Columbia Estuary Ecosystem Restoration Program

2018 SYNTHESIS MEMORANDUM

FINAL REPORT

Edited by:
Gary E. Johnson, Pacific Northwest National Laboratory
Kurt L. Fresh, National Marine Fisheries Service (retired)
Nichole K. Sather, Pacific Northwest National Laboratory

August 2018

ABSTRACT

Periodic synthesis and evaluation of results from program implementation (about every 5 years) is a critical element of the Columbia Estuary Ecosystem Restoration Program's (CEERP's) adaptive management process because it informs adjustments to future program strategy and actions. Based on the first CEERP synthesis, which covered data and information through 2012, CEERP managers adjusted the program. They increased scientific rigor for the Expert Regional Technical Review process; formalized and implemented programmatic action effectiveness monitoring and research; researched the indirect effects of wetland restoration on fish migrating downstream in the mainstem estuary; and pursued focused research topics (e.g., relationships between vegetation and prey production). Using data and information gathered since 2012, the report herein incorporates new scientific findings; presents new summarizations, analyses, and syntheses; and uses the collective findings to reevaluate program strategy and provide recommendations for future activities to advance the program. The report is organized around key scientific and management questions related to CEERP's main strategy to reconnect tidal floodplain habitats to the mainstem lower Columbia River and estuary.

Important new data and information since 2012 follow:

1. From 2004 through 2017, 58 restoration projects restored hydrologic connection to 5,412 acres (2,190 ha) of tidal *floodplain* habitat, which included 2,555 acres (1,034 ha) of additional connected *wetland* habitats, an 11.6% relative increase in wetland area over 12 years.
2. Action effectiveness monitoring data from 23 project sites collected in various years since 2004 indicated that restoration actions were reestablishing ecological processes by restoring hydrologic connectivity. Juvenile salmon, especially subyearling Chinook salmon, were present at all 13 restoration sites where researchers attempted to capture fish.
3. The findings did not support the general paradigm that yearling-sized fish migrate rapidly through the estuary, feed little, and make little use of wetlands. Data showed that yearling salmon fed in the mainstem and inhabited tidal wetland channels.
4. Studies showed direct and indirect benefits of ecosystem restoration on juvenile salmon.
5. Limiting factors in the estuary continued to include reduced spring freshet magnitude, insufficient habitat opportunity and capacity for juvenile salmon rearing and refuge, ecological impacts from non-native flora and fauna, intra- and inter-specific competition, and piscivorous and avian predation.
6. New data and analyses that inform the design of restoration projects are available for predicting plant community composition, reed canarygrass control, mounds, channel network design, and large wood.
7. CEERP managers are beginning to consider how climate change should be incorporated in restoration project design and CEERP strategy, despite uncertainty about the strength, timing, and duration of any changes.
8. Reconsideration of the evidence-based evaluation of CEERP substantiated the conclusion of the original 2013 evidence-based evaluation "…the restoration program is having a cumulative beneficial effect on juvenile salmon."

The report concludes with a summary of responses to the management and science questions, a list of key uncertainties, and recommendations for future scientific and programmatic activities. This synthesis

provides managers, policy-makers, restoration sponsors, and others with a comprehensive, scientific understanding of the state of the science to inform program strategy and decision-making in the near and long terms. CEERP is successfully restoring estuary ecosystems and should be encouraged to continue this mission.

PREFACE

The U.S. Army Corps of Engineers, Portland District (Corps) funded development of this 2018 Synthesis Memorandum (Memo) for the Columbia Estuary Ecosystem Restoration Program (CEERP) under agreements with the U.S. Department of Energy and the U.S. Department of Commerce for work by Pacific Northwest National Laboratory (PNNL) and the National Marine Fisheries Service (NMFS), respectively. The 2012 Synthesis Memo (SM1), the first synthesis document for CEERP, covered the state of the science through 2012 for salmon ecology in the lower Columbia River and estuary (LCRE, or "estuary" for short). The 2018 Synthesis Memo (SM2) builds from SM1 to summarize new scientific data and information since 2012, and synthesize them with previous knowledge and new analyses.[1] The two synthesis memoranda provide the scientific basis for CEERP restoration strategies, which in turn are used to implement restoration actions and perform supporting research, monitoring, and evaluation. The synthesis memoranda are intended to inform, as appropriate, the Action Agencies for the estuary habitat program (Bonneville Power Administration [BPA] and Corps), the Northwest Power and Conservation Council (NPCC), NMFS, restoration project sponsors, researchers, and various interested parties.

The process for developing SM2 included a Steering Team and sub-teams. The Steering Team comprises Catherine Corbett (Lower Columbia Estuary Partnership [LCEP]), Jason Karnezis (BPA), Lynne Krasnow (NMFS), and Mike Turaski (Corps). The Steering Team provided guidance and oversight, reviewed the deliverables, and helped coordinate with interested stakeholders. Sub-teams developed material for certain appendices in the report. The report's editors drew from this material to support content in the main body of the report. The following sub-team scientists authored appendices in this report:

- Appendix C – Site Evaluation Cards: Heidi Stewart;
- Appendix D – Habitat Connectivity: Amy Borde, Heida Diefenderfer, Shon Zimmerman, Cailene Gunn, and Alex McManus;
- Appendix E – Action Effectiveness Monitoring: Sarah Kidd, and Matt Schwartz;
- Appendix F – Juvenile Salmon Diet: Adam Martin-Schwarze, Nikki Sather, Jen Zamon, Mary Ramirez, and Jeff Cordell;
- Appendix G – Tidal Marsh Food Web: Jeff Cordell, Roger Fuller, Jeff Grote, Amanda Hanson, Susan Hinton, Sarah Kidd, Regan McNatt, Joe Needoba, Tawnya Peterson, Katrina Poppe, Mary Ramirez, and Catherine Corbett (ed.).

The schedule for the progression of draft SM2 reports was as follows:

- April 1, 2017 – began work.
- May 31, 2017 – 30% draft report – completed a detailed outline for entire report and drafts of the preface, introduction, and CEERP progress sections.

[1] SM2 does not cover compliance with the estuary provisions in the 2008 Biological Opinion (BiOp) on operation of the Federal Columbia River Power System. This is because BiOp compliance is officially reported in annual progress reports and periodic comprehensive evaluations.

- October 2, 2017 – 60% draft report – completed an interim draft report with additions of draft findings for sections on habitat connectivity and the state of the science, and detailed data analysis methods for sections on site-scale action effectiveness monitoring and salmon diet.
- February 1, 2018 – 90% draft report – delivered a complete draft report, including appendices, for review by the Steering Team and contributing authors.
- April 24, 2018 – 95% draft distributed for review to the region, including restoration project sponsors, NPCC staff, the Estuary Partnership's Science Work Group, the Corps' Studies Review Work Group, and the Expert Regional Technical Group.
- June 2018 – 100% final report. Internal and external reviews of the 30%, 60%, 90%, and 95% drafts were critical to assuring the usefulness and quality of SM2.

A suggested citation for the entire report is: Johnson GE, KL Fresh, and NK Sather (eds.). 2018. *Columbia Estuary Ecosystem Restoration Program, 2018 Synthesis Memorandum*. PNNL-27617, Final report submitted by Pacific Northwest National Laboratory to U.S. Army Corps of Engineers, Portland District, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Index.

A suggested citation for an appendix in the report is: Kidd S and M Schwartz. 2018. "Action Effectiveness Monitoring." Appendix E in: Johnson GE, KL Fresh, and NK Sather (eds.), *Columbia Estuary Ecosystem Restoration Program, 2018 Synthesis Memorandum*. PNNL-27617, Final report submitted by Pacific Northwest National Laboratory to U.S. Army Corps of Engineers, Portland District, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Index.

ACKNOWLEDGMENTS

We are grateful to many people for helping with the 2018 CEERP Synthesis Memo, including the following:

- Keith Marcoe (LCEP) and Chris Read (BPA) provided material on CEERP progress;
- Heidi Stewart (PNNL) built the Site Evaluation Cards;
- Siena Lopez-Johnston and Anne Creason (BPA) authored material in the annual CEERP Restoration and Monitoring Plans that served as an important resource for SM2;
- Alex McManus and Phil Trask (PC Trask and Associates, Inc.) supplied the polygons for the constructed restoration projects and geographic information system (GIS) layers from the Landscape Planning Framework;
- Charles Cannon and Jim O'Connor (USGS) provided the 2012 versions of GIS layers for the floodplain, the geomorphic catena, and the ecosystem complexes;
- Chris Collins (LCEP), Nicole Czarnomski, and Alex Uber (Washington Department of Fish & Wildlife), Madeline Ishikawa and Tom Josephson (Columbia River Estuary Study Taskforce), Matt Schwartz (LCEP), Rudy Salakory (Cowlitz Tribe), and Ian Sinks (Columbia Land Trust) provided Expert Regional Technical Group (ERTG) revisit templates, observations, and information on restoration projects;
- Regan McNatt (NMFS), Curtis Roegner (NMFS), and Laurie Weitkamp (NMFS) provided preliminary results from action effectiveness monitoring and research and reviewed the chapters on the state of the science;
- Heida Diefenderfer and Adam Martin-Schwarze (PNNL), Kim Jones (ODFW-retired), Lynne Krasnow (NMFS), Cindy Studebaker (Corps), Ron Thom (PNNL-retired), Alex Uber (WDFW), and Karl Weist (NPCC) reviewed the report's technical content;
- Shubha Pandit (Terraqua) performed a biostatistical, technical review as part of the peer-review process for the Corps' Anadromous Fish Evaluation Program;
- Susan Ennor and Mike Parker (PNNL) edited the document.

We are also thankful to the SM2 Steering Team and contributing authors noted in the Preface. SM2 is dedicated to the memory of Blaine D. Ebberts.

EXECUTIVE SUMMARY

The Bonneville Power Administration and the U.S. Army Corps of Engineers implement the Columbia Estuary Ecosystem Restoration Program (CEERP) to understand, conserve, and restore ecosystems in the lower Columbia River and estuary (LCRE or "estuary" for short). Periodic synthesis and evaluation of results from program implementation (~5 years) is a critical element of CEERP's adaptive management process, because it acknowledges new scientific findings, affirms what is going well and why, identifies needs for improvement, and informs adjustments to future program strategy and actions. CEERP managers call such a synthesis and evaluation effort a "synthesis memo." The first CEERP Synthesis Memo (SM1) covered data and information about juvenile salmon ecology, restoration action effectiveness, and estuary status through 2012. Since 2012, CEERP has been implementing restoration actions and conducting monitoring and research. This 2018 Synthesis Memo (SM2) integrates scientific findings from SM1 with new findings obtained after 2012; presents new summarizations, syntheses, and analyses; uses the collective results to reaffirm program strategy; and provides recommendations for future actions for the program. Building from SM1, SM2 provides managers, policy-makers, restoration sponsors, and others with a comprehensive, scientific understanding of the state of the science to inform CEERP decision-making in the near and long terms.

SM2 assesses CEERP's primary hypothesis—ecosystem restoration actions in the estuary have a cumulative beneficial effect on juvenile salmon. It also addresses CEERP's two secondary hypotheses: 1) habitat-based indicators of ecosystem controlling factors, processes, and structures show positive effects from restoration actions, and 2) fish-based (salmon) indicators of ecosystem processes and functions show positive effects from restoration actions and habitats undergoing restoration. The hypotheses are based on a general organizing model and an ecosystem conceptual model of restoration effects in the LCRE.

Primary CEERP Strategy

The primary strategy that CEERP employs to restore LCRE ecosystems is hydrologic reconnection of tidal wetlands to the mainstem estuary. CEERP has made significant progress to date reconnecting a large amount of tidal floodplain area to the mainstem estuary and restoring lost ecological processes. The cumulative evidence from Action Effectiveness Monitoring (AEM) projects in the LCRE shows that restoration actions are improving ecological processes in the estuary, although spatial and temporal variability influence site-scale responses. Based on analyses primarily conducted since SM1 was published, ecosystem restoration is improving habitat conditions for juvenile salmon in the estuary. These improvements are reflected in both direct (onsite) and indirect (offsite) benefits to salmon.

Responses to the Management Questions

Based on input from CEERP managers and policy-makers, we designed SM2 to address particular management questions.

Progress – *What progress has been made to date by CEERP in terms of the number of restoration projects and acreage restored? How much wetland area has been restored under CEERP? Quantitatively, how has habitat connectivity changed estuary-wide and by estuary zone?*

From 2004 through 2017, restoration sponsors implemented 58 projects restoring hydrologic connection to 5,412 ac (2,190 ha) of tidal *floodplain* habitat that included 2,555 ac (1,034 ha) of *wetland* habitats. This represented a ~11.6% relative increase in wetland area over the 14-year period. Due to increased efforts of CEERP managers and restoration practitioners, restoration was most active from 2012 to 2017, when 35 projects were constructed. Floodplain reconnection projects included dike and levee breaching or lowering (4,068 ac; 1,646 ha), tide gate removal (457 ac; 185 ha), and tide gate upgrades (887 ac; 359 ha). In addition, sponsors improved riparian habitats (55 mi; 89 km) and worked to control invasive plants in wetland habitats (2,210 ac; 894 ha). Overall, CEERP restoration actions resulted in a 2.5% increase in the habitat connectivity index. As of 2016, 32.1% of total *wetland* area (24,567 of 76,496 ac; 9,942 of 30,957 ha) was connected to the mainstem estuary, i.e., 67.9% was disconnected by dikes and levees, but could potentially be reconnected (51,929 ac; 21,015 ha).

Site-Scale Action Effectiveness Monitoring – *At the site scale, are restoration actions having the expected physical and biological effects?*

Data collected from 23 restoration sites since 2004 indicated that ecological processes were being reestablished, although physical and biological responses were best interpreted within the context of project-specific goals and objectives. Results from site-scale AEM revealed that, in general, some monitored indicators supported the hypothesis that restoration actions are having positive effects (i.e., water-surface elevation, sediment accretion, channel cross sections, and fish data). However, for other indicators, results were inconclusive, data have yet to be analyzed, or it was too soon to tell because few years have elapsed since restoration construction (i.e., water temperature and vegetation). Of the 23 restoration sites, fish monitoring occurred at 13 locations and juvenile salmon, predominantly subyearling Chinook salmon, were present at all of these locations. While upriver stocks were rarely encountered through direct capture techniques, the presence of these stock groups was confirmed by detections on passive integrated transponder antenna arrays within restored tidal wetland channels.

State of the Science: Update of SM1 – *What are updates to the findings and uncertainties regarding the four science questions identified in SM1?*

What are the contemporary patterns of juvenile salmon habitat use in the estuary? Data collected since 2012 corroborate the initial findings of SM1 and provide additional insight into contemporary patterns of estuarine habitat use by juvenile salmon. Habitat use and life history patterns of juvenile salmon in the LCRE, and especially yearlings, are more diverse than previously thought, which helps promote salmon population resilience. In particular, new research has dispelled the previously held notion that yearling-sized fish spend little time feeding in the estuary and using wetland habitats. Researchers detected tagged fish from the interior Columbia River basin in tidal channels in the estuary. In addition to spring and summer being important periods for migrating juvenile salmon in the estuary, new research indicated some juvenile salmon (mostly from west of the Cascades) overwinter in shallow-water habitats in tidal freshwater segments of the estuary. Results of several studies indicated dissolved and particulate organic matter, as well as insects, are exported from restoring wetlands to the mainstem estuary. Much of the energy consumed by juvenile salmon, whether in the mainstem or in wetland, was derived from Diptera, an order of insects commonly encountered in aquatic habitats. Amphipods were also important components of juvenile salmon diets, particularly in the Lower Estuary zone (rkm 0–38), and may also be important prey resources for larger size-classes of fish in off-channel habitats.

Do factors in the estuary limit recovery of at-risk salmon populations and evolutionarily significant units? The combination of flow regulation and the development of an extensive system of dikes and levees has isolated much of the historical floodplain from the mainstem. As outlined in SM1, limiting factors in the estuary continue to include insufficient habitat opportunity and capacity for rearing and refuge of salmon. Major factors that limit salmon opportunity and capacity are hypothesized to include reduction in peak flows in spring, ecological impacts from non-native flora and fauna, intra- and inter-specific competition, and piscivorous and avian predation.

Are estuary restoration actions improving the performance of juvenile salmon in the estuary? Salmon performance may be defined by growth, foraging success, spatial distribution, and life history diversity. Restoration effects on salmon performance can be direct (onsite) and indirect (offsite). One direct (onsite) benefit is that wetland food production supports foraging and growth within the wetland. Prey items produced within wetlands are also exported into mainstem and off-channel habitats where they become available to salmon migrating in these locations. Thus, while fish may not directly enter a tidal wetland channel, they derive indirect (offsite) benefits from wetland habitats. This provides evidence for supporting efforts to increase the connectivity among aquatic habitats throughout the LCRE. Analyses indicated that restoration actions are reestablishing ecological processes, although results are variable among the monitored indicators. Using new action effectiveness results and information (2012 to present), a revisit of the evidence-based evaluation of the CEERP hypotheses substantiated the original evaluation's conclusion that restoration is improving the performance of juvenile salmon in the estuary. In fact, new evidence indicated improved ability to accurately predict restoration outcomes.

What is the status of the estuary? Are estuarine conditions improving or declining? As noted in SM1, anthropogenic actions have altered the LCRE significantly since the beginning of the twentieth century. The estuary is in a degraded state, but it is not clear whether estuary conditions overall are trending to the positive or negative. Many factors that influence the status of the estuary are outside CEERP's mission or influence, e.g., land use practices, industrial development, non-native species, hydrosystem operations, and contaminant loading.

State of the Science: Additional Science Questions – *What additional science questions are relevant to CEERP and why?*

What effect does the mixture of hatchery and wild origin juvenile salmon have on CEERP strategy? The prevalence of hatchery origin (HO) compared to natural origin (NO) fish raises several issues from the perspective of the CEERP. A major uncertainty concerning HO and NO fish is whether competition for food and space between these two fish types in the LCRE is affecting benefits of restoration actions to listed populations.

How does the linkage between the estuary and ocean affect salmon population dynamics? What are the implications of this linkage to CEERP strategy? The estuary plays a critical role in supporting early life history requirements for juvenile salmon, and the interconnectedness of habitats supporting various life stages cannot be disregarded. Actions taken in the estuary can affect fish survival upon entering the ocean. For example, habitat enhancements that improve capacity (e.g., prey productivity) may lead to increased growth and condition of migrating juvenile salmonids in the estuary. Improved condition of fish in the estuary can contribute to the likelihood of survival into the ocean.

What new data and information are relevant to restoration project design? Data and analyses to inform the design of restoration projects have been collected and developed in recent years. Guidance for predicting plant community composition and density, controlling reed canarygrass, understanding seed banks, constructing mounds, designing channel networks, and incorporating large woody debris has been, or is being, developed specifically for the LCRE. Considerably less is known about the mechanisms that relate these factors to biological responses such as resource subsidies (e.g., prey for salmon) and condition of fish (e.g., growth, residence time).

How might climate change affect environmental conditions in the estuary and be taken into account in restoration project design and CEERP strategy? Major physical changes that will occur in the LCRE because of climate change are alterations in water temperature regimes, changes in local tributary and mainstem flow, and sea-level rise. While there is uncertainty about the strength, timing, location, and duration of any changes that may occur, actions that help make projects resilient to climate change should be emphasized in restoration project design and CEERP strategy.

New Techniques and Resources

Since 2012, many new techniques and resources have become available to support CEERP activities. We describe the following tools in Appendix H (in alphabetical order): area-time inundation model, Center for Coastal Margin Observation and Prediction, early life history diversity index, ecosystem classification system, ecosystems function model, habitat change analysis, habitat performance index, landscape planning framework, *Oncor* data management system, plant community look-up tables, potential sum exceedance value, salmon estuarine habitat index, and unmanned aerial vehicles.

Uncertainties Assessment

Using the scientific uncertainties identified in SM1, we evaluated new data and information and reassessed these uncertainties (Table ES.1). This assessment led to the recommendations that follow Table ES.1.

Table ES.1. Summary of Status of Uncertainties Identified in SM1. Suggested priority for CEERP based on the professional judgment of SM2 editors: Yes or No.

SM1 Id#	Comment	Priority
1. Contemporary Patterns of Use		
1.1 Rearing behaviors of under-represented or at-risk (wild) stocks	While additional information about estuarine habitat use by under-represented and at-risk stocks may help to more effectively target restoration to benefit these fish, this uncertainty has been difficult to resolve because of the rarity of these fish in samples, as well as the inability to distinguish an unmarked fish as wild or hatchery origin. At-risk stocks are simply at very low levels of abundance and are difficult to adequately sample. It is unlikely that additional sampling would improve encounter rates to a level sufficient enough to systematically evaluate rearing behaviors of under-represented or at-risk (wild) stocks.	No
1.2 Use of shallow-water habitats in tidal river zones and main channel habitats	Significant knowledge gaps exist in habitat use by fish in several zones of the LCRE. Much research has focused on wetland channels, but the use of other habitat types (main channel and off-channel) may help to understand the how restoration provides indirect benefits (e.g., resource subsidies) across the LCRE landscape. In terms of location within the LCRE, less is known about the Lower Tidal River zone compared with other zones. Moreover, the main channel has only recently been sampled estuary-wide (2016 and 2017); therefore, continuing to improve	Yes

SM1 Id#	Comment	Priority
	understanding of habitat use and migration of yearling-sized fish in the main channel is needed.	
1.3 Genetic stock-specific use	A great deal has been learned about stock-specific habitat use, largely because genetic stock identification has been routinely performed on juvenile salmon collected in the LCRE. Genetic stock of fish sampled should continue to be determined whenever possible in field studies.	Yes
1.4 Habitat-specific growth rates	Some information on juvenile salmon growth rates has been obtained since SM1. While additional information about growth would be useful, dedicated studies of habitat-specific growth rates would require intensive, expensive research. Even a well-designed study can be limited in its ability to draw inferences between habitats (especially at fine spatial scales) and growth.	No
1.5 Flux of organic material and salmon prey	While the flux studies conducted at Karlson Island and Steamboat Slough in 2017 provided important new data, better understanding is needed of material flux over full tidal cycles and over other estuary zones. Not all habitats are equal; aspects associated with hydrologic conditions, landscape position, and channel morphology, will determine if habitats are sources or sinks for prey export. Determining if and how much variability in flux occurs based upon zone or location in the landscape will support development of predictive models for restoration project prioritization and project design criteria.	Yes
2. Factors Limiting Recovery		
2.1 Habitat capacity	Habitat capacity is an important concept in understanding and evaluating the benefits of restoration because it includes indicators that relate directly to salmon performance. A comprehensive evaluation of the full suite of factors affecting capacity (e.g., water temperature, non-native plant species) would be difficult to do well. However, for some selected capacity indicators (e.g., prey productivity and flux) further study is warranted and results would directly benefit CEERP.	Yes
2.2 Importance of estuary rearing to population viability and salmon recovery	This is a key uncertainty for CEERP, because of the premise that habitat restoration benefits juvenile salmon (direct or indirect use) and thereby ultimately has population-level effects. There are several ways to analyze this issue. First, including an estuary component for life cycle models (currently it is combined with ocean conditions) would make it possible to isolate the effects of the estuary from that of the ocean. Second, much of the evaluation of benefits of estuary restoration has focused on evaluating effects of restoration on abundance and survival and productivity. Other measures of viable salmon population measures (spatial structure and diversity) should be included in evaluating benefits of restoration, which to date have not been included.	Yes
2.3 Interactions of hatchery and natural origin salmon	For HO/NO interactions, the question is if and how HO could affect viability of NO populations (e.g., by way of density-dependent mechanisms). From the perspective of restoration, the major issue is if HO fish are affecting the benefits of restoration actions for NO fish. We do not rate this as a high priority for CEERP for several reasons. First, this is a very challenging subject to study and obtaining clear and unambiguous results is problematic. Second, and most importantly, any	No

SM1 Id#	Comment	Priority
	ability to address this issue by modifying hatchery production programs is outside the purview of CEERP.	
2.4 Competition and predation with native and non-native species	Competition and predation interactions involving salmon populations occur throughout the LCRE. These interactions can have significant effects on salmon population viability. Further, competition and predation can involve both native species (e.g., birds and northern pikeminnow) and non-native species (e.g., shad, bass, and killifish). From the perspective of restoration, the main concern is if and how these interactions can affect benefits of restoration for salmon. Because competition and predation can have significant population-level affects, CEERP needs a basic understanding of the impacts of species interaction on restoration to make informed decisions about restoration prioritization—e.g., targeting most at-risk locations or designing projects to maximize export of prey resources and minimize occupation by large predatory fish.	Yes
3. Action Effectiveness		
3.1 Effectiveness of restoration actions at the site, landscape, and estuary-wide scales	Direct effects of restoration at the site scale have been examined much more than indirect effects at the landscape or estuary-wide scales. Results from effectiveness studies indicate restoration actions, while variable, generally improve site-scale habitat conditions. Preliminary results from new landscape-scale research indicate benefits to juvenile salmon migrating in the mainstem, but more analysis and study are warranted, especially concerning *how* restoration directly and indirectly benefit juvenile salmon. Understating the *how* can contribute to restoration design and prioritization. Furthermore, study designs need to specifically consider the spatial inference of the data; this is an important programmatic consideration with site- and project-scale implications.	Yes
4. Status of the Estuary		
4.1 Impacts of non-native species	SM1 considered the issue of competition and predation effects of native and non-native species on benefits of restoration. Consideration of non-native species impacts on restoration is a broad issue that includes fish, vegetation, zooplankton, as well as mechanisms such as food-web interactions and habitat modification. It also could include how increases in water temperatures (considering climate change) might affect non-native fish presence, proliferation, and competition with native fishes. The uncertainty is if and how non-native species may be affecting the benefits of restoration for juvenile salmon.	Yes
4.2 Net ecosystem improvement and anthropogenic effects	There has been positive net ecosystem improvement due to restoration, although the exact magnitude is uncertain because data on the floodplain area recently (since 2010) lost to development are lacking. While the ecological impacts from individual anthropogenic effects have been studied to various degrees, they are not well understood collectively or relative to one another. It is important that CEERP managers understand these effects so they can account for them in restoration strategy and planning.	Yes

Recommendations

Based in part on the reassessment of SM1 uncertainties (summarized in Table ES.1), we provide recommendations aimed at reducing uncertainty and enhancing knowledge relevant to CEERP habitat restoration and salmon response in the LCRE. These uncertainty topics were deemed relevant to CEERP because expertise and capabilities to address them are readily available and obtaining resolution will improve programmatic performance (Table ES.2). Programmatic recommendations pertain to restoration and research, monitoring, and evaluation (RME) efforts (Table ES.3). For some, work is already underway, while others have not yet been started.

Table ES.2. Summary of the Priority, High-Level Scientific Recommendations.

SM1 Uncertainty Topic	SM1 Id#	Report Section	SM2 Recommendation	Status (as of June 2018)
Action effectiveness at site, landscape, and estuary-wide scales	3.1	4.3	Determine the effectiveness of restoration actions at multiple spatial sales, and ensure study designs support programmatic goals.	Ongoing
Habitat use, flux, genetic stock identification, and habitat capacity	1.2,1.3, 1.5,2.1	4.1, 4.3	Continue to investigate mechanisms for direct and indirect benefits of restoring wetlands, especially for yearling-sized fish.	Ongoing
Ecological impacts of native and non-native species	2.4, 4.1	4.2, 4.4	Determine if benefits of restoration are affected by ecological interactions between at-risk stocks and non-native species as well as other native species.	Not started
Population viability and salmon recovery	2.2	4.2	Determine relationships between restoring estuary habitat and the spatial structure and diversity of salmon populations emigrating through the estuary.	Not started
Net ecosystem improvement and anthropogenic effects	4.2	4.4	Assess the feasibility of determining the aggregate and separate effects of anthropogenic development on estuary ecosystem conditions.	Not started

Table ES.3. Summary of the programmatic recommendations for CEERP.

SM2 Recommendation	Status (as of June 2018)
Continue the CEERP strategy of reconnecting wetland floodplain habitats to the mainstem estuary, and seek opportunities to maximize the effectiveness of this approach.	Ongoing CEERP strategy
Explore the feasibility of using dredged material placement to create new shallow-water and aquatic habitats.	Being considered by the Corps
Develop and apply methods to incorporate climate change scenarios into restoration strategy, planning, project design, and monitoring.	Some work is under way
As appropriate, review and revise the RME program for CEERP.	Not started
Perform focused investigations or experiments at selected restoration sites to test key uncertainties concerning restoration implementation.	One experiment is under way
Investigate new or emerging technologies for reducing RME costs while increasing the quality of data and information supporting CEERP.	Some work is under way

Closing

A CEERP Synthesis Memo provides an opportunity to look back at previous program documents and reflect on their relevancy today. CEERP's ecosystem restoration strategy is founded on basic principles of ecological science. The National Research Council said: "Wherever possible...restoration of aquatic resources...should not be made on a small-scale, short-term, site-by-site basis, but should instead be made to promote the long-term sustainability of all aquatic resources in the landscape." Ecological science, as applied in the CEERP's restoration strategy, includes principles worth revisiting in light of SM2. The italicized statements that follow are from the 2012 CEERP Strategy Report; see that document for definitions of key terms. Pertinent findings for each principle from SM2 or the LCRE literature follow.

Reestablishment of natural controlling factors is required to build and maintain ecosystem structures, processes, and functions that support juvenile salmon. AEM data on water-surface elevation, sediment accretion, and channel cross section indicate natural controlling factors are being reestablished. Restoring wetlands are trending toward more native plant species composition. Restoring wetlands are producing prey that are consumed by juvenile salmon onsite and offsite.

Returning the LCRE ecosystem to a less altered state is desirable. The historical condition of the LCRE has been altered by agricultural and industrial development; the status of the estuary is not entirely desirable from an ecological point of view. A habitat change analysis quantified the habitat types that have been most impacted (i.e., lost to development). SM2 provides a recommendation for tracking trends in estuary status to inform CEERP management.

The success of a restoration project will vary depending on the level of disturbance (anthropomorphic or natural) of the site and the landscape within which the site resides. The action effectiveness monitoring and research data presented in SM2 are not extensive enough to distinguish results based on the level of disturbance at the site and its landscape to begin with. In fact, disturbance levels are not determined *a priori* as part of CEERP process, except to the degree a site is disconnected from the mainstem estuary and whether it was created historically by dredged material placement.

Landscape ecology concepts such as minimum area, shape, corridors, and buffers are applicable to ecosystem restoration. The related concepts of habitat size, accessibility, and capacity are employed by the Expert Regional Technical Group (ETRG) during scoring of proposed restoration projects. The concepts mentioned in the three previous paragraphs are used by CEERP practitioners and managers to develop and design restoration projects. The ERTG is currently working to identify, explain, and justify additional science-based landscape concepts, principles, and uncertainties for CEERP strategy.

In closing, SM2 is an important component of CEERP's adaptive management process. The memo herein provides managers, policy-makers, restoration sponsors, and others with a comprehensive, scientific understanding of the state of the science to inform program strategy and decision-making in the near and long terms.

ACRONYMS AND ABBREVIATIONS

°C	degree(s) Centigrade (or Celsius)
AEM	action effectiveness monitoring
AEMR	action effectiveness monitoring and research
ATIIM	Area-Time Inundation Model
BDA	beaver dam analog
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CEERP	Columbia Estuary Ecosystem Restoration Program
CLT	Columbia Land Trust
CMOP	Coastal Margin Observation and Prediction
CNEI	cumulative net ecosystem improvement
Corps	U.S. Army Corps of Engineers
CPUE	catch per unit effort
CREC	Columbia River Estuary Conference
CREDDP	Columbia River Estuary Data Development Program
CREST	Columbia River Estuary Study Taskforce
EBE	evidence-based evaluation
ELHD	early life history diversity
EFM	Ecosystems Function Model
ERTG	Expert Regional Technical Group
ESA	Endangered Species Act
ESU	evolutionarily significant unit
FL	fork length
GIS	geographic information system
HO	hatchery origin
ISAB	Independent Scientific Advisory Board
ISRP	Independent Scientific Review Panel
ITIS	Integrated Taxonomic Information System
LCEP	Lower Columbia Estuary Partnership
LCRE	lower Columbia River and estuary
LE	Lower Estuary zone
LPF	Landscape Planning Framework
LR	Lower Tidal River zone
LWD	large woody debris
MR	Middle Tidal River zone
NAIP	National Agricultural Imagery Program

NMFS	National Marine Fisheries Service
NO	natural origin
NPCC	Northwest Power and Conservation Council
OHSU	Oregon Health Science University
PDT	project delivery team
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
POM	particulate organic matter
RCG	reed canarygrass
RME	research, monitoring, and evaluation
SE	standard error
SEC	Site Evaluation Card
SM1	Synthesis Memo 1
SM2	Synthesis Memo 2
SME	subject matter expert
SRF	Snake River Fall Chinook salmon
SRWG	Studies Review Work Group
SWG	Science Work Group
UE	Upper Estuary zone
UR	Upper Tidal River zone
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
UW	University of Washington
WSE	water-surface elevation

CONTENTS

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1.0 INTRODUCTION

The Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers, Portland District (Corps) developed the Columbia Estuary Ecosystem Restoration Program (CEERP[1]) to understand, conserve, and restore ecosystems in the lower Columbia River and estuary (LCRE or "estuary" for short). The Action Agencies (BPA and Corps) conceived CEERP in response to three main drivers: the Northwest Power and Conservation Council's (NPCC's) Fish and Wildlife Program (NPCC 2014), Water Resources Development Acts (Sections 206, 536, and 1135), and Biological Opinions (BiOps) for operation of the Federal Columbia River Power System (FCRPS) (e.g., NMFS 2000, 2004, 2008a). In particular, the National Marine Fisheries Service (NMFS) has included estuary restoration as "offsite" mitigation to help avoid jeopardizing 13 populations of Pacific salmon and steelhead (hereafter collectively referred to as "salmon") in the Columbia River basin listed under the Endangered Species Act (ESA). The Action Agencies conduct CEERP using an adaptive management process (Figure 1.1). Since 2004, ecosystem restoration in the LCRE has progressed from being adaptively managed in an ad hoc manner to becoming a fully functioning program (Figure 1.2). Ebberts et al. (2017) provide a detailed explanation of implementation and institutionalization of CEERP's adaptive management process.

CEERP's main strategy for restoring ecosystems supporting juvenile salmon[2] is hydrologic reconnection of tidal floodplain wetlands to the mainstem LCRE.

Figure 1.1. CEERP's adaptive management process. As used here, "Monitoring" includes research and "Learning" includes synthesis and evaluation.[3] (From Ebberts et al. 2017.)

A key element of CEERP adaptive management is periodic (about every 5 years) synthesis and evaluation of the program. Previously, using data and information up to the end of 2012, Thom et al. (2013) synthesized the state of the science of salmon ecology and its implications to CEERP habitat restoration in the 2012 Synthesis Memorandum (SM1). The 2012 memo, referred to as SM1 because it was the first of its kind, summarized the knowledge base and provided an integrated scientific basis for the strategic direction of ecosystem restoration in the LCRE. Since 2012, CEERP has been steadily implementing restoration actions and conducting associated monitoring and research. The 2018 Synthesis Memo (SM2) incorporates new scientific findings relevant to CEERP after 2012; conducts new

[1] CEERP is an acronym coined in 2011 for the joint federal (BPA and Corps) effort to restore LCRE ecosystems. By definition, CEERP includes federal restoration actions prior to 2011.

[2] For purposes of brevity, the term "juvenile salmon" also includes juvenile steelhead.

[3] Synthesis is the compilation and summarization of data from multiple sources to discern patterns, commonalities, consistencies, and contradictions in the findings. It also attempts to address relevant hypotheses. Evaluation is answering a question about the performance of or a hypothesis about the system.

summarizations, syntheses, and analyses; and uses the collective results to evaluate program strategy to date and provide recommendations for the future. SM2 provides CEERP managers, policy-makers, restoration sponsors, and others with a comprehensive, scientific understanding of the state of the science to inform program strategy and decision-making in the near and long terms. NMFS (2016) noted "New information available since the last status review indicates that many restoration and protection actions have been implemented in freshwater and estuary habitat but does not reveal overall trends in habitat quality, quantity, and function." SM2 aims to evaluate this concern.

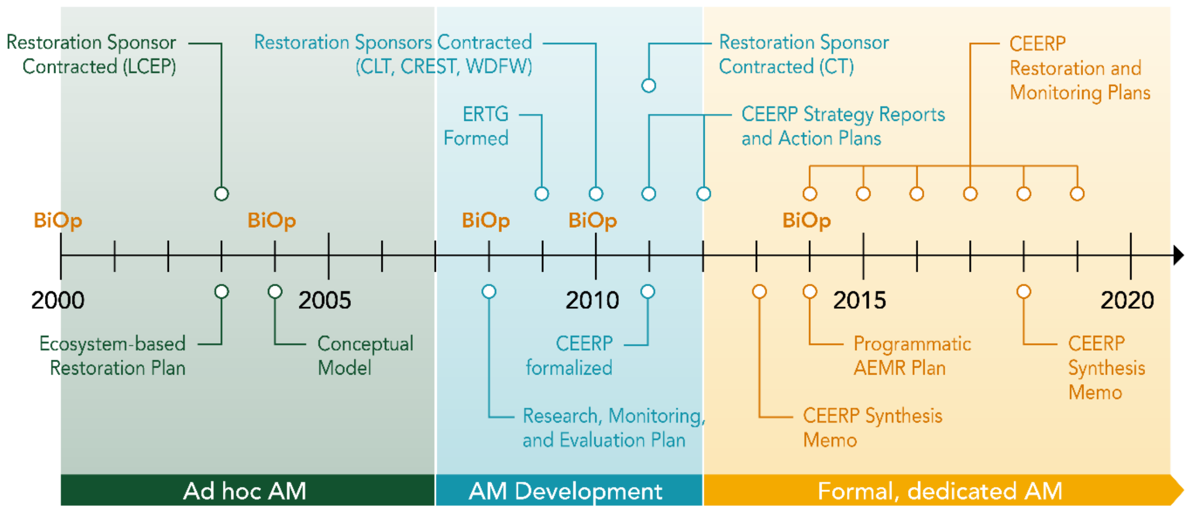


Figure 1.2. Timeline of key events and programmatic documents in development of CEERP and its adaptive management process. (From Ebberts et al. 2017.)

1.1 Conceptual Model and Hypotheses

SM2 addresses CEERP's primary hypothesis (after Diefenderfer et al. 2016a)—ecosystem restoration activities in the estuary have a cumulative beneficial effect on rearing and migrating juvenile salmon. We also address CEERP's two secondary hypotheses: 1) habitat-based indicators of ecosystem controlling factors, processes, and structures show positive effects from restoration actions, and 2) fish-based indicators of ecosystem processes and functions show positive effects[4] from restoration actions and habitats undergoing restoration.[5] Using data and information developed herein, the memo closes with an evidence-based reevaluation of these hypotheses (see Section 6.1).

The hypotheses reflect a general organizing model (Figure 1.3a and Table 1.1) and an ecosystem conceptual model of restoration effects (Figure 1.3b). The conceptual model was designed to apply to the effects on juvenile salmonids, both directly onsite and indirectly offsite, of hydrologic reconnections of

[4] What constitutes "positive effects" is explained in Section 3.1 for each monitored indicator.

[5] To ascribe effects on fish survival from habitat restoration, it is impractical technically and logistically to estimate survival rates of fish at the scale of a restoration site. Diefenderfer et al. (2010; see Section 4) noted: "There are no established empirical methods to quantitatively estimate the site-specific survival benefits of LCRE restoration projects." Instead, we employ fish-based indicators such as juvenile salmon diet, growth, and residence time to evaluate this hypothesis.

the LCRE to its historical floodplain. The site-scale model has three tiers of response variables. First, the physical tier includes the hydrogeologic environment (physical and hydrodynamic features), water properties (temperature, salinity, etc.), and the sediment and soil profile. Physical conditions affect the biotic environment, the second tier in Figure 1.3, where primary and secondary production and microbial decomposition occur. Prey for juvenile salmon, such as insects, benthic organisms, and zooplankton, is a key element of the biotic tier. Juvenile salmon in the main channel are linked to secondary production by export of prey from the site by tidal flows, flooding, or airborne transport. The third tier is salmon and includes biotic interactions, physiological responses, behavior, and population metrics. The strength of the understanding of the linkages between various components, however, has varied from strong, e.g., the

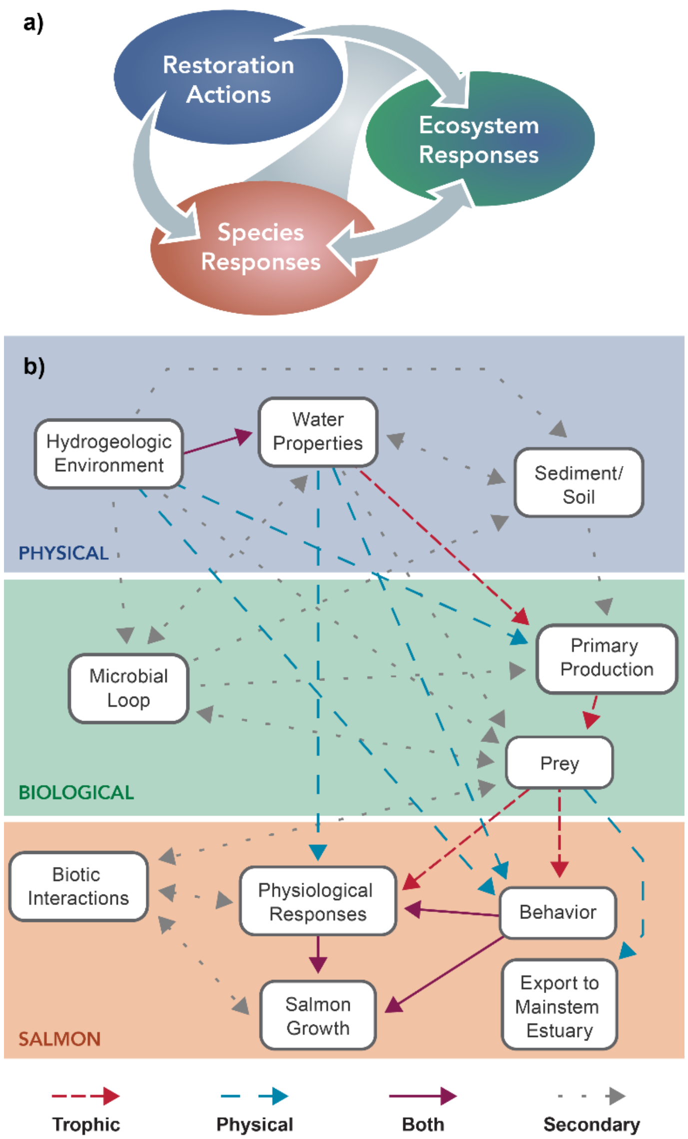


Figure 1.3. Conceptual models for CEERP restoration: a) general organizing model; b) ecosystem model distinguishing trophic and physical relationships for direct and indirect effects of restoration on juvenile salmon. Indirect effects occur when prey and other materials are exported from a restoration site to the mainstem estuary. (From Buenau et al. 2016b; Diefenderfer et al. 2016a.)

relationship between inundation and marsh vegetation, to weak, e.g., the relationship of benthic and planktonic production to prey (Buenau et al. 2016a). Many of the conceptual model's attributes (boxes) and processes (arrows) are covered in SM2 (Table 1.1).

Table 1.1. Description of attributes in the conceptual model of restoration effects on juvenile salmon in the Columbia River estuary (Figure 1.3). The descriptions are based on Buenau et al. (2016b).

Attribute	Description
	Tier 1 Physical
Hydrogeologic Environment	Physical structure and hydrodynamics of a restoration site. This component is directly affected by hydrological reconnection, e.g., dike breach, and necessarily must affect other attributes related to ecosystem processes for restoration to be successful.
Water Properties	Includes water temperature, dissolved oxygen, and turbidity, all of which affect the biota. Water properties affect salmon physiology and behavior, as well as primary production and prey.
Sediment/Soil	This is the structure, composition, and profile of sediment and soils at the site. Wetland sediment/soil provides habitat for an abundance of benthic fauna, and is substrate for aquatic plants.
	Tier 2 Biological
Microbial Loop	The microbial loop connects the biotic community and physical environment through the breakdown of detritus and organic matter. It is the flow of energy from dissolved organic carbon through heterotrophic bacteria and fungi to flagellates and ciliates, and subsequently into higher trophic levels.
Primary Production	Includes benthic algae, wetland and marsh plants, and phytoplankton. Three broad categories of wetland plants are emergent herbaceous (marshes), shrub-dominated, and forested wetlands.
Prey	Includes the invertebrate taxa of secondary production (e.g., worms, insects, zooplankton, and crustaceans) whose food web is based upon the primary producers and microbial loop, and that are themselves food sources for salmon.
Export to Mainstem Estuary	Prey export to the mainstem estuary is hypothesized to be a primary mechanism for how wetland restoration indirectly benefits juvenile salmon. Also termed flux.
	Tier 3 Salmon
Biotic Interactions	Includes competition and predation, which directly affect juvenile salmon health or survival. Competition can be intra- or inter-species specific. Predators include birds and fish. Includes interactions with *non-native* plants, invertebrates, and fishes.
Physiological Responses	Stress, osmoregulation, and other physiological responses in fish to their environment. Fish physiology affects survival.
Behavior	Includes predator avoidance, foraging, and residence time at a site. Foraging on prey produced at restoration sites is a key piece of evidence for the benefits of restoration to salmon and their ecosystems. Foraging is characterized by analyses of salmon stomach contents.
Salmon Growth	Growth can be defined as the change in size (biomass and/or length) or calories stored in somatic or reproductive tissues over a period of time, and can be measured as an increment or a rate of change. Growth is an important indicator of salmon performance.

1.2 Management Questions and Objectives

Based on input from the Action Agencies, NMFS, and other policy-makers and managers, SM2 is designed to address the following management questions, associated objectives (location in SM2 is in parentheses), and sub-objectives, as explained in the respective chapters, sections, or appendices of the memo.

What progress has been made to date by CEERP[6] *in terms of the number of restoration projects and floodplain area restored? How much wetland*[7] *area has been restored under CEERP? Quantitatively, how has habitat connectivity*[8] *changed estuary-wide and by estuary zone*[9]*?*

- Summarize restoration activities in the estuary since 2004 (Section 2.1, Appendices A and B).
- Index habitat connectivity estuary-wide and by zone for 2004 (baseline), 2010 (intermediate), and 2016 (current conditions) (Section 2.3, Appendix D).

At the site scale, are restoration actions having the expected physical and biological effects?

- At the site scale, assess the effectiveness of CEERP restoration projects based on available monitoring data (Chapter 3, Appendix E).

What are updates to the findings and uncertainties regarding the science questions identified in SM1?

- Update the state of the science underlying the CEERP as laid out in SM1 by revisiting the key findings and uncertainties for each science question posed in SM1 (Chapter 4, Appendices C, D, E, F, and H).

What additional science questions are relevant to CEERP and why?

- Discuss the effect the mixture of hatchery and wild origin juvenile salmon has on CEERP strategy (Section 5.1).
- Describe the linkage between the estuary and ocean and how it could affect salmon population dynamics (Section 5.2).
- Identify new data and information to inform restoration project design (Section 5.3).
- Assess how climate change might affect environmental conditions in the estuary and be taken into account in restoration project design and CEERP strategy (Section 5.4).

What does the updated evidence-based evaluation performed in SM2 reveal concerning progress toward achieving program goals?

[6] This includes restoration projects funded by the Action Agencies prior to formal establishment of CEERP in 2011.

[7] This report distinguishes between floodplain and wetland areas.

[8] For purposes of SM2, habitat connectivity is a landscape descriptor concerning the ability of resources and organisms to move among wetland habitats, and includes structural connectivity (spatial arrangement of wetlands) and functional connectivity (transfer of energy among wetlands). This definition is consistent with CEERP's goal to improve wetland habitat access and quality for juvenile salmon by implementing a restoration strategy that reconnects disconnected habitats.

[9] Zones are defined in Section 1.4.2.

- Revisit the evidence-based evaluation of CEERP performance (Chapter 6).

What key findings can be drawn from CEERP restoration and research, monitoring, and evaluation (RME) activities since 2012? What key scientific uncertainties are affecting CEERP management? What are scientific and programmatic recommendations for CEERP?

- Summarize key findings and uncertainties, and make recommendations relative to CEERP strategy and implementation (Sections 7.1 and 7.2).

1.3 Monitoring and Research

The Action Agencies and others have conducted at least 21 published monitoring and research studies in the LCRE since 2004 (Table 1.2). (For purposes of SM2, monitoring involves spatially extensive sampling of basic indicators, whereas research involves locally intensive sampling to characterize ecosystem structures, processes, and functions.) This work has broadened and deepened the body of knowledge concerning physical and biological processes, as well as juvenile salmon migration characteristics and ecology (see the list of references following Table 1.2). The basic CEERP strategy of hydrologic reconnection is supported by this knowledge base. Articles published in 2012 and before helped inform SM1. Articles published after 2012 and the ongoing monitoring and research projects (Table 1.3) provide new data and information for Chapter 4, State of the Science.

Table 1.2. List of estuary RME studies. Shading signifies when the study was conducted. The numbers refer to the list of peer-reviewed publications following the table; the publication list is not exhaustive. Complete citations are in Chapter 8, References. Studies for rows without publication numbers are reported in gray literature.

Name	Funding Agency	Research Lead(s)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Estuary Ocean Subgroup (EOS)	BPA	PNNL																	
Survival Studies	Corps	PNNL/NMFS											7						
Habitat Linkages (data)	Corps	NMFS																	
Habitat Linkages (analysis)	BPA	NMFS								12			15						
RPA 159, Restoration Approach	BPA	PNNL																	
Conceptual Model	Corps	PNNL																	
Ecosystem Monitoring Program	BPA	LCEP										19							
Cumulative Effects	Corps	PNNL/NMFS							2, 3		14	4	5		8	1	6, 8		20
Crims Is Action Effectiveness	Corps	USGS																	
Action Effectiveness Tide Gates	Corps	USFWS																	
Tidal Freshwater Monitoring	BPA	PNNL																	
Reference Site Study	BPA	LCEP																	
Ocean Entry	BPA/NMFS	NMFS														21	16		
EOS/ERTG	BPA	PNNL																11	
Salmon Benefits	Corps	PNNL													9				
Tidal Freshwater Research	Corps	PNNL														10	17		
Contribution of Tidal Fluvial	Corps	NMFS													18		13		
Synthesis and Eval (Oncor)	Corps	PNNL																	
AEM	BPA	LCEP																	
Multnomah Ch. Wetland Mon.	Metro	NMFS																	
AEMR	Corps	NMFS/PNNL																	

1. Coleman et al. 2015. Area-Time Inundation Model. Ecological Engineering.
2. Diefenderfer and Montgomery. 2008. Pools and channels. Restoration Ecology.
3. Diefenderfer et al. 2009. Hydraulic geometry and microtopography. J. Ecohydrology.
4. Diefenderfer et al. 2011. Evidence-based approach. Ecological Restoration.
5. Diefenderfer et al. 2012. Diminishing returns. Ecological Restoration.
6. Diefenderfer et al. 2016. Evidence-based evaluation. Ecosphere.
7. Harnish et al. 2012. Migration pathways. Transactions Amer. Fish. Society.
8. Jay et al. 2014 and 2016. Tidal and fluvial processes (Parts I&II). Est. Coast.
9. Johnson et al. 2014a. Early life history diversity index. Ecological Indicators.

10. Johnson et al. 2015. Residence times off-channel. Canadian Journal Fisheries and Aquatic Science.
11. Krueger et al. 2017. ERTG process. J. Environmental Management.
12. Maier and Simenstad. 2009. Estuary food webs. Estuaries and Coasts.
13. McNatt et al. 2016. Estuary usage by upriver stocks. Transactions Amer. Fish. Society.
14. Roegner et al. 2010. Fish use post-restoration Kandoll. Transactions Amer. Fish. Society.
15. Roegner et al. 2012. Migration characteristics. Marine and Coastal Fisheries.
16. Roegner et al. 2016. Comparative use of deep and shallow habitats. Marine and Coastal Fisheries.
17. Sather et al. 2016. Juvenile salmon ecology in tidal freshwater. Transactions Amer. Fish. Society.
18. Teel et al. 2014. Genetic stocks using tidal freshwater. North Amer. Journal Fish. Management.
19. Thom et al. 2011. Restoration prioritization. Ecological Restoration.
20. Thom et al. In Press. Particulate organic matter flux. Ecological Applications.
21. Weitkamp et al. 2015. Size and timing at ocean entry. Marine and Coastal Fisheries.

Table 1.3. Estuary RME studies under way as of 2018.

Title	Ecosystem Monitoring Program—Status and Trends	Ecosystem Monitoring Program—Action Effectiveness Monitoring and Research (AEMR)	Action Effectiveness Monitoring and Research	Restoration Design Challenges
Funding Agency	BPA	BPA	Corps	BPA
Project No.	2003-07-00	2003-07-00	EST-P-15-01	2002-077-00
Research Agency(s)	LCEP[(a)]	LCEP	NMFS/PNNL[(b)]	PNNL
Principal Investigators	Corbett/Kidd	Corbett/Schwartz	Jacobson/Sather	Diefenderfer/Borde
Goal	Monitor the long-term status and trends of ecosystem conditions in the LCRE	Coordinate with restoration practitioners on AEMR data collection and conduct AEMR at selected sites.	Evaluate how restoration actions provide ecological benefits for juvenile salmon in the LCRE using AEMR Level 1 indicators[(c)].	Provide information regarding aspects of restoration techniques that currently pose known challenges and uncertainties.
Key Reports	Hanson et al. (2016a)	Schwartz et al. (2016)	Sather et al. (2017)	Diefenderfer et al. (2016b)

(a) LCEP = Lower Columbia Estuary Partnership.
(b) PNNL = Pacific Northwest National Laboratory.
(c) As defined in the *Programmatic Plan for Action Effectiveness Monitoring and Research* (BPA and Corps 2017a), Level 1 AEMR, the most intensive of the three levels, includes sampling for fish density, diet, growth, prey, material flux, etc.

1.4 Study Area

1.4.1 General Description

The LCRE begins at Bonneville Dam, the head-of-tide in the Columbia River, and covers the 234 km downstream to the Pacific Ocean. For purposes of SM2, the study area includes the portion of the plume immediately (~10 km) outside the jetties at the mouth of the river because this is where juvenile salmonids enter the ocean after migrating through the estuary. Thus, the study area for the SM2 includes the continuum of floodplain and mainstem habitats in the Columbia River from Bonneville Dam into the plume in the Pacific Ocean.

Water-surface elevations in the estuary are influenced by oceanic tides (mixed, semi-diurnal pattern) and river flows. The relative effects of these physical mechanisms vary longitudinally: the relative effects of tides on water-surface elevations in the floodplain decreases with distance from the ocean and as the effect of mainstem flow increases (see Jay et al. 2014 for details). In addition, regional and local climate factors (e.g., wet/dry years) and weather affect water-surface elevations. These dynamics have resulted in a prominent tidal freshwater region in the upper ~176 km. Columbia River flows are heavily influenced by flood management operations at upstream dams and to a lesser extent by “load following” for hydropower production. As a result, the hydrograph has changed in this basin where snowpack melting is the primary driver of spring runoff. Winter flows are higher (release of stored water) and the spring freshet is smaller (40%) and earlier in time compared to the undammed system (Jay and Naik 2011), as conveyed in Figure 1.4 from NMFS (2008b). The contemporary change in flow patterns affects habitat restoration in the estuary because of the influence of river flow on habitat-forming processes in the reconnected floodplain (Ward and Stanford 1995).

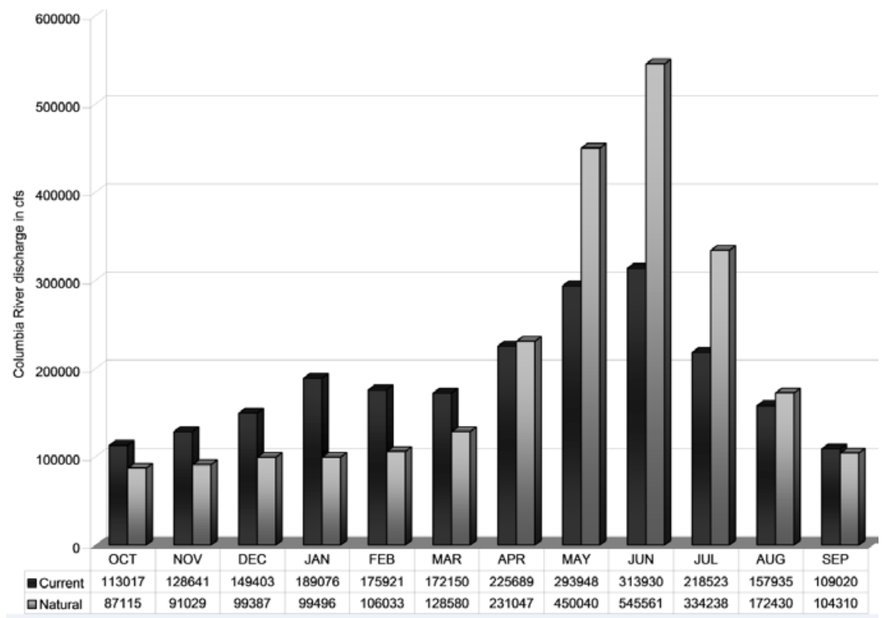


Figure 1.4. Simulated contemporary (current) and unregulated (natural) monthly flows at Bonneville Dam.[10]

Additionally, in the last century, there have been significant changes to estuary morphology due to improvements for navigation between the ocean and Portland/Vancouver, including building jetties at the Columbia River mouth, dredging the shipping channel, and installing pile dikes. As a result, the tidal prism has decreased by about 15% (Sherwood et al. 1990).

[10] From NMFS 2008b, Figure 5.1-2, caption: “Simulated mean monthly Columbia River flows at Bonneville Dam under current conditions and flows that would have occurred without water development (water years 1929 – 1978). Source: Current Condition Flows – Bonneville Power Administration, HYDSIM model run FRIII_07rerun2004biop.xls; Pre-Development Flows – USBR (1999) Cumulative Hydrologic Effects of Water Use: An Estimate of the Hydrologic Impacts of Water Resource Development in the Columbia River Basin."

Shallow-water habitats in the estuary have also changed significantly in the past 150 years. Due to diking and bank armoring, floodplain habitats with native wetland vegetation have been cut off from the mainstem estuary and converted to agriculture and industrial lands (Text Box 1.1). Moreover, habitat loss is ongoing. For example, Ke et al. (2013) determined there was a net loss of 13.3 km^2 of forested habitat on the 1,468 km^2 historical floodplain from 1996 to 2006. CEERP is working to regain estuary habitat lost due to development and conserve existing habitats (see Section 2.1).

Text Box 1.1. Habitat Change Analysis

The Lower Columbia Estuary Partnership quantified native habitat loss and conversion subsequent to large-scale agricultural, urban, and industrial development beginning in the late 1870s (published by Marcoe and Pilson 2017). Using spatial land-cover analysis techniques, they compared historic General Land Office Survey data collected roughly to the 1870s to 2009 land-cover data. They found large losses of forested upland habitats (55% reduction), tidal herbaceous wetland habitats (68% reduction), tidal forested wetlands (75% reduction), and tidal wooded wetland habitats (69% reduction) from historic extent. In total, 114,050 acres of native habitats were lost or converted, representing 50% of historic native habitat coverage. The majority of the loss of these habitats was due to conversion of land for agriculture and urban development. Also important was conversion of tidal wetlands to non-tidal wetlands.

1.4.2 Reaches and Zones

Three system classifications for the 234-km LCRE have been developed. Simenstad et al. (2011) delineated eight hydrogeomorphic reaches (Figure 1.5). Jay et al. (2016) recognized six zones based on the physical dynamics of water-surface elevation and five zones based on vegetation patterns (Figure 1.6). For SM2 purposes, we employ the five vegetation zones because of the fundamental relationship between habitat restoration and vegetation. We include the map of hydrogeomorphic reaches (Figure 1.5) for reference because some subject matter from previous research cited in SM2 used this classification. Conversions from one classification system to another are shown in Table 1.4.

Table 1.4. Equivalencies of the vegetation zones to the physical (Figure 1.5) and hydrogeomorphic (Figure 1.4) classification systems for the estuary. For ease of use in SM2, we apply the naming scheme for the physical zones to the vegetation zones, with an exception for "Vegetation 1." The fractions for the hydrogeomorphic zones are approximations.

Name	Rkm	Vegetation Zone	Physical Zone	Hydrogeomorphic Zone
Lower Estuary	~0-38	Vegetation 1	Lower Estuary + Energy Minimum	A + ½ B
Upper Estuary	~38-91	Vegetation 2	Upper Estuary	½ B + ½ C
Lower Tidal River	~91-138	Vegetation 3	Lower Tidal River	½ C + D + E
Middle Tidal River	~138-198	Vegetation 4	Middle Tidal River	F + ¾ G
Upper Tidal River	~198-234	Vegetation 5	Upper Tidal River	¼ G +H

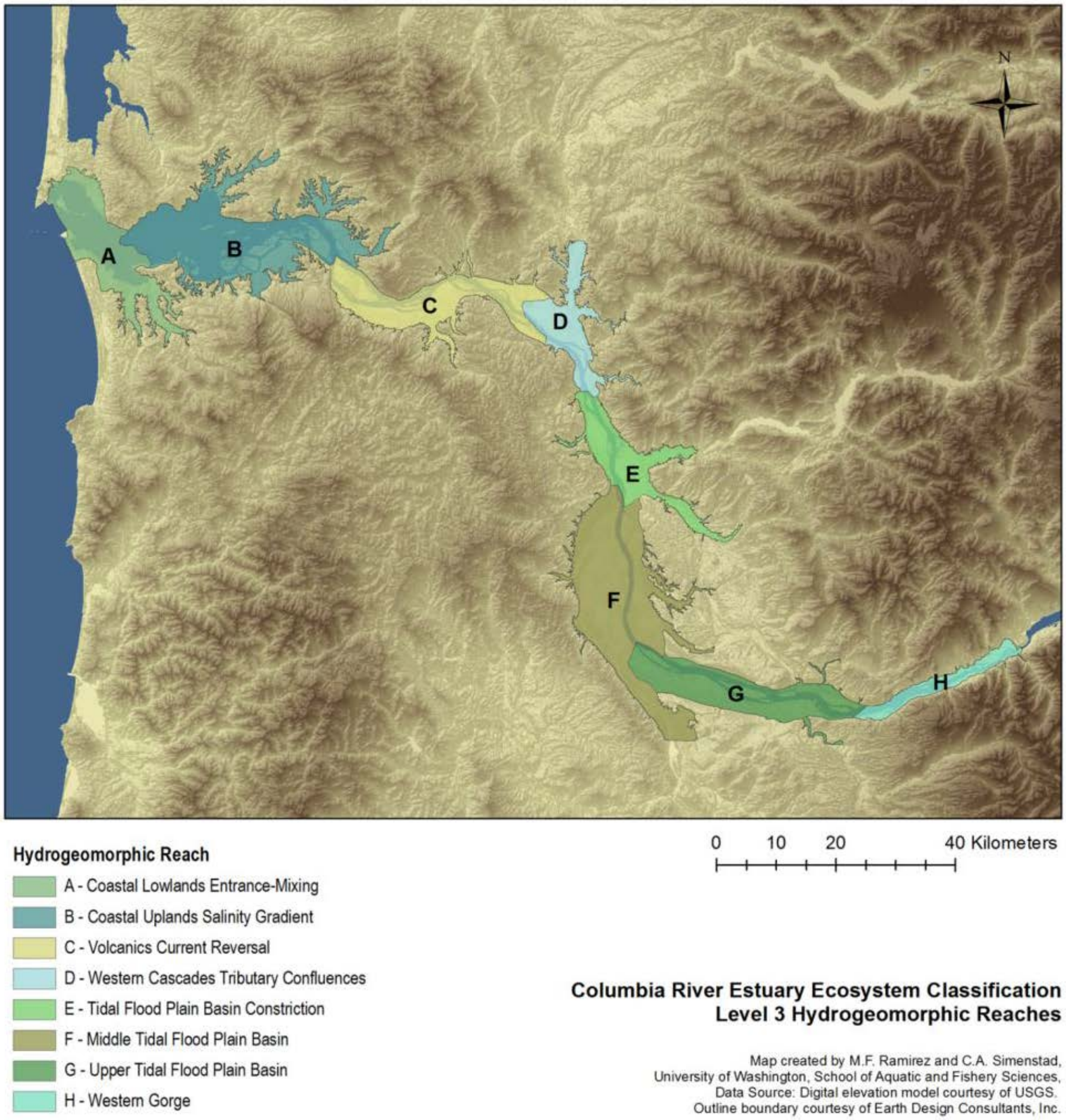


Figure 1.5. Map of the LCRE study area showing the hydrogeomorphic reaches. (Based on Simenstad et al. 2011.)

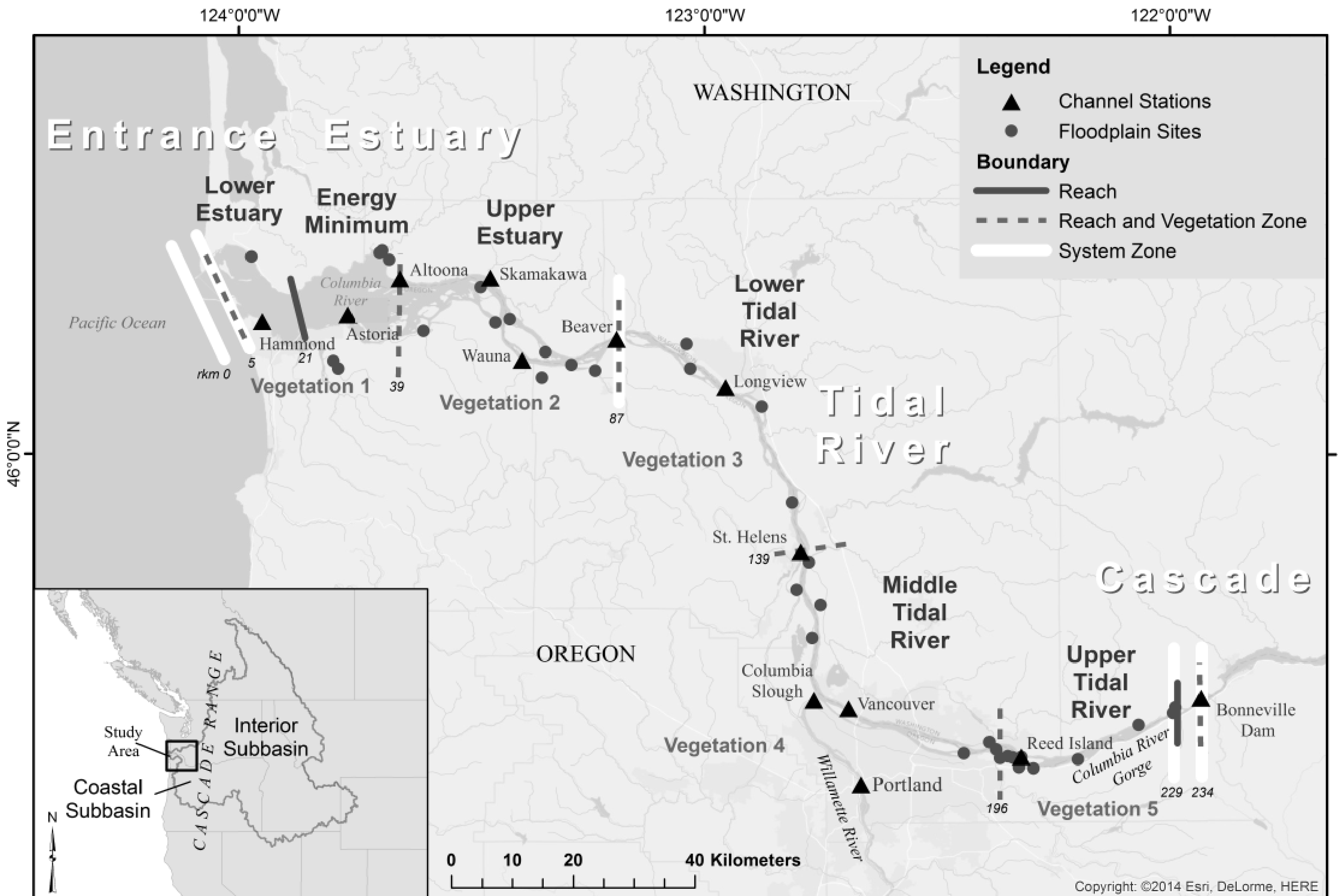


Figure 1.6. Map of the LCRE study area showing physical and vegetation zones. (Reproduced from Jay et al. 2016.)

1.4.3 Environmental Conditions 2004–2017

During the 2004–2017 study period for SM2, average daily river discharge for the Columbia River at Bonneville Dam for January through December ranged from 91 to 324 kcfs, with a mean of 181 kcfs and median of 164 kcfs. The timing and magnitude of the spring freshet varied annually (Figure 1.7). Discharge was lowest during summer. For the peak outmigration period April through June (Figure 1.7), daily discharge averaged over 2004–2017 had a mean of 275 kcfs, median of 271 kcfs, minimum of 223 kcfs, and maximum of 324 kcfs.

Year	Daily Discharge (kcfs; Jan-Dec)	Difference from Mean	Mean		Daily Discharge (kcfs; Apr-Jun)	Difference from Mean	Mean
2017			229				392
2016			173				245
2015			159				176
2014			186				284
2013			172				260
2012			218				349
2011			236				387
2010			150				221
2009			163				264
2008			173				283
2007			169				242
2006			194				324
2005			148				195
2004			160				223
Mean			181				275

Figure 1.7. Sparklines and difference from the daily mean over 2004–2017 for daily river discharge (kcfs) for January–December and April–June (peak outmigration period). For the sparklines, the x-axis is time and the y-axis is magnitude. Means over the days in a given year are also presented. For a given day of the year, blue is higher and red is lower discharge compared to the mean for that date over 2004–2017. Measurements were collected by the Corps at Bonneville Dam, river kilometer (rkm) 234. Data were obtained on January 18, 2018 from http://www.cbr.washington.edu/dart/query/river_graph_text.

Average daily water temperature during the same study period for the Columbia River at Bonneville Dam for January through December ranged from 3.5 to 22.1°C, with a mean of 12.4°C and median of 12.6°C. Temperatures steadily warmed during the April through June period (Figure 1.8). Water temperature was highest during summer. For the peak outmigration period April through June (Figure 1.8), daily water temperature averaged over 2004–2017 had a mean of 12.8°C, median of 13.2°C, minimum of 7.6°C, and maximum of 18.1°C.

Year	Daily Water Temperature (deg C; Jan-Dec)	Difference from Mean	Mean		Daily Water Temperature (deg C; Apr-Jun)	Difference from Mean	Mean
2017			11.9				12.2
2016			12.8				14.1
2015			13.6				14.8
2014			12.7				12.6
2013			12.7				13.3
2012			12.2				12.0
2011			11.8				11.3
2010			12.6				12.5
2009			12.2				12.7
2008			12.0				11.6
2007			12.4				13.2
2006			12.7				13.1
2005			13.2				13.4
2004			12.4				12.4
Mean			12.5				12.8

Figure 1.8. Sparklines and difference from the daily mean over 2004–2017 for daily water temperature (°C) for January–December and April–June (peak outmigration period). For the sparklines, the x-axis is time and the y-axis is magnitude. Means over the days in a given year are also presented. For a given day of the year, blue is cooler and red is hotter water temperature compared to the mean over 2004–2017. Measurements were collected by the Corps at Bonneville Dam, rkm 234. Data were obtained on January 18, 2018 from http://www.cbr.washington.edu/dart/query/river_graph_text.

Overall, river discharge and water temperatures varied from year to year (Table 1.5). Years 2011, 2012, and 2017 had relatively high discharges and cool water compared to the 2004–2017 average. In contrast, 2005 and 2015 were characterized by relatively low discharge and warm water. Focusing on the April through June period, there were more years with low discharges and high-temperature conditions than during the January through December period. Annual mean river discharge and water temperature were negatively related (Figure 1.9).

Table 1.5. Deviations of annual river discharge and water temperature measured at Bonneville Dam from the 2004–2017 average. Discharge level: blue > 15% from 2004–2017 mean (higher than average); red <-15% from mean (lower than average); and white > -15% and < 15% (average). Temperature level: red > 2% from 2004–2016 mean (hotter than average); blue < -2% from mean (cooler than average); and white > -2% and < 2% (average). Values are percentages. The threshold percentages were based on professional judgment. The means used in the calculations are presented in the respective figures above (Figures 1.7–1.8).

	04	05	06	07	08	09	10	11	12	13	14	15	16	17
Discharge (Jan-Dec)	-10	-19	9	-4	-1	-8	-17	26	19	-2	5	-11	-1	23
Discharge (Apr-Jun)	-18	-35	19	-9	7	0	-19	32	25	-1	7	-49	-8	33
Water Temperature (Jan-Dec)	-1	5	1	-1	-5	-3	0	-7	-3	1	1	7	2	-6
Water Temperature (Apr-Jun)	-3	4	2	3	-11	-1	-3	-13	-7	3	-1	13	9	-5

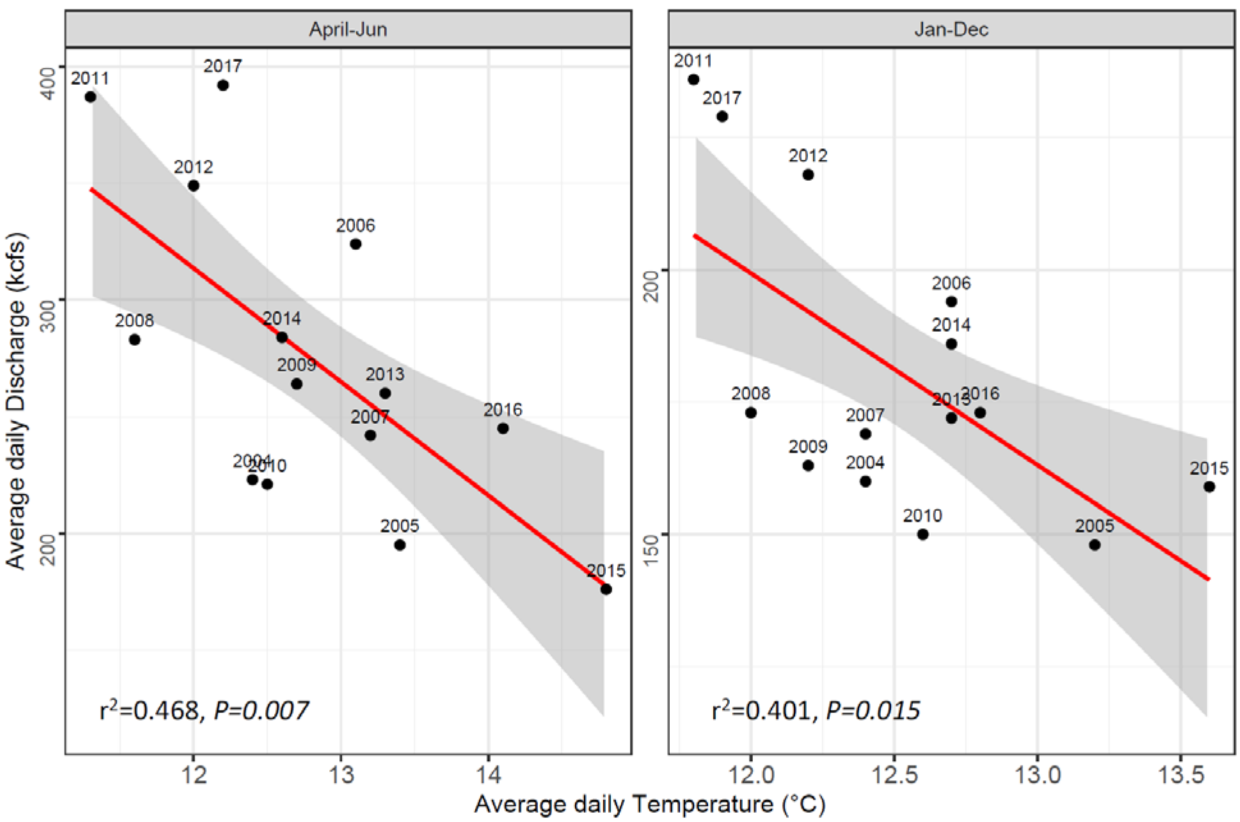


Figure 1.9. Relationship between annual mean daily river discharge and water temperature. Based on data from Figures 1.7 and 1.8. Courtesy of S. Pandit (Terraqua, May 2018).

1.5 Report Contents

In the ensuing chapters we first describe CEERP progress in terms of on-the-ground restoration actions constructed and increased habitat connectivity (Chapter 2). This is followed by monitoring data on the effectiveness of the restoration actions (Chapter 3). Using action effectiveness monitoring results and published presentations, reports, and journal articles, we revisit the state of the science for the estuary as determined in SM1 by Thom et al. (2013) (Chapter 4). Next, we provide additional important discussion of topics pertinent to the state of the science supporting the CEERP, such as climate change (Chapter 5). Given new data and information since 2012, we reassess the original (Diefenderfer et al. 2016) evidence-based evaluation for CEERP (Chapter 6). The main body of the report closes with conclusions, uncertainties, and recommendations for future activities (Chapter 7).

This report contains eight appendices: Restoration Project Metrics (Appendix A), Restoration Project Descriptions (Appendix B), Site Evaluation Cards (Appendix C), Habitat Connectivity Analysis (Appendix D), Action Effectiveness Monitoring (Appendix E), Juvenile Salmon Diet (Appendix F), Summary of the Juvenile Chinook Salmon Food Web at Tidal Emergent Marsh Wetland Habitats (Appendix G), and New Techniques and Resources (Appendix H).

2.0 CEERP PROGRESS

The objective of this chapter is to summarize restoration activities conducted in the estuary since 2004. The relevant management questions (Section 1.2) are: What progress has been made to date by CEERP in terms of the number of restoration projects, acreage restored, etc.? For example, how much wetland area has been restored under the CEERP? Quantitatively, how has habitat connectivity changed estuary-wide and by estuary zone?

CEERP's efforts to restore estuary floodplain wetlands are taking place under the scrutiny of the NPCC's peer-review processes, among other inputs as part of CEERP's adaptive management process. The Independent Scientific Review Panel (ISRP 2013) reviewed the restoration program in the estuary. In addition to other responses, CEERP managers committed to updating CEERP documents and sharing them regionally. The Independent Scientific Advisory Board (ISAB 2012) commented that new approaches to research and action effectiveness monitoring should be identified, scientifically evaluated, and implemented. Adjustments based on these comments were incorporated into and implemented as part of the CEERP Programmatic Plan for Action Effectiveness Monitoring and Research (AEMR) (Johnson et al. 2014b). The ISAB also reviewed the Expert Regional Technical Group (ERTG) process for assessing restoration project proposals and recommended it be substantiated in the scientific literature (ISAB 2014). Accordingly, CEERP managers supported ERTG's development and publication of Krueger et al. (2017). Peer-review is an important part of CEERP's adaptive management process as progress is made to restore floodplain wetland ecosystems.

2.1 Restoration Actions

We used the CEERP database in cbfish.org and other restoration records to obtain data for the restoration projects constructed from 2004 through 2017. The database contained records by project which were classified as acquisition, restoration, or both. We isolated projects involving restoration and extracted metrics by project for the restoration subactions (Appendix A) and project descriptions (Appendix B). The project list includes 58 projects from 2004 through 2017 (Figure 2.1, Table 2.1). Project construction ramped up during the 2012–2017 period when 35 projects encompassing 3,935 acres (6,333 ha) were constructed (Figure 2.2).

Photograph. Removing a culvert and berm to create a tidal channel outlet. Courtesy of T. Josephson.

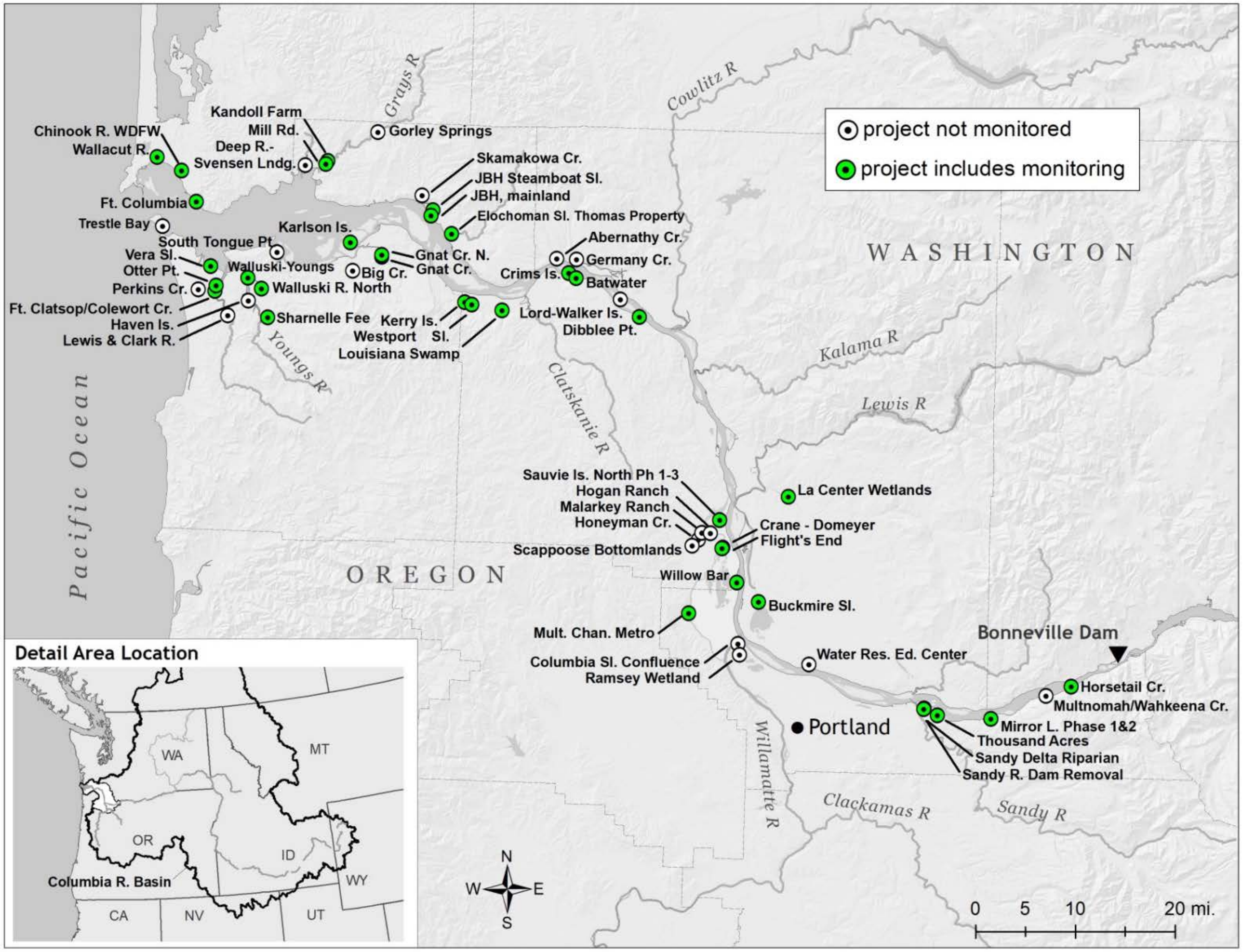


Figure 2.1. Locations of estuary restoration projects by the Action Agencies, 2004 through 2017. In this map, monitoring at a project refers to action effectiveness and can also include research on critical uncertainties. See Tables 3.1 and 3.2 for information on any monitoring for a given project. (Map provided by Keith Marcoe, LCEP.)

Table 2.1. Estuary restoration projects[a] funded by the Action Agencies 2004–2017. Year is when the project was constructed. Sponsors are in parentheses. See Appendices A and B for project metrics and descriptions, respectively. See Tables 3.1 and 3.2 for information about any monitoring for a given project.

Project (sponsor[b])	Year	Project	Year
Abernathy Creek (WDFW)	2012	Lewis & Clark River (CREST)	2006
Batwater Station (LCEP)	2015	Lord - Walker Islands (Corps)	2004
Big Creek (CREST)	2008	Mill Road (CLT)	2011
Buckmire Slough (CREST and WDFW)	2015	Mirror Lake (Phases 1+2) (LCEP)	2008
Chinook River Estuary (WDFW)	2014	Multnomah & Wahkeena Creeks (LCEP)	2014
Colewort Creek (CREST and NPS)	2012	Multnomah Channel (Metro)	2014
Columbia Slough (City of Portland)	2009	North Unit (NU)--Ruby Lake (CREST)	2013
Crane Slough-Domeyer (CREST)	2016	NU--Widgeon/Deep/Millionaire (CREST)	2014
Crims Island (Corps)	2005	NU--Three Fingered Jack (CREST)	2015
Deep River, Svensen's Landing (CLT)	2005	Otter Point (CREST and NPS)	2012
Dibblee Point (CREST)	2013	Perkins Creek (CREST)	2009
Elochoman Slough Thomas (WDFW)	2015	Ramsey Lake	2007
Flight's End (CREST)	2017	Sandy River Dam Removal (Corps)	2013
Fee-Simon (CLT)	2014	Sandy River Delta Riparian Forest (LCEP)	2008
Fort Clatsop (CREST and NPS)	2007	Scappoose Bay - Malarkey Ranch (SBWC)	2005
Fort Columbia (CREST)	2011	Scappoose Bay 2007-2009 (SBWC)	2008
Germany Creek (CLT)	2011	Scappoose Bottomlands (SBWC)	2007
Gnat Creek #1 (CREST)	2012	Skamokowa Creek - Dead Slough[c]	2013
Gnat Creek #2 (CREST)	2013	South Tongue Point (Liberty Lane) (CREST)	2012
Gorley Springs (CREST)	2009	Steamboat Slough (Corps)	2014
Haven Island (CLT)	2010	Thousand Acres (LCEP)	2014
Honeyman Creek (LCEP)	2013	Trestle Bay (Corps)	2016
Horsetail Creek (LCEP)	2013	Vancouver Water Resources Center (Corps)	2009
JBH Mainland (USFWS)	2010	Vera Slough (CREST)	2006
Kandoll Farm #2 (CLT)	2013	Wallacut River (CLT)	2016
Karlson Island (CREST)	2014	Walluski River North, Elliot #1 (CLT)	2008
Kerry Island (CLT)	2016	Walluski-Youngs (Cowlitz Tribe)	2017
LA (Louisiana) Swamp (LCEP)	2013	Westport Slough (USFWS)	2016
La Center Wetlands (LCEP)	2015	Willow Bar (CREST)	2016

(a) The Sandy River riparian and invasive plant control projects were combined into one project. The Brownsmead, Hamilton Creek, and Stephens Creek projects were excluded because they did not target benefits to juvenile salmon and steelhead from the Interior Columbia Basin, an objective of the CEERP per the 2008 FCRPS Biological Opinion. The tide gate replacement project at Tenasillahe Island was not included because a new restoration project with full hydrologic connectivity is being developed to replace it.
(b) CLT = Columbia Land Trust; CREST = Columbia River Estuary Study Taskforce; NPS = National Park Service; WDFW = Washington Department of Fish and Wildlife.
(c) Cowlitz-Wahkiakum Conservation District.

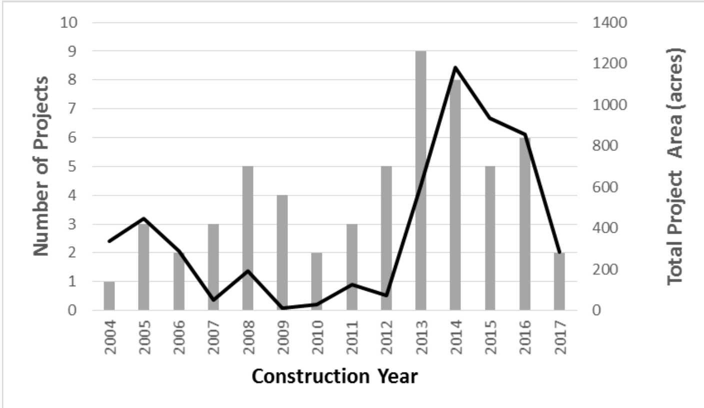


Figure 2.2. Number of restoration projects constructed by year (bars) and total area for the CRE 10 series (line) from 2004 through 2017.

The primary restoration activities, called "subactions" after the Estuary Module (NMFS 2011), have involved riparian improvements, establishment of floodplain tidal channels, full hydrologic reconnection through dike or levee breaching, and invasive plant control (Table 2.2). NMFS (2011) recommended these subactions to address habitat factors in the estuary that are limiting the viability of salmon and steelhead in the Columbia River basin. From 2004 through 2017, CEERP project sponsors[1] have restored a total of 55 mi of riparian habitat and 5,412 acres (2,190 ha) of floodplain wetlands[2] (Table 2.2). In addition, about 2,500 ac (1,012 ha) of functioning floodplain habitat have been acquired for conservation.[3] Most of the area restored has been created by dike breaching to restore floodplain connectivity (CRE 10.1; Table 2.2). In addition, the Action Agencies are currently developing projects related to beneficial use of dredged materials (CRE 6, Estuary Module), e.g., creation of shallow-water habitat in new embayments behind islands in the lower Columbia River (Moritz et al. 2018). The total area restored (5,412 acres) and conserved (2,500 acres; 1,012 ha) is about 9.3% of the approx. total 85,000 acres that are considered potentially restorable (Diefenderfer et al. 2016).

Photograph. Restoring wetlands. Courtesy of I. Sinks.

[1] The restoration sponsors (entities who implemented the projects) are primarily the Columbia Land Trust, Columbia River Estuary Study Taskforce, Cowlitz Tribe, Lower Columbia Estuary Partnership, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and Washington Department of Fish and Wildlife.
[2] This total only includes the sum of acreages for Subactions 10.1, 10.2, and 10.3 (floodplain reconnection), because the acreages affected by Subactions 9.4 and 15.3 (channel reconnection and invasive plant control) often overlap with those restored under Subactions 10.1, 10.2, and 10.3.
[3] The acreage total for conservation does not include acreage acquired for purposes of subsequent restoration, e.g., future breaching dikes and levees.

Table 2.2. Module subactions and accomplishments, 2004–2017. See ERTG (2012) for further description and clarification of the subactions. A given project could have included more than one subaction. "CRE" numbers are from the Estuary Module (NMFS 2011). The Estuary Module did not include a CRE action for acquisition for purposes of conservation or protection.

Module Subaction	Number of Projects That Included This Subaction	Mean Amount per Project	Total Amount Accomplished
CRE-1.4: Restore and maintain ecological benefits in riparian areas.	35	2 miles	55 miles
CRE-9.4: Restore degraded off-channel habitats where juvenile salmon can feed and rear.	36	10 acres	350 acres
CRE-10.1: Breach or lower the elevation of dikes and levee to create and/or restore tidal marshes, shallow-water habitats, and tide channels.	34	121 acres	4,068 acres
CRE-10.2: Remove tide gates to improve the hydrology between wetlands and the channel and to provide juveniles with physical access to off-channel habitat.	6	76 acres	457 acres
CRE-10.3: Upgrade tide gates where no other options exist; upgraded structures can provide access for juveniles, and ecosystem function would be improved over current conditions.	10	89 acres	887 acres
CRE-15.3: Control invasive plants to support salmon food-web dynamics.	35	63 acres	2,210 acres

2.2 Site Evaluation Cards

Site Evaluation Cards (SECs) were developed for 37 projects, with priority given to those that had ERTG revisit templates[4] or action effectiveness monitoring (AEM) data or both (Appendix C). Thom et al. (2008) first proposed SECs as a mechanism for systematically capturing descriptions, lessons learned, and AEM data from restoration projects. BPA and Corps (2017a) provided a template for SECs from which SECs were prepared for purposes of SM2. In cases where project sponsors had completed ERTG "revisit" templates (Krueger et al. 2017), pertinent information was transferred to the SEC. Any available AEM data for the project were also added. Otherwise, SECs were generated from scratch using information from cbfish.org or published reports about the restoration project. The intent was to interpret a given project's descriptive summary to ascertain how much progress the project was making toward its goal. The SECs include a "Post-Construction Assessment" section. Here, years since construction are noted and conclusions are made relative to the three ERTG scoring categories: certainty of success, habitat opportunity/access, and habitat capacity/quality. The SECs close with "Concluding Remarks" about whether the project was successful in meeting its goals and if, not, suggestions for what should be changed for future projects of this type. For SM2, 37 SECs were completely populated with information and data, except for the Post-Construction Assessment and Concluding Remarks sections. An independent review team could be assigned this work. Results from independent reviewers are not

[4] ERTG revisit templates provide a summary of the project's objectives, the actual restoration construction activities, observations and lessons learned, and any available monitoring data. They are called revisit templates because project sponsors prepare them in advance of the ERTG revisiting a site post-construction to compare conditions to those observed during their visit preconstruction as part of the ERTG scoring process (Krueger et al. 2017).

available for SM2, but may be in the future and could be synthesized as another line of evidence to assess CEERP progress at a programmatic level.

2.3 Habitat Connectivity

Given CEERP's primary strategy to reconnect tidal wetlands to the mainstem estuary (BPA and Corps 2012), managers and stakeholders have asked: Quantitatively, how has habitat connectivity for juvenile salmon changed since 2004 due to reconnection-restoration actions (Table 2.2, CRE 10)? How much is CEERP improving habitat connectivity[5] by estuary zone? How much potential is there for tidal hydrologic reconnection by estuary zone? Therefore, over the past nine years researchers worked to develop an index for habitat connectivity for the purpose of tracking the progress of the CEERP (Diefenderfer et al. 2010; Borde et al. 2016; Diefenderfer et al. In Preparation). Habitat connectivity was assessed estuary-wide and by zone for 2004 (baseline), 2010 (intermediate), and 2016 (current conditions). This section contains a summary of the quantitative analysis of habitat connectivity; detailed methods and results are presented in Appendix D.

Spatial scales for application of the index are the estuary zones (Figure 2.3) and the entire LCRE floodplain from Bonneville Dam to the Pacific Ocean. The index inherently evaluates connectivity within the floodplain and this floodplain connectivity can be examined longitudinally by comparison across estuary zones. The index covers 2004 through 2016 because 2004 was when restoration essentially commenced and 2016 was the last full year before data compilation was initiated in 2017 for SM2.

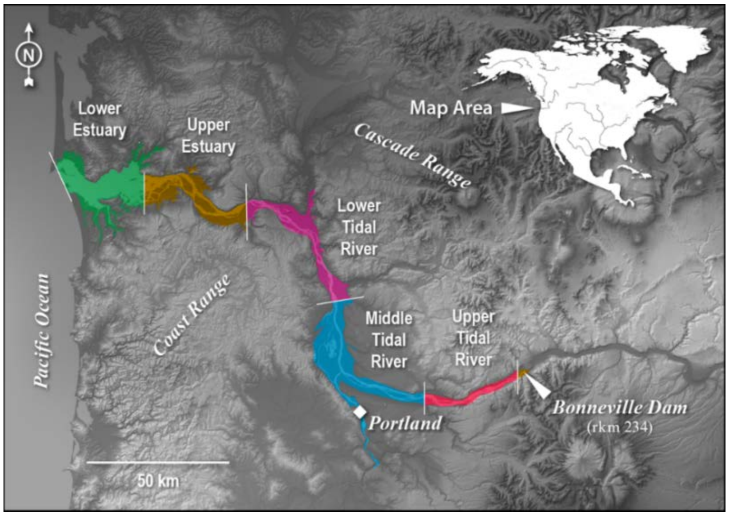


Figure 2.3. Map of the LCRE showing the five zones used in the habitat connectivity analysis. The boundaries of the colored segments depict the historical floodplain as defined by J. O'Connor (A. Borde, pers. comm.). Zones based on Jay et al. (2016); see Figure 1.6 above.

A geographic information system (GIS) technology and data layers covering the entire estuary floodplain were used to measure and count attributes to obtain the data for variables used in calculations for the index (see Appendix D for details). The index ranges from 0 to 100 with 0 representing no

[5] Previously (Section 1.2, footnote 5), we defined habitat connectivity as a landscape descriptor concerning the ability of resources (e.g., organic matter) and organisms (e.g., fish) to move among wetland habitats; it includes structural connectivity (spatial arrangement of habitats) and functional connectivity (transfer of energy among habitats).

connectivity whatsoever and 100 representing complete connectivity. A connectivity value of 50 implies an average 50% value across variables composing this index. The eight variables included aspects of connectivity, such as wetland size, open outlets, and channel edge length. A key point is that index values are non-dimensional and can be compared across space and time. Essentially, we integrated structural and hydrologic connectivity metrics to derive an index of functional habitat connectivity for migratory juvenile salmon on a tidal river floodplain.

The habitat connectivity index increased from 2004 to 2010 to 2016 (Figure 2.4a). Overall from 2004 to 2016, the index increased by 2.5%. This increase in connectivity is directly attributable to the restoration projects because the calculation method explicitly incorporates the spatial features of the restoration projects. Both patch[6] and wetland[7] connectivity increased over time (Figures 2.4b and 2.4c). These increases were more pronounced between 2010 and 2016 than between 2004 and 2010. As of 2016, about 32.2% of wetland habitat area was connected to the mainstem. There were 144 more open channel outlets in 2016 than in 2004 (Figure 2.4d). Tables with results for all variables used in the index are presented in Appendix D.

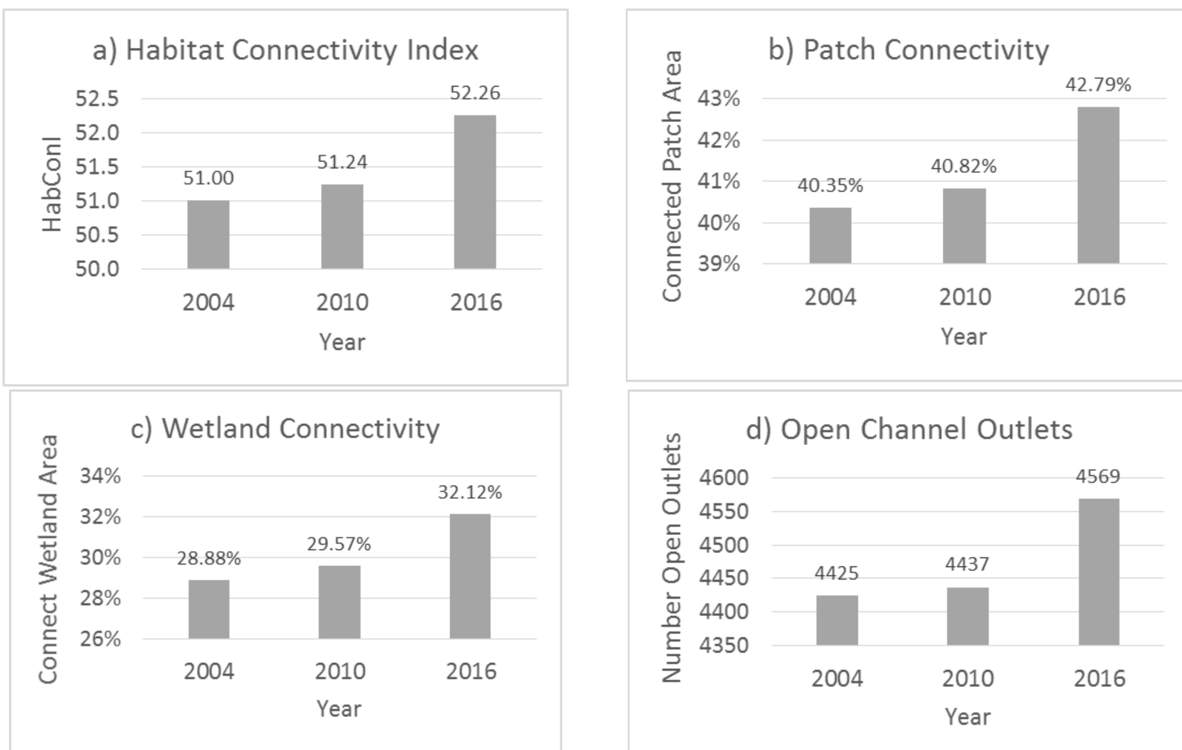


Figure 2.4. Habitat connectivity analysis for all zones combined in the LCRE by year for 2004, 2010, and 2016. Error bars are not applicable because the values are based on calculations from GIS data.

[6] Patches are floodplain areas containing tidally connected wetlands, flats, and channels (<120 m wide) and also include other contiguous, undeveloped forest, shrub-scrub, and herbaceous upland and non-tidal wetland polygons within hydrologic boundaries. Patch connectivity is a proportion of connected patch area out of total non-developed area.

[7] Wetlands are areas within patches containing tidal herbaceous, shrub-scrub, deciduous, and coniferous forested wetlands. Wetland connectivity is a proportion of wetland area connected to the mainstem estuary.

Habitat connectivity, as assessed in 2016, was highest in the Upper Tidal River zone (69.5) and lowest in the Middle Tidal River zone (44.7) (Figure 2.5). The Upper Tidal River zone also had the highest patch connectivity (66.6%), and the Lower Tidal River zone had the lowest (31.1%). The Upper Tidal River zone had the highest wetland connectivity (95.5%). The largest number of open channel outlets (2,356 outlets) was in the Upper Estuary zone where Cathlamet Bay and its many natural wetlands are located. The fewest number of open channel outlets (137) was in the Upper Tidal River zone, i.e., the Columbia River gorge, where there are not many outlets naturally.

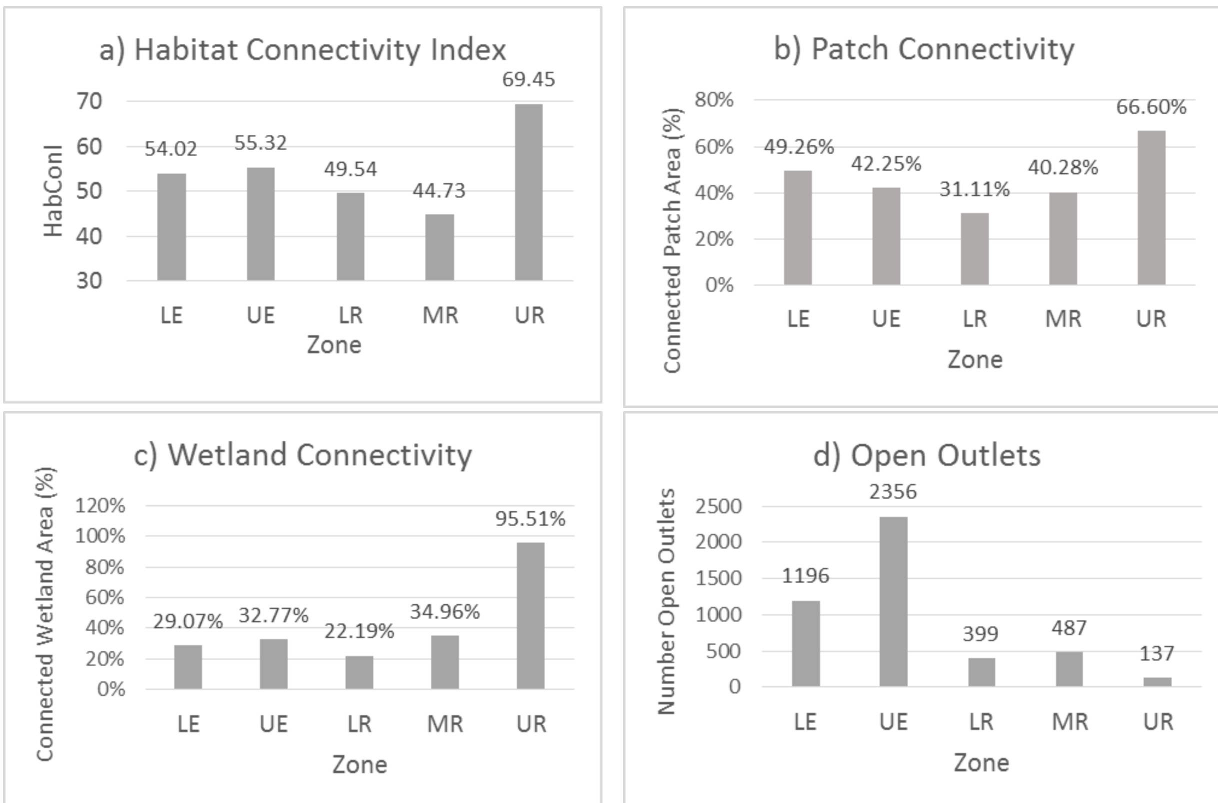


Figure 2.5. Habitat connectivity analysis for 2016 by zone: Lower Estuary (LE), Upper Estuary (UE), Lower Tidal River (LR), Middle Tidal River (MR), and Upper Tidal River (UR). Error bars are not applicable because the values are based on calculations from GIS data.

As of 2016, 32.1% of total wetland area (76,496 acres; 30,957 ha) was connected wetlands (24,570 acres; 9,943 ha) (Table 2.3). For context, there were 22,015 acres (8,909 ha) of connected wetlands in 2004. CEERP restoration resulted in 2,555 acres (1,034 ha) of additional connected wetland habitats in the LCRE, with 2,034 acres (823 ha) contributed during 2010–2016, according to the habitat connectivity analysis (Table 2.3). This amount differs from that reported above for CEERP progress (5,412 acres; 2,190 ha; Table 2.2) because the connectivity analysis incorporated data from the land cover classification for wetlands within the 2-year flood boundary, whereas CEERP project size determinations were based on 2-year flood perimeters for restoration projects. This difference does not affect the understanding of trends. (For project-specific details concerning this difference, see Appendix D, Attachment D.4). CEERP restoration resulted in a relative 11.6% increase in connected wetlands from 2004 to 2016 (24,570 acres relative to 22,015 acres) (9,943 ha relative to 8,909 ha).

Table 2.3. Summary of key patch and wetland connectivity results in the context of CEERP progress. The letters are for the variables in the index (see Appendix D). Data were reproduced from Appendix D.

Patch Connectivity		2004	2010	2016
A	Percentage of connected patch area out of total historical floodplain area, excluding areas unrecoverable (i.e., permanently developed)	40.4%	40.8%	42.8%
L	Total area of connected patches (ha)	22,723	23,002	24,126
R	Total recoverable wetland area (ha)	21,942	21,725	21,014
M	Total remaining natural area within the historical floodplain (ha)	11,647	11,617	11,236
Wetland Connectivity				
W	Percentage of connected wetland area out of total connected and recoverable wetland area	28.9%	29.6%	32.1%
X	Total area of all connected wetlands (ha)	8,909	9,120	9,943
Z	Total area connected wetlands plus recoverable wetland (X+R) (ha)	30,850	30,845	30,957
Channel Connectivity				
E	Percentage of class 1–5 channel edge length inside or adjacent to a patch out of total class 1–5 channel edge length	62.9%	63.4%	64.9%
F	Percentage of class 6 channel edge length inside or adjacent to a patch out of total class 6 edge length	72.9%	72.9%	73.8%
O	Percentage of open outlets out of total open and closed	84.4%	84.6%	86.1%
o	Number of open outlets	4,425	4,437	4,569
C[a]	Number of closed outlets	818	810	739

[a]The number of closed outlets was underestimated because the delineation technique and data sets did not count all closed channels inside disconnected areas.

In conclusion, we demonstrated a viable method for quantifying habitat connectivity. The habitat connectivity index increased by 2.5% due to CEERP restoration actions. This is a net increase because we assumed the amount of unrecoverable area (i.e., permanently developed) did not change. (This assumption was necessary because we did not have data on changes to unrecoverable area.) The index indicated about 50% overall connectivity. The results herein may be compared to similar analyses in future years to track CEERP progress. But, while much has been accomplished over the last 18 years, more remains to be done. According to the habitat connectivity analysis (Appendix D), there are at least 51,927 ac (21,014 ha) of "recoverable wetland" theoretically available for future restoration as of 2016. The recoverable wetland areas are located throughout the estuary (Figure 2.6).

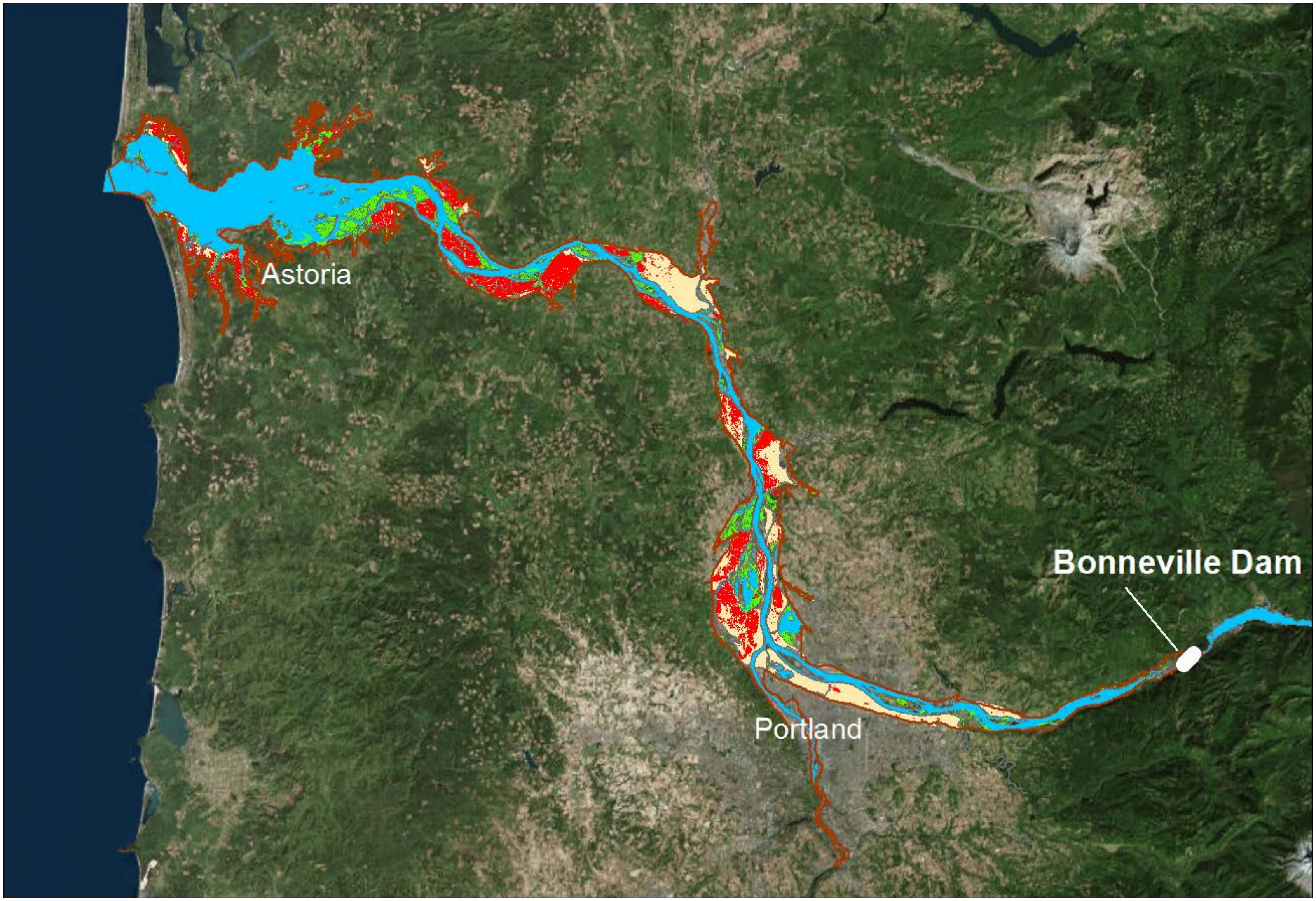


Figure 2.6. Map of recoverable wetland area based on GIS analysis for habitat connectivity. Legend: blue – mainstem LCRE; green – connected wetland area; red – recoverable wetland area; tan – permanently developed area.

3.0 ACTION EFFECTIVENESS

3.1 Introduction

Monitoring the physical and biological performance of restoration projects is an essential component of the adaptive management of an ecosystem restoration program (NAS 2016). In the LCRE, the extent and intensity of restoration project monitoring has increased dramatically since 2012 (Table 3.1) when CEERP was formalized (Ebberts et al. 2017) and managers responded to the clear recommendation from Thom et al. (2013) in SM1 for more AEM. AEM is implemented under a programmatic framework (BPA and Corps 2017a), which mandates basic AEM[1] for all projects. AEM data are comparable across space and time, at least since 2009, because most data have been collected using standard protocols (Roegner et al. 2009). The basic question CEERP managers and stakeholders ask is: At the site scale, are restoration actions having the desired physical and biological effects?

The time frame for achieving desired physical and biological effects after hydrologic reconnection varies depending on the effect, i.e., there are fast- and slow-response monitored indicators (Suding and Gross 2006). For example, water-surface elevation in a newly reconnected wetland will respond immediately after a dike breach, whereas plant communities can take years to evolve under the new hydrologic conditions. Water temperature response can be complex because of the interaction of local water conditions, groundwater, onsite vegetation, and mainstem estuary conditions. Sediment accretion rates can vary depending on ambient sediment loads in water inundating the restoration site (French 2006). Tidal channel morphology can change dramatically soon after the reconnection, then evolve relatively slowly after that as historical channels are reenergized (Verbeck and Storm 2001). Based on Roegner et al. (2010), we expect juvenile salmon to access newly reconnected areas soon after restoration. The restoration projects included in the AEM analysis described in this document were constructed 1–3 years previously, except for 6 years for Mirror Lake (Table 3.1). Thus, the timeframe post-restoration for the AEM analysis is relatively short; the results should be interpreted accordingly.

Photograph. Fyke net deployed in a tidal channel at low tide. Courtesy of N. Sather.

The overall objective of this chapter is to address the basic question of restoration effectiveness by summarizing fish monitoring data and conducting a meta-analysis of AEM data from individual project sites. We singled out fish data here because of their importance to CEERP. For six[2] other monitored

[1] Basic AEM is called "Level 3" in the *Programmatic Plan for Action Effectiveness Monitoring and Research* (BPA and Corps 2017a). Basic AEM includes water-surface elevation, water temperature, sediment accretion, channel cross-sections, and photo points.

[2] A seventh variable, habitat opportunity, is derived from water-surface elevation and water temperature.

indicators (water-surface elevation, water temperature, sediment accretion, channel cross section, vegetation, and macroinvertebrates), we present rationale, descriptions of desired physical and biological effects, analysis methods, and results in Appendix E. The material in Chapter 3 draws heavily from Appendix E. Instead of presenting this material under "new data and information" in Chapter 4, State of the Science, we devoted a chapter and an appendix to AEM, because these data are important and deserve maximum coverage. Key AEM findings, though, are incorporated into the state of the science in Chapter 4.

Table 3.1. Action effectiveness monitoring by project[(a)] by year since 2004. The bolded red "**M**" indicates construction and some monitoring occurred in that year. The bolded red "**C**" indicates construction but no monitoring occurred in that year. Highlighting indicates data are available (as of 9/29/17) for the analyses undertaken and reported herein.

`	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Batwater Station									X	X		**M**	X	X
Buckmire Slough											X	**M**	X	
Chinook River Estuary									X	X	**M**	X	X	X
Colewort Creek					X	X	X	X	**M**	X	X	X		
Crane Slough-Domeyer												X	**M**	X
Crims Island	**M**	**M**	X	X	X	X								
Dibblee Point									X	**M**	X	X	X	X
Elochoman Slough Thomas												**M**	X	X
Fee-Simon									X	X	**M**	X		
Fort Clatsop (South Slough)				**C**	X	X	X	X	X					
Fort Columbia								**M**						
Gnat Creek #1									**M**	X	X	X		
Gnat Creek #2										**C**	X	X		
Horsetail Creek										**M**	X	X	X	
JBH Mainland					**M**	**M**	X	X	X					
Kandoll Farm #2										**M**	X		X	
Karlson Island					X					X	**M**	X	X	X
Kerry Island												X	**M**	X
LA (Louisiana) Swamp									X	**M**	X	X		
LaCenter Wetlands										X	X	**M**	X	
Mill Road								**C**	X					
Mirror Lake Phase 1+2					**M**	X	**M**	X	X	X	X	X	X	X
Multnomah Channel Metro											**M**	X	X	
North Unit Ruby								X	X	**M**	X	X		
North Unit Widgeon/Deep/Millionaire										X	**M**	X		
North Unit Three Fingered Jack											X	**M**	X	
Otter Point									**M**	X	X	X		
Sandy River Dam Removal				X	X	X	X	X	X	**M**	X	X		
Steamboat Slough										X	**M**	X	X	X
Thousand Acres											**M**	X	X	
Vera Slough		X	**M**			X								
Wallacut River											X	X	**M**	X
Walluski River North, Elliot #1					**C**							X		X
Westport Slough USFWS #1												X	**M**	X
Willow Bar												X	**M**	X

(a) Kandoll Farm #1 is not included because the culverts installed for the project were subsequently removed and the dike at the location was restored as part of the Kandoll Farm #2 project. Essentially the Kandoll Farm #2 project replaced the Kandoll Farm #1 project.

3.2 Methods

AEM has been conducted at 35 of the 58 restoration projects completed under CEERP since 2004 (Table 3.1). It included before/after monitoring at 27 of the 35 projects; 10 of the 27 projects included restoration/reference site pairs, and 8 projects had only post-restoration monitoring (Table 3.2).

Table 3.2. AEM monitored indicators by project. An X means data were collected. Green highlighting indicates data were available for analysis or citation (as of 9/29/17). A check mark means "yes" and a dash means "no." Names of the reference sites are noted at the end of the table.[(a)]

Project	Reference Site	Pre-Restoration Monitoring	Water Surface Elevation	Water Temp	Sediment Accretion	Channel X-sec	Photo Points	Vege-tation	Macro-inverts	Fish Capture	Fish PIT
Batwater Station	√	√	X	X	X		X		X	X	
Buckmire Slough	-	√	X	X	X		X				
Chinook River Estuary	-	√	X	X	X		X	X			
Colewort Creek	-	√	X	X	X				X		X
Crane Slough-Domeyer	-	√	X	X			X				
Crims Island	√	√	X	X	X	X	X	X	X	X	
Dibblee Point	√	√	X	X	X		X	X	X	X	
Elochoman Slough Thomas	-	√	X	X	X		X	X	X		
Fee-Simon	-	√	X	X	X		X				
Fort Clatsop (South Slough)	-	-	X	X		X		X		X	
Fort Columbia	-	√		X		X	X			X	X
Gnat Creek #1	-	-		X	X		X	X			
Gnat Creek #2	-	-			X		X				
Horsetail Creek	-	√	X	X	X	X	X				X
JBH Mainland	-	√	X	X						X	
Kandoll Farm #2	-	-	X	X	X	X	X	X	X		
Karlson Island	√	√	X	X	X		X			X	
Kerry Island	-	-	X	X	X	X	X				
LA (Louisiana) Swamp	-	√	X	X	X	X	X	X			
La Center Wetlands	-	√	X	X	X		X	X	X		
Mill Road	-	-	X		X	X	X	X			
Mirror Lake Phase 1+2	-	√		X		X			X	X	
Multnomah Channel Metro	-	√	X	X						X	X
North Unit Ruby	√	√	X	X	X		X	X	X		
North Unit Widgeon/Deep/Mil	√	√	X	X	X		X	X	X		
North Unit Three Fingered Jac	-	√	X	X	X		X				
Otter Point	-	√	X	X	X	X	X				
Sandy River Dam Removal	√	√	X	X		X	X	X	X	X	
Steamboat Slough	√	√	X	X	X	X	X	X	X	X	X
Thousand Acres	-	√	X	X	X		X				
Vera Slough	√	√	X	X	X	X	X	X		X	
Wallacut River	√	√	X	X	X	X	X	X			
Walluski River North, Elliot #	-	-	X		X	X	X	X			
Westport Slough USFWS #1	-	√	X	X	X		X				
Willow Bar	-	√	X	X			X				

(a) Project/reference site: Batwater/Crims Island, Crims/Gull Island, Dibblee/Fisher Island, Karlson/Karlson Island old (historical breach), North Unit Ruby/Cunningham Lake, North Unit Widgeon/ Cunningham Lake, Vera/Vera east, Wallacut/Ilwaco Slough.

The indicators monitored at a given project site depended on the restoration project objectives (BPA and Corps 2017a). Various data from 22 of these 35 sites were available and suitable for analysis for SM2 (Tables 3.1 and 3.2). Not all data that have been collected were available for analysis because some are yet to be compiled, quality assured, and transferred to a central data repository. For macroinvertebrate data in particular, samples were collected from 12 sites, but had been processed for only 1 site.

For the meta-analysis, the site-specific AEM data from the SECs and analysis results were used to *qualitatively* assess the effectiveness of a given project in terms of physical and biological responses for specific monitored indicators. For each applicable monitored indicator, researchers identified relevant expected outcomes, as described in the Introduction (Section 3.1). Responses were based on professional judgment and took a standard form: data support the expected outcome; data are suggestive of the expected outcome; data are inconclusive or inadequate; and data do not support the expected outcome.

3.3 Results

AEM results are presented here for juvenile salmon (Section 3.3.1) and the meta-analysis of AEM results (Section 3.3.2). Specific AEM results for the other monitored indicators are presented in Appendix E.

3.3.1 Juvenile Salmon

Juvenile salmon presence/absence data were available for 14 restoration sites (Table 3.2). Researchers collected direct capture data by seining or trap netting at 11 sites and by detections at passive integrated transponder (PIT) arrays at 5 sites; both methods were employed at 3 of the 14 sites. Fish sampling usually occurred during spring and summer. Juvenile salmon, mostly subyearling Chinook salmon, were present at all 13 restoration sites (Table 3.3). Abundance varied from few to many fish. More quantitative data were difficult to obtain for SM2 because catch per unit effort or fish density data were not usually reported.

Table 3.3. Juvenile salmon data from restoration sites. LCRE zone (Table 1.4) and state where the site is located are in parentheses.

Restoration Site	Juvenile Salmon Data
Batwater (LR, Oregon)	PNNL sampled for juvenile salmon at the Batwater restoration site and associated reference site (Crims) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile Chinook salmon (CH) dominated the catch (N. Sather, pers. comm.). They were present during all months sampled (April–July) and were mostly of the genetic stock West Cascades fall CH.
Colewort (LE, Oregon)	The Columbia River Estuary Study Taskforce (CREST) sampled fish at the Colewort Creek site before and after dike breaching in 2012. As reported by Thom et al. (2013), catch per unit effort was low (<10 fish) for chum fry and subyearling Chinook salmon and medium (10–100 fish) for subyearling coho. A PIT array was installed and sampled pre- and post-construction. One subyearling CH classified as a Spring Creek hatchery fish (above Bonneville Dam) was detected in 2012 and another one in 2014.
Crims Island (LR, Oregon)	Haskell and Tiffan (2011) captured fish using beach seines and fyke nets at the Crims Island restoration site and a reference site (Gull Island) during 2004 (pre-restoration) and 2006–2008 (post-restoration). Subyearling Chinook salmon catch was highest from mid-March to late May. Densities were highest in subtidal channels 0.005–0.323 fish/m^2) and intermediate channels (0.003–0.340), and lowest on the marsh plains (0.022–0.069 fish/m^2). However,

Restoration Site	Juvenile Salmon Data
	these results were not statistically significant (P = 0.08). In general, catch per unit effort was higher post-restoration than pre-restoration.
Dibblee (LR, Oregon)	PNNL sampled for juvenile salmon at the Dibblee restoration site and associated reference site (Fisher Island) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile CH dominated the catch (N. Sather, pers. comm.). Juvenile salmon were captured at the sites in April and May, but not in June and July. Genetic stocks included Spring Creek fall CH, Upper Columbia summer/fall CH, and West Cascades fall CH.
Fort Clatsop (South Slough) (LE, Oregon)	During annual sampling 2007–2012, CREST researchers captured five salmonid species and the most abundant species was juvenile coho and Chinook salmon (CREST 2012). The fish-size data indicated multiple life history strategies evident at both the restored and reference sites.
Fort Columbia (LE, Washington)	CREST captured juvenile Chinook and coho salmon at the Fort Columbia restoration site (Thom et al. 2013; CREST revisit template/SEC). Here the Washington State Department of Transportation replaced an undersized culvert under U.S. Highway 101 east of Ilwaco with a large 12 ft × 12 ft box culvert. Fish traversed ~50 m from Baker Bay to the restoration area on the upstream side of the culvert. A hand-held PIT reader sampled the net catch and detected two Chinook salmon (CH) tagged and released at Astoria High School on the other side of the estuary.
Horsetail (UR, Oregon)	Fish sampling only employed PIT technology. The LCEP detected juvenile salmon on the PIT array on the Columbia River side and the Horsetail of the Interstate-84 (I-84) culvert (M. Schwartz, pers. comm.). Detections on the PIT array on the Horsetail side of the culvert showed that a few fish transited the culvert. A diversity of genetic stocks was represented on the Columbia River side of the culvert; however, genetic stock data for the fish transiting the culvert were not available. Use of the restored area by juvenile salmon accessing it from the mainstem river was equivocal.
JBH Mainland (UE, Washington)	After new tide gates were installed, juvenile salmon capture rates in terms of number of species and individuals were higher entering the sloughs with new tide gates than the reference slough (Johnson J et al. 2011). Juvenile Chinook salmon were the most abundant salmon species captured, followed by coho with some chum and steelhead present only in the restored, tide-gated slough. Juvenile salmon entered the new fish-friendly tide gates, although the proportion of non-native species of the total catch was higher in the restored areas than the reference site.
Karlson Island (UE, Oregon)	During spring 2016 and 2017, PNNL sampled juvenile salmon at the Karlson restoration site and associated reference site, “Karlson old,” the naturally breached area next to the new restoration site. Preliminary results for 2016 (N. Sather, pers. comm.) indicate unmarked juvenile CH were most dominant (77% of the catch); chum salmon composed 17%, and marked CH 2% and coho 2% of the catch. Juvenile salmon were present during all months sampled (April–July). Stock diversity was highest in April. West Cascades fall CH were captured in all months sampled.
Mirror Lake (UR, Oregon)	Sol et al. (2013) observed that juvenile salmon and steelhead appeared to be moving into the site by swimming upstream through the I-84 culvert from the Columbia River. Salmonids captured in beach seines at sampling sites in the restoration areas included cutthroat, steelhead, chum, coho, and CH (e.g., Mirror Lake samples). Juvenile coho salmon are from a spawning population in the Mirror Lake watershed.

Restoration Site	Juvenile Salmon Data
Multnomah Channel Metro (MR, Oregon)	McNatt et al. (2017) performed pre- and post-restoration sampling at wetlands and ponds off Multnomah Channel. Juvenile Chinook and coho salmon and coastal cutthroat trout were present in small numbers. From R. McNatt (pers. comm. Jan 16, 2018), "In the second year of post-restoration sampling the water-control structure for the north pond was left open. This resulted in a greater number of salmonids collected in the north pond, indicating that if given access, salmon will use the habitat." Genetic stock data from fin clips are not available at this time. Tagged salmon detected at the PIT arrays included mostly wild and hatchery fish from the Willamette River.
Sandy River Dam Removal (MR, Oregon)	Johnson and Sather (2016) reported fish community composition at a site at the outlet to the restored channel (Site C) and within the new channel (Site N). At both sites post-restoration, the fish community was dominated by juvenile salmon; this was not the case pre-restoration.
Steamboat Slough (UE, Washington)	PNNL sampled for juvenile salmon at the Steamboat restoration site and at its reference site (Welch Island) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile CH dominated the catch (93% of the total). West Cascades fall CH were present during all months sampled (April–July). In 2017, NMFS monitored the Steamboat restoration site and its reference site (Welch Island) for PIT-tagged salmon and steelhead. Fall Chinook salmon were most frequently detected, yet 9% of the 57 fish detected at Steamboat and 14% of the 33 fish detected at Welch were listed interior stocks. PNNL did not collect steelhead via fyke net sampling; however, steelhead were detected at both restoration and reference sites.
Vera Slough (LE, Oregon)	Salmon were a minor component of the fish community at sites inside and around the Vera Slough restoration site (Thom et al. 2012). Only 11 juvenile salmon were captured out of 75 seine samplings.

The Corps' Level 1 AEMR study currently is analyzing the most intensive fish data with respect to CEERP restoration action effectiveness. From this study, salmon species composition and Chinook salmon genetic stock data were available from post-restoration sampling at four sites from April through July 2016: Batwater, Dibblee, Karlson, and Steamboat. Researchers captured juvenile Chinook salmon at all four restored and reference site pairs (N. Sather, pers. comm, January 2018). Unmarked Chinook salmon were the most abundant salmonid in restored wetland channels. Marked Chinook salmon and chum salmon accounted for less than 3% of the total salmon catch. Coho salmon (unmarked) and cutthroat trout were rarely captured in restored wetland channels and accounted for less than 1% of the total salmon catch in 2016. Steelhead and marked coho salmon were not captured at restoration sites in 2016. For all sites and months combined, 80% of fish sampled were West Cascades fall Chinook salmon. Upper Columbia summer/fall Chinook salmon composed 15% of the total samples and were found at all sites. Spring Creek fall Chinook salmon were 3% of the total and were present in April and May at all sites except Karlson. Willamette River spring Chinook salmon were 1% of the total samples and were found only at Karlson and Steamboat. Other results from the intensive AEMR Level 1 study comparing restoration and reference site pairs (Dibblee/Fisher, Batwater/Crims, Steamboat/Welch, and Karlson new/Karlson old) will not be available until after SM2 is completed in June 2018.

Overall the genetic stock data indicated West Cascades fall Chinook salmon generally were present April through July at most sites where fin clips were collected for genetics analysis. Other common stocks of juvenile salmon were Spring Creek fall Chinook, Upper Columbia summer/fall Chinook, and Willamette River spring Chinook. Snake River stocks were rarely represented from direct capture samples at restoration sites as part of the AEMR study, which was not surprising given their overall rarity (Teel et al. 2014).

While upriver stocks were rarely encountered through direct capture techniques, the presence of these stock groups in restored tidal wetland channels has been confirmed using PIT antenna arrays. Of particular interest are the preliminary results from the Corps' AEMR study at Steamboat. McNatt and Hinton (2017) reported 9% of the 57 unique detections inside the Steamboat restoration site were from listed salmon and steelhead populations in the interior Columbia River basin. Of the 57 fish, 4 were yearling spring Chinook salmon and 5 were yearling steelhead, with median residence times of 11 sec and 30 min, respectively. For 40 subyearling fall Chinook salmon, median residence time was 3.5 d. The other eight fish detected were northern pikeminnow (*Ptychocheilus oregonensis*), similar to findings of these fish in shallow-water areas in the vicinity of Cottonwood Island (Diefenderfer et al. 2010). Overall, the data indicate the actions were effective in terms of juvenile salmon being present on newly constructed restoration sites.

3.3.2 Meta-Analysis of AEM Monitored Indicators

The qualitative meta-analysis of AEM monitored indicators was based on assessment of AEM data relative to the *a priori* expected outcome for an effective project. An effective restoration project (see Appendix E for further explanation) achieves an expected outcome whereby water-surface elevation (WSE) matches the "outside" condition indicating full hydraulic control for the site is normal and unmanaged; water temperatures match or are cooler than the mainstem estuary; sediment accretion rates are positive and the standard error is less than the mean; channel cross-sectional areas have decreasing width-to-depth ratios and smoothing longitudinal gradients through time; species richness and percent cover of native compared to non-native plants are increasing over time; macroinvertebrate fish prey are being produced on the site; and juvenile salmon are present and foraging on the site.

Of the seven monitored indicators used in the meta-analysis, WSE data more than any other indicator were sufficient to support the expected outcome, in this case reestablishment of hydrologic connectivity (Table 3.4). Water temperature data were often inconclusive or inadequate to support the expected outcome of matching temperatures when compared to the mainstem. Sediment accretion data were mixed; some sites displayed the expected outcome of positive sedimentation rates and others did not. Available results for channel cross section, which were based on the researcher's observations because width-to-depth ratio data were not available, were suggestive of support for expected channel evolution. Vegetation results were variable; some sites showed positive development of native plant communities, but others did not, usually due to the presence of reed canarygrass. Fish capture data revealed juvenile salmon to be present at all restoration sites, but few foraging data were collected. Therefore, fish capture data were suggestive but not sufficient to support the expected outcome. Fish PIT data were inconclusive because too few PIT arrays were deployed and, therefore, relatively few PIT-tagged fish were detected at restoration sites. In closing, future meta-analyses should be quantitative and underpinning by a statistical model should be considered.

3.4 Conclusion

In conclusion, the AEM data generally indicate restoration of physical and biological processes was under way. As fast-response indicators, WSE and fish capture data supported the hypothesis that restoration actions are having positive effects. In other instances, however, the results were inconclusive, sufficient data had yet to be analyzed, or it was too soon to tell because only a few years have elapsed since restoration construction. Water temperature, sediment accretion, and vegetation were in this category. Given that AEM data are intended to track restoration progress, it is worth recalling from Section 3.1 that different indicators have different time scales for response.

Table 3.4. Qualitative meta-analysis of site-specific AEM data. Results are categorized as follows: (A) the data were sufficient to support the expected outcome; (B) the data were suggestive but not sufficient; (C) the data were inadequate, inconclusive, or mixed; and (D) the data were adequate, but suggestive of a trend away from the expected outcome. See the text for descriptions of the expected outcomes. "X" without color highlighting means data were collected but were not available for SM2 because the data had not yet been processed, analyzed, or made available. A blank cell means that data were not collected. Results are based on data presented in Section 3.3.1 and Appendix E, unless otherwise cited in table footnotes after the table. When SM2 was written, too few macroinvertebrates had been processed to warrant their inclusion in this table.

Project	WSE	Water Temperature	Sediment Accretion	Channel Cross Section	Vegetation	Fish Capture	Fish PIT
Batwater Station	A	C	A			B	
Colewort Slough	X	X	X				C[c]
Crims Island	A[a]	C[a]	B[a]	B[b]	B[a]	B[a]	
Dibblee Slough	A	C	X		A	B	
Elochoman Sl.	C	C	A		X		
Fort Clatsop	A[a]	B[a]		X	X	C[a]	
Fort Columbia		X		X		B[3]	C[c]
Horsetail Creek	X	X	X	X			B
JBH Mainland	C[a]	C[a]				B[a]	
Kandoll #2	X	X	D	B	D		
Karlson Island	A	B	D			B	
LA Swamp	B	C	C	X	X		
La Center Wet.	A	C	C		X		
Mill Road	X		X	B	X		
Mirror Lake		X		X		B	
Mult. Ch Metro	X	X				B	C
North Unit Ruby	A	C	A		A		
NU Millionaire	A	C	C		D		
NU Widgeon	B	C	C		D		
NU 3 Fingered	A	B	X				
Sandy R. Dam	C[d]	C[d]		A[d]		B	
Steamboat Sl.	X	X	X	X	A	B	B
Vera Slough	D[a]	D[a]	B[a]	C[e]	D[a]	C[a]	
Wallacut	X	X	C	C	X		

Results based on [a]Diefenderfer et al. (2016a), [b]Haskell and Tiffan (2011), [c]Thom et al. (2013), [d]Johnson and Sather (2016), [e]Diefenderfer et al. (Ecological Responses; In Preparation).

4.0 STATE OF THE SCIENCE: UPDATE OF SYNTHESIS MEMO 1

The objective of this chapter is to update the state of the science underlying the CEERP as laid out in SM1—the first CEERP Synthesis Memo (Thom et al. 2013). Separately for the four SM1 science questions, we first summarize key findings and uncertainties (highlighted in bold font) from SM1, followed by updates based on new data and information published since SM1 was released in January 2013. Each subsection closes with a description of uncertainties. New data and information were derived from earlier chapters and appendices in SM2, journal articles, technical reports, and presentations at the biennial Columbia River Estuary Conference (CREC).[1] Such material is periodically compiled and assessed for its implications to restoration and monitoring in annual CEERP Restoration and Monitoring Plans. A given year's plan covers data and information mostly from the previous year. We used plans for 2014 through 2017 as a basic resource for this chapter (BPA and Corps 2014, 2015, 2016, 2017b). We summarize the findings from this exposition and remaining uncertainties in Chapter 7.

SM1 was the first synthesis of scientific data and information for CEERP's adaptive management process (Ebberts et al. 2017). Previous synthesis-type reports by Bottom et al. (2005) and Fresh et al. (2005), findings from the Columbia River Data Development Program (CREDDP 1984a,b; Simenstad et al. 1990), and various technical publications supported the scientific basis for CEERP. Applying SM1, managers writing the CEERP Strategy Report for the following year (BPA and Corps 2012) concluded the knowledge base regarding juvenile salmon ecology and ecosystem restoration in the LCRE supported taking hydrologic reconnection actions to restore wetland habitats. Although important uncertainties remained, CEERP managers concluded the existing knowledge base provided a science-based foundation for CEERP restoration and RME actions. BPA and Corps (2012) especially noted the following conclusions from SM1:

- All salmon from the Columbia River basin migrate through the LCRE; there are stock- and species-specific degrees to which these populations directly benefit from estuary ecosystems.
- Better understanding of the contribution of estuary restoration to adult salmon returns remains a need.
- The ecological effects of reed canarygrass and other non-native species continue to be an important uncertainty.
- There is a need for increased focus on AEMR to support the CEERP.

Based on these findings from SM1, CEERP managers adjusted the program strategy and implementation. SM1 reaffirmed CEERP's basic strategy to reconnect disconnected wetlands to the mainstem estuary, although it was evident there were still significant areas for improvement, especially in RME. CEERP managers adjusted the program strategy by taking the following actions, thereby resulting in the new data and information we use below to update SM1 findings and uncertainties:

- Increased emphasis on the scientific rigor for ERTG project reviews and encouraged peer-reviewed publication of the ERTG process (completed and published by Krueger et al. 2017).

[1] CREC is a biennial conference held in May every even year in Astoria, Oregon. CREC brings together people with interest in the LCRE and Columbia River plume to highlight new findings and perspectives regarding ecosystem restoration, research, and monitoring.

- Formalized AEMR, starting with the AEMR Programmatic Plan in 2014 (Johnson et al. 2014b), updated in 2017 (BPA and Corps 2017a).
- Increased the intensity of AEMR studies. Starting in 2012, BPA funded at least some AEM at all restoration projects. In 2015, the Corps established a major 3-year study within the Anadromous Fish Evaluation Program for Level 1 AEMR (NMFS and PNNL 2017).
- Began research on the indirect effects of wetland restoration on fish migrating downstream in the mainstem estuary. Thom et al. (2013) hypothesized about indirect benefits; the Corps' ongoing AEMR study (Table 2.4) is researching this hypothesis in a study that compares material flux (e.g., insects) from restoring wetlands to the gut contents of salmon migrating downstream in the mainstem channel (NMFS and PNNL 2017).
- Pursued focused research on the relationships between vegetation and prey production for two vegetation types—non-native reed canarygrass (RCG) and native *Carex spp*. (Hanson et al. 2016b).
- Asked the ERTG to describe the literature and observations about large wood and its potential influence on the physical and vegetative structure of tidal habitats and associated aquatic communities in estuaries, with a focus on emergent wetland habitats (ERTG 2016).

Here, we summarize and update the key findings and uncertainties (bolded for emphasis) related to the four science questions posed in SM1 by Thom et al. (2013). The uncertainties identified in Chapters 4 and 5 on the state of the science form the basis for the recommendations in Chapter 7, Conclusion.

Photograph. Tidal channel following restoration. Courtesy of N. Czarnomski.

4.1 What are the contemporary patterns of juvenile salmon habitat use in the estuary?[2]

4.1.1 Key Findings and Uncertainties from SM1

Thom et al. (2013) noted that patterns of estuary habitat use and the life histories of juvenile salmon are directly tied to their freshwater sources. Estuary residency and habitat use varied among species and stocks and their associated life history characteristics that dictated entry locations, times, and sizes. This

[2] This SM1 science question also included "What factors or threats potentially limit salmon performance?" We cover this topic under the second SM1 science question, "Do factors in the estuary limit recovery…?" Generally, we cover patterns of juvenile salmon habitat use under the first SM1 science question and limiting factors for juvenile salmon under the second.

had important implications for strategic prioritization of estuary restoration projects to satisfy the diverse estuary migration pathways and habitat requirements of salmon from different evolutionarily significant units (ESUs). In addition, large releases of salmon from hatchery sources were a major driver of contemporary stock abundances and the arrival times, sizes, habitat preferences, and residence times of juvenile salmon in the estuary. Thom et al. (2013) also noted an improved genetic baseline for Chinook salmon, along with parental-based tagging for Snake River hatchery fish that provided data about the hatchery of origin and release date, had greatly expanded our capabilities to interpret stock-specific patterns of estuary rearing and migration. Genetic results had documented variations in the stock composition of Chinook salmon in various estuary reaches and habitats. And, genetic stock identification for some steelhead stocks was now possible. Moreover, tagging studies and otolith chemical methods had been applied to describe life history variations for a few genetic stock groups. Key findings from application of these techniques since 2012 are described below because they help address contemporary patterns of use.

A major uncertainty in SM1 was whether the dominant estuary rearing behaviors today reflect habitat needs of at-risk stocks. This is because many of the salmon being produced by the Columbia River system are large-sized hatchery fish produced from a limited number of sources. Therefore, the uncertainty is in understanding the ***rearing behaviors of under-represented or at-risk (wild) stocks*** or wild stocks that are under-sampled due to their low abundance and comingling with hatchery fish. Thom et al. (2013) pointed out that most RME studies as of 2012 had targeted fish presence in shallow-water and nearshore areas, including habitat types that have been most intensively modified by historical development and that are the primary focus of estuary restoration. Less, however, was known about ***juvenile salmon ecology and genetic stock use of shallow-water habitats in tidal river zones and main channel habitats throughout the estuary***. Additional surveys in main channel habitats were needed to compare stock-specific life histories (i.e., subyearling and yearling migrants) across a wider range of estuarine habitat types. SM1 also noted the need to understand the genetic stock-specific use of the full range of estuary habitat types over various seasons for different genetic groups. This was particularly true in the three tidal river zones, which had been surveyed less intensively than those in the Lower and Upper Estuary zones. A related uncertainty was that few estimates of ***habitat-specific growth rates*** for juvenile salmon were available. In addition, characterization of juvenile life history variations within and among genetic stock groups was still incomplete. Finally, Thom et al. (2013) noted that there was also only a limited amount of evidence about ***flux of organic material and salmon prey*** from floodplain wetlands to the mainstem estuary.

4.1.2 New Data and Information

Since publication of SM1, which covered data and information through 2012, studies of habitat use in the estuary in addition to wetlands have occurred, including sampling in mainstem, off-channel, and shoreline areas. Weitkamp et al. (2017) used tow netting and purse seining during April, May, and June 2016 and 2017 to sample juvenile salmon in the main channel near Rooster Rock (rkm 215), Willow Grove (rkm 92), Steamboat Slough (rkm 61), and the Astoria Bridge (rkm 15). They captured 2,365 juvenile salmon in 2016 and 1,729 in 2017. Catch was highest in May and comprised

Photograph. Purse seine vessel. Courtesy of L. Weitkamp.

steelhead and coho, sockeye, and yearling and subyearling Chinook salmon. Subyearling Chinook salmon dominated the catch in June. Catch composition and genetic stock composition, which included steelhead and salmon from the interior basin, were similar among the four sampling sites down the mainstem estuary.

Generally, fish size influences migration pathways; larger fish are more likely than smaller fish to use the main channel and vice versa for shallow-water shoreline or off-channel habitats. This was originally noted for the LCRE by Dawley et al. (1986) and corroborated by Roegner et al. (2016). This is not to say, however, that no yearling salmon and steelhead use shallow-water, wetland habitats. McNatt and Hinton (2017) deployed PIT arrays at various wetland sites from rkm 36–139 and detected PIT-tagged fish from the interior Columbia River basin in shallow-water estuary habitats (Figure 4.1). Hanson et al. (2015), as noted above, detected yearling Chinook salmon from the interior basin at Campbell Slough. At a floodplain marsh on Multnomah Channel, McNatt et al. (2017) also detected juvenile salmon tagged upstream as part of other studies, including Willamette spring Chinook salmon, summer steelhead from Idaho, Spring Creek fall Chinook salmon, and Warm Springs hatchery Chinook salmon.

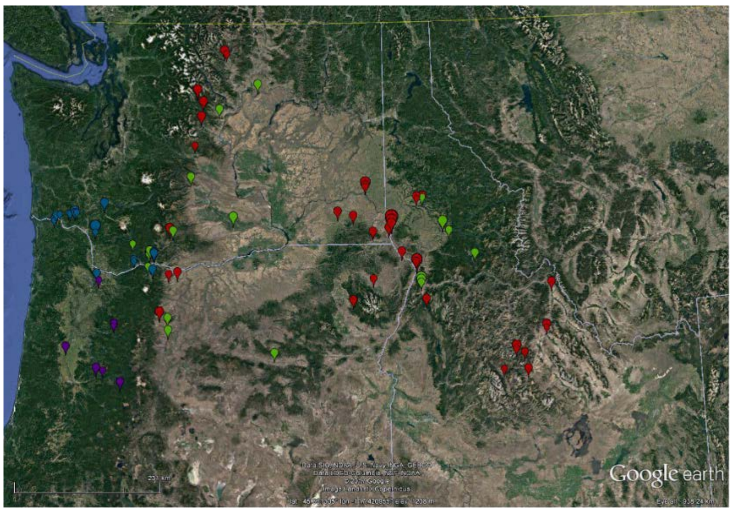


Figure 4.1. Detections of PIT-tagged fish in LCRE tidal wetlands. Blue: lower river; green: not listed; red: listed interior; purple: upper Willamette River. Obtained from R. McNatt (AFEP 2017 presentation).

Moreover, new PIT detection data suggest that yearling-size juvenile salmonids may use wetland tidal channels more so than previously understood. McNatt et al. (2015, 2016) related detections of PIT-tagged fish in tidal channels to the stage of the tide on Russian Island. They found ESA-listed stocks from the interior Columbia River basin tended to enter small tidal channels at or after slack high tide. Because fyke or trap nets are traditionally deployed at high tide to sample fish being flushed from a tidal channel on the ebb tide (see Bottom et al. 2011a), this sampling method would undersample fish that would have entered at or just after high slack tide. Traditional sampling in shallow-water habitat using seines and trap nets likely underestimates densities of yearling-size fish due to the limitations of sampling methods. No single gear type is best for sampling a single habitat and multiple life histories of salmon.

In general, juvenile salmon migration behavior in the estuary is variable and complex, as illustrated by Snake River fall Chinook salmon (SRF). SRF subyearlings and yearlings have different migration behaviors through the estuary—ranging from rapid migration to extended rearing. Yearlings migrate downstream rapidly and typically use main channels and large distributaries during their migration. Based on sampling in shallow habitats such as wetlands, there is little evidence of extended rearing (weeks to months) by most SRF yearlings in the estuary. In contrast, SRF subyearlings exhibit a diversity of migration behaviors, e.g., migration rates, residence times, and rearing locations. Some subyearlings from the SRF population use shallow nearshore and off-channel areas (including wetland and floodplain areas) below Bonneville Dam for rearing and for migrating (Fresh et al. 2005).

New data and information from research on residence times, migration patterns, and threats to salmon performance are available that support or complement SM1 findings. McNatt et al. (2016) were able to quantify habitat-specific residence times using the PIT and batch-marking techniques of fish captured at Russian Island in the lower estuary. They estimated residence times of 2–4 weeks for juvenile Chinook salmon (40 mm or greater; genetic stock was not determined). In an acoustic telemetry study, Johnson et al. (2015) estimated residence times for two life history strategies for juvenile salmonids that are expressed in off-channel tidal freshwater habitats of the estuary: 1) active migrations by upper river Chinook salmon and steelhead during the primary spring and summer migration periods, and 2) overwinter rearing in tidal freshwater habitats by coho salmon and naturally produced Chinook salmon mostly from lower river sources. During spring–summer 2007–2008, acoustic-tagged fish originating above Bonneville Dam had short residence times in off-channel areas of less than 4 hours (river kilometer [rkm] 192–203) regardless of fish size or species.[3] Residence time in off-channel areas increased dramatically during winter (late January and early February 2010, 2011, and 2012). Median residence times in off-channel areas in winter were 11.6–25.5 days for juvenile Chinook (106, 115, and 118 mm, respectively by year) and 11.2 days for coho salmon (116 mm). The residence times reported by Johnson et al. (2015) are conservative because it was not known how long a given fish was in the study area before it was captured, tagged, and released.

The general paradigm for the migration behavior of yearling-size fish has been that they migrate rapidly through the estuary and make little use of wetlands. While this appears true for most fish of this size (>120 mm fork length [FL]; e.g., Harnish et al. [2012] and McMichael et al. [2010]), there is evidence that some yearlings may take longer to migrate and use wetlands during this downstream migration. Johnson et al. (2015) noted that residence time can increase dramatically during winter. In a study of Willamette-origin salmon, Rose et al. (2015) found that yearling salmon, previously considered rapid estuarine migrants, can reside in the tidal-fluvial Columbia River for extended periods before entering the ocean. In the Lower Estuary zone, Roegner et al. (2016) showed substantial differences in shallow versus deep water habitat use by Columbia River salmon species.

In another acoustic telemetry study, Harnish et al. (2012) tagged yearling Chinook salmon (mean FL ~155 mm), subyearling Chinook salmon (~111 mm), and steelhead (~260 mm) collected at John Day Dam with acoustic transmitters and characterized the migration pathways of the tagged fish in the Upper and Lower Estuary zones. From rkm 86 to rkm 37, most fish migrated in the main navigation channel. However, around rkm 37, many tagged fish moved from the river-influenced navigation channel to the north toward Grays Bay to complete their migration in the main secondary channel on the north side of the estuary. Harnish et al. (2012) also reported survival rates did not differ among migration pathways and travel times were fastest in the main channel. Johnson et al. (2015) found the percentage of fish in off-channel areas out of the total for main- and off-channel areas combined was highest for yearling

[3] For yearlings mean lengths were 134 and 158 mm; for subyearlings mean lengths were 104 and 116 mm; and for yearling steelhead 215 mm.

Chinook salmon (8.1% and 9.3% for 2007 and 2008, respectively) and lowest for steelhead (4.0% for 2008) and subyearling Chinook salmon (3.6% and 6.1% for 2007 and 2008, respectively). This counterintuitive finding could be related to higher flows and lower temperatures in off-channels during the yearling migration period (spring) compared to the subyearling migration period (early summer).

Several studies provide estimates of the growth rates or stomach fullness of juvenile salmon in the estuary. McNatt et al. (2016) estimated growth rates of 0.53 mm/d for subyearling Chinook salmon sampled in Cathlamet Bay tidal marshes on Russian Island (Lower Estuary zone, Figure 1.5). Goertler et al. (2016) sampled subyearling Chinook salmon with beach seines and estimated they grew on average 0.23 mm/d in the tidal river zones of the estuary. Schiller (2016) studied stomach fullness for wild and hatchery subyearling Chinook salmon and found fullness levels were not statistically different between the two production types. Diefenderfer et al. (2016) reported active feeding for various juvenile salmon species, defined as >24% stomach fullness of identifiable prey taxa, increased from 5 to 7% at Bonneville Dam to 68% at the estuary mouth (rkm 17). Hanson et al. (2016) reported juvenile salmon sampled at wetland sites in the Lower and Upper Estuary zones during 2015 had fuller stomachs (mostly amphipods) than fish sampled at a site in the Upper Tidal River zone (mostly chironomids[4]). Researchers in the LCEP Ecosystem Monitoring Program noted a shift in juvenile salmon diet from mostly Diptera and other wetland insects at their site in the Upper Tidal River zone to more amphipods in the Lower Estuary zone (Appendices F and H). An analysis of growth rate data from the Ecosystem Monitoring Program study found that growth rates decreased as fish migrated through the estuary. These patterns may be related to lower prey density and richness as well as environmental variables such as salinity and tidal fluctuations (Chittaro et al. 2018).

An important finding by Weitkamp et al. (2017) from fish sampled in the mainstem river concerned diet and growth. The most common prey items in fish diets were chironomids and the amphipod *Americorophium*; diet was similar across four sampling locations from Rooster Rock (rkm 215) to the lower estuary (rkm 15). Insulin-like growth factor values, an indicator related to fish growth, increased as fish moved downstream in 2017, and less so in 2016 (Figure 4.2). The preliminary insulin-like growth factor and diet data suggest yearling salmon in the main channel were growing while moving downstream from the Upper Tidal River zone to the Lower Estuary zone.

Preliminary results from a retrospective, integrative analysis of juvenile salmon diet data from four separate research studies indicated most biomass consumed by juvenile salmon, in all zones, was derived from Diptera (Appendix F). This is notable given the habitat variation across the zones. Crustaceans accounted for half of the biomass consumed in the Lower Estuary zone. Contribution by this taxonomic group to biomass consumed by juvenile Chinook in other zones ranged from 15–25%. Chinook salmon appear to consume a diversity of prey items in all zones, which is generally indicative of an opportunistic feeding strategy. Some prey categories are relatively consistent in their contribution across all zones (e.g., Diptera, insects), whereas the frequency of occurrence for other prey groups (cladocera, arachnida, collembola) appears to be concentrated in a particular zone. In sum, combining the four data sets

[4] Chironomids are a dipteran insect produced in wetland marsh habitats (Lott 2004). They begin their life history in aquatic systems, hatching from epibenthic eggs, forming pupae, and moving up in the water column before emerging as adults (Oliver 1971). Chironomids consume plant detritus (Campeau et al. 1994) and are themselves a preferred prey of juvenile salmon (e.g., Lott 2004; Storch and Sather 2011). Chironomids are common world-wide (Ferrington 2008).

supported a systematic landscape-scale analysis and evaluation that would not otherwise have been possible by summarizing the results of each study individually.

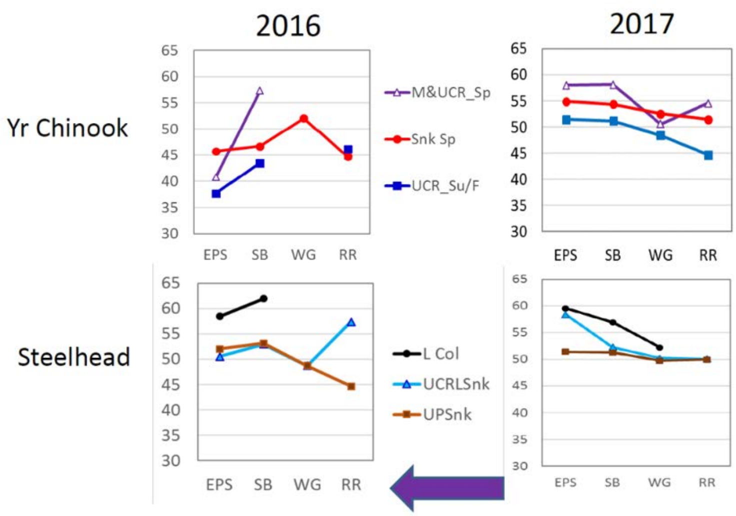


Figure 4.2. Insulin-like growth factor levels for yearling Chinook salmon and steelhead. Samples from the main channel at the estuary purse seine site (EPS; Rkm 15), Steamboat (SB; Rkm 57), Willow Grove (WG; Rkm 100), and Rooster Rock (RR; Rkm 205). Obtained from L. Weitkamp (AFEP 2017 presentation).

Stock-specific juvenile use of shallow-water habitat varies by season, life history type, and between natural and hatchery origin fish. From beach seine samples in the three tidal river zones (Figure 1.5), Teel et al. (2014) performed genetic stock identification analyses of the Chinook salmon that were captured. They found that the Lower Tidal River zone was dominated by fall-run juveniles from West Cascade tributaries (>70%); the Middle Tidal River zone was diverse—no one stock contributed more than 30% of the catch; and the Upper Tidal River zone was characterized by a large proportion of fish (>60%) from the Upper Columbia River summer–fall stock. Sather et al. (2016) genotyped 1,706 unmarked Chinook salmon in the vicinity of the Sandy River delta in the Upper Tidal River zone. Major contributors to the catch were the Spring Creek fall (35%) and Upper Columbia River summer/fall stocks (34%), with intermediate proportions of the West Cascade fall (13%) and Willamette River spring (9%) stocks, and low proportions of Deschutes River fall (3%), Snake River fall (3%), and West Cascade spring stocks (2%). Proportions varied significantly among seasons. In contrast, in the Middle Tidal River zone, Sather et al. (2016) found 73% of the genotyped fish (n = 1,193) were of the West Cascade fall stock group. Other contributors included the Upper Columbia River summer/fall (11%), Spring Creek group fall (6%), and West Cascade spring (5%) stocks. Rose et al. (2015) concluded that tidal-fluvial habitats in the middle and Lower Tidal River zones contribute to the performance and life history diversity of a Willamette River basin population, the McKenzie River spring Chinook salmon.

Sather et al. (2016) used beach seines to sample juvenile salmon and associated fish community seasonally during 2007–2012 in shallow-water habitats in the Lower Tidal River and Upper Tidal River zones (Figure 1.5). Their study, along with research by Teel et al. (2014), Hanson et al. (2016), and others, addressed the uncertainty about juvenile salmon ecology in tidal freshwater that was identified in SM1. Sather et al. (2016) reported unmarked, subyearling Chinook salmon dominated the salmon catch. These fish were present year-round and occupied a diversity of habitat types. Other relevant findings included the fact that seasonality caused changes in fish community to a greater extent than spatial gradients and salmon densities tended to be higher in off-channel habitats behind mainstem islands compared to wetland channels and main channel areas.

In the Lower Estuary zone, Roegner et al. (2016) compared life history types and genetic stock composition from beach seine samples along shorelines with purse seine samples from the main channel. Subyearling Chinook, chum, and coho salmon were the dominant species/life histories in shoreline samples taken in shallow-water areas, whereas larger yearling fish from the interior basin, including steelhead and sockeye, were captured in main channel samples. Interior basin stocks were more likely to be found in the main channel than along the shoreline. Middle and upper Columbia spring and Snake River spring yearling Chinook stocks were present in the main channel samples, but not in the shoreline samples.

Regarding the SM1 uncertainty about the flux of material from wetlands to the mainstem estuary, Thom et al. (2013) hypothesized that there was transport (flux) of organic material (prey and organic detritus) from wetlands to the mainstem estuary where it would be available to juvenile salmon (including larger subyearlings and yearlings) outside of the wetlands. Overall, the results of several studies indicate dissolved and particulate organic matter (POM), such as wetland macrodetritus and insects, are exported from restoring wetlands to the mainstem estuary. Woodruff et al. (2012) studied material flux from the Kandoll Farm restoration site (culvert replacement in 2005). Results indicated that the Kandoll Farm restoration site was a sink for total organic carbon, silicate, and total suspended sediments. In contrast, the site appeared to be a source of nitrite, i.e., there was net export of nitrite. In a related study, Thom et al. (In Press) used numerical hydrodynamic and transport modeling methods to estimate the mass of POM derived from the annually senescent aboveground parts of herbaceous marsh plants. Results indicated that the exported mass of POM amounted to about 19% of the summer peak aboveground biomass measured at the Kandoll Farm study site. Of that 19%, about 52% of the POM derived from herbaceous plant material reached the mouth of Grays River in the LCRE, about 7 km downstream from the site.

Roegner (2017) presented the objectives and methods for an investigation of the flux of insects to the mainstem estuary from restoration sites in the Lower Estuary (Karlson Island) and Lower Tidal River (Steamboat Slough) zones (Text Box 4.1). Insect transport was determined by measuring time series of plankton and drift organisms using calibrated neuston net and time series of water discharge measured with a Sontek IQ acoustic Doppler current profiler, which computed discharge by measuring velocity and extrapolating over channel cross-sectional area. Organisms were identified to the lowest possible taxon, and the concentrations of taxa were expressed as individuals/m^3 or converted to biomass (g/m^3) using literature values. From time series of discharge and prey concentration, instantaneous transport (T; individuals/s) and total ebb transport (individuals/tide) were calculated. To address potential benefit to

Text Box 4.1: Transport of Juvenile Salmon Prey from Wetlands to the Mainstem
(by GC Roegner; edited for SM2)

Material transport (flux) is the mechanism linking energy in the form of nutrients, plankton, and drift organisms, and other materials from wetland systems to the mainstem estuary, where it is available to the wider ecosystem, including yearling-sized salmonid migrants in the main channel. Of interest is the transport of invertebrate prey, and especially insects, hypothesized to directly benefit juvenile salmon and steelhead during migration. This export of insect prey constitutes a direct link between site-specific processes (e.g., production within wetlands) and landscape-scale features (e.g., supply of prey for migrating salmonids), and is an important potential benefit of restoration actions for juvenile salmon. As part of the Corps' AEMR study, the first experiments measuring insect prey transport in the CRE were conducted in restoring and reference wetlands at Karlson Island and Steamboat Slough in spring 2017.

salmon, prey export was converted to energy density and compared to salmon basal energetic requirements. This metric, salmon energy equivalents, provides a convenient framework within which to relate wetland production to salmon fitness. Preliminary results revealed about 28,000 chironomids were transported from a channel on Karlson Island on an ebb tide May 9, 2017 (Figure 4.3). This corresponded to an estimated daily ration for 438 subyearling salmon or 36 yearlings. At a channel on Steamboat Slough on May 22, 2017, about 320,000 chironomids were transported from the wetland to the mainstem. This corresponded to an estimated daily ration for 4,640 subyearling salmon or 386 yearlings. Findings from this study are scheduled to be finalized and reported later in 2018. The preliminary data clearly indicate chironomids, known prey for juvenile salmon, were being exported from wetlands to the mainstem estuary.

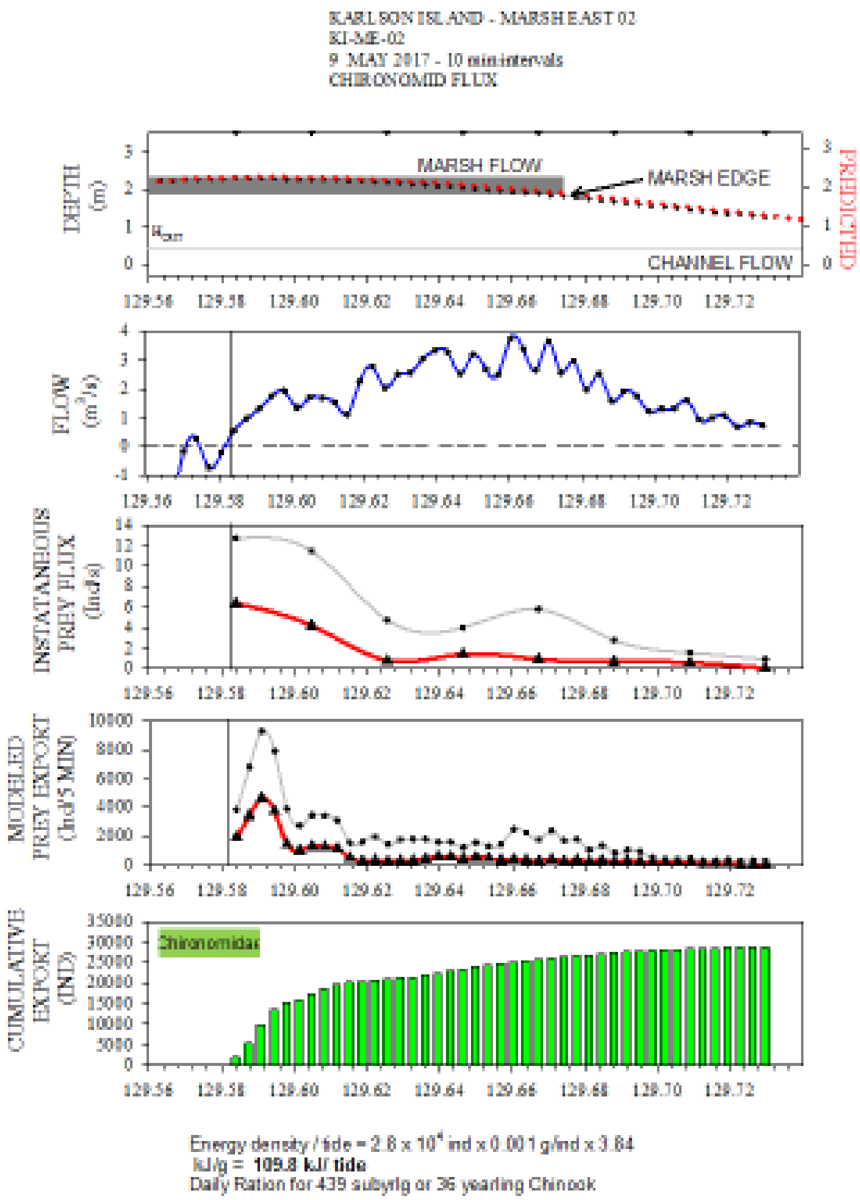
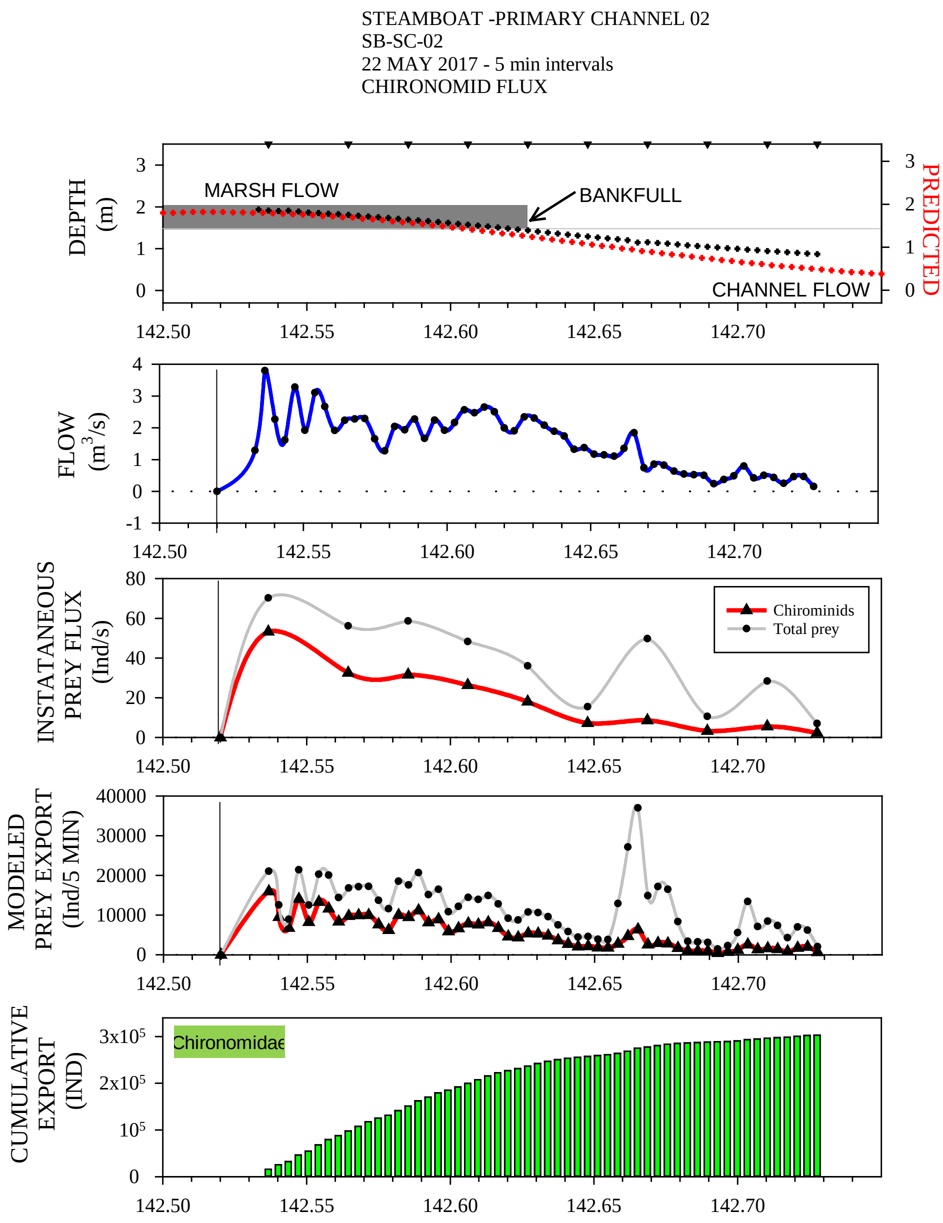


Figure 4.3a. Preliminary estimates of the flux of chironomids from channels at Karlson Island. The x-axis is Julian date. Provided by GC Roegner (pers. comm., April 23, 2018).



Energy density / tide = 3.02 x 10^5 ind x 0.001 g/ind x 3.83 kJ/g = **1160 kJ/ tide**
Daily Ration for 4640 subyrlg or 386 yearling Chinook

Figure 4.3b. Preliminary estimates of the flux of chironomids from channels at Steamboat Slough. The x-axis is Julian date. Provided by GC Roegner (pers. comm., April 23, 2018).

4.1.3 Uncertainties Assessment

The assessment of uncertainties related to contemporary use patterns is summarized in Table 4.1 at the end of this section.

Uncertainty 1.1. Understanding the rearing behaviors of under-represented or at-risk stocks. Studies of the estuarine behavior and residency of juvenile salmon have continued since the publication of SM1. While some of these studies have continued in the lower estuary, others have been conducted in middle and upper estuary habitats. SM1 identified a lack of studies in the tidal river zones as a major uncertainty. In aggregate, these studies continue to support the general notion that habitat use and residency vary among stocks based on factors such as when the fish enter the estuary, where they enter the estuary, and their size. Size is an especially important determinant of habitat use; most salmon found in wetlands are <90 mm in size. But, although many or most yearling-size juvenile salmon migrate rapidly through the estuary (e.g., McMichael et al. 2010), studies conducted since publication of SM1 show a greater than expected use of wetlands by larger fish. Some yearling-size fish clearly use wetlands. This type of alternate life history pathway (as opposed to rapid migration), even if rare in the population, is important because it adds to the resilience of the population by increasing early life history diversity.

Direct information about estuarine habitat use by at-risk and under-represented stocks continues to be lacking. This is primarily because many of the stocks of interest (ESA-listed fish and fish from the Snake River) are at very low levels of abundance. As a result, these stocks are rare in samples taken in the estuary using seines, and especially when mixed with large numbers of hatchery fish or non-listed fish. While some stocks at risk are tagged (e.g., Snake River spring Chinook salmon with PIT tags) and hence can be identified even when mixed with large numbers of hatchery fish, tagging enough fish is problematic. We see three primary ways to address the issue of studying habitat use by stocks at risk in wetlands: 1) tag more fish, 2) increase sampling, and 3) use surrogates[5] for stocks of interest.

Uncertainty 1.2. Juvenile salmon use of habitats in the tidal river zones and main channel of the estuary. Since publication of SM1, clear advances have been made in addressing this uncertainty, especially in the Middle and Upper Tidal River zones (e.g., Teel et al. 2014; Sather et al. 2016). This information has demonstrated that the composition of populations using their associated wetlands and other shallow-water habitat among zones in the estuary is variable, and that seasonality drives salmon species and genetic stock composition. Telemetry work has provided some insight into the use of some of these mainstem habitats (Harnish et al. 2012). The AEMR studies have included additional surveys in deep channel habitats throughout the estuary (Weitkamp et al. 2017), helping to provide a more complete picture of habitat use in the estuary. Nevertheless, gaps remain in understanding salmon use of the Lower Tidal River zone and the main channel and large distributary habitats.

Uncertainty 1.3. Genetic stock-specific use of LCRE habitats. The advent of genetic stock identification technology for Chinook salmon (e.g., Seeb et al. 2007) was seminal to advancing knowledge of juvenile salmon ecology and use of LCRE habitats. Genetic stock should be identified as a matter of routine for fish sampled under CEERP.

Uncertainty 1.4. Habitat-specific growth rates. Some information about juvenile salmon growth rates has been obtained since SM1 was published (e.g., McNatt et al. 2016). But, generally, growth rate

[5] A surrogate population would be one that is not at risk and has similar biology to the at-risk stock.

estimates for juvenile salmon are not common and moreover are rarely related to specific habitats. Habitat-specific growth rates are difficult to achieve because fish make extensive use of a diversity of habitat types (see Sather et al. 2016).

Uncertainty 1.5. Flux of organic material and salmon prey from wetlands. Thom et al. (2013) posited that there was flux of organic material from wetlands to the mainstem that would be available to support juvenile salmon feeding and growth. Additional work conducted in the last 5 years indicates support for this hypothesis. For example, the POM export study showed that wetland-derived detrital material could be transported to the mainstem estuary 7 km away (Thom et al. In Press). The Corps' AEMR study demonstrated flux of salmon prey (chironomids) from restoring wetlands (C. Roegner, pers. com.). AEMR also revealed that juvenile salmon migrating downstream in the main channel ate material likely exported from wetlands (Weitkamp et al. 2017). The linkage between restoring wetlands and the mainstem estuary via flux of prey items is important to salmon migrating in the mainstem estuary because it would suggest that direct occupation of a wetland is not needed for the wetland to provide support to juvenile salmon. Uncertainty remains about how flux varies from wetlands in different zones of the river and different wetland types and estimated fluxes at the landscape scale. Understanding the mechanisms that influence patterns of flux will help inform prioritization of restoration as well as restoration design criteria.

Table 4.1. Comments on uncertainties identified in SM1 for Contemporary Use Patterns. Suggested CEERP priority: Yes or No.

SM1 Id#	Comment	Priority
1.1 Rearing behaviors of under-represented or at-risk (wild) stocks	While additional information about estuarine habitat use by under-represented and at-risk stocks may help to more effectively target restoration to benefit these fish, this uncertainty has been difficult to resolve because of the rarity of these fish in samples, as well as the inability to distinguish an unmarked fish as being wild or of hatchery origin. At-risk stocks are simply at very low levels of abundance and are difficult to adequately sample. It is unlikely that additional sampling would improve encounter rates to a level sufficient enough to systematically evaluate rearing behaviors of under-represented or at-risk (wild) stocks.	No
1.2 Use of shallow-water habitats in tidal river zones and main channel habitats	Significant knowledge gaps exist in habitat use by fish in several zones of the LCRE. Much research has focused on wetland channels, but the use of other habitat types (main channel and off-channel) may help to understand the how restoration provides indirect benefits (e.g., resource subsidies) across the LCRE landscape. In terms of location within the LCRE, less is known about the Lower Tidal River zone than other zones. Moreover, the main channel has only recently been sampled estuary-wide (2016 and 2017); therefore, continuing to improve understanding of habitat use and migration of yearling-sized fish in the main channel is needed.	Yes
1.3 Genetic stock-specific use	A great deal has been learned about stock-specific habitat use, largely because genetic stock identification has been routinely performed on juvenile salmon collected in the LCRE. Genetic stock of fish sampled should continue to be determined whenever possible in field studies.	Yes
1.4 Habitat-specific growth rates	Some information about juvenile salmon growth rates has been obtained since SM1 was published. While additional information about growth would be useful, dedicated studies of habitat-specific growth rates would require intensive, expensive research. Even a well-designed study can be limited in	No

SM1 Id#	Comment	Priority
	its ability to draw inferences between habitats (especially at fine spatial scales) and growth.	
1.5 Flux of organic material and salmon prey	While the flux studies conducted at Karlson Island and Steamboat Slough in 2017 provided important new data, better understanding of material flux over full tidal cycles and over other estuary zones is needed. Not all habitats are equal; aspects associated with hydrologic conditions, landscape position, and channel morphology will determine whether habitats are sources or sinks for prey export. Determining if and how much variability in flux occurs based upon zone or location in the landscape will support development of predictive models for restoration project prioritization and project design criteria.	Yes

4.2 Do factors in the estuary limit recovery of at-risk salmon populations and evolutionarily significant units?

4.2.1 Key Findings and Uncertainties from SM1

Thom et al. (2013) concluded habitat opportunity[6] appeared to be a major limitation to salmon performance. The loss of wetlands in the estuary and the reduction of a macrodetritus-based food web may have reduced the overall habitat capacity[7] of the system compared to historical capacities. An uncertainty related to this was there was only limited information about ***habitat capacity*** to support juvenile salmon, indicating more research on this subject was needed. An important aspect of habitat capacity is having suitable water temperature. Another major uncertainty from Thom et al. (2013) was that, despite a wealth of new data about stock-specific habitat use, life histories, and performance of juvenile salmon in the estuary, there was still considerable uncertainty about the ***importance of estuary rearing to population viability and salmon recovery***. The estuary's linkages to salmon population dynamics have not been adequately quantified. This information was needed to evaluate the relative importance of estuarine habitat restoration potential to aid salmon recovery at population and ESU scales. In addition, the ***interactions of hatchery and natural origin salmon*** and the potential effects of hatchery releases on estuary ecosystems have not been investigated. Moreover, it was unclear whether continued subsidies of similarly sized hatchery smolts released in concentrated pulses during the spring have enhanced bird or other predator populations in the estuary. ***Competition and predation*** within shallow-water habitats required more research, although present data have not documented adverse effects on salmon performance. Predation studies have not been conducted in wetland sites, where avian and piscivorous predators could be a concern. Additional research was needed, including potential direct or indirect ***interactions with non-native species***.

[6] Habitat opportunity/access is a habitat assessment concept that "appraises the capability of juvenile salmon to access and benefit from the habitat's capacity"; for example, tidal elevation and geomorphic features (cf. Simenstad and Cordell 2000).

[7] Habitat capacity/quality is a habitat assessment concept involving "habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality"; for example, invertebrate prey productivity, salinity, temperature, and structural characteristics (cf. Simenstad and Cordell 2000).

4.2.2 New Data and Information

Thom et al. (2013) stated that to restore life history diversity to Columbia River salmon, it would be critical to protect, restore, and enhance the wetland habitats that support these fish. New support for their argument comes from Jones et al. (2014) who found that hydrologic reconnection was related to increased early life history diversity in the Salmon River estuary on the central Oregon coast. They said, "Juvenile *O. kisutch* responses to the reconnection of previously unavailable estuarine habitats have led to greater life history diversity in the population and reflect greater phenotypic plasticity of the species in the U.S. Pacific Northwest than previously recognized." Several differences between the Salmon River and Columbia River estuaries, however, should be considered when applying these results. For one, the two estuaries have very different geographic scales; the Salmon River estuary is small compared to the Columbia River estuary. The Salmon River estuary supports mostly ocean-type Chinook salmon life histories, compared to a great diversity of life history patterns in the Columbia River Estuary. Jones et al. (2014) support the notion that restoration of shallow-water, wetland habitats in tidal areas supports recovery of at least stream-type fish that rear in the estuary during the winter prior to entering the ocean as yearlings in the spring. This strategy was a fundamental part of the conceptual ecosystem framework of Bottom et al. (2005). Similarly, Sather et al. (2016) found subyearling Chinook salmon occupying a wide range of shallow-water habitats spatially and temporally in the Middle and Upper Tidal River zones. They concluded that their "…findings support a strategy that involves restoring a diversity of shallow tidal freshwater habitats to facilitate the recovery of threatened and endangered salmon populations in the Columbia River basin."

Threats to salmon performance in the estuary likely include high water temperatures. In fact, shallow-water off-channel habitats generally warm faster than mainstem areas due to the warm air temperatures in summer (Appendices E and G). Hanson et al. (2015b) concluded that juvenile salmon tended to not inhabit shallow-water habitats where water temperatures exceed 22°C. These authors observed lower abundances (and sometimes absence) of juvenile salmon in the late spring and summer months. Storch (2011) studied growth-temperature relationships using a bioenergetics model and showed that there was a temperature threshold (~22°C) at which juvenile salmon growth dropped sharply. These authors also reported that, while warm temperatures can be stressful for salmon, these effects can be mitigated by ample food resources, both quality and quantity. However, Roegner and Teel (2014) found that high water temperatures (maximum observed 23.5°C) were not related to decreased morphological condition in juvenile salmon in the Lower and Upper Estuary zones, but were correlated with movement to cooler water.

Another potential factor limiting salmon performance that has received considerable attention since SM1 was published is the colonization of marshes by non-native vegetation, especially RCG. Sager et al. (2014) concluded macrodetritus production was greater in vegetation communities dominated by native Lyngby sedge (*Carex lyngbyei*) than those dominated by non-native RCG. Klopfenstein et al. (2016) and McNatt et al. (2017) reported native vegetated habitats encouraged faster growth in juvenile salmonids than RCG-dominated areas. In a specially designed experiment at Multnomah Channel Marsh, these authors compared invertebrate samples, fish growth rates, and stomach contents in RCG-dominated versus natural emergent vegetation sections of the study site. The difference in salmon growth over 10 days in 2015 was 6.4 mm vs. 4.7 mm (natural vs. RCG) and the RCG-dominated area diets of juvenile salmon were dominated by zooplankton, while their natural vegetation-dominated area diets were dominated by chironomids. Invertebrate prey availability in both habitat types based on fallout and emergence traps was similar. Hanson et al. (2016) compared the quantity and quality of macroinvertebrates and macrodetritus in RCG-dominated plots and Lyngby sedge plots. Decomposition rates of macrodetritus were lower in the RCG plots, while the overall density and biomass of invertebrates in the two plant communities were similar. Macroinvertebrate diversity was less in RCG plots than in native Lyngby sedge plots. The winter standing stock of vegetation was greater in RCG than Lyngby sedge plots. Data indicated that RCG reduces the diversity of macroinvertebrates and vegetation, slows decomposition rates, and reduces the quality of detritus compared to Lyngby sedge vegetation communities. In another component of this study, Ramirez et al. (2016) found the density and biomass of salmon prey taxa (chironomids and other Diptera) were higher in native sedge than in non-native RCG, but the overall macroinvertebrate assemblage and diversity were not statistically different between the two plant communities. By inference, negative effects of RCG on salmon prey imply negative effects of RCG on salmon performance.

In sum, limiting factors in the estuary continue to include insufficient habitat opportunity and capacity for rearing and refuge of salmon. Major factors that limit salmon opportunity and capacity include reduction in peak flows in spring, adverse water temperatures affecting habitat use and fish physiology, ecological impacts from non-native flora and fauna, intra- and inter-specific competition, and piscivorous and avian predation.

4.2.3 Uncertainties Assessment

The assessment of uncertainties related to factors limiting recovery is summarized in Table 4.2 at the end of this section.

Uncertainty 2.1. Habitat Capacity. Habitat capacity involves habitat attributes that promote juvenile salmon foraging, growth, growth efficiency, and/or decreased mortality. We are unaware of any studies that have estimated mortality associated with wetlands (restored or natural). In aggregate, the research described above (Section 4.1.1) demonstrates that fish are foraging under current conditions and that growth rates are comparable to studies in other estuarine systems such as the Salmon River (Volk et al. 2010).

Understanding the functional response of habitat restoration is key to restoration design because functional aspects of a habitat provide an understanding of how organisms benefit without having to directly interface with a specific location or habitat (Weinstein et al. 2005). Recent work by the Corps' AEMR study provides evidence for this concept. Weitkamp et al. (2017) documented that yearling salmon and steelhead are growing and feeding as they migrate through the estuary from Bonneville Dam, which suggests these fish are likely benefiting from ‘‘donor habitats” via the export of prey resources (see Weinstein et al. 2005).

To understand aspects related to habitat capacity, it is necessary to determine the efficacy of management actions on trophic pathways as opposed to understanding how actions influenced physical habitats (Wipfli and Baxter 2010). Therefore, we recommend additional studies of habitat capacity be coupled to measures of opportunity and realized function, perhaps using bioenergetics modeling, and conducted at a diversity of habitat types and restoration sites. Some of this work likely could be done using existing information (e.g., diet and temperature) that could be organized into bioenergetics models. Furthermore, there is limited information about the patterns and mechanisms driving prey productivity in aquatic habitats of the LCRE. Several studies have evaluated prey resources in wetland channels, but few have explored the contribution of other aquatic habitats to prey productivity. Approaches aimed at understanding mechanisms driving prey productivity across the landscape as well as those that evaluate salmon growth potential through bioenergetics models could be useful for exploring the relationships between habitat and biological responses.

Uncertainty 2.2. Importance of estuary rearing to population viability. This is a key uncertainty for the CEERP, because a premise of the restoration effort is that rearing or use of the estuary (direct or indirect use) has population-level effects on salmon. This point remains an uncertainty from SM1 to SM2 because we found little evidence of progress on addressing this hypothesis. The evidence-based evaluation of CEERP (Diefenderfer et al. 2016) employed a causal criteria synthesis approach and concluded that restoration was likely benefiting juvenile salmon, but this study did not examine population-level effects. The estuary's linkages to salmon population dynamics have not been adequately quantified and are needed to evaluate the relative importance of estuarine habitat opportunities for salmon at population and ESU scales. The importance of the estuary will vary between populations and ESUs because there is considerable variation in juvenile life histories within and among genetic stock groups. To date, however, life cycle models typically roll the estuary into Bonneville-to-Bonneville survival. Thus variation in Bonneville-to-Bonneville survival is not partitioned into ocean and estuary, nor is it partitioned into downstream, ocean, and upstream migration components. Moreover, the effects of estuary restoration have been assessed relative to a theoretical index of survival (Survival Benefit Units; explained by Krueger et al. 2017), but not relative to two other "viable salmon population" parameters: spatial structure and diversity (Fresh et al. 2005). These latter two elements are important because they provide resilience to populations and ESUs (Bottom et al. 2009).

Uncertainty 2.3. Interactions of hatchery and natural origin salmon (HO and NO, respectively). Little progress had been made on this uncertainty. Within the LCRE, migration of large numbers of HO fish through an area could potentially cause short-term declines in food supply or result in large HO fish preying on NO fish. A review of density-dependent interactions by the ISRP (2015) concluded that available evidence was insufficient to determine if there were adverse effects of HO fish on NO fish in the estuary. Conditions clearly can occur (large numbers of HO fish overlapping with ESA-listed NO fish) where competition or predation could be occurring. Mixtures of HO and NO fish from throughout the Columbia River basin can co-occur in the Lower Estuary zone at the mouth of the river (Weitkamp et al. 2015). HO/NO interactions could affect the benefits of restoration actions if HO fish crop prey resources in restoring wetlands or prey on NO fish using these habitats. We point this out to increase awareness of the issue of HO/NO fish interactions in the estuary. There are, however, technical challenges to studying these interactions, such as the availability of NO fish. Additional discussion of HO/NO issues is available in a Section 5.1.

Uncertainty 2.4. Competition, predation, and interactions of juvenile salmon with other species in shallow-water habitats. We found some new information in the estuary concerning species' interactions in wetlands. McNatt and Hinton (2017) detected five PIT-tagged northern pikeminnow at Steamboat Slough and one at Welch Island during sampling in 2017, indicating these native predators are present in wetland tidal channels. Similarly, Diefenderfer et al. (2010) reported detections of PIT-tagged northern pikeminnow in shallow-water habitats near Cottonwood Island. In addition to predatory fish occurring in shallow-water habitats used by salmon, there are also considerations relevant to interactions with non-native species. At shallow-water sampling sites in the Middle and Upper Tidal River zones, Sather et al. (2016) found an abundance of non-native fish, such as banded killifish (*Fundulus diaphanus*), bluegill (*Lepomis macrochirus*), and smallmouth bass (*Micropterus dolomieu*), in shallow-water habitats also used by juvenile salmon. Competition between non-native fishes and juvenile salmon in wetlands is an uncertainty. In general, a key uncertainty remains how non-native fish affect the salmon food web (Naiman et al. 2012). Bird predation also is a concern, especially in the Lower Estuary zone. Evans et al. (2017), synthesizing PIT-tag recovery data and analyses of avian predation rates collected since 2006, reported "…hatchery Snake River spring/summer Chinook and hatchery Upper Columbia River spring Chinook were consistently more susceptible to East Sand Island tern predation than their wild counterparts…." Trends for other fish species or for double-crested cormorants were not consistent. Competition and predation and interactions with non-native species in shallow-water habitats remains an uncertainty for restoration because high levels of predation or competition for food could diminish the benefits of restoration.

Table 4.2. Comments on uncertainties identified in SM1 for Factors Limiting Recovery. Suggested CEERP priority: Yes or No.

SM1 Id#	Comment	Priority
2.1 Habitat capacity	Habitat capacity is an important concept in understanding and evaluating benefits of restoration because it includes indicators that relate directly to salmon performance. A comprehensive evaluation of the full suite of factors affecting capacity (e.g., water temperature, non-native plant species) would be difficult to do well. However, for some selected capacity indicators (e.g., prey productivity and flux) further study is warranted and results would directly benefit CEERP.	Yes
2.2 Importance of estuary rearing to population viability and salmon recovery	This is a key uncertainty for CEERP, because of the premise that habitat restoration benefits juvenile salmon (direct or indirect use) and thereby ultimately has population-level effects. There are several ways to analyze this issue. First, including an estuary component for life cycle models (currently it is combined with ocean conditions) would make it possible to isolate the effects of the estuary from that of the ocean. Second, much of the evaluation of benefits of estuary restoration has focused on evaluating the effects of restoration on abundance, survival, and productivity. Other measures of viable salmon population measures (spatial structure and diversity) should be included in evaluating benefits of restoration, which to date have not been included.	Yes
2.3 Interactions of hatchery and natural origin salmon	For HO/NO interactions, the question is if and how HO could affect the viability of NO populations (e.g., by way of density-dependent mechanisms). From the perspective of restoration, the major issue is whether HO fish are affecting the benefits of restoration actions for NO fish. We do not rate this as a high priority for CEERP for several reasons. First, this is a very challenging subject to study and obtaining clear and unambiguous results is problematic. Second, and most importantly, any ability to address this issue by modifying hatchery production programs is outside the purview of CEERP.	No
2.4 Competition and predation with native and non-native species	Competition and predation interactions involving salmon populations occur throughout the LCRE. These interactions can have significant effects on salmon population viability. Further, competition and predation can involve both native species (e.g., birds and northern pikeminnow) and non-native species (e.g., shad, bass, and killifish). From the perspective of restoration, the main concern is whether and how these interactions can affect benefits of restoration for salmon. Because competition and predation can have significant population-level affects, CEERP needs a basic understanding of the impacts of species interaction on restoration to make informed decisions about restoration	Yes

prioritization; e.g., targeting the most at-risk locations or designing projects to maximize export of prey resources and minimize occupation by predatory fish.

4.3 Are estuary restoration actions improving the performance of juvenile salmon in the estuary?

4.3.1 Key Findings and Uncertainties from SM1

Thom et al. (2013) posited that restoration actions be associated with increased opportunity, capacity, and realized function to provide benefits to juvenile salmon in the estuary. Despite limitations in the amount and content of available data, they concluded estuary habitat restoration appeared to offer positive benefits to juvenile salmon in these regards. In fact, several positive trends were observed in the studies reviewed in SM1. Hydrologic reconnections appeared to increase opportunity for fish to access restored sites, as noted for restoration projects at Crims Island, Kandoll Farm #1, and Ft. Columbia. In terms of capacity, improvements in water temperature were noted at Kandoll Farm #1 and Ft. Clatsop (South Slough), while improvements in prey production were observed at Crims Island. Thom et al. (2013) concluded the primary direct beneficiaries of restoration of mainstem wetland habitats would likely be subyearling Chinook and chum salmon, and that smaller numbers of larger yearling Chinook salmon would be found in shallow areas. They noted, though, that restoration of mainstem wetland habitats also likely has indirect benefits to juvenile salmon through export of organic materials, nutrients, and prey resources from shallow-water to mainstem areas

While results from some individual projects were encouraging, Thom et al. (2013) concluded there was still considerable uncertainty about whether restoration is improving the overall performance of juvenile salmon in the estuary, because of limited data available as of 2012. Of the 42 aquatic restoration projects started in the estuary since 2004 and completed by 2012, only 9 included AEM that addressed elements relevant to juvenile salmon ecology, i.e., opportunity, capacity, and realized function (Simenstad and Cordell 2001). In many cases, the available studies lacked pre-restoration data, reference sites, and/or statistical analyses aimed at specifically evaluating the response of monitored metrics within the context of restoration actions. Furthermore, of the 9 relevant studies, 7 were conducted in the lower 90 km of the estuary (mostly the Lower and Upper Estuary zones), and thus provide only limited spatial coverage from which to draw inferences at landscape or system scales. Thus, the shortage of direct evidence of linkages between restoration actions and biological performance led to the SM1 uncertainty about the ***effectiveness of restoration actions at the project, landscape, and estuary-wide scales***.

4.3.2 New Data and Information

After SM1, CEERP managers made a major push to investigate the effectiveness of restoration actions in the estuary through LCEP studies funded by BPA and by NMFS/PNNL studies funded by the Corps (Table 1.3). Preliminary LCEP results have been reported by Schwartz et al. (2015, 2016, 2017, and others). In-depth results and analyses from data collected for the LCEP analyses are presented in Chapter 3 and Appendix E. Overall, the AEM data indicated mixed results among the various monitored indicators in terms of achieving desired outcomes. (See Section E.1 for explanations of desired outcomes for effective restoration projects.) To summarize, water-surface elevation and fish capture data indicated restoration projects were having positive effects—water-surface elevations indicated restored sites were hydraulically connected to the mainstem and fish data indicated salmon were using restored wetland channels. For other monitored indicators, the results were inconclusive, data were insufficient, or it was too soon since restoration to observe noticeable changes.

Preliminary results from the Corps' Level 1 AEMR study were presented at the annual meeting of the Anadromous Fish Evaluation Program, on November 28, 2017. The overall goal of the study is to examine how restoration directly and indirectly affects juvenile salmon in terms of fish density, yearling/subyearling life history types, genetic stock, diet, and fish condition at selected restoration sites and mainstem locations. This multifaceted research has four main components: landscape-scale sampling in the mainstem estuary (Weitkamp et al. 2017), PIT sampling in tidal wetland restoration and reference sites (McNatt and Hinton 2017), prey flux from wetlands to the mainstem estuary (Roegner 2017), and site-scale sampling at four pairs of restoration-reference sites (Sather et al. 2017). We described the first three components earlier in this chapter because the research is relevant to the first two SM1 questions. Here, regarding action effectiveness, we note the findings of Weitkamp et al. (2017) at the *landscape scale* that demonstrate downstream migrating juvenile salmonids in the main channel are growing by feeding on wetland, benthic, and water column-derived prey items. The inference from these preliminary data is that wetlands, and hence restored wetlands, are indirectly benefiting juvenile salmon migrating downstream in the mainstem estuary, including interior basin stocks.

Sather et al. (2017), as part of the Corps' Level 1 AEMR study, evaluated the site-scale effects of restoration on juvenile salmon. They deployed fyke nets and beach seines monthly during March, April, May, and June 2016 and 2017. Sather et al. (2017) captured juvenile Chinook salmon at all restoration-reference site pairs sampled: Dibblee/Fisher (rkm 105/96), Batwater/Crims (rkm 92/90), Steamboat/Welch (rkm 56/53), and Karlson new/Karlson old (rkm 43/42). Catch per unit effort for juvenile salmon was higher in 2016 than 2017, possibly due to gear inefficiencies in 2017 resulting from high river discharge during the majority of the sampling period. The dominant genetic stock of Chinook salmon in both years was the West Cascades fall stock, a mix of wild and hatchery origin fish (Figure 4.4). The Spring Creek hatchery fall stock was prevalent in 2017 but not 2016. Salmon prey resources were measured from three locations: 1) the benthos (primarily composed of insects, amphipods, worms, and other organisms), 2) the water-surface (including chironomids, other Diptera, and zooplankton), and 3) the marsh surface (largely consisting of chironomids, other Diptera, and hymenoptera). In sum, Sather et al. (2017) reported juvenile salmon were present at newly restoring sites (Batwater, Dibblee, and Steamboat more so than at Karlson) and their gut contents largely reflected prey resources measured at the sites. In-depth analyses comparing restoration and reference site conditions will be forthcoming in 2018.

Other restoration effectiveness results throughout the Pacific Northwest are pertinent to restoration in the estuary. David et al. (2014) reported juvenile salmon quickly repopulated recently constructed restoring sites in the Nisqually National Wildlife Refuge in Puget Sound. Rybczyk et al. (2015) found that sediment accretion happened quickly after levee removal and a scrape-down in the Stillaguamish River delta in Puget Sound where there was 4 cm accretion of sediment in year one vs. 0.5 cm in that year in a reference marsh. Whiting et al. (2015) monitored the Sauvie Island North Unit site where a water-control structure was removed, areas were scraped down, and riparian plantings were made. They observed that Wapato (*Sagittaria latifolia*) became established within 1–2 years after construction of the restoration sites. As noted in SM1, Roegner et al. (2010) documented an immediate response in WSE and juvenile salmon movement into a restored area at Kandoll Farm on the Grays River. Thus, in general, ecosystems respond to tidal reconnection-restoration actions, although the nature (timing, degree, and magnitude) of the responses varies depending on the particular variable being considered.

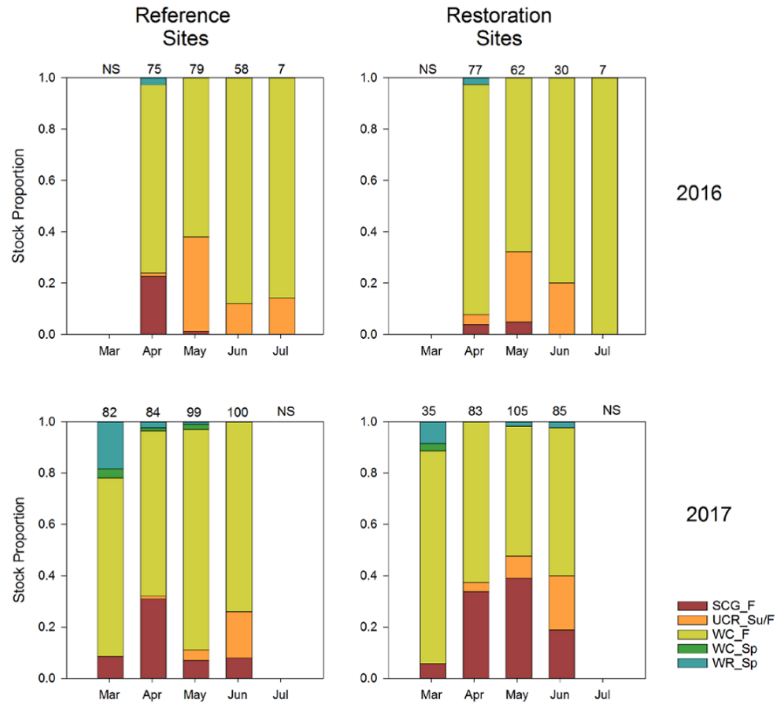


Figure 4.4. Genetic stock composition for juvenile Chinook salmon captured at AEMR site-scale sampling sites. Obtained from N. Sather (AFEP 2017 presentation).

4.3.3 Uncertainties Assessment

The assessment of uncertainties related to action effectiveness is summarized in Table 4.3 at the end of this section.

Uncertainty 3.1. Effectiveness of restoration actions at the site, landscape, and estuary-wide scales. In SM1, the authors concluded that while results from some individual projects were encouraging, there was still considerable uncertainty about whether restoration is improving the overall performance of salmon in the estuary. This was because of the limited data available as of 2012 that were reviewed in SM1. Since 2012, much progress has been made as noted in the previous section. And, new results regarding the action effectiveness uncertainty will be forthcoming later in 2018 for the Corps' AEMR study. A critical element of the AEMR study is understanding how site-scale attributes (vegetation communities, channel characteristics, local hydrology, etc.) influence salmon locally and at landscape and estuary-wide scales. The AEMR study should improve understanding of the lateral connectivity between prey production in restoring wetlands, their flux from wetlands to the mainstem, and consumption in the mainstem. Note, however, that the AEMR study was limited to two years of data collection (2016 and 2017) and the very high water year in 2017 (Figure 1.7) could be a source of variability in the monitored indicators. In sum, direct effects of restoration at the site scale have been examined much more than indirect effects at the landscape or estuary-wide scales. The degree to which the effectiveness of restoration actions remains an uncertainty, both directly and indirectly, will be best assessed after the AEMR study technical report.

Table 4.3. Comments on uncertainties identified in SM1 for Action Effectiveness. Suggested CEERP priority: Yes or No.

SM1 Id#	Comment	Priority
3.1 Effectiveness of restoration actions at the site, landscape, and estuary-wide scales	Direct effects of restoration at the site scale have been examined much more than indirect effects at the landscape or estuary-wide scales. Results from effectiveness studies indicate restoration actions, while variable, generally improve site-scale habitat conditions. Preliminary results from new landscape-scale research indicate benefits to juvenile salmon migrating in the mainstem, but more analysis and study are warranted, especially concerning *how* restoration directly and indirectly benefit juvenile salmon. Understating the *how* can contribute to restoration design and prioritization. Furthermore, study designs need to specifically consider the spatial inference of the data; this is an important programmatic consideration that has site- and project-scale implications.	Yes

4.4 What is the status of the estuary? Are estuarine conditions improving, declining?

4.4.1 Key Findings and Uncertainties from SM1

In SM1, Thom et al. (2013) noted that although physical changes, including floodplain development (diking), dredging of the navigation channel and harbors, and flow regulation, had significantly altered the historical geomorphic and ecological state of the estuary prior to the CREDDP studies, the rate of physical alteration has slowed compared to the late 19th and early 20th century. Significant physical changes, however, were still occurring. For example, the navigation channel was deepened (~1 m) early in the present century, and channel maintenance, including dredge material disposal in the estuary, was conducted annually. Pile dikes, designed to maintain the navigation channel location and depth, have resulted in the deposition of sediments and, in some cases, the formation of shallow-water habitats. Logging and road construction continued in the watersheds of the estuary. Thus, the habitat complexes within the present floodplain formed a highly altered mosaic compared to historical conditions. Very few natural, unmodified wetland habitats remained in the system. Non-native species were abundant and dominate vegetation, plankton, fish, and benthos assemblages. Moreover, there was a legacy of contamination in sediments. Contamination of water and sediment from persistent chemicals was identified in SM1 as a significant concern.

Thom et al. (2013) pointed out the number of restoration projects focused on reconnecting floodplain habitats has increased over the past decade. These actions seem to have shown immediate benefit to juvenile salmon by providing access to habitats as well as processes supportive of ecosystem functions of benefit to the entire estuary. Further, they noted natural breaching of levees and dikes had opened areas of former floodplain habitats. The land surfaces formerly behind the levees had obviously subsided and most sites remained dissimilar to nearby reference sites even after several decades. Hence, the full return of floodplain habitats to their historical state was likely to be protracted, especially those dominated by tidal forested swamps. Yet these systems should continue to provide services during the ecological development phase. Emergent marsh habitats show large changes during the first 4 to 7 years and full development to reference conditions is predicted to be on the order of 75 years or more (Simenstad and Thom 1996; Thom et al. 2002). As evidenced in historical natural breaches, estuarine riparian and tidal forested habitats can develop within several decades of reconnection, and have intermediate stages that are contributing services to the system.

Thom et al. (2013) noted uncertainties regarding the status of the estuary. For one, the rate of introductions of ***non-native species*** may been decreasing, but this was difficult to quantify. There was a prevalence of invasive, non-native species such as RCG and killifish, but their impacts on estuary ecosystems were not well understood. In addition, the effect of ***climate change*** on a regional and a local basis was unclear. Through alteration of river flow dynamics and discharges, increases in water temperature, and sea-level rise, climate change is expected to affect the ecological processes of shallow-water habitats and the capacity of the habitats to support young salmon. Even with focused floodplain habitat restoration, ***net ecosystem improvement*** was still difficult to predict. Positive benefits of floodplain habitat restoration can be hampered by development activities such as road construction and resource extraction in tributary watersheds that drain into the lower floodplain habitats and broader estuary (Ke et al. 2013). These upstream alterations can affect the rate and level of recovery of restoring habitats in the floodplain, as well as the resilience of these restored sites to periodic large-scale disturbances such as major flooding events and climate change. We discuss non-native species and net ecosystem improvement and anthropogenic impacts below; the other uncertainty from SM1 relative to the state of the estuary—effects of climate change—is discussed in Chapter 5.

4.4.2 New Data and Information

New data and information that lead to understanding how conditions in the estuary are changing are important because changing conditions could influence the effectiveness of restoration actions. (Recall the change analyses described in Section 1.4.1, referencing Ke et al. 2013 and Marcoe and Pilson 2017.) Positive benefits of floodplain habitat restoration can be offset by development activities such as road construction and resource extraction in tributary watersheds that drain into the lower floodplain habitats and broader estuary. These upstream alterations can affect the rate and level of the recovery of restoring habitats in the floodplain, as well as the resilience of restoring sites to large-scale disturbances such as major flooding events and climate change. That said, the state of the estuary has improved due to increased habitat connectivity (index +2.6% from 2004 to 2016) as a result of hydrologic reconnections of diked floodplain wetlands to the mainstem estuary (see Section 2.3).

One change of concern is the proliferation of non-native species, especially the colonization of wetlands by RCG. To summarize studies described earlier (Section 4.2.2), marshes dominated by this non-native plant resulted in slower growth in juvenile salmonids than marshes with plant native species (Klopfenstein 2016; McNatt et al. 2017). Reed canarygrass homogenized the diversity of macroinvertebrates and vegetation, had a slower decomposition rate, and reduced the quality of detritus compared to native *Carex* vegetation communities (Hanson et al. 2016b). Griffiths et al. (2012) found that RCG decomposes slowly, possibly because of its relatively high lignin content.

In addition to non-native RCG, several studies have considered the effects of invasive zooplankton. Bollens et al. (2016) investigated the dynamics of invasive zooplankton species in the estuary. In particular, Asian copepods have invaded the estuary and penetrated hundreds of kilometers upriver. They are very abundant in late summer and early autumn, and they compete with native zooplankton and are selected against by native predators, such as juvenile salmon. These authors concluded that invasive copepods could adversely affect native food webs in the estuary. The impacts of other non-native fauna, such as shad (*Alosa sapidissima*), which have become prevalent in the lower Columbia River, are not understood. Banded killifish are often the second most abundant fish species in beach seine catches from shallow-water habitats (Sather et al. 2016) and may compete for resources with juvenile salmon. Other non-native fish such as bass, perch, walleye, and catfish all pose predation risk to juvenile salmon.

Thom et al. (2005) defined net ecosystem improvement for a given restoration project as the change in a given ecological function (e.g., prey production) multiplied by project size multiplied by the probability of success of the restoration action. Cumulative net ecosystem improvement (CNEI) is the sum of these values over multiple restoration projects. Diefenderfer et al. (2016) applied this method to monitoring of prey production from restoration projects in the Lower and Upper Estuary zones (0–87 km) and plant biomass production from projects in these zones plus the Lower Tidal River zone (0–139 km). They reported, "The mean aboveground biomass values for emergent marshes and recently reconnected marshes were 600–1125 and 449–813 g dry/m^2, respectively. Typically, the non-biting midges (family Chironomidae) and other dipterans were the most abundant prey; chironomids averaged 627 and 323 insects/m^2 from fallout traps in reference and restored emergent marshes, respectively." Diefenderfer et al. (2016) concluded that net cumulative ecosystem improvement is at least suggested by the causal relationship between biomass and prey production and restoration.

Anthropogenic activities impacting LCRE ecosystems, and hence net ecosystem improvement, include FCRPS operations (flow regulation, flood management), land use (agriculture, industry, urban and suburban development), and navigation (dredging, pile dikes, and jetties). For example, flow is a major ecosystem controlling factor in the LCRE (Thom et al. 2004) because, along with dikes and levees, it affects the frequency and magnitude of the flooding of wetlands (Kukulka and Jay 2003b). The ecological impacts from individual activities have been studied to various degrees, but are not well understood collectively or relative to one another.

4.4.3 Uncertainties Assessment

The assessment of uncertainties related to the state of the estuary is summarized in Table 4.4 at the end of this section.

<u>Uncertainty 4.1. Non-native species impacts</u>. Recall we discussed species interactions including those involving non-native fishes (Uncertainty 2.4). The issue of non-native species impacts is broad, and includes fish, invertebrates, and plants. Several reviews of non-native species issues in the Pacific Northwest (Carey et al. 2012) suggest that non-native species are prevalent in the Columbia River basin, including the estuary, and could have important impacts on ESA-listed salmonid populations. Invasive species can inhibit or prevent the restoration of habitat quality and quantity for native species by preying on juvenile salmonids, competing for prey, decreasing diversity, and limiting habitat availability. A number of non-native species are of concern, including RCG, shad, killifish (*Fundulus diaphanous*), smallmouth and largemouth bass (*Micropterus spp.*), and a number of species of zooplankton. The impacts of most of these species are still unknown. Impacts of some species may be more local (reed canarygrass), while impacts of other species (e.g., shad) may be much broader. Most of the attention from the perspective of non-native species has been on RCG (see Section 4.2.2). With respect to restoration actions in the estuary, the issue is whether and how non-native species may be affecting the benefits of restoration. Further understanding the food web of fish in shallow-water habitats would be useful (for more information on juvenile salmon food webs, see Appendix G). There has been a

considerable amount of research on prey items consumed by juvenile salmon (see Appendix F, Juvenile Salmon Diets), but relatively little about other (non-native) fish that occupy the same habitats. It would be unfortunate to learn that restoration activities provided equal or greater benefits to non-native fish if the result was a net-negative effect for imperiled salmon stocks, e.g., predation.

Uncertainty 4.2. Net ecosystem improvement and anthropogenic activities. Evidence has indicated that restoration actions have had benefits to the condition of the estuary ecosystem, e.g., increased habitat connectivity (Section 2.3) and sediment accretion at newly constructed restoration sites (Sections 3.3.2). And, as noted above (Sections 4.2.3 and 4.4.1), the combined effects of flow regulation and the construction of dikes and levees are an overriding factor controlling LCRE ecosystems. Upstream alterations can affect the rate and level of the recovery of restoring habitats in the floodplain. Moreover, the ecological impacts from individual anthropogenic activities have been studied to various degrees, but are not well understood collectively or relative to one another. Overall, there was a net increase in connected floodplain and wetland habitat area due to restoration, although we do not know exactly how much because we lacked data on changes to the amount of unrecoverable, permanently developed area. The amount of new development certainly did not exceed the 5,412 ac (2,190 ha) of tidal *floodplain* habitat that have been reconnected since 2004 (see Section 2.1).

Table 4.4. Comments on uncertainties identified in SM1 for the state of the estuary. Suggested CEERP priority: Yes or No.

SM1 Id#	Comment	Priority
4.1 Impacts of non-native species	SM1 considered the issue of competition and predation effects of native and non-native species on the benefits of restoration. Consideration of non-native species' impacts on restoration is a broad issue that includes fish, vegetation, zooplankton, as well as mechanisms such as food-web interactions and habitat modification. It also could include how increases in water temperatures (considering climate change) might affect non-native fish presence, proliferation, and competition with native fishes. The uncertainty is whether and how non-native species may be affecting the benefits of restoration for juvenile salmon.	Yes
4.2 Net ecosystem improvement and anthropogenic effects	There has been positive net ecosystem improvement due to restoration, although the exact magnitude is uncertain because data on the floodplain area recently (since 2010) lost to development are lacking. While the ecological impacts from individual anthropogenic effects have been studied to various degrees, they are not well understood collectively or relative to one another. It is important that CEERP managers understand these effects so they can account for them in restoration strategy and planning.	Yes

5.0 STATE OF THE SCIENCE: ADDITIONAL SCIENCE QUESTIONS

In 2017, we had new data and information that allowed us to address additional science questions relevant to CEERP management. The objective of this chapter is to discuss science questions that were beyond the scope of SM1, but are relevant to CEERP management. The four questions covered in this chapter are: 1) What effect does the mixture of hatchery and wild origin juvenile salmon have on CEERP strategy? 2) How does the linkage between the estuary and ocean affect salmon population dynamics? What are the implications of this linkage to CEERP strategy? 3) How might climate change affect environmental conditions in the estuary and be taken into account in restoration project design and CEERP strategy? 4) What new data and information are relevant to restoration project design and CEERP strategy? Similar to the format in Chapter 4 for a given science question, we present data and information relevant to the question and identify pertinent uncertainties.

5.1 What effect does the mixture of hatchery and natural origin juvenile salmon have on CEERP strategy?

Salmon and steelhead emigrations from the Columbia River basin are dominated by releases of hatchery fish. All listed ESUs are supported by large numbers of hatchery fish and in fact some hatchery stocks are considered part of a listed ESU. The prevalence of hatchery fish raises several issues from the perspective of estuary ecosystem restoration. We examine these issues in this section.

5.1.1 New Data and Information

An important question for CEERP is how does production type, i.e., HO (hatchery origin) vs. NO (natural origin), affect migration, habitat use, residence time, and survival in the LCRE? There are several issues with understanding NO behavior and ecology. First, incomplete marking of HO fish affects data on the origin of fish in the estuary. Weitkamp and Teel (2015) explained that unclipped fish may not necessarily be of natural origin due to inconsistent clipping and tagging operations in the basin. Their analysis showed that production and mark rates vary widely among regions, although marking rates have generally increased over time, none are 100%. Thus, if research mostly samples HO fish, are correct inferences made about NO fish? Second, Thom et al. (2013) concluded that production type affects estuary habitat use, residence time, and migration. They concluded that patterns of estuary habitat use and the life histories of juvenile salmon are directly tied to their freshwater sources. Data collected since 2012 support this conclusion. Sather et al. (2016) found 69% of the salmon captured in beach seines in the Middle and Upper Tidal River zones were unmarked. In the lower part of the estuary, NO West Cascades fall Chinook salmon are most abundant, likely because they enter the system from tributaries of the mainstem estuary (Roegner et al. 2012; N. Sather pers. comm. January 11, 2018). Roegner et al. (2016) demonstrated fine-scale spatial segregation; unmarked fish made up a much higher proportion of juvenile salmon in shoreline habitats than in adjacent mainstem habitats.

It is unclear, however, whether there is something inherent in being HO that affects use of the estuary. Much of the literature compares hatchery and wild fish and shows both similarities and differences in life history and ecology of the two types of fish (Fresh 1997). Some studies suggest that HO and NO fish have similar performance (e.g., survival), behavior, and ecology when factors such as size can be accounted for (e.g., Sweeting and Beamish 2009; Weitkamp 2010; Daly et al. 2012; Woodson et al. 2013; Chittaro et al. 2018). Other studies suggest there can be behavioral or survival differences (Fresh 1997). Nickelson (2003) described the competitive effect of larger hatchery presmolts on wild coho salmon in Oregon coastal streams, linking the effect to the returning adult abundance of NO and HO. He found the presence of large numbers of HO fish reduced the productivity of NO fish.

Competition for food and space between HO and NO fish in the LCRE is not well understood. Because all anadromous juveniles pass through the estuary on their way to the ocean, HO and NO fish from all parts of the basin may be in the estuary at the same time—even fish that are deliberately spatially segregated in their natal rivers—providing a clear opportunity for competition (Weitkamp et al. 2015). Studies elsewhere in the Pacific Northwest have collected data on competition between NO and HO fish and a number of workshops have been conducted on this subject over the last several decades (e.g., Fresh 1997). The ISAB (2015) reviewed density dependence in the Columbia River basin and found little information about estuarine interactions. The review suggested there were some high-risk times and places at which competition could be occurring in the Columbia River basin, but the estuary was not included in the list of high-risk places. Storch and Sather (2011) analyzed data on prey densities, modeled foraging behaviors, and diet compositions collected at shallow-water habitats in the Upper Tidal River zone. Their results, while cursory, indicated that intra-specific competition was relatively weak among juvenile Chinook salmon.

Although competition is of considerable interest to fish managers, it is also relevant to restoration sponsors because competition that negatively affects NO fish could affect benefits of restoration actions to listed populations. One particular issue is hatchery releases resulting in the arrival of large numbers of fish in the estuary within narrow time windows, in contrast to presumably more protracted arrival timing historically. Hatchery release practices could create high-density conditions whereby HO fish might compete with and negatively affect the growth rates of listed populations. If the overall consumptive demand (a function of both fish abundance and fish size) of hatchery fish was sufficient (i.e., how much prey do the hatchery fish eat relative to what is present?), the growth rates of individuals from listed populations could be reduced. This could depend upon the environmental conditions, species being considered, relative amount of prey available in the environment, and habitat where the interaction occurred.

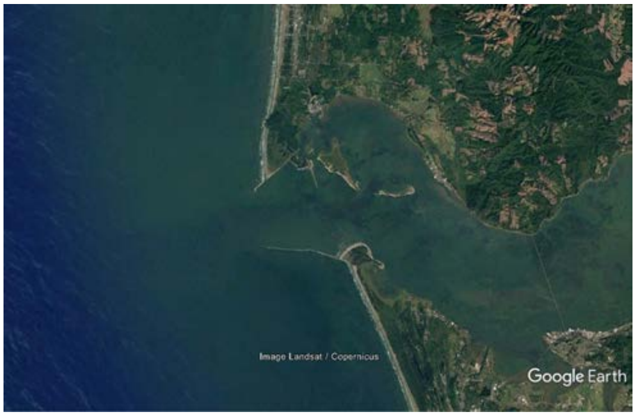
Many diet studies suggest that juvenile HO and NO salmon of the same species often have similar diets and high spatial overlaps (Armstrong et al. 2008; Daly et al. 2009; Sweeting and Beamish 2009). Thus, if food was limiting in these situations, the likelihood that competition would occur is high, because the fish eat similar items. For example, Daly et al. (2012) evaluated several parameters associated with HO and NO yearling spring Chinook salmon during early marine life to evaluate the potential for competition between these two types of fish. They found that both HO and NO Chinook had high dietary and spatial overlaps during early marine life as well as similar growth rates. Most importantly, the overlaps in diet and spatial occurrence, size, condition, and growth appeared to change at the same time for both NO fish and HO fish, suggesting fish were responding synchronously to changes in environmental conditions.

5.1.2 Uncertainties Assessment

From the perspective of the CEERP, there are two major uncertainties relative to HO and NO fish in the estuary. The first of these uncertainties is the complicating effects HO fish generate in understanding fish behavior in the estuary and the ecology of populations at risk. As noted previously, tagging more NO fish is seemingly too costly and logistically challenging. There are also regulatory concerns about excessive handling of NO fish. There is potential for redesigning some studies to increase the numbers of NO fish captured, but there are associated issues with this as well, e.g., permitting.

A second uncertainty involving HO and NO salmon is the possibility that the former are affecting the benefits of estuary restoration through competition or predation effects on the latter, as noted in Section 4.3.2. The strength of this interaction will depend on factors such as the wild stock involved, the size of the HO and NO fish, and the timing and density of hatchery fish releases. This issue is more likely to be a local effect rather than widespread issue in the estuary. The ISAB (2015) concluded there was not enough information to determine whether density-dependent interactions were occurring in the ocean. The types of situation of concern are, for example, when Spring Creek hatchery releases overlap with the presence of NO fish in the upper part of the estuary. As these fish move downstream, they will spread out and there will be less potential for direct interactions. It will be very challenging to determine whether these types of impacts are occurring and how severe they will be. It will require focused research studies and coordination between science teams and hatchery managers (sampling would need to occur when hatchery and wild fish migration overlaps).

5.2 How does the linkage between the estuary and ocean affect salmon population dynamics? What are the implications of this linkage to CEERP strategy?



Photograph. Estuary/ocean linkage.

Salmon move from the estuary into the ocean where they feed and mature before returning by way of the estuary to freshwater spawning grounds. Knowledge of salmon ocean ecology would not change the way we choose sites or plan restoration projects in the estuary. But, estuary restoration actions that help improve the condition and increase the size of juvenile salmon and steelhead exiting the estuary could increase survival rates during early ocean entry (e.g., Scheuerell et al. 2009). Understanding salmon dynamics during early ocean entry is also important to interpreting ESU/DPS status. Managers can misinterpret the value of freshwater and estuary habitat improvements if they do not understand what happens to these fish once they reach the ocean.

5.2.1 New Data and Information

The effects of variability in ocean productivity can mask, enhance, or even override underlying trends in estuarine (and freshwater) habitat productivity and lead to a misinterpretation of the proximate causes of variability in survival or adult returns. As the ISRP stated in its review of the Ocean Synthesis report (ISRP 2012), "...effectiveness of restoration as estimated from adult returns must account for all sources of mortality, including ocean mortality. Ideally, this partitioning will be accomplished for wild and hatchery stocks, in-river vs. barged, individual ESUs, and different life histories to help determine in-river, estuarine, or ocean responses to the 4-Hs." (The 4-Hs are hatchery, harvest, hydrosystem, and habitat.) In their 2009 Fish and Wildlife Program, the NPCC noted (page 31) that "…accurate monitoring and evaluation of inland efforts depends on the ability to isolate the effects of the ocean from the effects of inland actions. Without the ability to distinguish ocean effects from other effects, the Council may be tempted to correlate large salmon returns with successful mitigation practices. Likewise, poor returns of adult fish may lead the Council to abandon mitigation actions that are highly beneficial but which are overshadowed by the effects of poor ocean conditions unless the Council can determine the poor returns are in spite of, and not because of, the mitigation actions." The National Research Council (NRC 1996, page 3) also identified the potential masking effect of ocean conditions in their evaluation of the plight of anadromous salmon: "Variations in ocean conditions—especially in water temperature and currents and the associated biological communities—also contribute to the rise and fall of salmon abundance, often thwarting the interpretation of events in freshwater and surrounding terrestrial systems." Although the estuary was not mentioned specifically in the Council or NRC's comments, the effects of estuary restoration actions can also be masked by variation in ocean survival.

Actions taken in the estuary will affect what happens to the fish in the ocean. How the fish use the estuary and what happens to them in the estuary likely affects their subsequent survival in the ocean. Management actions that affect fish size, their timing of ocean entry, the density of salmonids in the estuary and ocean, and the condition of the fish can affect growth and survival of the salmonids during later life stages (Scheuerell et al. 2009; Tomaro et al. 2012). For example, mean body size at ocean entry and early marine growth in yearling Chinook salmon are positively correlated with adult returns (Claiborne et al. 2011), the body condition of subyearling Chinook salmon is correlated with adult returns (Miller et al. 2013), and the time and size at which salmon are released from hatcheries can affect adult return rates (Bilton et al. 1982). Holsman et al. (2012) found a relationship between the temperature difference between the estuary and ocean that was correlated to survival of Columbia River Chinook salmon; larger temperature differences were associated with lower survival rates. Scheuerell et al. (2009) reported that the timing of ocean entry was related to the survival of Columbia River basin Chinook salmon and steelhead; earlier migrating fish generally perform better that later migrating fish. Weitkamp et al. (2015) showed that stocks within a single basin can differ in their size and timing of ocean entry, and also differ in early marine growth and survival. This suggests that fish size and time of ocean entry, which are in part due to conditions in the estuary, can affect salmon growth and survival in the ocean. Under the Corps' AEMR study, NMFS has proposed to develop a conceptual model to integrate the estuary and ocean data sets concerning migrating juvenile salmon, including metrics relevant to evaluate growth and survival of fish along the continuum from upriver sources through the estuary to the river plume. The analysis should be available in 2019.

5.2.2 Uncertainties Assessment

One uncertainty associated with the estuary-ocean linkage is how estuary restoration actions may be affecting the early ocean ecology of salmon. Potentially, estuary conditions can affect the timing of ocean entry and the size of some fish. Larger fish, for example, can have higher survival rates during early ocean life. Understanding how estuary restoration actions affect early ocean life would involve increased integration between estuary and ocean researchers. The CEERP should be aware of the variability in ocean survival for stocks of concern because the effects of variability in ocean productivity can mask, enhance, or even override underlying trends in estuary and tributary habitat productivity.

5.3 What new data and information are relevant to restoration project design and CEERP strategy?

Since 2012, considerable progress has been made in increasing the knowledge base supporting restoration project design. While it is beyond the scope of SM2 (and our expertise) to offer recommendations or best practices for restoration design, we feel it is important to present new data and information that are likely useful to restoration managers and sponsors. This section covers predicting plant community composition and density, RCG control, seed banks, mounds, channel network design, large woody debris, beaver dams, and beneficial use of dredged materials.

5.3.1 New Data and Information

Environmental and ***plant community*** data for tidal wetlands have been synthesized and reported to aid the design of restoration projects throughout the entire 234 km LCRE (Diefenderfer et al. 2013a). This synthesis was based on data from 55 tidal wetlands and 3 newly restored sites collected as part of 5 different studies. The authors present tables of data about the distribution of individual plant species in terms of river extent (longitudinal position) and elevation. The data tables identify the most abundant herbaceous, shrub, and tree species by zone and wetland type. The tables are intended to provide data about the longitudinal and vertical distributions at which native plant species are likely to survive in a given area. The tables provide additional information important to planning, including whether the plant species is native or not, invasive/weedy or not, and its wetland status (e.g., facultative, obligate).

Project sponsors have worked to manage and discourage ***RCG*** colonization at new restoration sites using scrape-down and various other control methods. Diefenderfer et al. (2016b) provided recommendations concerning the state of the science for controlling RCG at restoration sites. Examples include identifying target elevations that promote native plant establishment and planting native plants at high densities in low and high marshes to outcompete RCG for space (horizontal and vertical), among others. Key environmental controls are shade, salinity, and elevation. It is practical in the long run to control RCG to the greatest extent possible during the restoration project’s construction phase, because funding for post-restoration stewardship or maintenance can be limited. A statistically designed, 6-year field experiment on RCG control methods (see Appendix C in Johnson 2016) is currently under way by the Columbia Land Trust at restoration projects at Kandoll Farm (commenced in 2016) and Kerry Island (commenced in 2017); preliminary results are expected in 2018.

Seed banks can potentially affect plant recolonization at restoration sites. In a greenhouse experiment, Kidd and Yeakley (2016) examined seed bank composition and germination response across a gradient of tidal flooding and salinity treatments. They found native species germinated at the same rate across all treatments, but non-native species germinated most readily under low-frequency flooding. They also examined seed bank samples from wetlands in Youngs Bay and found non-native species were the most abundant species. Kidd and Yeakley (2016) found that non-native species germinated most readily under low-frequency flooding; thus, tidal flooding created by restoration has the potential to affect non-native seed germination and plant community development. Kidd (2017) studied the restoration trajectories of tidal reconnection projects. She specifically evaluated why high marsh zones of restoration sites were not recovering native wetland plant communities after tidal reconnection, whereas low marsh zones of the same sites were found to recover native plant communities very quickly—within 3 years. Kidd (2017) determined that high and low marsh seed banks had similar compositions of native and non-native seeds, but the non-native seeds were expressing themselves more readily in the high marsh due to more variable conditions; they germinated more readily under high marsh freshwater conditions than under low marsh brackish conditions.

Several considerations related to the morphology or structure of a restoration project can influence the function of the site. One of these considerations is ***mounds***, also called hummocks, peninsulas, or berms. Some sponsors have included mounds as a way of creating topographic diversity and promoting habitat complexity while disposing of material from excavations, breaches, or levee lowerings (e.g., Colewort Creek, Kandoll Farm #2, Mill Road). Diefenderfer et al. (2016b) offered several recommendations for restoration practice concerning mounds, including consideration of the source of mound material and placement of topsoil on the mound apex. Moreover, the fact that soil moisture is negatively correlated with elevation reinforces the importance of the relative vertical position in the placement of mounds and their planting plans. Data from the field for the Mill Road project indicate the "…mound configuration of spoils is working fairly well to establish woody vegetation, including Sitka spruce" (see Appendix C, Site Evaluation Card for Mill Road).

Another consideration important in the design of a restoration project is the ***channel network design***, e.g., the location, density, and number of outlets, because it directly influences the hydrologic regime of the site after hydrologic reconnection. One issue relates to dike breaching vs. dike removal. Hood (2014) performed research on the relative benefit of dike breaching versus dike removal at sites in the Skagit River delta in Puget Sound. The study showed "Dike breach sites were found to have fewer tidal channel outlets than reference sites, but greater total channel surface area and length." Using allometric analyses of reference marshes in the Puget Sound and the lower estuary, Hood (2015) concluded that the number of channel outlets for a marsh was correlated with marsh size. Diefenderfer et al. (2016b), however, concluded the LCRE is too complex and variable to derive universal relationships between the optimum number of channel outlets and restoration site metrics. They stated the approach for channel outlet design that uses historical channel data for a given site is valid and inherently practical. Further analysis and discussion are needed to ensure efficiencies in this aspect of restoration project design.

Related to channel network design and vegetative structure of a restoration site is the placement of ***large woody debris*** (LWD). ERTG (2016) described literature about and observations of large wood and its potential influence on the physical and vegetative structure of tidal habitats and associated aquatic communities in estuaries, with a focus on emergent wetland habitats. They concluded there is limited primary literature about LWD's role in estuarine environments and the associated response of salmonids. The ecological and physical functions of LWD in tidal systems could be different than those in stream systems. Similarly, Simenstad et al. (2003) concluded that the ecological effects of LWD in tidal environments are uncertain. Restoration project designs can include LWD placement to benefit juvenile salmon, western pond turtles (*Actinemys marmorata*), western painted turtles (*Chrysemys picta bellii*), and other aquatic species. ERTG (2016) recommended practitioners explain the need for and ecological purpose of prospective installation of LWD within the context of CEERP's ecosystem-based approach in project proposals and, if LWD is used, how it should be placed to mimic LWD distribution in reference marshes. Furthermore, participants at an LCEP workshop in 2015 in Portland, Oregon, suggested not using mechanical anchors to hold LWD in place. Rather, they recommended placing wood in high marshes to simulate fallen trees from adjacent riparian forest or drift wood, and using tree piles as ballast to simulate a wood jam. Borde et al. (2017) presented an analysis of satellite imagery and on-the-ground photo point data on LWD distribution and movements in emergent marsh wetlands. One observation was that the highest densities of wood were found on the marsh plain at five of seven sites studied; channels had the highest wood densities at the other two sites. Observations from Chinook River estuary and South Bachelor Island along the Columbia River shoreline revealed that large concentrations of LWD seemed to be racked up as a result of the synergy of large storm events during spring tides during spring freshets (A. Uber, WDFW, pers. comm., May 2018). Thus, it is evident that large pieces of dead, downed wood are a part of the floodplain ecosystem of the LCRE.

Although not commonplace in the CEERP, project designers sometimes consider natural ***beaver dams*** and beaver dam analogs (BDAs) when designing channels. Bouwes et al. (2016) performed a watershed-scale experiment to determine the effects of BDAs on a population of steelhead in the John Day River watershed. They reported increases in juvenile steelhead density, survival, and production after BDA installation in a highly degraded, incised stream. Although CEERP restoration sites do not typically involve highly incised channels, it may be worth considering BDAs if conditions at estuary restoration sites warrant them. Hood (2012), studying natural beaver dams in shrub marsh tidal habitat in the Skagit River delta, found that juvenile salmon densities were three times higher in low-tide pools behind beaver dams than in pools in shallows not associated with beaver dams. In the LCRE, Laszlo and Loeb (2016) collected preliminary reconnaissance data from over a dozen restoration sites including over 30 natural beaver dams and BDAs to develop guidance on the suitability, general efficacy, design considerations, and actual use of BDAs in the estuary. The Flight's End restoration project, constructed in 2017, incorporated BDAs, which will be monitored for effectiveness. Use of beaver ponds by juvenile salmon has not been documented in the LCRE.

The ***beneficial use of dredged material*** is under consideration by the Corps as a way to enhance estuary ecosystems. Using the dredged material can create or enhance shallow-water habitat and provide for placement of sediment dredged from the navigation channel. As part of the Corps' Lower Columbia River Ecosystem Restoration General Investigations Feasibility Study, PC Trask and Associates, Inc. (PCTA 2009) inventoried dredged material placement sites that had naturally evolved over the years. They also drafted initial planning and design criteria for new dredged material placement for purposes of habitat creation. Dredged material placement is a disturbance history category, as defined by Diefenderfer et al. (2013a). These authors categorized 20 of 58 marshes examined as dredged material placement sites, although disturbance locally from adjacent pile dikes could have also contributed to net sediment deposition at some sites. Compared to other disturbance categories, dredged material placement sites had shorter distances to the main channel (<1,000 m), lower elevations, higher proportions of low marsh, lower total organic carbon, and relatively high proportions of native plant cover. For 2018, the Corps is considering pre-construction monitoring of physical and biological indicators at potential restoration sites at Woodland Islands and South Bachelor Island, where dredged materials would be placed to create habitat. To understand the efficacy of dredged material use as a tool for enhancing habitat, it will be important to approach the project with a robust experimental design to ensure results can inform future strategies for beneficial use.

5.3.2 Uncertainties Assessment

Since 2012, considerable growth has occurred in the knowledge base supporting restoration project design. Advances relevant to restoration design concern plant community composition, RCG control, seed banks, mounds, channel network design and development, breaching dikes vs. removal, LWD, beaver dams, and beneficial use of dredged materials. The importance of any of these topics will vary between projects, so, to some degree, all remain uncertainties in the design of restoration projects.

5.4 How might climate change affect environmental conditions in the estuary and be taken into account in restoration project design and CEERP strategy?

Climate change will affect the estuary through its connections to the Columbia River basin and the ocean. Climate change effects on local conditions will also be a factor influencing environmental conditions in the estuary (Text Box 5.1). This section discusses these effects and offers recommendations for incorporating climate change considerations into project design and CEERP strategy.

Text Box 5.1. Climate Change

Climate change has been a major science issue in the conservation and management of salmon populations for the last several decades. Much of the focus of climate change science dealing with salmon has been on predicting the biological and physiochemical effects of climate change in salmon and their ecosystems. For example, Schindler et al. (2008) and Crozier et al. (2008) provided general discussions of climate change effects on salmon; see reviews by Griffis et al. (2013) for a nation-wide perspective and King et al. (2011) for a "California Current" perspective on climate change. Less attention, however, has been paid to mitigating and accommodating climate change impacts and monitoring effects moving into the future, including ecosystem restoration design and strategy.

5.4.1 New Data and Information

Although our focus here is on effects in the LCRE, the overall effect of climate change on any anadromous stock must consider all habitats and life stages simultaneously and cumulatively (Crozier et al. 2008a; Healey 2011; Wainwright and Weitkamp 2013). The scope and magnitude of any effect experienced by salmon will be a function of how the climate actually changes (e.g., rate and magnitude), how these changes ultimately affect physical and biological processes, and the stock or population being considered (Tolimieri and Levin 2004). Many of these processes interact, making predicting the effects of climate change especially problematic (Crozier et al. 2008b). As an illustration of this, Wainwright and Weitkamp (2013) summarized the potential physical changes that could potentially result from the effects of climate change on Oregon coast coho salmon. Although developed for coho salmon, this synoptic analysis provides useful guidance for considering climate change effects on other salmon populations as well, including those from the interior Columbia River basin.

From the CEERP perspective, there is some information about potential climate change effects on the LCRE. According to ISAB (2007), the major physical changes that may be expected include changes in temperature, flow, and sea level (water level in the estuary). The water temperatures in the estuary could increase as a result of continued increases in water temperature in the Columbia River basin, increasing air temperatures, and increases in the temperature of ocean water entering the estuary. Over the last 60 years, there has been a steady increase in the temperature of water entering the estuary as a result of basin-scale changes such as precipitation increasingly falling as rain rather than snow in higher elevations, snowpack decreasing, spring peak flows increasing, and late summer/early fall flows diminishing (ISAB 2007; Beechie et al. 2013). In related research, Talke and Jay (2016) developed a physics-based statistical model of water temperature as a function of air temperature and river flow. Model results suggested water temperatures in the Columbia River at Astoria were 2°C warmer in 2015 than in the mid-19th century. The authors concluded changing air temperatures and flow alterations are likely driving changes in water temperatures in the estuary. Using a regression modeling approach, Overman (2017) found water temperature in the lower Columbia River was more sensitive to changes in flow than changes in atmospheric heating and cooling. In a comprehensive planning effort, the Corps (USACE 2015) identified stressors and impacts, including the following: 1) higher ambient air and water temperatures (especially in summer) could affect the biota, including exotic species; 2) sea-level rise could affect plant communities and risk overtopping levees; 3) changes in river discharge timing and magnitude could affect habitat opportunity and risk levee overtopping; and 4) changes in turbidity and sediment transport could affect accretion rates at restoration sites.

In particular, the effects of climate change on ***water temperature*** and subsequently on salmon and their ecosystems will depend on species and life stage. First, we can expect changes in the amount of time juvenile salmon, primarily subyearling Chinook salmon, occupy certain shallow-water wetland habitats (i.e., tidal-fluvial habitats) due to increases in temperature. What is especially critical is the amount of time temperatures will exceed sublethal and lethal levels. Studies suggest that salmon will abandon marshes when the temperature exceeds 22°C or so (e.g., Roegner et al. 2010). Before temperatures exceed sublethal or lethal thermal limits, we can expect other thermal responses to occur. In particular, all species and life stages will respond bioenergetically, e.g., moderately elevated temperatures can increase metabolic rates. Thus, at more modest temperature increases, growth rates of salmon may actually increase, assuming food resources do not diminish. Roegner and Teel (2014) found that the condition of subyearlings was better at summer temperatures >19°C than during cooler temperatures in spring. High food levels may offset the negative effects of temperature-induced metabolic demands. Many salmon stocks, particularly yearling-size migrants, move through the estuary before temperatures reach stressful levels. It is unclear how migration and rearing timing will respond to changes in the LCRE temperature regime. Restoration practitioners should design restoration projects so that egress is possible when water levels drop and water temperatures increase.

We can also expect some temperature-mediated changes to occur in the food web of the estuary, in ways that are difficult to predict (Naiman et al. 2012; Limburg et al. 2016; Lynch et al. 2016). There may be changes in the community structure of invertebrates available to the salmon to feed on and in the plant communities in the estuary. It is not clear what the net effects of these temperature-related changes will be. There are many uncertainties associated with this type of water temperature changes such as how tolerant different organisms are to temperature changes and the rate and magnitude of temperature changes that will occur. Of particular concern are the proliferation of warm-water fishes that may either compete with or consume salmon, such as killifish and bass (Naiman et al. 2012; Rehage and Blanchard 2016). Sources for these fishes include the downstream movement of freshwater species (e.g., bass, pike), or northward movement in marine waters of exotic anadromous species (e.g., striped bass).

The second major type of physical change that will impact the LCRE is ***sea-level rise***. As the level of the sea rises, several changes can be expected. Rising sea levels will push the saline portion of the estuary upstream into freshwater areas and change the location of freshwater-saltwater ecotones (Flitcroft et al. 2013). Tidal wetlands may become submerged or have longer periods of inundation than they do currently; nearby terrestrial habitats may be flooded (Kirwan et al. 2010). Borde et al. (2015) reported data indicating that inundation changes due to climate change, whether from sea-level rise or altered runoff patterns of the Columbia River, could eventually change vegetation communities in the estuary. Also, shallow-water habitats such as wetlands may erode as sea levels rise. Erosion impacts may be exacerbated by diking and other barriers that prevent wetlands from expanding and keeping up with erosion impacts. The net effect of these physical changes on estuarine habitats depends on the rate of sea-level rise, the rate of vegetation growth and sedimentation, and the land contours in and adjacent to the estuary (Roessig et al. 2004; Kirwan et al. 2010). The global rate of sea-level rise is faster than the colonization rate for new wetlands (Roessig et al. 2004). The Chesapeake Bay has already experienced massive wave-induced erosion of marsh areas due to the rising sea level (Stevenson et al. 2002). It is clear the biological characteristics of affected wetlands and other shallow-water habitats are likely to be altered by increasing sea level (Borde et al. 2015; Stevenson et al. 2002). Such changes will affect how these estuarine habitats function for salmon. For example, the head-of-tide in tributaries to the Columbia River such as the Lewis and Cowlitz Rivers will move upstream in these tributaries with accompanying changes in the physical structure of the estuary (due to changes in the tidal prism) and the biological characteristics of these river mouth systems. Areas of increased risk to public safety due to sea-level rise could be identified and assessed for their suitability for habitat restoration versus anthropogenic development.

A third type of climate-related change that can affect salmon in the estuary (and the coastal plume) is ***flow-related changes*** below Bonneville Dam that can occur as a result of changes in precipitation patterns, runoff, and water-management practices. Climate forecasts for the Pacific Northwest suggest there will be a reduction in precipitation that occurs as snowfall and an increase in rainfall, which would increase winter flow levels and diminish summer/fall flows (Mote and Salathé 2010; Beechie et al. 2013). Coupled with increased temperatures, such a scenario could critically limit salmon migration periods. In the estuary, there is a relationship between flow, tides, and salinity at any point. Changes in salinity (e.g., either the upstream extent of measurable salinity or the regime at any particular place) will depend on freshwater flow, tides, and basic sea-level rise (polar and glacial melting). As noted previously, changes in salinity or water levels in the estuary will alter the biological community structure and accessibility of these locations to salmon. Flow changes are also important in terms of downstream fish migration rates through the estuary. Reduced flows during the time salmon are emigrating, for example, could slow the downstream migration of salmon and affect the timing of their ocean entry. Given the rapid migration of larger, yearling-size fish, it is not clear whether flow-related delays of hours or days would result in changes in the growth and survival of these larger migrants.

The potential effects of climate change on both freshwater and estuarine restoration programs has been explicitly recognized in the Puget Sound. For example, policy-makers and researchers organized a workshop on the effects of climate change on the Skagit River watershed, including analyses of effects in the estuary (Northwest Science, Volume 90, Issue 1, 2016). Hood et al. (2016) reported tidal marshes historically (since 1937) had been mostly prograding (expanding) into Skagit Bay, but in recent decades the progradation rate has been declining and in some places marshes have been eroding, despite heavy sediment load entering the estuary delta from the Skagit drainage. Sea-level rise will only exacerbate this erosion. To adaptively manage for sea-level rise by maximizing sediment delivery to tidal marshes, Hood et al. (2016) recommend restoring historical distributaries in the delta and moving levees back from channels. Furthermore, the Puget Sound Salmon Recovery Program, led by the Puget Sound Partnership, has developed guidance for project sponsors to incorporate climate change into project design and implementation of salmon recovery projects (PSP 2017).

Conceptually, it is clear long-term changes in temperature, water level, and flow due to climate change will need to be considered in CEERP planning and management. While we are uncertain about the strength, timing, and duration of any changes that occur, climate change should be considered in restoration project design and CEERP strategy. Corbett et al. (2015) recommended integrating climate change mitigation by allowing wetland migration to higher elevations inland, protection and restoration of cold water refugia, and taking an adaptive approach to shifting native plant community establishment. In a formal study as part of the Corps' Lower Columbia River Ecosystem Restoration General Investigation Study, the Corps (USACE 2015) assessed the issue of climate change effects on restoration project design and program strategy. Based on a case study for the Steamboat Slough restoration project, they recommended specific actions to consider during project design to help adapt to climate change: deepen the levee breach and excavated channels, provide gradients in substrate elevation rather than benches, include mounds, and encourage revegetation by planting native species.

5.4.2 Uncertainties Assessment

In essence, the implications of climate change for estuary restoration present another uncertainty to be explored and adaptively managed. We know that there will be changes in sea level, water temperature, and freshwater outflow that will affect ecological processes and the capacity and opportunity of restoring habitats to support juvenile salmon. What is unknown is the magnitude and timing of these changes. In addition, there will be changes in freshwater conditions for juvenile salmon that could affect their physiology and behavior in the estuary. An example of this would be accelerated emergence caused by warmer incubation regimes. This could cause emigrants to enter the estuary earlier than historically, which could be either detrimental or beneficial depending on conditions in the estuary.

Given the uncertainties associated with climate change effects, how should a restoration program account for this? Some guidance is available from Puget Sound where climate change is becoming an explicit part of salmon recovery (PSP 2017). Other guidance is available from the Corps, which states, "Mainstreaming climate change adaptation means that it will be considered at every step in the project lifecycle for all USACE projects, both existing and planned…to reduce vulnerabilities and to enhance the resilience of our water resource infrastructure" (USACE 2013).

6.0 EVIDENCE-BASED EVALUATION REVISITED

Evidence-based evaluation (EBE) is a systematic, hypothesis-based approach to synthesizing and evaluating the cumulative system-wide effects of multiple restoration actions. In CEERP's adaptive management process (Figure 1.1), EBE is a part of "Learning." This technique, developed under the Corps' Cumulative Effects study, was established by Diefenderfer et al. (2011) and applied to CEERP using data and information through 2012 by Diefenderfer et al. (2013; 2016). Given that 5 years have elapsed since the first EBE for CEERP, we ask: What does an updated EBE performed in SM2 reveal concerning progress toward achieving program goals?

6.1 Background

EBE involves four main elements: 1) ecosystem conceptual model, 2) lines of evidence, 3) causal criteria synthesis, and 4) evaluation of cumulative effects (Figure 6.1). For SM2, we employed the conceptual model and associated hypotheses and monitored indicators from Diefenderfer et al. (2016) (see Section 1.1). "Lines of evidence" are categories of data and information applicable to the evaluation. In the original EBE for CEERP, there were seven lines of evidence that provided the foundation from which to assess the causal criteria and evaluate cumulative effects. Examples included meta-analysis of action effectiveness and modeling of CNEI (for the full list, see Figure 6.1). "Causal criteria" are factors one can use to ascertain whether a cause-and-effect association, in this case restoration and benefits to salmon, is reasonable. EBE uses "Hill's criteria" which have been applied in the fields of occupational health and epidemiology (Hill 1965). Examples of causal criteria include strength of association and biological plausibility (again, for the full list, see Figure 6.1). EBE culminates in an evaluation of cumulative effects based on CEQ (1997). As stated by Diefenderfer et al. (2016), the essence of EBE is that the "… primary focus of our approach is on the consideration that a reasonable person uses in reflective inquiry to determine when a cause-and-effect interpretation of an association is acceptable."

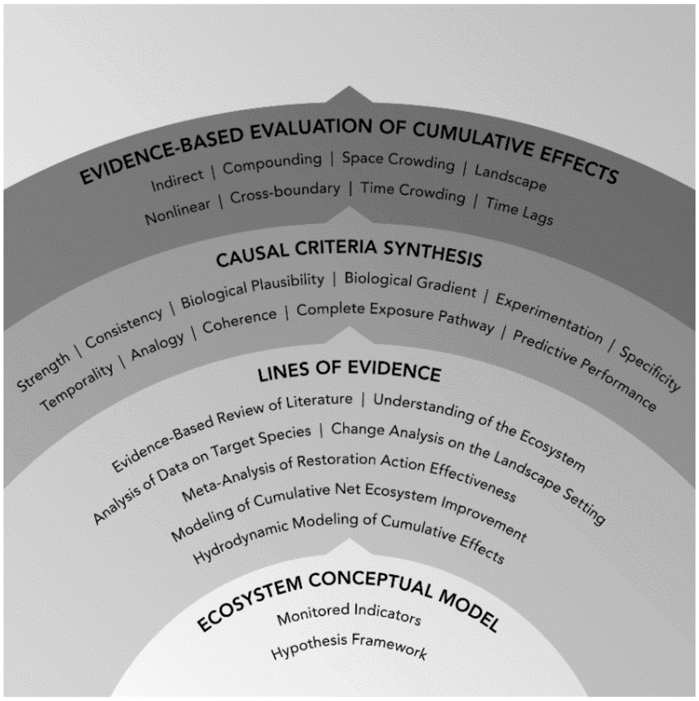


Figure 6.1. EBE process for CEERP. Modified from Diefenderfer et al. (2016).

6.2 New Data and Information

While it is beyond the scope of SM2 to repeat the lines of evidence for scoring literature and the CNEI analysis conducted by Diefenderfer et al. (2016), we do have new data and information (as presented in Chapters 2–5 and various appendices) to use to revisit the original EBE. Therefore, we reexamined the summary analysis results by monitored indicator and the causal criteria synthesis. The new data and information for various lines of evidence that were available to revisit the EBE included the following:

- change analysis of landscape setting (new; habitat change analysis Section 1.4.1, habitat connectivity analysis Section 2.3, and Appendix D)
- meta-analysis of AEM data (updates; Section 3.3.2)
- critical uncertainties (updates; genetic stock distribution, juvenile salmon ecology in tidal freshwater, residence times, etc. Sections 4.1 and 4.2)
- analysis of data on target species (updates; PIT-tag detections in wetlands Sections 4.1 and 4.2 and fish diet analysis Section 4.1 and Appendix F).

6.3 Findings and Conclusion

Summary results of analyses revealed the new data and information continue to be suggestive, but not sufficient, evidence of a causal relationship between hydrologic reconnection-restoration actions and the fish and habitat response variables (Table 6.1). That is, the data and information about fish and habitat responses were promising concerning a cause-and-effect relationship with restoration actions, but were not extensive or consistent enough to conclude this unequivocally.

The revisit of the causal criteria synthesis resulted in the same conclusions as those of Diefenderfer et al. (2016), except for predictive performance (Table 6.2). The evidence supporting the ability to accurately and precisely predict restoration outcomes has improved from being insufficient to being suggestive of a relationship. Hence, we found that the hypothesis was partially supported because some uncertainty about restoration outcomes remains. In conclusion, the evidence to date substantiates the findings of Diefenderfer et al. (2016), who said: "…we concluded that the restoration program is having a cumulative beneficial effect on juvenile salmon."

Table 6.1. Summary of the results of new or updated analyses using past and new data of habitat-based and fish-based monitored indicators. Conclusion categories (USDHHS 2004): (A) sufficient; (B) suggestive but not sufficient; (C) inadequate, inconclusive, or mixed; (D) suggestive of no causal relationship. No code means that the response was not studied in a particular analysis. Responses are: 1) fish presence, 2) residence, 3) survival, 4) prey, 5) diet, 6) fullness, 7) growth, 8) water-surface elevation, 9) water temperature, 10) sediment accretion, 11) vegetation, and 12) biomass export. Blank cells mean that data were not available. Sources of new data and information used to support these determinations are in Section 6.2.

	Fish Responses							Habitat Responses				
Analysis	1	2	3	4	5	6	7	8	9	10	11	12
Research on critical uncertainties	B				B						B	B
Analysis of data on target species	B	B			B		B					

	Fish Responses							Habitat Responses				
Analysis	1	2	3	4	5	6	7	8	9	10	11	12
Meta-analysis of AEM data	B							A	C	B		
Fish diet analysis					B							

Table 6.2. Summary of causal criteria synthesis of the new and updated lines of evidence related to the habitat and fish hypotheses (see SM2, Section 1.1) concerning responses to tidal reconnection-restoration actions. Based on Table 10 in Diefenderfer et al. (2013b) and Table 11 in Diefenderfer et al. (2016). "Supported" means the analyses for the lines of evidence substantiate or corroborate the causal criterion.

Causal Criterion	Short Definition (from Diefenderfer et al. 2013b)	Ecosystem Response (modified from Diefenderfer et al. 2016)	Conclusion Revisited for SM2
Strength and Consistency of Association	Magnitude of the effect of an exposure relative to non-exposure and its repeated observation in varied times and circumstances by multiple observers	As shown in the analysis of action effectiveness monitoring data from numerous projects sites (Section 3.3 and Appendix E), monitored indicators are trending away from the "before" condition.	Supported
Biological Plausibility	Knowledge of the mechanism (not a necessary condition of causation because it depends on the state of the science)	The indirect and direct ecological relationships between tidal wetlands and juvenile salmon depicted in the ecosystem conceptual model (Section 1.1) are reasonable based on the body of evidence from the LCRE and similar estuarine and tidal freshwater ecosystems.	Supported
Biological Gradient	The level of response is associated with a gradient in the hypothesized cause	Hydrologic connectivity, biological fluxes, and access to salmon habitat are modified on a nonlinear gradient by tide gates, dike breaches, dike removal, etc.; tide gates provide significantly less connectivity than breaches.	Supported
Experimentation	Manipulation of the hypothesized cause	Experimentation has occurred on a limited basis using hydrodynamic modeling of various dike breach scenarios; formal field experiments have not been conducted.	Insufficient evidence
Specificity of Association	Limitation of the association to particular sites and effects	With hydrologic reconnection, the specificity of association to habitat and fish responses at specific restoration project sites is conclusive (Chapter 3, Appendix E).	Supported
Temporality	The effect follows the hypothesized cause through time.	There is an immediate response of water-surface elevation from hydrologic reconnection (Section 2.2; Appendix C); analogous ecosystems and historically reconnected sites indicate positive marsh and salmon responses.	Supported
Analogy	Comparison to similar ecosystems	By analogy to other similar ecosystems, results of the global literature review by Diefenderfer et al. (2016) showed strong support for the salmon-response hypothesis based on four indicator categories: salmon	Supported

Causal Criterion	Short Definition (from Diefenderfer et al. 2013b)	Ecosystem Response (modified from Diefenderfer et al. 2016)	Conclusion Revisited for SM2
		presence, residence, diet, and growth (Section 4.1).	
Coherence	Lack of serious conflict between the cause-and-effect interpretation and known facts about the case under consideration	As Diefenderfer et al. (2016) found, there is no evidence of a conflict with the state of the science (Chapters 4 and 5) in concluding that hydrologic reconnection of tidal floodplain habitats with a mainstem river has a beneficial effect on juvenile salmonids.	Supported
Complete Exposure Pathway	Ability of the cause to physically reach the biological or ecological receptor	The new evidence and known ecosystem processes and functions indicate viable exposure pathways via hydrologic connectivity to realize benefits to juvenile salmon from habitat restoration (Chapters 4 and 5).	Supported
Predictive Performance	Ability to predict, accurately and precisely, restoration outcomes	The ability to predict restoration outcomes cannot be fully evaluated with existing action effectiveness monitoring data (Chapters 3 and 4).	Partially supported

7.0 CONCLUSION

Periodic synthesis and evaluation of results from program implementation (~5-year intervals) is a critical element of the CEERP's adaptive management process because it evaluates progress, identifies weaknesses, and thus informs managers about possible adjustments to future program strategy and actions. This synthesis memo (SM2) was built off of a previous synthesis report (SM1). In SM2 we have incorporated new scientific findings; presented new summarizations, syntheses, and analyses of information; and used the collective results to reevaluate program strategy and provide recommendations for future activities to advance the program. The report is organized around key management and scientific questions related to CEERP's main strategy to reconnect tidal floodplain habitats to the mainstem estuary.

In this chapter, we briefly summarize major results from SM2 and present a set of recommendations for CEERP pertaining to two management questions: What key findings can be drawn from addressing the science questions in Chapters 4 and 5? What are recommendations for future CEERP activities?

Photograph. Restoring wetlands. Courtesy of R. Salakory.

7.1 Summary

This section provides responses to the management questions outlined in Section 1.2. The responses are based on material reported in Chapters 2–6 and Appendices A–H.

Progress – *What progress has been made to date by CEERP in terms of the number of restoration projects and acreage restored? How much wetland area has been restored under CEERP? Quantitatively, how has habitat connectivity changed estuary-wide and by estuary zone?*

From 2004 through 2017, restoration sponsors implemented 58 projects restoring hydrologic connection to 5,412 ac (2,190 ha) of tidal *floodplain* habitat that included 2,555 ac (1,034 ha) of *wetland* habitats. This represented a ~11.6% relative increase in wetland area over the 14-year period. Due to increased efforts of CEERP managers and restoration practitioners, restoration was most active from 2012 to 2017, when 35 projects were constructed. Floodplain reconnection projects included dike and levee breaching or lowering (4,068 ac; 1,646 ha), tide gate removal (457 ac; 185 ha), and tide gate upgrades

(887 ac; 359 ha). In addition, sponsors improved riparian habitats (55 mi; 89 km) and worked to control invasive plants in wetland habitats (2,210 ac; 894 ha). Overall, CEERP restoration actions resulted in a 2.5% increase in the habitat connectivity index. As of 2016, 32.1% of total *wetland* area (24,567 of 76,496 ac; 9,942 of 30,957 ha) was connected to the mainstem estuary, i.e., 67.9% was disconnected by dikes and levees, but could potentially be reconnected (51,929 ac; 21,015 ha).

Site-Scale Action Effectiveness Monitoring *– At the site scale, are restoration actions having the expected physical and biological effects?*

Data collected from 23 restoration sites since 2004 indicated that ecological processes were being reestablished, although physical and biological responses were best interpreted within the context of project-specific goals and objectives. Results from site-scale AEM revealed that, in general, some monitored indicators supported the hypothesis that restoration actions are having positive effects (i.e., water-surface elevation, sediment accretion, channel cross sections, and fish data). However, for other indicators, results were inconclusive, data have yet to be analyzed, or it was too soon to tell because few years have elapsed since restoration construction (i.e., water temperature and vegetation). Of the 23 restoration sites, fish monitoring occurred at 13 locations and juvenile salmon, predominantly subyearling Chinook salmon, were present at all of the locations. While upriver stocks were rarely encountered through direct capture techniques, the presence of these stock groups was confirmed by detections on PIT antenna arrays within restored tidal wetland channels.

State of the Science: Update of SM1 *– What are updates to the findings and uncertainties regarding the four science questions identified in SM1?*

<u>What are the contemporary patterns of juvenile salmon habitat use in the estuary</u>? Data collected since 2012 corroborate the initial findings of SM1 and provide additional insight into contemporary patterns of estuarine habitat use by juvenile salmon. Habitat use and life history patterns of juvenile salmon in the LCRE, and especially yearlings, are more diverse than previously thought, which helps promote salmon population resilience. In particular, new research has dispelled the previously held notion that yearling-sized fish spend little time feeding in the estuary and using wetland habitats. Researchers detected tagged fish from the interior Columbia River basin in tidal channels in the estuary. In addition to spring and summer being important periods for migrating juvenile salmon in the estuary, new research indicated some juvenile salmon (mostly from west of the Cascades) overwinter in shallow-water habitats in tidal freshwater segments of the estuary. Results of several studies indicated dissolved organic matter and POM as well as insects, are exported from restoring wetlands to the mainstem estuary. Much of the energy consumed by juvenile salmon across the LCRE landscape, whether in the mainstem or in wetland, was derived from Diptera (see Appendix F). Amphipods were also important components of juvenile salmon diets, particularly in the Lower Estuary zone (rkm 0–38), and may also be important prey resources for larger size-classes of fish in off-channel habitats.

<u>Do factors in the estuary limit recovery of at-risk salmon populations and evolutionarily significant units</u>? The combination of flow regulation and the development of an extensive system of dikes and levees has isolated much of the historical floodplain from the mainstem. As outlined in SM1, limiting factors in the estuary continue to include insufficient habitat opportunity and capacity for rearing and refuge of salmon. Major factors that limit salmon opportunity and capacity are hypothesized to include reduction in peak flows in spring, ecological impacts from non-native flora and fauna, intra- and inter-specific competition, and piscivorous and avian predation.

Are estuary restoration actions improving the performance of juvenile salmon in the estuary? Salmon performance may be defined by growth, foraging success, spatial distribution, and life history diversity. Restoration effects on salmon performance can be direct (onsite) and indirect (offsite). One direct (onsite) benefit is that wetland food production supports foraging and growth within the wetland. Prey items produced within wetlands are also exported into mainstem and off-channel habitats where they become available to salmon migrating in these locations. Thus, while fish may not directly enter a tidal wetland channel, they derive indirect (offsite) benefits from wetland habitats. This provides evidence for supporting efforts to increase the connectivity among aquatic habitats throughout the LCRE. Analyses indicated that restoration actions are reestablishing ecological processes, although results are variable among the monitored indicators. Using new action effectiveness results and information (2012 to present), a revisit of the evidence-based evaluation of the CEERP hypotheses substantiated the original evaluation's conclusion that restoration is improving the performance of juvenile salmon in the estuary. In fact, new evidence indicated improved ability to accurately predict restoration outcomes.

What is the status of the estuary? Are estuarine conditions improving or declining? As noted in SM1, anthropogenic actions have altered the LCRE significantly since the beginning of the twentieth century. The estuary is in a degraded state, but it is not clear whether estuary conditions overall are trending to the positive or negative. Many factors that influence the status of the estuary are outside CEERP's mission or influence, e.g., land use practices, industrial development, non-native species, hydrosystem operations, and contaminant loading.

State of the Science: Additional Science Questions *– What additional science questions are relevant to CEERP and why?*

What effect does the mixture of hatchery and wild origin juvenile salmon have on CEERP strategy? The prevalence of HO (hatchery origin) as compared to NO (natural origin) fish raises several issues from the CEERP perspective. A major uncertainty concerning HO and NO fish is whether competition for food and space between these two fish types in the LCRE is affecting benefits of restoration actions to listed populations.

How does the linkage between the estuary and ocean affect salmon population dynamics? What are the implications of this linkage to CEERP? The estuary plays a critical role in supporting early life history requirements for juvenile salmon, and the interconnectedness of habitats supporting various life stages cannot be disregarded. Actions taken in the estuary can affect fish survival upon entering the ocean. For example, habitat enhancements that improve capacity (e.g., prey productivity) may lead to increased growth and condition of migrating juvenile salmonids in the estuary. The improved condition of fish in the estuary can contribute to the likelihood of their survival into the ocean.

What new data and information are relevant to restoration project design? Data and analyses to inform the design of restoration projects have been collected and developed in recent years. Guidance for predicting plant community composition and density, controlling reed canarygrass, understanding seed banks, constructing mounds, designing channel networks, and incorporating LWD has been, or is being, developed specifically for the LCRE. Considerably less is known about the mechanisms that relate these factors to biological responses such as resource subsidies (e.g., prey for salmon) and the condition of fish (e.g., growth, residence time).

How might climate change affect environmental conditions in the estuary and be taken into account in restoration project design and CEERP strategy? Major physical changes that will occur in the LCRE because of climate change are alterations in water temperature regimes, changes in local tributary and mainstem flow, and sea-level rise. While there is uncertainty about the strength, timing, location, and duration of any changes that may occur, actions that help make projects resilient to climate change should be emphasized in restoration project design and CEERP strategy.

7.2 Recommendations

In this section, we address the following management question: What are the major scientific and programmatic recommendations for CEERP? The recommendations are classified into two general categories. First, we recommend actions to address key scientific uncertainties. While there is clearly much to be learned about the ecology, benefits, and restoration of estuarine habitats, we have focused on uncertainties that can be addressed (i.e., questions that can be answered using current scientific methods), and which could have a considerable effect on the CEERP. The second category includes programmatic recommendations that concern large-scale strategies for the program. The latter category includes recommendations for new tools and approaches that, if implemented, would substantially help some element of the program.

7.2.1 Scientific Recommendations

Previously we summarized the state of the science regarding many uncertainties related to CEERP. Many of these uncertainties originated from SM1 (Chapter 4), while others are new and emerging issues (Chapter 5). These state-of-the-science summaries form the basis of our current understanding, including what has been learned, remaining questions or uncertainties, their importance and relevance to CEERP, and the capability to resolve them in the future. In the state of the science discussion (Chapters 4 and 5), we identified scientific uncertainties that in our opinion should be high priorities for CEERP to address because they are “doable” and their resolution will improve CEERP performance (see Table 7.1 for a summary list).

Table 7.1. Summary of the priority scientific recommendations. Status is as of June 2018.

SM1 Uncertainty Topic	SM1 Id#	SM2 Section	SM2 Recommendation	Status
Action effectiveness at site, landscape, and estuary-wide scales	3.1	4.3	Determine the effectiveness of restoration actions at multiple spatial sales, and ensure study designs support programmatic goals.	Ongoing
Habitat use; flux; genetic stock identification, habitat capacity,	1.2,1.3, 1.5,2.1	4.1, 4.3	Continue to investigate mechanisms for direct and indirect benefits of restoring wetlands, especially for yearling-sized fish.	Ongoing
Ecological impacts of native and non-native species	2.4, 4.1	4.2, 4.4	Determine if benefits of restoration are affected by ecological interactions between at-risk stocks and non-native species as well as other native species.	Not started
Population viability and salmon recovery	2.2	4.2	Determine relationships between restoring estuary habitat and the spatial structure and diversity of salmon populations emigrating through the estuary.	Not started

SM1 Uncertainty Topic	SM1 Id#	SM2 Section	SM2 Recommendation	Status
Net ecosystem improvement and anthropogenic effects	4.2	4.4	Assess the feasibility of determining the aggregate and separate effects of anthropogenic development on estuary ecosystem conditions.	Not started

***Recommendation**: Determine the **effectiveness of restoration actions** at multiple spatial sales.*

Pertinent research questions include: At the site scale, are restoration projects having the desired physical and biological effects? At the landscape scale, is there a cumulative effect of multiple restoration projects? At the estuary-wide scale, is the restoration program improving LCRE ecosystems? These questions could be evaluated through AEM, AEMR, and EBE.

***Recommendation**: Continue to investigate mechanisms for **direct and indirect benefit**s of restoring wetlands, especially for yearling-sized fish.*

Through the Corps' AEMR project, research has begun to provide information about the mechanisms for how restoration directly and indirectly benefits juvenile salmon. We recommend that these investigations continue. Improving this knowledge base will advance the ability to build numerical ecological models for the LCRE, make informed predictions about the success of restoration projects, and inform restoration design and prioritization. Specific recommendations related to this investigation include the following:

- Improve our understanding of habitat use and migration of all life history types, but especially yearling-sized fish in shallow-water habitats in tidal river zones and main channel habitats throughout the estuary.
- Evaluate the effects of selected capacity-related factors important to performance of salmon juveniles. This includes broadening our understanding of the diet of yearling-sized fish by stock in the mainstem and other key habitats as well as evaluating the mechanisms driving primary and secondary production in wetlands, i.e., controlling factors for productivity.
- Improve the understanding of offsite (indirect) benefits of restoration.
- Broaden our understanding of how different floodplain habitats contribute prey resources both within wetlands and outside the boundaries of the wetlands
- Continue studies of prey flux associated with wetland-derived salmon prey and organic matter from different wetland types across the estuary.
- Address potential questions arising from the analysis and reporting of current AEMR research. For example, does prey export vary with vegetation community? How does location or position of a restoration site within the landscape influence prey export from the site? Do the number of dike breaches or channel network configuration influence flux?
- Ensure that all studies involving salmon assess the genetic stock of any subject salmon.

***Recommendation**: Determine if benefits of restoration are impacted by ecological interactions between stocks at risk and both native species and non-native species.*

While ecological interactions are pervasive throughout the LCRE, of concern is how these interactions may be impacting the benefits of restoration. AEMR should be designed to investigate how non-native fish may be affecting the ability of restored sites to provide benefits for juvenile salmon. In particular,

- Determine if and how the benefits of restoration are being affected by ecological interactions (e.g., competition, predation, habitat modification) between salmon populations and native species (including fish and birds).
- Determine if and how non-native species may be affecting benefits of restoration.

  Given the level of effort devoted to implementing CEERP, there is ample reason to ensure habitat restoration actions are not creating conditions that favor non-natives over native species, such as juvenile salmon. This issue concerns fish species, vegetation (especially RCG), and invertebrates.

***Recommendation**: Determine the relationships between restoring estuary habitat and the **spatial structure and diversity** of salmon populations emigrating through the estuary.*

This type of approach would integrate data from a number of different studies and can be population/ESU-specific. There are two major components to this recommendation:

- First, evaluate the effects of estuary restoration on two viable salmon population parameters: spatial structure and diversity (Fresh et al. 2005).
- Second, build off spatial structure and diversity, along with survival data, to develop population/ESU-specific life cycle models that include the estuary as a separate component of the models.

***Recommendation**: Assess the feasibility of determining the aggregate and separate effects of **anthropogenic development** on estuary ecosystem conditions.*

Major factors affecting LCRE ecosystems are flow regulation, diking, and land use. The ecological impacts of anthropogenic development, however, are not well understood. Therefore we make the following recommendations:

- Assess the technical feasibility of conducting an investigation of the ecological impacts of anthropogenic factors affecting the LCRE. Use the findings to enable managers to understand the ecological impacts of anthropogenic development in order to apply their understanding to future considerations for CEERP strategy.
- As a first step, conduct research to predict the evolution of wetland vegetation under selected scenarios for Columbia River flows and sea-level rise. The findings will help better manage CEERP and estuary actions in the face of uncertain future hydrologic conditions. Next, periodically perform a habitat change analysis (like Marcoe and Pilson 2017 and Ke et al. 2013) and a habitat connectivity analysis (like Appendix C) to track changes.
- Conduct studies to examine how human land use changes and ongoing urbanization in LCRE watersheds affect estuary habitats.

***Recommendation**: Continue to understand the **effects of climate change** scenarios on estuary habitat characteristics and salmon.*

Understanding potential climate change effects is critical to CEERP. We know that there will be changes in sea level, water temperature, and mainstem and tributary freshwater outflow that will affect ecological processes and the capacity and opportunity of restoring habitats to support juvenile salmon. While type and direction of changes are understood, the duration, magnitude and timing of changes is uncertain.

7.2.2 Programmatic Recommendations

The programmatic recommendations include aspects of restoration strategy and RME implementation (Table 7.2).

Table 7.2. Summary of the programmatic recommendations for CEERP.

SM2 Recommendation	Status (as of June 2018)
Continue the CEERP strategy of reconnecting wetland floodplain habitats to the mainstem estuary, and seek opportunities to maximize the effectiveness of this approach.	Ongoing CEERP strategy
Explore the feasibility of using dredged material placement to create new shallow-water and aquatic habitats.	Being considered by the Corps
Develop and apply methods to incorporate climate change scenarios into restoration strategy, planning, project design, and monitoring.	Some work is underway
Review and revise, as appropriate, the RME program for CEERP.	Not started
Perform focused investigations or experiments at selected restoration sites to test key uncertainties concerning restoration implementation.	One experiment is underway
Investigate new or emerging technologies for reducing RME costs, while increasing the quality of data and information supporting CEERP.	Some work is underway

***Recommendation**: Continue the CEERP strategy of **reconnecting wetland floodplain habitats** to the mainstem estuary, and seek opportunities to maximize the effectiveness of this approach.*

We recommend that CEERP continue its main strategy of restoring LCRE ecosystems by restoring hydrologic reconnection of tidal floodplain wetlands to the mainstem estuary. As we have noted, CEERP has made significant progress to date reconnecting tidal floodplain areas to the mainstem estuary (Section 2.3). The cumulative evidence from AEM projects in the LCRE shows that restoration actions generally are improving ecological processes in the estuary, although results are variable. These improvements support and benefit juvenile salmon as well as number of other fish and wildlife species that rely on the LCRE. Furthermore, an important consideration for CEERP restoration strategy associated with reconnecting wetlands is system- and landscape-scale aspects. We recognize that restoration will always have an element of opportunism because of land availability. However, applying principles of landscape ecology and system resiliency in restoration strategy will add rigor to the program; i.e., CEERP managers should continue to support integration of landscape principles and implementation forecasting into the program.

***Recommendation**: Investigate use of **dredged material placement** to create new shallow-water and aquatic habitats.*

We recommend that CEERP investigate the efficacy of using dredged material as a CEERP strategy. While reconnection of wetland floodplain habitats to the mainstem estuary has been the primary focal point of CEERP, this strategy is limited by land availability. The use of dredge material placement to create habitat provides a possible additional restoration tool and may result in additional opportunities to create positive ecological benefits in the LCRE. Some evidence in the LCRE suggests dredge material placement can naturally develop through time into marsh habitats (PCTA 2009). Diefenderfer et al. (2013a) found that, compared to other disturbance categories, dredged material placement sites had shorter distances to the main channel (<1,000 m), lower elevations, higher proportions of low marsh, lower total organic carbon, and relatively high proportions of native plant cover. Another opportunity is to use dredge material to increase the elevation of diked and deeply subsided floodplain or wetland habitat. Because of the uncertainty associated with use of dredge material to create habitat, our recommendation is to focus on researching the efficacy of dredge material placement as a tool for habitat creation and enhancement in the LCRE.

***Recommendation**: Develop and apply methods to incorporate **climate change** scenarios into restoration strategy, planning, project design, and monitoring.*

We recommend that CEERP continue to incorporate climate change into its program, specifically within restoration strategies. Because there is uncertainty regarding the specific changes in habitat conditions (e.g., amount of sea-level rise, changes in local and mainstem flows, etc.), the general approach to incorporating climate change should be to enhance the resilience of the system. This type of approach would simultaneously support a strategy of increasing life history diversity and resilience of salmon, as recommended by Bottom et al. (2005). Ongoing work aimed at predicting wetland evolution under various flow scenarios for the Columbia River would be applicable here. Also, CEERP could incorporate guidance from Puget Sound (PSP 2017) and the Corps for the Columbia River (USACE 2015). This guidance could be annually reviewed and modified as appropriate and incorporated into annual CEERP Restoration and Monitoring Plans.

***Recommendation**: Review and revise, as appropriate, the **RME program** for CEERP.*

The existing RME program has substantially contributed to the state of science in the LCRE. A strong RME program that evaluates restoration effectiveness, especially benefits to salmon, at site, landscape/reach, and system scales is the foundation of a successful CEERP. Relevant programmatic considerations include a comprehensive review and evaluation of the current monitoring program and integration of estuary and ocean monitoring. The general RME plan for the estuary was developed a decade ago (Johnson et al. 2008) and has been implemented since then as part of the 2008 Biological Opinion of FCRPS operations (NMFS 2008). The Programmatic AEMR Plan (BPA and Corps 2017a) is more recent, but based on experience from analyzing and synthesizing data for SM2, it should be revised. A comprehensive review of status and trends monitoring is also warranted. The major focus of these reviews should be to determine whether these programs are meeting the needs of CEERP and whether program refinement would add value and increase the collective understanding of restoration effectiveness and the LCRE ecosystem. The revised RME program should include post-construction compilation of AEMR results from restoration projects that the ERTG reviews, scores, and documents in SECs.

***Recommendation**: Perform focused **investigations or experiments** at selected restoration sites to test key uncertainties concerning restoration implementation.*

While it was beyond the scope of SM2 (and our expertise) to offer specific recommendations or best practices for restoration project design, we identified some important uncertainties in restoration project design (Section 5.4). These uncertainties could be addressed with a focused investigative or experimental research approach. As a tactic for addressing these uncertainties, we recommend that CEERP consider applying focused investigative or experimental approaches at selected restoration sites. While the purpose of the actions at these sites would still be restoration, we recommend they be designed to acquire information about key uncertainties. For example, these uncertainties include RCG control. Restoration projects often include control of RCG using methods such as scrape-down, plantings, and herbicides, but it is clear what the most effective approach is in the long term. Another uncertainty concerns floodplain lakes. Reconnecting floodplain lakes to the mainstem estuary is a potential restoration activity, but a major issue is how many fish will access the lakes through new reconnections and whether the full floodplain lake area contributes to salmonid habitat versus the perimeter or edge habitats. Another issue for floodplain lake restoration could be the presence of non-native piscivores. Finally, the considerable uncertainty about the use of LWD in restoration projects should be the subject of focused investigation.

***Recommendation**: Investigate **new or emerging technologies** for reducing RME costs, while increasing the quality of data and information supporting CEERP.*

Since CEERP's inception, technology development has contributed to the success of the program (see Appendix H, New Techniques and Resources). Starting with the review and revision of the RME program (mentioned above) to identify priority monitoring and research needs, we recommend white paper(s) be developed pairing RME applications with potential new or emerging technologies. Examples of new or emerging technologies that could be considered for further development for CEERP RME include unmanned aerial vehicles and application of unobtrusive means to sample fish.

7.3 Closing

A CEERP Synthesis Memo provides an opportunity to look back at previous program documents and reflect on their relevancy today. BPA and Corps (2012) explained the foundation of CEERP's ecosystem restoration strategy being on basic principles of ecological science. They concurred with the National Research Council (NRC 1992, pp. 347–348) who said, "Wherever possible...restoration of aquatic resources...should not be made on a small-scale, short-term, site-by-site basis, but should instead be made to promote the long-term sustainability of all aquatic resources in the landscape." Ecological science, as applied in the CEERP's restoration strategy, includes principles worth revisiting in light of SM2. The italicized statements that follow are from the 2012 CEERP Strategy Report (BPA and Corps 2012), which contains the definitions of key terms. Pertinent findings for each principle from SM2 or the LCRE literature follow.

Reestablishment of natural controlling factors is required to build and maintain ecosystem structures, processes, and functions that support juvenile salmon. AEM data on WSE, sediment accretion, and channel cross sections indicate natural controlling factors are being reestablished. Restoring wetlands are trending toward more native plant species composition. Restoring wetlands are producing prey that are consumed onsite. Offsite, juvenile salmon are eating insects produced in wetlands.

Returning the LCRE ecosystem to a less altered state is desirable. The historical condition of the LCRE has been altered by agricultural and industrial development; the current status of the estuary is not entirely desirable from an ecological point of view. The habitat change analysis by Marcoe and Pilson (2017) quantified the habitat types that have been most impacted, i.e., lost to development. SM2 provides a recommendation for tracking trends in estuary status to inform CEERP management.

The success of a restoration project will vary depending on the level of disturbance (anthropomorphic or natural) of the site and the landscape within which the site resides (NRC 1992). The AEMR data presented in SM2 are not extensive enough to distinguish results based on the level of disturbance at the site and its landscape to begin with. In fact, disturbance levels are not determined *a priori* as part of CEERP process, except to the degree that a site is disconnected from the mainstem estuary and that it was created historically by dredged material placement.

Landscape ecology concepts such as minimum area, shape, corridors, and buffers are applicable to ecosystem restoration. The related concepts of habitat size, accessibility, and capacity from Simenstad and Cordell (2000) are employed by the ERTG during scoring of proposed restoration projects (ERTG 2010). All the previous concepts are used by CEERP practitioners and managers to develop and design restoration projects. The ERTG is working to identify, explain, and justify additional science-based landscape concepts, principles, and uncertainties for CEERP strategy.

In closing, SM2 is an important component of CEERP's adaptive management process. This memo provides managers, policy-makers, restoration sponsors, and others with a comprehensive, scientific understanding of the state of the science to inform program strategy and decision-making in the near and long terms.

8.0 REFERENCES

Adamus PR. 2005. *Science Review and Data Analysis for Tidal Wetlands of the Oregon Coast. Part 2 of a Hydrogeomorphic Guidebook*. Report to Coos Watershed Association, U.S. Environmental Protection Agency and Oregon Department of State Lands, Salem, Oregon.

Amoros C and G Bornette. 2002. "Connectivity and Biocomplexity in Waterbodies of Riverine Floodplains." *Freshwater Biology* 47:761–776.

Anderson GO. 2006. "Variations in Estuarine Life History Diversity of Juvenile Chinook Salmon Based on Stable Isotope Analysis of Food Web Linkages." Masters of Science Thesis, University of Washington.

Armitage PD. 1995. *The Chironomidae: Biology and Ecology of Non-biting Midges*. "Behaviour and Ecology of Adults," pp 194-224. Editors PD Armitage, PS Cranston, and LCV Pinde. Chapman & Hall, London. doi: 10.1007/978-94-011-0715-0.

Armstrong JL, KW Myers, DA Beauchamp, ND Davis, RV Walker, and JL Boldt. 2008. "Interannual and Spatial Feeding Patterns of Hatchery and Wild Juvenile Pink Salmon in the Gulf of Alaska in Years of Low and High Survival." *Transactions of the American Fisheries Society* 137:1299–1316.

Arnold TW. 2010. "Uninformative Parameters and Model Selection using Akaikes Information Criterion." *Journal of Wildlife Management* 74(6):1175–1178.

Bates D, M Maechler, B Bolker, and S Walker. 2015. "Fitting Linear Mixed-Effects Models Using lme4." *Journal of Statistical Software*, 67(1):1–48. doi:10.18637/jss.v067.i01.

Batzer, DA, R Cooper, and SA Wissinger. 2014. "Wetland Animal Ecology." In: *Ecology of Freshwater and Estuarine Wetlands*. Second Edition. Edited by DP Batzer and RR Scharitz.

Beck MW, KL Heck, KW Able, DL Childers, DB Eggleston, BM Gillanders, B Halpern, CG Hays, K Hoshino, TJ Minello, RJ Orth, PF Sheridan, and MP Weinstein. 2001. "The Identification, Conservation and Management of Estuarine and Marine Nurseries for Fish and Invertebrates." *BioScience* 51:633–641.

Beechie T, H Imaki, J Greene, A Wade, H Wu, G Pess, P Roni, J Kimball, J Standford, P Kiffney, and N Mantua. 2013. "Restoring Salmon Habitat for a Changing Climate." *River Research and Applications* 29:939–960. doi.org/10.1002/rra.2590.

Bilton HT, DF Alderdice, and JT Schnute. 1982. "Influence of Time and Size at Release of Juvenile Coho Salmon (*Oncorhynchus kisutch*) on Returns at Maturity." *Canadian Journal of Fisheries and Aquatic Sciences* 39(3):426–447. doi.org/10.1139/f82–060.

Bollens S, G Rollwagen-Bollens, E Dexter, W Hassett, J Adams, A Bowen, J Zimmerman, J Cordell, O Kalata, and T Counihan. 2016. "Invasive Species and Plankton Dynamics of the Columbia River Estuary." Columbia River Estuary Conference 2016, May 24–26 Astoria, Oregon. doi: 10.3391/ai.2012.7.1.011.

Borde AB and HL Diefenderfer. 2017. "Predicting Wetland Evolution under Hydrologic Change: Research Plan for the Lower Columbia River and Estuary." Appendix B, editor GE Johnson. *Scientific Support for the Columbia Estuary Ecosystem Restoration Program, FY 2017 Annual Report*. PNNL-27016, final report prepared for the Bonneville Power Administration, Portland, Oregon by the Pacific Northwest National Laboratory, Sequim, Washington.

Borde AB, VI Cullinan, HL Diefenderfer, RM Thom, RM Kaufmann, J Sagar, and C Corbett. 2012a. *Lower Columbia River and Estuary Ecosystem Restoration Program Reference Site Study: 2011 Restoration Analysis*. PNNL-21433, prepared for the Lower Columbia River Estuary Partnership by Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, Washington. Available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21433.pdf.

Borde AB, RM Kaufmann, VI Cullinan, SA Zimmerman, and CL Wright. 2012b. *Lower Columbia River and Estuary Habitat Monitoring 2011 Annual Report*. PNNL-21128, prepared for the Lower Columbia River Estuary Partnership by Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, Washington.

Borde A, H Diefenderfer, D Jay, S Zimmerman, R Thom, A Hanson, and C Corbett. 2015. "Tidal wetland response to changes in inundation patterns in the lower Columbia River and estuary." Presentation at the *Conference of the Coastal and Estuarine Research Federation*, November 8–12, Portland, Oregon. http://www.erf.org/cerf2015.

Borde A, A Coleman, and S Zimmerman. 2016. "Pilot Application of the LCRE Habitat Connectivity Index." Appendix B, editor GE Johnson. *Scientific Support for the Columbia Estuary Ecosystem Restoration Program*, FY2016 Annual Report. PNNL-25709, final report prepared for the Bonneville Power Administration, Portland, Oregon by the Pacific Northwest National Laboratory, Sequim, Washington.

Borde AB, HL Diefenderfer, CM Gunn, and E Whattam. 2017. "Distribution of Large Wood on Selected Tidal Wetlands in the Lower Columbia River and Estuary." Appendix A, editor GE Johnson. *Scientific Support for the Columbia Estuary Ecosystem Restoration Program, FY 2017 Annual Report*. PNNL-27016, final report prepared for the Bonneville Power Administration, Portland, Oregon by the Pacific Northwest National Laboratory, Sequim, Washington.

Borde AB, HL Diefenderfer, VI Cullinan, SA Zimmerman, CA Corbett, and RM Thom. In Preparation. *Spatial Distribution and Temporal Variation of Tidal Wetland Plant Communities in the Columbia River Estuary. Diversity and Distributions*.

Bottom DL, CA Simenstad, J Burke, AM Baptista, DA Jay, KK Jones, E Casillas, and M Schiewe. 2005. *Salmon at River's End: the Role of the Estuary in the Decline and Recovery of Columbia River Salmon*. NOAA Fisheries, Northwest Fisheries Science Center, Seattle, Washington. NOAA Technical Memorandum NMFS-NWFSC-68, p. 246.

Bottom DL, KK Jones, CA Simenstad, and CL Smith. 2009. "Reconnecting Social and Ecological Resilience in Salmon Ecosystems." *Ecology and Society* 14(1):5. [online] available at: http://www.ecologyandsociety.org/vol14/iss1/art5/.

Bottom DL, A Baptista, J Burke, L Campbell, E Casillas, B Craig, C Eaton, S Hinton, K Jacobson, D Jay, MA Lott, R McNatt, GC Roegner, S Schrode, CA Simenstad, S Spilseth, V Stamatiou, D Teel, and JE Zamon. 2011a. *Salmon Life Histories, Habitat, and Food Webs in the Columbia River Estuary: An Overview of Research Results, 2002–2006*. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers and Bonneville Power Administration, Portland, Oregon.

Bottom DL, A Baptista, J Burke, L Campbell, E Casillas, S Hinton, DA Jay M Austill Lott, G McCabe, R McNatt, M Ramirex, GC Roegner, CA Simenstad, S Spilseth, L Stamatiou, D Teel, and JE Zamon. 2011b. *Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary Final Report 2002-2008*. Fish Ecology Division, Northwest Fisheries Science Center, U.S. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington.

Bouwes N, N Weber, CE Jordan, WC Saunders, IA Tattam, C Volk, JM Wheaton, and MM Pollock. 2016. "Ecosystem Experiment Reveals Benefits of Natural and Simulated Beaver Dams to a Threatened Population of Steelhead (*Oncorhynchus mykiss*)." *Nature Scientific Reports* 6:28581. https://doi: 10.1038/srep28581.

BPA and Corps (Bonneville Power Administration and U.S. Army Corps of Engineers). 2012. *Columbia Estuary Ecosystem Restoration Program: 2012 Strategy Report*. Final report, prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

BPA and Corps (Bonneville Power Administration and U.S. Army Corps of Engineers). 2014. *Columbia Estuary Ecosystem Restoration Program: 2014 Restoration and Monitoring Plan*. Final report, prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Documents.

BPA and Corps (Bonneville Power Administration and U.S. Army Corps of Engineers). 2015. *Columbia Estuary Ecosystem Restoration Program: 2015 Restoration and Monitoring Plan*. Final report, prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Documents.

BPA and Corps (Bonneville Power Administration and U.S. Army Corps of Engineers). 2016. *Columbia Estuary Ecosystem Restoration Program: 2016 Restoration and Monitoring Plan*. Final report, prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Documents.

BPA and Corps (Bonneville Power Administration and U.S. Army Corps of Engineers). 2017a. *Columbia Estuary Ecosystem Restoration Program: Programmatic Plan for Action Effectiveness Monitoring and Research*. Prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Documents.

BPA and Corps (Bonneville Power Administration and U.S. Army Corps of Engineers). 2017b. *Columbia Estuary Ecosystem Restoration Program: 2017 Restoration and Monitoring Plan*. Final report, prepared by the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon. Available at: https://www.cbfish.org/EstuaryAction.mvc/Documents.

Braga RR, H Bornatowski, and JRS Vitule. 2012. "Erratum to: Feeding Eecology of Fishes: An Overview of Worldwide Publications." *Reviews in Fish Biology and Fisheries* 22(4):931–932. doi:10.1007/s11160-012-9273-7.

Breckenridge JK, SM Bollens, G Rollwagen-Bollens, and GC Roegner. 2015. "Plankton Assemblage Variability in a River-dominated Temperate Estuary during Late Spring (high-flow) and Late Summer (low-flow) Periods." *Estuaries and Coasts* 38:93–103.

Brett JR. 1979. "Environmental Factors and Growth." *Fish Physiology* 8:599–675.

Buenau KE, NK Sather, AB Borde, and GE Johnson. 2016a. *Assessment of Data Availability for Salmon Estuarine Habitat Index (SEHI) Modeling*. PNNL-25853, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon by the Pacific Northwest National Laboratory, Richland, Washington.

Buenau K, H Diefenderfer, L Aston, A Borde, J Brandenberger, R Kropp, N Sather, C Woodley, and D Woodruff. 2016b. "Literature Review and Conceptual Model of the Habitat Benefits to Salmon from the LCRE Floodplain Wetlands: Component Descriptions: Chapter 2." In *Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, Study Completion Report*, edited by HL Diefenderfer and GE Johnson. PNNL-25728, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon by the Pacific Northwest National Laboratory, Richland, Washington.

Bürkner P-C. 2016. "brms: An R Package for Bayesian Multilevel Models using Stan." *Journal of Statistical Software* 80(1):1–28.

Burnham KP and DR Anderson. 2003. *Model Selection and Multimodel Inference a Practical Information-theoretic Approach*. Springer Science & Business Media, New York.

Cade BS. 2015. "Model averaging and Muddled Multimodel Inferences." *Ecology* 96(9):2370–82.

Cahoon DR, PE Marin, BK Black, and JC Lynch. 2000. "A Method for Measuring Vertical Accretion, Elevation, and Compaction of Soft, Shallow-Water Sediments." *Journal of Sedimentary Research* 70(5):1250–53. https://doi.org/10.1306/020800701250.

Callaway JC, RD DeLaune, and WH Patrick, Jr. 1997. "Sediment Accretion Rates from Four Coastal Wetlands Along the Gulf of Mexico." *Journal of Coastal Research* 13(1):181–191. http://www.jstor.org/stable/4298603.

Campeau S, HR Murkin, and RD Titman. 1994. "Relative Importance of Algae and Emergent Plant Litter to Freshwater Marsh Invertebrates." *Canadian Journal of Fisheries and Aquatic Sciences* 51:681–692.

Caraco N and JJ Cole. 2004. "When terrestrial organic matter is sent down the river: the importance of allochthonous carbon inputs to the metabolism of lakes and rivers." In *Food Webs at the Landscape Level*, editors GA Polis, ME Power, and GR Huxel, University of Chicago Press, Chicago, Illinois.

Carey MP, BL Sanderson, KA Barnas, and JD Olden. 2012. "Native Invaders – Challenges for Science, Management, Policy, and Society." *Frontiers in Ecology and the Envirnment* 10(7):373–381. doi:10.1890/110060.

CEQ (Council on Environmental Quality). 1997. *Considering Cumulative Effects Under the National Environmental Policy Act*. Executive Office of the President, Washington, D.C. https://www.energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/G-CEQ-ConsidCumulEffects.pdf.

Chamberlain SA and E Szöcs. 2013. "Taxize: Taxonomic Search and Retrieval in R." *F1000 Research* 2:191. http://f1000research.com/articles/2-191/v2.

Claiborne AM, JP Fisher, SA Hayes, and RL Emmett. 2011. "Size at Release, Size-Selective Mortality, and Age of Maturity of Willamette River Hatchery Yearling Chinook Salmon." *Transactions of the American Fisheries Society* 140:1135–1144.

Chittaro P, L Johnson, D Teel, P Moran, S Sol, K Macneale K, and R Zable. 2018. "Variability in the performance of juvenile Chinook salmon is explained primarily by when and where they resided in estuarine habitats." *Ecology of Freshwater Fish*. DOI: 10.1111/eff.12398.

Coleman AM, HL Diefenderfer, DL Ward, and AB Borde. 2015. “A Spatially Based Area-time Inundation Index Model Developed to Assess Habitat Opportunity in Tidal-fluvial Wetlands and Restoration Sites.” *Ecological Engineering* 82:624–642.

Coleman A, TE Seiple, GE Johnson, NK Sather, AB Borde, HE Stewart, and SA Zimmerman. 2018. *Oncor: A Research and Monitoring Information System for the Columbia Estuary Ecosystem Restoration Program*. Completion report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, PNNL-27481, Pacific Northwest National Laboratory, Richland, Washington.

Corbett C, D Tomasko, C Loeb, S Crooks, and C Collins. 2015. “Introduction to restoration for a changing climate session.” Presentation at the Conference of the Coastal and Estuarine Research Federation, November 8-12, Portland, Oregon. http://www.erf.org/cerf2015.

Cordell JR, JD Toft, A Gray, GT Ruggerone, and M Cooksey. 2011. “Functions of restored wetlands for juvenile salmon in an industrialized estuary.” *Ecological Engineering* 37:343–353.

Coutant CC. 1977. “Compilation of Temperature Preference Data.” *Journal of the Fisheries Board of Canada* 34:739–745.

Craft CB, ED Seneca, and SW Broome. 1993. “Vertical Accretion in Microtidal Regularly and Irregularly Flooded Estuarine Marshes.” *Estuarine Coastal Shelf Science* 37:371–386.

Cranston PS. 1995. “Introduction to the Chironomidae.” The *Chironomidae: The Biology and Ecology of Non-biting Midges*, edited by PD Armitage, PS Cranston, and LCV Pinder, 1–7. Chapman & Hall, London. doi: 10.1007/978-94-011-0715-0.

CREDDP (Columbia River Estuary Data Development Program). 1984a. Index to CREDDP Data. Compiled by HT Mercier, edited by S. Bell. Astoria, Oregon.

CREDDP (Columbia River Estuary Data Development Program). 1984b. Abstracts of Major CREDDP Publications. Compiled by D Fox. Astoria, Oregon.

CREST (Columbia River Estuary Study Taskforce). 2012. *Habitat, Salmon, and Salmon Prey Effectiveness Monitoring. Ft. Clatsop South Slough & Alder Creek Synthesis Report 2007-2011*. Prepared for the Lower Columbia River Estuary Partnership, Astoria, Oregon.

Crozier LG, AP Hendry, PW Lawson, TP Quinn, NJ Mantua, J Battin, RG Shaw, and RB Huey. 2008a. “Potential Responses to Climate Change in Organisms with Complex Life Histories: Evolution and Plasticity in Pacific Salmon.” *Evolutionary Applications* 1:252–270.

Crozier LG, RW Zabel, and AF Hamle. 2008b. “Predicting Differential Effects of Climate Change at the Population Level with Life-cycle Models of Spring Chinook Salmon.” *Global Change Biology* 14:236–249.

Cummins KW and JC Wuycheck. 1971. “Calorific Equivalents for Investigations in Ecological Energetics.” *Mitteilungen Internationale Vereiningung fuer Theoretische und Angewandte Limnologie* 18:1-151.

Daly EA, JA Scheurer, RD Brodeur, LA Weitkamp, BR Beckman, and JA Miller. 2014. “Juvenile Steelhead Distribution, Migration, Feeding, and Growth in the Columbia River Estuary, Plume, and Coastal Waters.” *Marine and Coastal Fisheries* 6(1):62–80. doi:10.1080/19425120.2013.869284.

Daly EA, RD Brodeu, and LA Weitkamp. 2009. "Ontogenetic Shifts in Diets of Juvenile and Subadult Coho (*Oncorhynchus kisutch*) and Chinook Salmon (*O tshawytscha*) in Coastal Marine Waters: Important for Marine Survival?" *Transactions of the American Fisheries Society* 138(6):1420–1438. https://doi.org/10.1577/T08-226.1.

Daly EA, RD Brodeur, JP Fisher, LA Weitkamp, DJ Teel, and BR Beckman. 2012. "Spatial and Trophic Overlap of Marked and Unmarked Columbia River Basin Spring Chinook Salmon during Early Marine residence with Implications for Competition between Hatchery and Naturally Produced Fish." *Environmental Biology of Fishes* 94(1):117–134.

David AT, CA Simenstad, JR Cordell, JD Toft, CS Ellings, A Gray, and HB Berge. 2016. "Wetland Loss, Juvenile Salmon Foraging Performance, and Density Dependence in Pacific Northwest Estuaries." *Estuaries Coasts* 39:767–780.

David AT, CS Ellings, I Woo, CA Simenstad, JY Takekawa, KL Turner, AL Smith, and JE Takekawa. 2014. "Foraging and Growth Potential of Juvenile Chinook Salmon after Tidal Restoration of a Large River Delta." *Transactions of the American Fisheries Society* 143(6):1515–1529. https://doi.org/10.1080/00028487.2014.945663.

Davis JS. 1978. "Diel Activity of Benthic Crustaceans in the Columbia River Estuary." Master of Science, p. 170, Oregon State University.

Dawley EM, RD Ledgerwood, TH Blahm, CW Sims, JT Durkin, RA Kirn, AE Rankis, GCE Monan, and FJ Ossiander. 1986. *Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966–1983*. Final Report to the Bonneville Power Administration, Project 81-102, Portland, Oregon.

Diefenderfer HL and DR Montgomery. 2009. "Pool Spacing, Channel Morphology, and the Restoration of Tidal Forested Wetlands of the Columbia River, U.S.A." *Restoration Ecology* 17:158–168.

Diefenderfer H, A Coleman, A Borde, and I Sinks. 2008. "Hydraulic Geometry and Microtopography of Tidal Freshwater Forested Wetlands and Implications for Restoration, Columbia River, U.S.A." *Ecohydrology & Hydrobiology* 8(2):339–61. https://doi.org/10.2478/v10104-009-0027-7.

Diefenderfer HL, GE Johnson, NK Sather, JR Skalski, EM Dawley, and AM Coleman. 2010. *Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, Annual Report 2009*. PNNL-19410, prepared by the Pacific Northwest National Laboratory, Richland, Washington, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Diefenderfer HL, RM Thom, GE Johnson, JR Skalski, KA Vogt, BD Ebberts, GC Roegner, and EM Dawley. 2011. "A Levels-of-evidence Approach for Assessing Cumulative Ecosystem Response to Estuary and River Restoration Programs." *Ecological Restoration* 29:111–132.

Diefenderfer HL, GE Johnson, JR Skalski, SA Breithaupt, and AM Coleman. 2012. Application of the diminishing returns concept in the hydroecologic restoration of riverscapes. *Landscape Ecology* 27:671–682.

Diefenderfer HL, AB Borde, and VI Cullinan. 2013a. *A Synthesis of Environmental and Plant Community Data for Tidal Wetland Restoration Planning in the Lower Columbia River and Estuary*. PNNL-22667, prepared by the Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, Washington, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Diefenderfer HL, GE Johnson, RM Thom, AB Borde, CM Woodley, LA Weitkamp, KE Buenau, and RK Kropp. 2013b. *An Evidence-Based Evaluation of the Cumulative Effects of Tidal Freshwater and Estuarine Ecosystem Restoration on Endangered Juvenile Salmon in the Columbia River*. PNNL-23037. Final report prepared for the U.S. Army Corps of Engineers Portland District, Portland, Oregon by Pacific Northwest National Laboratory and NOAA Fisheries. Richland, Washington.

Diefenderfer HL, AB Borde, VI Cullinan, LL Johnson, and GC Roegner. 2014. “Exploring the Ecosystem and Salmon Habitat Functions of Large-River Floodplain Marshes with Altered Disturbance Regimes.” Presented at the Columbia River Estuary Workshop, May 2014, Astoria, Oregon. Available: http://www.estuarypartnership.org/sites/default/files/resource_files/Diefenderfer_CREW_2014.pdf.

Diefenderfer HL, GE Johnson, RM Thom, KE Buenau, LA Weitkamp, CM Woodley, AB Borde, and RK Kropp. 2016a. “Evidence-based Evaluation of the Cumulative Effects of Ecosystem Restoration.” *Ecosphere* 7(3):e01242. 10.1002/ecs2.1242.

Diefenderfer HL, AB Borde, IA Sinks, VI Cullinan, and SA Zimmerman. 2016b. *Columbia Estuary Ecosystem Restoration Program: Restoration Design Challenges for Topographic Mounds, Channel Outlets, and Reed Canarygrass*. PNNL-24676. Final report prepared for the Bonneville Power Administration, Portland, Oregon by the Pacific Northwest National Laboratory, Sequim, Washington and Columbia Land Trust, Vancouver, Washington.

Diefenderfer HL, AB Borde, and others. In Preparation. “An Aquatic Habitat Connectivity Index for Migratory Species on River Floodplains.” *Landscape Ecology*.

Diefenderfer HL et al. In Preparation. “Ecological Responses to Reconnections on a Coastal River Floodplain: Hydrologic Regime, Geomorphology, and Plant Communities.” *Ecological Monographs*.

Duffy EJ, DA Beauchamp, RM Sweeting, RJ Beamish, and JS Brennan. 2010. “Ontogenetic shifts of Juvenile Chinook Salmon in Nearshore and Offshore Habitats of Puget Sound.” *Transactions of the American Fisheries Society* 139:803–823.

Dyer KR and RJ Orth (eds.). 1994. “Changes in Fluxes in Estuaries: Implications from Science to Management.” In —*Proceedings of ECSA22/ERF Symposium*, 13-18 September 1992, Institute of Marine Studies, University of Plymouth. Olsen & Olsen, Fredensborg.

Eaton CD. 2010. “Resource Partitioning, Habitat Connectivity, and Resulting Foraging Variation Among Salmonids in the Estuarine Habitat Mosaic.” Masters of Science Thesis, University of Washington.

Ebberts BD, BD Zelinsky, JP Karnezis, CA Studebaker, S Lopez-Johnston, AM Creason, L Krasnow, GE Johnson, and RM Thom. 2017. “Implementing and Institutionalizing Adaptive Management of the Columbia Estuary Ecosystem Restoration Program.” *Restoration Ecology*. Published online: doi: 10.1111/rec.12562.

Ennis S. 2009. “Effects of Tide Gate Replacement on Water Temperature ina Freshwater Slough in the Columbia River Estuary.” Master of Environmental Management Project Reports. 12. https://pdxscholar.library.pdx.edu/mem_gradprojects/12.

ERTG (Expert Regional Technical Group). 2010. *Scoring Criteria*. ERTG 2010-02, available from Bonneville Power Administration or the U.S. Army Corps of Engineers, Portland, Oregon.

ERTG (Expert Regional Technical Group). 2012. *Guidance on Estuary Module Actions and Subactions Relevant to the ERTG Process*. ERTG 2011-02, Rev. 1, prepared for the Bonneville Power Administration, U.S. Army Corps of Engineers, and NOAA Fisheries. Portland, Oregon.

ERTG (Expert Regional Technical Group). 2013. *ERTG Analysis of Water Levels for Site Delineation in Tidal-Dominated Regions*. ERTG 2012-01, Rev. 1, prepared for the Bonneville Power Administration, U.S. Army Corps of Engineers, and NOAA Fisheries. Portland, Oregon. Available from https://www.cbfish.org/EstuaryAction.mvc/Documents.

ERTG (Expert Regional Technical Group). 2016. *Large Wood in Estuaries: Structure, Hydrologic and Ecological Functions, and Influence on Fish Survival*. ERTG 2016-01, prepared for the Bonneville Power Administration, U.S. Army Corps of Engineers, and NOAA Fisheries. Portland, Oregon. Available from https://www.cbfish.org/EstuaryAction.mvc/Documents.

Fernandes R, LC Gomes, FM Pelicice, and AA Agostinho. 2009. "Temporal Organization of Fish Assemblages in Floodplain Lagoons: The Role of Hydrological Connectivity." *Environmental Biology of Fish* 85:99–108.

Ferrington LC. 2008. "Global diversity of non-biting midges (*Chironomidae; Insecta-Diptera*) in Freshwater." *Hydrobiologia* 595:447–455. doi: 10.1007/s10750-007-9130-1.

Ferrington LC, MB Berg, and WP Coffman. 2008. "Chironomidae." *An Introduction to the Aquatic Insects of North America, 4th edn.*, Merritt RW, KW Cummins, and MB Berg (eds.). Kendall Hunt, Dubuque.

Flitcroft R, K Burnett, and K Christiansen. 2013. "A Simple Model that Identifies Potential Effects of Sea-Level Rise on Estuarine and Estuary-Ecotone Habitat Locations for Salmonids in Oregon, USA." *Environmental Management* 52(1):196–208.

French PW. 2006." Managed realignment – The developing story of a comparatively new approach to soft engineering." *Estuarine, Coastal and Shelf Science* 67:409–423.

Fresh KL. 1997. "The Role of Competition and Predation in the Decline of Pacific Salmon and Steelhead." In *Pacific salmon and their ecosystems: Status and future options*, pp 245–276. Editors DJ Stouder, P Bisson, R Naiman. Chapman and Hall, New York.

Fresh KL, E Casillas, LL Johnson, and DL Bottom. 2005. "Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability." NOAA Technical Memorandum NMFS-NWFSC-69. U.S. Department of Commerce.

Gelman A and DB Rubin. 1992. "Inference from Iterative Simulation Using Multiple Sequences." *Statistical Science* 7:457–511.

Gray A, CA Simenstad, DL Bottom, and TJ Cornwell. 2002. "Contrasting Functional Performance of Juvenile Salmon Habitat in Recovering Wetlands of the Salmon River Estuary, Oregon, U.S.A." *Restoration Ecology* 10(3):514–526. doi: 10.1046/j.1526-100X.2002.01039.x

Griffis R, B Helmuth, J Howard, and L Petes. 2013. "Sustaining the Assessment of Climate Impacts on Oceans and Marine Resources." *Oceans and Marine Resources in a Changing Climate. NCA Regional Input Reports*. Editors R Griffis and J Howard. Island Press, Washington, D.C. https://doi.org/10.5822/978-1-61091-480-2_7.

Griffiths NA, JL Tank, SS Roley, and ML Stephen. 2012. "Decomposition of Maize Leaves and Grasses in Restored Agricultural Streams." *Freshwater Science* 31(3):848–864.

Hanson AC, AB Borde, LL Johnson, TD Peterson, JA Needoba, J Cordell, M Ramirez, SA Zimmerman, PM Chittaro, SY Sol, DJ Teel, P Moran, GM Ylitalo, D Lomax, CE Tausz, M Schwartz, HL Diefenderfer, and CA Corbett. 2016a. *Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 11* (October 1, 2014 to September 30, 2015). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration. Available from the Lower Columbia Estuary Partnership, Portland, Oregon.

Hanson AC, AB Borde, JR Cordell, M Ramirez, V Cullinan, J Sagar, EE Morgan, J Toft, M Schwartz, CA Corbett, and RM Thom. 2016b. *Lower Columbia River Reed Canarygrass Macroinvertebrate and Macrodetritus Production Study*. Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration. Available from the Lower Columbia Estuary Partnership, Portland, Oregon.

Hanson AC, AB Borde, LL Johnson, TD Peterson, JA Needoba, J Cordell, M Ramirez, SA Zimmerman, PM Chittaro, SY Sol, DJ Teel, P Moran, GM Ylitalo, D Lomax, R McNatt, VI Cullinan, CE Tausz, M Schwartz, C Gunn, HL Diefenderfer, and CA Corbett. 2017. *Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 12 (October 1, 2015 to September 30, 2016)*. Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration. Available from the Lower Columbia Estuary Partnership, Portland, Oregon.

Harnish R, G Johnson, G McMichael, M Hughes, and B Ebberts. 2012. "Effect of Migration Pathway on Travel Time and Survival of Acoustic-Tagged Juvenile Salmonids in the Columbia River Estuary." *Transactions of the American Fisheries Society* 141:507–519.

Haskell CA and KF Tiffan. 2011. *Crims Island—Restoration and monitoring of juvenile salmon rearing habitat in the Columbia River Estuary, Oregon, 2004–10.* Scientific Investigations Report 2011–5022, U.S. Geological Survey, Seattle, Washington.

Haskell CA, KF Tiffan, and DW Rondorf. 2006. "Food Habits of Juvenile American Shad and Dynamics of Zooplankton in the Lower Columbia River." *Northwest Science* 80:47–64.

Healey MC. 1979. "Detritus and Juvenile Salmon Production in the Nanaimo Estuary: I. Production and Feeding Rates of Juvenile Chum Salmon (*Oncorhynchus keta*)." *Journal of the Fisheries Research Board of Canada* 36(5):488–496. doi:10.1139/f79-072.

Healey MC. 1982. *Juvenile Pacific Salmon in Estuaries: The Life Support System*. "Estuarine Comparisons." Editor VS Kennedy, pp. 315–341. New York: Academic Press.

Healey MC. 1991. *Life history of Chinook salmon* (Oncorhynchus tshawytscha). "Pacific Salmon Life Histories." Editors C Groot and L Margolis, pp. 313–393. University of British Columbia Press, Vancouver, B.C., Canada.

Healey MC. 2011. "The Cumulative Impacts of Climate Change on Frasier River Sockeye Salmon (*Oncorhynchus nerka*) and Implications for Management." *Canadian Journal of Fisheries Aquatic Sciences* 68:718–737.

Hill AB 1965. "The Environment and Disease: Association or Causation?" In —*Proceedings of the Royal Society of Medicine* 58:295–300.

Holsman KK, MD Scheuerell, E Buhle, and R Emmett. 2012. "Interacting Effects of Translocation, Artificial Propagation, and Environmental Conditions on the Marine Survival of Chinook Salmon from the Columbia River, Washington, U.S.A." *Conservation Biology* 26(5):912–922. doi: 10.1111/j.1523-1739.2012.01895.x.

Hood WG. 2012. "Beaver in Tidal Marshes: Dam Effects on Low-Tide Channel Pools and Fish Use of Estuarine Habitat." *Wetlands* 32(3):401. https://doi.org/10.1007/s13157-012-0294-8.

Hood WG. 2015. "Predicting the Number, Orientation, and Spacing of Dike Breaches for Tidal Marsh Restoration." *Ecological Engineering* 83:319–327.

Hood WG, EE Grossman, and C Veldhuisen. 2016. "Assessing Tidal Marsh Vulnerability to Sea-Level Rise in the Skagit Delta." *Northwest Science* 90:79–93.

Integrated Taxonomic Information System (ITIS). http://www.itis.gov/.

ISAB (Independent Scientific Advisory Board). 2007. *Climate Change Impacts on Columbia River Basin Fish and Wildlife*. ISAB 2007-2, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isab/isab2007-2/.

ISAB (Independent Scientific Advisory Board). 2011. *Columbia River Food Webs: Developing a Broader Scientific Foundation for Fish and Wildlife Restoration.* ISAB 2011-1, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isab/isab2011-1/.

ISAB (Independent Scientific Advisory Board). 2012. *Review of the Columbia Estuary Ecosystem Restoration Program: Evaluation of three draft documents: 2012 Synthesis Memorandum, 2013 Strategy Report, and 2013 Action Plan*. ISAB 2012-6, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isab/isab2012-6/.

ISAB (Independent Scientific Advisory Board). 2014. *Review of the Expert Regional Technical Group (ERTG) Process for Columbia River Estuary Habitat Restoration*. ISAB 2014-1, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isab/isab2014-1/.

ISAB (Independent Scientific Advisory Board). 2015. *Density Dependence and Its Implications for Fish Management and Restoration Programs in the Columbia River Basin*. ISAB 2015-1, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isab/isab2015-1/.

ISRP (Independent Scientific Review Panel). 2012. *ISRP Review of the Ocean Synthesis Report: The Marine Ecology of Juvenile Columbia River Basin Salmonids: A Synthesis of Research 1998-2011*. ISRP 2012-3, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isrp/isrp2012-3/.

ISRP (Independent Scientific Review Panel). 2013. *Final Report for the Geographic Review: Evaluation of Anadromous Fish Habitat Restoration Projects*. ISRP 2013-11, prepared for the Northwest Power and Conservation Council, Portland, Oregon. Available at: http://www.nwcouncil.org/fw/isrp/isrp2013-11/.

Jay DA and PK Naik. 2011. "Distinguishing Human and Climate Influences on Hydrological Disturbance Processes in the Columbia River, USA." *Hydrological Sciences Journal* 56(7):1186–1209.

Jay DA, K Leffler, HL Diefenderfer, and AB Borde. 2015. "Tidal-Fluvial and Estuarine Processes in the Lower Columbia River: I. Along-Channel Water Level Variations, Pacific Ocean to Bonneville Dam." *Estuaries and Coasts* 38(2):415–433. doi: 10.1007/s12237-014-9819-0.

Jay DA, AB Borde, and HL Diefenderfer. 2016. "Tidal-Fluvial and Estuarine Processes in the Lower Columbia River: II. Water Level Models, Floodplain Wetland Inundation, and System Zones." *Estuaries and Coasts* 39(5):1299–1324.

Johnson GE (ed.). 2016. *Scientific Support for the Columbia Estuary Ecosystem Restoration Program, FY2016 Annual Report*. PNNL-25709, final report prepared for the Bonneville Power Administration, Portland, Oregon by the Pacific Northwest National Laboratory, Sequim, Washington.

Johnson GE. 2017. *Scientific Support for the Columbia Estuary Ecosystem Restoration Program, FY 2017 Annual Report*. PNNL-27016, final report prepared for the Bonneville Power Administration, Portland, Oregon by the Pacific Northwest National Laboratory, Sequim, Washington.

Johnson GE and NK Sather. 2016. "Effectiveness of a Channel Habitat Reconnection in Tidal Freshwater of the Columbia River: Sandy River Delta." Presentation at Columbia River Estuary Conference, Astoria, Oregon, May 2016.

Johnson GE, NK Sather, AJ Storch, DJ Teel, JR Skalski, EM Dawley, AJ Bryson, GR Ploskey, C Mallette, TA Jones, AB Borde, SA Zimmerman, ES Van Dyke, DR Kuligowski, and KL Sobocinski. 2011. *Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats of the Lower Columbia River, 2007–2010*. PNNL-20083, Pacific Northwest National Laboratory, Richland, Washington.

Johnson GE, JR Skalski, and J Tagestad. 2012. "Statistical and Other Considerations for Restoration Action-Effectiveness Monitoring and Research." Pp. F.1-F.23, in *Evaluation of Cumulative Ecosystem Response to Restoration Projects in the Lower Columbia River and Estuary*, Johnson et al., PNNL-20296, final report prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Johnson GE, NK Sather, JR Skalski, and DJ Teel. 2014a. "Application of Diversity Indices to Quantify Early Life-History Diversity for Chinook Salmon." *Ecological Indicators* 38:179–180.

Johnson G, C Studebaker, J Doumbia, M Schwartz, and C Corbett. 2014b. *Columbia Estuary Ecosystem Restoration Program: Programmatic Plan for Action Effectiveness Monitoring and Research.* Final report, prepared for the Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

Johnson GE, GP Ploskey, NK Sather, and DJ Teel. 2015. "Residence Times of Juvenile Salmon and Steelhead in Off-Channel Tidal Freshwater Habitats, Columbia River, USA." *Canadian Journal of Fisheries and Aquatic Sciences* 72:684–696.

Johnson J, J Poirier, and TA Whitesel. 2011. J*ulia Butler Hansen National Wildlife Refuge: Assessment of Fishes, Habitats, and Tide Gates in Sloughs on the Mainland, 2010 Progress Report*. U.S. Fish and Wildlife Service, Vancouver, Washington.

Jones KK, TJ Cornwell, DL Bottom, LA Campbell, and S Stein. 2014. "The Contribution of Estuary-Resident Life Histories to the Return of Adult *Oncorhynchus kisutch*." *Journal of Fish Biology*. doi:10.1111/jfb.12380, available online at wileyonlinelibrary.com.

Ke Y, AM Coleman, and HL Diefenderfer. 2013. "Temporal Land Cover Analysis for Net Ecosystem Improvement." *Ecohydrology and Hydrobiology* 13:84–96.

Kidd S. 2017. "Ecosystem Recovery in Estuarine Wetlands of the Columbia River Estuary." Ph.D. dissertation. Portland State University.

Kidd S and A Yeakley. 2016. “Tidal Wetland Restoration and Sea-Level Rise: Seed Bank Response to Changes in Tidal Flooding and Salinity.” Presentationd at the Columbia River Estuary Conference, May 2016, Astoria, Oregon. Available: http://www.estuarypartnership.org/sites/default/files/resource_files/S.A.Kidd_Columbia%20River%20Estuary%20Conference_Astoria_MAY_2016_SHARE.pdf.

King JR, VN Agostini, CJ Harvey, GA McFarlane, MGG Foreman, JE Overland, E Di Lorenzo, NA Bond, and KY Aydin. 2011. “Climate Forcing and the California Current Ecosystem.” *ICES Journal of Marine Science* 68:1199–1216.

Kirwan ML, GR Guntenspergen, A D’Alpaos, JT Morris, SM Mudd, and S Temmerman. 2010. “Limits on the Adaptability of Coastal Marshes to Rising Sea Level.” *Geophysical Research Letters* 37(23). https://doi.org/10.1029/2010GL045489,

Klopfenstein R. 2016. “Restoring the Columbia River estuary: Chinook Salmon Recovery and Invasive Species Management.” Thesis for Masters of Science in Marine Resource Management, Oregon State University.

Krueger KL, DL Bottom, WG Hood, GE Johnson, KK Jones, and RM Thom. 2017. An expert panel process to evaluate habitat restoration actions in the Columbia River Estuary. *Journal of Environmental Management* 188:357–350.

Kuhn M, J Wing, S Weston, A Williams, C Keefer, and A Engelhardt. 2016. “caret: Classification and Regression Training. R package. 6.0-80.”

Kukulka T and DA Jay. 2003a. “Impacts of Columbia River Discharge on Salmonids Habitat: 1. A Nonstationary Fluvial Tide Model.” *Journal of Geophysical Research* 108(C9):3293.

Kukulka T and DA Jay. 2003b. “Impacts of Columbia River Discharge on Salmonids Habitat: 2. Changes in Shallow-Water Habitat.” *Journal of Geophysical Research* 108(C9):3294.

Lara-Lara JR, BE Frey, and LF Small. 1990. “Primary Production in the Columbia River Estuary I. Spatial and Temporal Variability of Properties.” *Pacific Science* 44:17–37.

Lasne E, S Lek, and P Laffaille. 2007. “Patterns in Fish Assemblages in the Loire floodplain: The Role of Hydrological Connectivity and Implications for Conservation.” *Biological Conservation* 139:258–268.

Laszlo A and C Loeb. 2016. “Evaluating the Effectiveness of Constructed Beaver Dam Analogs in Recently Restored Floodplains of the Lower Columbia River Estuary.” Presentation at the Columbia River Estuary Conference, May 24–26, 2016, Astoria, Oregon.

Levings CD. 1991. “Strategies for Restoring and Developing Fish Habitats in the Strait of Georgia--Puget Sound Inland Sea, northeast Pacific Ocean.” *Marine Pollution Bulletin* 23:417–422. doi: 10.1016/0025-326x(91)90710-a.

Levings CD. 1994. “Feeding Behaviour of Juvenile Salmon and Significance of Habitat during Estuary and Early Sea Phase.” *Nordic Journal of Freshwater Research* 69:7–16.

Lewis WM, SK Hamilton, MA Lasi, M Rodriguez, and JF Saunders. 2000. “Ecological Determinism on the Orinoco floodplain.” *BioScience* 50:681–692.

Liaw A and M Wiener. 2002. “Classification and Regression by Random Forest.” *R News* 2(3):18–22.

Limburg, K, R Brown, R Johnson, B Pine, R Rulifson, D Secor, K Timchak, B Walther, and K Wilson. 2016. “Round-the-Coast: Snapshots of Estuarine Climate Change Effects.” *Fisheries* 41.7:392–394.

Lott MA. 2004. “Habitat-Specific Feeding Ecology of Ocean-type Chinook Salmon in the Lower Columbia River Estuary.” Masters of Science,. University of Washington.

Lynch AJ, BJ Myers, C Chu, LA Eby, JA Falke, R P Kovach, TJ Krabbenhoft, TJ Kwak, J Lyons, CP Paukert, and JE Whitney. 2016. “Climate Change Effects on North American Inland Fish Populations and Assemblages.” *Fisheries* 41.7:346–361.

Macdonald JS, IK Birtwell, and GM Kruzynski. 1987. “Food Habitat Utilization by Juvenile Salmonids in the Campbell River Estuary.” *Canadian Journal of Fisheries and Aquatic Science* 44:1233–1246.

Maier MA. 2014. “Ecology of Diatoms and Their Fungal Parasites in the Columbia River.” Ph.D. Dissertation, Oregon Health & Science University.

Maier G and C Simenstad. 2009. “The Role of Marsh-Derived Macrodetritus to the Food Webs of Juvenile Chinook Salmon in a Large Altered Estuary.” *Estuaries and Coasts 32*(5):984–998. doi: 10.1007/s12237-009-9197-1

Marcoe K and S Pilson. 2017. “Habitat Change in the Lower Columbia River Estuary, 1870-2009.” *Journal of Coastal Conservation*. Published online June 16, 2017. doi:10.1007/s11852-017-0523-7.

Marine KR and JJ Cech. 2004. “Effects of High Water Temperature on Growth, Smoltification, and Predator Avoidance in Juvenile Sacramento River Chinook Salmon.” *North American Journal of Fisheries Management* 24:198–210.

McCabe GT, Jr., RL Emmett, WD Muir, and TH Blahm. 1986. “Utilization of the Columbia River Estuary by Subyearling Chinook Salmon.” *Northwest Science* 60:113–124.

McCullough DA. 1999. *A Review and Synthesis of the Effects of Alterations to the Water Temperature Regime on Freshwater Life Stages of Salmonids, with Special Reference to Chinook Salmon*. Report 910-R-99-010, U.S. Environmental Protection Agency, Portland, Oregon.

McCullough D, S Spalding, D Sturdevant, and M Hicks. 2001. *Summary of Technical Literature Examining the Physiological Effects of Temperature*. EPA-910-D-01-005, Issue Paper 5, Water Quality Criteria Guidance Development Project. U.S. Environmental Protection Agency, Region 10, Seattle, Washington.

McLusky DS. 1993. “Marine and Estuarine Gradients – An Overview.” *Netherlands Journal of Aquatic Ecology* 27:489, https://doi.org/10.1007/BF02334809.

McMichael GA, RA Harnish, BJ Bellgraph, JA Carter, KD Ham, PS Titzler, and MS Hughes. 2010. *Migratory Behavior and Survival of Juvenile Salmonids in the Lower Columbia River and Estuary in 2009*. PNNL-19545, Pacific Northwest National Laboratory, Richland, Washington.

McNatt R and S Hinton. 2017. “Evidence for Direct use of Tidal Wetlands by Interior Stocks of Juvenile Salmon.” Presentation at the Anadromous Fish Evaluation Program, Annual Meeting, November 28, 2017, Richland, Washington.

McNatt R, S Hinton, D Teel, and D Bottom. 2015. “Use of the Columbia River Estuary by Interior Salmon and Steelhead Stocks.” Presentation at the *Conference of the Coastal and Estuarine Research Federation*, November 8-12, 2015, Portland, Oregon. http://www.erf.org/cerf2015.

McNatt RA, DL Bottom, ad SA Hinton. 2016. “Residency and Movement of Juvenile Chinook Salmon at Multiple Spatial Scales in a Tidal Marsh of the Columbia River Estuary.” *Transactions of the American Fisheries Society* 145:774–785.

McNatt RA, B Cannon, SA Hinton, LD Whitman, R Klopfenstein, TA Friesen, and DL Bottom. 2017. *Multnomah Channel Wetland Restoration Monitoring Project*. Report prepared by NMFS and ODFW for Sustainability Center, Oregon Metro Natural Areas Program, Portland, Oregon.

Miller JA, DJ Teel, A Baptista, and C Morgan. 2013. "Disentangling Bottom-Up and Top-Down Effects during a Critical Period in the Life History of an Anadromous Fish." *Canadian Journal of Fisheries and Aquatic Sciences* 70:617–629.

Mitsch WJ and JG Gosselink. 1993. *Wetlands*, 2nd Edition. Van Nostrand Reinhold, New York, 722 p. ISBN 0-442-00805-8.

Moritz HR, M Favier, L Negherbon, M Turaski, A Hodgson, V Ringold, and L Landre. 2018. *Habitat restoration using dredged material placement within the lower Columbia River at Woodland Islands, Washington*. Presentation at the Columbia River Estuary Conference, April 12, 2018, Astoria, Oregon.

Mote PW and EP Salathé. 2010. "Future Climate in the Pacific Northwest." *Climatic Change* 102:29–50.

Naiman RJ, JR Alldredge, DA Beauchamp, PA Bisson, J Congleton, CJ Henny, N Huntly, R Lamberson, C Levings, EN Merrill, WG Pearcy, BE Rieman, GT Ruggerone, D Scarnecchia, PE Smouse, and CC Wood. 2012. "Developing a Broader Scientific Foundation for River Restoration: Columbia River Food Webs." *Proceedings of the National Academy Sciences of the United States of Amarica.* doi:10.1073/pnas.1213408109.

NAS (National Academies of Sciences, Engineering, and Medicine). 2016. *Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico.* The National Academies Press, Washington, D.C. doi:10.17226/23476.

Netboy A. 1980. *The Columbia River Salmon and Steelhead Trout, Their Fight for Survival*. Seattle: University of Washington Press.

Nickelson T. 2033. "The Influence of Hatchery Coho Salmon (*Oncorhynchus kisutch*) on the Productivity of Wild Coho Salmon Populations in Oregon Coastal Basins." *Canadian Journal of Fisheries and Aquatic Sciences* 60:1050–1056.

NMFS (National Marine Fisheries Service). 2000. *Biological Opinion: Reinitiation of Consultation on Operation of the Federal Columbia River Power System, Including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin*. National Marine Fisheries Service – Northwest Region, Seattle, Washington. Available at: http://www.salmonrecovery.gov/implementation.

NMFS (National Marine Fisheries Service). 2004. *Biological Opinion: Operation of the Federal Columbia River Power System (FCRPS) Including 19 Bureau of Reclamation Projects in the Columbia Basin* (Revised and reissued pursuant to court order, NWF v. NMFS, Civ. No. CV 01-640-RE (D. Oregon)). National Marine Fisheries Service (NOAA Fisheries) – Northwest Region, Seattle, Washington. Available at http://www.salmonrecovery.gov/implementation.

NMFS (National Marine Fisheries Service). 2008a. *Biological Opinion – Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program*. NMFS (National Oceanic and Atmospheric Administration Fisheries) – Northwest Region, Seattle, Washington.

NMFS (National Marine Fisheries Service). 2008b. *Supplemental Comprehensive Analysis of the Federal Columbia River Power System and Mainstem Effects of the Upper Snake and other Tributary Actions*. NMFS (National Oceanic and Atmospheric Administration Fisheries) – Northwest Region, Seattle, Washington.

NMFS (National Marine Fisheries Service). 2011. *Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead*. NMFS Northwest Region. Portland, Oregon. (Prepared for NMFS by the Lower Columbia River Estuary Partnership (contractor) and PC Trask & Associates, Inc., subcontractor.)

NMFS (National Marine Fisheries Service). 2016. *Summary and Evaluation of Upper Columbia River Steelhead Upper Columbia River Spring-Run Chinook Salmon*. National Marine Fisheries Service, West Coast Region, Portland, Oregon. Available from: http://www.nmfs.noaa.gov/pr/listing/reviews.htm#fishes. Accessed on September 30, 2017.

NMFS and PNNL (National Marine Fisheries Service and Pacific Northwest National Laboratory). 2017. *Action Effectiveness Monitoring and Research of Habitat Restoration Actions in the Lower Columbia River and Estuary, 2015-2016*. Progress report submitted to the Portland District, U.S. Army Corps of Engineers, Portland, Oregon.

NPCC (Northwest Power and Conservation Council). 2014. *Columbia River basin Fish and Wildlife Program 2014*. Document 2014-12, Northwest Power and Conservation Council, Portland, Oregon. Available at: https://www.nwcouncil.org/fw/program/2014-12/program/.

NRC (National Research Council). 1992. *Restoration of Aquatic Ecosystems – Science, Technology, and Public Policy*. Committee on Restoration of Aquatic Ecosystems – Science, Technology, and Public Policy, Water Science and Technology Board, Commission on Geosciences, Environment, and Resources, National Research Council. National Academy Press, Washington, D.C.

NRC (National Research Council). 1996. *Upstream: Salmon and Society in the Pacific Northwest.* National Academy Press, Washington, D.C.

Odum EP. 1980. "The status of three ecosystem-level hypotheses regarding salt marsh estuaries: tidal subsidy, outwelling, and detritus-based food chains." p.485-495. In VS Kennedy (ed.), *Estuarine perspectives*. Academic Press.

Odum WE, TJ Smith III, JK Hoover, and CC McIvor. 1984. "The Ecology of Tidal Freshwater Marshes of the United States East Coast: A Community Profile." FWS/OBS-83/17, U.S. Fish and Wildlife Service, Washington, D.C.

Oksanen FJ, FG Blanchet, M Friendly, R Kindt, P Legendre, D McGlinn, PR Minchin, RB O'Hara, GL Simpson, P Solymos, MH Stevens, E Szoecs, and H Wagner. 2017. "VEGAN: Community Ecology Package. R package version 2.4-4." *CRAN. R-project*. org/package = vegan.

Oliver DR. 1971. "Life History of the Chironomidae." *Annual Review of Entomology* 16:211–230. https://www.annualreviews.org/doi/pdf/10.1146/annurev.en.16.010171.001235.

Overman CCM. 2017. "A Statistical Investigation of Lower Columbia River Water Temperature, 1915-2003." Civil and Environmental Engineering Undergraduate Honors Thesis. Available at: http://pdxscholar.library.pdx.edu/cengin_honorstheses/8.

Paerl HW and J Huisman. 2008. "Blooms Like It Hot." *Science* 320:57–58.

Paerl HW, JL Pinckney, JM Fear, and BL Peierls. 1998. “Ecosystem responses to internal and watershed organic matter loading: consequences for hypoxia in the eutrophying Neuse River Estuary, North Carolina, USA”. *Marine Ecology Progress Series* 166:17–25.

PCTA (PC Trask and Associates, Inc.). 2009. *Habitat Creation and Enhancement Feasibility Investigation*. Prepared for the U.S. Army Corps of Engineers, Portland, Oregon.

Polis GA, WB Anderson, and RD Holt. 1997. “Toward an Integration of Landscape and Food Web Ecology: The Dynamics of Spatially Subsidized Food Webs.” *Annual Review of Ecology and Systematics* 28:289–316.

PSP (Puget Sound Partnership). 2017. *Chinook Salmon Projects and Climate Change: Guidance on Questions to Ask When Reviewing and Evaluating Restoration and Protection Projects*. Prepared by the Puget Sound Partnership, Tacoma, Washington. Available: http://www.ecoadapt.org/data/library-documents/Lead%20Entity%20Guidance%20Chinook%20and%20Climate%20FINAL%209_6_17.pdf.

Ramirez MF. 2008. “Emergent Aquatic Insects: Assemblage Structure and Patterns of Availability in Freshwater Wetlands of the Lower Columbia River Estuary.” Masters of Science Thesis, University of Washington.

Rameriz M, J Cordell, and A Hanson. 2016. “Comparisons of macroinvertebrate structure and availability in reed canarygrass and Lyngbye’s sedge habitats.” Presentation at the Columbia River Estuary Conference, May 24-26, Astoria, Oregon.

Rehage JS and JR Blanchard. 2016. “What can we expect from climate change for species invasions?” *Fisheries* 41.7:405–406.

Roegner GC. 2017. “Linking Direct and Indirect Benefits: Fluxes Connect Site-Scale Prey Production to Landscape-Scale Consumption.” Presentation at the Anadromous Fish Evaluation Program, Annual Meeting, November 28, Richland, Washington.

Roegner GC and EM Dawley. 2012. “Estimating Realized Habitat Utilization for Chinook, Chum, and Coho Salmon in a Restoring Tidal Freshwater Wetland.” Pp. C.1-C.11, *Evaluation of Cumulative Ecosystem Response to Restoration Projects in the Lower Columbia River and Estuary, 2010*, Johnson et al. PNNL-20296, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Roegner GC and DJ Teel. 2014. “Density and Condition of Subyearling Chinook Salmon in the Lower Columbia River and Estuary in Relation to Water Temperature and Genetic Stock of Origin.” *Transactions of the American Fisheries Society* 143(5):1161–1176. doi: 10.1080/00028487.2014.918055.

Roegner GC, HL Diefenderfer, AB Borde, RM Thom, EM Dawley, AH Whiting, SA Zimmerman, and GE Johnson. 2009. *Protocols for monitoring habitat restoration projects in the lower Columbia River and estuary*. NOAA Technical Memo NMFS-NWFSC-97, U.S. Department of Commerce, Seattle, Washington.

Roegner GC, EW Dawley, M Russell, A Whiting, and DJ Teel. 2010. “Juvenile Salmonid Use of Reconnected Tidal Freshwater Wetlands in Grays River, Lower Columbia River Basin.” *Transactions of the American Fisheries Society* 139:1211–1232.

Roegner GC, R McNatt, DJ Teel, and DL Bottom. 2012. “Distribution, Size, and Origin of Juvenile Chinook Salmon in Shallow-Water Habitats of the Lower Columbia River and Estuary, 2002−2007.” *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 4:450–472.

Roegner CG, LA Weitkamp, and DJ Teel. 2016. "Comparative Use of Shallow and Deepwater Habitats by Juvenile Pacific Salmon in the Columbia River Estuary Prior to Ocean Entry." *Marine and Coastal Fisheries* 8(4):536–552.

Roessig JM, CM Woodley, JJ Cech, and LJ Hansen. 2004. "Effects of Global Climate Change on Marine and Estuarine Fishes and Fisheries." *Reviews in Fish Biology and Fisheries* 14:251–275.

Rose G, D Bottom, and J Miller. 2015. "Connecting tidal-fluvial estuary life-history patterns to survival of McKenzie River spring Chinook salmon." Presentation at the Conference of the Coastal and Estuarine Research Federation, November 8-12, Portland, Oregon.

Sagar JP, AB Borde, LL Johnson, CA Corbett, JL Morace, KH Macneale, WB Temple, J Mason, RM Kaufmann, VI Cullinan, SA Zimmerman, RM Thom, CL Wright, PM Chittaro, OP Olson, SY Sol, DJ Teel, GM Ylitalo, and ND Jahns. 2013. *Juvenile Salmon Ecology in Tidal Freshwater Wetlands of the Lower Columbia River and Estuary: Synthesis of the Ecosystem Monitoring Program, 2005–2010.* Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration, Available from the Lower Columbia Estuary Partnership, Portland, Oregon.

Sagar JP, AB Borde, L Johnson, TD Peterson, JA Needoba, KH Macneale, M Schwartz, A Silva, CA Corbett, VI Cullinan, SA Zimmerman, RM Thom, PM Chittaro, OP Olson, SY Sol, DJ Teel, GM Ylitalo, MA Maier, and CE Tausz. 2015. *Juvenile Salmon Ecology in Tidal Freshwater Wetlands of the Lower Columbia River and Estuary: Synthesis of the Ecosystem Monitoring Program, Trends (2005–2013) and Food Web Dynamics (2011-2013)*. Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration. Available from the Lower Columbia Estuary Partnership, Portland, Oregon.

Sather NK, GE Johnson, DJ Teel, AJ Storch, JR Skalski, and VI Cullinan. 2016. "Shallow Tidal Freshwater Habitats of the Columbia River: Spatial and Temporal Variability of Fish Communities and Density, Size, and Genetic Stock Composition of Juvenile Chinook Salmon." *Transactions of the American Fisheries Society* 145:734–753.

Sather N, H Stewart, A Martin-Schwarze, K Mackereth, and G Johnson. 2017. "Direct Benefits of Habitat Restoration on Juvenile Salmon: Site-Scale Evaluation." Presentation at the Anadromous Fish Evaluation Program, Annual Meeting, November 28, Richland, Washington.

Scheuerell MD, RW Zabel, and BP Sandford. 2009. "Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (*Oncorhynchus spp.*)." *Journal of Applied Ecology* 46:983–990.

Schindler DE, X Augerot, E Fleishman, NJ Mantua, B Riddell, M Ruckelshaus, J Seeb, and M Webster. 2008. "Climate Change, Ecosystem Impacts, and Management for Pacific Salmon." *Fisheries* 33:502–506.

Schwartz MD, AB Borde, J Smith, N Elasmar. 2015. *Action Effectiveness Monitoring for the Lower Columbia River Estuary Habitat Restoration Program. Program Annual Report (October 2013 to September 2014)*. Prepared by the Lower Columbia Estuary Partnership, Portland, Oregon. BPA Document ID# P144412, available at https://www.cbfish.org/PiscesPublication.mvc/SearchByProjectAndContract.

Schwartz MD, AB Borde, A Silva, N Elasmar, C Kenny, and M Vesh. 2016. *Action Effectiveness Monitoring for the Lower Columbia River Estuary Habitat Restoration. Program Annual Report (October 2014 to September 2015)*. Prepared by the Lower Columbia Estuary Partnership, Portland, Oregon. BPA Document ID# P150096, available at https://www.cbfish.org/PiscesPublication.mvc/SearchByProjectAndContract.

Schwartz MD, A Silva, N Elasmar, C Kenny, and M Vesh. 2017. *Action Effectiveness Monitoring for the Lower Columbia River Estuary Habitat Restoration. Program Annual Report (October 2015 to September 2016)*. Prepared by the Lower Columbia Estuary Partnership, Portland, Oregon. BPA Document ID# P155664, available at https://www.cbfish.org/PiscesPublication.mvc/SearchByProjectAndContract.

Seeb LW, A Antonovich, MA Banks, TD Beacham, MR Bellinger, SM Blankenship, MR Campbell, NA Decovich, JC Garza, CM Guthrie, TA Lundrigan, P Moran, SR Narum, JJ Stephenson, KT Supernault, DJ Teel, WD Templin, JK Wenburg, SF Young, and CT Smith. 2007. “Development of a Standardized DNA Database for Chinook Salmon.” *Fisheries* 32:540–552.

Sherwood CR, DA Jay, HR Bradford, P Hamilton, and CA Simenstad. 1990. “Historical Changes in the Columbi River Estuary.” *Progress in Oceanography* 25:299–352.

Simenstad CA and JR Cordell. 2000. “Ecological Assessment Criteria for Restoring Anadromous Salmonid Habitat in Pacific Northwest Estuaries.” *Ecological Engineering* 15:283–302.

Simenstad CA and RM Thom. 1996. “Functional Equivalency Trajectories of the Restored Gog-Le-Hi-Te Estuarine Wetland.” *Ecological Applications* 6:38–56.

Simenstad CA, LF Small, CD McIntire, DA Jay, and C Sherwood. 1990. “Columbia River Estuary Studies: An Introduction to the Estuary, a Brief History, and Prior Studies.” *Progress in Oceanography* 25:1–13.

Simenstad CA, A Wick, and DL Bottom. 2003. “Dynamics and Ecological Functions of Wood in Estuarine and Coastal Marine Ecosystems.” Pp. 265–277, editors SV Gregory, KL Boyer, and AM Gurnell, *Ecology and Management of Wood in World Rivers*. American Fisheries Society, Bethesda, Maryland.

Simenstad CA, JL Burke, JE O’Connor, C Cannon, DW Heatwole, MF Ramires, IR Waite, TD Counihan, and KL Jones. 2011. *Columbia River Estuary Ecosystem Classification-Concept and Application*. U.S. Geological Survey Open-File Report 2011–1228, Reston, Virginia.

Smith SM and RS Warren. 2012. “Vegetation Responses to Tidal Restoration.” In *Tidal Marsh Restoration*, edited by CT Roman, DM Burdick, J Aronson, KD Holl, DA Falk, RJ Hobbs, and MA Palmer, 59–80. *The Science and Practice of Ecological Restoration*. Island Press/Center for Resource Economics. http://www.springerlink.com.proxy.lib.pdx.edu/content/u7n4718300014t64/abstract/.

Sol SY, OP Olson, KH Macneale, P Chittaro, D Teel, G Yitalo, and LL Johnson. 2013. *Fish Monitoring Component of the Mirror Lake Complex Action Effectiveness Monitoring Project 2008-2012*. Final report from NMFS National Marine Fisheries Service to the Lower Columbia Estuary Partnership, Portland, Oregon.

Sommer TR, ML Nobriga, WC Harrell, W Batham, and WJ Kimmerer. 2001. “Floodplain Rearing of Juvenile Chinook Salmon: Evidence of Enhanced Growth and Survival.” *Canadian Journal of Fish and Aquatic Science* 58:325–333.

Stevenson JC, MS Kearny, and EW Kock. 2002. “Impacts of Sea Level Rise on Tidal Wetlands and Shallow Water Habitats: A Case Study from Chesapeake Bay.” Editor NA McGinn, *Fisheries in a Changing Climate. American Fisheries Society Symposium 32*, Bethesda, Maryland 23–36.

Storch AJ. 2011. “Bioenergetics.” In *Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats of the Lower Columbia River*, *2007–2010*. Johnson et al., pp. 5.1–5.19, PNNL-20083, Pacific Northwest National Laboratory, Richland, Washington. Doi: 10.2172/1009747 Johnson GE, A Storch, JR Skalski, AJ Bryson, C Mallette, AB Borde, E Van Dyke, KL Sobocinski, NK Sather, D Teel, EM Dawley, GR Ploskey, TA Jones, SA Zimmerman, and DR Kuligowski. 2011. “Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats of the Lower Columbia River, 2007–2010.” United States. doi:10.2172/1009747. https://www.osti.gov/servlets/purl/1009747.

Storch AJ and NK Sather. 2011. “Feeding Ecology.” In: *Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats of the Lower Columbia River, 2007–2010*. Johnson et al., pp. 4.1–4.20, PNNL-20083, Pacific Northwest National Laboratory, Richland, Washington.

Strauss EA, WB Richardson, LA Bartsch, JC Cavanaugh, DA Bruesewitz, H Imker, JA Heinz, and DM Soballe. 2004. “Nitrification in the Upper Mississippi River: patterns, controls, and contribution to the NO3− budget.” *Journal of the North American Benthological Society* 23(1):1-4.

Suding KN and KL Gross. 2006. “The Dynamic Nature of Ecological Systems: Multiple States and Restoration Trajectories.” In *Foundations of Restoration Ecology*, edited by DA Falk, MA Palmer, and JB Zedler, 190–209. Washington, D.C. Island Press.

Suding KN, KL Gross, and GR Houseman. 2004. “Alternative States and Positive Feedbacks in Restoration Ecology.” *Trends in Ecology & Evolution* 19(1):46–53. https://doi.org/10.1016/j.tree.2003.10.005.

Sweeting RM and RJ Beamish. 2009. “A comparison of the diets of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in the Strait of Georgia from 1997–2007.” *North Pacific Anadromous Fish Commission Bulletin No* 5:255–264.

Systema MD, JR Cordell, JW Chapman, and RC Draheim. 2004. *Lower Columbia River Aquatic Nonindigenous Species Survey 2001-2004*. Final technical report submitted to the U.S. Coast Guard and the U.S. Fish and Wildlife Service. Portland State University, Portland, Oregon.

Talke S and D Jay. 2016. “How Extreme were 2015 Water Temperatures in the Lower Columbia and Willamette Rivers?” Presentation at the *Columbia River Estuary Conference*, May 24-26, Astoria, Oregon.

Tarkowska-Kukuryk M. 2013. “Periphytic Algae as Food Source for Grazing Chironomids in a Shallow Phytoplankton-Dominated Lake.” *Limnologica - Ecology and Management of Inland Waters* 43:254–264.

Teel DJ, DL Bottom, SA Hinton, DR Kuligowski, GT McCabe, R McNatt, GC Roegner, LA Stamatiou, and CA Simenstad. 2014. “Genetic Identification of Chinook Salmon in the Columbia River Estuary: Stock-specific Distributions of Juveniles in Shallow Tidal Freshwater Habitats.” *North American Journal of Fisheries Management* 34:621–641.

Thom RM. 1992. "Accretion Rates of Low Intertidal Salt Marshes in the Pacific Northwest." *Wetlands* 12(3):147–56. https://doi.org/10.1007/BF03160603.

Thom RM, R Zeigler, and AB Borde. 2002. "Floristic Development Patterns in a Restored Elk River Estuarine Marsh, Grays Harbor, Washington." *Restoration Ecology* 10:487–496.

Thom RM, AB Borde, NR Evans, CW May, GE Johnson, and JA Ward. 2004. *A Conceptual Model for the Lower Columbia River Estuary*. Final report to the U.S. Army Corps of Engineers by Pacific Northwest National Laboratory, Richland, Washington.

Thom RM, GD Williams, and HL Diefenderfer. 2005. "Balancing the Need to Develop Coastal Areas with the Desire for an Ecologically Functioning Coastal Environment: Is Net Ecosystem Improvement Possible?" *Restoration Ecology* 10:487–496.

Thom RM, HL Diefenderfer, BD Ebberts, GE Johnson, DA Putman, and JR Skalski. 2008. "Adaptive Management." Chapter 3.0, in *Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, Annual Report 2007*, edited by GE Johnson and HL Diefenderfer. PNNL 17437, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington, and the National Marine Fisheries Service, Seattle, Washington.

Thom RM, E Haas, NR Evans, and GD Williams. 2011. "Lower Columbia River and Estuary Habitat Restoration Prioritization Framework." *Ecological Restoration* 29:94–110.

Thom R, H Diefenderfer, A Coleman, A Borde, GC Roegner, J Tagestad, and G Johnson. 2012. "Ecology and Hydrology of Restoring Wetlands in the Lower Columbia River and Estuary." Chapter 2, in *Evaluation of Cumulative Ecosystem Response to Restoration Projects in the Lower Columbia River and Estuary, 2010*, Johnson et al., PNNL-20296, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Thom RT, NK Sather, D Bottom, and GC Roegner. 2013. *Columbia Estuary Ecosystem Restoration Program: 2012 Synthesis Memorandum*. Final report prepared by the Pacific Northwest National Laboratory and the National Marine Fisheries Service, submitted to U.S. Army Corps of Engineers, Portland, Oregon.

Thom RM, SA Breithaupt, HL Diefenderfer, AB Borde, GCs Roegner, GE Johnson, and DL Woodruff. In Press. "Storm-Driven Particulate Organic Matter Flux Connects a Tidal Tributary Floodplain Wetland, Main Stem River, and Estuary." *Ecological Applications*.

Thorp JH and AP Covich. 2010. *Ecology and Classification of North American Freshwater Invertebrates*. p. 1036, 3rd ed., Academic Press, Burlington, Massachusetts, USA.

Tolimieri N and P Levin. 2004. Differences in responses of Chinook salmon to climate shifts: implications for conservation. *Environmental Biology of Fishes* 70:155–167.

Tomaro LM, DJ Teel, WT Peterson, and JA Miller. 2012. "When is bigger better? Early marine residence of middle and upper Columbia River spring Chinook Salmon." *Marine Ecology Progress Series* 452:237–252.

Trask PC and the University of Washington. 2014. *The Landscape Planning Framework for Juvenile Salmonids: Science Foundation and Vetting Report*. Prepared for the Bonneville Power Administration (BPA), Portland, Oregon. Available from J. Karnezis (BPA).

Triplehorn CA and NF Johnson. 2005. *Borror and DeLong's Introduction to the Study of Insects*. 7th edn. Brooks/Cole, Cengage Learning. Belmont, California.

Turner RE. 2004. "Coastal Wetland Subsidence Arising from Local Hydrologic Manipulations." Estuaries 27(2):265–272. https://doi.org/10.1007/BF02803383.

USACE (U.S. Army Corps of Engineers). 2013. 2013 Strategic Sustainability Performance Plan. Office of the Assistant Secretary of the Army for Civil Works, Washington, D.C. http://www.usace.army.mil/missions/sustainability/strategicsustainabilityperformanceplans.aspx.

USACE (U.S. Army Corps of Engineers). 2015. *Phase 2: Developing a Framework for Incorporating Climate Change and Building Resiliency into Restoration Planning, Case Study – Lower Columbia River Estuary*. Final study report. Prepared by the USACE Institute of Water Resources for the USACE Portland District, Portland, Oregon. Available from M Turaski at USACE.

USDHHS (U.S. Department of Health and Human Services). 2004. *The health consequences of smoking: a report of the Surgeon General*. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health, Atlanta, Georgia, USA. ISBN 0-16-051576-2.

USEPA (U.S. Environmental Protection Agency). 2003. "USEPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards." USEPA Region 10 Office of Water, 910-B-03-002, Seattle, Washington.

Vaida F and S Blanchard. 2005. "Conditional Akaike Information for Mixed-effects Models." *Biometrika* 92(2):351–370.

Verbeek H and C Storm. 2001. "Tidal wetland restoration in The Netherlands." *Journal of Coastal Research* 27:192-2-2.

Zanden MJV, JD Olden, C Gratton, and TD Tunney. 2016. "Food Web Theory and Ecological Restoration." In Foundations of Restoration Ecology, 2nd edition. Editors MA Palmer, JB Zedler, and DA Falk, pp. 301–329. Island Press, Washington, D.C. https://doi.org/10.5822/978-1-61091-698-1_11.

Vigg S and CC Burley. 1991. "Temperature-dependent Maximum Daily Consumption of Juvenile Salmonids by Northern Squawfish (*Ptychocheilus oregonensis*) from the Columbia River." *Canadian Journal of Fisheries and Aquatic Sciences* 48:2491–2498.

Volk EC, DL Bottom, KK Jones, and CA Simenstad. 2010. "Reconstructing Juvenile Chinook Salmon Life History in the Salmon River Estuary, Oregon, Using Otolith Microchemistry and Microstructure." *Transactions of the American Fisheries Society* 139:535–549.

WADOE (Washington Department of Ecology). 2011. "Fresh water designated uses and criteria." Available at: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-200.

Wainwright TC and LA Weitkamp. 2013. "Effects of Climate Change on Oregon Coast Coho Salmon: Habitat and Life-Cycle Interactions." *Northwest Science* 87:219–242.

Ward JV and JA Stanford. 1982. "Thermal Responses in the Evolutionary Ecology of Aquatic Insects." *Annual Review of Entomology* 27:97–117.

Ward JV and JA Stanford. 1995. "Ecological Connectivity in Alluvial River Ecosystems and Its Disruption by Flow Regulation." *River Research and Applications* 11:105–109.

Weinstein MP, SY Litvin, and VG Guida. 2005. "Considerations of habitat linkages, estuary landscapes, and trophic spectrum in wetland restoration design." *Journal of Coastal Research* SI 40: 51- 63.

Weitkamp LA. 2010. "Marine Distributions of Chinook Salmon from the West Coast of North America Determined by Coded Wire Tag Recoveries." *Transactions of the American Fisheries Society* 139:147–170.

Weitkamp L and D Teel. 2015. "Hatchery production and marking rates of juvenile salmon stocks along the West Coast of North America." Presentation at the Salmon Ocean Ecology Meeting, March 24-26, 2015, Victoria, British Columbia.

Weitkamp LA, DJ Teel, M Liermann, SA Hinton, DM Van Doornik, and PJ Bentley. 2015. "Stock Specific Size and Timing at Ocean Entry of Columbia River Juvenile Salmon and Steelhead: Implications for Early Ocean Growth." *Marine and Coastal Fisheries* 7:370–392.

Weitkamp L, K Jacobson, B Beckman, K Fresh, and A Munguia. 2017. *Indirect benefits of habitat restoration on juvenile salmon: landscape-scale evaluation*. Presentation at the Anadromous Fish Evaluation Program, Annual Meeting, November 28, Richland, Washington.

Welcomme RL. 1979. *Fisheries Ecology of Floodplain Rivers*. Longman Group Limited, London, United Kingdom.

Whiting, A, T Josephson, and C Loeb. 2015. C*olumbia River Estuary Restoration: Sauvie Island North Unit project*. Presentation at the Conference of the Coastal and Estuarine Research Federation, November 8-12, Portland, Oregon. http://www.erf.org/cerf2015.

Williams PB and MK Orr. 2002. "Physical Evolution of Restored Breached Levee Salt Marshes in the San Francisco Bay Estuary." *Restoration Ecology* 10(3):527–42. https://doi.org/10.1046/j.1526-100X.2002.02031.x.

Wilson SL. 1983. "The Life History of *Corophium Salmonis* in the Columbia River Estuary." Master of Science, p 66, Oregon State University.

Wipfli MS and CV Baxter. 2010. "Linking Ecosystems, Food Webs, and Fish Production: Subsidies in Salmonid Watersheds." *Fisheries* 35(8):373–387. doi: 10.1577/1548-8446-35.8.373.

Wolf E, B Morson, and K Fucik. 1983. "Preliminary Studies of Food Habits of Juvenile Fish, China Poot Marsh and Potter Marsh, Alaska, 1978." *Estuaries and Coasts* 6(2):102–114. doi: 10.2307/1351701.

Wolf KL, GB Noe, and C Ahn. 2013. "Hydrologic Connectivity to Streams Increases Nitrogen and Phosphorus Inputs and Cycling in Soils of Created and Natural Floodplain Wetlands." *Journal of Environmental Quality* 42(4):1245–55. doi: 10.2134/jeq2012.0466.

Woodruff D, RM Thom, GC Roegner, and S Breithaupt. 2012. "Material and Nutrient Flux from Restoring Wetlands in Tidal Freshwater of the Lower Columbia River and Estuary." Pp. E.1-E.26, in *Evaluation of Cumulative Ecosystem Response to Restoration Projects in the Lower Columbia River and Estuary, 2010*, Johnson et al. PNNL-20296, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Woodson L, BK Wells, RC Johnson, P Weber, RB MacFarlane, and G Whitman. 2013. "Evaluating Selective Mortality of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) Across Years of Varying Ocean Productivity." *Marine Ecology Progress Series* 487:163–175.

Xu H, HW Paerl, B Qin, G Zhu, and G Gaoa. 2010. “Nitrogen and Phosphorus Inputs Control Phytoplankton Growth in Eutrophic Lake Taihu, China.” *Limnology and Oceanography* 55:420–432.

Appendix A: Restoration Project Metrics

Prepared by Gary Johnson and Chris Reed

Appendix A contains restoration project metrics. “CRE” refers to an action in the Estuary Module (NMFS 2011). The actions below were listed in Table 2.2. Units for CRE 1.4 are miles; the others are in acres. Zones (Figure 2.5) are the lower estuary (LE), upper estuary (UE), lower tidal river (LR), middle tidal river (MR), and upper tidal river (UR). Data were obtained from internal Action Agency records.

Project	Zone	Year	CRE-1.4	CRE-9.4	CRE-10.1	CRE-10.2	CRE-10.3	CRE-15.3
Abernathy Creek	LR	2012	0.9	1.8			2.7	
Batwater Station	LR	2015	0.2	1	25.6			25.6
Big Creek	UE	2008	0.3				13.3	2.8
Buckmire Slough	MR	2015		22.2	64.8			
Chinook River Estuary	LE	2014		41			310	3
Colewort Creek (Nutel)	LE	2012	0.4	3.9	14			17.5
Columbia Slough Confluence	MR	2009	0.8	3.4				
Crane Slough-Domeyer	MR	2016		1.3	34.9			4.6
Crims Island	LR	2005			291.6			
Deep River, Svensen	LE	2005			155			
Dibblee Point	LR	2013	0.4	1.1		12.1		2.1
Elochoman Slough Thomas	UE	2015	0.19	10.76		255.4		296.5
Fee-Simon	LE	2014			50			
Flight’s End	MR	2017		1.5	42.5			7.8
Fort Clatsop	LE	2007				45		
Fort Columbia	LE	2011		5.1		80		
Germany Creek	LR	2011	0.4	2.01				6.6
Gnat Creek #1	UE	2012	0.5		19			
Gnat Creek #2	UE	2013			67.81			
Gorley Springs	LE	2009	1.9					
Haven Island	LE	2010	1.5	1.6	27.8			67.6
Honeyman Creek	MR	2013				58		
Horsetail Creek	UR	2013	1.3	12			96.02	30
JBH Mainland	UE	2010		110				210
Kandoll Farm #2	LE	2013	6.2	8.6	163			84
Karlson Island	UE	2014			313.53			6.02
Kerry Island	UE	2016	1.95	5.56	95.5			110
LA (Louisiana) Swamp	UE	2013	0.7	1.9	31.7			31.7
La Center Wetlands	MR	2015	1.6	6.5	453			14
Lewis & Clark River	LE	2006			25			
Lord – Walker Islands	LR	2004			335			
Mill Road	LE	2011	0.5	1.5	46.2			46.2
Mirror Lake (Phases 1+2)	UR	2008	2.1	6.3			165	
Multnomah & Wahkeena	UR	2014		3.5			23	
Multnomah Channel Metro	MR	2014			296			

Project	Zone	Year	CRE-1.4	CRE-9.4	CRE-10.1	CRE-10.2	CRE-10.3	CRE-15.3
North Unit (Ruby Lake)	MR	2013	0.5	0.64	122.78			16.38
North Unit (Widgeon/Deep)	MR	2014	1.73	3.3	129.8			20.1
North Unit (3 Fingered Jack)	MR	2015	0.4	2.2	90.6			6.4
Otter Point	LE	2012		3.9	30			19.3
Perkins Creek	LE	2009	0.3				1.1	1.1
Ramsey Lake	MR	2007					5	
Sandy River Dam Removal	MR	2013	1	5.8	50.7			1
Sandy River Delta Riparian	MR	2008	4.0					641.0
Scappoose Bay – Malarkey	MR	2005	6					
Scappoose Bay 2007-2009	MR	2008	2					41.3
Scappoose Bottomlands	MR	2007	2					30
Skamokowa Creek	UE	2013	4	31.9			8.6	30
South Slough (Lewis&Clark)	LE	2007			45			
South Tongue Point	LE	2012	0.3	0.5		6.8		7.7
Steamboat Slough	UE	2014	1.6	7.7	67.6			67.6
Thousand Acres	MR	2014	3.9	3.5	28			75
Trestle Bay	LE	2016			628			
Vancouver Resources Center	MR	2009			10			
Vera Slough	LE	2006					261.9	
Wallacut River	LE	2016	3.43	2.98	45.64			80
Walluski River, Elliot #1	LE	2008	0.7	3.9	15			5.5
Walluski-Youngs	LE	2017	0.8	23.5	240.8			193.1
Westport Slough USFWS #1	UE	2016		1.3	49.4			
Willow Bar	MR	2016	0.9	6.2				8.7
Totals			55.4	349.9	4068.4	457.3	886.6	2210.2

Appendix B: Restoration Project Descriptions

Prepared by Gary Johnson and Chris Reed

These descriptions are from internal Action Agency records.

Project	Year	Description
Abernathy Creek	2012	This Washington Department of Fish & Wildlife (WDFW)-sponsored project improved habitat complexity and hydrology in the lower tidal reaches of Abernathy Creek. The site is located adjacent to the Columbia River at river mile (RM) 55 on the Washington side of the river. Restoration actions included the removal of a road within the floodplain, installation of large wood along the Abernathy Creek Channel, and riparian edge treatments for exotic plants and native plantings.
Batwater Station	2015	This project restored 25.6 acres of floodplain habitat by removing existing tide gates acting as fish passage barriers by breaching to allow fish access and to restore estuarine processes to the site. The existing ditch network patterns were enhanced and expanded to emulate complex, sinuous tidal slough patterns. The western portion of the property is dominantly pasture, which is rotational grazed. The eastern portion is a mix of shrub-scrub wetland with some large cottonwoods.
Big Creek	2008	The project included placing large woody debris in reaches of Big Creek to provide off-channel habitat and structural complexity. It also included 2.8 acres of riparian enhancement and replacement of a culvert on a Big Creek tributary. The project eliminated a velocity barrier in Big Creek by returning the river to its historical channel thereby opening approximately 8 miles of steelhead and cutthroat habitats.
Buckmire Slough	2015	The WDFW and Columbia River Estuary Study Taskforce (CREST) are implementing a multiphase ecosystem restoration project located adjacent to the Columbia River near RM 101. Public lands associated with Phase I and II represent over 240 acres of floodplain slough and seasonal wetland complex that historically provided juvenile salmonid rearing and also refugia during estuary freshets. Phase I restoration (to be completed by CREST) included the removal of two in-channel structures that limit natural hydrology and contribute to poor water quality to approximately 41 acres of slough and off-channel habitats. CREST also improved the riparian edge along the slough network and removing exotic plant species. Phase II restoration (to be completed by WDFW) includes reestablishing Buckmire Slough direct hydrologic connection to the estuary in the vicinity of Caterpillar Island to provide juvenile salmonid ingress/egress to a complex of diverse habitats associated with the South Unit of Shillapoo Lake Wildlife Area, Buckmire Slough, and the Lake River/Vancouver Lake complex. Restoration plans also include the removal of internal site tide gates, hydrologic constrictions, and other barriers. Other restoration actions include native riparian plantings and exotic plant control. A third phase will potentially connect the southern arm of Buckmire Slough to the Vancouver Lake Flushing Channel to create additional ingress/egress points to the estuary for juvenile Salmonids.
Chinook River Estuary	2014	The restoration was intended to partially address over a century of habitat impacts at the Chinook Estuary. The objectives of this project were to: 1. Enhance salmon habitat access and capacity through improved tide gate management at SR-101: Tide gates will be managed to maximize fish passage, tidal flux, and increased salinity intrusion—all of which are expected to enhance juvenile salmonid rearing and foraging conditions. 2. Enhance salmon habitat access and capacity by removing tidal channel blockages: Excavation at up to 14 locations will allow juvenile salmonids access to areas currently not accessible. This action will also improve juvenile salmonid capacity by improving water quality and vegetation community structure.

<table>
<tr><th>Project</th><th>Year</th><th>Description</th></tr>
<tr><td></td><td></td><td>3. Enhance salmon habitat capacity by restoring historical channel width in select locations, filling ditches, planting riparian areas, and controlling noxious weeds: Ditch filling and excavation of historical channel area will shift hydrological controlling factors toward historical conditions, enabling tidal wetland plant communities and associated food-web functions to be reestablished.</td></tr>
<tr><td>Colewort Creek (Nutel Landing)</td><td>2012</td><td>This CREST-sponsored project enhanced approximately 14 acres of former Sitka spruce swamp in the tidal reaches of the Lewis and Clark River. The Colewort Creek project site is located adjacent to the Lewis and Clark River approximately 4 miles upstream of its confluence with the Columbia River at RM 12. The project site, owned by the National Park Service, is part of a larger 45-acre wetland complex that was reconnected to the Lewis and Clark River in 2007 by CREST. Restoration elements included channel excavation, removal of fill material in historical wetlands, and improved hydrologic connection to an additional three acres of wetlands.</td></tr>
<tr><td>Columbia Slough</td><td>2009</td><td>This City of Portland-sponsored project improved in-stream, riparian, and floodplain wetland habitat with an emphasis on rearing and refuge habitat for juvenile salmonids. The site is located in the Columbia Slough immediately upstream of its confluence with the Willamette River (less than 1 mile from the Columbia River at RM 105). The project installed multiple large wood structures along both sides of Columbia Slough and performed native vegetation and erosion control for approximately 1 mile.</td></tr>
<tr><td>Crane - Domeyer</td><td>2016</td><td>The Crane Slough portion of the project reestablished unimpeded hydraulic and tidal connection to wetlands behind a poorly functioning water-control structure at the confluence of Crane Slough, Gilbert River, and Multnomah Channel on Sauvie Island. Restoration actions included removal of a water-control structure, scrape-down of placed fill material, and excavation of tidal channels. The Domeyer wetland portion enhanced hydraulic and tidal connection to Domeyer wetland near Crane Lake on Sauvie Island. Restoration actions included excavation of tidal channels and invasive species control. In total, approximately 35 acres of wetland habitat will be reconnected thereby providing access, rearing, and refugia for juvenile salmonids.</td></tr>
<tr><td>Crims Island -</td><td>2005</td><td>The purchase included 473 acres of off-channel tidal, riparian, and upland black cottonwood habitats. The restoration included scrape-down, tidal channel construction, and replantings on 292 acres of this acquired parcel.</td></tr>
<tr><td>Deep River, Svensen's Landing</td><td>2005</td><td>Acquisition followed by restoration work on the 155 acre Svensen's Landing property. Project work included improvements to the existing cross dike on the northern edge of the property, removal of interior forestry roads and channel crossings, removal of tide gates, removal of dike sections and vegetation control/enhancement.</td></tr>
<tr><td>Dibblee Point</td><td>2013</td><td>Dibblee Point is a peninsula-shaped landform that juts into the edge of the Columbia River near RM 65, across from Longview, Washington. During the last 80 years, dredge materials have been placed onto the side of the river. Gaps and shallow areas in the placement areas have emerged as protected embayment habitat and freshwater wetlands. These isolated wetlands are connected to the mainstem Columbia River only during high river flows (typically during high freshet years). The vision of the project was to connect this valuable shallow-water habitat back to the mainstem and tidal processes, allowing the site to become inundated on a daily basis. The objectives of this project were to:
1. Objective: Connect 12 acres of shallow freshwater wetland habitat within the interior of Dibblee Point to the mainstem Columbia River, thereby increasing rearing and forage habitat capacity for juvenile salmonids.
2. Objective: Create additional in-stream habitat through the newly constructed channel.
3. Objective: Increase habitat complexity and edge densities throughout the connected wetland and channel through the placement of large wood and enhancement of existing native wetland vegetation.</td></tr>
</table>

Project	Year	Description
Elochoman Slough West	2015	Restoration activities on the western portion of property (purchased in 2009) included culvert removal, tide gate removal, road abandonment, invasive treatment, and riparian enhancement. Restoration activities on the eastern portion (purchased in 2012) will include reestablishing tidal hydrology through the removal of dike structure along the mainstem of the Elochoman River. Excavation of pilot channels will jump-start channel forming processes to inundate relic tidal channel signatures within the site's interior. Project also removes exotic plant species and plants native estuarine plant communities consistent with reintroduced estuarine processes.
Fee-Simon (also called Sharnelle Fee)	2014	Project involved reconnecting remnant Sitka spruce swamp to tidal influence. A cross dike has already been constructed to protect adjacent property owners. Project is immediately adjacent to reference tidal swamp to facilitate tracking of project effectiveness.
Flight's End	2017	The Flights End Restoration project will reconnect more than 42 acres of floodplain wetlands to the lower Columbia River via Crane Slough and Multnomah Channel. The objectives of the project were to: Objective 1: Reestablish hydrologic connectivity to Crane Slough and Multnomah Channel • Remove artificial earth berm that currently overtops at elevation 15.0 (NAVD88). • Remove two additional undersized culverts blocking the historical channel. • Create two channel openings from Crane Slough into the wetlands. • Expand tidal prism in the Crane Lake/Slough system. • Retain existing water-control structure to avoid North American Wetlands Conservation Act review and allow managers additional stewardship options for a late summer drawdown of water for moist soil management. Objective 2: Increase wetland plant diversity. • Lower marsh plain surfaces to increase frequency, duration, and magnitude of water inundation. • Replant lowered marsh plain with native emergent species and wet prairie species. • Design beaver analog structures to prolong duration of inundation. Objective 3: Retain recreational use at the site. • Install channel-spanning light-duty bridge in replacement of earth berm and culvert to retain recreational and hunting access at the site.
Fort Clatsop	2007	CREST, in partnership with the Lewis and Clark National Historical Park, restored tidal connection to 45 acres of floodplain near Astoria, Oregon. Restoration actions included the removal of a tide gate and installation of a culvert to permit fish access to high-quality rearing habitat along the Lewis and Clark River. Partners include the Lewis and Clark National and State Historical Park, the Conservation Fund, the Ness Family, Clatsop County Road Department, Youngs Bay Watershed Council, the Youngs Bay Diking District.
Fort Columbia	2011	This CREST-sponsored project was implemented to return tidal hydrology and juvenile salmonid access to a historical 96-acre wetland with additional connection to the Chinook River. The site is located adjacent to Baker Bay on the Columbia River at RM 6 in Pacific County, Washington. The primary restoration action was to replace an undersized and perched culvert with a 12-foot x 12-foot box culvert. Initial monitoring of the site demonstrated use of the restoration area by juvenile salmonids immediately after the restoration.
Germany Creek -	2011	This Columbia Land Trust (CLT)-sponsored project increased habitat complexity, reduced the need for road armoring, and restored native vegetation in the tidal reaches of Germany Creek. The site is located at the confluence of Germany Creek and the Columbia River at RM 56 in Wahkiakum County, Washington. Restoration actions included the placement of engineered log jams along 0.4 miles of creek, exotic plant control, and planted native species in 7 acres of the site.

Project	Year	Description
Gnat Creek - Phase 1	2012	This CREST-sponsored restoration project improved hydrology and physical access to approximately 19 acres of Gnat Creek tidal floodplain. The site is located approximately 4 miles upstream (via Blind Slough) of the Columbia River near RM 27. This initial phase of the project breached the site in several locations to improve hydrology and increase physical access to the site by juvenile salmonids. Future phases include removal of a dam structure and additional breaches in an adjacent site.
Gnat Creek - Phase 2	2013	Gnat Creek is located in the Nicolai-Wickiup watershed of Clatsop County, Oregon, and is a tributary of the Columbia River through Blind Slough at RM 27. The project site included approximately 60 acres of a 72-acre wetland owned by three private landowners. This wetland is immediately downstream from a restoration project that was completed in 2012 on a separate wetland property owned by the Oregon Department of Forestry. The goal of this project was to restore full tidal influence to currently diked tidal wetlands. Project actions included breaching the existing levee in three locations and expanding natural openings in two locations within two of the properties within the wetland complex. Reestablishing tidal influence to the site was intended to benefit native fish and wildlife species dependent on tidal wetlands.
Gorley Springs	2009	This CREST-sponsored project restored hydraulic complexity, improved sediment transport and storage, improved with-to-depth ratio and pool/riffle sequences, and increased localized hydraulic connectivity between main and side channels. The project site is located approximately 13 miles upstream of the Grays River confluence with the Columbia River at RM 22. The project included the installation of five in-stream structures and multiple engineered log jams to increase opportunities for large woody debris (LWD) recruitment to improve channel roughness and cover for migrating adult and juvenile salmonids.
Haven Island	2010	This CLT restoration project enhanced hydrologic connectivity to approximately 80 acres of disconnected tidal floodplain. The historical Sitka Spruce Island is located in the lower Youngs River near RM 4 on the Columbia River. The area affected by the breach included approximately 28 acres; about 68 acres were treated for exotic plant species, and 1.5 miles of riparian edge habitat were restored.
Honeyman Creek	2013	The Lower Columbia Estuary Partnership and Scappoose Bay Watershed Council sponsored this project to restore the Bottomlands, one of the few remaining freshwater tidal estuaries on the lower Columbia, and its connectivity to existing high-quality salmonid habitats within the Bay's Watershed. This project helps achieve this goal by restoring hydraulic connectivity between the lower Columbia River and the Malarkey Ranch, thereby improving water quality, restoring fish passage, and restoring the site's tidal hydrology.
Horsetail Creek	2013	Proposed: improve fish passage into site through Interstate-84 culvert, remove constructed berms, improve in-stream habitat complexity, reestablish riparian forests, encourage beaver activity, and retrofit human-made pond to allow for cooler conditions to reduce invasive predators dependent on warmer waters.
Julia Butler Hansen NWR - Mainland	2010	The Corps worked with the U.S. Fish and Wildlife Service (USFWS) to design and replace three tide gates and repaired a failing culvert at the Julia Butler Hanson Wildlife Refuge. The project site is located on the Washington side of the Columbia River at RM 36. The project replaced one derelict top-hinged tide gate with a more hydraulically efficient side-hinged tide gate (providing improved juvenile fish passage and water quality) and installed two new side-hinged tide gates on a blind slough, restoring a muted tidal signal and juvenile salmon passage for shallow-water habitat. The project restored 110 acres of slough/wetland habitat and 210 acres of riparian forest habitat.
Kandoll Farm #2	2013	Kandoll Farm is a 163-acre site located in the lower, tidal portion of the Grays River in Wahkiakum County, Washington. Phase 2 goals at this project site are to improve habitat structure and function and to address local landowner concerns regarding increased flooding from an increased tidal prism and erosion downstream on Seal Slough. For 100

Project	Year	Description
		years the 163-acre site was disconnected from the river by dikes and used for agricultural purposes. Phase 1 of the Kandoll Farm restoration project restored tidal connectivity to Seal Slough by installing two 13-foot culverts under Kandoll Farm Road, and restored tidal connectivity to the Grays River with three relatively minor dike notches along the Grays River. Phase 1 was reviewed in 2004 and implemented in 2005. CREST conducted 3 years of action effectiveness monitoring during 2007–2009, which shows fish benefits and overall improvement in ecological function. However, the culverts continue to impair the natural tidal exchange with the tidal floodplain, which has subsided approximately 70 centimeters since being diked, according to data from Pacific Northwest National Laboratory (PNNL). Although the culverts have increased tidal activity on the floodplain, PNNL projects that it will require decades (or longer) for the floodplain to recover from historic subsidence and gain topographic complexity due to the low annual average accretion rates. Invasive non-native reed canary grass has also increased in the floodplain since Phase 1 and its dense root mat is limiting natural channel formation at locations where the dike was previously breached. Phase 2 of the project will improve the near- and long-term ecological functionality of the site by improving hydrologic connectivity between the floodplain and the Grays River, increasing floodplain complexity with a dendritic network of off-channel habitat, increasing habitat capacity by adding large wood, and establishing processes that return natural sediment dynamics and organic material exchange to the site. Local landowners were consulted during the design process and support the final design.
Karlson Island	2014	Due to the construction of levees and dikes, the natural hydrology of Karlson Island has been severely altered. A 3-mile levee encircles 320 acres of marsh plain in a highly productive reach of the estuary. A portion of the levee has breached, allowing fish passage at certain tides. This limited opening significantly limits full fish access and tidal hydraulics at the site. The objectives of this project were to: 1. Maximize access to tidal marsh habitat for juvenile salmonids species. 2. Improve hydrologic exchange to more closely resemble natural conditions. 3. Improve hydraulics and flow patterns in the existing channels. 4. Maximize habitat structure and complexity. 5. Enhance food-web connectivity between the marsh and surrounding river. 6. Control invasive species in the project area.
Kerry Island	2016	The goal was a hydrologic reconnection of 110 acres of grazed wetland pasture to the mainstem Columbia River. The objectives were to: 1. Improve access for rearing and foraging salmonids and hydrologic connectivity to tidal and floodplain channels and the floodplain, via: a. Removal of portions of a flood control levee b. Excavation of channels where appropriate c. Placement of fill in agricultural drainage channels. 2. Restore and enhance aquatic, riparian and terrestrial vegetation to enhance overall juvenile salmonid flood plain habitat: a. Implement habitat restoration actions based on 1 and 2 above. b. Remove noxious weeds. c. Replant riparian with native vegetation.
LA (Louisiana) Swamp	2013	The Louisiana Swamp is made up of two tracts; the western 32 acres are behind a dike as pasture and the eastern 13 acres consist of native scrub-shrub wetland. The project restored 32 acres of floodplain habitat by breaching the dike along Westport Slough, the adjacent blind slough to the west, and along Tandy Creek in several strategic places. In addition, the existing drainage network behind the dike was enhanced and expanded to emulate complex, sinuous tidal channels. Exotic vegetation was removed across the entire property and riparian vegetation was planted along Tandy Creek, Westport Slough, and on created microtopography.

Project	Year	Description
La Center Wetlands	2015	The La Center Wetlands Restoration Design Project developed final restoration designs and permitting for restoration on Clark County and WDFW-owned land on the East Fork Lewis River (EFLR). The project restored salmonid access and the habitat capacity of two large wetland sites (Sites 43 and 43B) located between RM 3.2 and 5.1 within the LaCenter wetland complex. Site 43 is a 50-acre parcel owned by Clark County at RM 3.2, along the northern side of the EFLR. Site 43B is 400 acres owned by Clark County and WDFW, is between RM 3.9 and 5.1, and is along the southern side of the EFLR. Both sites are part of the East Fork Lewis River Greenway Plan. Adjacent to the project site, the EFLR is bordered by levees and is deeply incised with nearly vertical 15- to 20-foot high stream banks that isolate the floodplains in all but the highest flows. Additionally, floodplain wetlands and channel banks are predominantly colonized by invasive non-native reed canarygrass (RCG) and lack woody riparian vegetation, large wood habitat structure, and topographic complexity. Restoration actions at the two sites provided 453 acres of rearing and refugia habitat for juvenile salmonids and other aquatic species. Actions included: 1) breaching a levee in two locations to increase hydrologic connection between the mainstem EFLR and the site, resulting in fish access to 182 acres of floodplain wetlands during November-May when salmonids are known to be entering and exiting the site. The breach was on the 50-acre Clark County site and will also inundate private lands east of the breach; modifying or removing an unmaintained weir that limits fish passage and causes stranding; 2) realigning 1,300 feet of poorly engineered side channel; increasing habitat complexity with 200–300 pieces of large woody debris (to be divided between Site 43 and 43B as part of final design); and improving over 0.7 miles of riparian habitat with native plantings.
Lewis & Clark River Dike Breaches	2006	CREST reconnected 25 acres of the Lewis and Clark floodplain to tidal fluctuation near Astoria, Oregon. Restoration actions included the breaching of dikes, creation of tidal channels, and the planting of 750 native trees and shrubs to enhance fish habitat. Partners included Youngs Bay Watershed Council, Ducks Unlimited, and the City of Seaside.
Lord - Walker Islands	2004	Lord Island - Channel modification to improve embayment circulation for about 335 acres of marsh/swamp and shallow-water habitat. This project was implemented by the Corps as mitigation for the Columbia River Channel Improvement Project.
Mill Road	2011	This BPA-funded CLT project restored hydrologic connectivity to approximately 46 acres of historical spruce swamp habitat. The site is located approximately 3 miles upstream of the Grays River confluence with the Columbia River at RM 22. The project included construction of a setback levee, removal of an existing levee, and channel excavation to reconnect historical channel remnants, and native plantings/invasive control.
Mirror Lake - Phase 1	2008	This restoration project represented the first of several phases of restoration actions at Mirror Lake, which is located approximately 10 miles east of Troutdale in the Columbia River Gorge at RM 129. The project sponsor was Parametrix, working with Oregon State Parks. The primary goal of this restoration project was to increase salmonid access to potential spawning areas, lower water temperatures, and establish native streamside vegetation. Actions included removing riprap in a newly replaced culvert, installing baffles to improve a fish passage structure through the culvert by removing angular rock, and providing hydrologic refugia in an otherwise uniform channel. Large wood was placed to mimic historical in-stream habitat conditions and to promote beaver activity. The project also involved planting and protecting native vegetation along Youngs Creek.
Phase 2	2010	This restoration project represents the second of several phases of restoration actions at Mirror Lake, which is located approximately 10 miles east of Troutdale in the Columbia River Gorge at RM 129. The project, sponsored by Parametrix and the LCEP working with Oregon State Parks, improved habitat conditions in Youngs and Lattourell Creeks. In this phase, approximately 1.4 miles of riparian restoration and 3.3 acres of channel restoration occurred. These actions primarily addressed invasive plant control and the installation of large wood in creek channels.

Project	Year	Description
Multnomah & Wahkeena Creeks	2014	This site is located on approximately 60 acres of historic Columbia River floodplain at RM 136, which is miles downstream from Bonneville Dam. The site contains two perennial streams (Wahkeena and Multnomah Creeks), one unnamed intermittent stream, two man-made impoundments (Benson Lake and Hartman Pond), and wetland areas fringing the lake and pond. The site is bounded to the north by Interstate-84 and to the south by the Union Pacific Railroad. Short-term restoration actions included LWD placement, encourage beaver activity, riparian plantings, substrate augmentation, and engineering a rock weir/step-pool and culvert/diversion improvements.
Multnomah Channel	2014	From McNatt et al. (2017), "…restoration actions were undertaken in October 2014 to further improve habitat connectivity and floodplain-rearing opportunities for aquatic species, particularly juvenile salmon. The natural berm along the periphery of the MCM was breached in two locations to improve fish access from Multnomah Channel during high-flow events. Culverts between the north and south wetland ponds were also replaced with a bridge, and a segment of the access road was lowered to facilitate intra-wetland movement by fish in the marsh."
North Unit (Ruby Lake)	2013	Phase 1 of 3 - Ruby Lake - This restoration project removed the water-control structures and returned full hydrologic access to the site. In strategic locations, marsh plain surfaces were scraped down to lower elevations, allowing a larger portion of the wetlands to be inundated at deeper depths for longer periods of time, thereby benefiting native plant species. Removal of structures reestablished upriver and local volitional juvenile salmonid access to over 292 acres of historical habitats.
North Unit (Million., Widgeon/ Deep Lakes)	2014	Phase 2 of 3 - Millionaire, Widgeon & Deep Lakes - This restoration project removed the water-control structures and returned full hydrologic access to the site. In strategic locations, marsh plain surfaces were scraped down to lower elevations, allowing a larger portion of the wetlands to be inundated at deeper depths for longer periods of time, thereby benefiting native plant species. Removal of structures reestablished upriver and local volitional juvenile salmonid access to over 292 acres of historical habitats.
North Unit Restoration (Three Fingered Jack)	2015	Phase 3 of 3 - This restoration project removed the water-control structures and returned full hydrologic access to the site. In strategic locations, marsh plain surfaces were scraped down to lower elevations, allowing a larger portion of the wetlands to be inundated at deeper depths for longer periods of time, thereby benefiting native plant species. Removal of structures reestablished upriver and local volitional juvenile salmonid access to over 292 acres of historical habitats.
Otter Point	2012	This CREST-sponsored restoration project reestablished hydraulic and tidal connection between the Lewis and Clark River and a 33-acre historical spruce swamp wetland. The site is on National Park Service property about 3.5 miles upstream of the Lewis and Clark River confluence with the Columbia River at RM 12. Restoration activities included dike removal, invasive plant species control, and planting native plants. Other project actions included excavating tidal channels and adding large wood within the project site. Approximately 30 acres of historical habitat was reconnected providing access, rearing, and refugia for juvenile salmonids.
Perkins Creek	2009	This CREST and Skipanon Watershed Council project improved habitat and connectivity to approximately 1.1 acres of Perkins Creek. Perkins Creek is a tributary of the Skipanon River at approximately RM 10. This was accomplished by replacing an existing barrier with a 17-foot diameter aluminum culvert, performing riparian restoration on 0.3 miles of stream bank, and implementing exotic plant control on 1.1 acres.
Ramsey Lake	2007	The project, located at RM 2 on Columbia Slough, reestablished hydrologic connectivity to the lower Columbia Slough to reclaim and improved floodplain wetland functions (forested wetland and soft bottom, mud backwater sloughs) and increased the amount and quality of off-channel rearing and refuge habitat for juvenile salmonids. This project return apx. 5 acres of isolated habitat. Native vegetation will be planted along shorelines

Project	Year	Description
		and within the wetland restoration site. Reconstructed slough channels will provide approximately 2.5 acres of annually inundated off-channel habitat.
Sandy River Dam Removal	2013	The project removed a 1930 era diversion dam across the main channel of the Sandy River near the confluence with the Little Sandy River. Implementation of the project restored flows to the east channel, allowing natural physical/biological processes to occur in support of local and upstream evolutionarily significant units. The project reconnected approximately 51 acres of the historical channel with the estuary.
Sandy River Delta Riparian Forest	2008	The 1,500-acre Sandy River delta is located at the confluence of the Sandy and Columbia Rivers at RMs 120–125. The delta was historically a wooded, riparian wetland with ponds, sloughs, bottomland woodland, oak woodland, prairie, and low- and high-elevation floodplain. Both the Corps and BPA have invested in ecosystem restoration activities in support of juvenile salmonid habitat restoration since 2005. The focus of this 2008 phase was to remove exotic plant species and restore native plant species on approximately 155 acres of Sun Dial Island.
Scappoose Bay - Malarkey Ranch	2005	This project restored native plant communities and wetlands in the Scappoose Bay Watershed by removing barriers to aquatic species migration, fencing livestock out of emergent wetlands, removing invasive plant species, and replacing native species.
Scappoose Bay 2007-2009	2008	Several ecosystem restoration projects have been implemented by the Scappoose Bay Watershed Council in Scappoose Bay over the past decade. Scappoose Bay is located near RM 89 on the Columbia River south of the City of St. Helens, Oregon. The primary goal of this salmon restoration project was to restore the bottomlands, one of the few remaining freshwater tidal estuaries on the lower Columbia River. This project included riparian restoration on approximately 2 miles of Scappoose Creek and exotic plant control on approximately 41 acres of bottomlands.
Scappoose Bottom-lands	2007	The Scappoose Bay Watershed Council enhanced critical habitat connections between Scappoose Bay and salmon refugia habitat in the upper watershed. Actions included controlling invasive plant species, fence installation, and planting of native trees and shrubs. This project was part of a long-term effort to restore wetlands and salmon migration corridors in the Scappoose Bottomlands, one of the few remaining freshwater tidal estuaries on the lower Columbia. Partners included the Bureau of Land Management, private landowners, Soil and Water Conservation District, Oregon State University Extension Office, Oregon Watershed Enhancement Board.
Skamokowa Creek - Dead Slough	2013	This project reestablished tidal-fluvial hydrology to the historical Skamokawa Creek channel through interior culvert retrofits and channel enhancements. The site is located near RM 32 on the Columbia River. When complete, the project will restore 4.0 miles of meandering channel that historically was tide water. The project sponsor is the Cowlitz-Wahkiakum Conservation District. Phase I was completed in 2008 (upstream inlet structure); however, channel function will be restored after implementing Phase II in 2013 (downstream tide gate retrofit).
South Tongue Point (Liberty Lane)	2012	This CREST-sponsored restoration project replaced a derelict tide gate with an appropriately sized bottomless culvert. The site is located in Clatsop County adjacent to Cathlamet Bay in the Columbia River near RM 19. Historically, this site was a brackish wetland and was directly connected to Cathlamet Bay. However, the site was disconnected from the bay when Liberty Lane was constructed. The wetland is fed by a 95-acre tributary basin southeast of the project site. Improved hydrology and restored physical access for salmonids is further complemented by strategic scalping of the wetland to expand tidal prism and habitat-forming processes.
Steamboat Slough	2014	This Corps project constructed a setback levee and ecosystem restoration features on the Julia Butler Hansen Wildlife Refuge. Restoration measures were designed to fully restore tidal habitat in the project area between Steamboat Slough and the Columbia River and

Project	Year	Description
		reconnect Ellison Slough to the tidal influence of the Columbia River, Wahkiakum County, Washington.
Thousand Acres	2014	The project site is a portion of the Sandy River delta at the Sandy River's confluence with the Columbia River. The site is owned by the U.S. Forest Service, which manages the site to maintain a diversity of wetland and upland habitats along with passive recreational use and seasonal hunting. The primary goal of the project was to restore hydrologic connection to off-channel habitats and enhance habitat capacity for juvenile salmonids. With the removal of the closed tide gate and water-control structure, and expansion of the existing wetlands, the site now provides 28 acres of habitat during the Columbia River spring freshet period when migrating juvenile salmonids seek off-channel habitat (between mid-April and early July). Habitat complexity was enhanced by replacing invasive non-native RCG with structurally diverse native wetland plant communities, promoting beaver activity, and installing large wood habitat structures. Non-native invasive vegetation removal and riparian revegetation further enhanced habitat quality.
Trestle Bay Jetty Breach	2016	This project builds on initial success of a trestle removal project completed in the 1990s. Removal of additional trestle material expanded the tidal prism and duration of inundation patterns that inundate additional drainage channels and coastal lakes around the property.
Vancouver Water Education Center	2009	The Corps and City of Vancouver worked together to breach a levee that disconnected a 10-acre floodplain wetland. The site is located along the Columbia River at RM 109 adjacent to a regional environmental learning center. The floodplain wetland includes open water, emergent vegetation, scrub-shrub, and forested wetlands.
Vera Slough	2005	This CREST project was intended to restore 106 hectares of brackish marsh. All of the most common restoration actions aimed at restoring hydrologic connectivity that are in use on the LCRE were implemented in 2005. Common objectives of this restoration project were to develop tidal wetland plant communities, increase access for juvenile salmonid fishes, improve water quality (e.g., lower summer temperatures), and increase food-web productivity and export to the mainstem river system (e.g., macroinvertebrates). In 2005, a tide gate retrofit and replacement of a typical flap style tide gate with a regulated tide gate improved water flow in and out of the gate.
Wallacut River	2016	Restoration partially restored tidal influence to the Wallacut system through the upgrading of tide gates and removal of barriers throughout the system. Additional channel enhancements were conducted in areas that have aggradation and to expand channel density and access to wetland habitat.
Walluski River North, Elliot	2008	The Walluski River Tidal Restoration project restored and enhanced floodplain and side channel habitat along the Walluski River. The site is located approximately 2.5 miles upstream from its confluence with Youngs River and 6 miles from the confluence of Youngs Bay. Implementation elements included maintenance of a natural dike breach, removal of an additional 100 feet of the dike, addition of large wood to the tidal channels and floodplain, and channel edge native plantings. This CLT project will increase habitat complexity, enhance the hydrologic connection to the Walluski River, and improve juvenile salmonid rearing habitat.
Walluski-Youngs	2017	This project promotes tidal estuarine processes already under way and enhances intertidal wetland and juvenile rearing habitat through large wood placement and channel reconnection (dike removal). Restoration efforts sought to increase habitat complexity for fish and wildlife, restore hydrologic connectivity to interior wetlands, enhance riparian vegetation community, and test methods for placement of large wood within inaccessible tidal marsh through the use of a helicopter. The objectives were to: 1. Objective 1: Remove a portion of the remnant levee enhancing the hydrologic connection of the site to the Walluski River and Youngs Bay system. 2. Objective 2: Install large logs on tidal floodplain and within approximately 3.9 acres of tidal channels to increase habitat complexity for rearing juvenile salmonids.

Project	Year	Description
		3. Objective 3: Conduct native plantings along approximately 0.68 miles of riparian habitats.
Westport Slough (USFWS)	2016	Project reestablished tidal hydrology by removing a remnant dike structure on middle and upper portions of the property. Restoration actions would jump-start habitat processes to expand existing channel density and complexity. It is assumed that railroad bed would offer sufficient protection of Highway 30 right-of-way and would necessitate any additional cross-dike construction.
Willow Bar	2016	This CREST-sponsored project enhanced hydraulic and tidal connection to the Willow Bar backwater area along the mainstem Columbia River on Sauvie Island. Restoration actions included dredge material scrape-down and tidal channel enhancement. Approximately 42 acres of backwater wetland habitat were enhanced providing access, rearing, and refugia for juvenile salmonids.

Appendix C: Site Evaluation Cards (SECs)

Prepared by Heidi Stewart

We prepared an SEC for each of the 37 projects where data and information were available from ERTG revisits or action effectiveness monitoring or both. An example SEC is presented below (Dibblee). The SEC files are large, so we placed them on cbfish.org and created hyperlink to them:

CEERP SECs (on the website, page down; the SECs are "revision 2018-1.")

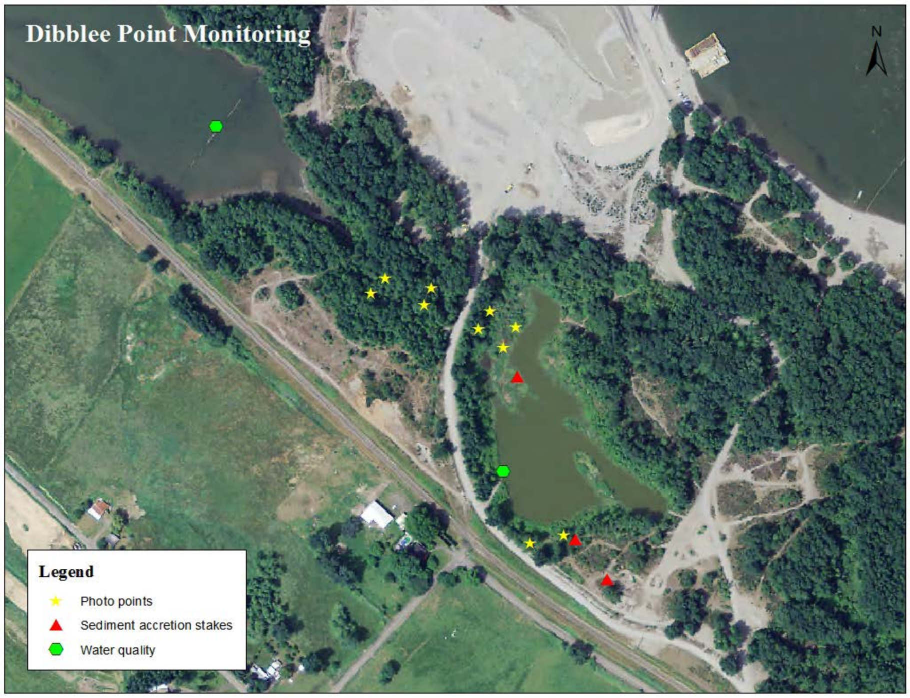
Abernathy Creek	Gnat Creek #2	North Unit (Widgeon/Deep)
Batwater Station	Horsetail Creek	North Unit (Three Fingered Jack)
Buckmire Slough	JBH Mainland	Otter Point
Chinook River Estuary	Kandoll Farm #2	Sandy River Dam Removal
Colewort Creek	Karlson Island	Skamokowa Creek - Dead Slough
Crane Slough-Domeyer	Kerry Island	Steamboat Slough
Crims Island	LA (Louisiana) Swamp	Thousand Acres
Dibblee Point	La Center Wetlands	Vera Slough
Elochoman Slough Thomas	Mill Road	Wallacut River
Fee-Simon	Mirror Lake	Walluski River North, Elliot #1
Fort Clatsop	Multnomah Channel Metro	Westport Slough USFWS #1
Fort Columbia	North Unit (Ruby Lake)	Willow Bar
Gnat Creek #1		

Site Evaluation Card – *Dibblee Point*

Header	
Date prepared:	January 23, 2018
Prepared by:	Heidi Stewart (PNNL) (based on the ERTG revisit template provided by CREST and AEM data provided by LCEP)
Sponsoring agency:	Columbia River Estuary Study Taskforce (CREST) Matt Van Ess, CREST Habitat Restoration Program Manager (503) 325-0435, ext. 221 mvaness@columbiaestuary.org
Funding agency:	Bonneville Power Administration (BPA) Anne Creason (503) 230-3859 amcreason@bpa.gov
Location:	7N-2W-Section 7 46.1113, -122.9893
Project Numbers	ERTG 2013-01
Project Description	
Problem statement	Dibblee Point is a peninsula-shaped landform that juts into the edge of the Columbia River near river mile 65, across from Longview, WA. During the last 80 years dredge materials have been placed onto the side of the river. Gaps and shallow areas in the

	placement areas have emerged as protected embayment habitat and freshwater wetlands. These isolated wetlands are connected to the mainstem Columbia River only during high river flows (typically during high freshet years). The vision of the project is to connect this valuable shallow-water habitat back to the mainstem and tidal processes, allowing the site to become inundated on a daily basis.
Vision/goal	The goal of this project is to provide off-channel rearing and refuge opportunities for juvenile salmonids by connecting Dibblee Point wetlands to mainstem tidal processes. Habitat complexity and predator avoidance can be improved through the placement of large wood in the newly created stream channel and emergent marsh areas. Food-web connections will be enhanced as nutrient exchanges between the wetlands and the river are increased.
Objectives	Objective: Connect 12 acres of shallow freshwater wetland habitat within the interior of Dibblee Point to the mainstem Columbia River, increasing rearing and forage habitat capacity for juvenile salmonids. Objective: Create additional in-stream habitat through the newly constructed channel. Objective: Increase habitat complexity and edge densities throughout the connected wetland and channel through the placement of large wood and enhancement of existing native wetland vegetation.
Construction	
Period and date	Constructed January-February 2013
Construction action(s) and extent(s)	Removed undersized culvert and replaced with a 14 foot wide culvert. Excavated a 250 yard channel and low elevation swale. Converted 2 acres of uplands into emergent marsh. Placed large wood as habitat features. Constructed pedestrian bridge to expand recreational opportunities. Planted over 2,000 native shrubs, trees, and emergent marsh species.
Construction issues	None. As we started construction we were approached by a company seeking mitigation credits for a nearby project. We were able to negotiate an arrangement with regulators and the contractor to expand the marsh plain by an additional .5 acres.
Monitoring Plan	
Experimental design	Dibblee Point is part of the Level II Action Effectiveness Monitoring and Research Program
Monitored indicators	**Pre:** Water-surface elevation Water temperature Photo points Vegetation **Post:** Water-surface elevation Water temperature Photo points Sediment accretion stakes

Monitoring locations



Photographs/Images

Pre-construction

Pre-construction aerial of Ruby (2012). Image courtesy of Google Earth


18" collapsed culvert prior to construction

Overland flow of water prior to construction

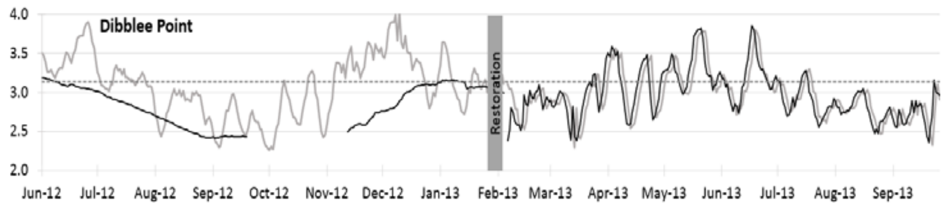
Post-construction	 Aerial of Dibblee post restoration (2014). Image courtesy of Google Earth.


Excavated swale and stream channel

14 foot culvert connecting wetlands to the river

Expanded wetland area (photo taken at low tide)

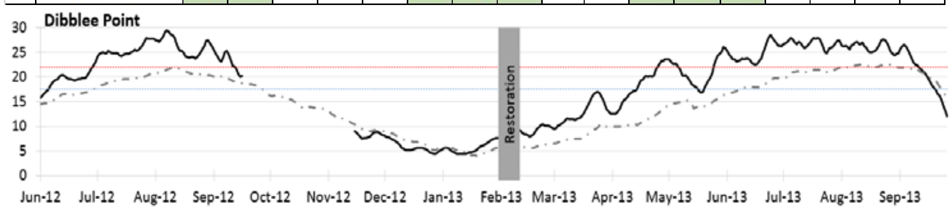
Post-construction Assessment Sponsor comments	Not available.
Monitoring Data WSE	Analyzed data provided by Matt Schwartz, Lower Columbia Estuary Partnership



Dibblee Point

	Year	2012							2013									
	Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	23	31	31	26		12	31	31	Restoration	31	30	31	30	31	31	30	3
	Mean	3.12	2.92	2.61	2.43		2.57	2.89	3.11		2.85	3.15	3.27	3.19	2.97	2.79	2.70	2.99
	SE	0.01	0.02	0.02	0.00		0.01	0.03	0.01		0.04	0.06	0.06	0.05	0.04	0.03	0.03	0.01
	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0		0	10	9	6	0	0	0	0
Reference	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30	3
	Mean	3.43	3.30	2.90	2.64	2.70	3.14	3.56	3.10		2.83	3.12	3.25	3.17	3.01	2.80	2.67	3.01
	SE	0.03	0.05	0.04	0.04		0.06	0.04	0.05		0.04	0.06	0.06	0.05	0.03	0.02	0.02	0.06
	Days Exceeded 2 yr Flood Elevation	11	6	0	0	0	4	24	4		0	7	9	4	0	0	0	0

Water Temp



Dibblee Point																	
Year		2012							2013								
Month		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Restored	n (days)	23	31	31	23		9	31	31		31	30	31	30	31	31	30
	Mean	18.9	24.0	26.6	24.2		8.0	6.6	5.0		11.9	16.4	20.6	24.1	26.9	26.4	22.3
	SE	0.3	0.3	0.3	0.5		0.2	0.2	0.1		0.4	0.5	0.4	0.2	0.2	0.1	0.6
Reference	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30
	Mean	18.9	22.9	25.2	22.0	15.8	11.0	7.2	5.0	Restoration	10.1	13.8	17.2	21	25.0	24.4	22.0
	SE	0.4	0.2	0.3	0.3	0.4	0.3	0.2	0.1		0.3	0.3	0.2	0.2	0.1	0.1	0.6
Main Stem	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30
	Mean	15.8	18.7	21	19.5	15.6	11.5	7.8	4.9		7.4	10.5	14.2	17	20.7	22.0	21
	SE	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.1		0.2	0.1	0.1	0.2	0.1	0.1	0.3

Habitat Suitability

Dibblee Point Opportunity (% Access)																	
Years	2012							2013									
Months	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 °C	0	0	0	0		0	0	0		84%	67%	10%	0	0	0	7%	100%
Fair 17.5-22 °C	0	0	0	0		0	0	0	Restoration	0	33%	52%	0	0	0	27%	0
Poor >22 °C	0	0	0	0		0	0	0		0	0	39%	100%	97%	87%	53%	0
Total	0	0	0	0		0	0	0		84%	100%	100%	100%	97%	87%	87%	100%

Juvenile Salmon

PNNL sampled for juvenile salmon at the Dibblee restoration site and associated reference site (Fisher Is) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile CH dominated the catch. Juvenile salmon were captured at the site sin April and May, but not June and July. Genetic stocks included Spring Creek fall CH, Upper Columbia summer/fall CH, and West Cascades fall CH.

Project	Presence	Chinook Genetic Stocks	Comments	Citation
Dibblee	Unmarked Chinook (97%), hatchery Chinook (<1%), coho (2%)	April: SCG_F, UCR_Su/F, and WC_F; May: UCR_Su/F and WC_F	Data from April-July 2016	N. Sather, pers. comm. Jan. 11, 2018

Post-Construction Assessment

Years after

Certainty of success

Score

Fish access

…Score

Habitat quality

…Score

Concluding Remarks

Was the project successful in meeting its goals? Explain the answer.

If not, what should be changed for future projects of this type?

Other remarks

Appendix D: Quantitative Analysis of Habitat Connectivity

Prepared by Amy Borde[1], Heida Diefenderfer[1], Shon Zimmerman[1], Gary Johnson[1], Caileen Gunn[1], Andre Coleman[1], and Alex McManus[2]

[1]Pacific Northwest National Laboratory
[2]PC Trask & Associates, Inc.

CEERP's primary strategy for ecosystem restoration is to reconnect tidal wetlands to the mainstem estuary (BPA and Corps 2012). Accordingly, CEERP managers and stakeholders ask the following questions: 1) Quantitatively, how has habitat connectivity for juvenile salmon changed since 2004 due to reconnection-restoration actions? 2) How much is CEERP improving habitat connectivity in the estuary? 3) How much more potential is there for tidal hydrologic reconnection in the estuary?

To answer these questions, we developed an index for habitat connectivity for the purpose of tracking the progress of the CEERP (Diefenderfer et al. 2010; Borde et al. 2016; Diefenderfer et al. In Preparation). The objective of this appendix is to document the methods and results of the habitat connectivity index calculations estuary-wide and by estuary zone for 2004 (baseline), 2010 (intermediate), and 2016 (current conditions).

D.1 Introduction

Habitat connectivity is a synonym of habitat connectance, a landscape descriptor concerning the ability of organisms to move among habitat or resource patches. Thus, it includes structural connectivity, describing the spatial arrangement of the habitats, and functional connectivity, which aggregates the target organism's perception and behavior into the potential for movement among habitat or resource patches.

Habitat connectivity is essential to well-functioning, self-maintaining ecosystems (e.g., Lasne et al. 2007). Habitat connectivity affects ecosystem controlling factors[1], including hydrodynamics, bathymetry and topography, and water temperature. The controlling factors in turn affect ecosystem structures, e.g., herbaceous vegetation, and ecosystem processes, e.g., primary and secondary production, sediment accretion, and food-web development. Ecosystem structures[2] and processes[3] influence ecosystem functions[4], such as salmon growth, condition, and migration timing. Overall, habitat connectivity facilitates the transfer, exchange, and movement of nutrients (Wolf et al. 2013), organic matter (Caraco and Cole 2004), fish (Fernandes et al. 2009), and other materials and organisms.

In estuaries around the world, however, diking and levee-building for purposes of agricultural, industrial, and urban development have reduced the connectivity between mainstem estuaries and shallow-water habitats supporting fisheries (Welcomme 1979). This is true in the Columbia River estuary,

[1] Controlling factors are the basic physical and chemical conditions that construct and influence the structure of the ecosystem.
[2] Ecosystem structures are the types, distributions, abundances, and physical attributes of the plant and animal species composing the ecosystem.
[3] Ecosystem processes are interactions among physicochemical and biological elements of an ecosystem that involve changes in character or state.
[4] Ecosystem function is defined as the role the plant and animal species play in the ecosystem, such as fish growth.

where 68-70% of tidal vegetated wetlands have been lost since the late 1800's (Marcoe and Pilson 2017). Furthermore, river flow regulation by hydropower and flood protection dams has affected estuary habitat, e.g., the system of over 130 dams in the Columbia River basin has reduced by about 29% the shallow-water habitat area used by juvenile salmon in the estuary (Kukulka and Jay 2003a,b). Efforts to reconnect disconnected habitats are fundamental to many ecological restoration programs (e.g., NPCC 2014).

The strategy guiding CEERP is that hydrologic reconnection will restore habitats used directly (onsite) and indirectly (offsite) by juvenile salmon. Because reconnection is fundamental to the program, CEERP managers and stakeholders require a metric to track restoration progress in terms of improved connectivity. Diefenderfer et al. (2010) initiated an approach to index habitat connectivity for juvenile salmon, called HabConI, based on elements of structural and functional connectivity. Borde et al. (2016) presented basic components and demonstrated proof-of-concept for the methodology. In this chapter, we explain HabConI methodology and apply it estuary-wide and by zone (Figure D.1) to estimated relative change in habitat connectivity from 2004 to 2016 due to CEERP restoration actions. This assessment serves as an example for managers and stakeholders elsewhere interested in quantifying restoration actions aimed at reconnecting habitats supporting juvenile salmon or other fishes.

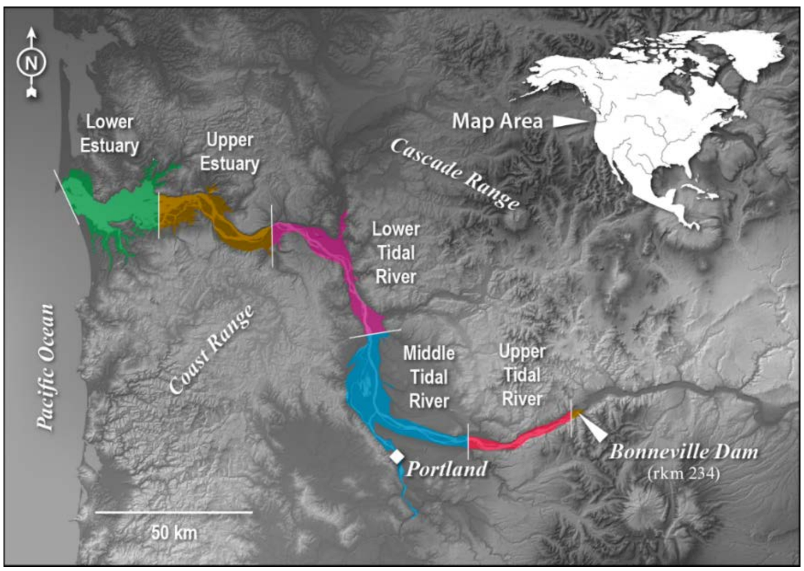


Figure D.1. Map of the Columbia River estuary showing the five vegetation zones. Based on Jay et al. (2016); Figure 1.6.

D.2 Methods

The material in this section provides a basic understanding of the methodology for quantifying habitat connectivity. Diefenderfer et al. (In Preparation) will be providing a complete, detailed description of the indexing method.

D.2.1 Basic Approach

The basic approach was to use land cover classification and other geospatial data to distinguish wetlands, channels, and other features in the floodplain of the Columbia River estuary and quantify how these features changed through time due to restoration. The rationale for this approach was that there is a continuum of habitat types in the river floodplain ecosystem that are accessible to and used by juvenile salmon, such as forested wetlands, shrub wetlands, marshes, and channels. We also included vegetated upland habitats located within the historical floodplain of the Columbia River that are connected to tidal wetland habitats through watershed hydrologic processes and contribute to the transport of salmonid prey, macrodetritus, sediment, and large woody debris. These upland areas also provide a buffer from disturbance and provide potential areas for wetland migration over time.

Spatial scales for application of the index are the estuary zones and the entire Columbia River estuary floodplain from Bonneville Dam to the Pacific Ocean (Figure D.1). The index inherently covers both longitudinal and lateral connectivity within a spatial area of interest. We cover 2000 thru 2016 because the 2000 BiOp introduced estuary restoration as mitigation and 2016 is end of the period of study for the 2018 Synthesis Memo. To our knowledge, only one restoration project was conducted before 2000, Trestle Bay in 1994 (Hinton and Emmett 2000). The approach assumes no area within the study area was lost due to development during 2010-2016.

D.2.2 Key Concepts, Terminology, and Datasets

Central to our analysis is the concept of a relatively undisturbed ecosystem patch (here after referred to simply as a patch). A patch contains tidally connected wetlands, flats, and channels (<120 m wide) (Figure D.2). (The patch concept is explained further below.) Within the floodplain there are additional tidal channels that, although not within patches, we have included in the analysis because the channels are hydrologically connected to the mainstem estuary and therefore may act as conduits to connected habitat and are also hydrologically accessible to juvenile salmon.

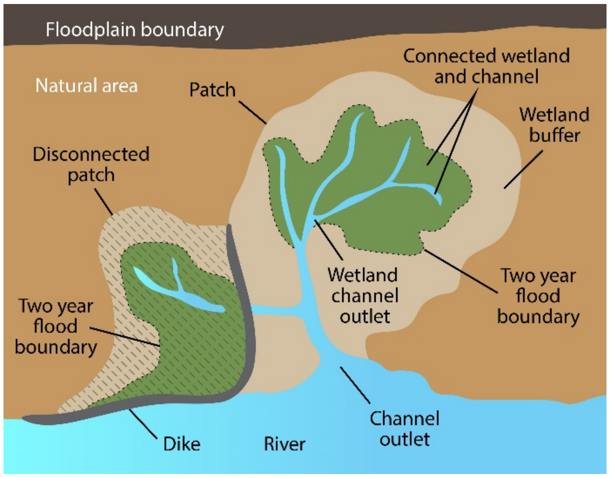


Figure D.2. Schematic depicting key concepts and terminology for the habitat connectivity index. Brown represents "natural" area within the floodplain that is not contiguous with wetland and therefore is not recoverable. Unhatched tan and green areas represent connected patches and wetlands, respectively. Hatched wetland represent disconnected but recoverable areas. Estuary-wide, the sum of brown areas is total remaining natural area (M), the sum of tan areas (including the green area within) is the total area of connected patches (L), and the sum of the hatched area is total recoverable area (R).

The datasets used in this analysis and the relationship to the variables in the habitat connectivity index are shown in Figure D.3. The index variables are described below (Table D.1).

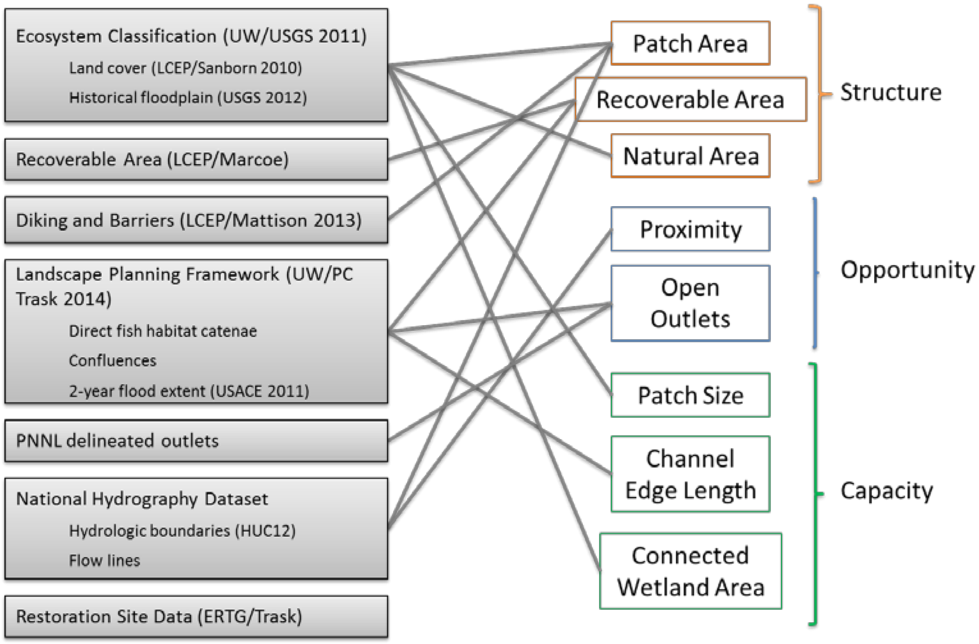


Figure D.3. Relationship of spatial datasets used in this analysis and the variables of HabConI.

Patch: A patch contains tidally connected wetlands, flats, and channels (<120 m wide) and also includes other contiguous, undeveloped forest, shrub-scrub and herbaceous upland, and non-tidal wetland polygons within hydrologic boundaries (Figure D.4). Patches do not include adjacent open water. The non-tidal buffer areas alleviate disturbance, provide a source of allocothonous material, and increase resiliency by allowing for wetland migration. Patches exclude categories of agricultural land, tidally-impaired wetlands, tree farms, or urban/developed areas. Data source: developed for this analysis from the 2010 land cover classification by LCEP.

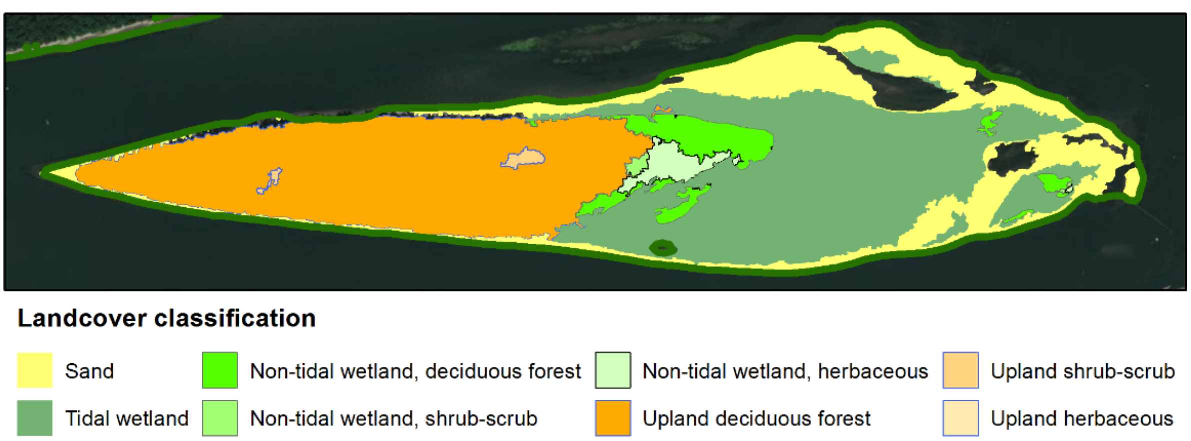


Figure D.4. Example of a patch. The dark green border delineates the patch boundary and the land cover polygons that are included in the patch are represented by the separate colored polygons. The non-tidal elements of a patch are referred to as buffer area.

Recoverable Area: Includes areas that are not developed and that could potentially be restored to become a part of the hydrologically connected wetlands – this includes agricultural lands, diked agricultural lands and non-tidal wetlands within the historical floodplain. Data source: developed by Keith Marcoe (LCEP) from the 2010 land cover classification and modified to include only those areas within the USACE 2-year floodplain boundary.

Natural Habitat (Uplands and Non-Tidal Wetlands): Includes forested, shrub-scrub, and herbaceous upland and non-tidal wetlands that were not included in the patches because they are not contiguous with tidal wetlands within a hydrologic boundary. Data source: developed for this analysis from the 2010 land cover classification.

Wetland: Includes tidal herbaceous, shrub-scrub, deciduous, and coniferous forested wetlands. The data were lumped by community type and polygons adjacent to each other were merged to make contiguous areas. However, there were a large number of small polygons that were located within a patch but not directly adjacent to channels. All wetlands are within patches. Data source: developed for this analysis from the 2010 land cover classification by LCEP.

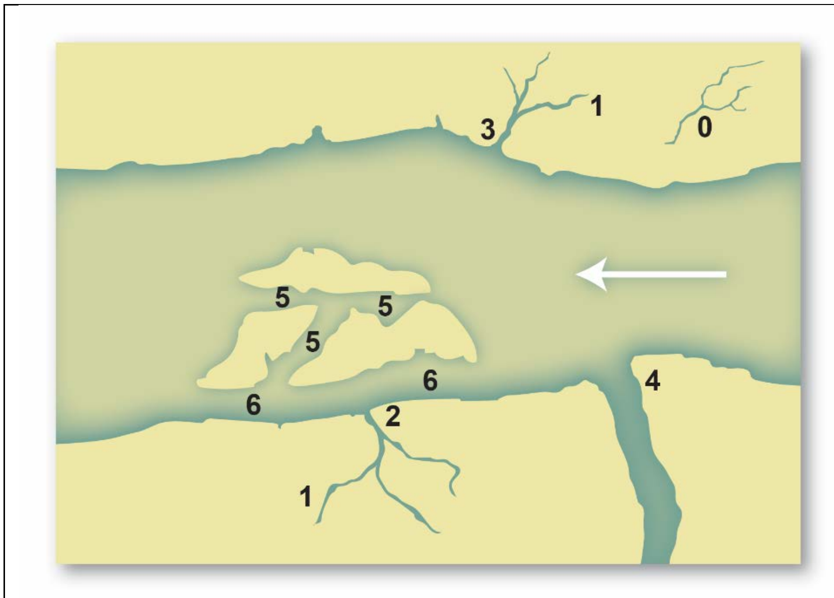
Channels: Includes all tidally connected channels in the estuary including: large side channels off the mainstem (off-channels), tributaries, tidal channels, sloughs, and interconnecting channels between islands. The edge length of channels was measured as the perimeter of the channel. For large channels the mouth was removed from the perimeter. Data source: off-channel areas were developed for this analysis and all other channels were from the Direct Fish Habitat Catena of the Landscape Planning Framework (LPF; Simenstad et al. 2015).

Channel Outlet: Defined as the outlet or confluence of a slough, channel, or tributary that empties into another water body or the mainstem of the River. Data source: developed for this analysis based of flow lines from the National Hydrography Database, LiDAR, National Agricultural Imagery Program (NAIP) 2010 aerial imagery, and then combined with the confluence data layer from the LPF.

Distance to Mainstem Estuary: Measured from the outlet of a wetland channel to the edge of the mainstem of the river. Data source: developed for this analysis from flow lines from the National Hydrography Database and NAIP 2010 aerial imagery.

D.2.3 Channel Classification

Applying Lasne et al. (2007), we developed a hydrologic connectivity classification system for the Columbia River estuary centered on channel type and position in the fluvial system. Using their typology, Lasne et al. (2007) found that connectivity was the main factor influencing the distribution of fish species (which did not include salmon). We postulate that the channel classification for Columbia River estuary represents a sequence of increasing connectivity with the mainstem estuary (Figure D.5). All channels and outlets in the estuary were classified according to the system shown in Figure D.5. We developed GIS layers based on the classification scheme for channels and outlets (Figure D.6).



0. Channels that are altered and therefore not connected to any other channel type.
1. Tributary, channel, or slough that drains into another tributary, channel, or slough.
2. Tributary, channel, or slough that drains into an off-channel.
3. Channel or slough that drains into the main channel.
4. Tributary river or stream that drains into the main channel.
5. Interconnecting channel, primarily between islands, that drains into the main channel or off-channel on both ends.
6. Off-channel (most connected) that is generally greater than 300 m wide and connected to main channel on both ends.

Figure D.5. Hydrologic connectivity classification system for the LCRE for purposes of the habitat connectivity analysis.

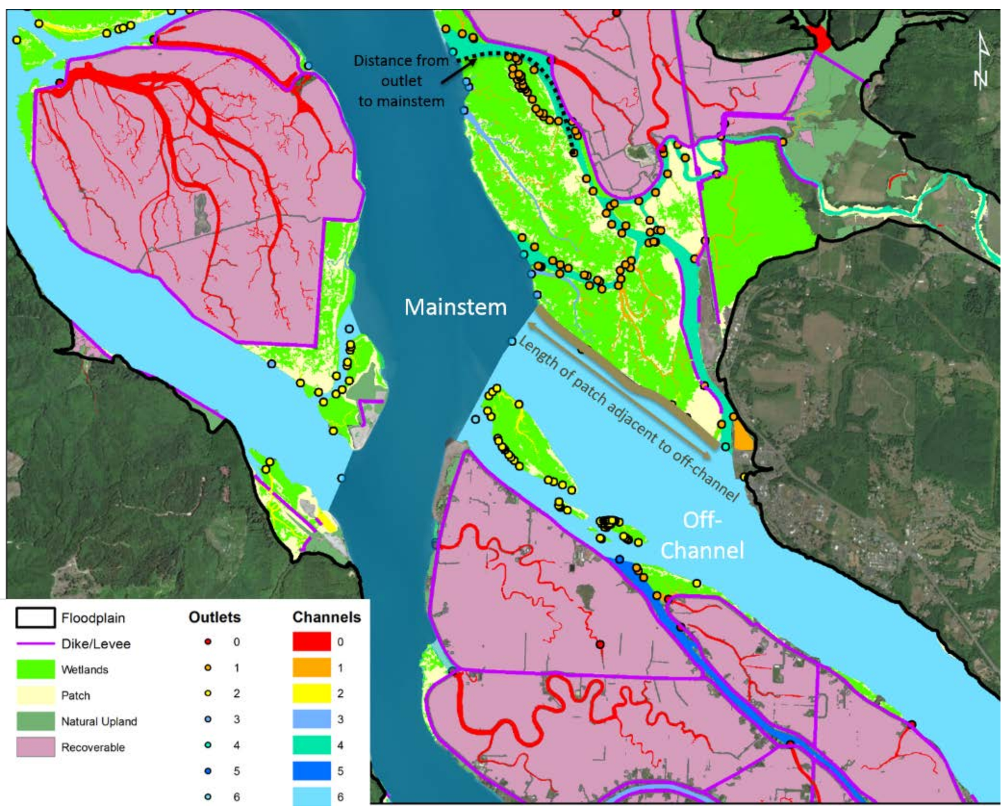


Figure D.6. Example of GIS data layers and classification scheme for channels and outlets.

D.2.4 GIS Analysis

The variables (described above, Section C.2.2) and equations for the habitat connectivity calculation are shown in Table D.1. The variables for the index are calculated for a given time t (in this case 2004, 2010, and 2016). We used ArcGIS ver 10.4 (ESRI, Redlands, CA) to calculate areas, perimeters, distances, and counts for each of the variables. The GIS output values for each variable were exported to an Excel workbook where HabConI was computed.

Table D.1. Variables and equations used in HabConI.

Variable	Description	Equation
Structural – A measure of patch area connected hydrologically to the mainstem, expressed as the proportion of connected patch area out of all non-developed area at time *t*		
A	Proportion of connected patch area to all non-developed area	$A = \frac{L}{L + R + M}$
L	Total area of connected patches (ha)	
R	Total wetland recoverable area, i.e., not currently connected but potentially could be in the future (ha)	
M	Total area of remaining natural habitats that are not wetland nor connected (ha)	
Functional – Measures of the opportunity for juvenile salmon to access habitats and the capacity of those habitats to provide ecological advantages for juvenile salmon		
Opportunity, involves three elements: proximity, open outlets, and open outlets weighted by channel class		
D_t	Proximity is the average normalized distance from wetland outlets to the mainstem river for time *t*	$D_t = \left(1 - \overline{d}_t\right)$ $\overline{d}_t = \frac{\sum_{i=1}^{P_t} \sum_{j=1}^{J_i} \left(\frac{d_{ij} - d_{min}}{d_{max} - d_{min}} \right)}{n_t}$
$\overline{d}_t$	mean normalized outlet distance to mainstem for time *t*	
d_{ij}	distance of the jth outlet in the ith wetland to mainstem	
d_{min}	the minimum distance of a wetland outlet to the mainstem over all times	
d_{max}	the maximum distance of a wetland outlet to the mainstem over all times	
J_i	the total number of outlets in the ith patch	
P_t	the total number of patches for time *t*	
n_t	total number of outlets for all patches combined for time *t*	
O	Proportion of open outlets	$O = \frac{o}{o + c}$
o	total number of open channel outlets	
c	total number of closed channel outlets	
K	proportion of open channel outlets weighted by class of outlet (l = 0-5)	$K = \frac{\sum_{l=0}^{5} \left(l * o_l \right)}{o * 6}$
o	total number of open channel outlets	
l*o	weighted outlets	

Variable	Description	Equation
Capacity, involves four elements: patch size, channel class 6 edge length, channel class 1-5 edge length, and connected wetland area.		
S_t	mean normalized patch size for time *t*	$$\overline{S}_t = \frac{\sum_{i=1}^{P_t}\left(\frac{S_i - S_{\min}}{S_{\max} - S_{\min}}\right)}{P_t}$$
S_i	size of the ith patch	
S_{min}	minimum patch size over all times (ha)	
S_{max}	maximum patch size over all times (ha)	
P_t	total number of patches for time *t*	
F	proportion of total class 6 channel edge length inside or adjacent to a patch	$$F = \frac{f_a}{f_a + f_n}$$
f_a	class 6 channel edge length adjacent to patches (m)	
f_n	class 6 channel edge length not adjacent to patches (m)	
E	proportion of total classes 0-5 channel edge length inside or adjacent to a patches	$$E = \frac{e_a}{e_a + e_n}$$
e_a	edge length of channel classes 1-5 (m)	
e_n	edge length of channels class 0 (altered) (m)	
W	proportion of wetland area connected to the mainstem	$$W = \frac{X}{X+R} = \frac{\sum_{i=1}^{P}\sum_{k=1}^{K_i} x_{ik}}{X+R}$$
X	total area of existing wetlands connected to the mainstem (ha)	
x_{ik}	area of the kth wetland in the ith patch (ha)	
K_i	total number of wetlands in the ith patch	
P	total number of patches	
R	Total recoverable wetland area, i.e., not currently connected but potentially could be in the future (ha)	
Habitat Connectivity		
HConI	habitat connectivity index	$$HabConI = \frac{\sum_{v=1}^{V}\left(Y_v * 100 * w_v\right)}{V}$$
Y_v	value of the v*th* variable (*A, D, O, K, S, F, E, W*)	
w_v	weighting factor for the vth variable (= 1 for all variables)	
V	total number of variables	

PC Trask and Associates provided GIS data for the restoration projects. Only projects that were categorized as attaining full hydrologic connectivity were included (see the attachment to this appendix for sites categorized with CRE-10.1 or CRE-10.2 actions). We used the 2010 land cover classification data as the basis for this analysis, because it provided the most complete, readily available data. But, to examine the effects of CEERP restoration actions, we adjusted the 2010 data layers. To represent the 2004 condition (pre-restoration), we used the 2010 version of the GIS data layers by manually converting areas restored from patches (L) in 2010 to unrestored, recoverable areas in 2004. For the year 2016, we created GIS data layers by manually converting areas recoverable in 2010 to wetlands, channels, and patches if they were restored during 2010-2016 (Figure D.7). We explain the treatment of the GIS polygons for the restoration areas in the attachment to Appendix D (Section D.4).

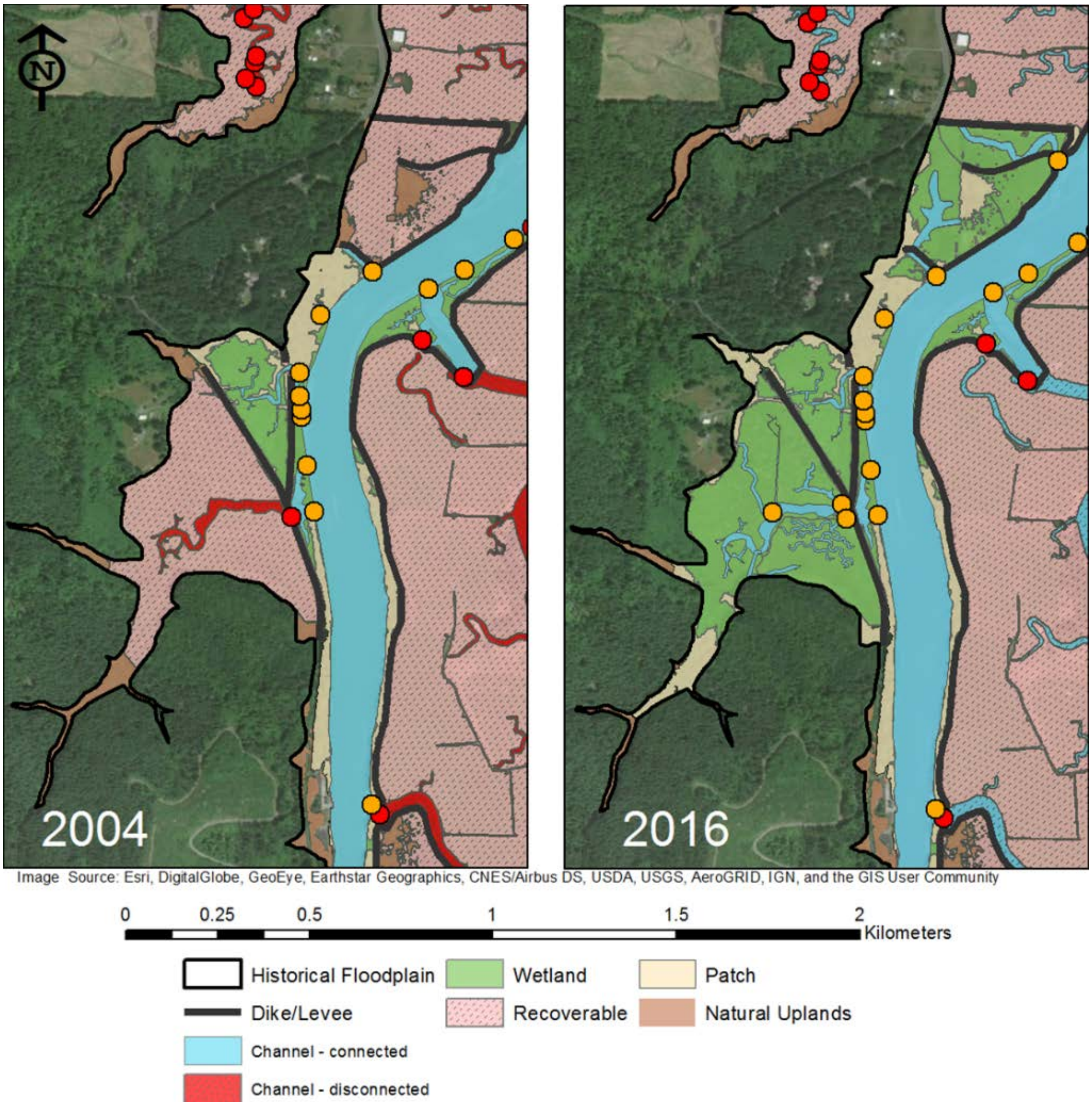


Figure D.7. GIS output showing effects on wetland and channel areas before (left panel) and after (right panel) dike breaching. Orange dots represent open channel outlets and red dots represent closed outlets.

D.3 Results and Conclusion

The habitat connectivity index increased from 2004 (51.0) to 2010 (51.24) to 2016 (52.26) (Figure D.8a; Table D.2). From 2004 to 2016, the increase was 1.26, or 2.5%. This increase in connectivity is directly attributable to the restoration projects because the calculation method explicitly incorporates the spatial features of the restoration projects. Both patch (variable A) and wetland (variable W) connectivity increased over time (Figures D.8b and D.8c). These increases were more pronounced between 2010 and 2016 than between 2004 and 2010. As of 2016, about 32.2% of wetland habitat area was connected to the mainstem. There were 144 more open channel outlets in 2016 than in 2004 (Figure D8d).

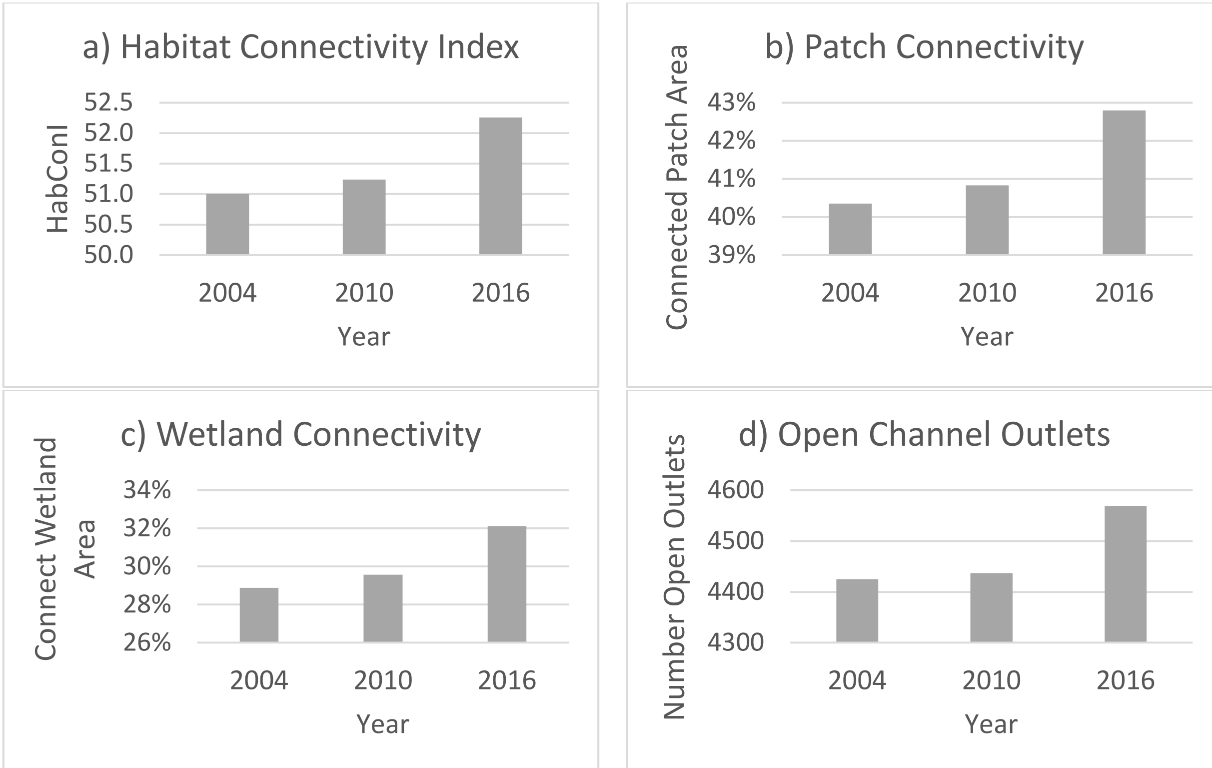


Figure D.8. Habitat connectivity analysis for all zones combined in the LCRE by year for 2004, 2010, and 2016.

Table D.2. Values for HabConI variables estuary-wide for 2004, 2010, and 2016. Variables are defined in Table D.1.

Variable	**2004**	**2010**	**2016**
A	0.4035	0.4082	0.4279
L	22723	23002	24126
R	21942	21725	21014
M	11647	11617	11236
D	0.8352	0.8352	0.8318
d/n	0.1648	0.1648	0.1683
d	588	590	617
n	3569	3582	3667
O	0.8440	0.8456	0.8608
o	4425	4437	4569
c	818	810	739
K	0.297	0.297	0.295
o	4425	4437	4569
*l*o*	6571	6585	6729
S	0.05366	0.05483	0.05683
∑*L*	17.49	17.71	18.58
P	326	323	327

Variable	2004	2010	2016
F	0.729	0.729	0.738
f a	349301	349332	353679
f a + f n	479173.9	479174	479174
E	0.6290	0.6338	0.6493
e a	3318024	3345557	3457716
e n	1957077	1932978	1867448
W	0.2888	0.2957	0.3212
X	8909	9120	9943
Z	30850	30845	30957
HabConI	51.00	51.24	52.26
Summary			
A	0.404	0.408	0.428
D	0.835	0.835	0.832
O	0.844	0.846	0.861
K	0.297	0.297	0.295
S	0.054	0.055	0.057
F	0.729	0.729	0.738
E	0.629	0.634	0.649
W	0.289	0.296	0.321

Habitat connectivity, as assessed in 2016, was highest in the Upper Tidal River zone (69.5) and lowest in the Middle Tidal River zone (44.7) (Figure D.9). The Upper Tidal River zone also had the highest patch connectivity (66.6%), while the Lower Tidal River zone had the lowest (31.1%). This was due in part because the amount of recoverable area was much lower (Table D.3). The Upper Tidal River zone had the highest wetland connectivity (95.5%). The largest number of open channel outlets (2,356 outlets) was the Upper Estuary zone where Cathlamet Bay and its many natural wetlands are located. The fewest number of open channel outlets (137) was in the Upper Tidal River zone, i.e., the Columbia River gorge, where there are not many outlets to begin with.

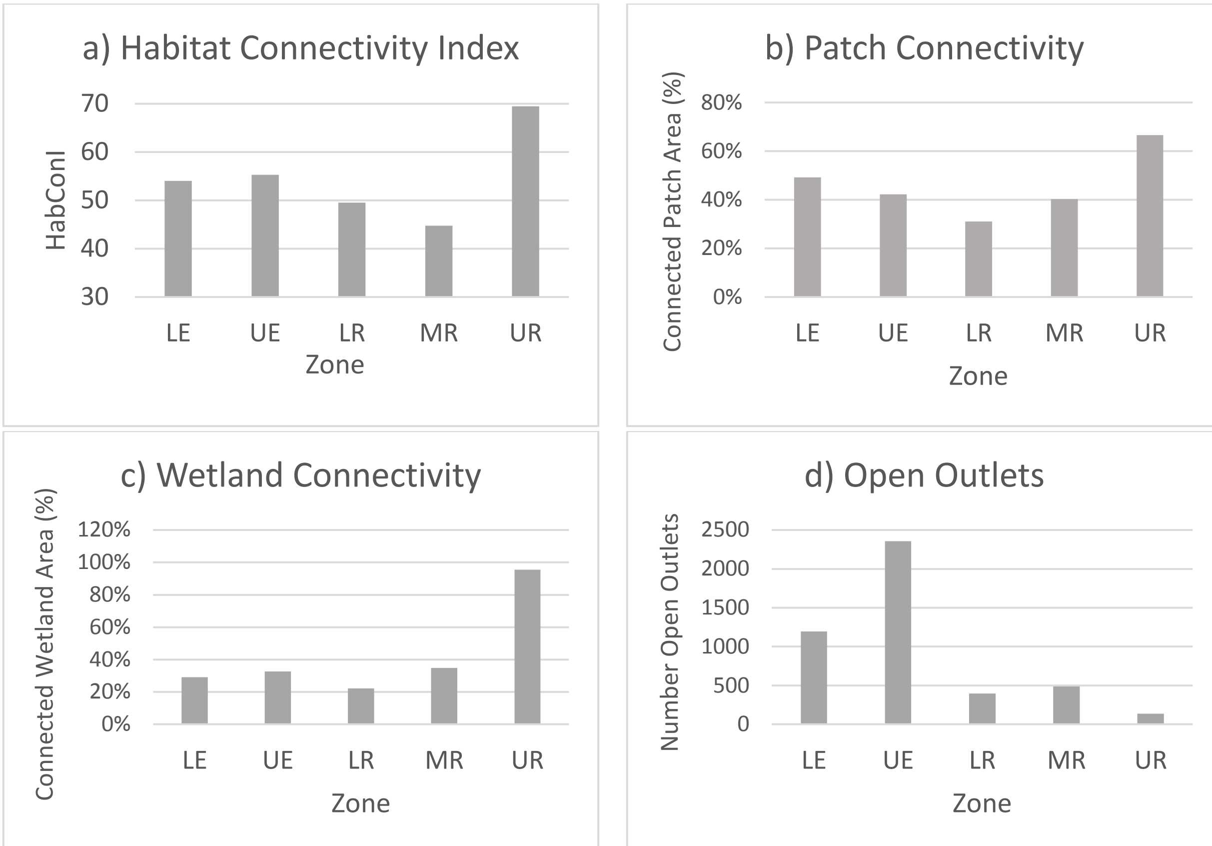


Figure D.9. Habitat connectivity analysis for 2016 by zone: lower estuary (LE), upper estuary (UE), lower tidal river (LR), middle tidal river (MR), and upper tidal river (UR).

In conclusion, we demonstrated a viable method for quantifying habitat connectivity. The habitat connectivity index showed a 2.5% increase in connectivity due to CEERP restoration actions. The index indicated about 50% overall connectivity. The results herein may be compared to similar analyses in future years to track CEERP progress. But, while much has been accomplished over the last 18 years, more remains to be done. According to our habitat connectivity analysis, there is at least 21,014 ha of “recoverable wetland” theoretically available for future restoration.

Table D.3. HabConI calculations by zone for 2004, 2010, and 2016. Variables are defined in Table C.1. Zones are Lower Estuary (LE), Upper Estuary (UE), Lower Tidal River (LR), Middle Tidal River (MR), and Upper Tidal River (UR) (Figure D.1).

	2004					2010					2016				
Variable	LE	UE	LR	MR	UR	LE	UE	LR	MR	UR	LE	UE	LR	MR	UR
A	0.469	0.410	0.295	0.354	0.638	0.481	0.410	0.307	0.364	0.638	0.493	0.423	0.311	0.403	0.666
L	5636	6584	2678	5571	2030	5790	6584	2795	5799	2033	5909	6787	2833	6452	2077
R	4306	8426	3515	5672	22	4151	8426	3456	5669	22	4082	8236	3443	5232	22
M	2087	1047	2887	4491	1132	2086	1047	2861	4488	1132	2005	1043	2832	4333	1020
D	0.777	0.813	0.862	0.680	0.854	0.776	0.813	0.863	0.681	0.854	0.771	0.811	0.863	0.671	0.844
	0.223	0.187	0.138	0.320	0.146	0.224	0.187	0.137	0.319	0.146	0.229	0.190	0.137	0.330	0.156
d	209	378	39	83	12	210	378	39	83	12	219	391	39	91	13
n	935	2018	279	258	79	940	2018	286	259	79	957	2063	287	277	83
O	0.774	0.916	0.865	0.703	0.852	0.777	0.916	0.867	0.705	0.852	0.787	0.923	0.867	0.776	0.884
o	1155	2310	391	436	132	1160	2310	398	437	132	1196	2356	399	487	137
c	338	212	61	184	23	333	212	61	183	23	323	196	61	141	18
K	0.355	0.280	0.265	0.251	0.333	0.354	0.280	0.263	0.252	0.333	0.350	0.279	0.263	0.246	0.330
o	1155	2310	391	436	132	1160	2310	398	437	132	1196	2356	399	487	137
*l*o*	2048	3236	517	547	220	2053	3236	524	550	220	2093	3289	525	600	226
S	0.082	0.093	0.102	0.051	0.114	0.085	0.0931	0.105	0.053	0.120	0.086	0.0945	0.107	0.058	0.107
∑*L*	5.88	7.08	7.15	4.46	2.40	6.05	7.08	7.47	4.47	2.40	6.16	7.30	7.57	4.97	2.24
P	72	76	70	87	21	71	76	71	85	20	72	77	71	86	21
F	0.978	0.825	0.765	0.454	0.948	0.978	0.825	0.765	0.454	0.948	0.978	0.825	0.765	0.486	0.946
f a	53373	147480	60119	64650	23679	53373	147480	60150	64650	23679	53373	147483	60110	69090	23623

Variable	2004 LE	2004 UE	2004 LR	2004 MR	2004 UR	2010 LE	2010 UE	2010 LR	2010 MR	2010 UR	2016 LE	2016 UE	2016 LR	2016 MR	2016 UR
$f a + f n$	54599	178729	78610	142258	24978	54599	178729	78610	142258	24978	54599	178729	78610	142258	24978
E	0.543	0.734	0.558	0.549	0.771	0.555	0.734	0.563	0.556	0.771	0.566	0.743	0.565	0.590	0.824
$e a$	631968	1551634	339591	682780	11115	644092	1551634	346673	691106	111158	671086	1579888	349611	736692	11954
$e n$	531937	562285	269230	560509	33116	516163	562285	269230	552184	33116	513750	547732	269230	511218	25518
W	0.2522	0.3097	0.2056	0.2899	0.9541	0.2778	0.3097	0.2189	0.2908	0.9541	0.2907	0.3277	0.2219	0.3496	0.9551
X	1452	3780	910	2316	451	1597	3780	969	2324	451	1673	4014	982	2813	462
Z	5758	12206	4425	7988	473	5748	12206	4425	7993	473	5754	12250	4425	8045	483
A	0.469	0.410	0.295	0.354	0.638	0.481	0.410	0.307	0.363	0.638	0.493	0.422	0.311	0.403	0.666
D	0.777	0.813	0.862	0.680	0.854	0.776	0.813	0.863	0.681	0.854	0.771	0.810	0.863	0.671	0.844
O	0.774	0.916	0.865	0.703	0.852	0.777	0.916	0.867	0.705	0.852	0.787	0.923	0.867	0.775	0.884
K	0.355	0.280	0.264	0.251	0.333	0.354	0.280	0.263	0.252	0.333	0.350	0.279	0.263	0.246	0.330
S	0.082	0.093	0.102	0.051	0.114	0.085	0.093	0.105	0.053	0.120	0.086	0.095	0.107	0.058	0.107
F	0.98	0.83	0.76	0.45	0.95	0.98	0.83	0.77	0.45	0.95	0.98	0.83	0.76	0.49	0.95
E	0.543	0.734	0.558	0.549	0.771	0.555	0.734	0.563	0.556	0.771	0.566	0.743	0.565	0.590	0.824
W	0.252	0.310	0.206	0.290	0.954	0.278	0.310	0.219	0.291	0.954	0.291	0.328	0.222	0.350	0.955
HabConI	**52.85**	**54.76**	**48.96**	**41.66**	**68.29**	**53.55**	**54.76**	**49.41**	**41.94**	**68.37**	**54.02**	**55.32**	**49.54**	**44.73**	**69.45**

D.4 Attachment

This table explains the GIS adjustments to wetland area for the restoration projects 2004-2017. Changes were based on the 2010 land cover data, the 2-year flood layer, and the ERTG restoration polygons. Assessments were also based on evaluation of restoration documents and Google Earth imagery. The reason for differences between the CRE-10.1 and CRE-10.2 areas and the GIS-based wetland areas from this study are documented in the Notes column.

Project	Year	CRE-10.1 (ha)	CRE-10.2 (ha)	2004 Wetland Area (ha)	2016 Wetland Area (ha)	Restored Wetland (ha)	Notes
Batwater Station	2015	10.4		0.0	8.4	8.4	Channel excavation connected lower elevation area
Buckmire Slough	2015	26.2		0.6	26.1	25.5	
Colewort Creek	2012	5.7		0.0	5.7	5.7	Added area of site that was focus of restoration actions in 2012.
Crane - Domeyer	2016	14.1		5.4	15.3	9.9	
Crims Island	2005	118.0		0.0	57.1	57.1	Updated to reflect recoverable wetland area vs. natural upland
Deep River	2005	62.7		0.0	55.1	55.1	
Dibblee Point	2013		4.9	0.0	5.0	5.0	
Elochoman Slough Thomas	2015		103.4	36.7	103.1	66.4	Some of the area was classified as tidal wetland in 2004 and 2010, prior to restoration. One restoration document indicated that existing wetlands were relatively intact and connected through north outlet so 36.7 ha were included pre-restoration.
Fee-Simon	2014	20.2		0.0	18.4	18.4	
Fort Clatsop	2007		18.2	0.0	12.8	12.7	Does not include area restored in 2012 (Colewort Creek)
Fort Columbia	2011		32.4	0.0	0.1	0.1	After careful consideration of the available data (LiDAR, 2yr flood layer, construction diagrams, land cover, time series aerial imagery) it was determined that the project as constructed does not provide tidal connectivity beyond the extent depicted by the tidal wetlands in 2016. It is conceivable that someday a more extensive tidal channel network may develop through a combination of distributary flow and tidal channel evolution.

Project	Year	CRE-10.1 (ha)	CRE-10.2 (ha)	2004 Wetland Area (ha)	2016 Wetland Area (ha)	Restored Wetland (ha)	Notes
Gnat Creek #1	2012	7.7		3.2	6.2	3.1	This site had been breached prior to restoration actions in 2012 and was therefore classified as tidal wetland in 2004 and 2010. In order to represent the enhancement actions that happened to the wetland area the drainage areas farther from the natural breach were removed in 2004 and 2010. These areas were added into the 2016 version to represent the restored condition.
Gnat Creek #2	2013	27.4		3.4	24.7	21.3	Same note as Gnat Creek #1
Haven Island	2010	11.3		12.0	22.8	10.8	2010 land cover indicates all of Haven Island is tidal wetland, however, some of the area was improved by 2010 restoration, therefore the wetland area in the vicinity of the restoration actions was removed from the pre-restoration condition.
Honeyman Creek	2013		23.5	0.0	35.0	35.0	2010 land cover indicates most of Honeyman Creek was tidal wetland, however the area was improved by the 2013 restoration, therefore the wetland area was removed from the pre-restoration condition.
Kandoll Farm #2	2013	66.0		0.0	58.2	58.2	Wetland area reflects restoration in 2005 and no further wetland change after 2013 restoration.
Karlson Island	2014	126.9		192.6	254.6	62.0	2010 land cover indicates all of the Karlson Island restoration site was tidal wetland, however the inner area was improved by the 2014 restoration, therefore the wetland area was removed from this portion of the site.
Kerry Island	2016	38.6		0.0	38.3	38.3	
LA Swamp	2013	12.8		0.0	12.8	12.8	
LaCenter Wetlands	2015	183.3		0.5	176.0	175.5	
Lewis & Clark River	2006	10.1		9.9	13.9	4.1	Restoration effects were changed from the ERTG polygons based on information found on EP restoration website. Dike removal and ditch filling occurred in portion of site south of tide channel. Report states that Phase 1 didn't happen, which was a separate parcel to the south.
Lord - Walker Islands	2004	135.6		54.9	54.9	0.0	No wetland change detectable due to the restoration effort.
Mill Road	2011	18.7		0.0	19.7	19.7	
Multnomah Channel Metro	2014	119.8		0.0	97.9	97.9	

Project	Year	CRE-10.1 (ha)	CRE-10.2 (ha)	2004 Wetland Area (ha)	2016 Wetland Area (ha)	Restored Wetland (ha)	Notes
North Unit (Ruby Lake) Phase 1	2013	49.7		0.0	49.7	49.7	2010 Land cover indicates most of Ruby Lake was tidal wetland, however water-control structures were removed as part of the 2013 restoration, therefore areas were classified as recoverable prior to 2013.
North Unit (Three Fingered Jack) Phase 3	2015	36.7		2.4	35.0	32.6	
North Unit (Widgeon/Deep/ Millionaire) Phase 2	2014	52.5		0.0	71.3	71.3	2010 Land cover indicates most of Widgeon, Deep, and Millionaire Lakes were tidal wetland, however water-control structures were removed as part of the 2014 restoration, therefore areas were classified as recoverable prior to 2014.
Otter Point	2012	12.1		0.0	8.9	8.9	
Sandy River Dam Removal	2013	20.5		13.4	27.9	14.5	The 2016 wetland area was modified based on the 2 yr flood layer. The resulting wetland area was 7 ha larger than SBU 10.1, however, 13.4 ha were categorized as tidal wetland prior to restoration. The net increase was 14.5 ha restored.
South Tongue Point	2012		2.8	0.0	0.6	0.6	
Steamboat Slough	2014	27.4		0.0	27.4	27.4	
Thousand Acres	2014	11.3		0.0	10.9	10.9	
Trestle Bay	2016	254.1		85.0	85.0	0.0	2010 land cover indicates that 85 ha were tidal wetland prior to restoration, since the hydrology didn't change and the site had previously been connected to the River no wetland area was changed due to the restoration. However, an additional 7 outlets were added to the site to represent additional access points.
Vancouver Water Resources Center	2009	4.1		0.0	7.8	7.8	
Wallacut River	2016	18.5		0.0	10.1	10.1	
Walluski River North, Elliot #1	2008	6.1		0.0	17.7	17.7	Part of the area breached naturally in 2005, so overall increase at the site was larger than just the restored area
Westport Slough USFWS #1	2016	20.0		4.4	21.3	16.9	

Appendix E: Action Effectiveness Monitoring

Prepared by Sarah Kidd and Matt Schwartz

E.1 Introduction

Monitoring the physical and biological performance of restoration projects is an essential component of ecosystem restoration program adaptive management (NAS 2016). This point is recognized by CEERP managers and stakeholders (Ebberts et al. 2017). Since 2004, the estuary Action Agencies have funded action effectiveness monitoring (AEM) at over two-thirds of the 58 restoration projects that have been completed in the LCRE from 2004 through 2016 (Table E.1). The Action Agencies implement AEM under a programmatic framework (BPA and Corps 2017a). Because the programmatic framework mandates basic AEM[1] at all projects, the extent and intensity of restoration project monitoring has increased dramatically since 2012 (Table E.1) when CEERP was formalized (Ebberts et al. 2017). AEM data are comparable across projects, at least since 2009, because most data have been collected using standard protocols (Roegner et al. 2009). Much more AEM data are now available than have been reported to date. Therefore, a new comprehensive compilation and analysis of AEM data for restoration projects in the LCRE are warranted and timely. AEM analyses will be useful to CEERP managers and stakeholders seeking to improve implementation and effectiveness of the restoration program.

The overall objective of this appendix is to assess the effectiveness of CEERP restoration actions based on available monitoring data from individual project sites. The basic question CEERP managers and stakeholders have is: At the site scale, are restoration actions having the desired physical and biological effects? Specific sub-objectives[2] with rationales follow.

Photograph. Fyke net deployed in a tidal channel at low tide. Courtesy of N. Sather.

[1] Basic AEM is called "Level 3" in the *Programmatic Plan for Action Effectiveness Monitoring and Research* (BPA and Corps 2017). Basic AEM includes WSE, water temperature, sediment accretion, channel cross-sections, and photo points.
[2] Photo point data were not analyzed.

Table E.1. Action effectiveness monitoring by project[(a)] by year since 2004. Bolded red "X" indicates construction and monitoring occurred in that year. Bolded red "C" indicates construction but not monitoring occurred in that year. Highlight indicates data available for analysis (9/29/17).

`	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Batwater Station									X	X		**X**	X	X
Buckmire Slough											X	**X**	X	
Chinook River Estuary									X	X	**X**	X	X	X
Colewort Creek					X	X	X	X	**X**	X	X	X		
Crane Slough-Domeyer												X	**X**	X
Crims Island	**X**	**X**	X	X	X	X								
Dibblee Point									X	**X**	X	X	X	X
Elochoman Slough Thomas												**X**	X	X
Fee-Simon									X	X	**X**	X		
Fort Clatsop (South Slough)				**C**	X	X	X	X	X					
Fort Columbia								**X**						
Gnat Creek #1									**X**	X	X	X		
Gnat Creek #2										**C**	X	X		
Horsetail Creek										**X**	X	X	X	
JBH Mainland					**X**	**X**	X	X	X					
Kandoll Farm #2										**X**	X		X	
Karlson Island					X					X	**X**	X	X	X
Kerry Island												X	**X**	X
LA (Louisiana) Swamp									X	**X**	X	X		
LaCenter Wetlands										X	X	**X**	X	
Mill Road								**C**	X					
Mirror Lake Phase 1+2					**X**	X	**X**	X	X	X	X	X	X	X
Multnomah Channel Metro											**X**	X	X	
North Unit Ruby								X	X	**X**	X	X		
North Unit Widgeon/Deep/Millionaire										X	**X**	X		
North Unit Three Fingered Jack											X	**X**	X	
Otter Point									**X**	X	X	X		
Sandy River Dam Removal				X	X	X	X	X	X	**X**	X	X		
Steamboat Slough										X	**X**	X	X	X
Thousand Acres											**X**	X	X	
Vera Slough		X	**X**			X								
Wallacut River											X	X	**X**	X
Walluski River North, Elliot #1					**C**							X		X
Westport Slough USFWS #1												X	**X**	X
Willow Bar												X	**X**	X

(a) Kandoll Farm #1 is not included because the culverts installed for the project were subsequently removed and the dike at the location restored as part of the Kandoll Farm #2 project. Essentially the Kandoll Farm #2 project replaced the Kandoll Farm #1 project.

1. **Water-surface elevation (WSE)**. a) Determine the extent of hydrologic reconnection at the restoration site by comparing the time series of WSE before and after restoration inside and outside the restoration area; b) determine the number of days the maximum water-surface elevation exceeded the 2-year flood elevation for the project site over the available sampling period.

   WSE is the primary indicator of hydrographic conditions at a site. As such, it is fundamental to assessing the effectiveness of hydrologic reconnection actions. The expected 2-year flood elevation, or 50% exceedance probability over a 20-year water record, is the basic elevation for determining restoration project size (wetted area[3]) in the CEERP implementation process (ERTG 2013). The method for its calculation is a well-developed, standard procedure that can be consistently applied in both the fluvial and tidal-dominated portions of the estuary. Use of this elevation recognizes the "…ecological importance of the upland-intertidal ecotone, and the processes structuring the assemblage and the organic matter export function" (ERTG 2013). An effective restoration project would have a WSE that matches the conditions nearby outside the site, indicating hydraulics for the site are normal and unmanaged.

2. **Water Temperature**. a) Determine how the 7-day maximum moving average of daily water temperature (7-DMA) pre- and post-restoration temperatures compare to those at reference measurement sites outside the restoration site and in the mainstem; and b) compare pre/post-restoration habitat suitability to mainstem conditions.

   Water temperature is important because it affects fish growth (Brett 1979), physiological stress (McCullough 1999), and other factors. A critical upper threshold for optimum temperature for regulatory purposes is 17.5°C for rearing and migrating juvenile salmon (WADOE 2011), although juvenile salmon are found in the estuary water exceeding 20°C (e.g., Roegner and Teel 2014). An upper threshold of 22°C has been identified for moderately acclimated juvenile salmon by Washington Departments of Ecology (WADOE 2011). Generally, water temperatures in shallow-water habitats of the estuary are driven by ambient conditions in the adjacent mainstem estuary or tributary (e.g., Grays River confluence and the Kandoll Farm restoration site; Roegner et al. 2010). Water temperature conditions within restoration sites will vary depending on the extent of hydrologic connectivity to the mainstem and the degree of groundwater input (or other fluvial water sources) into the restoration site before and after restoration, given this, hydrologic reconnection should generally result in water temperature more consistent with mainstem conditions (Ennis 2009). An effective restoration project would have water temperatures that are similar to adjacent reference stream conditions and the mainstem.

3. **Habitat Opportunity**. Determine how overall salmonid habitat opportunity changed pre- and post-restoration based on WSE (water depth ≥0.5 m) and temperature thresholds (optimal ≤17.5°C and marginal 17.5–22°C).

   Water temperature and water depth in combination are an indicator of habitat opportunity for juvenile salmon (Bottom et al. 2011a). An effective restoration project would have greater habitat opportunity, which accounts for both temperature, depth, and access, after restoration than before. Pre-restoration opportunity water depth is determined based on the pre-restoration water-control structure elevation (i.e., dike, tide gate, etc.), while post-restoration opportunity is based on post-restoration channel elevation. By definition, a water depth of 0.5 m or more is needed to provide adequate salmonid access (Bottom et al. 2011a).

4. **Sediment Accretion**. a) Estimate sediment accretion rates by year at each restoration site and reference site (when available), and b) investigate the relationship between land elevation and sediment accretion rate.

[3] As used here, project size or "wetted area" is not necessarily the same as connected wetland in the habitat connectivity analysis (Section 2.2, Appendix C) because the connectivity analysis used wetland delineations from the 2010 land cover classification and project size is derived from the 2-year flood elevation.

Most previously diked restoration sites have subsided due to lack of sediment input and compaction from drainage and livestock. Improving hydrological connections is intended to improve sediment delivery, a natural process critical to rebuilding elevations within a subsided wetland (Thom 2002). More generally, sediment accretion/degradation is an important geomorphic process affecting habitat change over time and is relevant when sea-level rise is considered by restoration managers. An effective restoration project, especially previously diked sites, would typically have positive sediment accretion rates due to long-term subsidence from hydrologic disconnection (e.g., Thom 1992, Williams and Orr 2002, Turner 2004).

5. **Channel Cross Sections**. a) Estimate channel cross-sectional area, width at bank full elevation, and mean depth before (if data are available) and after restoration; and b) compare cross-sectional areas at sites that use active and passive approaches to channel formation before and after construction and over time.

   Channels are essential to reestablishing hydrologic connectivity at a previously disconnected restoration site. CEERP restoration projects can involve active (excavated) or passive (natural) or both forms of channel restoration. Monitoring cross sections is important because cross sections are an indicator of whether the project is self-maintaining, a basic goal for CEERP projects (Diefenderfer et al. 2008, Adamus 2005). Cross-sectional area is also critical for determination of material fluxes through the wetland.

6. **Vegetation**. For the herbaceous vegetation community at a given restoration site, a) assess species richness and percent cover by native vs. non-native plants before and after restoration and by restoration year (Figure 1.5), and b) compare results for restoration sites to reference sites.

   A vegetation community at a site dominated by native species reflects a functioning ecosystem (e.g., Suding et al. 2004, Smith and Warren 2012). Unfortunately, one non-native plant in particular, reed canarygrass (*Phalaris arundinacea*; RCG), is pervasive in much of the estuary. Restoring native vegetation communities through removal and control of RCG and planting of native species is a common objective of CEERP projects. An effective restoration project would have increasing richness and percent cover of native compared to non-native plant species over time (e.g., Suding et al. 2004, Smith and Warren 2012, approaching reference wetland conditions within 3-5 years post-restoration (Kidd 2017)

7. **Macroinvertebrates[4]**. a) Estimate macroinvertebrate species composition, density (#/m^2), and energy content (kJ/m^2) separately for samples from insect fallout traps, neuston drift nets, benthic invertebrate cores, and flux measurements; and b) compare these data between restoration and reference sites.

   Macroinvertebrates are important prey for juvenile salmon and steelhead (e.g., Storch and Sather 2011). Prey availability, thus, provides an indication of the functional value of sites to support juvenile salmon. Macroinvertebrates as salmon diet are covered in detail in Appendix F. Here focus is on the site-specific AEM results of macroinvertebrate community post-restoration compared to a reference site nearby. An effective restoration project would have macroinvertebrate prey being produced on the site and exported off the site.

8. **Juvenile Salmon**. a) Determine whether juvenile salmon are present inside a restoration site, and b) determine which salmon stocks are represented.

[4] Macroinvertebrate data from AEM are not included in SM2; they will be presented elsewhere at a later date.

CEERP's overall goal is to restore estuary ecosystems, which in turn is intended to benefit the juvenile life history stage of listed stocks of salmon (Ebberts et al. 2017). An effective restoration project would have juvenile salmon present and foraging on the site. Note, this AEM section focuses on the presence/absence and genetic stocks; aspects relevant to feeding and growth are covered under State of the Science, Chapter 5.

E.2 Methods

The technical approach to synthesizing site-scale AEM data involved analyses of standardized metrics across multiple projects. Numerous parties collected and provided AEM data. Data for years prior to the advent of the formal CEERP in 2012 are from individual RME projects, e.g., the Corps' Cumulative Effects Study. From 2012 to present day, restoration practitioners and researchers have collected AEM data from restoration and reference sites under the CEERP Programmatic AEMR Plan (BPA and Corps 2017a). Many of these data are compiled by the LCEP. Detailed methods for the descriptive summaries and analyses are presented below.

AEM has been conducted at 35 of the 58 restoration projects. AEM included before/after monitoring at 27 of the 35 projects; 10 of the 27 projects included restoration/reference site pairs, and 8 projects had only post-restoration monitoring (Table E.1). Site-scale AEM data included eight monitored indicators: WSE, water temperature, sediment accretion, channel cross section, vegetation, macroinvertebrates, fish capture, and fish passive integrated transponder (PIT) detection. Which indicators were monitored at a given project site depended on the restoration project objectives, available AEM resources, and other factors (BPA and Corps 2017a). Various data from 22 of these 35 sites were available and suitable for analysis for SM2 (Tables E.1 and E.2). Not all data that have been collected were available for analysis because they are yet to be compiled, quality assured, and transferred to a central data repository. For macroinvertebrate data in particular, samples were collected from 12 sites, but had yet to be processed from 11 of these sites.

Analysis methods were specific for each of the AEM sub-objectives. After the data were checked for quality and any errors corrected, data were reduced and analyzed to address the sub-objectives. The AEM analyses compared pre- and post-data when available. Analytical methods specific for each of the AEM sub-objectives follow.

E.2.1 Water-Surface Elevation

To determine the extent of hydrologic reconnection at the restoration site, we qualitatively compared the WSE time series of daily data from inside the restoration area for before versus after restoration. WSE measurements were made at 30 sites and results from 9 sites are presented here (Table E.2). To determine the proportion of time and when WSE exceeded a site's 2-year flood elevation, we used ERTG (2013) to look up the 2-year flood elevation for the site and then compared the measured values for WSE to this value. Proportions of time exceeding the 2-year flood elevation were computed by dividing the total number of WSE measurements exceeding the 2-year flood elevation by the total number of measurements in a given time period. Exceedance proportions were calculated monthly and for all sample time combined at a given site.

Table E.2. AEM monitored indicators by project. An X means data were collected. Green highlighting indicates data were available for analysis or citation (as of 9/29/17). A check mark means "yes" and a dash means "no." [(a)]Names of the reference sites are noted at the end of the table.

Project	Reference Site	Pre-Restoration Monitoring	Water Surface Elevation	Water Temp	Sediment Accretion	Channel X-sec	Photo Points	Vege-tation	Macro-inverts	Fish Capture	Fish PIT
Batwater Station	√	√	X	X	X		X		X	X	
Buckmire Slough	-	√	X	X	X		X				
Chinook River Estuary	-	√	X	X	X		X	X			
Colewort Creek	-	√	X	X	X				X		X
Crane Slough-Domeyer	-	√	X	X			X				
Crims Island	√	√	X	X	X	X	X	X	X	X	
Dibblee Point	√	√	X	X	X		X	X	X	X	
Elochoman Slough Thomas	-	√	X	X	X		X	X	X		
Fee-Simon	-	√	X	X	X		X				
Fort Clatsop (South Slough)	-	-	X	X		X		X		X	
Fort Columbia	-	√		X		X	X			X	X
Gnat Creek #1	-	-		X	X		X	X			
Gnat Creek #2	-	-			X		X				
Horsetail Creek	-	√	X	X	X	X	X				X
JBH Mainland	-	√	X	X						X	
Kandoll Farm #2	-	-	X	X	X	X	X	X	X		
Karlson Island	√	√	X	X	X		X			X	
Kerry Island	-	-	X	X	X	X	X				
LA (Louisiana) Swamp	-	√	X	X	X	X	X	X			
La Center Wetlands	-	√	X	X	X		X	X	X		
Mill Road	-	-	X		X	X	X	X			
Mirror Lake Phase 1+2	-	√		X		X			X	X	
Multnomah Channel Metro	-	√	X	X						X	X
North Unit Ruby	√	√	X	X	X		X	X	X		
North Unit Widgeon/Deep/Mil	√	√	X	X	X		X	X	X		
North Unit Three Fingered Jac	-	√	X	X	X		X				
Otter Point	-	√	X	X	X	X	X				
Sandy River Dam Removal	√	√	X	X		X	X	X	X	X	
Steamboat Slough	√	√	X	X	X	X	X	X	X	X	X
Thousand Acres	-	√	X	X	X		X				
Vera Slough	√	√	X	X	X	X	X	X		X	
Wallacut River	√	√	X	X	X	X	X	X			
Walluski River North, Elliot #	-	-	X		X	X	X	X			
Westport Slough USFWS #1	-	√	X	X	X		X				
Willow Bar	-	√	X	X			X				

E.2.2 Water Temperature

To determine how monthly maximum 7-DMA pre- and post-restoration temperatures compare to outer reference tributary and mainstem conditions we calculated the maximum 7-DMA temperature for each site and its reference to determine monthly average. Data are available from 9 of 32 sites where water temperature data were collected (Table E.2). An average of the 7-day average maximum daily water temperatures from the three Columbia mainstem data collection stations S4 (Tongue Point, CMOP), S5 (Beaver Army Terminal, CMOP, EP), and S8 (Washougal, EP) were used for comparison. Previous research has shown that mainstem temperatures do not vary significantly and using an average of these three stations provides an adequate representation of general mainstem conditions for any given time period (Sager et al. 2014). Data quality assurance measures included removing times the data logger was not inundated.

E.2.3 Habitat Opportunity

We also determined how overall salmonid habitat opportunity (days/month) changed pre- and post-restoration for each site. To determine how the restoration site's hydrologic reconnection actions changed the proportion of time (days/month) salmonids have access to the site (>0.5 m water depth) the water elevation required for fish access pre-and post-restoration were determined for each site. Pre-restoration this elevation was determined to be the top of the water-control structure/levee which was removed/lowered due to restoration actions and post-restoration the elevation of the channel connection (or new levee elevation) near the point of reconnection (where the water-control structure or levee was removed) was used. Using the post-restoration WSE data the number of days the WSE was at or above 0.5 meters in depth at these pre/post site access elevations were calculated. These data were then used to summarize the pre-and post-restoration change in salmonid access to the site. This analysis was conducted on mean daily WSE data and 7-day average maximum daily water temperatures. When the depth of the water was 0.5 meters or greater than the elevation of the water-control structure pre-restoration or 0.5 meters or more than the channel elevation post-restoration and the temperature was ≤17.5 C access was considered optimal, when temperature was 17.5-22 C, access was considered marginal. There were no instances of ≥0.5 meters of depth and greater than 22 C in water temperature. When the depth of the water was <0.5 meters then there was no salmonid access.

E.2.4 Sediment Accretion

To estimate sediment accretion rates by year at each site, we used yearly measurements of the distance from the top-of-stake level to the ground surface level collected using a standard protocol (Roegner et al. 2009). (Note, the protocol does not include estimation of sampling error.) Data are available for 8 of 27 sites where sediment accretion data were collected (Table E.2). We calculated the sediment accretion rate from year to year by subtracting the prior year's distance measurement from the later year's measurement. We averaged these yearly values to estimate sediment accretion rate (cm/yr) for a given site elevation. For sites where practitioners measured land elevation (referenced to the Columbia River datum) at the sediment accretion sampling location, we aggregated the data across restoration sites and plotted land elevation versus sediment accretion rate to determine the relationship between these variables.

E.2.5 Channel Cross Section

Cross-section data have been collected at 15 sites; data were available for analysis for 3 sites (Table E.2). To estimate channel cross-sectional area, width at bank full elevation, and mean depth as restoration progressed, we applied the methods of Diefenderfer et al. (2008). Changes were calculated by subtracting the prior years' estimates for area, width, and depth from a later years' estimates for the same survey transect. We tabulated cross-sectional areas by transect and sample survey for each site. Graphs of channel cross sections are also presented.

E.2.6 Vegetation

To assess species richness (number of species) and percent cover for the herbaceous vegetation community at a given restoration site, we categorized plants species by native/non-native and by wetland status. Diefenderfer et al. (2013a) provide a list of herbaceous plant species commonly found in the estuary that includes native plant and wetland status attributes. Wetland status is defined by information in the U.S. Department of Agriculture (USDA) plants database at http://plants.usda.gov/wetinfo.html#categories. We calculated species richness, species diversity, and relative cover for native and non-native plants out of the total assemblage for sampling episodes before and after restoration for seven restoration sites for which data were available, out of 17 restoration projects where vegetation data were collected (Table E.2).

E.2.7 Juvenile Salmon

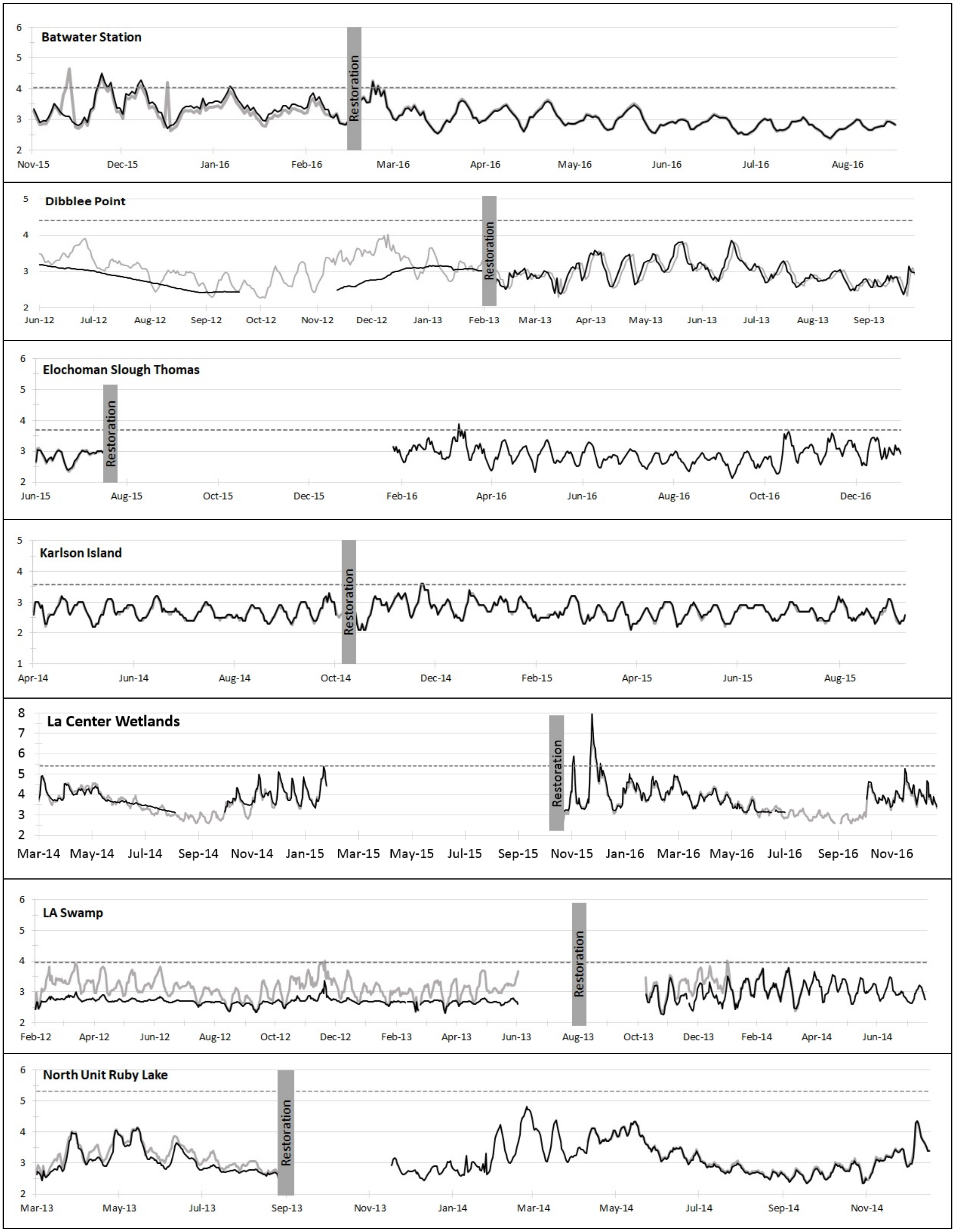
To assess the presence or absence of juvenile salmon or steelhead, and specifically determine whether salmon and steelhead from the interior Columbia River basin were present on the site, we used fish capture data from 10 sites and PIT detection data from 5 sites (Table E.2). Fish capture data included genetic stock identification (Teel et al. 2014) for at least 7 of the 10 fish capture efforts. We tabulated the fish findings by salmon species and stock for each applicable project. Similar analysis was performed for data from the five PIT sampling sites.

E.3 Results

We present results from analyses of AEM data specifically for SM2, along with legacy data from previously reported AEM. This section contains analytical results for WSE, water temperature, habitat suitability, sediment accretion rate, channel cross-sectional area, vegetation percent cover, macroinvertebrate density, and juvenile salmon presence/absence and genetic stock.

E.3.1 Water-Surface Elevation

Post-restoration WSE mirrored reference water elevations at sites and in a few cases achieved the 2-year flood elevation (Figure E.1; Table E.3). The magnitude of the change in WSE depended on the degree of hydrologic disconnection to adjacent mainstem river conditions. Batwater Slough, Dibblee Point, and Louisiana Swamp had poor connection to adjacent water bodies and restoration efforts resulted in a noticeable change in WSE, which matched that in an adjacent water body and the mainstem estuary. These sites achieved complete hydrographic reconnection. At sites with partial connectivity, a change in WSE was less pronounced but still indicated improved hydrologic function relative to pre-restoration and resulting in similar hydrology to adjacent reference sites. WSE exceeding the 2-year flood elevation was comparable between restoration and reference sites (Table E.4). Variability in climatic conditions between water years are the primary reason restoration sites did not exceed the 2-year flood elevation during the post-restoration data collection period. In cases in which hydrologic reconnection is not clear through the hydrograph, the habitat suitability/opportunity analysis which incorporates the removal of the hydrologic barrier through restoration is a better indicator of recovered/improved hydrologic connectivity (see habitat opportunity section).



Batwater Station
Restoration
Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16
Dibblee Point
Restoration
Jun-12 Jul-12 Aug-12 Sep-12 Oct-12 Nov-12 Dec-12 Jan-13 Feb-13 Mar-13 Apr-13 May-13 Jun-13 Jul-13 Aug-13 Sep-13
Elochoman Slough Thomas
Restoration
Jun-15 Aug-15 Oct-15 Dec-15 Feb-16 Apr-16 Jun-16 Aug-16 Oct-16 Dec-16
Karlson Island
Restoration
Apr-14 Jun-14 Aug-14 Oct-14 Dec-14 Feb-15 Apr-15 Jun-15 Aug-15
La Center Wetlands
Restoration
Mar-14 May-14 Jul-14 Sep-14 Nov-14 Jan-15 Mar-15 May-15 Jul-15 Sep-15 Nov-15 Jan-16 Mar-16 May-16 Jul-16 Sep-16 Nov-16
LA Swamp
Restoration
Feb-12 Apr-12 Jun-12 Aug-12 Oct-12 Dec-12 Feb-13 Apr-13 Jun-13 Aug-13 Oct-13 Dec-13 Feb-14 Apr-14 Jun-14
North Unit Ruby Lake
Restoration
Mar-13 May-13 Jul-13 Sep-13 Nov-13 Jan-14 Mar-14 May-14 Jul-14 Sep-14 Nov-14

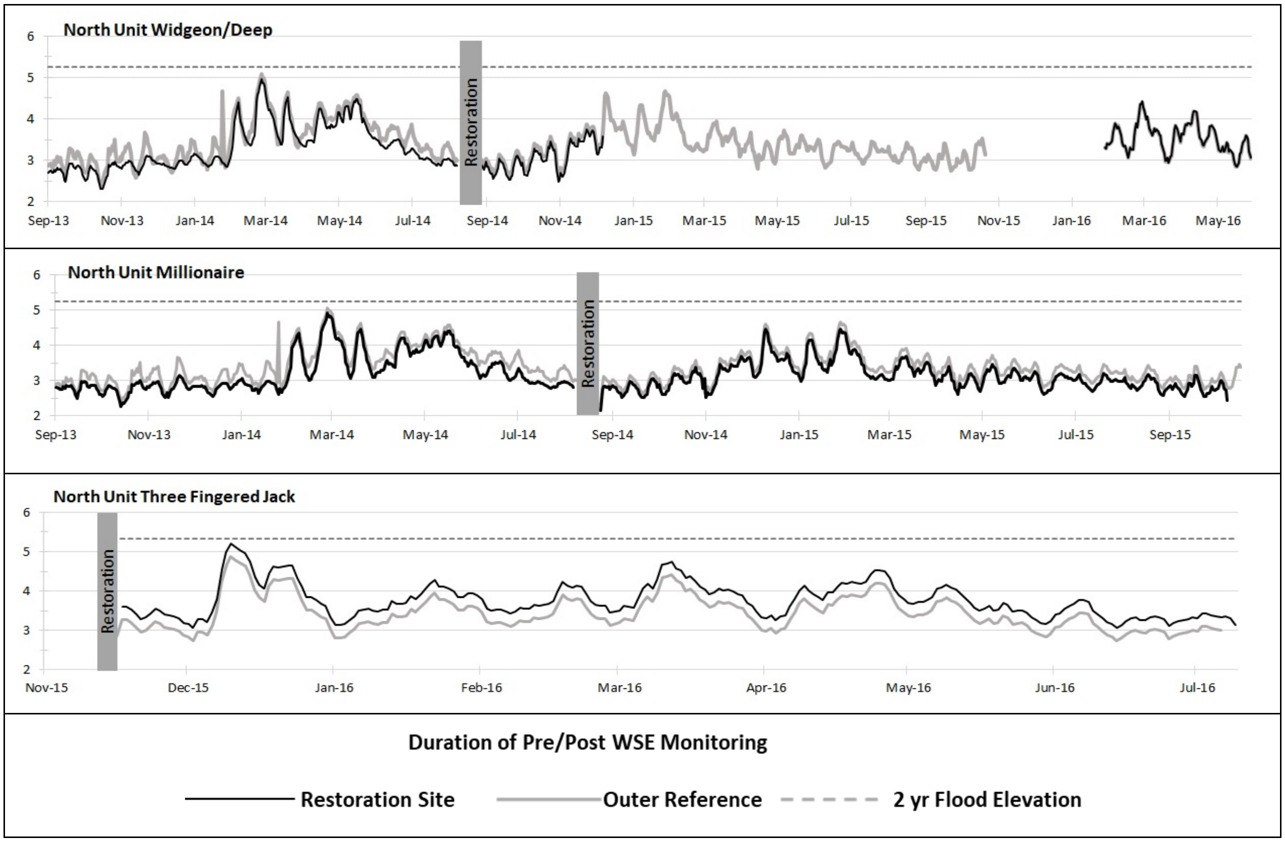


Figure E.1. Water-surface elevation (m, NAVD88) pre/post-elevation with 2-year flood elevation. The "reference" is located in a water body adjacent to the restoration site.

Table E.3. Number of days the maximum water-surface elevation exceeded the 2-year flood elevation for the project site. Mean and SE of WSE measurements (m, NAVD8) are also presented. Example for the Dibblee project. The "reference" is located in a water body adjacent to the restoration site.

Batwater Station													
Year		2015			2016								
Month		Octy	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Restored	n (days)	Restoration	14	31	31		31	30	31	30	31	31	2
	Mean Max		3.15	3.60	3.44		3.31	3.12	3.04	2.96	2.83	2.76	2.86
	SE		0.05	0.09	0.06		0.07	0.05	0.05	0.04	0.04	0.03	0.03
	Days Exceeded 2 yr Flood Elevation		0	8	1	0	2	0	0	0	0	0	0
Outside	n (days)		14	31	31		31	30	31	30	31	31	2
	Mean Max		3.37	3.48	3.33		3.32	3.13	3.05	2.97	2.83	2.76	2.86
	SE		0.14	0.09	0.06		0.07	0.05	0.05	0.05	0.04	0.03	0.03
	Days Exceeded 2 yr Flood Elevation		1	5	1	0	2	0	0	0	0	0	0

Dibblee Point

Year		2012							2013									
Month		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	23	31	31	26		12	31	31	Restoration	31	30	31	30	31	31	30	3
Restored	Mean	3.12	2.92	2.61	2.43		2.57	2.89	3.11		2.85	3.15	3.27	3.19	2.97	2.79	2.70	2.99
Restored	SE	0.01	0.02	0.02	0.00		0.01	0.03	0.01		0.04	0.06	0.06	0.05	0.04	0.03	0.03	0.01
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0
Reference	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30	3
Reference	Mean	3.43	3.30	2.90	2.64	2.70	3.14	3.56	3.10		2.83	3.12	3.25	3.17	3.01	2.80	2.67	3.01
Reference	SE	0.03	0.05	0.04	0.04		0.06	0.04	0.05		0.04	0.06	0.06	0.05	0.03	0.02	0.02	0.06
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0

Elochoman Slough Thomas

Year		2015		2016											
Month		Jun	Jul	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	30	Restoration	6	29	31	30	31	30	31	31	30	31	30	31
Restored	Mean	2.77		3.03	3.03	3.09	2.88	2.86	2.84	2.77	2.73	2.62	2.92	3.11	3.00
Restored	SE	0.04		0.05	0.04	0.06	0.05	0.04	0.04	0.03	0.03	0.04	0.07	0.05	0.05
Restored	Days Exceeded 2 yr Flood Elevation	0		0	0	1	0	0	0	0	0	0	0	0	0
Reference	n (days)	30													
Reference	Mean	2.75													
Reference	SE	0.04													
Reference	Days Exceeded 2 yr Flood Elevation	0		0	0	0	0	0	0	0	0	0	0	0	0

Karlson Island

Year		2014									2015									
Month		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	2	31	30	31	31	30	Restoration	21	31	31	28	31	30	31	30	31	31	30	9
Restored	Mean	2.8	2.81	2.70	2.71	2.62	2.64		2.66	3.03	2.84	2.87	2.68	2.59	2.64	2.66	2.74	2.71	2.67	2.56
Restored	SE	0.2	0.04	0.05	0.04	0.03	0.04		0.09	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.07
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0		0	2	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	2	31	30	31	31	30		30	31	31	28	31	30	31	30	31	31	30	9
Reference	Mean	2.85	2.82	2.69	2.68	2.60	2.63		2.75	3.03	2.85	2.87	2.68	2.58	2.63	2.63	2.73	2.68	2.64	2.52
Reference	SE	0.15	0.04	0.05	0.04	0.03	0.04		0.07	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.08
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0		0	2	0	0	0	0	0	0	0	0	0	0

La Center Wetlands

Year		2014									
Month		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	6	30	31	30	31	27		Restoration	30	31
Restored	Mean	4.44	4.03	4.18	3.74	3.53	3.24			3.87	4.10
Restored	SE	0.21	0.06	0.02	0.03	0.01	0.02			0.08	0.07
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0		0	0
Reference	n (days)	6	30	31	30	31	31	30		30	31
Reference	Mean	4.43	4.02	4.33	3.81	3.47	3.10	2.86		3.68	4.04
Reference	SE	0.19	0.07	0.03	0.03	0.04	0.03	0.03		0.10	0.07
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0		0	0

Year		2015											
Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	31	13									26	31
Restored	Mean	3.93	4.38									3.74	4.90
Restored	SE	0.08	0.17									0.15	0.21
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	2	9
Reference	n (days)	31	13									26	31
Reference	Mean	3.89	4.35									3.61	4.75
Reference	SE	0.07	0.14									0.14	0.19
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	1	8

Year		2016											
Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	31	29	31	30	31	28	12			19	30	31
Restored	Mean	4.05	4.08	4.23	3.85	3.50	3.26	3.16			4.04	3.99	3.93
Restored	SE	0.11	0.07	0.07	0.05	0.05	0.04	0.01			0.09	0.09	0.06
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	31	29	31	30	31	30	31	31	25	31	30	31
Reference	Mean	3.95	3.99	4.19	3.91	3.57	3.31	3.10	2.97	2.79	3.55	3.91	3.84
Reference	SE	0.09	0.06	0.07	0.06	0.05	0.05	0.03	0.03	0.03	0.10	0.07	0.05
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0	0

LA Swamp

Year		2012										
Month		Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	2	31	30	31	30	31	31	30	31	30	31
Restored	Mean	2.55	2.73	2.79	2.74	2.73	2.72	2.66	2.59	2.60	2.69	2.83
Restored	SE	0.12	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	2	31	30	31	30	31	31	30	31	30	31
Reference	Mean	2.71	3.24	3.35	3.25	3.29	3.22	3.00	2.77	2.87	3.17	3.48
Reference	SE	0.27	0.05	0.05	0.05	0.04	0.05	0.03	0.04	0.06	0.06	0.05
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	2

Year		2013											
Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	31	28	29	30	31	30	1		Restoration		23	30
Restored	Mean	2.69	2.66	2.64	2.65	2.68	2.67	2.61				2.75	2.85
Restored	SE	0.01	0.01	0.02	0.02	0.01	0.01					0.07	0.05
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0		0	0	0
Reference	n (days)	31	28	30	30	31	30	1				24	31
Reference	Mean	3.07	2.97	2.93	3.04	3.11	3.14	3.67				2.88	3.22
Reference	SE	0.05	0.04	0.04	0.06	0.06	0.03					0.07	0.05
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0		0	0	0

Year		2014							
Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Restored	n (days)	31	28	31	30	31	30	31	18
Restored	Mean	2.95	3.02	3.21	3.11	3.19	3.04	2.98	2.90
Restored	SE	0.05	0.06	0.05	0.07	0.04	0.04	0.04	0.05
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0
Reference	n (days)	31	28	31	15				
Reference	Mean	3.44	3.03	3.21	2.93				
Reference	SE	0.05	0.06	0.05	0.11				
Reference	Days Exceeded 2 yr Flood Elevation	1	0	0	0	0	0	0	0

North Unit Ruby Lake

Year		2013										2014											
Month		Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	17	30	31	30	31	31	Restoration			31	31	28	31	30	31	30	31	31	30	31	29	31
Restored	Mean	2.69	3.28	3.60	3.19	2.94	2.73				2.74	2.83	3.25	3.95	3.55	3.97	3.44	3.06	2.75	2.59	2.68	2.86	3.44
Restored	SE	0.03	0.07	0.08	0.05	0.03	0.01				0.03	0.03	0.09	0.10	0.07	0.04	0.04	0.03	0.02	0.02	0.03	0.05	0.07
Restored	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	17	30	31	30	31	31								7	31	30	31	31	30	31	30	31
Reference	Mean	2.85	3.46	3.71	3.41	3.17	2.90								3.98	3.97	3.46	3.10	2.80	2.63	2.72	2.89	3.46
Reference	SE	0.05	0.06	0.06	0.05	0.04	0.02								0.06	0.04	0.04	0.03	0.02	0.02	0.04	0.05	0.07
Reference	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

North Unit Widgeon/Deep																							
Year		2013				2014												2016					
Month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	26	31	30	19		20	31	30	31	10
	Mean	2.72	2.68	2.85	2.93	2.99	3.41	4.09	3.71	4.08	3.55	3.17		2.79	2.91	3.12	3.49		3.49	3.72	3.66	3.36	3.36
	SE	0.02	0.03	0.02	0.02	0.02	0.09	0.09	0.06	0.04	0.04	0.03		0.03	0.04	0.06	0.04		0.05	0.07	0.06	0.05	0.06
	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
Reference	n (days)	18	31	30	31	31	28	31	30	31	30	31		26	31	30	31		20	31	30	31	10
	Mean	2.90	2.91	3.06	3.09	3.17	3.61	4.24	3.86	4.23	3.78	3.43		2.91	3.03	3.24	3.80		3.49	3.71	3.64	3.34	3.34
	SE	0.04	0.04	0.04	0.04	0.04	0.10	0.09	0.07	0.04	0.03	0.04		0.03	0.04	0.06	0.06		0.05	0.07	0.06	0.05	0.06
	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0

North Unit Millionaire																											
Year		2013				2014												2015									
Month		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	26	31	30	31	31	28	31	30	31	30	31	31	30	20
	Max Mean WSE	2.77	2.70	2.81	2.83	2.86	3.27	4.03	3.62	4.06	3.48	3.08		2.74	2.86	3.09	3.63	3.52	3.77	3.25	3.11	3.07	3.01	2.99	2.96	2.81	2.74
	SE	0.03	0.03	0.02	0.03	0.02	0.10	0.10	0.07	0.04	0.05	0.03		0.03	0.04	0.05	0.06	0.06	0.08	0.04	0.05	0.03	0.04	0.03	0.02	0.03	0.04
	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)	18	31	30	31	31	28	31	30	31	30	31		26	31	30	31	31	28	31	30	31	30	31	31	30	29
	Mean	2.90	2.91	3.06	3.08	3.17	3.61	4.24	3.86	4.23	3.78	3.43		2.91	3.03	3.24	3.80	3.70	3.99	3.48	3.34	3.31	3.24	3.22	3.19	3.03	3.02
	SE	0.04	0.04	0.04	0.04	0.04	0.10	0.09	0.07	0.04	0.03	0.04		0.03	0.04	0.06	0.06	0.06	0.07	0.04	0.05	0.04	0.04	0.03	0.03	0.03	0.04
	Days Exceeded 2 yr Flood Elevation	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0

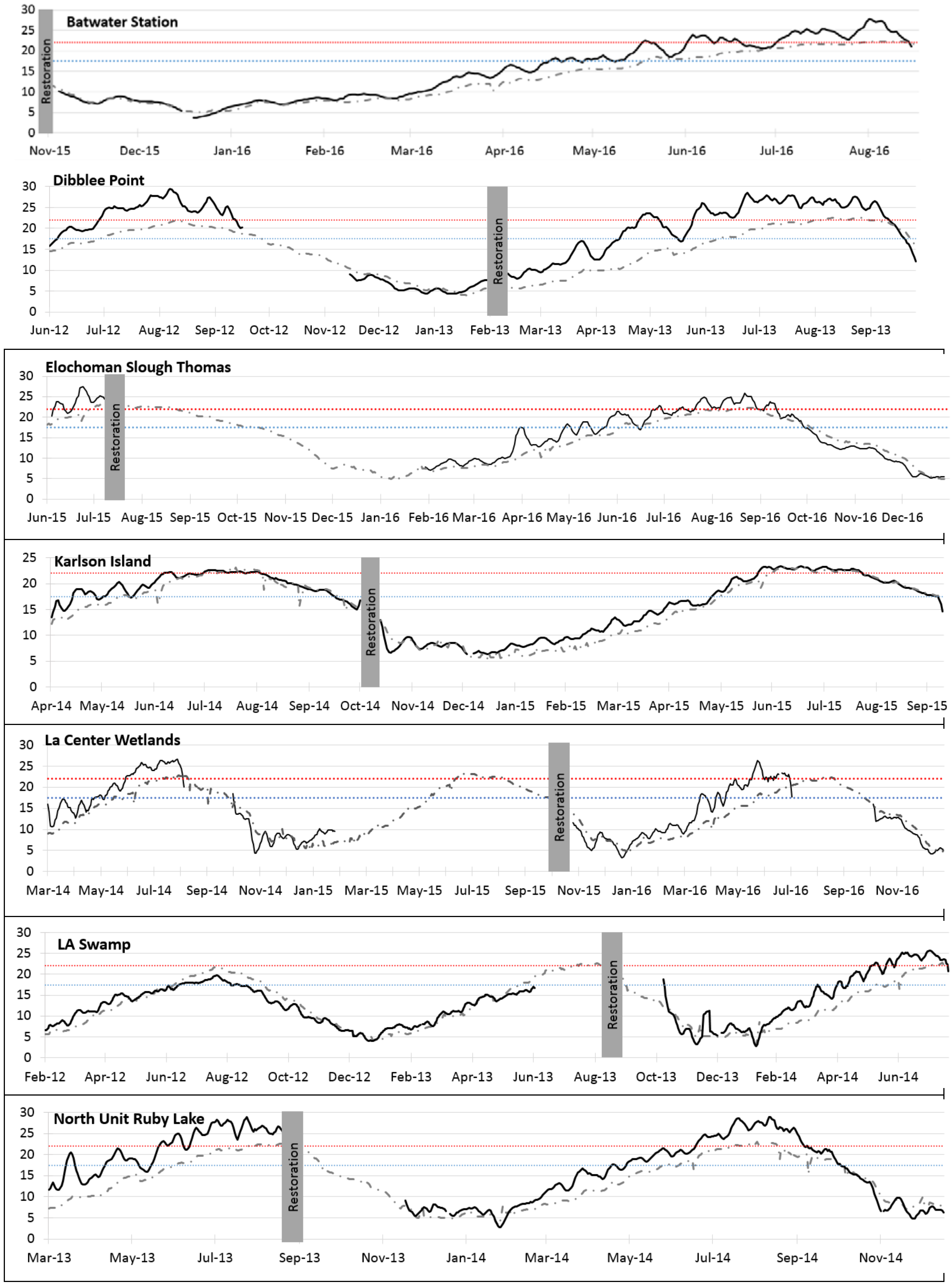
North Unit Three Fingered Jack															
Year		2015			2016										
Month		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Restored	n (days)	Restoration	14	31	31	28	31	30	31	30	9			19	15
	Mean		3.43	4.15	3.72	3.72	4.03	3.97	3.65	3.36	3.34			3.51	3.40
	SE		0.03	0.12	0.06	0.05	0.07	0.07	0.05	0.04	0.03			0.05	0.04
	Days Exceeded 2 yr Flood Elevation		0	0	0	0	0	0	0	0	0	0	0	0	0
Reference	n (days)		16	31	31	28	31	30	31	30	6			20	15
	Mean		3.08	3.82	3.39	3.39	3.71	3.65	3.32	3.04	3.05			3.15	3.07
	SE		0.03	0.12	0.06	0.05	0.07	0.07	0.05	0.04	0.02			0.05	0.04
	Days Exceeded 2 yr Flood Elevation		0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.4. Percent time post-restoration water-surface elevation exceeded the 2-year flood elevation for a given season.

Water Year	Site	Two Year Flood Elevation	Jan, Feb, Mar	Apr, May, Jun,	Jul, Aug, Sept	Oct, Nov, Dec
2013	Dibblee Point	4.4	0	0	0	0
	La Swamp	3.97	No Data			0
2014	Karlson	3.58	0	0	0	4%
	LA Swamp	3.97	0	0	0	0
	North Unit Millionaire	5.26	No Data			0
	North Unit Ruby Lake	5.31	0	0	0	0
	North Unit Widgeon/Deep	5.26	No Data			0
2015	Karlson	3.58	0	0	0	No Data
	La Center	5.24	0	No Data		19%
	North Unit Three Fingered Jack	5.34	No Data			0
	North Unit Millionaire	5.26	0		0	0
2016	Batwater	4.04	6%	0	0	0
	La Center	5.24	0	0	No Data	0
	Elochoman	3.69	0	2%	0	0
	North Unit Three Fingered Jack	5.34	0	0	0	0
	North Unit Widgeon/Deep	5.26	0	0	No Data	

E.3.2 Water Temperature

Variability in climatic conditions between water years are an important driver of differences in water temperature before and after restoration occurred among all of the restoration sites. Generally, water temperatures among the restored wetlands matched the mainstem conditions (Figure E.2). Restoration site water temperatures typically were similar to mainstem conditions in the early fall and conversely became slighter warmer than the mainstem in the early summer (Figure E.2). This pattern of seasonal differences between restoration sites and the mainstem is simply reflecting the seasonal influence climate has on these smaller water bodies compared to the mainstem conditions. The maximum mean monthly temperatures at most restoration sites stayed below 22°C during March through June; during July and August temperatures regularly exceeded 22°C, similar to the trend seen in the mainstem temperature conditions during these time periods. At restoration sites, diurnal changes in temperature were greater than in the mainstem estuary, although they followed the same general weekly trend as in the mainstem (Table E.5). Overall, the adjacent mainstem estuary had a higher proportion of days at < 17.5°C than the nearby restoration sites and a lower proportion of days > 22°C (Table E.6).


Batwater Station
Restoration
Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16
Dibblee Point
Restoration
Jun-12 Jul-12 Aug-12 Sep-12 Oct-12 Nov-12 Dec-12 Jan-13 Feb-13 Mar-13 Apr-13 May-13 Jun-13 Jul-13 Aug-13 Sep-13
Elochoman Slough Thomas
Restoration
Jun-15 Jul-15 Aug-15 Sep-15 Oct-15 Nov-15 Dec-15 Jan-16 Feb-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16 Sep-16 Oct-16 Nov-16 Dec-16
Karlson Island
Restoration
Apr-14 May-14 Jun-14 Jul-14 Aug-14 Sep-14 Oct-14 Nov-14 Dec-14 Jan-15 Feb-15 Mar-15 Apr-15 May-15 Jun-15 Jul-15 Aug-15 Sep-15
La Center Wetlands
Restoration
Mar-14 May-14 Jul-14 Sep-14 Nov-14 Jan-15 Mar-15 May-15 Jul-15 Sep-15 Nov-15 Jan-16 Mar-16 May-16 Jul-16 Sep-16 Nov-16
LA Swamp
Restoration
Feb-12 Apr-12 Jun-12 Aug-12 Oct-12 Dec-12 Feb-13 Apr-13 Jun-13 Aug-13 Oct-13 Dec-13 Feb-14 Apr-14 Jun-14
North Unit Ruby Lake
Restoration
Mar-13 May-13 Jul-13 Sep-13 Nov-13 Jan-14 Mar-14 May-14 Jul-14 Sep-14 Nov-14

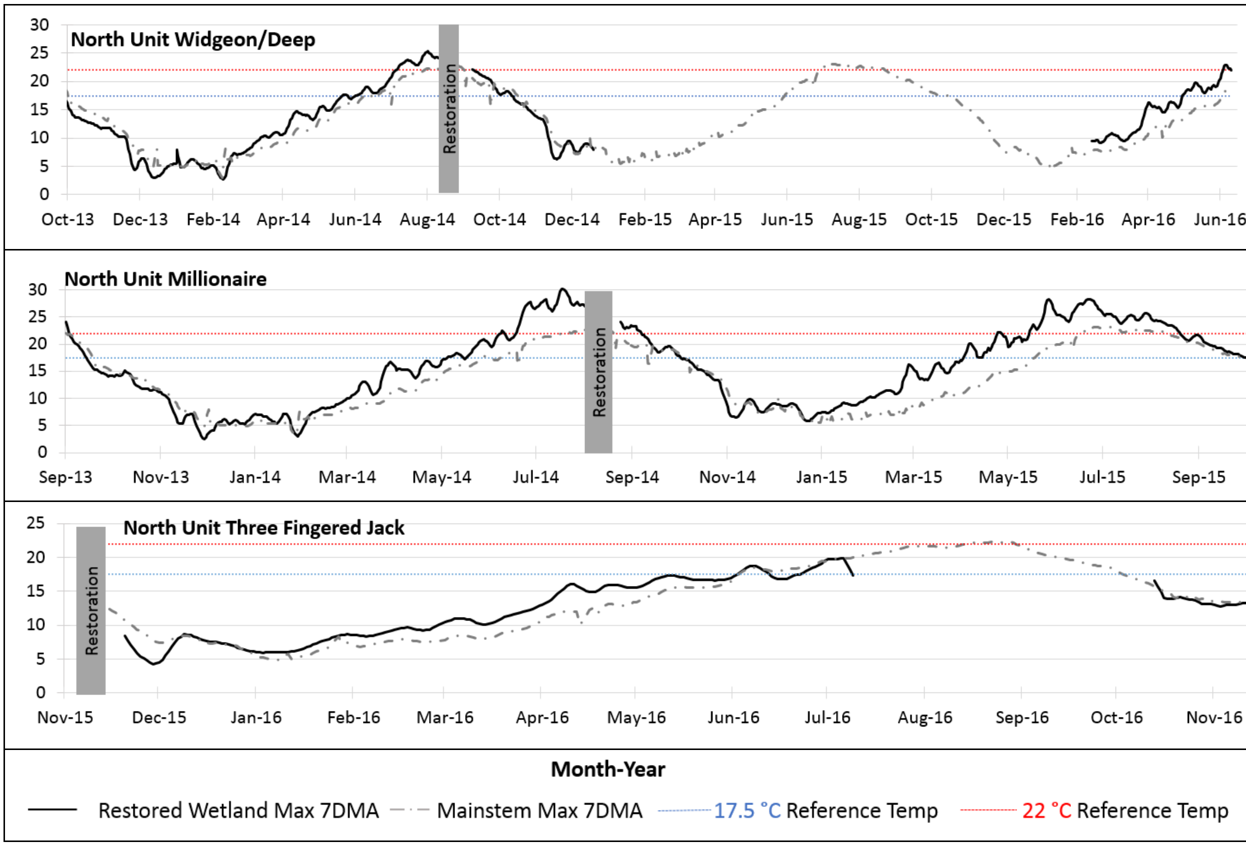


Figure E.2. Pre- and post-restoration water temperatures (°C) for restoration sites and mainstem estuary.

Table E.5. Monthly maximum mean water temperature at restoration, reference, and mainstem locations. Example for the Dibblee project. Temperatures greater than 17.5°C are in yellow and temperatures greater than 22°C are in red.

Batwater Station

	Year	2015			2016							
	Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Restored	n (days)		11	31	28		31	30	31	30	31	31
	Mean		8.7	7.6	6.1		10.0	14.9	18.1	21.7	22.7	24.8
	SE		0.3	0.2	0.3		0.3	0.2	0.1	0.3	0.3	0.3
Main Stem	n (days)	Restoration	14	31	31	29	31	30	31	30	31	31
	Mean		9.6	7.4	6.0	7.48	8.7	12.2	15.2	18.3	20.6	21.9
	SE		0.4	0.1	0.2	0.06	0.1	0.2	0.1	0.1	0.1	0.1

Dibblee Point

	Year	2012							2013								
	Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Restored	n (days)	23	31	31	23		9	31	31		31	30	31	30	31	31	30
	Mean	18.9	24.0	26.6	24.2		8.0	6.6	5.0		11.9	16.4	20.6	24.1	26.9	26.4	22.3
	SE	0.3	0.3	0.3	0.5		0.2	0.2	0.1		0.4	0.5	0.4	0.2	0.2	0.1	0.6
Reference	n (days)	23	31	31	30	31	30	31	31	Restoration	31	30	31	30	31	31	30
	Mean	18.9	22.9	25.2	22.0	15.8	11.0	7.2	5.0		10.1	13.8	17.2	21	25.0	24.4	22.0
	SE	0.4	0.2	0.3	0.3	0.4	0.3	0.2	0.1		0.3	0.3	0.2	0.2	0.1	0.1	0.6
Main Stem	n (days)	23	31	31	30	31	30	31	31		31	30	31	30	31	31	30
	Mean	15.8	18.7	21	19.5	15.6	11.5	7.8	4.9		7.4	10.5	14.2	17	20.7	22.0	21
	SE	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.1		0.2	0.1	0.1	0.2	0.1	0.1	0.3

Elochoman Slough Thomas

	Year	2015							2016											
	Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	27	13							29	31	30	31	30	31	31	30	31	30	28
	Mean	23.7	24.2							8.6	10.6	14.7	17.8	20	22.2	23.7	20.8	13.8	11.1	6.0
	SE	0.4	0.2							0.1	0.5	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.2
Reference	n (days)	30	13	Restoration																
	Mean	22.9	24.6																	
	SE	0.3	0.3																	
Main Stem	n (days)	30	31		30	31	30	31	31	29	31	30	31	30	31	31	30	31	30	31
	Mean	20	22.8		19.6	17	11.8	7.4	6.0	7.5	8.7	12.2	15.2	18	20.6	21.9	19.8	15.4	12.4	6.6
	SE	0.2	0.1		0.2	0.2	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3

Karlson Island

	Year	2014									2015									
	Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	2	31	30	31	31	30		21	31	28	28	31	30	31	30	31	31	30	9
	Mean	14.0	17.3	19.1	21.8	22.3	20.3		8.7	8.0	7.2	8.7	10.9	13.6	16.7	21.3	23.0	22.3	19.5	17.1
	SE	0.5	0.2	0.2	0.1	0.0	0.2		0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.0	0.1	0.2	0.4
Reference	n (days)	2	31	30	31	31	30	Restoration	30	31	31	28	31	30	31	30	31	31	30	9
	Mean	17.1	18.1	20.8	23.9	23.7	20.6		10.8	8.3	6.8	8.4	10.3	13.2	16.5	21	23.0	22.3	19.5	18.2
	SE	0.0	0.2	0.2	0.2	0.2	0.2		0.7	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.0	0.1	0.2	0.1
Main Stem	n (days)	2	31	30	31	30	28		30	31	31	28	31	30	31	30	31	31	30	9
	Mean	12.6	14.7	17.5	20.7	22.5	19.7		11.0	7.9	6.1	6.8	8.6	11.6	15.5	20	22.8	22.2	19.6	17.8
	SE	0.4	0.2	0.1	0.2	0.0	0.2		0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1

La Center Wetlands

	Year	2014										2015				2016											
	Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	6	30	31	30	31	27		Restoration	30	31	31	13	23	31	31	29	31	30	31	28	12			19	30	31
	Mean	12.4	14.7	16.7	20.9	24.8	25.4			8.8	7.8	7.7	9.5	8.3	7.2	6.7	9.6	11.6	17	20.8	23.2	22.1			12.9	11.1	5.6
	SE	0.9	0.3	0.2	0.3	0.1	0.3			0.5	0.2	0.2	0.1	0.5	0.3	0.4	0.2	0.4	0.3	0.2	0.3	0.5			0.2	0.3	0.2
Reference	n (days)	6	30	31	30	31	31	30		30	31	31	10	26	31	31	29	31	30	31	30	31	31	25	31	30	31
	Mean	9.9	10.8	14.0	17.5	22.4	23.6	19.4		8.1	7.8	7.4	8.8	8.2	7.4	6.5	8.3	9.1	12.9	16.5	20	21.6	22.7	18	12.2	10.3	6.1
	SE	0.6	0.1	0.3	0.2	0.3	0.1	0.2		0.4	0.2	0.2	0.1	0.4	0.2	0.3	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.3	0.3	0.2	0.2
Main Stem	n (days)	6	30	31	30	31	30	28		30	31	31	28	30	31	31	29	31	30	31	30	31	31	30	31	30	31
	Mean	9.1	11.0	14.7	17.5	20.7	22.5	19.7		11.0	8.0	6.1	6.8	11.8	7.4	6.0	7.5	8.7	12.2	15.2	18	20.6	21.9	20	15.4	12.4	6.6
	SE	0.0	0.2	0.2	0.1	0.2	0.0	0.2		0.4	0.1	0.1	0.1	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3

LA Swamp

	Year	2012											2013												2014							
	Month	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Restored	n (days)	2	31	30	31	30	31	31	30	31	30	31	31	28	30	30	31	30			Restoration		24	31	28	28	31	30	31	30	31	19
	Mean	6.6	8.5	11.7	14.4	15.9	17.5	18.8	16.9	13.2	10.2	7.5	5.0	7.3	8.4	11.6	14.2	15.7					9.7	6.5	6.9	6.8	11.9	15.3	19	22	24.6	23.9
	SE	0.0	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.1	0.1	0.2	0.2	0.1	0.1					0.7	0.5	0.1	0.4	0.2	0.3	0.2	0.2	0.1	0.3
Reference	n (days)	2	31	30	31	30	31	31	30	31	30	28	31	28	31	30	31	30					24	31	31	28	31	16				
	Mean	8.1	10.6	13.8	17.7	19.5	21.6	23.7	21.6	16.0	10.4	7.5	5.9	8.8	10.3	13.4	17.5	19.3					10.5	5.3	6.6	7.6	12.4	15.6				
	SE	0.2	0.4	0.3	0.3	0.2	0.1	0.2	0.3	0.6	0.4	0.2	0.2	0.2	0.3	0.3	0.2	0.2					0.5	0.2	0.1	0.4	0.5	0.6				
Main Stem	n (days)	2	31	30	31	30	31	31	30	31	30	31	31	28	31	30	31	30	31	31		31	30	31	31	27	31	30	31	30	31	19
	Mean	5.6	6.6	9.6	13.1	15.5	18.7	21	19.5	15.6	11.5	7.8	4.9	5.7	7.4	10.5	14.2	17.3	20.7	22		14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	18	21	22
	SE	0.0	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1		0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2	0.1

North Unit Ruby Lake

	Year	2013										2014											
	Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Restored	n (days)	17	30	31	30	31	31	Restoration			31	29	28	31	30	31	30	31	31	30	31	29	31
	Mean	14.5	15.8	18.5	22.9	26.5	26.3				7.0	6.6	6.1	11.0	15.0	18.1	20.5	24.4	27.5	23.9	18	9.9	6.5
	SE	0.8	0.4	0.3	0.3	0.2	0.2				0.1	0.1	0.4	0.3	0.2	0.2	0.1	0.2	0.2	0.4	0.4	0.5	0.2
Reference	n (days)	15	30	31	30	31	31								5	31	30	31	31	30	31	30	31
	Mean	15.4	15.7	18.4	22.9	26.5	26.3								16.0	18.9	21.8	27.2	26.0	22.2	17	9.8	8.7
	SE	0.8	0.4	0.3	0.3	0.2	0.2								0.8	0.2	0.2	0.2	0.2	0.3	0.3	0.5	0.1
Main Stem	n (days)	17	30	31	30	31	31		31	30	31	31	27	31	30	31	30	31	24	28	31	30	31
	Mean	8.1	10.5	14.2	17.3	20.7	22		14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	17.5	20.7	22.4	19.7	17	11.0	8.0
	SE	0.2	0.1	0.1	0.2	0.1	0.1		0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.4	0.1

North Unit Widgeon/Deep

	Year	2013				2014												2016					
	Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	23	31	30	19		17	31	30	31	10
	Mean	19.2	13.0	8.9	4.6	5.4	5.5	9.9	13.5	16.3	18.6	23.2		20	16.4	9.6	8.3		9.7	11.2	15.7	18.9	22.2
	SE	0.5	0.2	0.5	0.2	0.1	0.3	0.2	0.2	0.2	0.1	0.2		0.3	0.2	0.5	0.1		0.1	0.3	0.1	0.1	0.2
Reference	n (days)	18	31	30	28	31	28	31	30	31	30	31		23	31	30	31		20	31	30	31	10
	Mean	19.4	13.4	9.2	4.5	5.5	5.8	10.2	14.0	17.1	19.5	23.6		22	17.2	10.1	8.4		10.0	12.0	15.4	19.2	22.8
	SE	0.5	0.2	0.5	0.3	0.1	0.3	0.2	0.2	0.2	0.1	0.2		0.4	0.3	0.5	0.1		0.1	0.3	0.2	0.2	0.6
Main Stem	n (days)	18	31	30	31	31	27	31	30	31	30	31		28	31	30	31	31	29	31	30	31	10
	Mean	20.2	14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	17.5	20.7		20	17.3	11.0	8.0	6.0	7.5	8.7	12.2	15.2	18
	SE	0.3	0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2		0.2	0.3	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0.2

North Unit Millionaire

	Year	2013				2014												2015									
	Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Restored	n (days)	18	31	30	31	31	28	31	30	31	30	31	Restoration	26	31	30	31	31	28	31	30	31	30	31	31	30	17
	Mean	19.4	14.1	9.4	5.0	6.2	6.2	10.5	14.8	17.1	20.7	27.2		22	17.3	9.9	8.4	7.6	10.2	14.2	17	21.2	25.8	25.9	24.2	20	18
	SE	0.56	0.17	0.45	0.24	0.11	0.34	0.28	0.26	0.14	0.18	0.29		0.3	0.3	0.49	0.11	0.19	0.18	0.31	0.3	0.21	0.27	0.3	0.16	0.2	0.1
Reference	n (days)	18	31	30	31	31	28	31	30	31	30	31		23	31	30	31	31	28	31	30	31	30	31	31	30	29
	Mean	18.9	13.4	9.2	4.6	5.5	5.8	10.2	14.0	17.1	19.5	23.6		21	17	10.1	8.4	7.4	9.8	12.6	15.2	19.3	24.6	25.9	24.2	21	17
	SE	0.4	0.2	0.5	0.2	0.1	0.3	0.2	0.2	0.2	0.1	0.2		0.3	0.3	0.5	0.1	0.2	0.1	0.3	0.2	0.2	0.4	0.2	0.1	0.2	0.2
Main Stem	n (days)	18	31	30	31	31	27	31	30	31	30	31		28	31	30	31	31	28	31	30	31	30	31	31	30	29
	Mean	20.2	14.9	10.6	5.8	5.5	5.9	8.1	11.0	14.7	17.5	20.7		20	17.3	11.0	8.0	6.1	6.8	8.6	11.6	15.5	20	22.8	22.2	20	17
	SE	0.3	0.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.2		0.2	0.3	0.4	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1

North Unit Three Fingered Jack													
Year		2015		2016									
Month		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Restored	n (days)	Restoration	31	31	28	31	30	31	30	9			19	15
	Mean		7.1	7.0	9.1	11.1	15.2	16.7	17.9	19.2			14.0	13.0
	SE		0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.3			0.2	0.1
Reference	n (days)		31	31	28	31	30	31	30	6			20	12
	Mean		6.7	6.2	9.5	12.0	17.7	21	23.7	22			14.2	13.8
	SE		0.2	0.4	0.2	0.4	0.2	0.2	0.4	0.7			0.3	0.1
Main Stem	n (days)		31	31	28	31	30	31	30	31	31	30	31	15
	Mean		7.4	6.0	7.5	8.7	12.2	15.2	18.3	20.6	21.9	19.8	15.4	13.4
	SE		0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.1

Table E.6. Percent time post-restoration mean monthly water temperature was <17.5°C, 17.5–22°C, and >22°C for spring and summer months. Columbia River temperature level is from Table 1.5.

			Spring - Apr, May, Jun,			Summer - Jul, Aug, Sept		
Water Year	Site		**<17.5°C**	**17.5 - 22°C**	**>22**	**<17.5°C**	**17.5 - 22°C**	**>22**
2013	Dibblee Slough	Restored	33	33	33			100
		Reference	66		33			100
	Mainstem		100				100	
2014	LA Swamp	Restored	33	33	33			100
		Reference	No Data			No Data		
	North Unit Ruby	Restored	33	66				100
		Reference	33	66				100
	Mainstem		66	33			66	33
2015	Karlason	Restored	66	33			33	66
		Reference	66	33			33	66
	North Unit Millionaire	Restored	33	33	33		33	66
		Reference	33	33	33		33	66
	Mainstem		66	33			33	66
2016	Batwater	Restored	33	66			33	66
		Reference	66	33			66	33
	Elochoman	Restored	33	66			33	66
		Reference	No Data			No Data		
	La Center	Restored	33	33	33			66
		Reference	66	33			66	33
	North Unit Three Fingered Jack	Restored	66	33		No Data		
		Reference		66	33	No Data		
	North Unit Widgeon Deep	Restored	33	33	33			33
		Reference	33	33	33			33
	Mainstem		66	33			100	

E.3.3 Habitat Opportunity

Post-restoration, juvenile salmon access to suitable habitat within restoration sites increased compared to pre-restoration conditions (Table E.7). Post-restoration site conditions with a depth 0.5 m or greater and a temperature threshold less than 17.5°C increased by 85% on average for all projects combined in April (Table E.7). In May and June for the same water depth and temperature criteria, post-restoration average increases in habitat opportunity were 30% and 4% respectively. Restoration site habitat opportunity for the same depth parameters but a temperature threshold between 17.5°C and 22°C increased 12% in April, 44% in May, and 29% June on average (Table E.8). The month of June primarily had a temperature threshold greater than 22°C and also had the most periods of no access (i.e., barrier or low water levels), however, the post-restoration periods of no access were lower than pre-restoration condition (Table E.9).

Table E.7. Percent time with 0.5 m water depth and water temperature used to establish site opportunity. Example for the Dibblee project.

Batwater Opportunity (% Access)											
Year	2015			2016							
Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Good <17.5 Pre	Restoration	0	0	0		97%	90%	13%	0	0	0
Fair 17.5-22 Pre		0	0	0		0	0	81%	37%	16%	3%
Poor >22 Pre		0	0	0		0	0	0	47%	48%	61%
No Access		100%	100%	100%		3%	10%	6%	17%	35%	35%

Dibblee Point Opportunity (% Access)																
Years	2012							2013								
Months	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 Pre	0	0	0	0		0	0	0	Restoration	84%	67%	10%	0	0	0	7%	100%
Fair 17.5-22 Pre	0	0	0	0		0	0	0		0	33%	52%	0	0	0	27%	0
Poor >22 Pre	0	0	0	0		0	0	0		0	0	39%	100%	97%	87%	53%	0
No Access	100%	100%	100%	100%		100%	100%	100%		16%	0%	0%	0%	3%	13%	13%	0%

Elochoman Slough Thomas Opportunity (% Access)															
Year	2015			2016											
Month	Jun	Jul	Aug	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	0	0	Restoration	100%	100%	97%	93%	52%	7%	0	0	3%	100%	100%	100%
Fair 17.5-22 Pre	0	0		0	0	0	0	0	0	0	0	0	0	0	0
Poor >22 Pre	0	0		0	0	0	0	0	10%	45%	97%	27%	0	0	0
No Access	100%	100%		0%	0%	3%	7%	48%	83%	55%	3%	70%	0%	0%	0%

Karlson Island Opportunity (% Access)																		
Year	2014								2015									
Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 Pre	0	0	0	0	0	Restoration	100%	100%	100%	100%	100%	100%	81%	0	0	0	0	33%
Fair 17.5-22 Pre	0	0	0	0	0		0	0	0	0	0	0	19%	70%	0	29%	100%	67%
Poor >22 Pre	0	0	0	0	0		0	0	0	0	0	0	0	30%	100%	71%	0	0
No Access	100%	100%	100%	100%	100%		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

LA Swamp Opportunity (% Access)																															
Years	2012											2013												2014							
Moths	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Good <17.5 Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		Restoration		79%	97%	100%	100%	100%	100%	19%	0	0	0
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				4%	0	0	0	0	0	0	0	0	0
Poor >22 Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	67%	100%	95%
No Access	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%				17%	3%	0%	0%	0%	0%	81%	33%	0%	5%

La Center Wetlands Opportunity (% Access)

Year	2014									
Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	50%	13%	0	0	0	0		Restoration	63%	87%
Fair 17.5-22 Pre	0	0	0	0	0	0			0	0
Poor >22 Pre	0	0	0	0	0	0			0	0
No Access	50%	87%	100%	100%	100%	100%			37%	13%

Year	2015											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	74%	92%									39%	84%
Fair 17.5-22 Pre	0	0									0	0
Poor >22 Pre	0	0									0	0
No Access	26%	8%									61%	16%

Year	2016											
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	61%	100%	94%	50%	0	0	0			89%	80%	81%
Fair 17.5-22 Pre	0	0	0	33%	42%	0	0			0	0	0
Poor >22 Pre	0	0	0	0	0	11%	0			0	0	0
No Access	39%	0%	6%	17%	58%	89%	100%			11%	20%	19%

North Unit Millionaire Opportunity (% Access)

Years	2013				2014												2015									
Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Good <17.5 Pre	0	0	0	0	0	0	10%	0	0	0	0	Restoration	0	48%	90%	100%	100%	100%	100%	50%	0	0	0	0	0	24%
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0	0	0		46%	42%	0	0	0	0	0	50%	74%	0	0	0	100%	76%
Poor >22 Pre	0	0	0	0	0	0	0	0	0	0	0		50%	0	0	0	0	0	0	0	26%	97%	100%	100%	0	0
No Access	100%	100%	100%	100%	100%	100%	90%	100%	100%	100%	100%		4%	10%	10%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%

North Unit Ruby Lake Opportunity (% Access)

Year	2013										2014											
Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good <17.5 Pre	0	0	0	0	0	0	Restoration			84%	100%	100%	100%	100%	29%	0	0	0	0	0	83%	100%
Fair 17.5-22 Pre	0	0	0	0	0	0				0	0	0	0	0	71%	100%	6%	0	23%	45%	0	0
Poor >22 Pre	0	0	0	0	0	0				0	0	0	0	0	0	0	94%	100%	50%	29%	0	0
No Access	100%	100%	100%	100%	100%	100%				16%	0%	0%	0%	0%	0%	0%	0%	0%	27%	26%	17%	0%

North Unit Three Fingered Jack Opportunity (% Access)

Years	2015		2016										
Months	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Good <17.5 Pre	0	0	0	0	0	0	0	0	0		Restoration	100%	100%
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0			0	0
Poor >22 Pre	0	0	0	0	0	0	0	0	0			0	0
No Access	100%	100%	100%	100%	100%	100%	100%	100%	100%			0%	0%

North Unit Widgeon Deep Opportunity (% Access)

Year	2013				2014												2016					
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Good <17.5 Pre	0	0	0	0	0	0	0	0	0	0	0	Restoration	0	65%	100%	100%		100%	100%	100%	0	0
Fair 17.5-22 Pre	0	0	0	0	0	0	0	0	0	0	0		96%	35%	0	0		0	0	0	100%	20%
Poor >22 Pre	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0	0	0	0	0
No Access	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%		4%	0%	0%	0%		0%	0%	0%	0%	80%

Table E.8. Site habitat opportunity post-restoration for April through June. By definition, a water depth of 0.5 m or more is needed to provide adequate salmonid access.

Water Year	Site	Condition	Opportunity Type	Apr	May	June
2013	Dibblee Point	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	0
			Good, <17.5	67%	10%	0
			Fair, 17.5-22	33%	53%	0
			Poor, >22	0	37%	100%
2014	LA Swamp	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	81%	33%
			Good, <17.5	100%	19%	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	67%

Water Year	Site	Condition	Opportunity Type	Apr	May	June
	North Unit Ruby	Pre	No Access	97%	74%	100%
			Good, <17.5	3%	0	0
			Fair, 17.5-22	0	26%	0
			Poor, >22	0	0	0
		Post	No Access	0	0	0
			Good, <17.5	100%	29%	0
			Fair, 17.5-22	0	71%	100%
			Poor, >22	0	0	0
2015	Karlson	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	0
			Good, <17.5	100%	81%	0
			Fair, 17.5-22	0	19%	70%
			Poor, >22	0	0	30%
	North Unit Millionaire	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	3%
			Good, <17.5	50%	0	0
			Fair, 17.5-22	50%	74%	0
			Poor, >22	0	26%	97%
2016	Batwater	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	10%	6%	17%
			Good, <17.5	90%	13%	0
			Fair, 17.5-22	0	81%	37%
			Poor, >22	0	0	47%
	Elochoman	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	7%	48%	83%
			Good, <17.5	93%	52%	7%
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	10%
	La Center	Pre	No Access	100%	100%	93%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0

Water Year	Site	Condition	Opportunity Type	Apr	May	June
			Poor, >22	0	0	0
		Post	No Access	17%	58%	83%
			Good, <17.5	50%	0	0
			Fair, 17.5-22	33%	42%	0
			Poor, >22	0	0	10%
	North Unit Three Fingered Jack	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	7%
			Good, <17.5	100%	100%	33%
			Fair, 17.5-22	0	0	60%
			Poor, >22	0	0	0
	North Unit Widgeon Deep	Pre	No Access	100%	100%	100%
			Good, <17.5	0	0	0
			Fair, 17.5-22	0	0	0
			Poor, >22	0	0	0
		Post	No Access	0	0	80%
			Good, <17.5	100%	0	0
			Fair, 17.5-22	0	100%	20%
			Poor, >22	0	0	0

Table E.9. Average habitat opportunity for all sites.

Pre-restoration	Apr	May	June
No Access	100%	97%	100%
Good, <17.5	0%	0%	0%
Fair, 17.5-22	0%	3%	0%
Poor, >22	0%	0%	0%
Post-restoration	Apr	May	June
No Access	3%	19%	31%
Good, <17.5	85%	30%	4%
Fair, 17.5-22	12%	44%	29%
Poor, >22	0%	6%	36%

E.3.4 Sediment Accretion

Sediment accretion or loss varied within and among the restoration sites (Table E.10). For example, sites at Kandoll Farm with similar high elevations showed both loss and gain. Slightly more than half of the restoration sites had a positive annual average rate; however variability in these data make generalizations within and between sites difficult to determine. While this study observed no trends with sediment accretion and elevation within or among sites, other researchers have identified strong correlations between marsh topography and hydrology (e.g., Craft et al. 1993, Callaway et al. 1997, Kidd

Unpublished Data) (Figure E.3). Future monitoring should consider the high data variability associated with sediment accretion benches within this system. Installing a greater number of sediment benches located across a restoration site's elevation and hydrologic gradient may provide more robust results for analysis and comparison, additionally, other more accurate methods such as Sedimentation-Erosion Tables (SET) and feldspar marker horizons should also be considered for comparison (Roelof and Day 1993, Cahoon et al. 2000).

Table E.10. Sediment accretion annual rate and restoration site average.

Site	Years Post Restoration	Reach	Site Average Annual Rate	Standard Error
Batwater Station	1.9	C	2.58	1.87
Elochoman Slough Thomas	2.4	B	4.10	3.25
Kandoll Farm	2.7	B	-1.19	1.19
Karlson Island	1.1	B	-3.68	6.05
La Center Wetlands	1.9	E	0.84	1.22
LA Swamp	2.7	C	4.01	-
North Unit Millionaire	1.5	F	-0.42	1.65
North Unit Ruby Lake	1.0	F	3.97	1.32
North Unit Widgeon/Deep	1.5	F	1.85	2.56
Wallacut Slough	1.7	A	-0.54	2.15

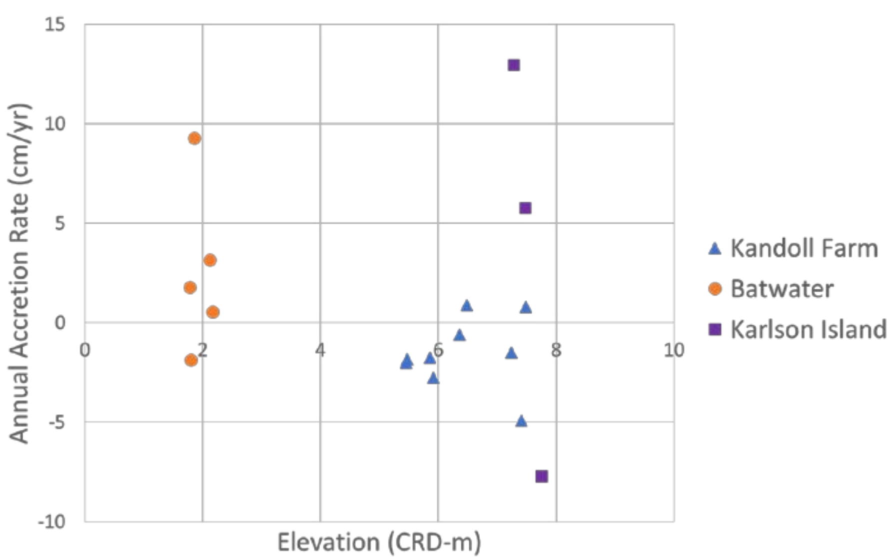


Figure E.3. Annual accretion rate by elevation for three restoration sites.

E.3.5 Channel Cross Section

Channel cross-section data from the AEM data collection effort included three sites located in the Lower Estuary zone: Kandoll #2, Mill Road, and Wallacut. Kandoll #2 and Mill Road involved new channel construction, while Wallacut was a reconnection to an existing channel. Other cross-section data for CEERP projects are available in the literature (Crims and Vera in Diefenderfer et al. In Prep; Sandy River delta in Johnson et al. 2011). For the three AEM sites, the relationship between area and years elapsed since restoration was equivocal (Figure E.4). The number of years post-restoration does not appear to be an indicator of change in channel cross-sectional area. The percent change in channel cross-sectional area was negatively related to channel order (Figure E.5). In general, channels in closer proximity to the mainstem water body will increase in channel volume while channels further in the wetland showed a reduction in channel area. Overall, more time post-restoration and additional sediment data is required to clearly understand the impact of restoration on channel cross-sectional area and channel development.

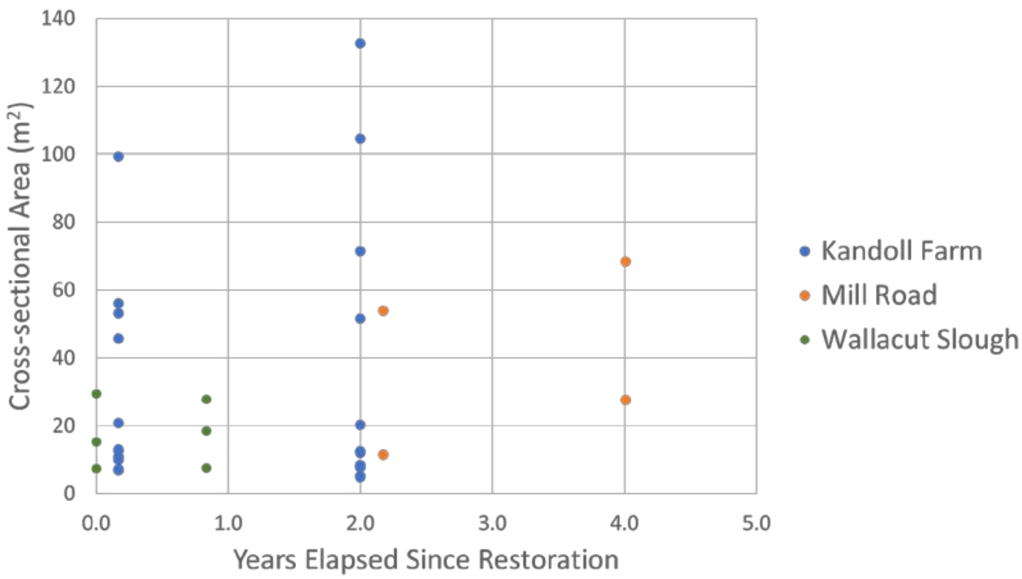


Figure E.4. Cross-sectional area after restoration.

Figure E.5. Change in channel cross-section area with channel order.

E.3.6 Vegetation

For the sites included in the vegetation analysis (Table E.2), relative native cover post-restoration was within 25% of reference conditions for Dibblee Slough, North Unit Ruby Lake, Steamboat Slough, and Sandy River Dam (Figure E.6-E.7, Table E.11), however relative non-native cover did appear to be increasing at the Sandy River Dam site between years 1 and 3 post restoration (Table E.12). Kandoll

Farm #2, North Unit Widgeon Deep and North Unit Millionaire did not show a trend toward increasing native cover similar to reference conditions (Figure E.6, Table E.12) and these sites also showed an increase in non-native cover between years 1 and 3 post-restoration (Table E.12). At reference sites for all years, relative native species cover was between 63 and 94% (Table E.11) and non-native relative cover ranged between 4 and 39 % among the sites (Table E.11).

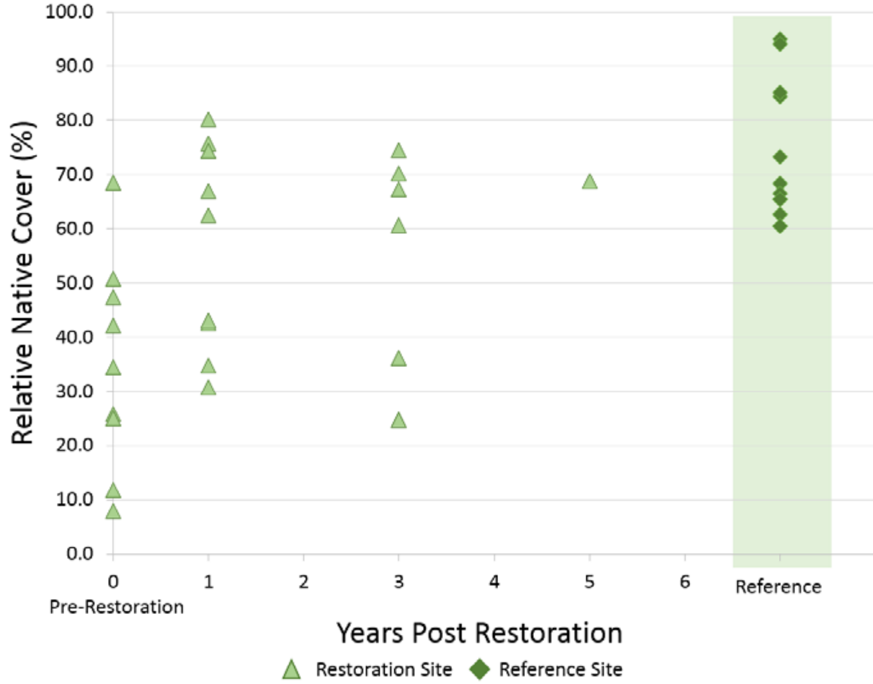


Figure E.6. Relative native cover for all sites pre-restoration, post-restoration, and reference.

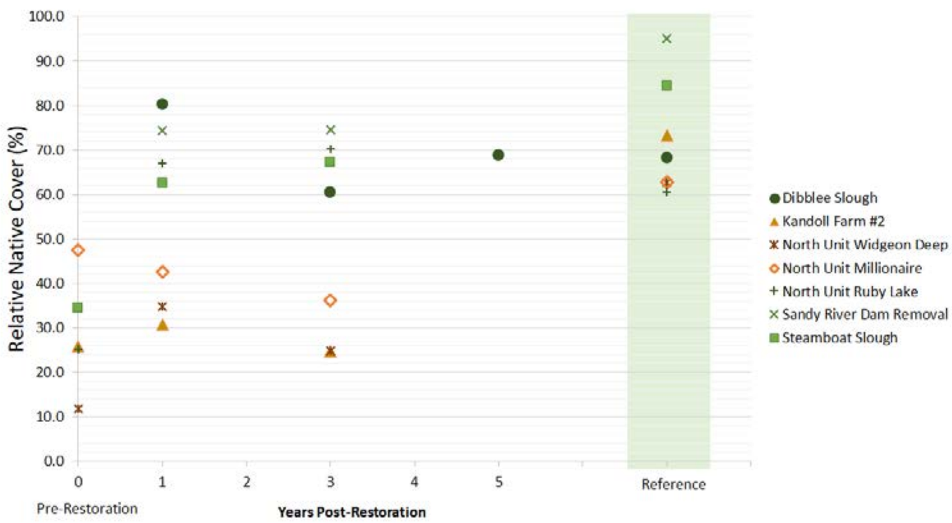


Figure E.7. Relative native cover for pre-restoration, post-restoration, and reference sites with independent projects highlighted, only including projects with three or more years of post-restoration project data.

Table E.11. Relative native cover for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress toward reference conditions: green = similar to reference within ±25%, orange = not similar to reference ± 25%.

Native Relative Cover	Pre-Restoration			Years Post-Restoration									Reference		
				1			3			5					
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	80.3	4	56	60.6	4.5	66	68.8	3.7	101	68.3	3.3
Kandoll Farm #2	72	25.8	3.1	72	30.7	4	60	24.7	4				61	73.3	3
La Center Wetlands	71	68.5	4	71	75.7	4.2							71	65.4	4.6
North Unit Flights End	60	50.7	3.9										69	66.5	3.5
North Unit Millionaire	72	47.5	5	72	42.6	4.4	72	36.2	4.9				174	62.7	2.6
North Unit Ruby Lake	79	25.1	4.1	55	67	5.2	59	70.3	4.3				139	60.5	3.2
North Unit Widgeon/Deep	72	11.9	3.2	72	34.7	4.3	70	24.8	4.3				174	62.7	2.6
Sandy River Dam Removal				56	74.4	4	61	74.4	3.9				49	95	1.2
Steamboat Slough	72	34.4	4.8	63	62.6	3.8	68	67.3	4.2				186	84.4	1.6
Wallacut River	72	42.2	3	72	43	3.5							83	85.1	2.1
Wallooskee River	68	8	2.6										36	94.1	2.3

Table E.12. Non-native relative cover for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress toward reference conditions: green = similar to reference within ±25%, light orange = < ± 25% difference but not trending toward reference, orange = > ± 25% difference and not trending toward reference.

Non-native Relative Cover (%)	Pre-Restoration			Years Post-Restoration									Reference		
				1			3			5					
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	15.7	3.6	56	37.3	4.4	66	12	2.8	101	27.1	3.4
Kandoll Farm #2	72	74.1	3.1	72	69.1	4	60	75.3	4				61	25.3	3
LaCenter Wetlands	71	28.5	3.9	71	24.3	4.2							71	32.5	4.6
North Unit Flights End	60	41.2	3.7										69	32.5	3.4
North Unit Millionaire	72	52.5	5	72	55.6	4.6	72	61.4	5				174	36.9	2.6
North Unit Ruby Lake	79	74.8	4.2	55	32.7	5.2	59	24.1	3.9				139	38.9	3.2
North Unit Widgeon Deep	72	87.7	3.1	72	63.5	4.4	70	65.8	4.6				174	36.9	2.6
Sandy River Dam Removal				56	12.5	2.7	61	23.7	3.7				49	4.2	1.2
Steamboat Slough	72	63.7	5	63	37.4	3.8	68	30.5	4.3				186	14	1.6
Wallacut River	72	54.9	3.2	72	56.8	3.5							83	5.5	1.4
Wallooskee River	68	82.6	2.9										36	5.9	2.3

Generally, native species richness increased following restoration (Figure E.8). Conversely, non-native species richness decreased as the number of years post-restoration increased (Tables E.13-E.14). Native species richness post-restoration was within ±1 species richness of reference conditions for Dibblee Slough, North Unit Ruby Lake, and Sandy River Dam (Figure E.8, Table E.13). Steamboat slough did not reach the ±1 native species richness threshold by year three post restoration but did show a strong trend of increasing native species richness between pre-restoration and three-year post-restoration conditions (Figure E.9, Table E.13). Kandoll Farm #2, North Unit Widgeon Deep and North Unit Millionaire did not show a strong trend toward increasing native species richness (Figure E.9, Table E.13), however, these sites did show a trend of decreasing non-native species richness between years one and three post-restoration (Table E.14). The Sandy River Dam site was the only restoration site which showed an increase in non-native species richness post-restoration (Table E.13). Across all reference sites for all years, mean native species richness ranged between 2.7 and 8.4 (Table E.14) and non-native species richness ranged between 0.9 and 2.2.

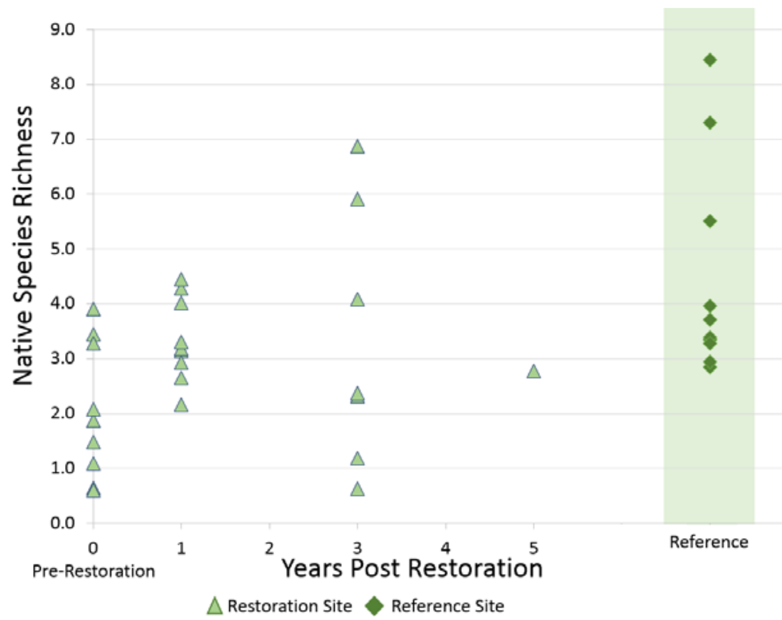


Figure E.8. Native species richness for all pre-restoration, post-restoration, and reference sites.

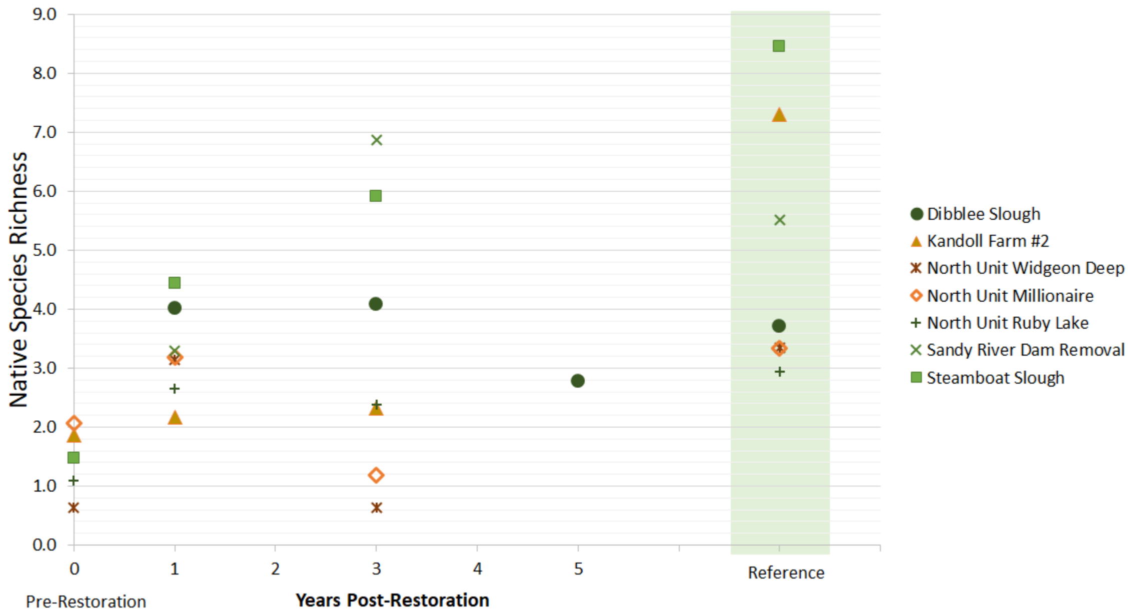


Figure E.9. Native species richness for pre-restoration, post-restoration, and reference sites with independent projects highlighted, only including projects with three or more years of post-restoration project data.

Table E.13. Native species richness for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress toward reference conditions: green = similar to reference within ±1, light green = > ±1difference but trending toward reference, yellow = > ±1difference and not trending toward reference.

Native Species Richness	Pre-Restoration			Years Post-Restoration 1			3			5			Reference		
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	4	0.3	56	4.1	0.3	66	2.8	0.2	101	3.7	0.2
Kandoll Farm #2	72	1.9	0.1	72	2.2	0.2	60	2.3	0.3				61	7.3	0.4
LaCenter Wetlands	71	3.4	0.2	71	4.3	0.3							71	2.8	0.2
North Unit Flights End	60	3.9	0.3										69	4	0.2
North Unit Millionaire	72	2.1	0.2	72	3.2	0.3	72	1.2	0.2				174	3.3	0.1
North Unit Ruby Lake	79	1.1	0.1	55	2.7	0.3	59	2.4	0.2				139	2.9	0.2
North Unit Widgeon Deep	72	0.6	0.1	72	3.1	0.4	70	0.6	0.1				174	3.3	0.1
Sandy River Dam Removal				56	3.3	0.3	61	6.9	0.5				49	5.5	0.4
Steamboat Slough	72	1.5	0.2	63	4.4	0.3	68	5.9	0.4				186	8.4	0.2
Wallacut River	72	3.3	0.2	72	2.9	0.2							83	3.4	0.3
Wallooskee River	68	0.6	0.2										36	3.3	0.3

Table E.14. Non-native species richness for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress toward reference conditions: green = similar to reference within ±1, yellow = > ±1 difference and not trending toward reference.

Non-native Species Richness	Pre-Restoration			Years Post-Restoration 1			3			5			Reference		
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	0.8	0.1	56	2.4	0.2	66	0.8	0.1	101	1.2	0.1
Kandoll Farm #2	72	2.5	0.2	72	2.3	0.2	60	2	0.2				61	2.2	0.1
LaCenter Wetlands	71	1.9	0.1	71	0.8	0.1							71	0.7	0.1
North Unit Flights End	60	3.1	0.2										69	1.1	0.1
North Unit Millionaire	72	1.2	0.1	72	1.7	0.1	72	0.9	0.1				174	1	0
North Unit Ruby Lake	79	1.1	0.1	55	1	0.1	59	0.7	0.1				139	1	0.1
North Unit Widgeon Deep	72	1	0	72	2.6	0.2	70	0.9	0				174	1	0
Sandy River Dam Removal				56	1.1	0.2	61	2	0.2				49	0.9	0.1
Steamboat Slough	72	3.2	0.3	63	2	0.1	68	2	0.2				186	1.7	0.1
Wallacut River	72	2.3	0.1	72	2.1	0.1							83	0.4	0.1
Wallooskee River	68	3.7	0.2										36	0.7	0.2

Reed canarygrass (RCG) relative cover followed a similar trend to the overall non-native relative cover for most sites (Figure E.10, Table E.12 and Table E.15), reaching within ± 25% of reference conditions at Dibble Slough, North Unit Ruby Lake, Sandy River Dam, and Steamboat Slough three to five years post-restoration. While Sandy River Dam and Steamboat Slough achieved RCG levels within the reference range they exhibit a trend toward an increase in mean RCG cover between years one and three post-restoration (Figure E.11, Table E.15). Kandoll Farm #2, North Unit Widgeon Deep, and North Unit Millionaire did not achieve levels of RCG cover within the reference range and all site show an increase in mean RCG between years one and three post-restoration (Figure E.11, Table E.15) Pre-restoration relative RCG cover ranged between 11 and 87%.

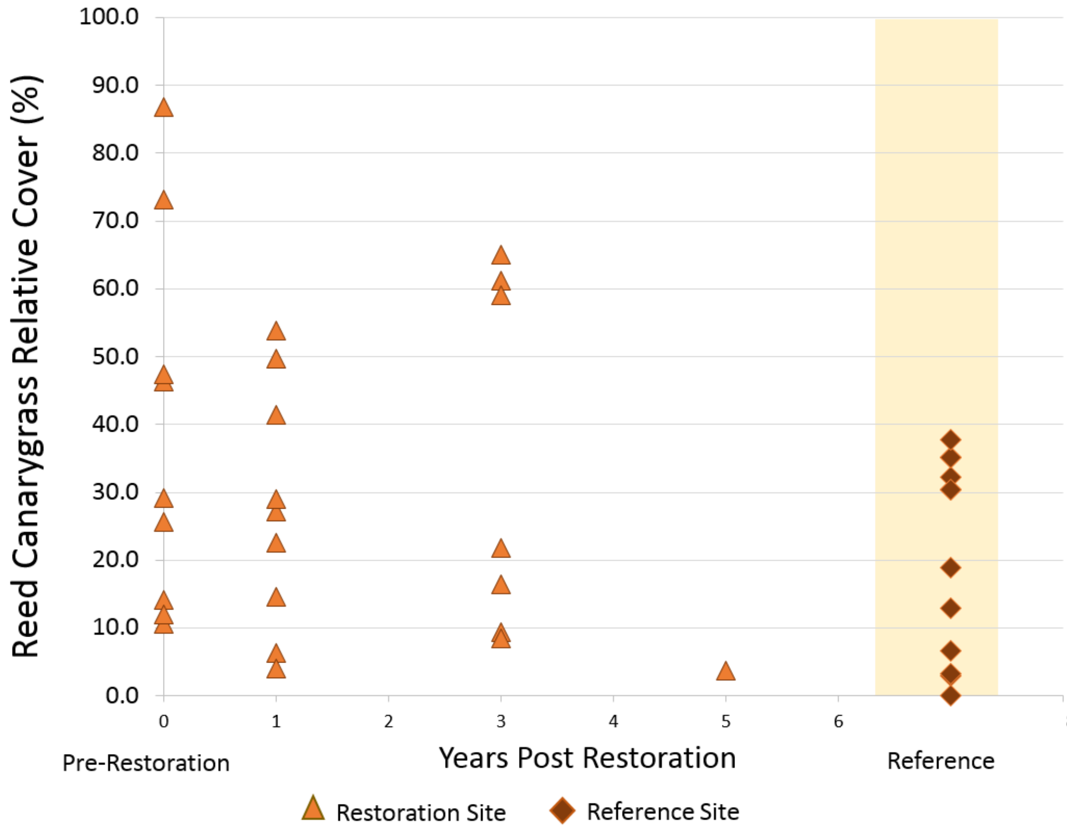


Figure E.10. Reed canarygrass cover at pre-restoration, post-restoration, and reference sites

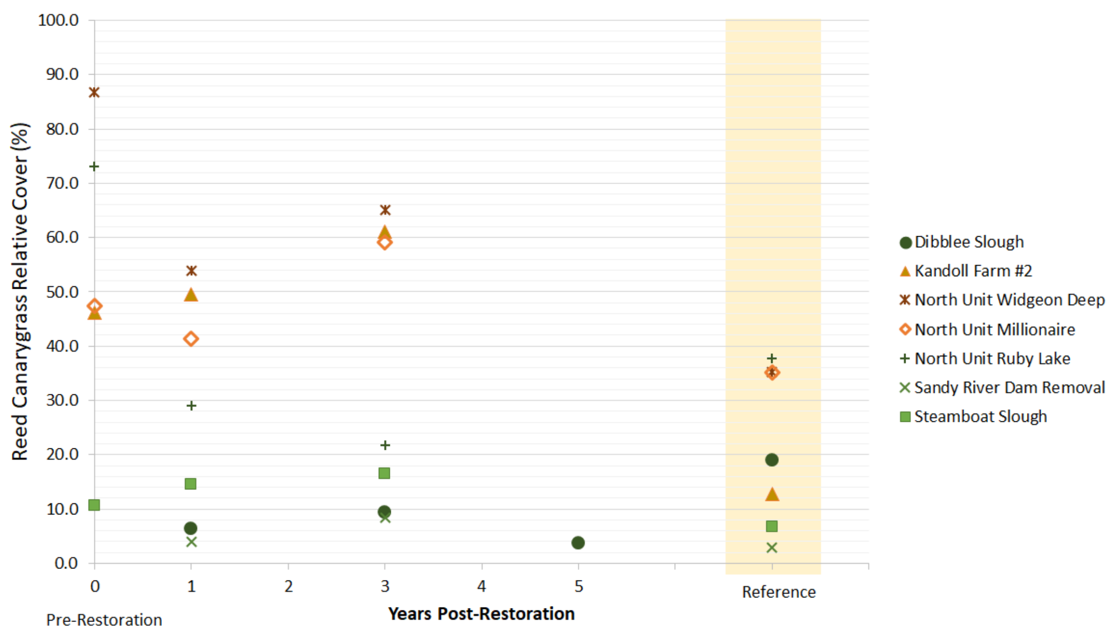


Figure E.11. Reed canarygrass relative cover at pre-restoration, post-restoration, and reference sites with independent projects highlighted, only including projects with three or more years of post-restoration project data.

Table E.15. Reed canarygrass relative cover for pre-restoration, post-restoration, and reference sites. Projects with three or more years of post-restoration project data highlighted based on progress toward reference conditions: green = similar to reference within ±25%, yellow = < ± 25% difference but not trending toward reference, orange = > ± 25% difference and not trending toward reference.

Reed Canarygrass Relative Cover (%)	Pre-Restoration			Years Post-Restoration 1			3			5			Reference		
Project	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE
Dibblee Point				60	6.3	2.5	56	9.3	2.6	66	3.7	2	101	19	3.1
Kandoll Farm #2	72	46.3	4.8	72	49.6	4.8	60	61.2	5.1				89	12.9	2.3
LaCenter Wetlands	71	14.2	3.5	71	22.6	4.2							71	32.3	4.6
North Unit Widgeon Deep	72	86.8	3.3	72	53.9	5.3	70	65.1	4.6				174	35.2	2.6
North Unit Flights End	60	12	2.7										69	30.3	3.5
North Unit Millionaire	72	47.5	5.1	72	41.4	4.7	72	59.1	5.1				174	35.2	2.6
North Unit Ruby Lake	79	73.1	4.4	55	29	5.3	59	21.8	3.9				139	37.7	3.3
Sandy River Dam Removal				56	4	1.3	61	8.5	2.6				49	2.9	1.1
Steamboat Slough	72	10.6	3.2	63	14.6	3.1	68	16.5	4.1				186	6.7	1.5
Wallacut River	72	25.7	4.1	72	27.2	4.7							83	0	0
Wallooskee River	68	29.2	4.1										36	3.2	1.5

There were significant relationships between various vegetation metrics. Relative percent cover of native plants was significantly ($p < 0.000$) positively correlated to the species richness of native plants (Figure E.12). Similarly, relative percent cover of *non-native* plants was significantly ($p < 0.000$) negatively correlated to the species richness of native plants (Figure E.13).

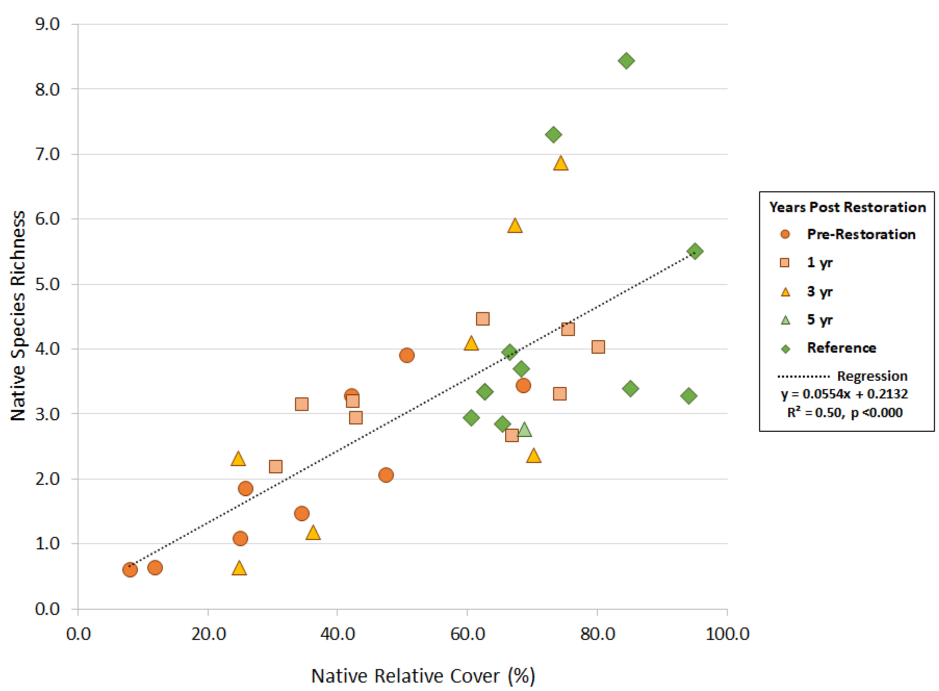


Figure E.12. Restoration and reference sites mean native species richness vs. native relative cover.

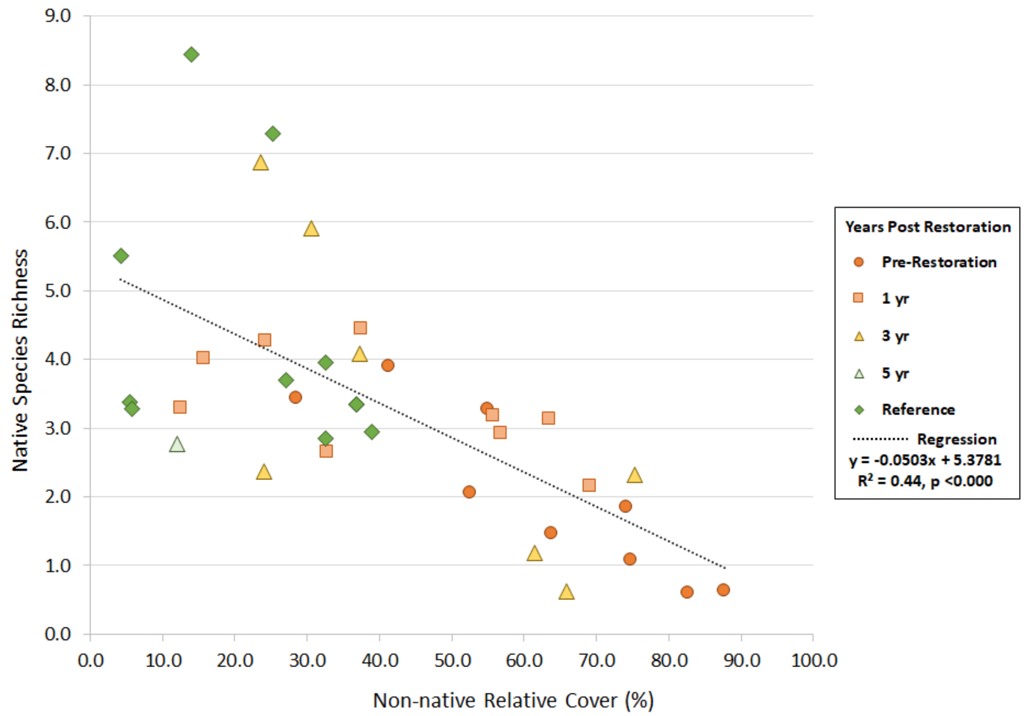


Figure E.13. Restoration and reference sites mean native species richness vs. non-native relative cover.

Relative percent cover of non-native plants was significantly positively correlated to non-native species richness ($P < 0.02$) (Figure E.14). Relative percent cover of native plants was negatively related to species richness on non-native plants ($p < 0.002$) (Figure E.15).

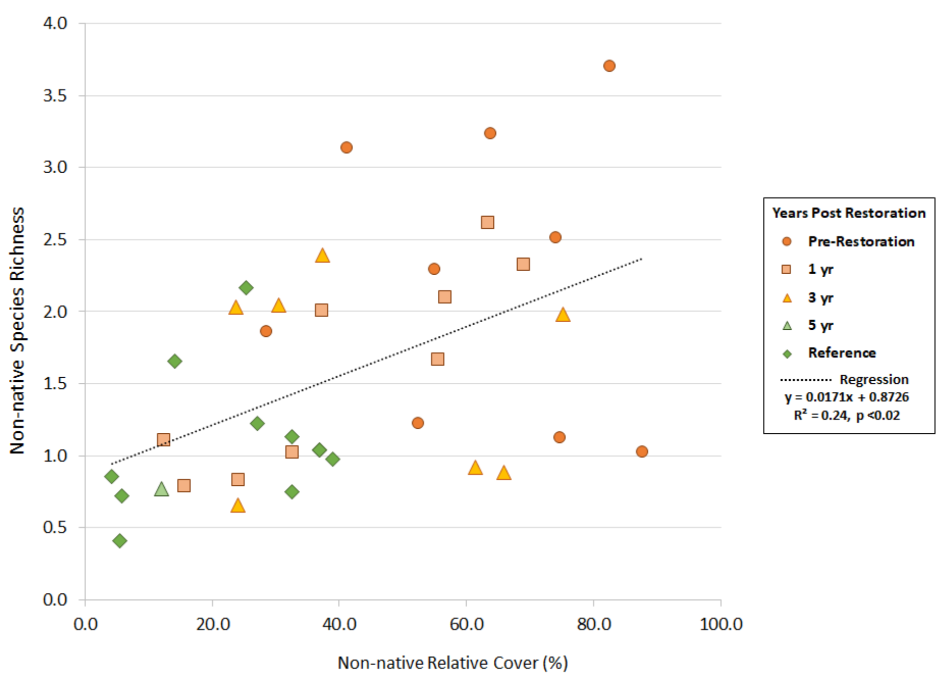


Figure E.14. Restoration and reference sites mean non-native species richness vs. non-native relative cover.

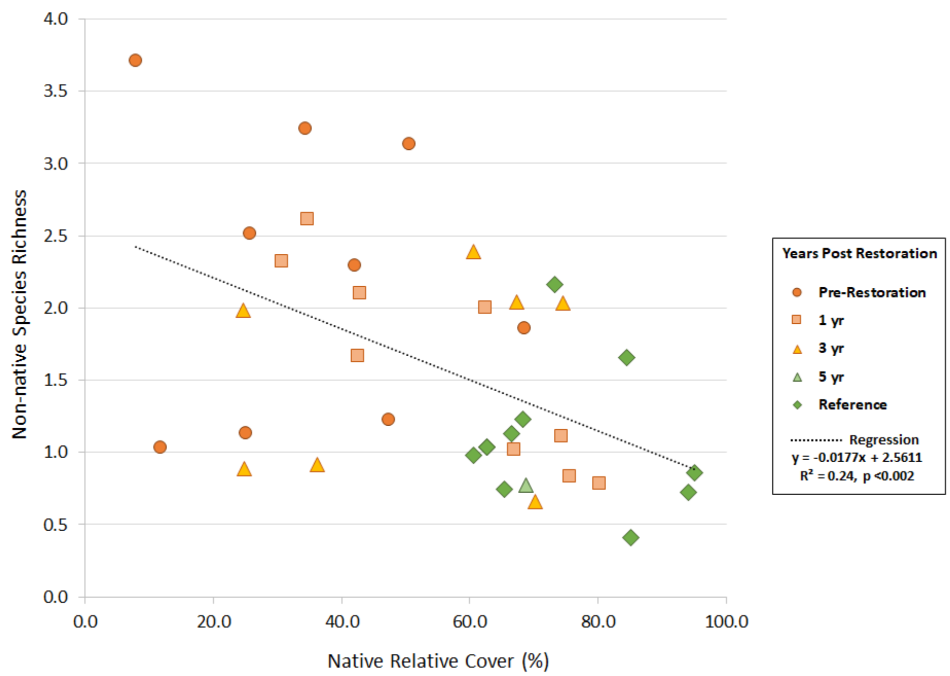


Figure E.15. Restoration and reference sites mean non-native species richness vs. native relative cover.

E.3.7 Juvenile Salmon

Juvenile salmon presence/absence data were available for 13 restoration sites (Table E.2). Researchers collected direct capture data by seining or trap netting at 11 sites and by detections at PIT arrays at 5 sites; both methods were employed at 3 of the 13 sites. Fish sampling usually occurred during spring and summer. Juvenile salmon, mostly subyearling Chinook salmon, were present at all 13 restoration sites (Table E.16). Abundance varied from few fish to many. More quantitative data were difficult to obtain because catch per unit effort or fish density data were not usually reported.

Table E.16. Juvenile salmon data from restoration sites.

Restoration Site	Juvenile Salmon Data Collected
Batwater	PNNL sampled for juvenile salmon at the Batwater restoration site and associated reference site (Crims) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile Chinook salmon (CH) dominated the catch (N. Sather, pers. comm.). They were present during all months sampled (April–July) and were mostly of the genetic stock West Cascades fall CH.
Colewort	The Columbia River Estuary Study Taskforce (CREST) sampled fish at the Colewort Creek site before after dike breaching in 2012. As reported by Thom et al. (2013), catch per unit effort was low (<10 fish) for chum fry and subyearling Chinook salmon and medium (10–100 fish) for subyearling coho. A PIT array was installed and sampled pre- and post-construction. One subyearling CH from Spring Creek hatchery (above Bonneville Dam) was detected in 2012 and another one in 2014.
Crims Island	Haskell and Tiffan (2011) captured fish using beach seines and fyke nets at the Crims Island restoration site and a reference site (Gull Island) during 2004 (pre-restoration) and 2006–2008 (post-restoration). Subyearling Chinook salmon catch was highest from mid-March to

Restoration Site	Juvenile Salmon Data Collected
	late May. Densities were highest in subtidal channels 0.005–0.323 fish/m^2) and intermediate channels (0.003–0.340), and lowest on the marsh plains (0.022–0.069 fish/m^2). However, these results were not statistically significant ($P = 0.08$). Catch per unit effort was generally higher post-restoration than pre-restoration.
Dibblee	PNNL sampled for juvenile salmon at the Dibblee restoration site and associated reference site (Fisher Island) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile CH dominated the catch (N. Sather, pers. comm.). Juvenile salmon were captured at the sites in April and May, but not June and July. Genetic stocks included Spring Creek fall CH, Upper Columbia summer/fall CH, and West Cascades fall CH.
Fort Clatsop (South Slough)	During annual sampling 2007–2012, CREST researchers captured five salmonid species with the most abundant species being juvenile coho and Chinook salmon (CREST 2012a). The fish-size data indicated multiple life history strategies evident at both the restored and reference sites.
Fort Columbia	CREST captured juvenile Chinook and coho salmon at the Fort Columbia restoration site (Thom et al. 2013; CREST revisit template/SEC). Here the Washington State Department of Transportation replaced an undersized culvert under U.S. Highway 101 east of Ilwaco with a large 12 ft × 12 ft box culvert. Fish traversed ~50 m from Baker Bay to the restoration area on the upstream side of the culvert. A hand-held PIT reader sampled the net catch and detected two Chinook salmon (CH) tagged and released at Astoria High School on the other side of the estuary.
Horsetail	Fish sampling only employed PIT technology. The LCEP detected juvenile salmon on the PIT array on the Columbia River side and the Horsetail side of the Interstate-84 (I-84) culvert (M. Schwartz, pers. comm.). Detections on the PIT array on the Horsetail side of the culvert showed a few fish transited the culvert. A diversity of genetic stocks was represented on the Columbia River side of the culvert and a limited number of genetic fish stocks transiting the culvert. Use of the restored area by juvenile salmon accessing it from the mainstem river was equivocal.
JBH Mainland	After new fish-friendly tide gates were installed, juvenile salmon capture rates in terms of number of species and individuals were higher entering the newly tide-gated sloughs than the reference slough (Johnson J et al. 2011). Juvenile Chinook salmon were the most abundant salmon species captured, followed by coho with some chum and steelhead present only in the restored, tide-gated slough. Juvenile salmon entered the new fish-friendly tide gates, although the proportion of non-native species of the total catch was higher in the restored areas than the reference site.
Karlson Island	During spring 2016 and 2017, PNNL sampled juvenile salmon at the Karlson restoration site and associated reference site, “Karlson old,” the naturally breached area next to the new restoration site. Preliminary results for 2016 (N. Sather, pers. comm.) indicate unmarked juvenile CH were most dominant (77% of the catch); chum salmon composed 17%, and marked CH 2% and coho 2% of the catch. Juvenile salmon were present during all months sampled (April–July). Stock diversity was highest in April. West Cascades fall CH were captured in all months sampled.
Mirror Lake	Sol et al. (2013) observed that juvenile salmon and steelhead appeared to be moving into the site by swimming upstream through the I-84 culvert from the Columbia River. Salmonids captured in beach seines at sampling sites in the restoration areas included cutthroat, steelhead, chum, coho, and CH (e.g., Mirror Lake samples). Juvenile coho salmon are from a spawning population in the Mirror Lake watershed.

Restoration Site	Juvenile Salmon Data Collected
Multnomah Channel Metro	McNatt et al. (2017) performed pre- and post-restoration sampling at wetlands and ponds off Multnomah Channel. Juvenile Chinook and coho salmon and coastal cutthroat trout were present in small numbers. From R. McNatt (pers. comm. Jan 16, 2018), "In the second year of post-restoration sampling the water-control structure for the north pond was left open. This resulted in a greater number of salmonids collected in the north pond, indicating that if given access, salmon will use the habitat." Genetic stock data from fin clips are not available at this time. Tagged salmon detected at the PIT arrays included mostly wild and hatchery fish from the Willamette.
Sandy River Dam Removal	Johnson and Sather (2016) reported fish community composition at a site at the outlet to the restored channel (Site C) and within the new channel (Site N). At both sites post-restoration, the fish community was dominated by juvenile salmon; this was not the case pre-restoration.
Steamboat Slough	PNNL sampled for juvenile salmon at the Steamboat restoration site and at its reference site (Welch Island) during spring 2016 and 2017. Preliminary results for 2016 indicate unmarked juvenile CH dominated the catch (93% of the total). West Cascades fall CH were present during all months sampled (April–July). In 2017 NMFS monitored the Steamboat restoration site and its reference site (Welch Island) for PIT-tagged salmon and steelhead. Fall Chinook salmon were most frequently detected, yet 9% of the 57 fish detected at Steamboat and 14% of the 33 fish detected at Welch were listed interior stocks. Steelhead were not collected by the PNNL fyke net sampling, yet were detected at both restoration and reference sites.
Vera Slough	Salmon were a minor component of the fish community at sites inside and around the Vera Slough restoration site (Thom et al. 2012). Only 11 juvenile salmon were captured out of 75 seine samplings.

The Corps' Level 1 AEMR study currently is analyzing the most intensive fish data with respect to CEERP restoration action effectiveness. From this study, salmon species composition and Chinook salmon genetic stock data were available from post-restoration sampling at four sites from April through July 2016: Batwater, Dibblee, Karlson, and Steamboat. Researchers captured juvenile Chinook salmon at all four restored and reference site pairs (N. Sather, pers. comm, January 2018). Unmarked Chinook salmon were the most abundant salmonid in restored wetland channels (Table E.16). Marked Chinook salmon and chum salmon accounted for less than 3% of the total salmon catch. Coho salmon (unmarked) and cutthroat trout were rarely captured in restored wetland channels and accounted for less than 1% of the total salmon catch in 2016. Steelhead and marked coho salmon were not captured at restoration sites in 2016. For all sites and months combined, 80% of fish sampled were West Cascades fall Chinook salmon. Upper Columbia summer/fall Chinook salmon composed 15% of the total samples and were found at all sites. Spring Creek fall Chinook salmon were 3% of the total and were present in April and May at all sites except Karlson. Willamette River spring Chinook salmon were 1% of the total samples and were found only at Karlson and Steamboat. In summary, diversity of genetic stocks was highest in April and lowest in July (Table E.15). Other results from the intensive AEMR Level 1 study comparing restoration and reference site pairs (Dibblee/Fisher, Batwater/Crims, Steamboat/Welch, and Karlson new/Karlson old) will not be available until after SM2 is completed.

Overall the genetic stock data indicated West Cascades fall Chinook salmon generally were present April through July at most sites where fin clips were collected for genetics analysis. Other common stocks of juvenile salmon were Spring Creek fall Chinook, Upper Columbia summer/fall Chinook and

Willamette River spring Chinook. Snake River stocks were rarely represented in the genetics data from direct capture samples at restoration sites as part of the AEMR study.

While upriver stocks were rarely encountered through direct capture techniques, the presence of these stock groups in restored tidal wetland channels has been confirmed with PIT antenna arrays. Of particular interest are the preliminary results from the Corps' AEMR study at Steamboat. McNatt and Hinton (2017) reported 9% of the 57 unique detections inside the Steamboat restoration site were from listed salmon and steelhead populations in the interior Columbia River basin. Of the 57 fish, 4 were yearling spring Chinook salmon and 5 were yearling steelhead, with median residence times of 11 sec and 30 min, respectively. For 40 subyearling fall Chinook salmon, median residence time was 3.5 d. The other eight fish detected were northern pikeminnow.

E.4 Discussion

The discussion is organized by monitored indicator, starting with water-surface elevation. Water-surface elevation is a proxy for hydrology for a site. WSE together of with marsh elevations are the strongest predictors of fish access and vegetation communities likely to develop at a site. The 2-year flood elevation is a good measure of project wetted area and should be monitored to ensure if that design criteria is achieved; however, it is not necessarily the best indicator for measuring the impact of restoration actions to out migrating juvenile salmonids potentially using a site. Of all the restoration sites that achieve the 2-flood elevation, most did so between October and March. Only one site achieved the 2-year flood elevation between April and June. Pairing post-restoration WSE data with mainstem data as a reference, show all sites achieving a similar hydrology. This indicates an important physical process was established which is a critical step to achieving a reference ecological state.

Water temperature is an important environmental factor that can impact if a site is suitable for juvenile salmonids. It is important to monitor temperatures to ensure restoration sites can be inhabited by juvenile salmonids when water levels are high enough to access the channel and floodplain. However, water temperature is strongly influenced by climatic conditions and a hydrologically connected tidal wetland will be strongly influenced by the mainstem Columbia River temperatures. Unless a site has a substantial cold water input, achieving a cooler water temperature post-restoration is not feasible objective.

A restored hydrology is an immediate impact of all tidal reconnection projects. Additionally, water temperatures that support juvenile salmonids during critical life stages is a key restoration project objective. Pairing WSE and water temperature together create a more meaningful a measure of habitat opportunity than either looked at separately. Furthermore, pre- and post-restoration conditions to assess increase in habitat opportunity and resolves issues related to the variability water years. In all instances restoration sites showed increases in habitat opportunity during periods of time when outmigrating juvenile salmonids could be potentially be accessing restoration sites.

A positive sediment accretion rate is expected due to subsidence of most previously dike restoration sites. Annual sediment accretion rates were low and a longer monitoring period is needed to determine a trend at sites. In the future, more sediment accretion stakes should be installed at sites across the elevation their gradient to better quantify where sediment loss and gain is occurring. Better yet, set tables should be considered. Sediment accretion monitoring is important to track to know the resilience of restored wetlands given shifting climate conditions.

Channel cross sections can provide important information regarding the amount of hydraulic exchange a site can have with the adjacent mainstem waterbody. There does not appear to be a trend in the change to channel cross-section volume related to the number of years post-restoration. A general trend in change in channel volume and channel order did emerge. Smaller channels higher in the wetland tend to accumulate sediment while channels lower in the wetland tend to lose sediment across time. A longer dataset is needed to determine if this trend continues or a sediment equilibrium is achieved. Although higher order channels are losing cross-section area, it is not known if the upper ends of these channels are growing. Tracking channel growth would complement channel cross-section data.

Plant communities showed clear trends toward native relative cover reference conditions at Dibblee Slough, North Unit Ruby Lake, Steamboat Slough, and Sandy River Dam, while trends toward reference conditions were not observed at Kandoll Farm #2, North Unit Widgeon Deep and North Unit Millionaire. Reed canarygrass levels, however, showed trends of increasing over the one to three-year post-restoration monitoring period for all sites except Dibblee Slough and Steamboat Slough, which showed trends of decreasing RCG cover. Further monitoring is required to identify if these trends continue and require sites to undergo adaptive management to control non-native plant community abundance. Future monitoring and evaluation should focus on comparing restored and reference wetland hydrologic zones to help identify areas requiring adaptive management.

Juvenile salmon were observed post-restoration at monitored sites. Results from intensive monitoring to juvenile salmonids and restored tidal wetlands ongoing and reflected in “State of the Science” section of this document. It should be noted that both limitation of PIT arrays (limited number of tagged fish) and the small number of previous fish sampling events, and the variability in fish being at a given restoration site during sampling makes it difficult accurately assess the number of fish that potentially could be accessing the site.

E.5 Recommendations

- The impact of soil scrape-down to the soil conditions should be considered. Changes in soil organic matter content and soil chemistry from both scrape-down activities and the reintroduction of wetland hydrology can impact plant community recovery trajectories.
- When selecting a reference site, ask: Does the site have similar restored hydrology to the reference site?
- Restored/Reference condition comparisons should focus on matching wetland hydrologic zones based on duration, frequency, and timing of inundation.
- Monitoring and comparing hydrologically similar areas within reference and restored sites is necessary for tracking response to restoration.
- Different trajectories of recovery can be expected and adaptive management likely will be needed.

E.6 Conclusion

The establishment of functional wetland processes and habitat that support juvenile salmonids is the goal of CEERP restoration efforts. Action effectiveness monitoring efforts are tracking the ecological impact of restoration work and providing valuable information to adaptively manage restoration sites. Furthermore, AEM shows the rate at which physical processes and habitats recover after the restoration project construction varies. For example, physical processes like water-surface elevation, water temperature, and habitat opportunity change immediately after the wetland is reconnected and have shown a positive trend when compared to pre-restoration or reference conditions over a short period of time. Although physical processes change quickly, other aspects of the wetland recover more slowly. Changes in vegetation community, sediment accretion, and channel formation occur over a longer time scale which makes it difficult to assess trends over the short term. It will be necessary to monitor these attributes over a longer period to determine the predominant trend. Limited fish monitoring shows juvenile salmonids are present in restoration sites after tidal reconnection, but the number of fish using the site can be difficult to ascertain. Furthermore, it is not known if the number of fish accessing a site increases as the habitat moves toward a reference state. Better understanding how physical processes influence habitat and how resulting habitat conditions support juvenile salmonids is key to quantifying the overall impact of restoration efforts.

Appendix F: Landscape-scale Analysis of Juvenile Salmon Diets in the Lower Columbia River and Estuary

Prepared by Adam Martin-Schwarze, Nichole K. Sather, Jeannette E. Zamon, Mary F. Ramirez, and Jeffery R. Cordell

F.1 Introduction and Background

Biological processes within estuarine landscapes are intricately linked to aquatic food webs. Locally, food webs are related to habitat complexity, position within the landscape, linkages between primary and secondary producers, and interactions among organisms (Vander Zanden et al. 2016; Beck et al. 2001). For example, the location of a given habitat within the landscape influences the degree to which macroinvertebrate prey resources are locally available (Wipfli and Baxter 2010; Polis et al. 1997). Production and export of prey resources are important considerations for understanding food-web dynamics in aquatic environments (Vander Zanden et al. 2016). This is particularly true in estuarine landscapes where strong spatial and temporal gradients influence environmental and biological processes (McLuskey 1993).

Tidally influenced wetlands are often central to discussions of the importance of estuarine habitats (Bottom et al. 2005). These habitats provide important feeding, rearing, and refuge opportunities for a diversity of fish, aquatic invertebrates, and terrestrial organisms (Batzer et al. 2014; Odum et al. 1984). In addition to providing benefits to organisms that directly access these habitats, tidal marshes, as described by Weinstein et al. (2005), act as "donor systems" that drive patterns responsible for export of material into adjacent habitats, which can provide benefits such as increased survival for juvenile aquatic organisms.

In the Pacific Northwest, the functional role of tidal marshes and adjacent estuarine habitats is the focal point of considerable research in studies of the early life history characteristics of salmonids (Oncorhynchus spp.). Studies have provided insights into habitat associations of juvenile salmon and have highlighted the importance of estuarine environments as nursery areas for early life stages of these migrating fishes (Healey 1982; Levings et al. 1994; Bottom et al. 2005). Research aimed at elucidating the feeding habitats of juvenile salmon has helped increase understanding of resource partitioning among species and habitats in estuaries from Alaska to Oregon (Healey 1979; Wolf et al. 1983; Gray et al. 2002; Duffy et al. 2010). Generally, juvenile Chinook salmon (O. tshawytscha) have been described as exhibiting an opportunistic feeding strategy; i.e., they take advantage of a variety of prey resources in the habitats they occupy (Healey 1991; Haskell et al. 2006; Duffy et al. 2010).

Environmental gradients and conditions, prey productivity, and ontogenetic shifts undertaken by juvenile salmon collectively influence the types of prey resources they use (Macdonald et al. 1987; Levings 1994; Duffy et al. 2010). Energetic support of salmon in estuarine habitats has been linked primarily to detritus-based food webs (Healey 1979; Maier and Simenstad 2009). Energy cycling associated with these food webs occurs largely through breakdown of allochthonous and autochthonous material by heterotrophic bacteria. The resulting detritus is then consumed by organisms such as insects and crustaceans, which form primary prey resource categories for juvenile salmon (Levings 1994). While the underlying processes supporting salmon food webs are likely similar across different regions of the Pacific Northwest, there are inherent differences among estuaries, habitats, and local disturbance regimes.

Research on the feeding patterns of juvenile salmon in the lower Columbia River and estuary (LCRE) has occurred across a wide range of environmental gradients—from tidally influenced freshwater habitats to the estuary mouth—and within a diversity of habitats—wetlands, shallow off-channel habitats, and nearshore areas adjacent to the mainstem. Despite the range in habitats and the spatial extent of these studies, there are some notable similarities in salmon diet patterns within the LCRE. Dipterans, particularly chironomids, have been reported to be a predominant prey item in the diets of juvenile Chinook salmon (Sagar et al. 2013; Bottom et al. 2011; Haskell and Tiffen 2011; Storch and Sather 2011; Eaton 2010). However, considerable variation in the predominance of this prey item has occurred across sites and seasons (Sagar et al. 2015; Storch and Sather 2011). In addition to dipterans, amphipods have composed large proportions of Chinook salmon diets (Bottom et al. 2011; Sagar et al. 2015; Haskell and Tiffan 2011; Storch and Sather 2011). Amphipods tend to occur in the guts of larger sizes (>80 mm fork length) of juvenile Chinook salmon (Eaton 2010; Bottom et al. 2011). Smaller-bodied prey items such as cladocerans have generally been encountered less frequently in the diets of Chinook salmon from the lower river and estuary, but have been reported to be seasonally important in some locations (Bottom et al. 2011; Storch and Sather 2011; Sagar et al. 2015).

The analysis of the gut contents of fish in aquatic habitats provides an opportunity to understand aspects of feeding ecology such as prey selection, energy transfer, resource partitioning, and habitat preference (Braga et al. 2012). The breadth of diet data collected in the LCRE has been substantial, and individually these studies have contributed to increased understanding of how juvenile salmon derive benefits from the habitats they occupy. As resource managers begin to incorporate functional metrics into restoration targets, aspects relevant to understanding of food webs that support salmon become increasingly important (ISAB 2011; Weinstein et al. 2005; Vander Zanden et al. 2016).

To inform landscape perspectives about prey resource usage for migrating juvenile salmon, we analyzed salmon diet data collected from four separate investigations conducted in the LCRE. For the purpose of this analysis, landscape is defined as the gradient of shallow-water habitats within the Columbia River floodplain, used by juvenile salmon, from Bonneville Dam to the river mouth. The objectives of our investigation were as follows:

1. Pool information into a common dataset and quantitatively evaluate landscape-scale spatio-temporal trends in diet patterns of juvenile Chinook salmon
2. Evaluate the spatial patterns of fish diets and determine if these patterns could inform strategies for restoration prioritization.

Combining the four data sets supports a systematic landscape-scale analysis and evaluation that might not otherwise be apparent by individually summarizing the results of each study. This evaluation is relevant to Columbia Estuary Ecosystem Restoration Program management because it increases emphasis on landscape perspectives and provides an opportunity to determine whether salmon prey resources are similar throughout the estuarine gradient. This information can potentially contribute to restoration strategies aimed at supporting prey resources critical to juvenile salmon growth and survival.

F.2 Methods

F.2.1 Study Area

The 234 km LCRE is one of the largest estuaries draining into the eastern Pacific, and it offers a prime example of the variability in environmental conditions and habitats across longitudinal gradients. Based on tidal and fluvial processes, topography, salinity, and emergent wetland vegetative conditions, the estuarine (rkm 5–87) and tidal river zones (rkm 87–229) within the LCRE have been characterized in distinct reaches (Figure F.1; Jay et al. 2016). Aquatic habitats in the main channel below rkm 87 are strongly influenced by daily tidal fluctuations and, to some extent, by coastal upwelling and downwelling processes. Within the tidally influenced river portions, water-level fluctuations caused by hydropower operations are spatially extensive, covering 150 km, and floodplain areas in the upper segments of these reaches experience seasonal isolation from river flow (Jay et al. 2015).

F.2.2 Data Sources

Our primary purpose in this analysis was to estimate longitudinal patterns in juvenile Chinook salmon diets spanning from Bonneville Dam to the estuary mouth, while accounting for effects such as fish size, seasonality, and timing of sample collections. To this end, we compiled fish diet data sets from four research programs that collectively sampled much of the river (Figure F.1). Data were analyzed as part of resource management strategies implemented by the U.S. Army Corps of Engineers' Anadromous Fish Evaluation Program and the Northwest Power and Conservation Council's Fish and Wildlife Program.[1]

The four studies that provided diet data for this analysis have been described in numerous annual reports; key citations for those studies include Sagar et al. (2013, 2015), Bottom et al. (2011), Johnson et al. (2011), and Sather et al. (2017). In all cases, the diet data associated with these studies are one of many metrics used to support project-level goals and objectives. In brief, the following listed items provide additional background associated with each of the studies:

- Ecosystem Monitoring Project (EMP). Driven by goals to understand the status and trends of ecosystem conditions in the LCRE, the EMP represents the longest monitored data sets in this analysis (Sagar et al. 2013, 2015). The overarching EMP is managed by the Estuary Partnership and the National Marine Fisheries Service (NMFS) and University of Washington (UW) have led the salmon diet investigations. The bulk of these data are focused on the spring/summer outmigration period for juvenile salmon, but intermittently, data have been collected during other seasons. The EMP diet data span the length of the LCRE and were collected within all zones except for the Lower Tidal River zone.
- Current and Historical Linkages (referenced throughout this chapter as EHJS). Led by the NMFS, this research project sought to evaluate historical habitat changes within the context of present environmental and biological conditions in the estuary. Sampling occurred in a range of habitats, including wetlands and shallow nearshore areas (Bottom et al. 2011). For the purpose of this

[1] AFEP research was largely driven by the need to satisfy the Reasonable and Prudent Alternative of Biological Opinions on operation of the Federal Columbia River Power System arising from Endangered Species Act listings of salmon and steelhead in the Columbia River basin. The primary impetus for the Fish and Wildlife Program research was to help meet the Bonneville Power Administration's environmental obligations under the Northwest Power Act.

analysis, diet data from a subset of this study were evaluated. These data comprised the bulk of data from the Lower Estuary zone (Figure F.1).

- Tidal Freshwater Research (TFR). In support of critical uncertainties research in the tidally influenced portion of the LCRE, the TFR study sought to understand the use of different habitat types by juvenile salmon (Johnson et al. 2011). The project was a collaboration between Pacific Northwest National Laboratory and Oregon Department of Fish and Wildlife. Many of the data were monitored monthly and across a number of years, which provides one of the more seasonally contiguous data sets in this analysis. Diet data were collected in the upper segments of the Middle Tidal River zone and the lower segments of the Upper Tidal River zone.
- Action Effectiveness Monitoring Research (AEMR). The goal of the Action Effectiveness Monitoring and Research project is to evaluate the ecological benefits of habitat restoration for juvenile salmon in the LCRE. The study design includes two spatial scales—site and landscape. The diet data used to support this analysis were derived from restoration and reference wetland habitats, i.e., data associated with the site-scale research objective (Sather et al. 2017). Research was focused on the spring/summer outmigration, and at the time of this analyses only diet data from 2016 were available. These data were collected from the Upper Estuary and Lower Tidal River zones.

Methodology varied in many respects across studies. Stomach contents were collected from juvenile Chinook salmon sampled in the LCRE (Figure F.1). Chinook salmon were captured from shallow-water nearshore areas using either beach seines (as described by Roegner et al. 2012, Sather et al. 2016, and Sagar et al. 2013) or fyke nets (as described by Bottom et al. 2011). Habitats sampled included wetland channels, off-channels, or shorelines adjacent to main channel habitats. Stomach contents were obtained by gastric lavage or by freezing fish and later removing whole stomachs. Lavaged stomach contents were preserved in the field using ethanol. After dissecting the frozen fish, their gut contents were preserved in ethanol or 10% neutral buffered formalin. In the laboratory, the stomach contents of juvenile salmon were identified to the lowest practical taxonomic level. The number of prey items within each taxonomic group was recorded and a blotted wet weight for each group was measured. Unidentified material from the TFR study were not recorded. A summary of collection techniques is available in Table F1.

F.2.3 Analytical Approach

We chose analytical methods that reflect both the above objectives and the constraints of pooling data across research programs, each featuring its own sampling design and methodology. In particular, the pooling of data sets limited our choice of explanatory variables for use in statistical models, because not all variables were present in every data set. When faced with a trade-off between incorporating extra explanatory variables or keeping all four data sources in the analysis, we always chose to keep the data sources. We intend to consider these extra explanatory variables (e.g., genetic stock assignment, water quality parameters) in future analyses.

In structuring a model, we had no *a priori* consensus about a best model form. We therefore adopted an exploratory approach based on Akaike's Information Criterion (AIC) model selection rather than traditional hypothesis testing. Model selection uses the data to choose among possible model forms while avoiding overfitting the model to the data. It emphasizes prediction and variable importance, whereas hypothesis testing measures the statistical significance of variables with respect to null models. In our results, we do not present *p*-values, and we present standard errors and confidence interval only as context for effect sizes.

F.2.4 Data Summary

The response and explanatory variables, sampling structure, data limitations, and analyses are summarized below.

F.2.4.1 Response Variables

We analyzed two fish-level indicators of dietary benefit to juvenile salmon: prey biomass and frequency of prey occurrence. The distribution of prey biomass within sampling occasions is right-skewed but becomes approximately normal after log transformation.

We quantified the frequency of occurrence as the proportion of fish guts (with identifiable stomach contents) that contained selected taxonomic groups of prey. We selected prey taxa that accounted for the largest biomass and/or frequency of occurrence across studies: Amphipoda, Branchiopoda (mostly Cladocera), Copepoda, Collembola, Arachnida, Diptera, Paraneoptera (mainly Hemiptera and Psocodea), and Lophozoa (combined annelida and mollusca).

F.2.4.2 Explanatory Variables

Explanatory variables available across all four data sources included time (sampling time of day, Julian date, and year), location (site and hydrologic zone), and fish size (fork length). Variables not available across all data sources in all years were not included in the analysis. These included genetic stock assignment and probabilities, physical environment metrics (e.g., temperature, flow, dissolved oxygen, and salinity), and fish mass. Fish mass was missing for many fish, but when available, it correlated very highly with the cube of fish fork length ($r = 0.99$), so we used fork length in the analyses. Fork length and Julian-date predictors were somewhat positively correlated (Pearson correlation; $r = 0.33$) and fish exhibited a consistent decrease in size during June (Figure F.2). Upon closer examination of the TFR data set, this decrease coincided with a shift in predominant genetic stocks between Spring Creek group fall and Upper Columbia River summer/fall stocks. We centered and scaled all continuous predictors before model fitting.

F.2.4.3 Sampling Structure and Data Limitations

Because individual studies were not designed to sample at a landscape scale, explanatory variables such as hydrologic zone (Table F.2), year (Table F.3), and habitat stratum (Table F.4) were confounded with data source relationships. For example, almost all samples from the Lower Estuary estuary came from a single study (EHJS) for which sampling year did not overlap with other studies. Given this degree of interrelation, there is no reliable way to entirely separate the effects from each of these causes. We eventually disregarded habitat stratum because it was considered too inter-related with other modeled terms.

While we would like to disregard effects of data sources or treat them as random variations statistically, there were too many methodological differences to dismiss them out of hand. Of particular concern were differences in site selection, sampling gear, gut content preservation practices, analysts' approaches to preparing and weighing prey items, taxonomic resolution of prey classification and life history stage recording, and protocols used for classification of unidentifiable and possibly indigestible stomach contents.

We restricted our analyses to March–July, the months most sampled across data sets. The EMP sampled relatively few fish outside this time period, and the AEMR project sampled no fish outside of April–June.

With respect to preprocessing of data, two important differences between sources were the recording of empty guts and the taxonomic resolution of prey classification. Patterns in the occurrence of empty guts undeniably should inform the analysis of benefits to juvenile salmon diet, but disparities in empty gut recording practices (both methods and numbers) left us uncertain about the true extent of this issue from study to study. Our uncertainty led us to exclude empty guts from analysis, so interpretation of prey biomass results was thus conditional on the presence of biomass in stomach samples. In all, we excluded 11 EHJS, 8 AEMR, 57 EMP, and 267 TFR fish for zero-biomass guts. The effects of this exclusion should be mitigated because the mechanisms leading to empty guts are likely the same mechanisms that explain patterns in biomass. Prey biomass measurements from the TFR data were precise to 0.001 g wet mass, whereas all other sources measured to at least 0.0001 g. This resulted in the comparably large incidence of zero-biomass prey items reported in the TFR data set.

Empty guts also affected calculations of the frequency of occurrence by prey taxon. Comparisons across data sources were further complicated by each study's 1) prevalence of unidentifiable stomach contents and 2) categorization of digestible versus indigestible contents. To make frequencies of occurrence more comparable across studies, we conditioned analysis upon the presence of at least one identifiable prey item in each fish's gut.

We standardized and aggregated taxonomy according to the Integrated Taxonomic Information System (ITIS; http://www.itis.gov/) with help from the `R` package `taxize`, version 0.9.0 (Chamberlain and Szöcs 2013). Studies differed in taxonomic resolution; the coarsest scheme was classified to the order rank (e.g., Diptera, Amphipoda, Cladocera).

F.2.5 Analytical Methods

F.2.5.1 Prey Biomass Analysis

We used linear mixed models (LMMs) to estimate hydrologic zone effects on prey biomass while accounting for variability due to sampling, temporal effects, and fish size. While only a limited number of explanatory variables appeared in all data sets, many interactions were possible among them, almost all of which were biologically plausible. To sort among model terms and interactions, we used AIC-based model selection (Burnham and Anderson 2003). We based model selection on marginal AIC (mAIC), which is appropriate when inference focuses on new observations from new data clusters (e.g., sites and years) (Vaida and Blanchard 2005).

Prior to fitting the LMMs, we examined data structures in prey biomass using a random forest—a flexible machine learning algorithm that combines decision trees and bootstrapping. Random forests are prediction tools that provide measures of the relative importance of predictor variables. Insights from the random forest informed our model selection process described below. The analysis used the R packages randomForest, version 4.6-12 (Liaw and Wiener 2002), and caret, version 6.0-78 (Kuhn et al. 2016). Feature elimination tools applied to the random forest suggested removing none of the explanatory variables. The best fit model explained 43% of the variability, suggesting that residual variation may account for roughly half of the variability in the data set.

We considered all model terms shown in Table F.5 when fitting LMMs. Due to strong patterns associating data sources with hydrologic zones (Table F.2), we treated source × zone as a single predictor. However, we formulated interaction terms with respect to zones only (e.g., Julian date × zone) and not with respect to source (e.g., Julian date × source), because zones were of biological interest while interactions with source lacked a biological interpretation. All models obeyed heredity; i.e., they included interactions only when each main effect was present. Decisions to include certain terms in all models (italicized in Table F.5) resulted from data exploration, early mixed model fits, and random forests. We fit models for all combinations (all subsets) of terms in Table F.5 subject to the constraints above.

Many models in our analysis suffered from convergence problems and high correlation in the estimation of random effects, resulting from strong associations among predictor variables and the attempted inclusion of multiple interaction terms. Such models were eliminated from our analysis.

We fit models using the lmer package in R (Bates et al. 2015) and narrowed results to a top model set consisting of all models within 13.8 mAIC of the best-supported model (an evidence ratio of 1:1000). To alleviate redundancy resulting from the all-subsets approach, we eliminated models that had uninformative parameters (Arnold 2010)—i.e., models for which a reduced form with lower mAIC existed.

F.2.5.2 Frequency of Occurrence Analysis

We employed mixed effect logistic regression to explore patterns in the presence-absence of prey taxa in Chinook salmon diets. A common problem encountered in logistic regression is quasi-separation, caused when prey in some sampling units are either always absent or always present. In these cases, maximum likelihood estimates for effects and variances tend toward infinity. To minimize issues with quasi-separation, we 1) only included sites with at least 25 fish sampled, 2) applied a single model to all prey without a formal model selection process, 3) strategically limited interaction terms in the model, and 4) fit the model using Bayesian techniques, which rely on samples of the posterior parameter distribution instead of asymptotic normality, and thereby avoid some quasi-separation issues. We chose the following model for all species based on inspection of data patterns, prey biomass model selection results, and preliminary logistic models fit via maximum likelihood:

$$\text{logit}(p) = (\text{Source} \times \text{Zone}) + \log(\text{Fork Length}) + \text{Julian Date}_{\text{cubic}} + \text{Time of Day}_{\text{quadratic}} + (\text{Julian Date} \times \text{River Kilometer}) + (1 \mid \text{Site} \times \text{Year})$$

where, p was the probability of observing a prey taxon in a stomach, (Source × Zone) was a single predictor reflecting the strong associations between project and location, Julian dates featured a cubic trend that varied linearly with respect to river kilometer, time of day had a quadratic trend, and (1 | Site × Year) indicated random effects for Site, Year, and Site × Year.

We fit models using the `brms` package (Bürkner 2016). Bayesian models require prior probability distributions for parameters, which we now describe. For each Source × Zone effect, we specified a central student-t prior with 5 df and a scaling of 2.5. The central 95% probability from this prior approximately spanned from 1-in-650 present to 649-in-650 present on the data scale, where 650 was about the sampling size for the largest source-zone. For all other parameters, we accepted the `brms` default improper uniform priors (population-level terms) and half student-t(3) priors (group-level standard deviations). We conducted Markov chain Monte Carlo (MCMC) sampling with 4 chains for 1,000 iterations each (half discarded as warmup) and diagnosed convergence with the Gelman-Rubin potential scale reduction factor (Gelman and Rubin 1992).

F.3 Results

F.3.1 Data Trends

The following section describes raw data trends in juvenile Chinook salmon diets with respect to prey biomass and the frequency of occurrence of prey items in fish guts.

F.3.1.1 Prey Biomass

Prey biomass generally increased downstream and showed a noticeable drop in the Lower Tidal River (Figure F.3). Due to strong relationships between sampling design elements, the same prey biomass patterns observed with respect to hydrologic zones were also manifested with respect to data sources and sampling years (e.g., larger biomass in the Lower Estuary was also apparent in the main channel, EHJS, and 2002–2006). Prey biomass increased with both fish size and changing seasons (Figure F.4), although size and season were correlated. There was some indication that the magnitude of both patterns changed depending on hydrologic zone. Prey biomass showed large variability from fish to fish (for context, three units on the log scale are equivalent to a 20-fold difference).

The composition of identified prey biomass (Figure F.5) came primarily from fish, Amphipoda and other crustaceans, Diptera, and other insects. Diptera accounted for the most biomass identified in juvenile Chinook salmon guts. Insects as a whole accounted for 60–80% of non-fish biomass from guts in tidal river zones but only 20–40% in estuary zones (except the AEMR Upper Estuary zone). Crustaceans, especially Amphipoda, accounted for a sizable proportion of prey biomass in estuary zones and in the TFR study of Middle and Upper Tidal River zones. Fish were a rare-event, large-payoff prey item, accounting for 10–25% of identifiable prey biomass in three of the zones but never present in more than 5% of stomachs. They were usually found in the guts of larger Chinook salmon (average 88 mm fork length versus the 70 mm overall average across data sets).

Biomass in Figure F.3 and Figure F.4 quantifies all gut biomass, including unidentifiable contents, and reflects trends in total consumption. Figure F.5 is based only on identifiable prey items to reflect taxonomic patterns. Values are affected both by source-specific methodological factors and by taxon-specific degrees of digestion in guts. In particular, a substantial proportion of biomass (60%) in the Lower Estuary zone was unidentifiable, so comparisons to other zones rely on the assumption that identifiable prey were representative of unidentifiable prey.

F.3.1.2 Frequency of Occurrence

Raw prey composition data, as measured by taxon frequency of occurrence in guts, shifted across hydrologic zones, data sources, sites, and years (Figure F.6). Diptera were present in most Chinook salmon guts throughout the river but were relatively less common in the Lower Estuary. The stomachs of fish from tidal river zones more often contained zooplankton (Branchiopoda and Copepoda), Hymenoptera, and a variety of other insect taxa than did those of fish from the estuary zone. The stomachs of fish from estuary zones more often contained Lophozoa, Amphipoda, and a variety of other crustacean species. Plant matter appeared in roughly one-sixth of the guts of fish from the Lower Estuary in EHJS. The guts of fish from AEMR and the Lower Tidal River zone frequently contained taxa that appeared rarely in other source-zones (Branchiopoda, Collembola, and Arachnida). Using the `R` package `vegan,` version 2.4-4 (Oksanen et al. 2017), we employed nonmetric multidimensional scaling for an alternate plot of the occurrence data with respect to sites by zone (Figure F.7); it reinforces many of the patterns stated above.

F.3.2 Model Results

F.3.2.1 Prey Biomass

Model selection yielded 25 models. The top eight models accounted for 0.92 of the total weight, and the top two models accounted for 0.65 (Table F.6). The frequent inclusion of several interaction terms revealed complicated relationships among location, seasonality, and fish size in predicting prey biomass. Model weights should be interpreted cautiously. They are sometimes misinterpreted as directly measuring the probability that a model is the best or true model, but strictly speaking, they quantify model likelihood functions and therefore provide relative support across models (Cade 2015). Likewise, weights do not directly measure the importance of individual variables within models but rather models as a whole (Cade 2015).

The largest source of variation in prey biomass came from fish size; i.e., the log(Fork Length) model term (Figure F.8). In many models, fish size interacted with both location (zone or site) and Julian date. Models displayed in Figure F.8 as flat lines (i.e., they featured a fish-size × site interaction instead of a fish-size × zone interaction) had an estimated average fish-size effect between (0.65, 0.70) in mid-May. Converting to the data scale (because models were fit to a centered and scaled version of log-transformed fork length), this meant roughly that $Biomass \propto (Fork\ Length)^{2.6}$. Models with fish-size × zone interaction terms suggested larger fish-size effects in estuary zones than tidal river zones, but standard errors were on the order of 0.07–0.08 (0.17 for the Lower Tidal River), and other models did not include the interaction term. Most models featured a fish-size × Julian-date interaction wherein fish-size effects were larger early in the season than later.

Figure F.9 shows estimated prey biomass across source-zones from each model in the 25-model selection set. Estimates consistently showed higher prey biomass downriver. With source-zone standard errors ranging on average from (0.15–0.35), many of the differences in biomass would be considered significant outside a model selection framework. However, zone effects were entangled with source effects, bookended by large unidentifiable biomass in EHJS (Lower Estuary) versus unreported unidentifiable biomass in TFR (Middle and Upper Tidal River). Arrangement by Julian date in Figure

F.9 illustrates the temporal variation in source-zone patterns, particularly in tidal river zones. As noted above, source-zone effects also changed with respect to fish size (Figure F.8).

Seasonality played a prominent role across models via linear and quadratic Julian-date effects. In addition, most other effects varied seasonally, as shown by Julian-date interaction terms. Figure F.10 visualizes model-averaged seasonal patterns in prey biomass for a variety of fish sizes for a typical site, year, sampling occasion, and time of day. Seasonal effects were larger upriver than downriver. Julian-date estimates relied on frequently sampled sites in TFR, EHJS, and EMP sites, because many study sites (AEMR and some EMP) were sampled on no more than three dates.

The bulk of models supported a modest time-of-day effect on the scale of a 5–8.5% increase in prey biomass per hour for mid-late May, with 95% confidence intervals among these models spanning 1% to 14%. Sampling largely occurred between 5:30 a.m. to 5:30 p.m., with AEMR sampling occurring particularly early (5:30–8:00 a.m.). Several models, including the top two, also supported a negative linear interaction with Julian date, meaning that time-of-day effects in these models were higher in March (14–17% per hour) but lower in July (-2 to 0%). Model-specific 95% confidence intervals for these months spanned (5%–27%) and (-11%–9%), respectively.

Data were highly variable at multiple scales. Model-weighted residual variance was 1.28 (a 3.1-fold difference in prey biomass between fish separated by one standard deviation). Residuals from EHJS had smaller variances than other sources (0.75; 2.4-fold), while AEMR and EMP variances were both near 1.5 (3.4-fold). Variance across sampling occasions (Site × Date) was 0.26 (1.7-fold difference per standard deviation). Site × Year variance was estimated as zero, being amply explained by variation across sampling occasions. However, year-to-year variance was 0.03 (1.19-fold), while site-to-site variance was 0.04 (1.22-fold).

F.3.2.2 Frequency of Occurrence

Estimates of frequency of occurrence by zone and source (Figure F.11) largely mirrored patterns in the raw data (Figure F.6). Several taxonomic groups displayed apparent differences between estuary and tidal river zones. Amphipoda were generally more abundant in estuary zones, while Branchiopoda and Copepoda were more prevalent in tidal river zones. Diptera were common everywhere but less so in the Lower Estuary.

Estimated data source effects were often noticeable for AEMR vis-à-vis EMP within the Upper Estuary zone, with higher occurrence of Arachnida, Collembola, and Paraneoptera and lower occurrence of Amphipoda. Additionally, TFR samples contained Amphipoda more often than EMP samples in the Middle Tidal River zone and contained Paraneoptera less often. There was no evidence of source effects between EHJS and EMP in the Lower Estuary. The existence of both source and zone effects complicated interpretation among locations.

Random effect variability across sites and years (Figure F.12) contributed to the larger standard errors seen for some taxonomic groups in Figure F.11. Potential year-to-year variation explained a large proportion of the wide credible intervals for Lophozoa, Branchiopoda, and Copepoda. Unexplained site-to-site variability led to standard deviations of about one for some taxonomic groups (where a unit on the logit scale represents a 2.7-fold change in the odds of presence), but site variability was small in Diptera, and Paraneoptera. Variability across sites-within-years (or equivalently years-within-sites) contributed to roughly 2- to 10-fold shifts in frequency of occurrence per standard deviation across taxa.

Feeding patterns varied according to fish size (Figure F.13). Stomachs of larger fish more often contained Lophozoa and Amphipoda, while guts from smaller fish more often held Branchiopoda, Copepoda, Collembola, and Diptera.

Frequency of occurrence changed for some species across the five-month study period (Figure F.14) relative to baseline detection probabilities in Figure F.11. Arachnida, Branchiopoda, and Paraneoptera exhibited the largest changes, with over 10-fold increases (>2.3 logit units) in the odds of gut presence from early to late season. All three were rare in March. The model allowed for a linear Julian date × river kilometer interaction (i.e., a seasonality effect that varied linearly along the river). This effect was most prevalent in Copepoda but also somewhat apparent in Amphipoda and Branchiopoda. Because Branchiopoda and Copepoda were both rarely observed in the Lower Estuary (Figure F.11), the estimated interaction really reflected data patterns between the tidal river zones.

Model fits suggest a diversity of diurnal trends in frequency of occurrence (Figure F.15): morning taxa (Amphipoda, Branchiopoda, and Collembola), afternoon (Paraneoptera), morning-and-afternoon (Diptera), mid-day (Copepoda), and no clear trend at all (Lophozoa and Arachnida).

F.4 Discussion

By compiling existing data sets, we sought to increase the understanding of landscape-scale trends in feeding patterns by juvenile Chinook salmon in the LCRE. Our efforts have added to the current research through an analysis of over 2,800 guts sampled from 42 locations spanning the length of the LCRE and representing over a decade of research. Results indicated a contrast in salmon diets between estuary and tidal river zones. Diets of fish from estuary zones generally consisted of a larger proportion of amphipods, such as Corophium (David et al. 2016), other Crustacea (e.g., shrimp, isopods, barnacles), and taxa such as bivalves, molluscs, and worms. Diets of fish in the fluvially dominated, tidal river zones of the estuary contained a greater proportion of zooplankton (e.g., daphnids, copepods) and insects than diets of fish from the estuarine zones. These general patterns in diets of juvenile salmon in the LCRE likely reflect differences in environmental gradients such as salinity, river discharge, and vertical mixing.

While the diets of juvenile salmon showed some distinctions along the longitudinal LCRE gradient, there was considerable overlap. Most notable was the predominance of Diptera in all zones. Some data sets in this study did not identify specific families within the order Diptera, but for those that did, chironomids composed the greatest proportion of abundance in the diets of juvenile salmon. Chironomids are found in nearly all freshwater aquatic habitats and often compose appreciable portions of invertebrate abundance (Batzer et al. 2014; Ferrington et al. 2008). These organisms provide an important prey resource for a variety of wetland biota, including birds, fish, and predatory wetland invertebrates, and therefore play an important role in the flow of energy within wetland habitats (Batzer et al. 2014; Thorp and Covich 2010). Dipterans and chironomids are common prey items for juvenile salmon and have been documented in a variety of systems throughout the Pacific Northwest including estuarine habitats in Alaska (Wolf et al. 1983), the Puget Sound (Cordell et al. 2011; Duffy et al. 2010), and Oregon (Gray et al. 2002), as well as within freshwater regions of the upper Columbia River (Dauble et al. 1980).

As one of the most taxonomically diverse families, Chironomidae account for over 1,000 species in North America (Triplehorn and Johnson 2005). The distribution of chironomids has been used to distinguish gradients and characterize environmental conditions among aquatic habitats (Ferrington et al. 2008). For instance, within the Upper Estuary zone of the LCRE, Ramirez (2008) collected prey samples and described an estimated 23 genera of Chironomidae at Russian Island (rkm 39). The distribution and abundance of the genera helped to distinguish microhabitats within the tidal marsh complex. Despite a diversity of habitats and environmental gradients across the LCRE, our analysis of salmon diets found little apparent spatial pattern associated with the most abundant prey item. The apparent lack of partitioning among Diptera across LCRE zones is likely related to several factors: 1) the coarse taxonomic resolution of some data sets, which was driven by project-specific protocols for analysis; 2) the ability of fish to migrate, suggesting diet samples do not reflect conditions at place of capture as well as prey samples do; and 3) the coarse spatial definition of LCRE zones relative to smaller spatial distinctions among functional habitats.

The data used for the diet analysis were collected from a diversity of habitat types in the LCRE. For the purpose of this analysis, we broadly characterized these habitats as wetland, off-channel, and main channel (see Sather et al. 2016). For the statistical models we employed, habitat type was so confounded with data source and hydrologic zone that we rejected its use as an explanatory variable; however, it is important to note that evaluating feeding patterns among different habitat types was not explicitly part of any of the original study designs. That said, the TFR and EMP data sets in the Upper and Middle Tidal River zones may offer insights into some habitat differences with regard to amphipod prey resources. Gut contents from the TFR study, which largely sampled fish from main- and off-channel habitats, had a higher frequency of occurrence and biomass of amphipods, largely composed of Corophium, than did fish sampled from wetland habitats in these two zones by the EMP study (Figure F.6).

Estuarine wetlands are highly productive habitats and contribute to estuarine food webs through the input of detritus (Odum 1980; Mitsch and Gosselink 1993). In the LCRE, tidal wetland habitats and aboveground biomass, a key contributor to detritus, are more prevalent in the estuarine zones than in tidal-fluvial zones. Greater availability of favorable habitats may explain, in part, the increase in the biomass of gut contents of fish from the fluvial zones relative to the Lower Estuary zone. However, in a study examining growth of juvenile Chinook salmon across the LCRE zones, Chittaro et al. (2018) described reduced mean density and richness of prey items within the lower segments of the estuary coupled with a decrease in the growth of juvenile Chinook salmon. In their study, prey densities were not important indicators of variability in the growth rate of fish in their study. In our investigation, based on results from the AEMR study, gut content biomass was lowest in the Lower Tidal River zone (~rkm 90–102). This zone is characterized by a confined floodplain with low habitat complexity and few off-channel habitats (Jay et al. 2016). These factors may constrain prey resources for juvenile salmon in this zone; however, the limited data from this zone, compared with other zones (Table F.2), constrains our ability to make inferences about what may be driving this pattern.

Fish size is also an important factor related to the foraging patterns of juvenile salmon. In the Campbell River estuary, Macdonald et al. (198 7) noted as juvenile salmon moved seaward their diet shifted toward benthic and marine organisms. This shift was attributed to differences in availability of prey, changes in habitat conditions, as well as changes in fish size. Our investigation noted similar shifts in the selectivity of prey by juvenile salmon. The interaction between location and fish size indicates the difficulty in isolating these factors. We noted larger fish consumed a greater proportion of amphipods and Lophozoa (i.e., annelids and molluscs), which also occurred more frequently and with a higher biomass in lower segments of the estuary. Similarly, within wetland habitats of the Lower and Upper Estuary zones, Bottom et al. (2011) found that, as juvenile salmon increased in size, amphipods and annelids became more predominant prey items, and the contribution of chironomids and other insects to salmon diets decreased. While it is possible these prey items may be encountered in the water column, its likely larger fish exploited prey resources in the benthos. Ontogenetic habitat shifts from shallow to deeper habitats, with increasing size, may maximize the opportunity to capitalize on food availability (Macdonald et al. 1987).

F.5 Conclusions and Recommendations

Key Findings – In all zones of the LCRE, Diptera, especially chironomids, were common in juvenile salmon diets. In the Lower and Upper Estuary zones, juvenile salmon diets were dominated by amphipods, other Crustacea (e.g., shrimp, isopods, barnacles), and taxa such as bivalves, molluscs, and worms. In the tidal river zones, juvenile salmon diets contained a high proportion of zooplankton (e.g., daphnids, copepods) and insects. In statistical models predicting prey biomass in juvenile salmon diets, fish size (fork length) explained the largest source of variation. There were complicated relationships among location, seasonality, and fish size. Diet data were highly variable at multiple scales, e.g., site-to-site, year-to-year. In the Upper Tidal River zone, Corophium were more prevalent in diets of fish sampled in off-channel and main-channel habitats than wetland habitats.

Limitations and Recommendations – For this analysis, we assembled data post hoc from multiple studies with differing objectives and data collection and processing methods. As such, the analysis of diet by habitat type was limited. We offer three recommendations to address the limitations we encountered: (1) develop protocols for fish gut content sampling and analysis (e.g., sampling design, common environmental variables, sample processing methods, taxonomic resolution); (2) improve coordination among studies, not just among researchers but at a programmatic level—each project should target priorities and knowledge gaps as identified in an overarching plan; and (3) evaluate a suite of alternative biotic response metrics to determine whether gut content analysis provides information that is both adequate and the best for supporting CEERP goals, especially given the program's landscape-scale objectives. Review and coordination would augment and help lead to a more robust research and monitoring program for future studies.

Taxonomic resolution of prey items in diets varied among data sets. Energy content—a response variable more closely aligned with benefits accrued by juvenile salmon—could not be applied to the data sets in this analysis, in large part due to limitations in taxonomic resolution. However, there are gaps in the existing knowledge of energy density values for many prey and life stages, and there are conflicting values between sources (cf David et al. 2016 and Cummins and Wuycheck 1971). More research is necessary to fill existing gaps before energy density can become a useful response metric for the CEERP.

Management Implications – The goal of this analysis was to inform CEERP management of landscape-scale perspectives concerning diet of migrating juvenile salmon that may be used during restoration prioritization. The results, barring limitations described above, did not highlight a particular habitat type or zone in the LCRE that should be the focus of habitat restoration. Some findings, such as lower biomass of gut contents in the Lower Tidal River zone or greater occurrence of Corophium in the diets of fish in off-channel habitats in the fluvially dominated zones, provide some indication of locations and habitat types that should be considered for future research.

F.6 Tables

Table F.1. Summary of studies and methods used to capture fish and collect gut contents.

Source	Funding Agency	Research Leads by Agency	Fish Capture Methods	Field Diet Collection Method	Diet Preservation Method	Biomass Precision	Proportion of biomass categorized as 'other' or UID*	Proportion of samples identified within a given taxonomic category
EHJS	COE	NMFS	Beach seine	Whole fish, frozen in field	Formalin; 10% buffered	10^{-4}	0.61	Order: 0.80 Family: 0.36 Genus: 0.30
AEMR	COE	PNNL	Fyke net	Whole fish frozen in field, and gastric lavage	ETOH**; 70%	10^{-4}	0.07	Order: 0.89 Family: 0.64 Genus: 0.15
EMP	BPA	EP, NMFS, UW	Beach seine	Whole fish, frozen in field	ETOH (2008-15) Formalin; 10% buffered (2016-17)	10^{-4}	0.05	Order: 0.94 Family: 0.24 Genus: 0.07
TFR	BPA/ COE	PNNL, ODFW	Beach seine	Gastric lavage	ETOH; 70%	10^{-3}	<0.01	Order: 0.93 Family: 0.71 Genus: 0.22

*UID = unidentified; **ETOH = ethanol.

Table F.2. Total fish sampled from each data source classified by stomach contents and by hydrologic zone. Zone totals are for fish with nonzero prey biomass.

Source	With nonzero prey biomass	With identified stomach contents	Lower Estuary	Upper Estuary	Lower Tidal River	Middle Tidal River	Upper Tidal River
EHJS	718	663	718				
AEMR	242	302		53	189		
EMP	1035	927	43	543		386	63
TFR	737	920				176	561
Total	2732	2812	761	596	189	562	624

Table F.3. Total fish sampled each year from each data source. Totals are for fish with nonzero prey biomass.

Source	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EHJS	92	128	144	196	158										
AEMR															250
EMP							64	56	234	86	275	150		72	98
TFR							178	222	160	71	106				
Total	92	128	144	196	158	-	242	278	394	157	381	150	-	72	348

Table F.4. Total fish sampled from March–July and by habitat stratum from each data source. Totals are for fish with nonzero prey biomass.

Source	Mar	Apr	May	Jun	Jul	Main Channel	Off-Channel	Wetland
EHJS	52	70	299	73	224	606	112	
AEMR		78	78	86				242
EMP	41	202	464	261	67		48	987
TFR	121	126	126	187	177	128	602	7
Total	214	476	967	607	468	734	762	1236

Table F.5. Effects considered in model selection. We modeled Julian Date (JDate) in both linear and quadratic forms. We treated the combination of data Source and Hydrologic Zone as a single fixed effect predictor variable. We enforced heredity for all interactions and random slopes. Italicized terms were included in all model fits.

	Location	Time	Fish
Fixed Effects	*Source × Hydrologic Zone*	*Julian Date* *(Julian Date)^2* Time of Day	*log(Fork Length)*
Interactions	All two-way interactions among Hydrologic Zone, JDate / (JDate)^2, Time of Day, and log(Fork Length)		
Random Intercepts	*Site, Year, Site × Year, Sampling Occasion*		
Random Slopes	JDate / (JDate)^2 and log(Fork Length) with respect to both Sites and Years		

Table F.6. Summary of the most preferred models and terms from model selection. The selection set of models contained 25 models with ΔmAIC < 13.8. 'log(FL)' = 'log(Fork Length)'.

	Top Models				**Total Weight**
	Best	**Second**	**Third**	**Effect Type**	**Across All Models**
ΔmAIC	-	0.410	2.910		
Model Weight	0.356	0.290	0.083		
Terms in All Models	*Fixed*: Source-Zone, log(Fork Length), Julian Date, (Julian Date)2 *Random*: Site, Year, Site × Year, Sampling Occasion				
Time of Day	+	+	+	Fixed	0.998
Julian Date × Zone	+	+	+	Fixed	0.958
(Julian Date)^2 × Zone	+	+	+	Fixed	0.933
log(FL) × Julian Date	+	+	+	Fixed	0.889
Julian Date × Time of Day	+	+	-	Fixed	0.779
log(FL) × Zone	+	-	+	Fixed	0.496
log(FL) × Site	-	+	-	Random	0.472
Terms Below 0.05 Weight	*Fixed*: log(FL) × Time of Day, log(FL) × (Julian Date)^2 *Random*: Julian Date × Site, (Julian Date)^2 × Site				
Terms in No Models	*Fixed*: Time of Day × Zone *Random*: log(FL) × Year, Julian Date × Year, (Julian Date)^2 × Year				

Table F.7. Frequency of occurrence (FoO) by taxonomic group for EMP and AEMR samples collected in the Upper Estuary at Welch Island in April and May 2016. 'P' denotes the number of stomach samples containing each taxonomic group. Groups more common in EMP appear at the top while those more common in AEMR appear at the bottom.

	April				May			
	EMP		AEMR		EMP		AEMR	
	P	FoO	P	FoO	P	FoO	P	FoO
Amphipoda	12	0.92	11	0.58	15	1.00	8	0.40
Branchiopoda	9	0.69	3	0.16	1	0.07	2	0.10
Copepoda	2	0.15	0	0.00	0	0.00	0	0.00
Other Insecta	1	0.08	2	0.11	6	0.40	6	0.30
Lophozoa	0	0.00	0	0.00	1	0.07	0	0.00
Fish	0	0.00	0	0.00	1	0.07	1	0.05
Other	0	0.00	0	0.00	0	0.00	0	0.00
Diptera	11	0.85	18	0.95	15	1.00	20	1.00
Other Crustacea	0	0.00	5	0.26	2	0.13	0	0.00
Collembola	0	0.00	1	0.05	0	0.00	4	0.20
Paraneoptera	0	0.00	5	0.26	1	0.07	4	0.20
Arachnida	0	0.00	1	0.05	1	0.07	9	0.45
	13		19		15		20	

F.7 Figures

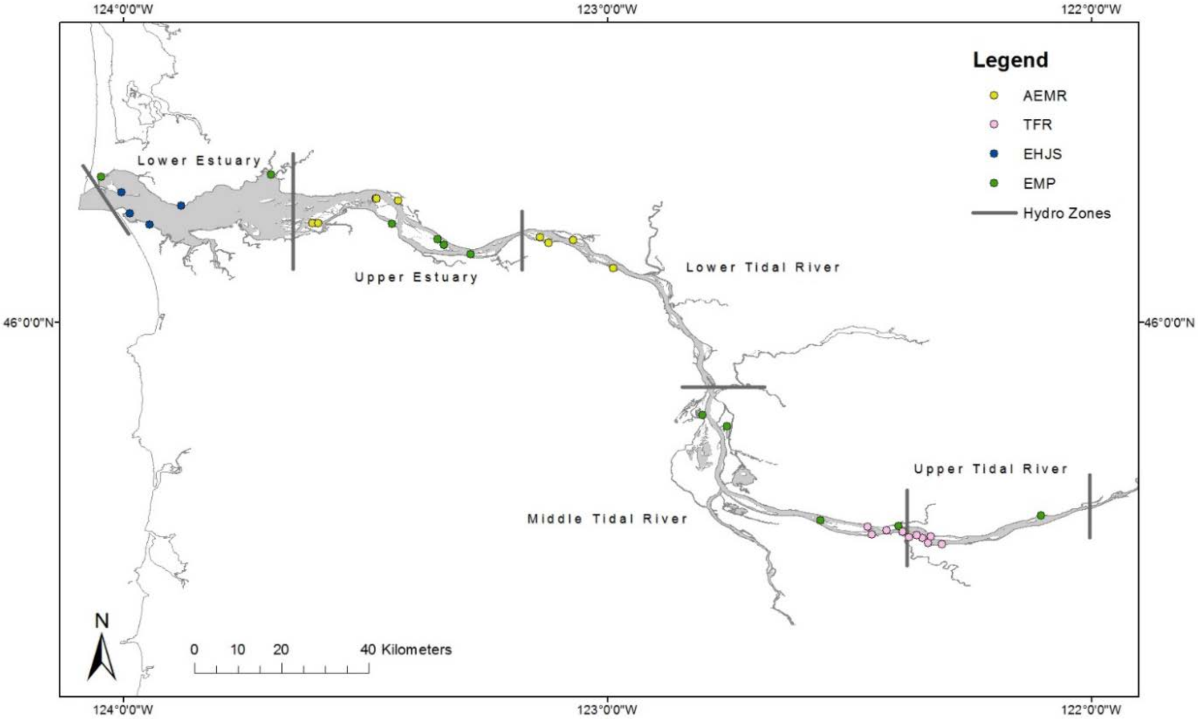


Figure F.1. Lower Columbia River and estuary study area. The five zones are defined by Jay et al. (2016). Sites correspond to four research studies.

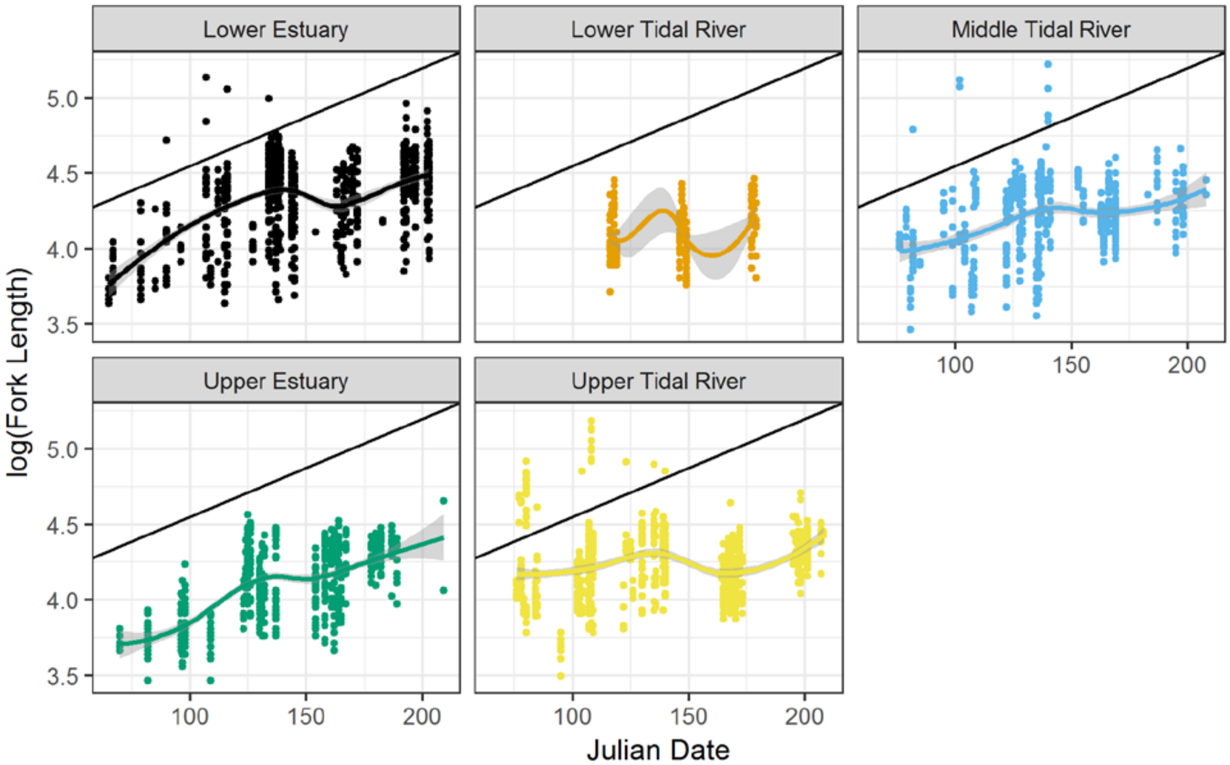


Figure F.2. Fork length (mm) versus sampling date faceted by hydrologic zone and fit with spline trend lines. Black lines divide the bimodal distribution of fish sizes, which approximately distinguishes yearling and subyearling salmon (see Johnson et al. 2014 and Roegner et al. 2016 for additional information on the use of size and timing to distinguish life history stages of juvenile salmon in the LCRE).

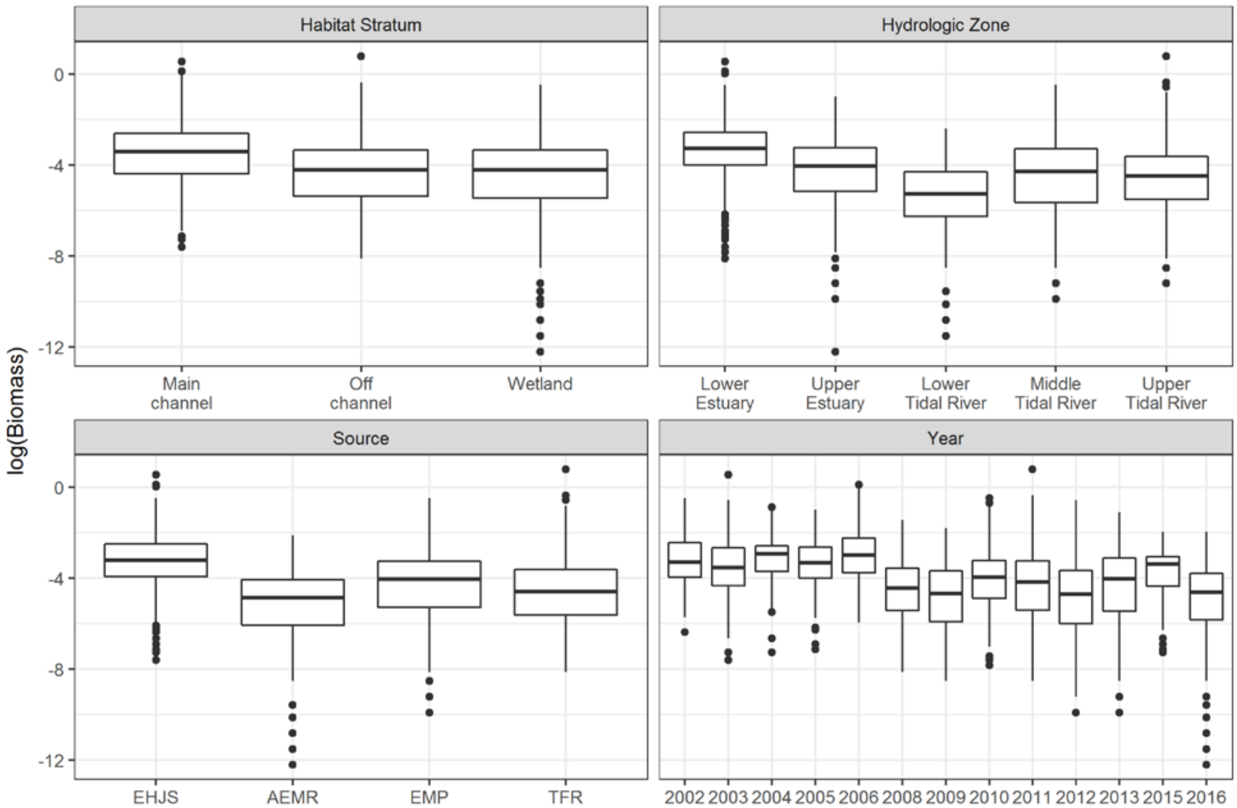


Figure F.3. Distribution of log-scale prey biomass (g) against categorical explanatory variables. The upper and lower bounds (hinges) of the boxes show the interquartile range (IQR; 25th and 75th quartiles). Median log biomass is represented as the horizontal line inside the box. Vertical lines extend outside the boxes to the largest (smallest) value up to 1.5 x IQR beyond the hinges. Dots are outliers.

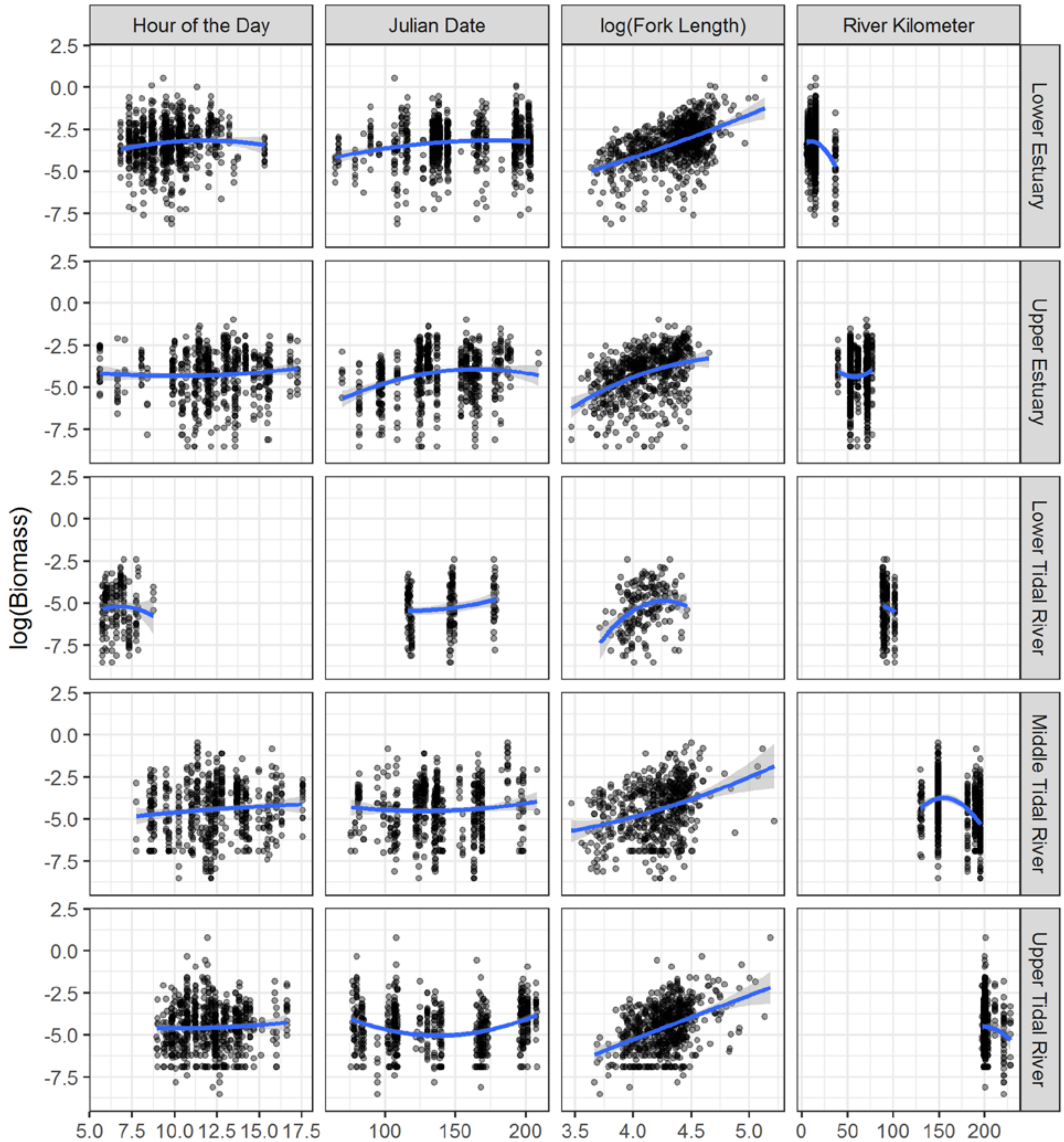


Figure F.4. Scatterplots of log-scale prey biomass versus continuous explanatory variables with quadratic trend lines. The plots are faceted by explanatory variable (columns) and hydrologic zone (rows). Log-scale biomass samples below -8 are excluded from the plots.

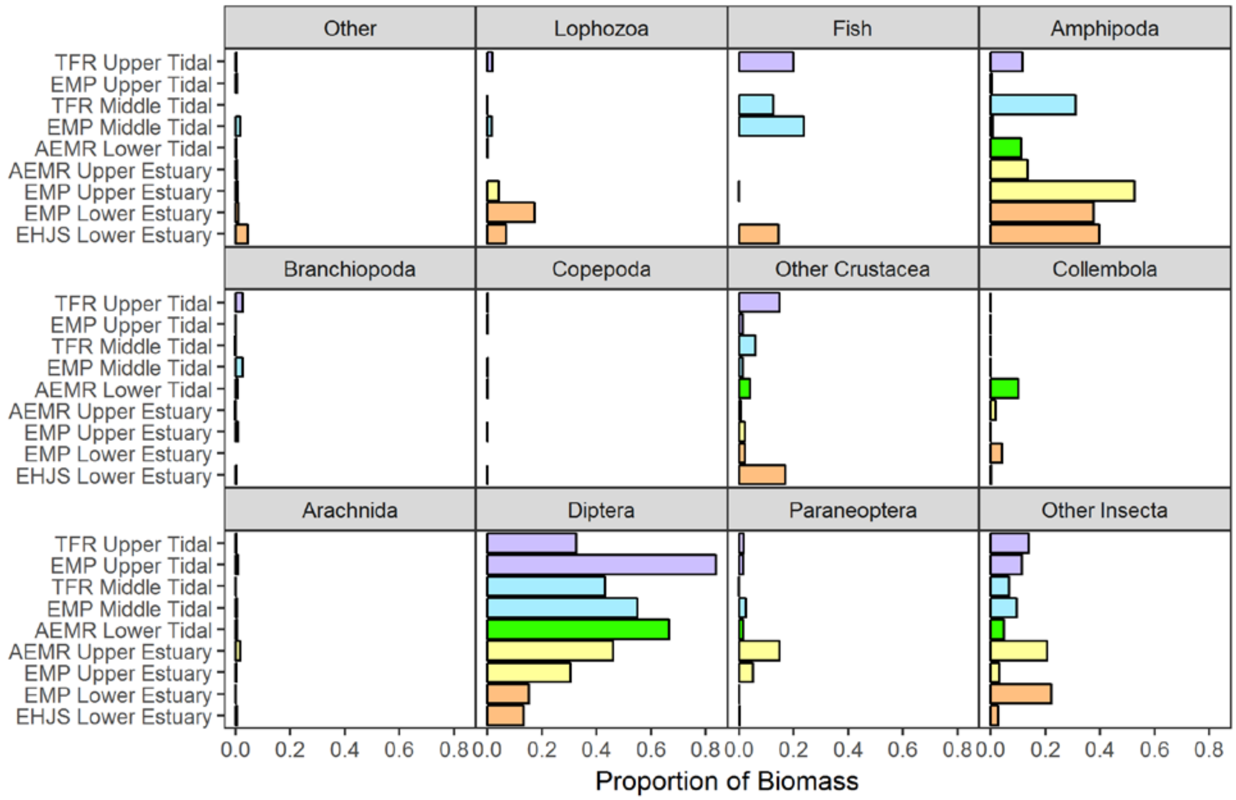


Figure F.5. Proportion of total identified prey biomass by taxonomic grouping within each source × hydrologic zone. Bar colors depict hydrologic zones. 'Lophozoa' consist of Annelida and Mollusca. 'Branchiopoda' are mainly Cladocera. 'Other Crustacea' consist of Cirripedia, Cumacea, Decapoda, Isopoda, and Mysida. 'Paraneoptera' are Hemiptera and Psocodea. And 'Other Insecta' consist mainly of Coleoptera, Ephemeroptera, Hymenoptera, and Trichoptera.

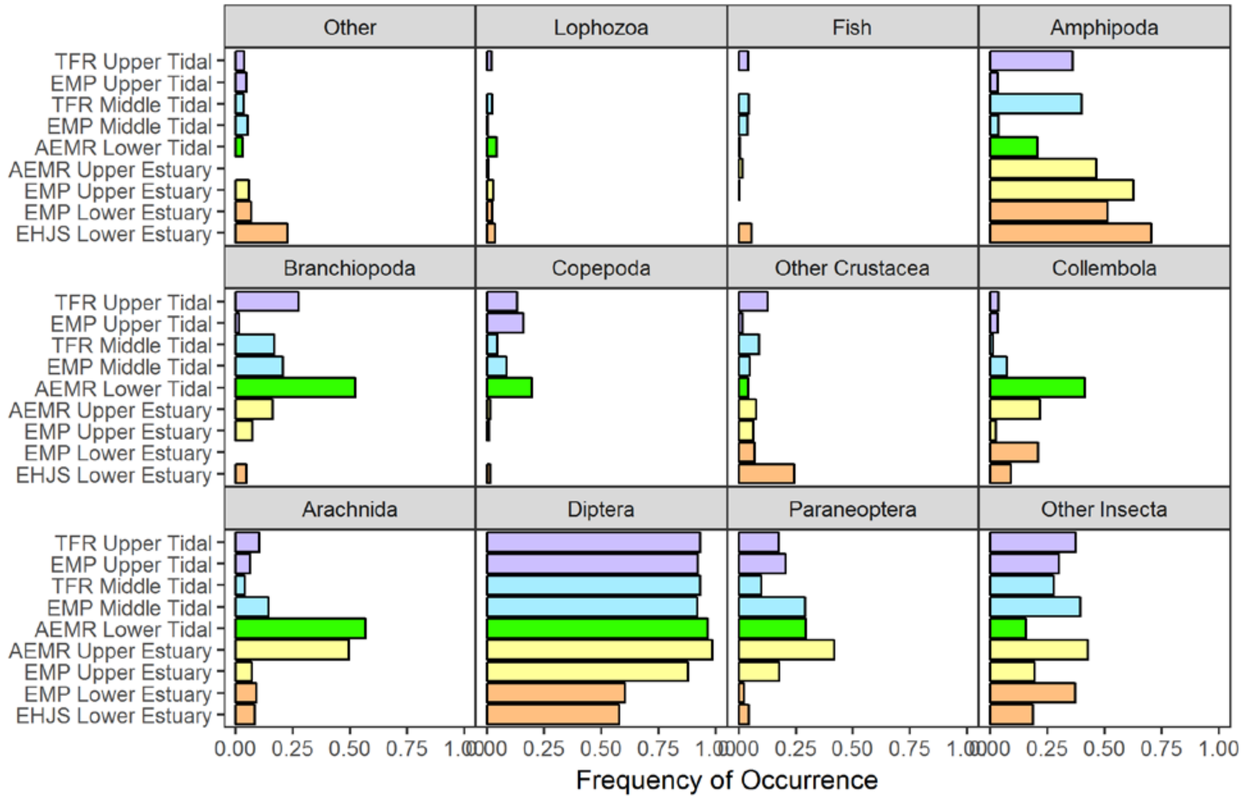


Figure F.6. Taxon-specific frequency of occurrence by hydrologic zone. 'Lophozoa' consist of Annelida and Mollusca. 'Branchiopoda' are mainly Cladocera. 'Other Crustacea' consist of Cirripedia, Cumacea, Decapoda, Isopoda, and Mysida. 'Paraneoptera' are Hemiptera and Psocodea. And 'Other Insecta' consist mainly of Coleoptera, Ephemeroptera, Hymenoptera, and Trichoptera.

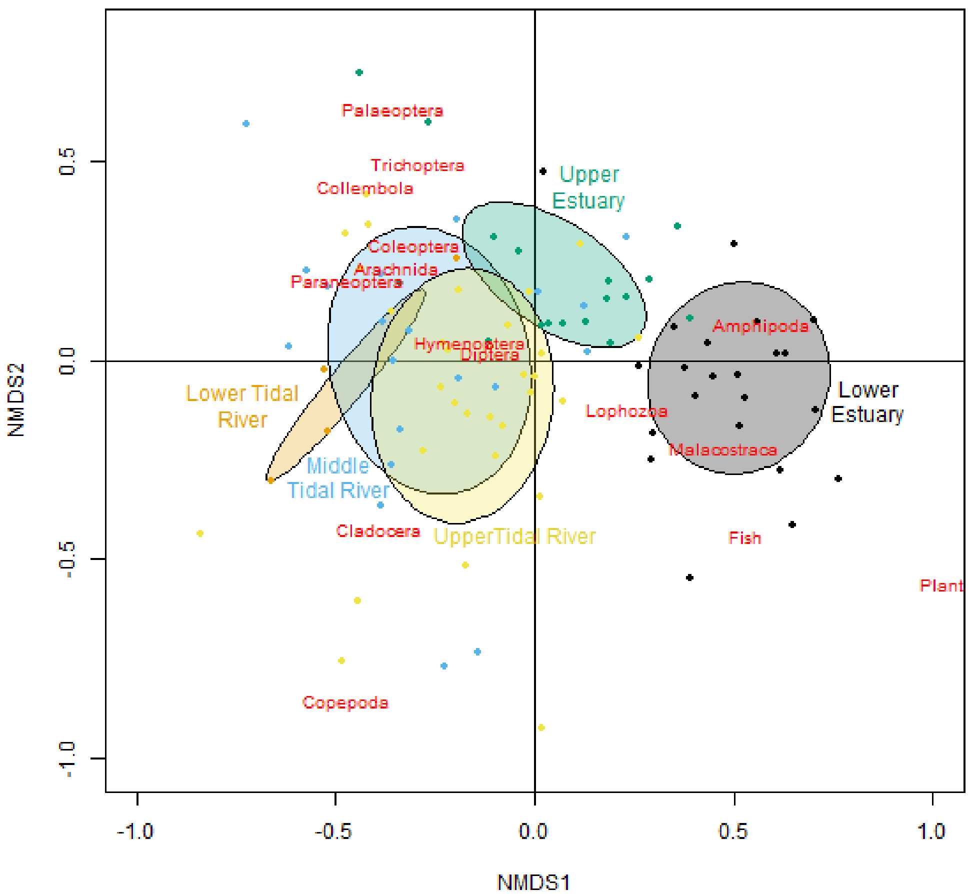


Figure F.7. Nonmetric multidimensional scaling plot of frequency of occurrence data (stress = 0.18). Each point represents samples from a site-year. Ellipses represent color-coded hydrologic zones. Red text locates taxonomic group vectors along the MDS axes. Sites are generally positively correlated with species sharing the same direction from the origin. 'Lophozoa' consist of Annelida and Mollusca. 'Malacostraca' consist of Decapoda, Isopoda, Mysida, and Cumacea.

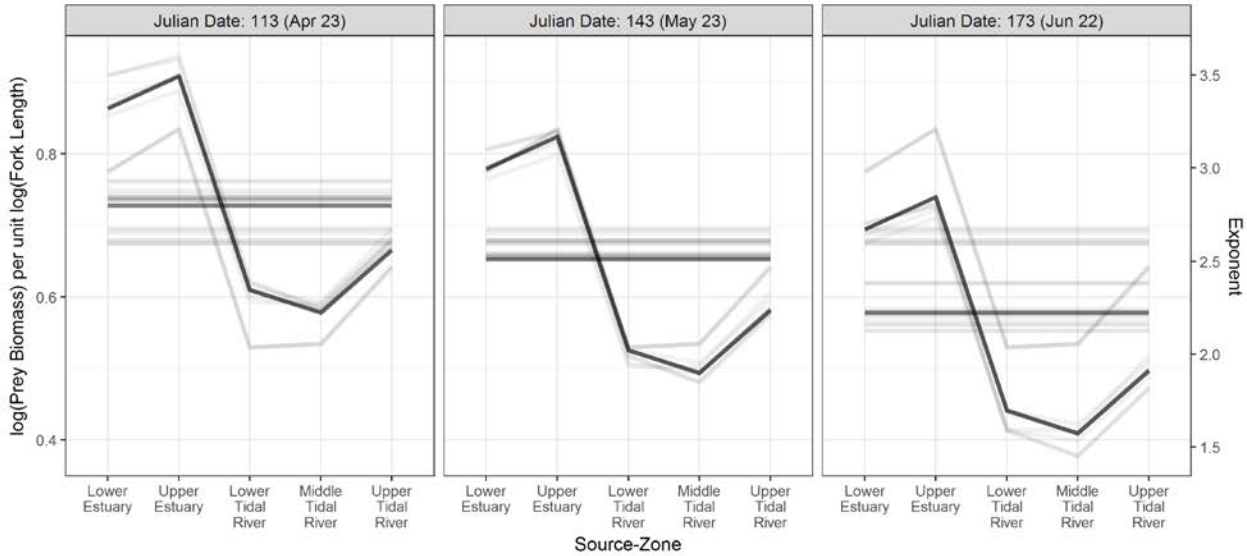


Figure F.8. Estimated effects of fish size on prey biomass across zones from mid-April to mid-June. Each line displays the estimates from a single model, with transparency depicting model weights. Plots do not display within-model standard errors. The left-hand axis portrays the model estimate with respect to centered and scaled log-scale fork lengths. The right-hand axis portrays the equivalent effect (*x*) on the data scale expressed as: $\boldsymbol{Biomass} \propto (\boldsymbol{Fork\ Length})^{\boldsymbol{x}}$. Models shown as a flat line (i.e., without a fish-size × zone interaction term) nearly all do feature a term for random fish-size × site variability.

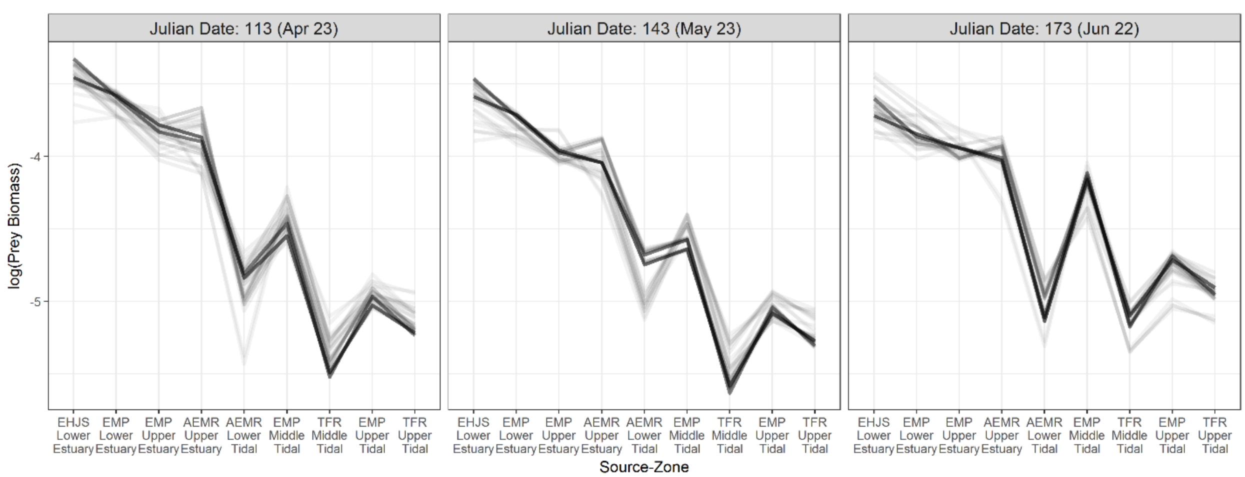


Figure F.9. Estimated prey biomass by source-zone from mid-April to mid-June for an average (68 mm) fish near mid-day for an average site and year. Each line displays estimates from a single model, with transparency depicting model weights. Plots do not display within-model estimation errors.

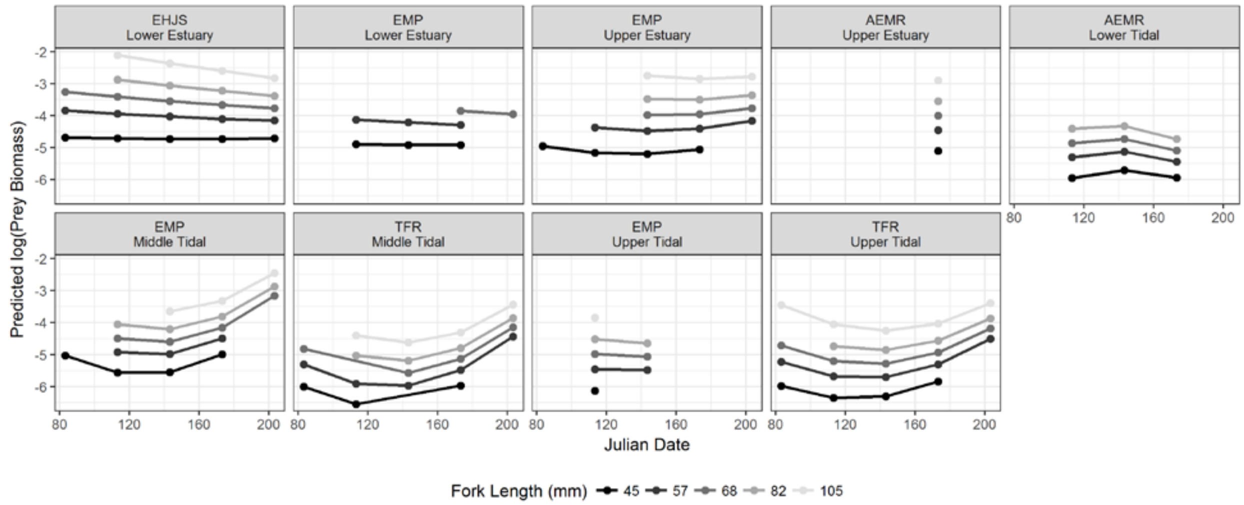


Figure F.10. Model-averaged predictions of seasonal patterns in prey biomass for a variety of fish sizes for a typical site, year, sampling occasion, and time of day. Standard errors for predictions not shown. Predictions are only shown for dates and fish sizes present in the original data. Fish size was positively correlated with Julian date, so for example, a typical fish caught in July (83 mm) was larger than a typical fish in March (60 mm). Fork lengths display the approximate 5, 25, 50, 75, and 95th percentiles of fish observed (across sampling dates).

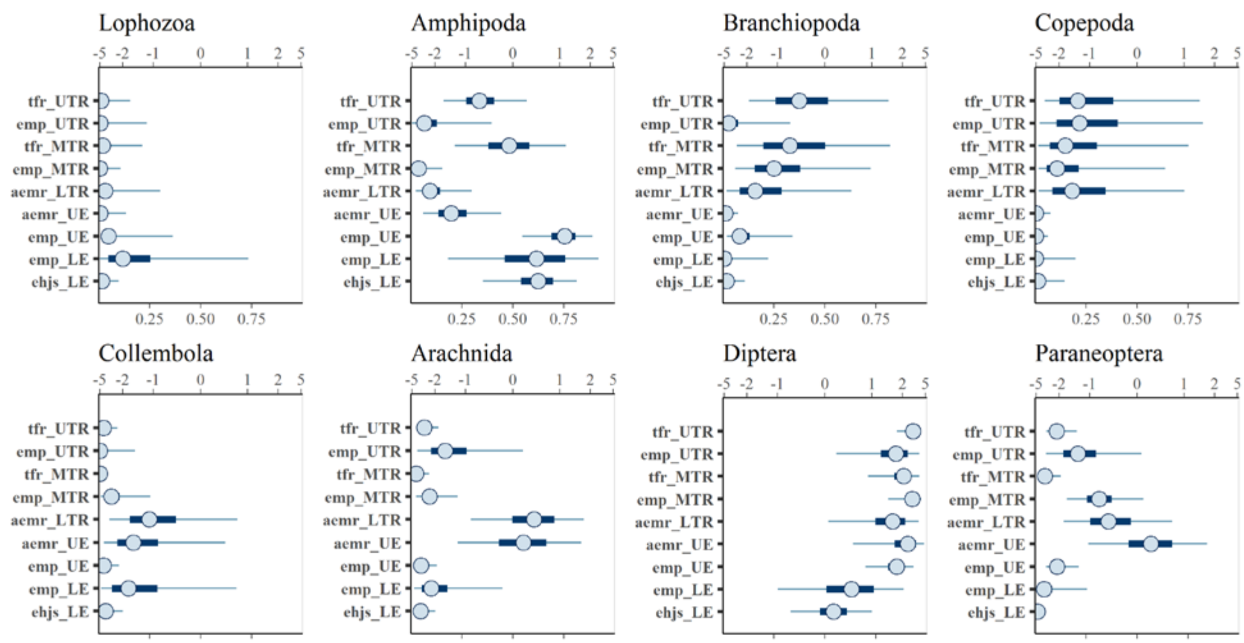


Figure F.11. Posterior estimates for frequency of occurrence by source-zone, arranged by zone. Thin lines are 95% credible intervals, thicker lines are 50% credible intervals, and dots are posterior medians. Probability values appear on the lower (primary) axis with associated logit-scale values on the upper axis. Estimates reflect a typical site and year at the dataset average fish size, date, and time of day.

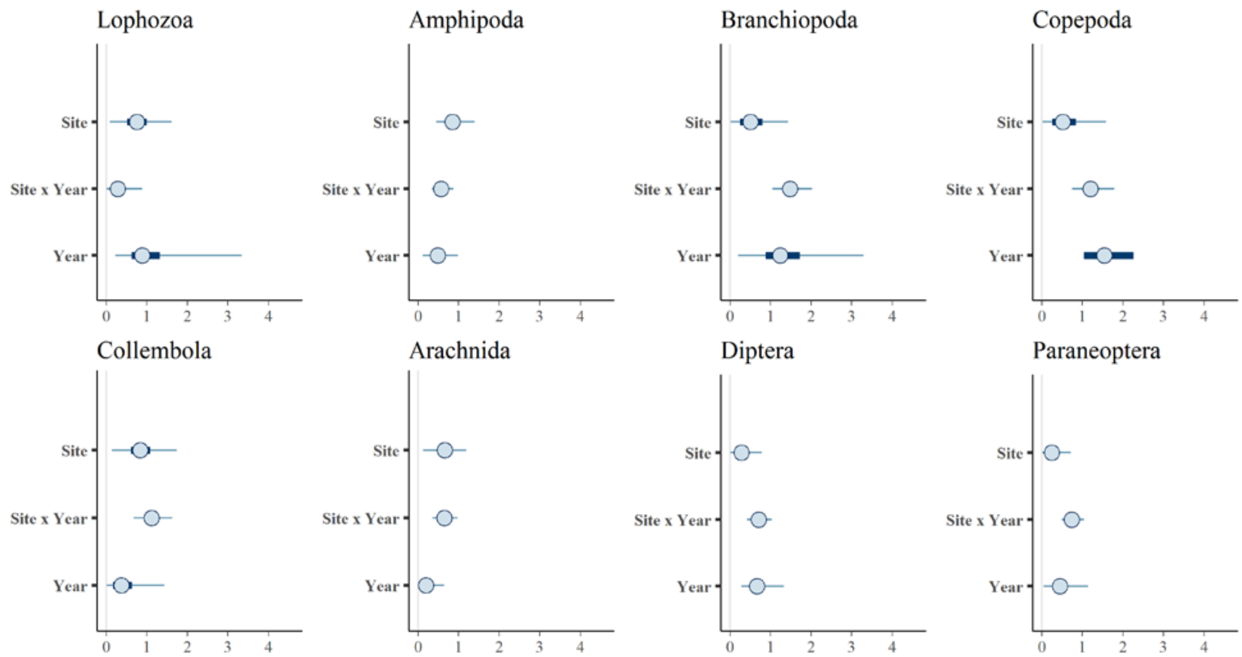


Figure F.12. Estimates of site, year, and site-year random effect standard deviations on the logit scale. Thin lines are 95% credible intervals, thicker lines are 50% credible intervals, and dots are posterior medians. For context, a one-unit increase represents a 2.7-fold increase in the odds of a taxonomic group being present.

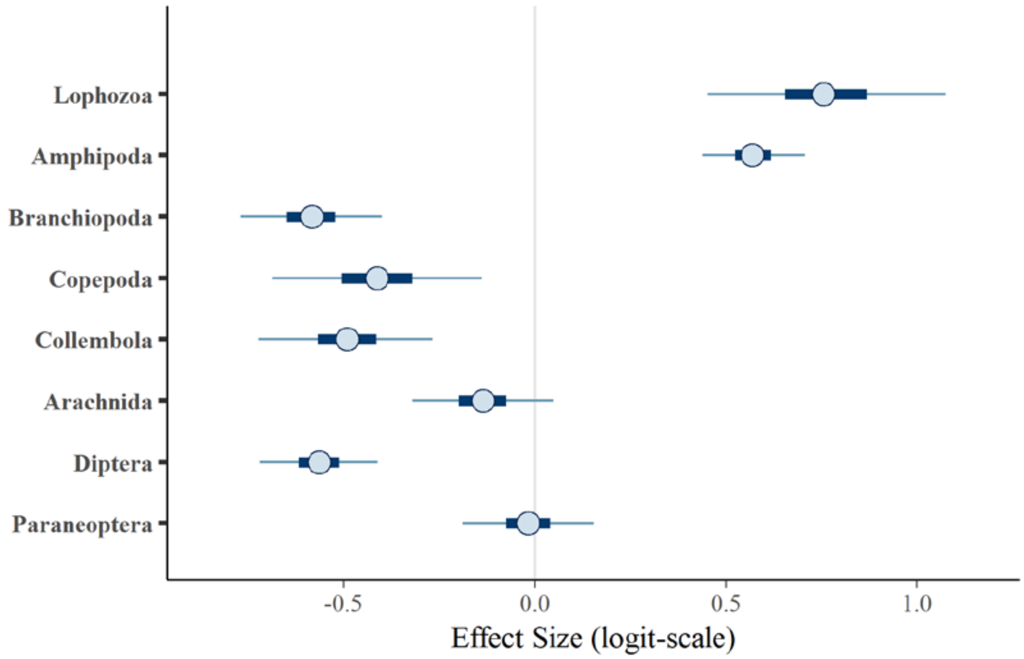


Figure F.13. Logit-scale increase in the log(odds) of presence due to a 30% increase in fish size (i.e., due to a per-unit increase in standardized log(Fork Length)). Thin lines are 95% credible intervals, thicker lines are 50% credible intervals, and dots are posterior medians. For context, a one-unit increase on the logit scale represents a 2.7-fold increase in the odds of a taxonomic group being present.

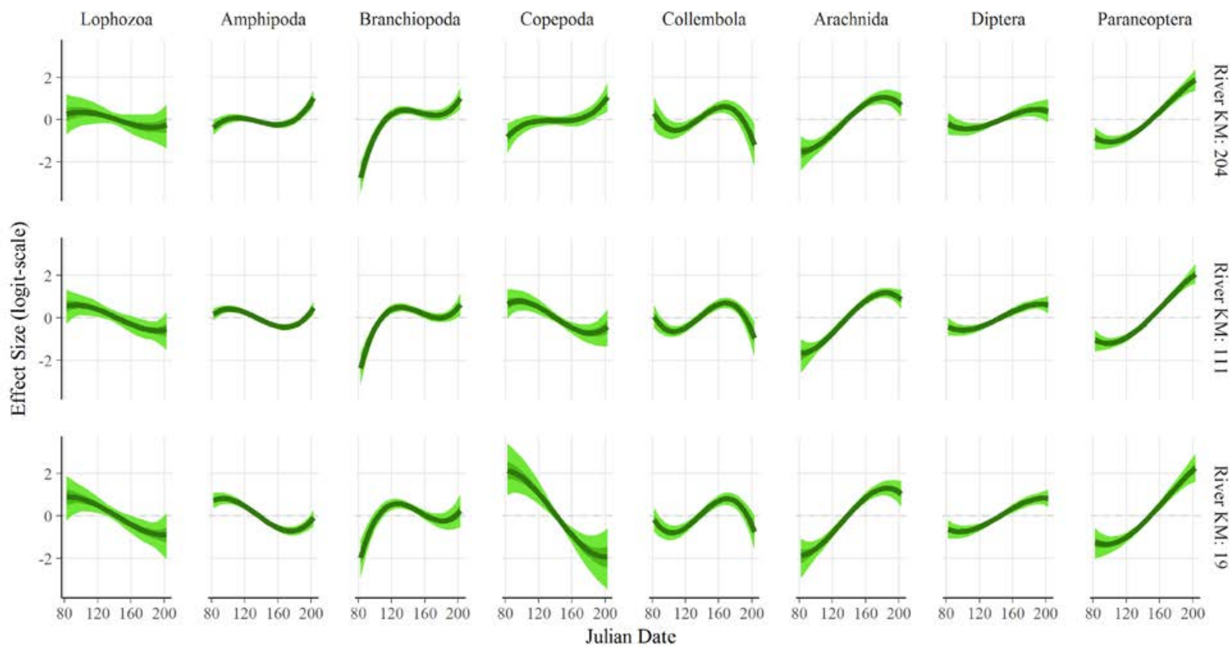


Figure F.14. Julian-date trends on the logit scale with 50% and 95% credible intervals by taxon. Each row of plots depicts a location on the river: lower estuary (18 km), lower tidal river (111 km), and upper tidal river (203 km), reflecting a modeled Julian date × Rkm interaction. For context, a one-unit increase represents a 2.7-fold increase in the odds of a taxonomic group being present.

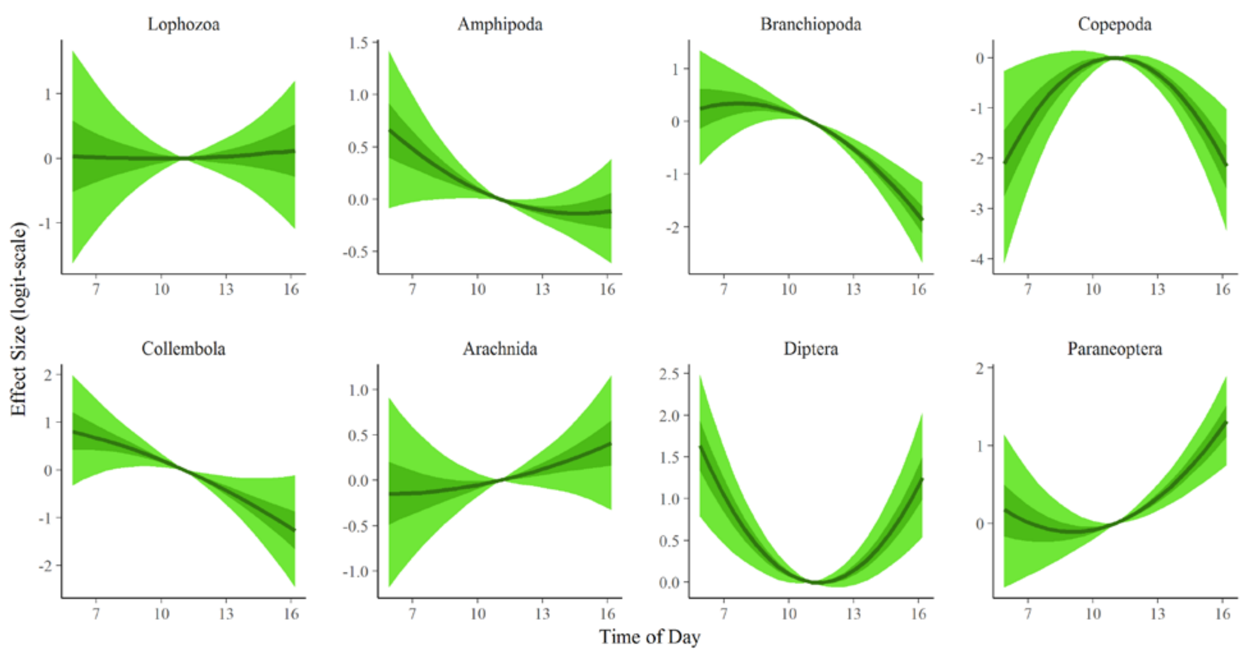


Figure F.15. Quadratic time-of-day trends on the logit scale with 50% and 95% credible intervals by taxon. Results are centered at the data set average, 11:03 a.m. For context, a one-unit increase represents a 2.7-fold increase in the odds of a taxonomic group being present.

F.28

Appendix G: Summary of the Juvenile Chinook Salmon Food Web at Tidal Emergent Marsh Wetland Habitats

Prepared by (in alphabetical order): Jeff Cordell, Roger Fuller, Jeff Grote, Amanda Hanson, Susan Hinton, Sarah Kidd, Regan McNatt, Joe Needoba, Tawnya Peterson, Katrina Poppe, Mary Ramirez, and Catherine Corbett (ed.)

G.1 Introduction

The Columbia River historically supported diverse and abundant populations of fish and wildlife and is thought to have been one of the largest producers of Pacific salmonids in the world (Netboy 1980). Anthropogenic changes since the 1860s including dike construction, land use conversion, and the construction of the hydropower system in the Columbia River basin have resulted in alterations to the hydrograph (i.e., timing, magnitude, duration, frequency, and rate of change in river flows); degraded water quality and increased presence of toxic contaminants; introduction of invasive species; and altered food-web dynamics. Subsequently, these changes within the Columbia River basin have significantly reduced the quantity and quality of habitat available to fish and wildlife species. The quantity and quality of available habitats affects the diversity, productivity, and persistence of salmon populations (Fresh et al. 2005). Degradation and loss of estuarine habitats can threaten salmon population viability, thus highlighting the importance of identifying limiting factors to salmon survival and filling key knowledge gaps across the habitat gradient of the lower Columbia River to promote salmon recovery.

The Lower Columbia Estuary Partnership (LCEP), as part of the Environmental Protection Agency's National Estuary Program, implemented a long-term monitoring through the Ecosystem Monitoring Program (EMP) in order to develop a better understanding of the structure and function of the gradient of salmonid habitat types throughout the LCRE. The EMP has been collecting ecosystem condition data in the LCRE since 2005. The work has focused on collecting data from relatively undisturbed emergent wetlands. The goal was to provide information about habitat structure, fish use, abiotic site conditions, salmon food web dynamics, and river mainstem conditions. This information could be used to assess the biological integrity of the lower river, enhance our understanding of estuary function, and support recovery of threatened and endangered salmonids. The creation and maintenance of long-term datasets are vital for documenting the history of change within important resource populations. Therefore, through this program, we aim to assess the status (i.e., spatial variation) and track the trends (i.e., temporal variation) in the overall condition of the LCRE, provide a better basic understanding of ecosystem function, provide a suite of reference sites for use as end points in regional habitat restoration actions, and place findings from other research and monitoring efforts (e.g., action effectiveness monitoring) into context with the larger ecosystem. The synthesis below is a summary of juvenile salmon food-web[1] information developed from the past 12 years of data collection in the LCRE.

G.2 Characterization of Salmonids in the LCRE

All anadromous salmonids common in the Columbia River basin have been observed in tidal emergent wetland and backwater slough sites typical of the Lower Columbia Estuary Partnership's EMP

[1] Methods and data can be found in the 2017 annual Ecosystem Monitoring Report (LCEP. In Preparation).

sites (Figure G.1). The degree of wetland utilization varies with species and life history type. For example, species with yearling life histories, such as sockeye salmon, steelhead, and cutthroat trout, were rarely observed. However, coho salmon, which also has a yearling life history strategy, were frequently caught in Reach H closest to Bonneville Dam. Chum salmon, which have a subyearling life history, were the second most frequent species observed. Chum were seen at all sites, and their use of tidal wetlands peaked in April and was limited temporally from March–May. Chinook salmon, which have both yearling and subyearling life histories, were the predominant species observed in tidal wetlands. Subyearling Chinook salmon, in particular, represented 90% of the total salmonid catch. In contrast to chum, subyearling Chinook salmon demonstrate protracted use of tidal wetland as evidenced by the presence of fry (<60 mm fork length [FL]) and fingerlings (60–115 mm) from February–June. Peak density of Chinook salmon occurred in May at all sites (Figure G.2). These results support the findings of other studies of tidal wetlands and shallow-water habitat in the lower Columbia River (Bottom et al. 2011b; Roegner et al 2012; Sather et al. 2016; Teel et al. 2014). However, newly emerging evidence suggests that the timing of sampling that occurs in tidal wetlands excludes yearling life histories, implying that yearlings may be under-represented by traditional sampling methods (McNatt et al. In Prep).

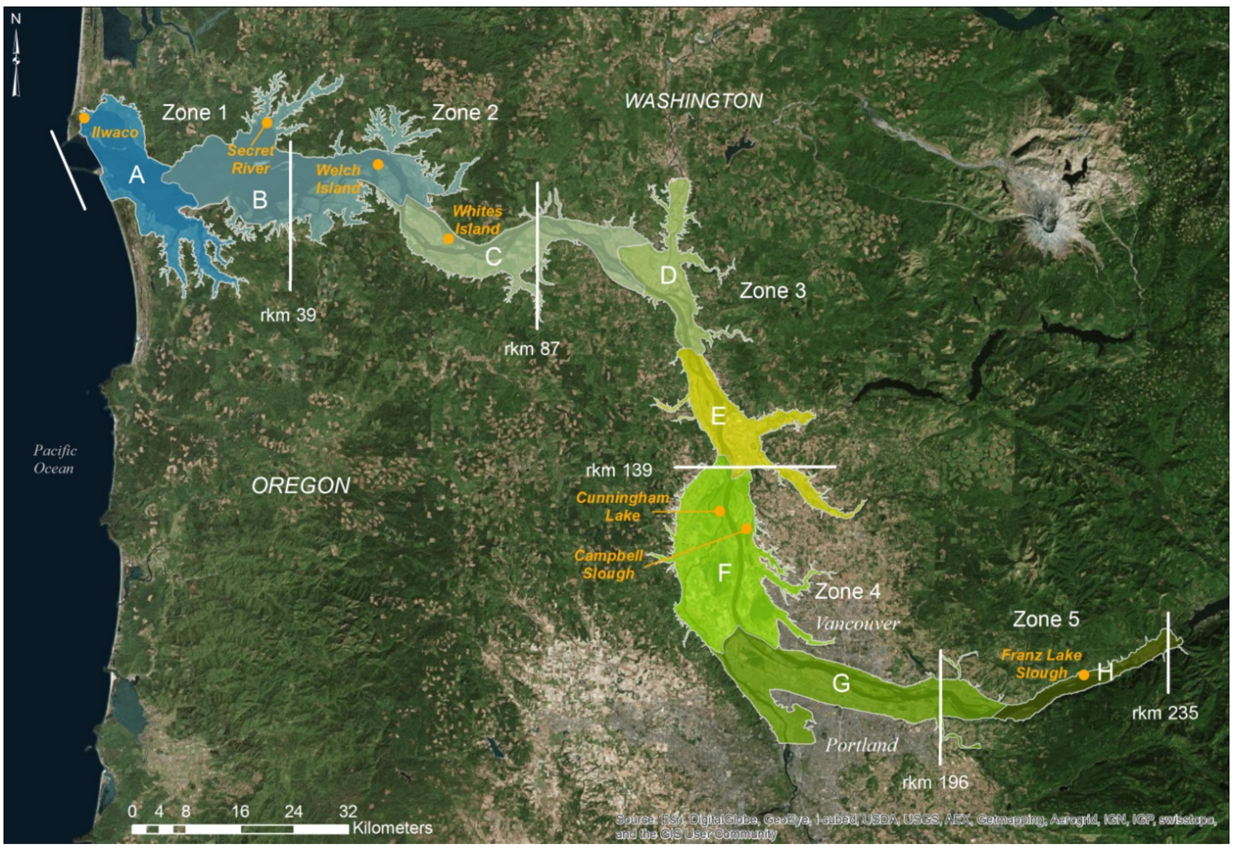


Figure G.1. Lower Columbia River and estuary with hydrogeomorphic reaches (A-H) specified by color (Simenstad et al. 2011) and wetland zones (1-5) delineated by white lines (Jay et al. 2016). The 2017 EMP trends sites are shown in orange.

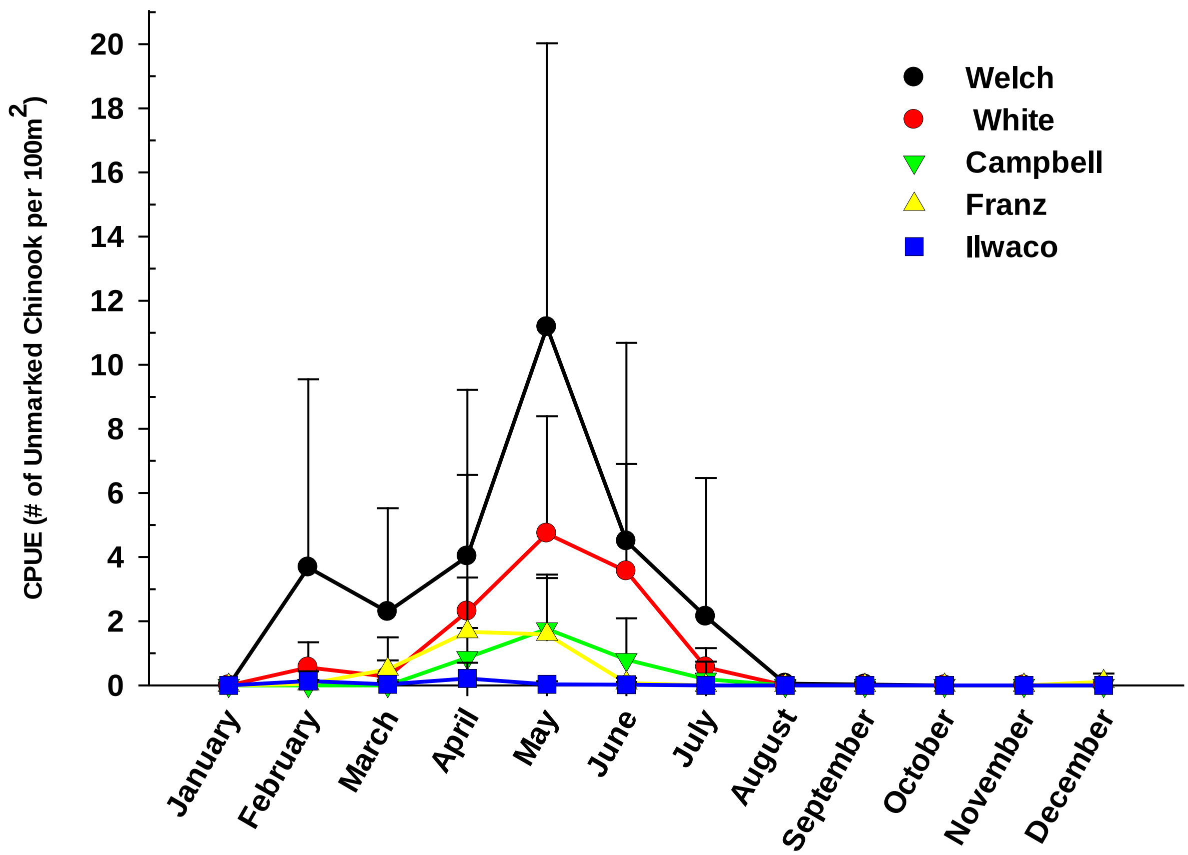


Figure G.2. Monthly average density (number of individuals/100 m^2) of unmarked Chinook salmon at trend sites, 2008-2017. Errors bars indicate one standard deviation.

Hatchery releases influenced the demographics of our salmonid catches. For example, coho peak abundance at Franz Lake (Reach H) occurred in May and was driven by hatchery releases. However, a smaller peak of natural origin coho also occurred at Franz Lake in late fall–early winter, leading us to infer that the site provides important over-wintering habitat (Figure G.3). Across all of the sites mean Chinook salmon fork length remained close to 40 mm from February–April and was indicative of the influx of newly emerged fry (Figure G.4). However, in May, mean fork length increased by ~20 mm and was coincident with hatchery releases of fall Chinook sized 80–90 mm. Mean fork length of unmarked subyearling Chinook also increased during the April–May timeframe. Likely causes for this trend include influx of larger fish that had reared in natal streams, and fish growing as they reside and rear in the estuary for an extended period. Increases in mean fork length may also coincide with seasonal increases of prey and water temperature.

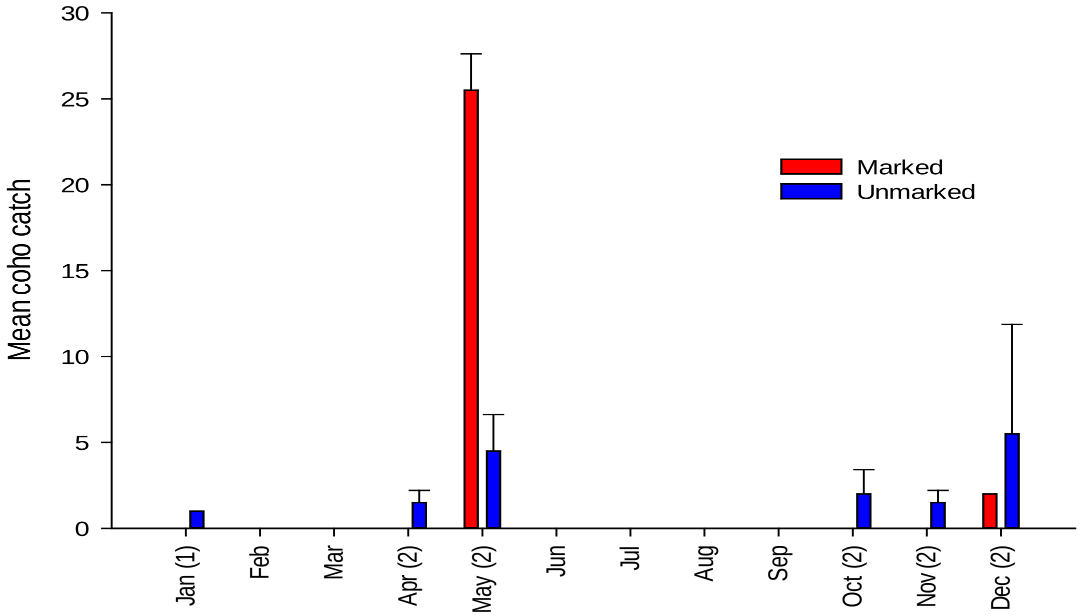


Figure G.3. Mean monthly abundance of coho at Franz Lake (2008–2016). Errors bars indicate one standard deviation.

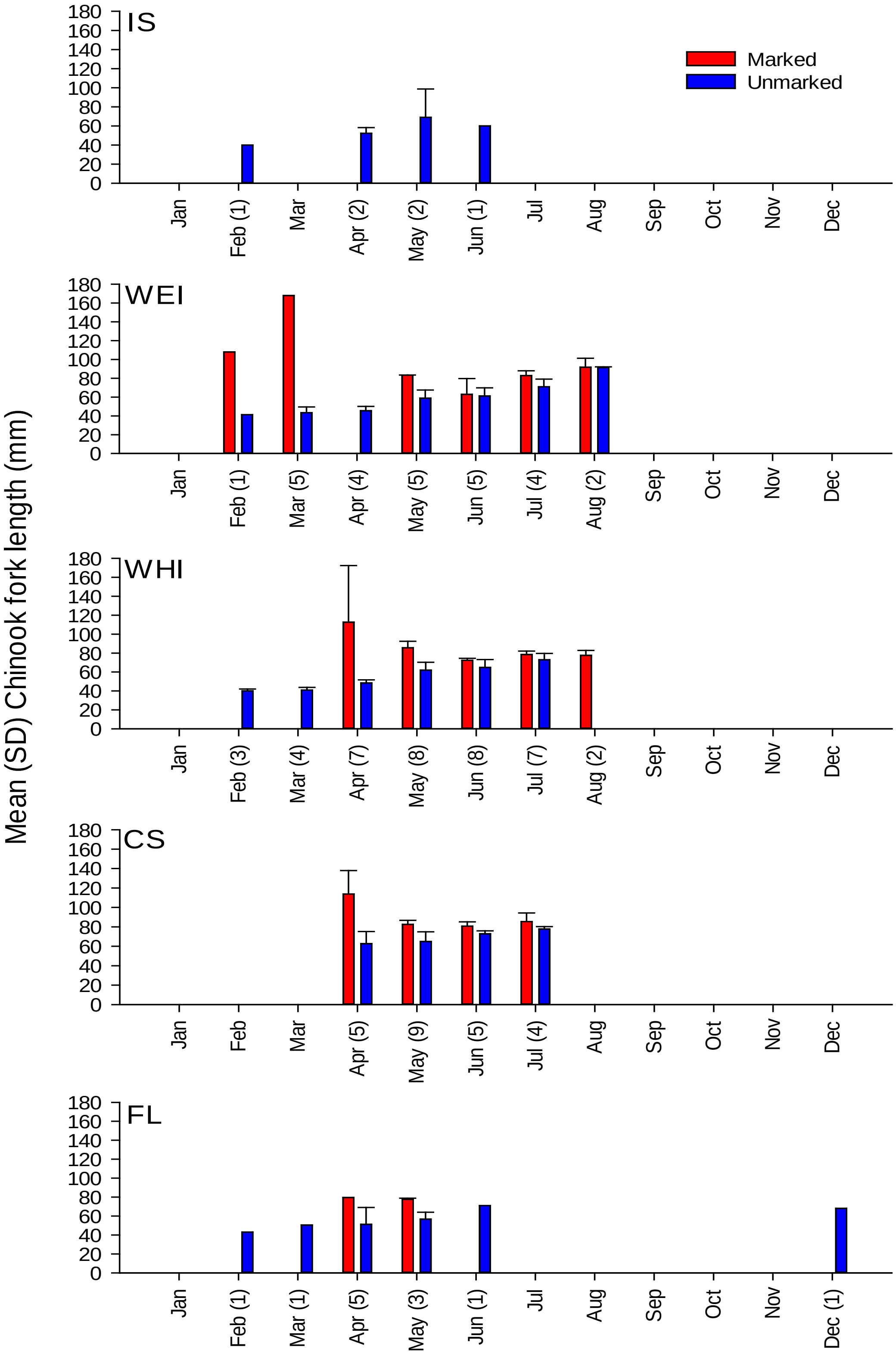


Figure G.4. Mean (SD) monthly fork length of Chinook salmon at each trend site (2008-2016). Errors bars indicate one standard deviation.

G.3 Characterization of Habitat Conditions in the LCRE

Salmonid access to tidal wetlands is influenced by hydrologic connectivity, water depth, water temperature, dissolved oxygen, and other physical conditions. Access to tidal wetlands varies spatially, with daily tidal connection at lower river sites, and annually and seasonally in middle to upper river sites with mainstem river flows. At sites closer to the river mouth (Ilwaco and Welch Island), tidal influence and winter storms have a stronger influence on surface water levels than the spring freshet. The influence of the freshet increases farther upstream and contributes to a mixed set of tidal and freshet drivers at Whites Island. At Cunningham Lake and Campbell Slough, the primary driver shifts to the freshet while at the farthest upstream trend site at Franz Lake, the tidal signal is difficult to discern from the influence of dam operations. Additionally, Welch and Whites islands in Reach B and C, respectively, are closer and more well connected to the mainstem; they have a greater similarity to river conditions compared to Campbell Slough (Reach F) and Franz Lake Slough (Reach H), which are further afar from the mainstem and comparatively more isolated once water recedes after the spring freshet (Jay et al. 2014).

Shallow floodplains typically differ from deeper channels in a river's mainstem in terms of temperature, light availability, flow velocity, and dissolved oxygen concentration (Amoros and Bornette 2002) (Lewis et al. 2000), which contribute to the site's "capacity" (Simenstad and Cordell 2000) to support juvenile salmonids. Since off-channel habitats are often much shallower than the main channel, they tend to warm faster when air temperatures rise in the summer months. Temperature is one of the most important environmental parameters controlling aquatic community structure because of its influence on metabolic processes as well as its effect on density stratification and thus gas exchange. High temperatures can negatively affect physiological functions in vertebrates, particularly among species of fish (Coutant 1977). Water temperature can have a direct impact on juvenile salmon usage of shallow-water habitats, since suboptimal growth and increased predation risk increases for juvenile salmon reared at temperatures above 16 °C (Marine and Cech 2004). If waters in shallow, refuge habitats are too warm, juvenile salmonids may avoid those habitats altogether and instead risk predation and starvation in deeper, cooler areas (Vigg and Burley 1991, Sommer et al. 2001). Temperature is also an important variable that influences life cycle events, or phenology, in many organisms. For example, many aquatic insects use temperature as a cue for larval emergence, which can influence food availability for insectivorous fish (Ward and Stanford 1982).

In addition to direct physiological effects, warmer temperatures typical of off-channel habitats may negatively affect habitat quality, or capacity, in indirect ways. For example, high temperatures can exacerbate nutrient-driven eutrophication through increased rates of nitrification, carried out by nitrifying bacteria, observed at higher temperatures (Strauss et al. 2004). As surface temperatures warm, water column mixing is reduced, which often leads to blooms of high-temperature and high-light–adapted phytoplankton such as cyanobacteria (Paerl and Huisman 2008), particularly when nutrient loads are high (Xu et al. 2010).

In productive aquatic systems, warm temperatures are sometimes associated with hypoxia, particularly in environments where water residence times are long and biological oxygen demand is high. Hypoxic conditions have been associated with spatial and temporal avoidance of particular habitats by juvenile fish (Craig and Crowder, 2005; Ludsin et al., 2009), including salmonids (Birtwell and Kruzynski, 1989). Dissolved oxygen concentrations below 2 mL/L are considered harmful; a threshold of 6 mL/L has been set for optimal performance (Washington Department of Ecology). Based on these criteria, both Ilwaco Slough and Franz Lake Slough have been shown to have frequent suboptimal dissolved oxygen levels, as demonstrated by the number of hours of levels below thresholds of 2, 4, and 6 mL/L each month. Juvenile salmon are also susceptible to high and low pH levels. At high pH, ammonium (NH_4^+) becomes the toxic ammonia gas (NH_3). Among the trends sites in the lower Columbia, wide pH fluctuations have been observed at Ilwaco and at Campbell Slough and Franz Lake Slough. The fluctuations at Ilwaco follow the intrusion of ocean water during upwelling periods in the summer when low-pH, low-oxygen water can enter Baker Bay in Reach A. At Campbell Slough and Franz Lake Slough, in contrast, low-pH waters occur in response to changes in carbonate chemistry that accompany strong growth of algae, which draw down CO_2 and drive pH upward. At night, CO_2 is produced through respiration, reducing pH. As algae blooms senesce, respiration by decomposing bacteria exceeds photosynthesis; in highly eutrophic systems, hypoxia and low pH conditions can persist throughout the diel cycle for extended periods and have detrimental effects on benthic organisms and fish (Paerl et al., 1998).

G.4 Characterization of Salmonid Prey Conditions in the LCRE

The EMP study has consistently identified two major prey items consumed by juvenile Chinook: Chironomidae and Amphipoda. Chironomidae is a ubiquitous family of small dipteran flies, commonly known as midges, that provide food for a wide range of predators (Armitage 1995). These insects are non-specialists, able to adapt to a variety of conditions (Cranston 1995, Ferrington 2008), and their abundance peaks in mid-June (Ramirez 2008). Lott (2004) found that emerging adults were the dominant life history stage appearing in the diets of juvenile Chinook in shallow-water wetland habitats of the estuary. The EMP study, however, finds that juvenile Chinook fed primarily on the adult and larval stages of chironomids. Emergent chironomids, as well as those in the pupal stage, were regularly consumed by fish, but less frequently than the adults and larvae.

Amphipoda is a diverse order of soft-bodied epibenthic crustaceans. Amphipods consumed by fish were primarily from the genus *Americorophium* in the family Corophiidae. *Americorophium* spp. are estuarine amphipods, commonly found in brackish to freshwater environments. They build tubes in sand and mud flats and adjoining shallow-water habitats that are intermittently exposed with the tide along larger channels in emergent marshes and along the mainstem river. *Americorophium* become available as prey for juvenile salmon and other fish when they leave their burrows to migrate or as part of reproductive behavior (e.g., males looking for mates) (Davis 1978, Wilson 1983).

Several studies have described a dietary transition from wetland insects to amphipods as juvenile Chinook grow and move toward the estuary mouth (McCabe et al. 1986, Lott 2004, Bottom et al. 2011b). This pattern is evident and consistent in results from the EMP study. Juvenile Chinook diets from the trends sites further upriver (Campbell Slough, Reach F, and Franz Lake, Reach H), are dominated by chironomids and other wetland insects. Fish collected from Welch and Whites Island, located in Reach B and C, respectively, mainly consume a combination of amphipods and chironomids or other dipteran flies. While the number of juvenile Chinook diets from Ilwaco Slough in Reach A is limited to five fish collected in April, 2015, they fed exclusively on amphipods. Roughly 40 percent of these amphipods were identified as *Americorophium*, with another 44 percent unidentified members of the Corophiidae family. Together, the trends sites demonstrate a shift in prey consumption along the estuarine gradient that is consistent with previous studies. According to stable isotope signatures of carbon and nitrogen (methods explained by Peterson and Fry 1987; Phillips et al. 2014), the organic matter source supporting chironomids appears to be primarily periphyton. This finding for the LCRE is similar to that from a study in which grazing larval chironomids fed on periphyton and diatoms in a shallow, hypertrophic lake in Poland (Tarkowska-Kukuryk 2013). Corophiid amphipods bore carbon isotopic signatures that were heavier on average than those of vascular plants or particulate organic matter (presumed to be dominated by fluvial phytoplankton), indicating that their primary dietary source of organic matter is heavier than either of those two sources; a likely candidate is benthic diatoms (Maier and Simenstad 2009), although there were times when periphyton also appeared to be an important food source to corophiids.

The current Columbia River estuarine landscape and distribution of habitats may explain some of the patterns seen in salmon diets across sites. Reach A and Reach B, both subject to coastal influences, have broad sand and mud flats (Reach A) and successional development of emergent marshes on sand and mud flats (Reach B) (Simenstad et al. 2011). Reach B contains complex channel islands with extensive networks of distributary and tidal channels. The widespread surge plain in these lower reaches supports relatively large areas of intermittently exposed shallow-water habitats, suitable for both juvenile salmon utilization and corophiid amphipod colonization. Up-estuary of Reach C, the river valley is more constricted and areas of intermittently exposed habitat are typically limited to narrow sandy beaches (Simenstad et al. 2011).

Zooplankton densities tend to be highest at Campbell Slough (Reach F) compared to other trends sites. Rotifers are very abundant early in the season (i.e., prior to the freshet) throughout the lower estuary, with the exception of Ilwaco (Reach A), while cladocerans and copepods are more abundant after the spring freshet. Similar to the spatial gradient in prey consumption by juvenile salmonids, there is a downstream gradient in zooplankton composition. In Reach A, at Ilwaco, the zooplankton community is always dominated by copepods, while upstream, the community transition from one dominated by rotifers in the early spring and shifting to copepods and cladocerans after the freshet. The seasonality of river discharge and water elevation is associated with changes in zooplankton abundance and composition and abundance, which has also been found to be reflected in the stomach contents of salmonids sampled across the sites. Zooplankton abundance increases throughout the lower estuary following spring growth of phytoplankton. During the spring freshet, abundances of zooplankton decrease due to dilution; during the summer, abundances increase substantially once water levels recede, particularly at Campbell Slough (Reach F), where connectivity to the mainstem is relatively low.

G.5 Characterization of Food Web Primary Productivity in the LCRE

The energy that supports a food web, and constrains its productivity, is provided by the system's primary producers, including plants, phytoplankton, and benthic microalgae. The productivity of invertebrate prey for salmon depends in part on the volume, quality, and timing of delivery of biomass from the marsh (Hanson et al. 2016a, Figure G.5). Marsh plants provide more biomass and are a higher source of energy than plankton or microalgae (Hanson et al. 2016 b). The productivity of marsh plants varies over both space and time, in response to changes in key biophysical drivers like water levels, sediment dynamics, invasive species, and other sources of stress. When plant biomass production, or its quality, declines there is less food to fuel the invertebrate food web that supports salmon. For this reason, it is important to understand the biophysical interactions that drive variation in plant productivity.

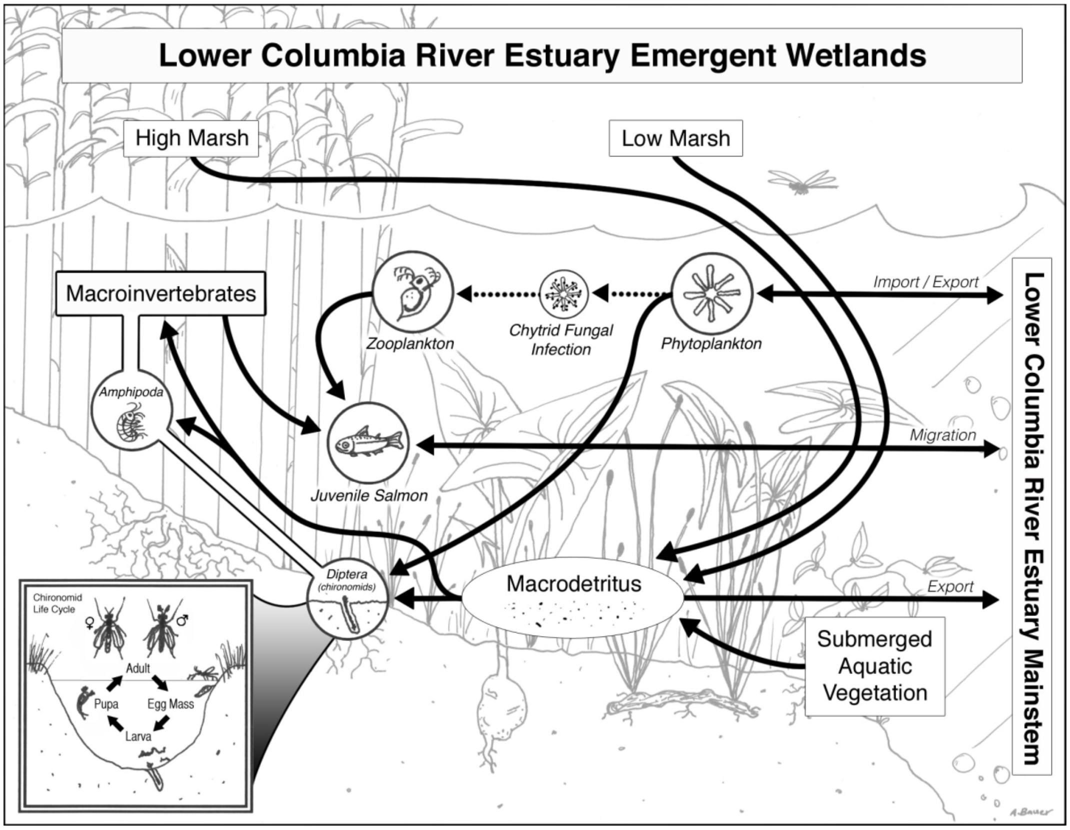


Figure G.5. Conceptual model of food-web interactions within LCRE emergent wetlands.

In addition to overall biomass productivity, the quality of biomass varies in ways that may affect its contribution as food for salmon prey. Low marsh plants contribute 80-93% of their annual aboveground biomass to the detrital food web, with particularly high values for *Sagittaria latifolia*, *Eleocharis palustris*, and submerged aquatic vegetation. Within the high marsh, communities that are dominated by the native sedge, *Carex lyngbyei*, contribute 68-80% of their annual aboveground biomass to the food web each year. In contrast, communities dominated by the non-native reed canarygrass, *Phalaris arundinacea*, contribute only 37-72% of their annual biomass to the food web in the same year. In addition to contributing less of its annual biomass to the detrital food web that supports salmon prey, *P. arundinacea*'s contribution is also substantially more variable. Overall, wetlands dominated by the native sedge *C. lyngbyei* contributed the highest and most consistent amount of organic material, signifying the importance of this species to the food web in the estuary. Furthermore, there is some evidence that the non-native plant species, *P. arundinacea*, produces biomass with a higher concentration of lignin which is difficult to decompose and may reduce the proportion of annual biomass that enters the detrital food web. This potential difference in biomass quality may reduce the food available to support salmon prey. Biomass quality is a new area of investigation, and may lead to new insights about the importance of adjusting restoration and management strategies to favor native wetland species.

Plant species composition and productivity responds to inundation periods and to the amount of variability in inundation. In general, plant productivity declines as the inundation period increases. High marsh generally produces greater biomass than low marsh. This pattern is consistent in the lower estuary, but becomes more variable in the upper estuary. In the upper estuary, freshet flows can inundate high marsh for extended periods of time, which can reduce productivity compared to sites closer to the river mouth. Low marsh is consistently flooded more often than high marsh, regardless of location in the upper or lower estuary, and there was no statistical difference in productivity in the low marsh strata between the lower and upper estuary sites.

Fluvial phytoplankton distributions in space and time are strongly influenced by the hydrograph, with high flows being characterized almost exclusively by colonial diatoms in the mainstem Columbia upstream of the salt-influenced estuary (Maier, 2014; Breckenridge et al. 2015). Lower in the estuary, seasonality in phytoplankton abundance and composition comes from river discharge and the seasonality in ocean influence. In general, the system is dominated by diatoms throughout much of the year and throughout most of the river (Lara-Lara et al. 1990). Prior to the spring freshet, colonial diatoms dominate the phytoplankton assemblage, with high similarity among all sites except Ilwaco (Hanson et al., 2016; Hanson et al., 2017). At Ilwaco, the phytoplankton assemblage contains a large proportion of benthic diatoms, which have been resuspended in the water column. At the other sites, the spring freshet dilutes populations of phytoplankton, leading to lower abundances during that period. Once water levels begin to decrease, phytoplankton populations once again increase, and the loss of connectivity between Campbell Slough and the mainstem and between Franz Lake Slough and the mainstem result in the development of distinct phytoplankton assemblages characterized by higher proportions of flagellate taxa, including chlorophyte, cryptophyte, and chrysophyte algae. These algal groups are less nutritious than are diatoms, likely resulting in a less high-quality organic matter source supporting consumers. In addition, at both of these sites, cyanobacteria populations increase as temperatures rise, often resulting in noxious blooms (Sagar et al., 2015; Tausz, 2014; Hanson et al., 2016; Hanson et al, 2017).

G.6 Conclusions

Despite the number of research studies completed in the Columbia River Estuary that provided valuable habitat data (focused mainly in Reaches A and B), the Ecosystem Monitoring Program is currently the only long-term monitoring program that consistently collects long-term habitat data in the lower river from the mouth to the upper, freshwater reaches. Data collected under the EMP provides context for action effectiveness monitoring results and EMP sites often act as reference sites to which habitat restoration sites are compared. These long-term observations are valuable for capturing the range of annual variability of environmental conditions, and the longer the monitoring program is implemented, the more descriptive the dataset becomes. This long-term data set provides a basis for evaluating how future environmental fluctuations predicted to be associated with climate change may impact salmonid habitat and food-web dynamics. Future EMP research will focus on synthesizing these environmental observations and identifying how shifting climatic and habitat conditions will impact the salmonid food web.

G.7 Acknowledgments

The data used in this synthesis, collected through the Ecosystem Monitoring Program, could not have been completed without the help of our partners. We are grateful to the Northwest Power and Conservation Council and the Bonneville Power Administration for funding the Ecosystem Monitoring Program through the Columbia Basin Fish and Wildlife Program. We extend much gratitude to Lyndal Johnson who retired from NOAA Fisheries in 2017. Lyndal was a part of the Ecosystem Monitoring Program from the beginning and contributed to the sampling design and analysis of fish community and contaminants. We also thank Sean Sol who contributed over 10 years of fish sampling effort. Whitney Temple and Jennifer Morace of USGS assisted with sampling design and prior years of data collection of abiotic conditions at four of the trends sites and portions of the food-web study, we thank them immensely for their collaborative work on this program. We additionally extent much gratitude to Amy Borde from PNNL who has made significant contributions to the EMP program over the years including the development of the habitat study design and analysis. This effort could not have been completed without the help of numerous field assistants: we would like to thank Nichole Sather, Cailene Gunn, Eric Fisher, Colleen Trostle, Heidi Stewert and Allison Cutting from PNNL; Stuart Dyer, Katherine Pippenger, and Lyle Cook from OHSU; David Buegli, Jacob Biron, and Wayne Haimes from Ocean Associates, Inc., Narayan Elasmar and April Silva from Columbia River Estuary Taskforce (CREST); Keith Marcoe and Daniel Evans from the Estuary Partnership. We also thank the land owners and managers who have allowed us to conduct research on lands they manage, including Alex Chmielewski (Ridgefield National Wildlife Refuge and Franz Lake National Wildlife Refuge), Paul Meyers (Lewis and Clark National Wildlife Refuge), Ian Sinks (Columbia Land Trust), and Stanley Thacker. USFWS Abernathy Fish Technology Center provided the fish feed samples for the stable isotope study. Finally, the Estuary Partnership's Science Work Group provided valuable input throughout the process and peer review on final drafts. The Science Work Group is composed of over 60 members and is integral in ensuring the Estuary Partnership represents the best available science.

Appendix H: New Techniques and Resources

Prepared by Gary Johnson

Since 2012, many new techniques and resources have become available to support Columbia Estuary Ecosystem Restoration Program (CEERP) activities. This appendix contains, in alphabetical order, short descriptions and sources for additional information for the new techniques and resources.

Area-Time Inundation Model (ATIIM) – Coleman et al. (2015) explained how the ATIIM can be applied during restoration planning and design to evaluate alternatives. ATIIM "…provides spatial and tabular data and metrics describing floodplain terrain and inundation that are not readily available elsewhere while using minimal data inputs and cost effective methods for suitable rapid assessment screening…Objectives [include] (1) rapid assessment of habitat opportunity and capacity for aquatic organisms (2) capture of microtopography and small channels with dendritic or other patterns in low relief riverscape (3) recognition of hydrological features associated with the contributions of multidirectional flows and the presence of multiple inlet/outlet locations in tidal or fluvial dominated sites (4) analyses at a resolution suitable for sites 1-500 ha in size (5) evaluation at varying time scales (6) comparisons of different sites and the effects of alternative terrain modification actions (7) customization of the model to easily accommodate future metrics." Links: ATIIM Software Download: https://tinyurl.com/zfgw9rq. ATIIM Workshop Slides: https://tinyurl.com/heqrs7o.

Center for Coastal Margin Observation and Prediction (CMOP) – Several in situ monitoring stations managed by Oregon Health Science University within the estuarine-tidal freshwater gradient are locations for collecting hourly biogeochemistry data. Two stations are of particular importance—SATURN 04 and 08 at Beaver Army Terminal and Camas, respectively. Data from these stations allow researchers to compare mainstem conditions in upstream and downstream locations, understand the influence of tributaries on conditions, compare mainstem conditions with conditions in Willamette River, and understand what is entering the estuary, nearshore ocean from the lower Columbia River. As stated on CMOP's website (see link below), "…integration of an autonomous robotic sampler, the Environmental Sample Processor, developed at the Monterey Bay Aquarium Research Institute, and SATURN (Science and Technology University Research Network), CMOP's observation and prediction system, the process of collecting data became substantially more precise and beneficial." For example, Needoba (2014 CREC) described monitoring of biogeochemical cycles using in situ sensors. These techniques could be applied to material flux from restoring wetlands; site and landscape-scale effects. Link: http://www.stccmop.org/.

Early Life History Diversity Index (ELHD) – Johnson et al. (2014a) developed an index of early life history diversity for quantifying ELHD for Chinook salmon to support comparisons across like locales and examinations of trends through time at a given locale. This research was undertaken by the U.S. Army Corps of Engineers (Corps) in response to Reasonable and Prudent Alternative 58.2 in the 2008 Federal Columbia River Power System Biological Opinion (NMFS 2008). The authors characterized early life history traits and prioritized fish size and timing as two appropriate, measurable dimensions for an ELHD. The recommended ELHD index is diversity expressed as the effective number of species for the Shannon entropy, modified to include an adjustment for missing species and a sample coverage factor. This index applies to multiple life history strategies of juvenile salmonids; incorporates fish abundance, richness, and evenness; and produces readily interpretable values. Citation: Johnson et al. 2014. Application of diversity indices to quantify early life history diversity for Chinook Salmon. *Ecological Indicators* 38:179–180.

Ecosystem Classification System[1] – LCEP (2015b) noted the Columbia River Estuarine Ecosystem Classification is a tool for analyzing current conditions, identifying risks, and finding ways to help maintain the estuary's vitality over the long term. The system comprises a hierarchical group of six geospatial data sets: Levels 1-2 EPA Ecoregions; Level 3 Hydrogeomorphic Reaches; Level 4 Ecosystem Complexes; Level 5 Geomorphic Catenae; and a layer for ancillary anthropogenic features. The diversity of ecosystems is moderate throughout the estuary, but certain important ecosystems are found in only a few reaches. More than half of the current land area in the estuary represents aquatic or terrestrial habitat that has been converted to human uses. The highest functioning patches of tidal wetlands (both forested and herbaceous) are in Reaches B, C, and F. With natural processes changing, decisions about the estuary's protection, restoration, and management take on added significance, and a long-range, strategic view is even more important. Information from the Ecosystem Classification tool is available to aid development of Expert Regional Technical Group templates and other project development activities. Link: http://www.estuarypartnership.org/columbia-river-estuarine-ecosystem-classification-level-3-hydrogeomorphic-reaches.

Ecosystems Function Model (EFM) – The Lower Columbia Estuary Partnership has been applying the Hydrologic Engineering Center (HEC)-EFM developed by the Corps (see http://www.hec.usace.army.mil/software/hec-efm/) on several projects to assess the feasibility of restoration scenarios, specifically the impacts of scenarios on native species of interest. The Corps website describes the hydrodynamic model as being designed "to help determine ecosystem responses to changes in the flow regime of a river or connected wetland. HEC-EFM analyses involve: 1) statistical analyses of relationships between hydrology and ecology, 2) hydraulic modeling, and 3) use of Geographic Information Systems (GIS) to display results and other relevant spatial data. Through this process, study teams will be able to visualize and define existing ecologic conditions, highlight promising restoration sites, and assess and rank alternatives according to predicted changes in different aspects of the ecosystem."

Habitat Change Analysis – Marcoe and Pilson (2017) provide the most comprehensive habitat change analysis to date for the LCRE. The following material is from their abstract: "We conducted a spatial analysis of long term land cover change for the lower Columbia River estuary and its floodplain by comparing GIS representations of late 1800's maps (Office of Coast topographic sheets and General Land Office survey maps) with recent, high resolution land cover data from 2009. In terms of combined spatial and temporal extents, ours is the most comprehensive of similar studies that have been done for the region in recent decades. Losses of 68–70% were noted for vegetated tidal wetlands, which are critical habitats for juvenile salmonids that utilize the estuary. These values are consistent with those derived from previous studies. A loss of 55% of forested uplands was also noted. The majority of loss of these habitats was due to conversion of land for agriculture and urban development. Also important was conversion of tidal wetlands to non-tidal wetlands. Tidal flats have changed more with respect to location than overall areal coverage, which could be expected for this high energy environment. Spatial patterns

[1] A new publication on this research is pending: O'Connor, JE, CA Simenstad, CM Cannon, MF Ramirez, K Marcoe and A Sihler. In review. Columbia River Estuary Ecosystem Classification—An Integrated Process-Based Hierarchy of Landforms and Ecosystems for the Tidally Affected Columbia River and Floodplain. U.S. Geological Survey professional paper.

of change in these habitats were variable throughout the study area, which may have practical implications for guiding restoration and conservation practices. Uncertainties with our analysis are present as a result of differences in methodologies used to develop the historical and present day data sets as well as unknowns about, and difficulties interpreting, the historical data sources. Despite these uncertainties, the analysis provides useful insight into the extent of change which has occurred in the lower Columbia River estuary and in particular the significant declines in vegetated tidal wetlands that have occurred." Citation: Marcoe K and S Pilson. 2017. Habitat change in the lower Columbia River estuary, 1870–2009. *Journal of Coastal Conservation*. Published online June 16, 2017. doi:10.1007/s11852-017-0523-7.

Habitat Performance Index – One challenge of restoration work is determining if a project met the intended ecological goals. Most restoration projects require several years to decades before they sufficiently recover to a mature ecological state. To answer questions related to current and future habitat conditions the LCEP is developing a Habitat Performance Index using an existing tool—the Oregon Watershed Rapid Assessment Protocol—as a template. The Habitat Performance Index is a rapid wetland assessment method that incorporates surrounding landscape, physical processes, and biological factors to evaluate the status of a site based on function and where the site is located on a trajectory of recovery. Using data from our Ecosystem Monitoring and Action Effectiveness Monitoring Programs, LCEP is creating data ranges of what might be expected for index metrics at various stages of recovery. Their objective is to create preferred habitat profiles for focal native species so the LCEP can identify habitat gaps and priorities for future restoration. The Habitat Performance Index is in the early stages of development, but early testing has shown interesting and promising results. Contact: C. Corbett, Lower Columbia Estuary Partnership.

Landscape Planning Framework (LPF) – Building from the Ecosystem Classification System, the LPF "…provides a landscape-scale platform for identifying and evaluating protection and restoration projects within the context of specific genetic stocks under various surface water elevations" (Trask et al. 2014). According to Trask et al. (2014), "Version 1.0 of FHC was completed in January, 2014 including significant channel classification enhancements to address data gaps in the Classification. Aerial photos, LiDAR and bankfull elevations were analyzed to extract as many "small" channels as possible, given the existing data." Contact: P. Trask, PC Trask and Associates.

Oncor – An estuary-wide, enterprise-scale, geospatial data management system called *Oncor* is being developed for research, monitoring, and evaluation studies and restoration project development under CEERP. Development of the estuary-wide, web-accessible data management and information discovery/retrieval system will provide an intuitive user environment and the necessary resources and tools to standardize and upload/download legacy, current and future data, facilitate data sharing, and be used as the basis for synthesis and evaluation of data across multiple entities. This system has been designed with regular input from managers, researchers, and restoration practitioners to enable users to quickly retrieve data elements by region, site, analysis question, data event, data type, collection type, location, proximal location, etc. In addition, a key attribute of *Oncor* enables a formal mechanism of data sharing while maintaining data pedigree and appropriate data use. Final transfer of technology from developers to implementers is scheduled for March 2018. Link: TBD. Contact: G. Johnson, PNNL.

Plant Community Look-Up Tables – Diefenderfer et al. (2013a) synthesized the distribution of individual plant species is related to longitudinal and lateral location and elevation. This led to identification of the most abundant herbaceous, shrub, and tree species in the region, by zone and wetland type. Data were presented in the form of easy look-up tables. Restoration practitioners can use these tables to plan and design restoration projects to optimize establishment of native plant communities. Citation: Diefenderfer HL, AB Borde, and VI Cullinan. 2013. *A Synthesis of Environmental and Plant Community Data for Tidal Wetland Restoration Planning in the Lower Columbia River and Estuary*. PNNL-22667, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by the Pacific Northwest National Laboratory, Marine Sciences Laboratory, Sequim, Washington.

Potential Sum Exceedance Value (pSEV) – Borde et al. (2016) applied pSEV (introduced in Jay et al. 2016), relating SEV during the growing season to wetland distribution, species composition, and vegetative cover. Coupling this with models to calculate historical and possible future inundation patterns, the authors predicted the extent of wetland migration, determined possible changes in vegetation species composition, and estimated potential changes to productivity and detrital contributions to the food web. The results indicated wetlands can migrate vertically in response to inundation regimes. Citation: Jay DA, AB Borde, HL Diefenderfer. 2016. Tidal-Fluvial and Estuarine Processes in the Lower Columbia River: II. Water Level Models, Floodplain Wetland Inundation, and System Zones. *Estuaries and Coasts* 39:1299–1324.

Salmon Estuarine Habitat Index (SEHI) – Buenau et al. (2016a) posited that SEHI could serve multiple purposes for planning, design, and monitoring, but additional effort is needed to develop a working model. The model, initially proposed in 2011, is intended to provide a quantitative means of indexing the benefits that juvenile salmon would receive directly or indirectly from restoration. Researchers developed a prototype model during 2012-2013 and in the process identified critical data gaps. Buenau et al. (2016a) recommended next steps for SEHI development: quantitative synthesis of existing data, development of a working model, and identification and prioritization of research needs. Citation: Buenau, KE, NK Sather, AB Borde, and GE Johnson. 2016a. *Assessment of Data Availability for Salmon Estuarine Habitat Index (SEHI) Modeling*. PNNL-25853, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon by the Pacific Northwest National Laboratory, Richland, Washington.

Unmanned Aerial Vehicles (UAV) – Sinks and Steele (2016) offered that UAV technology can detect, monitor, and manage invasive reed canary grass, marsh vegetation development, and other features within restoration areas. In an initial application of the technology, UAV imagery provided “as-built” surveys of constructed marsh channels, mounds, large wood structures, and an invasive species baseline. Roegner, Borde, and others have developed a remote sensing methodology to monitor plant communities in restoring wetlands. Others working on UAV applications in the estuary include Schwartz and Kolp for the LCEP. Link or citation: TBD.