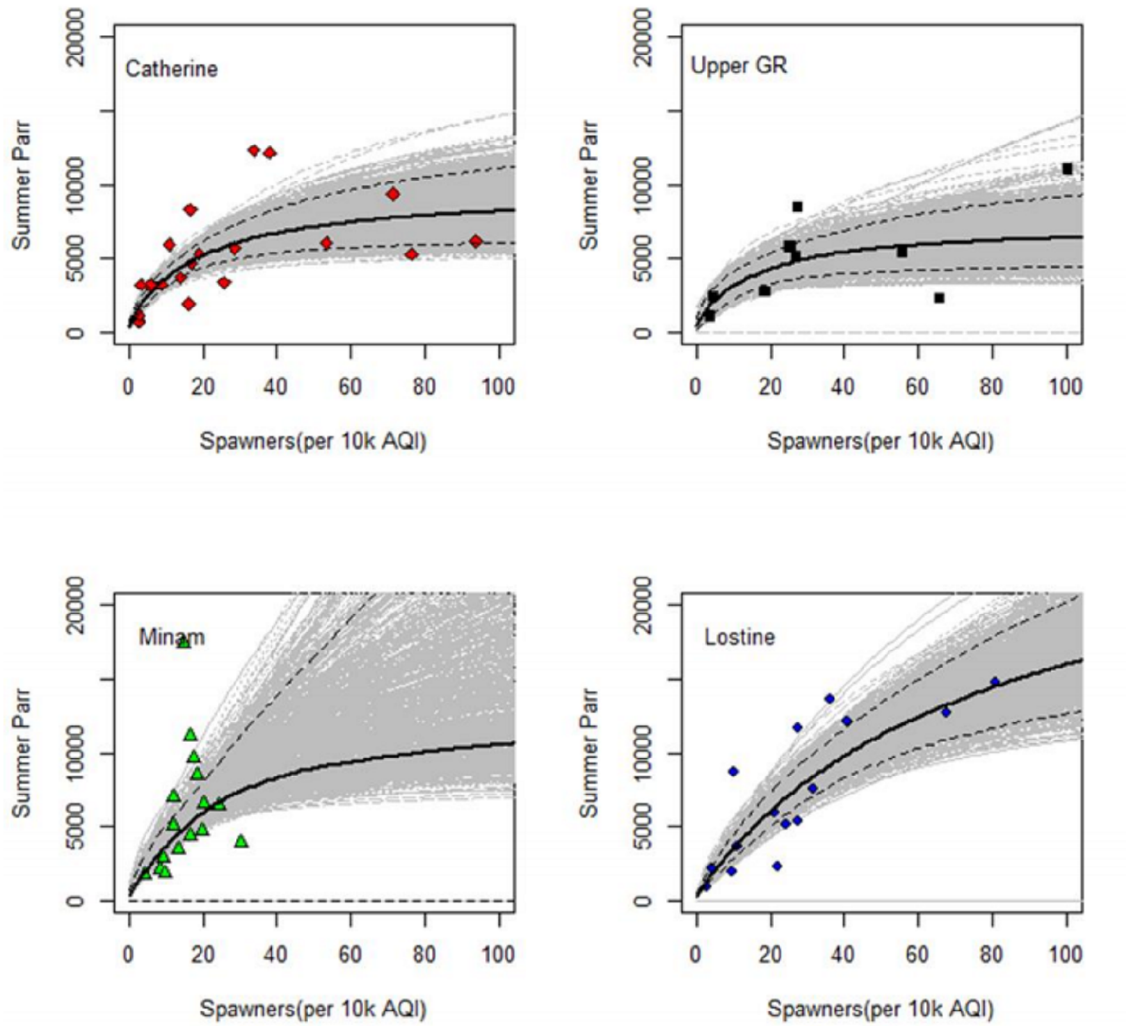


Figure 6.12. Spawner to summer parr relationships fitted to population specific estimates (points). Gray shaded zones reflect bootstrap joint parameter evaluation. Solid line: median across 4000 iterations, dashed lines contain the central 90% of results. Population estimates standardized to 1 hectare pool equivalent habitat.

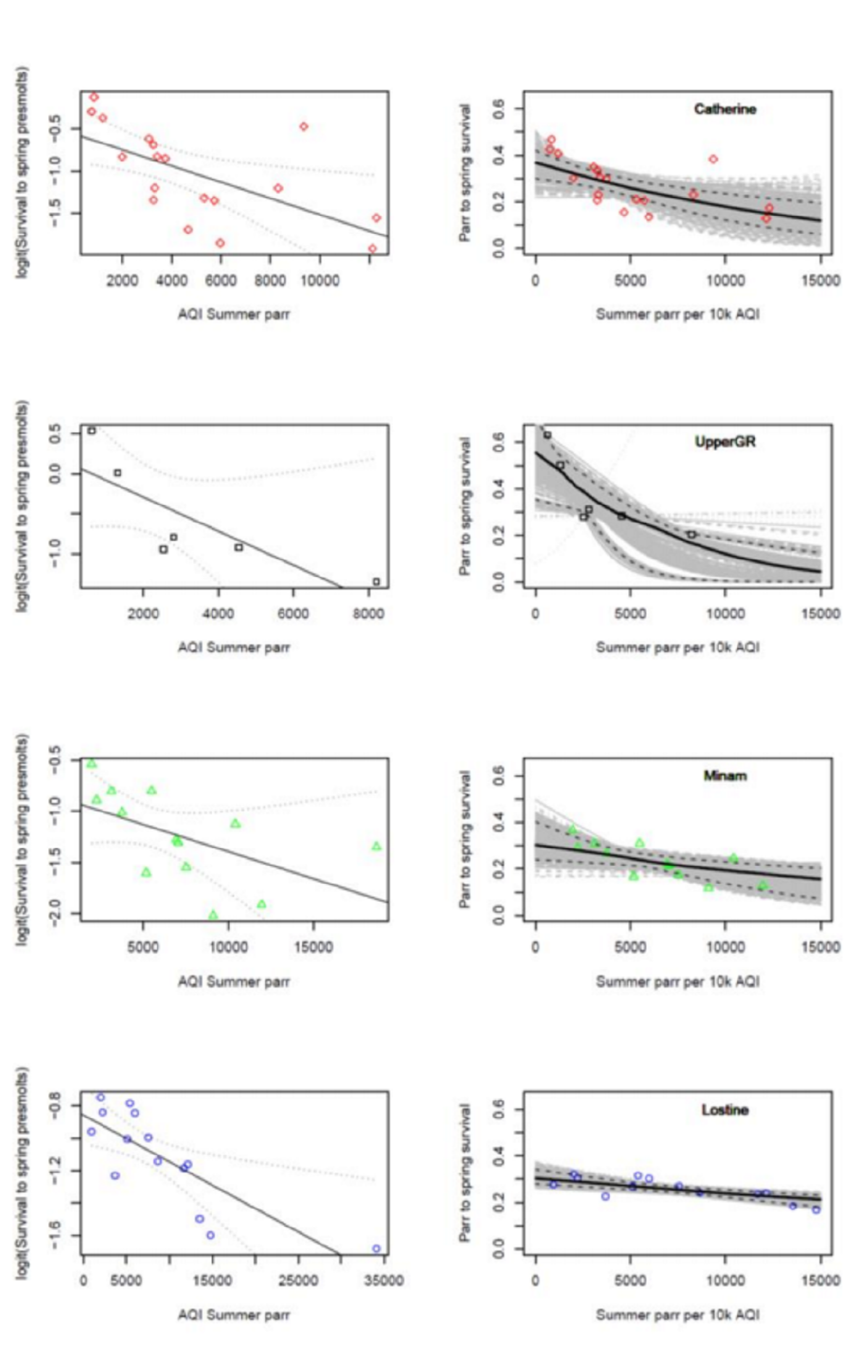


Figure 6.13. Summer parr to spring migrant survivals. 1992-2016 migration year estimates Gray zone represents 90% central interval for 4000 bootstrap samples. Left panels: logistic scale, right panels: transformed estimates

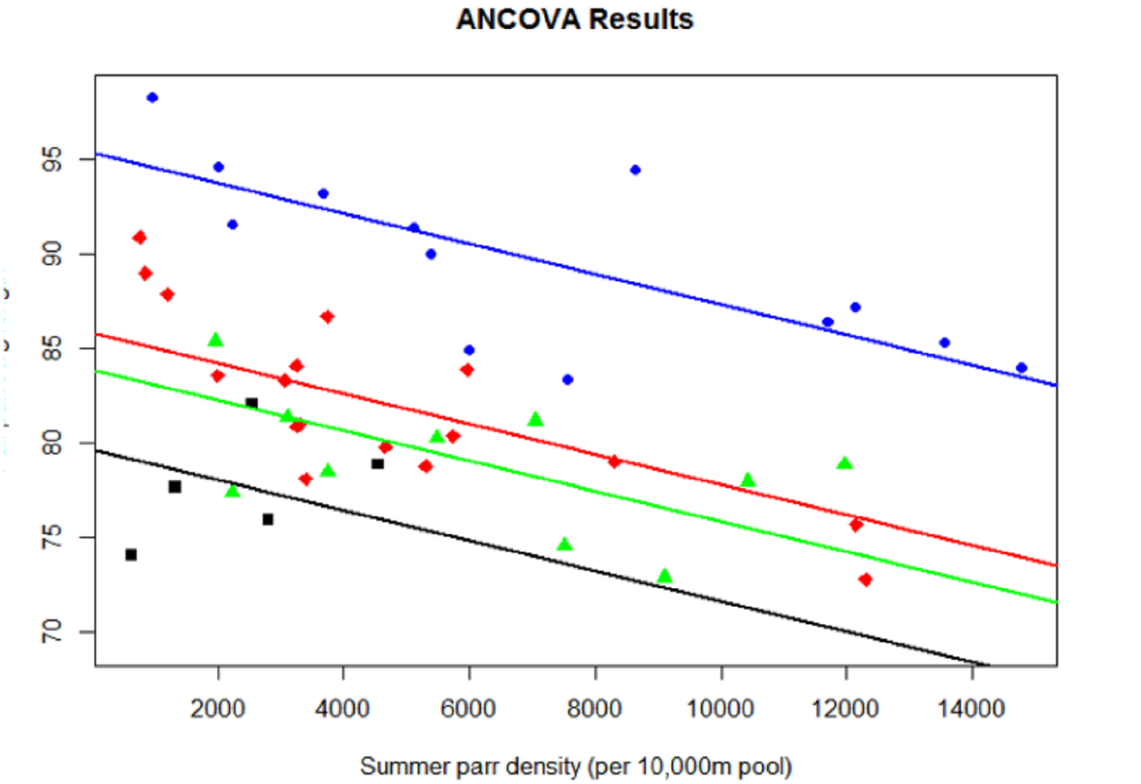


Figure 6.14. Analysis of covariance results. Points are individual year estimates by population. Lines: statistically significant common rate of decline in length vs summer parr density across populations . Intercepts differ by population.

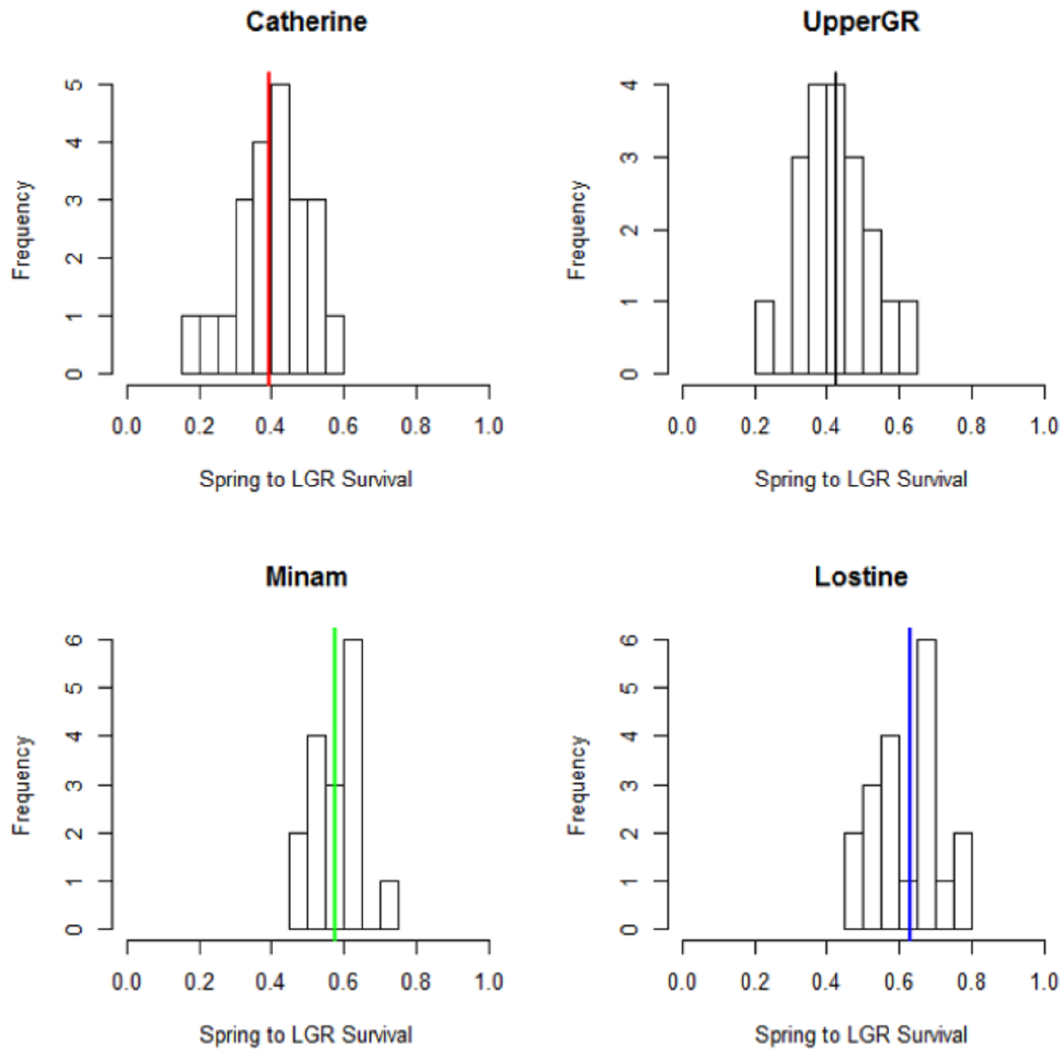


Figure 6.15. Estimated tributary spring migrant to detection at Lower Granite Dam by population. Vertical lines represent medians.

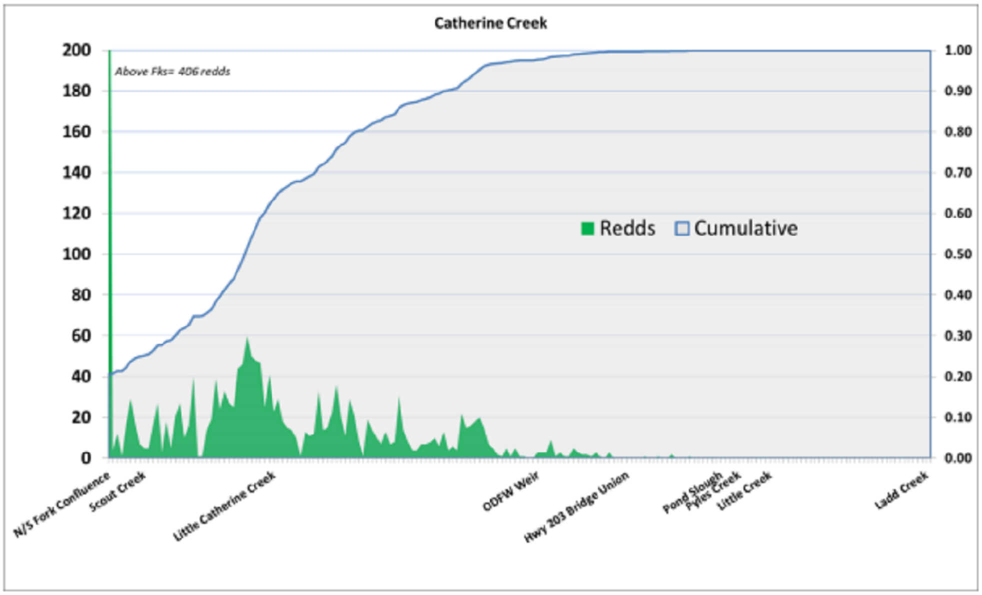


Figure 6.16. Catherine Creek distribution of redds (ODFW 2009-16 GPS) vs. reach location from North/South Fork confluence downstream. Redds in North and South Forks assigned to the first segment at the forks confluence. Green bars: red counts. Gray shaded area: cumulative proportion moving downstream (secondary axis).

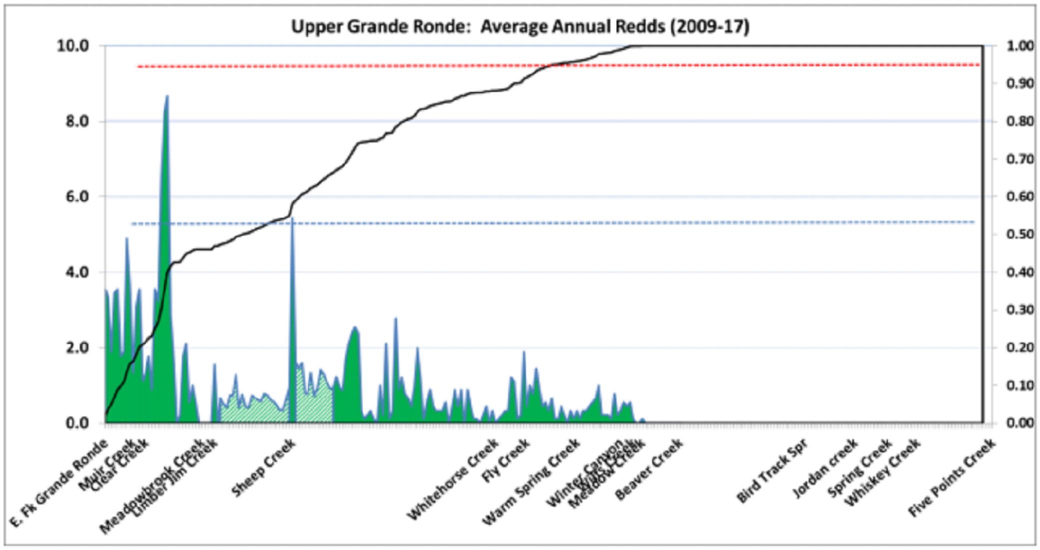


Figure 6.17. Upper Grande Ronde River distribution of redds (ODFW 2009-16 GPS) vs. reach location from upper extent of spawning to Meadow Creek confluence. Redds in Sheep Creek assigned to confluence. Green bars: red counts. Gray shaded area: cumulative proportion moving downstream (secondary axis). Vey Meadows reach estimated by extrapolation from adjacent reaches using 1991 Oregon AQI survey data. Redd dashed line: cumulative 95% of redds above this temperature.

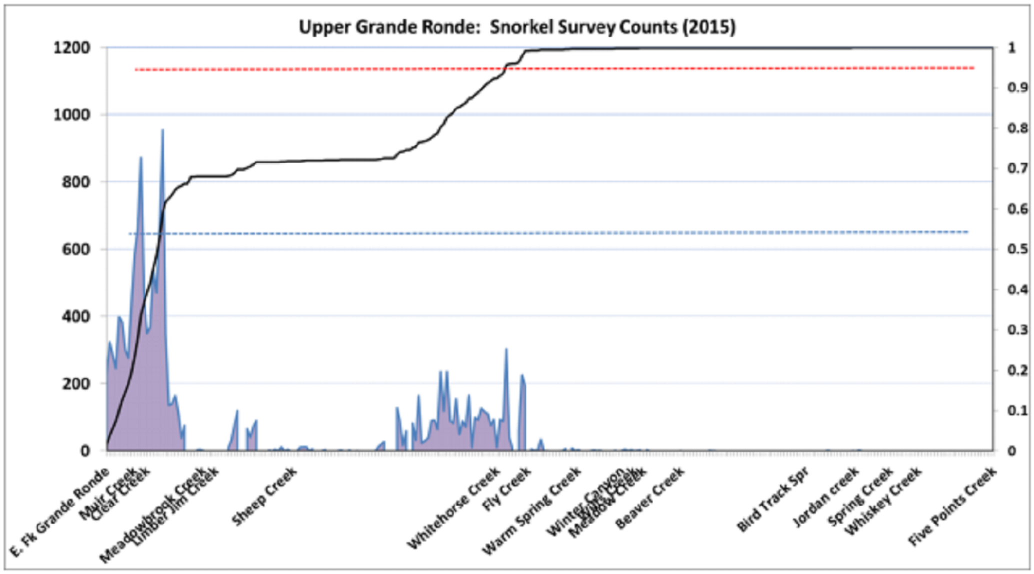


Figure 6.18. Upper Grande Ronde River. 2015 ODFW contiguous juvenile chinook snorkel surveys (Five Points Creek upstream to upper extent of spawning). Purple: individual reach survey estimates (note: no surveys in Vey Meadows reaches). Black line: cumulative abundance from upstream extent (right hand axis).

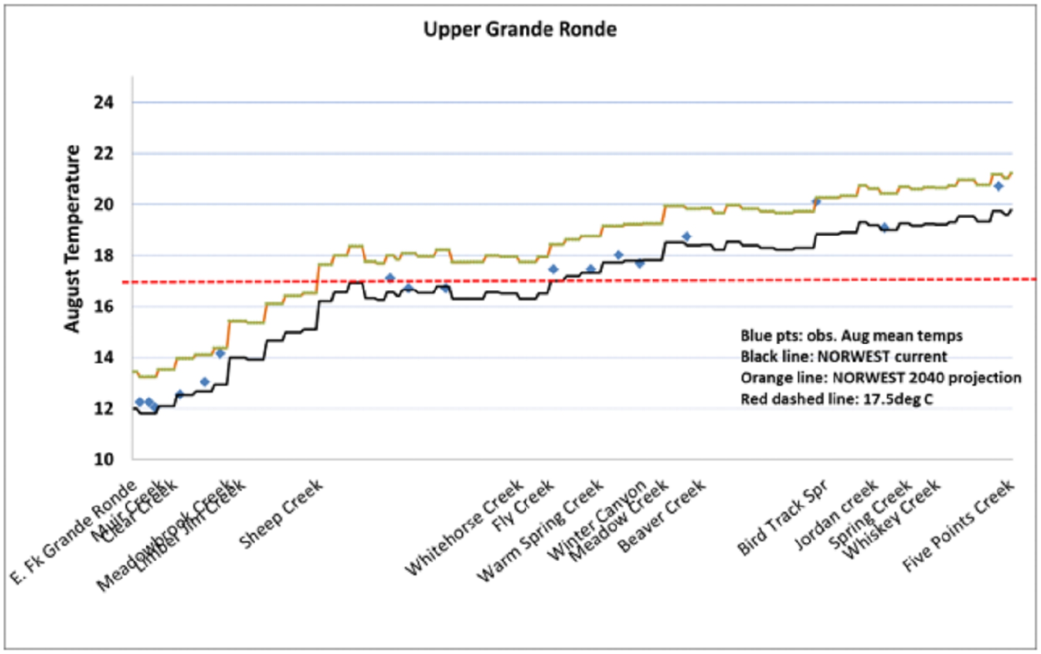


Figure 6.19. Upper Grande Ronde River population. NORWEST August average stream temperatures vs reach. Black line: current temperature (1993-2016 average). Gold line: NORWEST projected 2040 stream temperature. Red dashed line at 17.5 deg. C. estimated temperature threshold for spawning in this population.

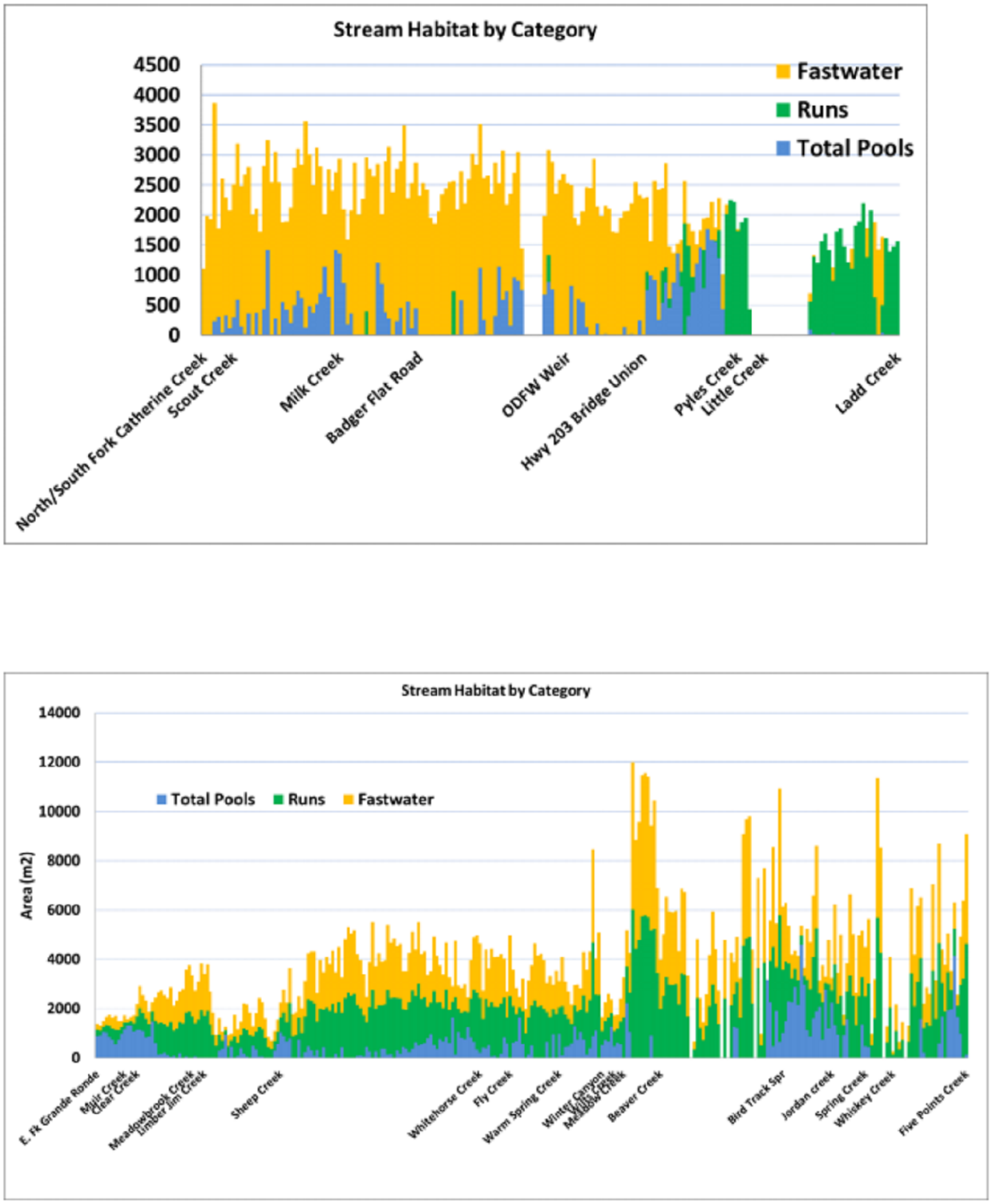


Figure 6.20. ODFW AQI survey results. Upper panel - Catherine Creek. Stream categories by reach Forks confluence downstream to Ladd Creek confluence. Lower panel - Upper Grande Ronde River. Upper extent of spawning downstream to Five Points Creek.