Lower Columbia Intensively Monitored Watershed Study Annual Report for 2021

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Prepared by:

Jamie Lamperth, Washington Department of Fish and Wildlife

Marisa Litz, Washington Department of Fish and Wildlife

Amelia Johnson, Lower Columbia Fish Recovery Board

Kirk Krueger, Washington Department of Fish and Wildlife

Will Dezan, Washington Department of Fish and Wildlife

Bill Ehinger, Washington Department of Ecology

Mara Zimmerman, Coast Salmon Partnership (formerly WDFW)

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Contents

1.0. Lower Columbia Intensively Monitored Watershed (IMW) Summary

1.1. Implementation Schedule

a. What restoration actions remain to be implemented and when do you anticipate completing them?

Restoration actions are completed in Abernathy Creek (Figure 1).

In Germany Creek, there are two active projects. Germany Creek Stream Restoration Kosiba (PRISM #19-1225) is scheduled to have instream construction completed in 2022. A new project proposed by the Cowlitz Conservation District was funded in 2021 and instream work is schedule to be completed in 2023 (Upper Germany Creek Restoration Project, PRISM #21-1078). This project was proposed as the first of five phases to address bedload sediment mobilization issues through Germany Creek. This project addresses work identified in the IMW Treatment Plan and Treatment Plan Update. The timeline for the remaining four phases is uncertain as they have not been funded at this time.

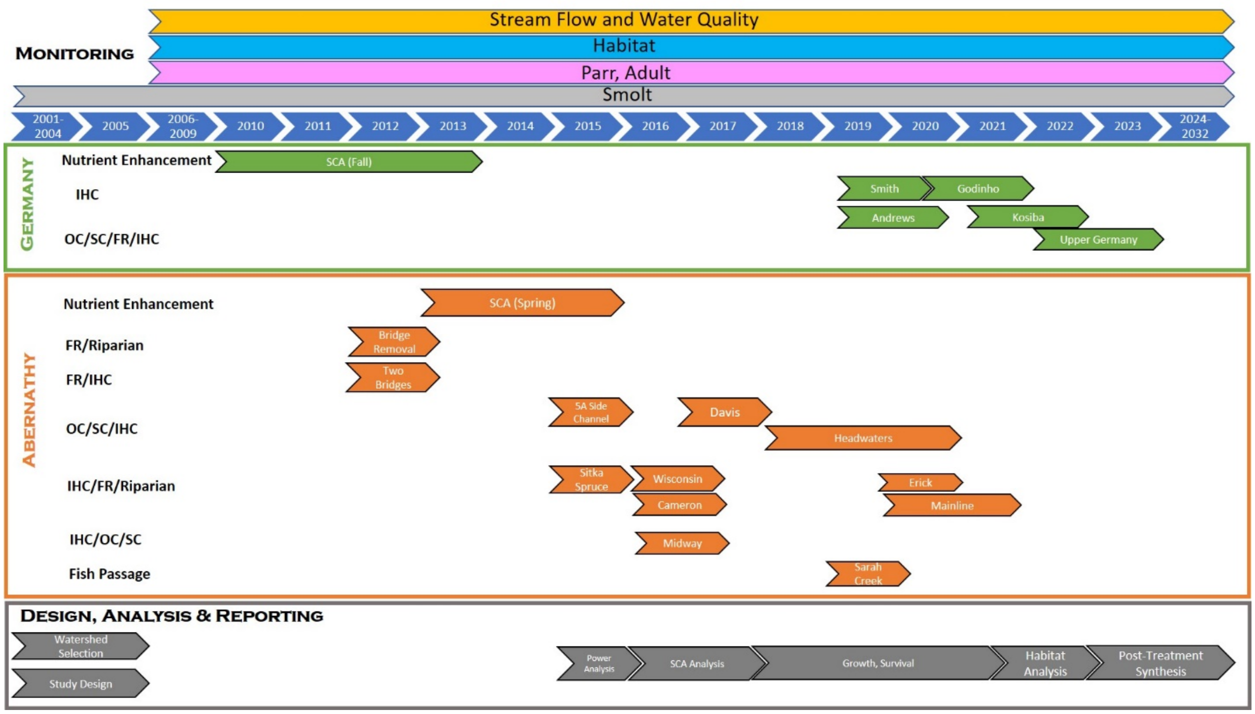


Figure 1. Timeline for monitoring, restoration treatments, analysis, and reporting in the Lower Columbia Intensively Monitored Watersheds stream complex.

b. Do you anticipate having to perform maintenance on existing projects and what is the justification for doing so?

No, we do not anticipate having to perform maintenance on existing projects.

1.2. Species of concern

a. What are your focal species and their associated listing status?

Coho Salmon (ESA threatened), Chinook Salmon (ESA threatened), Steelhead Trout (no listing status).

1.3. Effectiveness

a. What are the limiting factors believed to be in your watershed?

The primary limiting factors in the complex are:

- Channel complexity
- Off channel/side channel connectivity
- Floodplain connectivity
- Habitat accessibility

The 2009 Treatment Plan described a long list of limiting factors in the Abernathy and Germany creek watersheds (HDR Inc and Cramer Fish Sciences 2009). Additional discussion and refinement of this list occurred among members of the IMW Technical Oversight Group (TOG) during the summer of 2016 (LCFRB 2016). Rather than consider individual limiting factors, the TOG discussions focused on watershed processes. Watershed processes in the LC-IMW streams have been impacted by historical land use that has disrupted sediment transport processes and disconnected the riparian and instream ecosystems. In the long-term, recent laws requiring the development of riparian buffers and reduction of road densities should lead to the 'healing' of watershed processes. In the short-term, habitat treatments are needed to increase channel complexity (i.e., increase diversity in flows, substrate, and channel bathymetry), re-establish off-channel connectivity between instream channels and off-channel areas (i.e., inundate off-channel areas at winter flows), and increase the amount of habitat accessible to spawners by removing or improving impediments to fish passage. Indeed, existing habitat monitoring data shows that large wood is extremely limited and plane-bed channel type is common, indicating low channel complexity in these watersheds (Zimmerman et al. 2016).

b. How were completed restoration actions tied to limiting factors?

Limiting processes in these watersheds include processes that generate channel complexity and connectivity. Treatment types address (1) instream habitat complexity, (2) off-channel/side channel connection, (3) floodplain reconnection, (4) fish passage, and (5) riparian enhancement. The connection between these treatment types and the expected functional response of stream habitat is provided in Table 1 of the Updated Treatment Plan (LCFRB 2016).

c. Are the findings of this IMW applicable to other watersheds? Be specific about what findings are transferable and where? Specify criteria by which the findings translate to other watersheds (e.g., geomorphic conditions, climate regimes, landcover, ESUs, etc.).

The Lower Columbia IMW stream complex is representative of the basins of southwestern Washington and northeastern Oregon with respect species distribution, geomorphology, climate, history of land use, and land ownership. From this perspective, the results of this work and lessons learned should be applicable throughout the lower Columbia region. The applicability of our work to basins outside the region will come from comparing results from other IMWs. Most of the information gained will likely come from their differences - most of the IMWs have similar limitations in their steam-forming processes (i.e., lack of channel complexity and connectivity) and similar types of treatments (i.e., large wood debris, side channel reconnection). Similarities and differences in the responses among IMWs will provide an understanding of which types of treatments have universal or more localized benefits in their application.

1.4. Collaboration and Communication

a. Cite examples of how your program has collaborated with monitoring partners.

Participation in the Lower Columbia IMW complex is necessarily collaborative and involves monitoring and research partners as well as landowners, engineers, grant administrators, and restoration practitioners. The list of collaborators includes the Washington Department of Fish and Wildlife, Washington Department of Ecology, Washington Department of Natural Resources, Weyerhaeuser Corporation, Sierra Pacific, Lower Columbia Fish Recovery Board, Cowlitz Indian Tribe, Cowlitz County Conservation District, and USFWS Abernathy Fish Technology Center.

In addition to providing insight into fish population responses to habitat actions, the fish data are used for ESA status and trend monitoring and to generate adult coho forecasts to guide fishery decision making.

b. List reports and other technical products.

Bilby, R., W. Ehinger, T. Quinn, G. Volkhardt, K. Krueger, D. Seiler, G. Pess, C. Jordan, M. McHenry, and D. Poon. 2005. Study evaluates fish response to management actions. Western Forester **50**:14-15.

Bilby, R. E., W. J. Ehinger, C. Jordan, K. Krueger, M. McHenry, T. Quinn, G. Pess, Poon, Derek, D. Seiler, and G. Volkhardt. 2005. Evaluating Watershed Response to Land Management and Restoration Actions: Intensively Monitored Watersheds (IMW) 2005 Progress Report. Washington Department of Fish and Wildlife, Olympia, Washington. Available online: http://wdfw.wa.gov/publications/00781/.

Kinsel, C., P. R. Hanratty, M. S. Zimmerman, B. Glaser, S. Gray, T. Hillson, D. Rawding, and S. Vanderploeg. 2009. Intensively Monitored Watersheds: 2008 fish population studies in the Hood Canal and Lower Columbia stream complexes, FPA 09-12, Washington Department of Fish and Wildlife, Olympia, Washington. Available online: http://wdfw.wa.gov/publications/00783/.

LCFRB. 2016. Lower Columbia IMW Treatment Plan Update. Lower Columbia Fish Recovery Board, Kelso, Washington. Available online: https://www.lcfrb.gen.wa.us/libraryimwcomplex

Sturza, M. T. 2017. Effectiveness of Salmon Carcass Analogs as a Form of Nutrient Enhancement for Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Three Lower Columbia Watersheds. M. Sc. Thesis, Western Washington University, Bellingham, Washington. Available online: http://cedar.wwu.edu/wwuet/597/.

Zimmerman, M. S., K. Krueger, B. Ehinger, P. Roni, R. E. Bilby, J. Walter, and T. Quinn. 2012. Intensively Monitored Watersheds program: an updated plan to monitor fish and habitat responses to restoration actions in the Lower Columbia watersheds, FPA 12-03, Washington

Department of Fish and Wildlife, Olympia, Washington. Available online: http://wdfw.wa.gov/publications/01398/.

c. Provide examples of conferences/meetings in which your program presented or participated; a comprehensive list of every presentation is not necessary.

- PNAMP IMW Workshop, Online Meeting, November 16 – December 7, 2021
- LCFRB Meeting, Online Meeting, June 4, 2021
- 2021 Salmon Recovery Conference, Online Meeting, April 28-30, 2021
- 2019 Salmon Recovery Conference, Tacoma, WA, April 8-9, 2019
- PNAMP Intensively Monitored Watersheds Workshop, Portland, OR, November 1-2, 2018
- PIT Tag Workshop https://www.ptagis.org/resources/pit-tag-workshops
- Presented at local and regional AFS meetings
- Collaboration Workshop – Research in Mill, Abernathy, and Germany creek watersheds. Abernathy Fish Technology Center, Longview, Washington, July 21, 2016

1.5. Adaptive Management

a. Please identify any specific changes made in your methodology over the reporting period.

The smolt time series data were updated in their entirety in 2018. The background and analytical approach are described in Appendix E.

b. What challenges have you encountered in implementing your monitoring program?

We have had challenges with project effectiveness monitoring which we first addressed in the 2018 annual report. The science team worked with LCFRB staff and project sponsors to address uncertainties in the project effectiveness monitoring that were identified at the completion of the 2017 field season (Zimmerman et al. 2017). Our major concern was that the watershed-scale monitoring approach, while very effective at describing watershed-scale variability, was not adequately representing the localized changes in wood, substrate, and channel complexity that we were visually observing at the project sites. The interdisciplinary team conducted several field visits throughout 2018 to discuss the site-specific goals of each restoration project and to identify monitoring that would be needed to better represent local habitat responses to these projects.

As a result of this work, several specific changes have been made to the project effectiveness component of the LC-IMW habitat monitoring, including adjustments to protocols, new measurements, qualitative description, updated metrics, and updated analysis.

c. How will the findings of this IMW inform future salmon recovery (broad answers are appropriate)?

Salmon recovery efforts in Washington State rely heavily on the assumption that instream habitat restoration – especially the addition of large wood debris and opening of fish passage barriers – will cause a substantial increase in the numbers of salmon and steelhead returning to our rivers. This study tests that key assumption at a population scale and is designed to address the question ‘why or why not’?

2.0. LC-IMW Hypotheses and results

2.1. Objectives and hypotheses of the monitoring effort

The IMW study evaluates whether increasing the complexity and connectivity of the stream network will cause an increase in the freshwater capacity and productivity of salmon and steelhead trout at the watershed scale (Table 1). The study is designed to evaluate whether responses to stream restoration occur and why (or why not). We assume that the synchrony of habitat forming processes is consistent among the reference and treatment streams and that restoration treatments will generate changes in stream habitat. We hypothesize that changes in stream habitat resulting from the restoration treatments that target limiting factors in these basins (habitat complexity, off channel/side channel habitat, floodplain reconnection, and passage barriers) will increase capacity, productivity, survival, and growth of juvenile salmon and steelhead at the watershed scale. Our results should provide important insight into the mechanisms related to salmon production and test underlying assumptions related to limiting factors.

Table 1. Lower Columbia IMW goals, objectives/actions, and indicators measured.

Goal	Objective/Action	Indicator
Increase carrying capacity and productivity in natal streams	1) Increase habitat complexity 2) Increase off channel/side channel habitat 3) Increase flood plain reconnection 4) Nutrient enhancement	Density-dependent relationships, overwinter survival, population productivity, smolt abundance, juvenile growth
Increase spawning spatial distribution	1) Remove passage barriers 2) Increase habitat complexity	Redd distribution

The Lower Columbia IMW study was originally set up to be evaluated with a Before-After Control-Impact design (BACI; Smith 2002; Roni et al. 2005). This design includes the selection of control (hereafter reference) and impact (hereafter, treatment) watersheds. Mill Creek was selected as the reference watershed and Abernathy and Germany creeks were selected as the treatment watersheds. If annual fish metrics are correlated between the two watersheds prior to restoration occurring, this design provides additional statistical power to detect responses of the treatment watersheds by accounting for co-variation between the treatment and reference watershed due to non-restoration related factors. Alternately, measures of environmental conditions such as stream flows, pool frequencies, or large woody debris counts were incorporated into the sampling efforts to account for failures to meet the assumptions of the experimental design (Bendetti-Cecchi 2001; Steinbeck et al. 2005) and to strengthen the analyses by revealing mechanisms that affect freshwater production. If co-variation among treatment and reference watersheds do not exist, a Before-After (BA) design is a more appropriate approach to analyzing population responses.

Baseline data were analyzed to evaluate the adequacy of the BACI approach (co-variation between reference and treatments metrics), focusing on smolt abundance and outmigrant body size (Zimmerman et al. 2015). Results from this effort suggested the BACI approach could only be used to evaluate changes in steelhead and Chinook outmigrant abundance. Co-variation was not apparent with coho abundance nor outmigrant length among all species, suggesting a BA approach was more appropriate to analyze these indicators. Each of these designs (BACI and BA) assume a step change in conditions which is likely not the reality in the LC-IMW complex as treatments have occurred over an extended time period (2012-2021). Moving forward, we will be exploring additional analytical approaches that complement the Before-After approach and consider protracted change.

Our science team is exploring suitable analytical approaches to best model fish and habitat responses to restoration actions over time. For instance, a recent publication by members of our team concerning responses in the Hood Canal IMW (Anderson et al. 2019) used mixed-effects modeling to test changes in fish and habitat trends across time. This approach, though different than the BACI approach, provided useful answers to questions about restoration actions. As we move into the post-treatment phase, we will continue to discuss and explore alternative approaches to best answer our study questions (e.g., State-space models, Holmes et al. 2012; Staircase designs, Loughin et al. 2021).

Regardless of the analytical approach used, we have conducted power analyses to determine minimal detectable effect sizes of spring smolt abundance. The first analysis was conducted in 2015 (Zimmerman et al. 2015). At the time of the analysis, the amount of restoration planned for Abernathy was enough to detect changes in smolt abundance of coho, steelhead, and Chinook after a minimum of ten years post-monitoring. However, for Germany Creek, it was determined that the amount of restoration planned was not going to be enough to detect changes in smolt abundances. Currently, we estimate that 2-3 times more restoration than what has already occurred would need to be completed in order to increase smolt abundances to levels where they could be detected in Germany Creek. Is this amount of restoration considered feasible? The Cowlitz Conservation District has recently proposed a five-phase extensive restoration strategy for the headwaters of Germany Creek. The first phase was funded in 2021 (PRISM #21-1078). If funding is available and the monitoring timeline can support it, it appears there is interest by the Cowlitz Conservation District and the landowner (Sierra Pacific Industries, Inc) to pursue some relatively large-scale restoration in the upper portions of Germany Creek.

In 2019, we updated the analysis in Abernathy Creek to help determine the relative importance of the Erick Creek Culvert Replacement project which was being considered for funding. The updated analysis included updated information on restoration impacts and compared various scenarios that included or excluded the Erick Creek culvert project. The 2019 results were similar to the 2015 results in that the amount of restoration in Abernathy Creek should be enough to detect changes in smolt abundance; therefore, removing the Erick Creek culvert project did not change the outcome. The addition of the Abernathy Creek Mainline Restoration project (18-1397) to the restoration area (this project was not included in the 2016 analysis) partially explained this result. We plan to conduct additional power analyses with other indicator metrics such as overwinter survival and parr abundance in the future.

2.2 What we have learned so far

Salmon and steelhead life cycle monitoring in the LC-IMW complex has produced important information to inform habitat restoration actions.

- Density-dependent relationships in natal streams suggest freshwater habitat is limiting productivity
- Tributary and headwater reaches are important for coho rearing
- Coho fall outmigrants (life history diversity) may be affected by habitat conditions
- Nutrient enhancement did not have a significant effect on juvenile coho growth and survival

Salmon and steelhead populations in the LC-IMW complex show density-dependent relationships in their natal streams, suggesting that freshwater habitat is limiting productivity for these populations (LCFRB 2016). For instance, apparent overwinter survival of coho, driven by summer and winter habitat, is a density dependent function of summer parr abundance (Figure 2). Additionally, we have found that a density dependent relationship affects the migratory life history expression of juvenile fall Chinook (i.e., fewer parr with increasing juvenile abundance, Figure 3). These observations are important because an implicit assumption for habitat restoration is that the capacity, or the amount of suitable habitat of a stream network, is limiting population productivity. Therefore, we would expect to see a positive fish response (upward shift in density dependent trend lines) in the LC-IMW complex from habitat restoration actions, assuming enough suitable habitat is created (Roni et al. 2010).

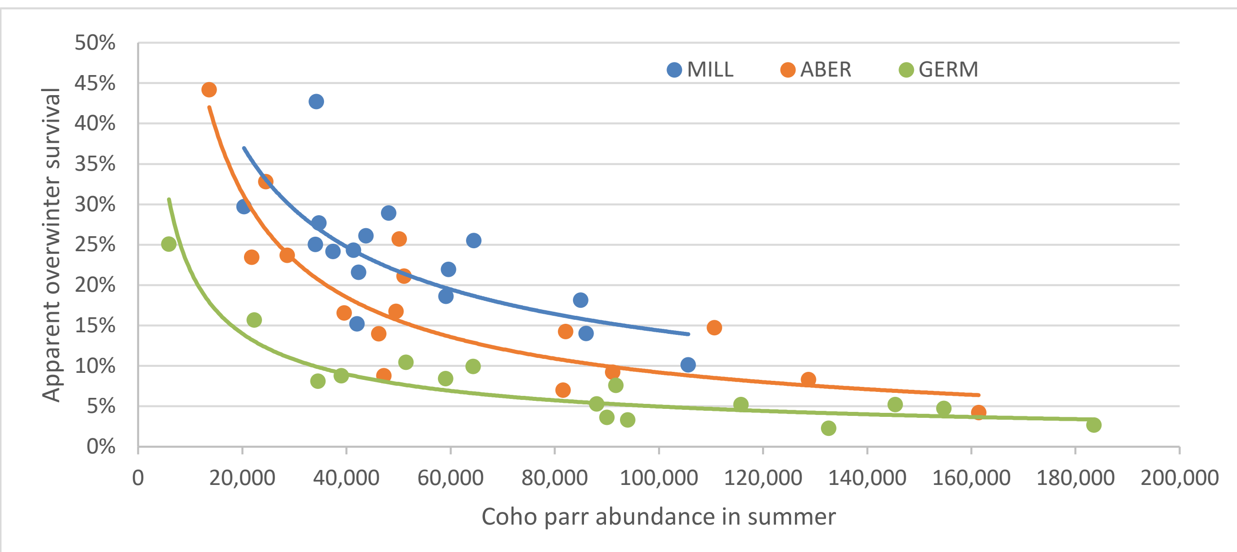


Figure 2. Juvenile coho apparent overwinter survival as a function of parr abundance, brood years 2004-2019. This plot demonstrates density-dependent survival of coho that overwinter in the LC-IMW Streams.

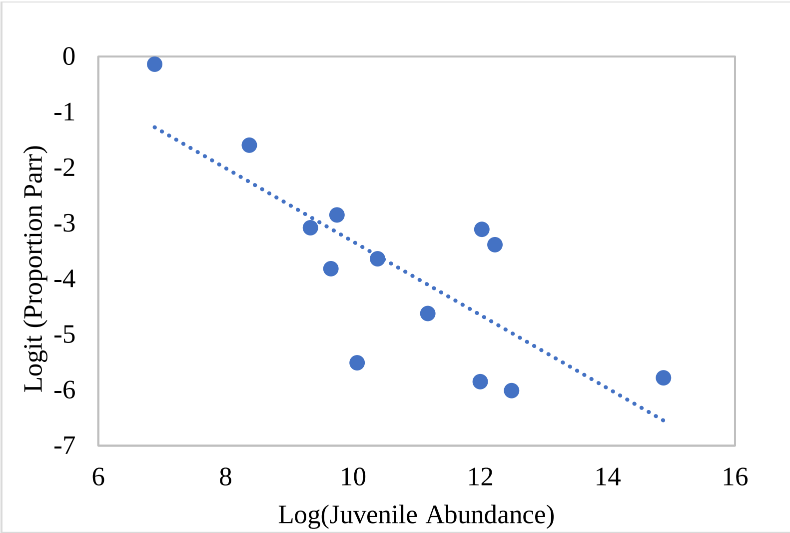


Figure 3. The relationship between the proportion of subyearling Chinook that exhibit extended residency in the natal stream (parr) and the total abundance of Chinook juveniles (fry + parr) in Germany Creek, brood years 2004-2017. This plot demonstrates a density-dependent relationship that affects migratory life history expression of fall Chinook.

We have also found that tributary and headwater reaches are important habitats for producing spring coho smolts (Johnson et al. 2015; Zimmerman et al. 2015; Figure 4). Analysis of coho apparent overwinter survival data showed that upper reaches of the LC-IMW basins were more likely to produce spring smolts, and coho that were larger at the end of the summer were more likely to be detected as spring smolts. This information guided restoration efforts in Abernathy Creek where the majority of projects occurred in upper reaches of the basin.

Additional insight into apparent overwinter survival of coho has come from observations of a fall migrant life history (Figure 5). The emigration of subyearling coho from their natal streams in fall may partially explain the observed overwinter survival patterns, suggesting that the expression of this life history may be affected by habitat conditions in the basin. Further investigations are warranted to better understand the fall outmigration of juvenile coho and how this life history affects our understanding of overwinter survival in natal streams, and the contribution of this life history to adult escapement. Plans to install a PIT array and to operate a screw trap in the fall have stalled due to complications related to COVID-19 in 2020 and loss of experienced staff in 2021 necessary to pursue this work.

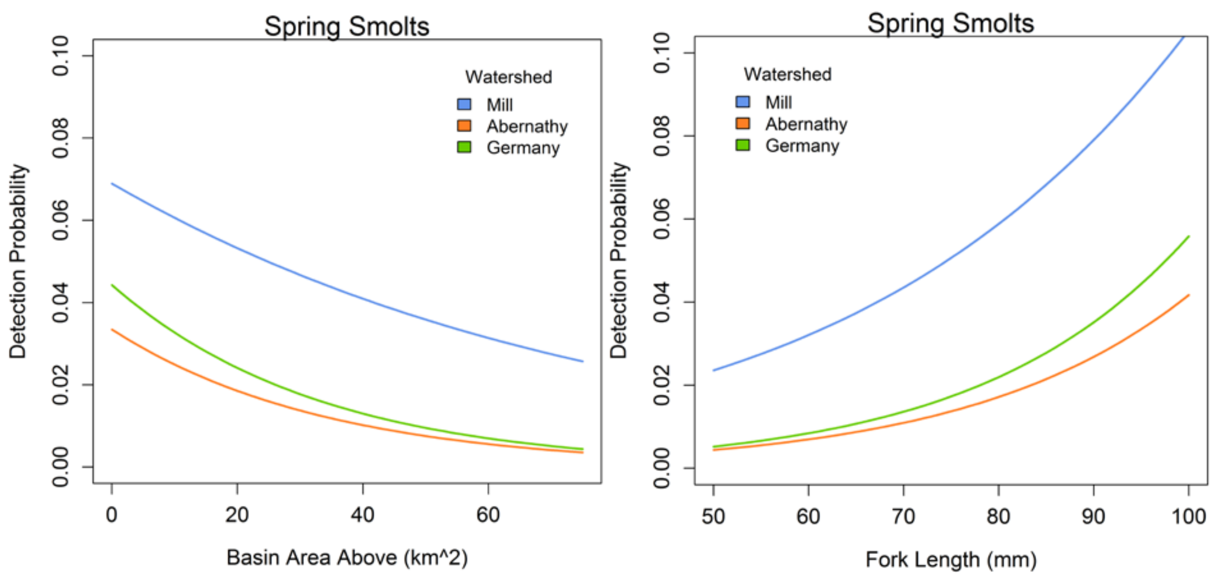


Figure 4. Probability of detection as a spring smolt for coho salmon based on rearing location (watershed area above sampling location) and growth (fork length in mm) the previous summer in the Mill, Abernathy, and Germany creek basins.

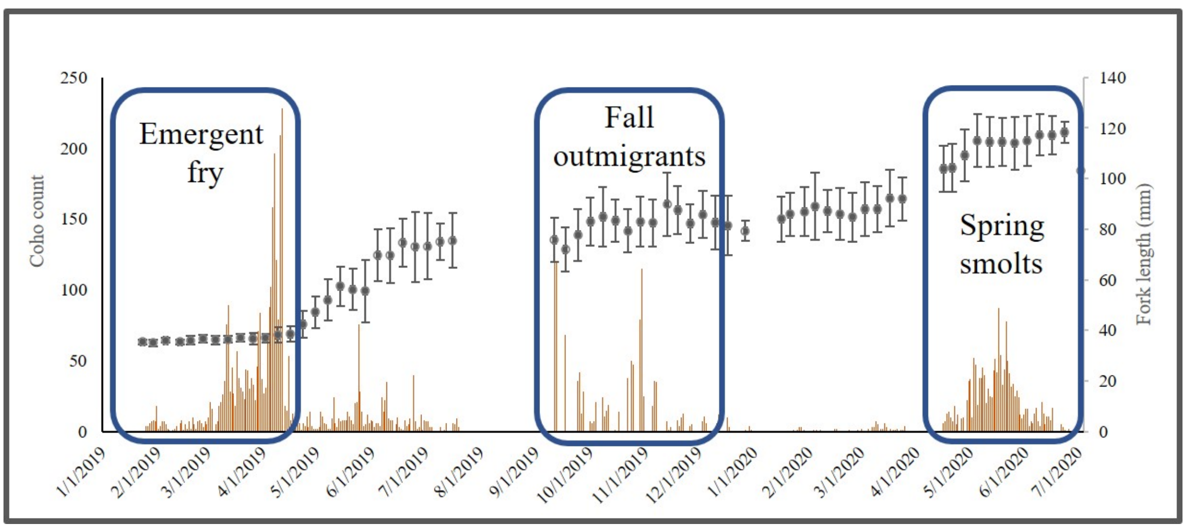


Figure 5. Daily counts (bars) and weekly mean ± 1SD fork length (circles with error bars) of coho captured in the Abernathy smolt trap showing major movement periods (brood year 2018). Fall outmigrants are emigrating from their natal stream during the first year of freshwater residency.

Finally, a watershed-scale nutrient enhancement study provided insight into this type of restoration treatment (Sturza 2017; https://cedar.wwu.edu/wwuet/597/). Salmon carcass analogs (SCA) were added in the fall in Germany Creek (2011-2013) and in the spring in Abernathy Creek (2013-2015). The primary take-home messages from the study were: 1) neither fall nor spring treatments had a significant effect on juvenile coho growth and survival; and 2) careful watershed selection and subsequent monitoring should be employed to ensure SCA investments are worthwhile.

2.3 Emerging trends related to population responses to habitat actions

Spatial distribution of redds

In 2020, we saw a shift in coho redd distribution in Sarah Creek resulting from the passage barrier removal project completed in 2019. Prior to 2019, spawning distribution (for all species) in Sarah Creek generally did not extend above a bedrock waterfall passage barrier located ~ 100 m upstream of the mouth. Only one redd was observed above the passage barrier across the entire time series, and we typically see 0-2 redds per year in Sarah Creek. However, in 2020, eleven coho redds (and 12 live, adult coho) were observed in the newly accessible habitat in Sarah Creek. The offspring of these fish were observed in pools of the project reach in spring of 2021. Through the first week of December 2021 (2021 fall spawning season), we observed 63 live adult coho and 12 coho redds in the Sarah Creek project reach.

Trends in density-dependent relationships

Spawner-outmigrant relationships in the Lower Columbia IMW vary by basin and species and generally show moderate to weak relationships depending on whether data are pooled across years or parsed into “before restoration” and “during restoration” phases (Figure 6). In addition to density-dependence, variability in these relationships can be attributed to observer error in point estimates and environmental conditions across multiple life stages (e.g., incubation, early rearing, overwinter rearing).

Habitat restoration in the LC-IMW has largely focused on increasing quality habitat for overwinter rearing and survival. Evaluating density dependent relationships related to overwinter survival may be a more direct evaluation of population response to habitat actions in these stream networks. “Before restoration” and “during restoration” comparison of overwinter survival density-dependent functions showed an increase in overwinter survival in the treatment watersheds (Abernathy and Germany) since restoration actions commenced (Figure 7).

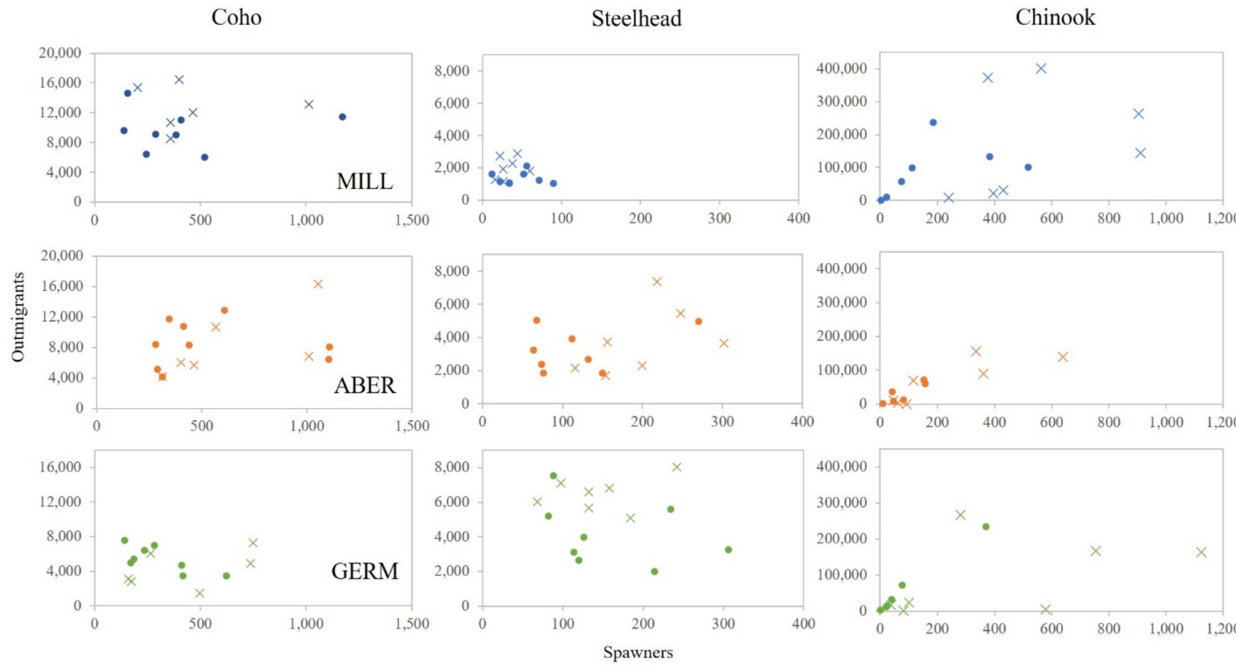


Figure 6. Before restoration (brood years 2006-2011; ×) and during restoration (brood years 2012-2019; ●) comparison of coho spawner-outmigrant relationships in the Lower Columbia Intensively Monitored Watersheds complex. Outmigrants are smolts for coho and steelhead and fry (young-of-year) for Chinook. Steelhead smolt abundances assumed 100% freshwater age-2 steelhead smolts. The steelhead data will be updated in the future with actual juvenile age data determined from scale collections.

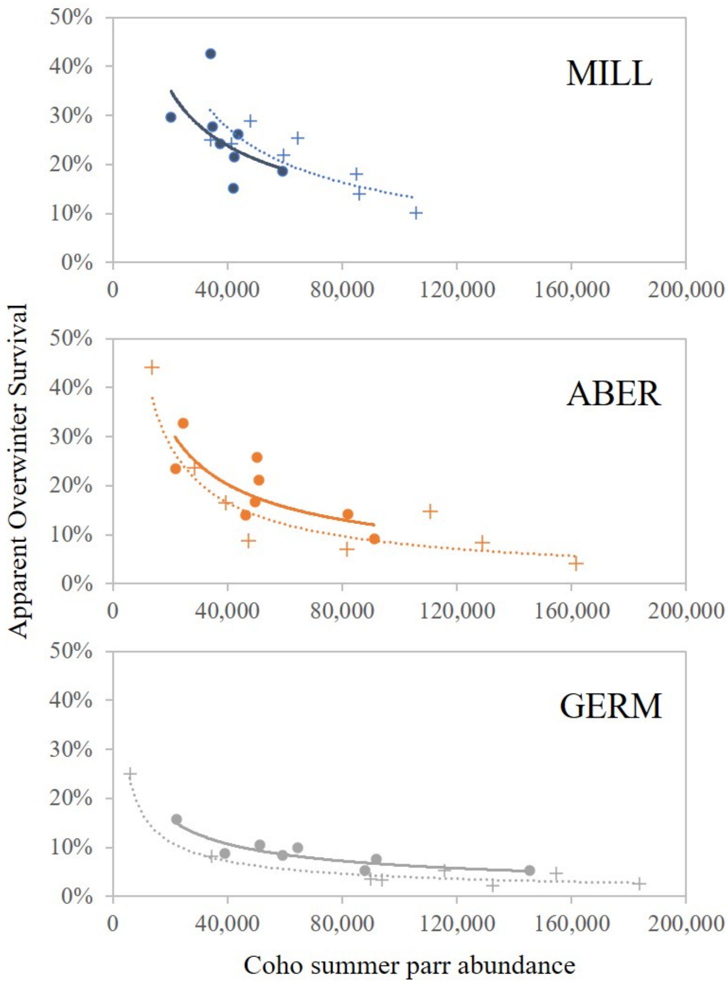


Figure 7. Before restoration (brood years 2004-2011; cross hatch and dashed line) and during restoration (brood years 2012-2019; circles and sold lines) comparison of juvenile coho overwinter survival density dependent functions in the Lower Columbia Intensively Monitored Watersheds complex. This graph shows a trend of increasing capacity in the treatment basins (Abernathy and Germany creeks) compared to the reference basin (Mill Creek).

3.0. LC-IMW Updates for 2021

3.1. Restoration Actions

This section describes the implementation of restoration projects in Abernathy and Germany creeks. Further details for each project are available in Appendix B-2 and on the Recreation Conservation Office PRISM website (https://secure.rco.wa.gov/prism/search/projectsearch.aspx).

In Abernathy Creek, thirteen of the fourteen projects identified for implementation were constructed through 2021 (Table 2). No further restoration is planned at his time. Although one additional treatment project was identified for Abernathy Creek, the Erick Creek Culvert Replacement effort, this project has no identified funding stream to date. An updated analysis in 2019 suggested that completion of this project was not necessary to support detectable coho salmon responses to habitat treatment in Abernathy Creek, meaning implementation of this treatment project is not essential to the Lower Columbia IMW program. At this time, funding is not being pursued to replace the Erick Creek culvert.

The completed instream habitat treatments in the Abernathy Creek basin have impacted approximately 30% of the habitat accessible to anadromous salmonids (Figure 8), including 11.8 kilometers (km) of instream habitat, 1.3 km of off-channel and side-channel habitat, 0.19 km^2 of riparian area, and 2.7 km of improved fish passage (Appendix B-2). The vast majority of these projects and treated areas focused on improving instream habitat complexity through the construction of large wood structures (see Figure 9 – Figure 13).

Activities in 2021 in Germany Creek included completion of on-the-ground work for one project (IMW Godinho Restoration), postponement of construction for another project (Germany Creek Stream Restoration Kosiba, construction postponed until 2022) and funding for a new project in upper Germany Creek on Sierra Pacific Industries timberland (Table 3).

The Cowlitz Conservation District was awarded funding in 2021 for a restoration project in upper Germany Creek (PRISM #21-1078) focused on reconnecting floodplain and side-channel habitat and improving instream habitat complexity through the installation of large woody debris along 1.85 km of stream. The district proposed this project as the first of five phases to address bedload sediment mobilization issues through Germany Creek. This project addresses work identified in the IMW Treatment Plan and Treatment Plan Update.

In the current funding landscape, future projects in Germany Creek will need to compete against other restoration project proposals under consideration by the Lower Columbia Fish Recovery Board (see Appendix B). This requirement will likely limit the spatial extent of Germany Creek projects to Tier 1 stream reaches identified in the 2009 Treatment Plan. The 2009 Treatment Plan estimated that restoration projects identified in Tier 1 stream reaches of Germany Creek would cost approximately $1.4 million (2009 dollars) after project design was completed.

The completed work in Germany Creek impacts 5.9 km of instream habitat, 0.5 km of off-channel and side-channel habitat and 0.20 km^2 of riparian habitat. Approximately 28% of the habitat accessible to anadromous salmonids in Germany Creek has been treated thus far.

Table 2. Habitat restoration projects for Abernathy Creek, 2009 to present. Project status includes completed (C), funded (F), and proposed (P). Primary treatments are Off-Channel/Side Channel (OC/SC), Floodplain Reconnection (FR), Instream Habitat Complexity (IHC), Fish Passage (FP). Acquisition projects are not included in this table. Additional details are available in the Updated Treatment Plan (LCFRB 2016; see Table 4 in plan).

PRISM ID	Project Name	Project Status[b]	Construction Complete[b]	Primary Treatment
10-1300-01	Abernathy Creek Tidal Restoration[a]	C	2013	OC/SC
11-1329	Abernathy Creek Bridge Removal Project	C	2012	FR
11-1386	Abernathy Creek Two Bridges	C	2012	FR
12-1333	Abernathy 5A Side Channel Project	C	2015	OC/SC
PCSRF[c]	Abernathy Sitka Spruce	C	2015	IHC
14-1296	Abernathy Creek Davis Site	C	2017	OC/SC/IHC
PCSRF[c]	Abernathy Creek Wisconsin Site Project	C	2016	IHC
14-1311	Abernathy Creek Cameron Site	C	2016	IHC
14-1310	Abernathy Creek Midway Project	C	2016	IHC
15-1127	Abernathy Creek Headwaters Implementation	C	2020	IHC
16-1533	Sarah Creek Habitat & Passage Enhancement	C	2019	FP & IHC
17-1115	Erick Creek Instream Habitat Restoration	C	2020	IHC
18-1397	Abernathy Creek Mainline Restoration IMW	C	2021	IHC
BAFBRB[d]	~~Erick Creek Culvert Replacement~~	~~P~~	~~Future~~	FP

[a] The majority of project 10-1300-01 occurred below the smolt trap location. As a result, the study design has not incorporated a direct evaluation of fish responses to this project.

[b] "Project Status" refers to the status of the sponsor's contract with the Washington State Recreation and Conservation Office where as "Construction Complete" refers to the year that on-the-ground work was completed. Several projects with construction completed are still in funded project status due to the time lapse between field implementation and final reporting. Completion dates for projects in proposed "Project Status" are provided as estimates only.

[c] These construction projects were funded through Pacific Coastal Salmon Recovery Funds (PCSRF) outside the Salmon Recovery Funding Board process.

[d] This project is not included in the 2021-2023 Brian Abbott Fish Barrier Removal Board (BAFBRB) Draft Proposal for Funding list, nor is it proposed for SRFB funding.

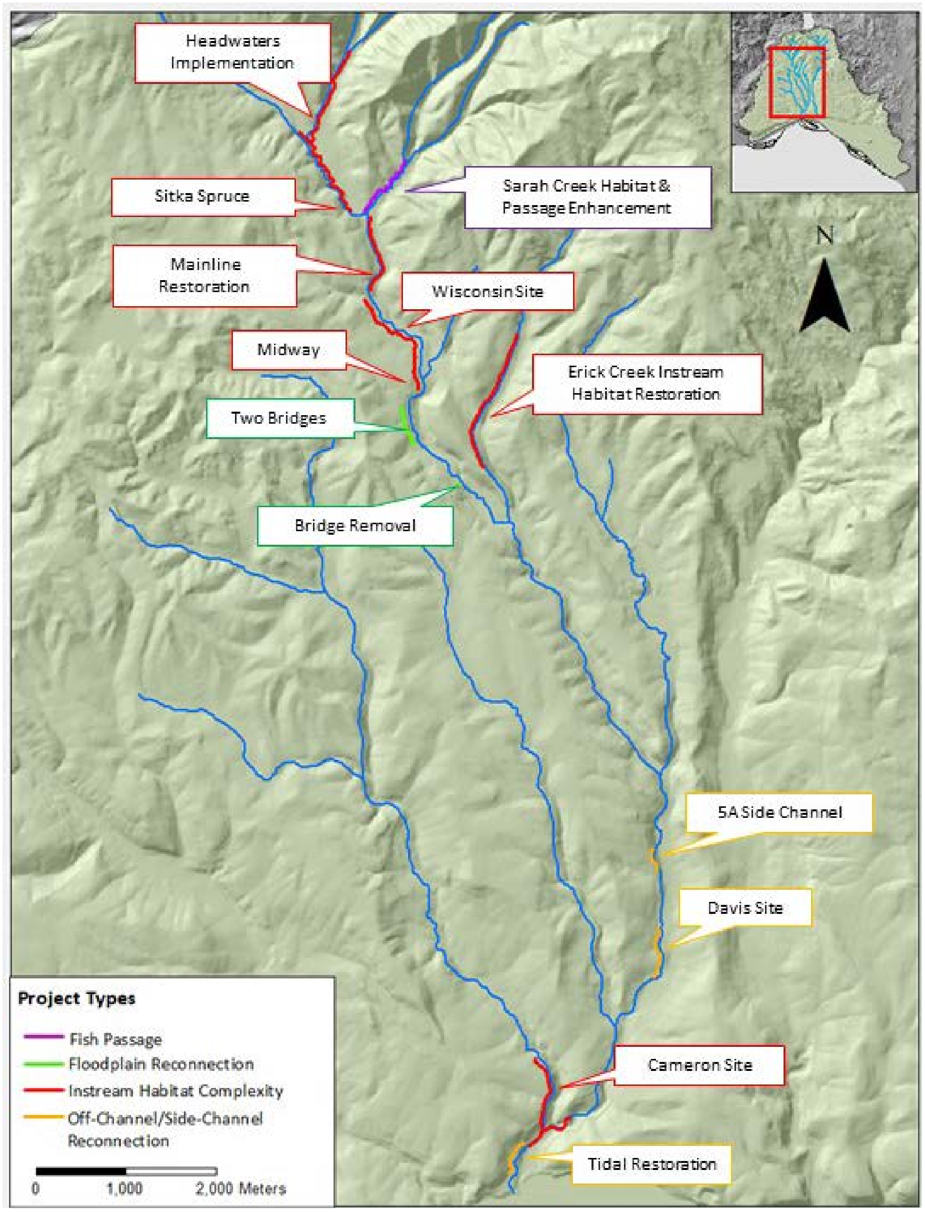


Figure 8. Habitat treatment projects in Abernathy Creek (completed, funded and proposed projects, see Table 2 for more information). Lines represent approximate treatment location. Line color indicates the primary treatment type for each project.

Figure 9. Pictures of the Abernathy Creek Headwaters Implementation project. The project was completed in March 2020. These photos were taken in October and November 2019 after the first phase of the project was completed.

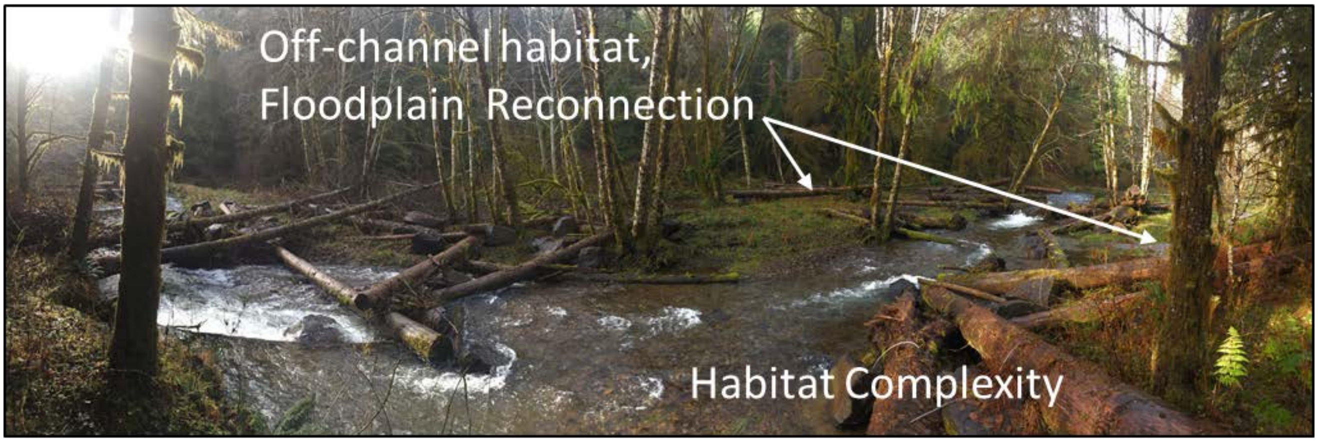


Figure 10. Pictures of the Sitka Spruce project. LWD placement resulted in floodplain reconnection, increased habitat complexity, and off-channel/side channel habitat, providing additional over-wintering habitat for juvenile salmonids.

Figure 11. Pictures of Sarah Creek before and after project implementation. Streambed aggradation and LWD placement effectively removed a barrier that opened-up nearly one mile of habitat to anadromous salmonids.

Figure 12. Pictures of the Wisconsin project. LWD placement has created off-channel/side channel habitat and has reconnected the creek to the floodplain.

Figure 13. Pictures of the Cameron Site project. LWD placement has created off-channel/side channel habitat and has reconnected the creek to the floodplain.

Table 3. Habitat restoration projects for Germany Creek, 2009 to present. Project status includes completed (C), funded (F), and proposed (P). Primary treatments are Off-Channel/Side Channel (OC/SC), Floodplain Reconnection (FR), Instream Habitat Complexity (IHC), Fish Passage (FP). Acquisition projects are not included in this table.

PRISM ID	Project Name	Project Status[b]	Construction Complete[b]	Primary Treatment
09-1378	Germany Creek Conservation and Restoration 2[a]	C	2012	IHC
15-1039	Germany Creek Restoration Smith Site	C	2020	IHC
15-1040	Germany Creek Andrews Site	C	2020	IHC
17-1027	IMW Godinho Restoration	F	2021	IHC
19-1225	Germany Creek Stream Restoration Kosiba	F	2022	IHC
21-1078	Upper Germany Creek Restoration Project	F	2023	OC/SC/FP/ IHC

[a] The majority of this project occurred below the smolt trap location. As a result, the study design has not incorporated a direct evaluation of fish responses to this project.

[b] "Project Status" refers to the status of the sponsor's contract with LCFRB where as "Construction Complete" refers to the year that the on-the-ground work was completed. Several projects with construction completed are still in funded project status due to the time lapse between field implementation and final reporting.

3.2 Monitoring Updates

NOTE: Detailed information about the habitat monitoring portion of this project is not included in this report. A separate, comprehensive habitat report is being compiled by the IMW Habitat Project Lead for submission to the Monitoring Panel.

Fish population, instream habitat, and water quality data are collected on an annual basis in the LC-IMW complex (Table 4). Fish data encompass three different life stages including outmigrating juveniles (e.g. smolts), rearing parr, and adult spawners using standard monitoring protocols of the American Fisheries Society (Crawford et al. 2007a; Crawford et al. 2007b; Volkhardt et al. 2007). Instream habitat monitoring includes data collection to describe habitat characteristics at a watershed scale and at the project scale using methods adapted from Environmental Monitoring and Assessment Program (EMAP, https://archive.epa.gov/emap/archive-emap/web/html/). Annual monitoring of water quantity and quality data occurs at stream gages operated at the lower end of each basin. The majority of parr sampling sites and all of the EMAP sites were selected using a random, spatially balanced approach; the screw traps are positioned in the lower end of each basin in order to estimate total basin juvenile production; and spawner surveys generally cover the extent of the anadromous zone (Figure 14.)

All monitoring tasks were completed in 2021.

Table 4. Annual monitoring tasks for the Lower Columbia Intensively Monitored Watershed study. Progress on these tasks for the lower Columbia River IMW study is shown for all years as well as the current reporting period (January 1 to December 31, 2021). Contributing agencies are Washington Department of Fish and Wildlife (WDFW), WeyCo. (Weyerhaeuser), and Washington Department of Ecology (WDOE).

Task	Contributing Agency	Time Frame	Years	Completion Status 2021
Outmigrant trapping	WDFW	Jan - Jul	2001-2021	Completed
Parr sampling and PIT tagging	WDFW, WeyCo., WDOE	Aug - Sep	2005-2021	Completed
Steelhead spawner surveys	WDFW	Feb - Jun	2005-2021	Completed
Chinook spawner surveys	WDFW	Sep - Nov	2005-2021	Completed
Coho spawner surveys	WDFW	Oct - Jan	2006-2021	Completed
Habitat sampling	WDFW	Jun - Oct	2007-2021	Completed
Water quality	WDOE	Jan - Dec	2005-2021	Completed

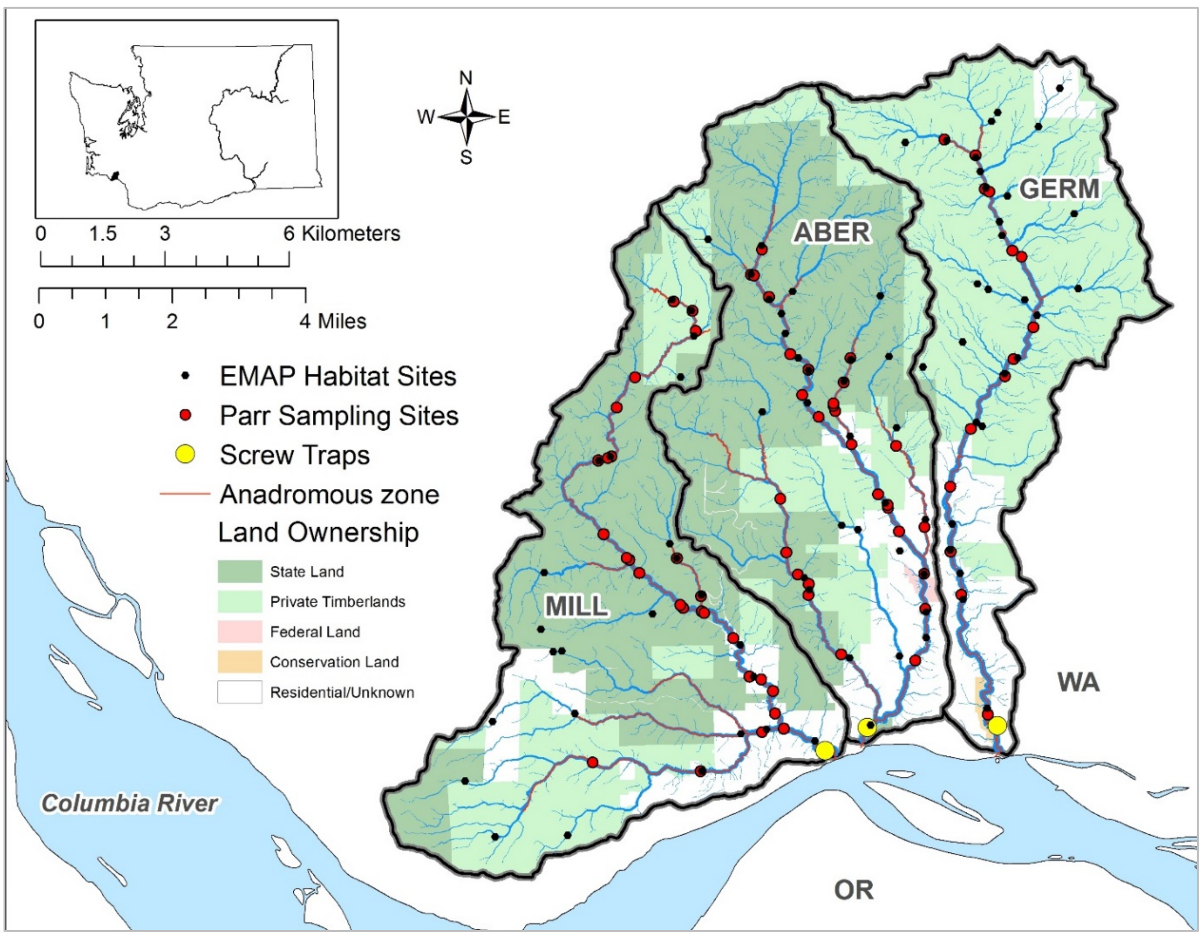


Figure 14. Map of the Lower Columbia Intensively Monitored Watershed complex in southwest Washington. The map shows monitoring sites and land ownership within the complex.

Habitat Sampling

In 2021, EMAP stream habitat sampling occurred as planned. We successfully collected standard samples at 28 Sites in Germany Creek, 29 Sites in Abernathy Creek, and 22 Sites in Mill Creek. Project monitoring of a few sites was not possible due to logistical constraints. We are collecting additional project monitoring data this winter.

Outmigrant trapping

Outmigrant trapping in 2021 was completed as planned. Abundance estimates were generated for all species.

One notable result from 2021 is the Abernathy basin produced the most coho smolts among the three basins for the fourth consecutive year (Figure 15). Prior to intensive restoration efforts, Mill Creek, the reference watershed for this study, consistently produced the most coho smolts. Coho smolt abundance in all three basins has been trending downward. Abernathy also produced the most steelhead smolts in 2021 (Figure 16), maintaining an increasing trend in the basin. Chinook production (Figure 17) continues to be well-below long-term averages due to very low escapement.

Spawner surveys

Spawner surveys were completed as planned in 2021.

At the time of this report, abundance estimates were available through 2020 for coho and 2021 for Chinook and steelhead (Figures 18-20). Coho adult abundance in 2020 in the LC-IMW complex was the 5th highest abundance across the time series. Most coho adults (44%) returned to Abernathy Creek, a typical pattern observed across the time series. Coho spawner abundance continues to trend upward. Steelhead and Chinook adult abundance showed minimal to no improvement in 2021 relative to 2020; abundance estimates for both species generally remain low (<100 in each stream) in the LC-IMW complex.

The proportion of hatchery origin spawners (pHOS) was calculated for both coho and Chinook salmon, but not for steelhead. Understanding pHOS is important because this factor has the potential to influence population fitness (e.g., Chilcote et al. 2011). Rearing origin data (natural = adipose fin intact, hatchery = adipose fin clipped) was collected from carcasses. The 2020 pHOS estimate for coho was 8%, below the-long term average of ~12%. Chinook pHOS in 2021 was 80%, similar to the long-term average. Steelhead adults are not encountered at levels similar to coho and Chinook, so pHOS values were not calculated.

Adult trends are largely driven by out-of-basin factors, including stray hatchery fish (Chinook) and ocean conditions that affect smolt-to-adult survival (coho, steelhead, and Chinook). The vast majority of Chinook spawners (~70%-97% annually) in the LC-IMW are out-of-basin hatchery strays. As for coho and steelhead, adult return trends in the LC-IMW streams generally followed declining trends since 2015 observed in other basins in the lower Columbia region, suggesting out-of-basin factors (e.g., predation, ocean conditions) are the main influence on our observations. New information from NOAA Fisheries suggests that ocean conditions were greatly improved in 2021, indicating that marine survival may increase in upcoming years (https://www.fisheries.noaa.gov/west-coast/science-data/ocean-indicators-summary-2021).

Summer Parr Sampling

Summer parr sampling is a collaborative effort among staff from Weyerhauser, WDFW, and WDOE. Funding reductions for Weyerhauser resulted in a reduced electrofishing effort in 2021 (fewer sites were sampled with electrofishing gear in 2021). However, WDFW was able to maintain the seining effort across all watersheds. Across the time series, we generally PIT-tag ~2,100 coho among the three basins each year (Mill ~ 400; Abernathy ~ 700; and Germany ~ 1,000). In 2021, we PIT-tagged 2,889 coho parr (Mill = 411 coho; Abernathy = 1,564 coho; and Germany = 914 coho).

Water quality monitoring

Water quality monitoring stations were affected by extreme high-water events in January 2020 and 2021. Data only available for the first half of water year 2021; discharge rating curves are currently under development due streambed channel changes; and some sensors were damaged and are under repair.

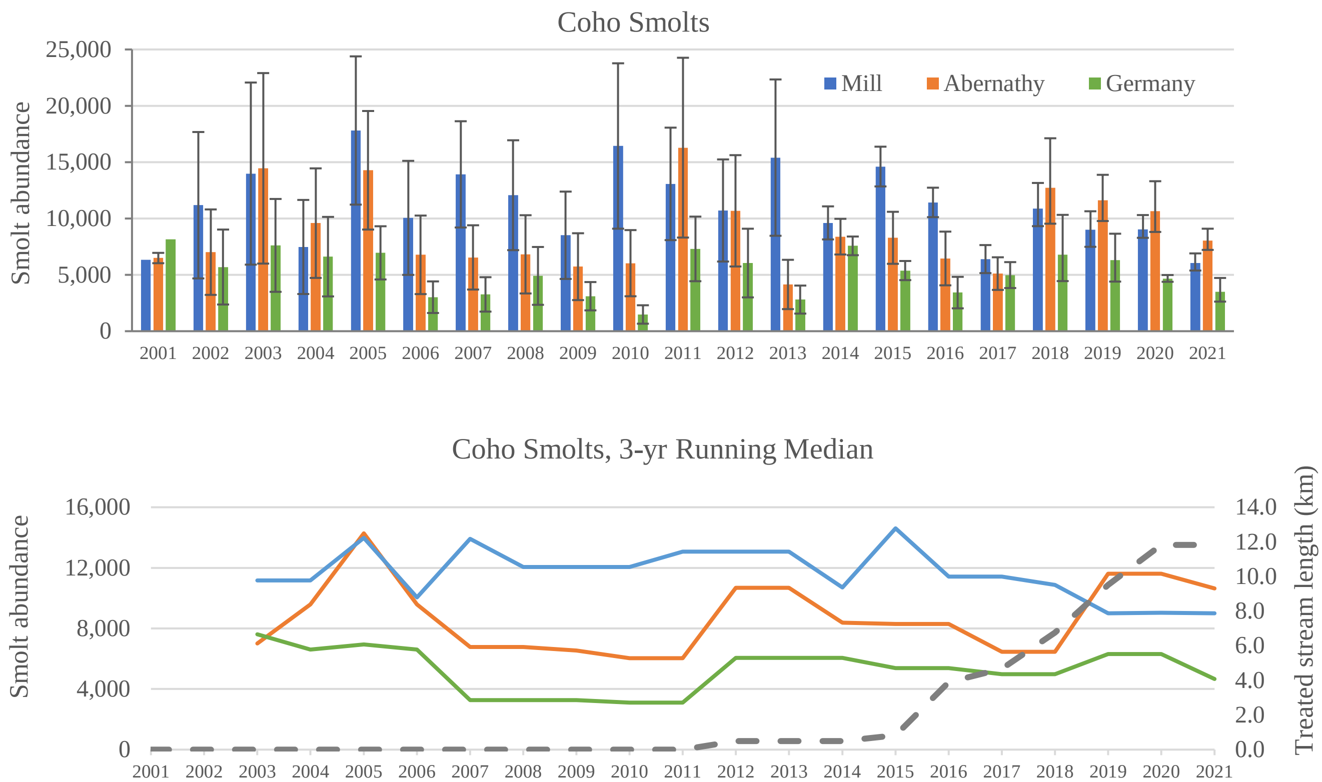
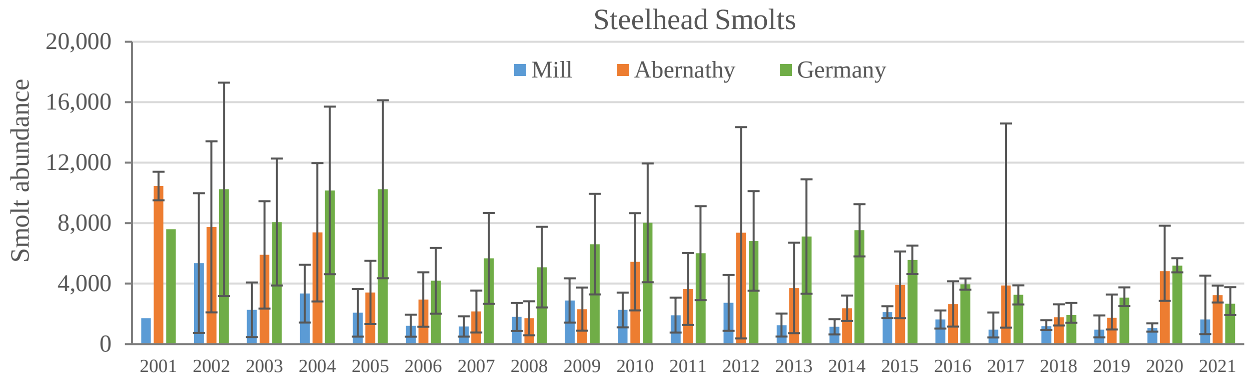


Figure 15. Time series of coho smolt abundance in Mill, Abernathy, and Germany creeks, 2001-2021. Top graph shows best available annual estimates and 95% confidence intervals. Bottom graph shows the 3-yr running median of abundance and the cumulative amount a stream length treated in Abernathy Creek. Coho abundance in Abernathy Creek has increased relative to the two other streams since intensive restoration treatments in Abernathy Creek.



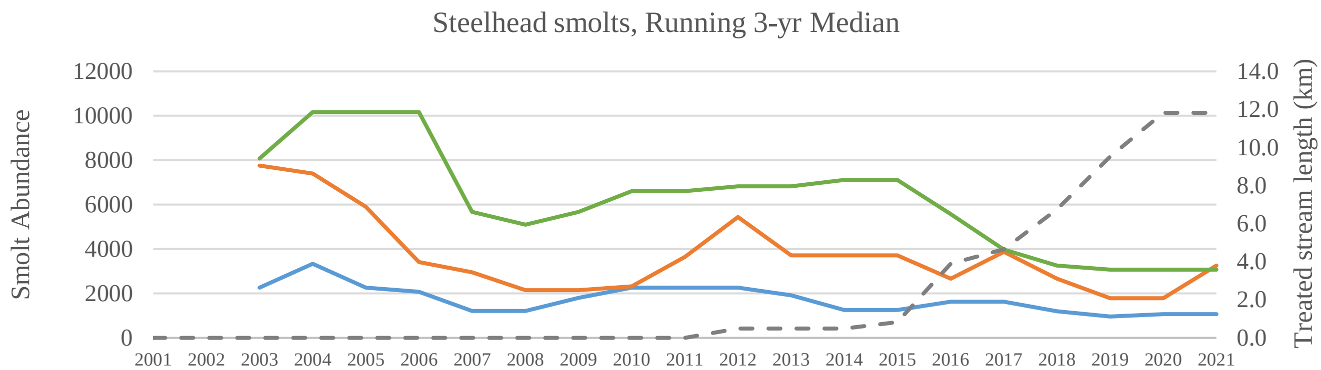
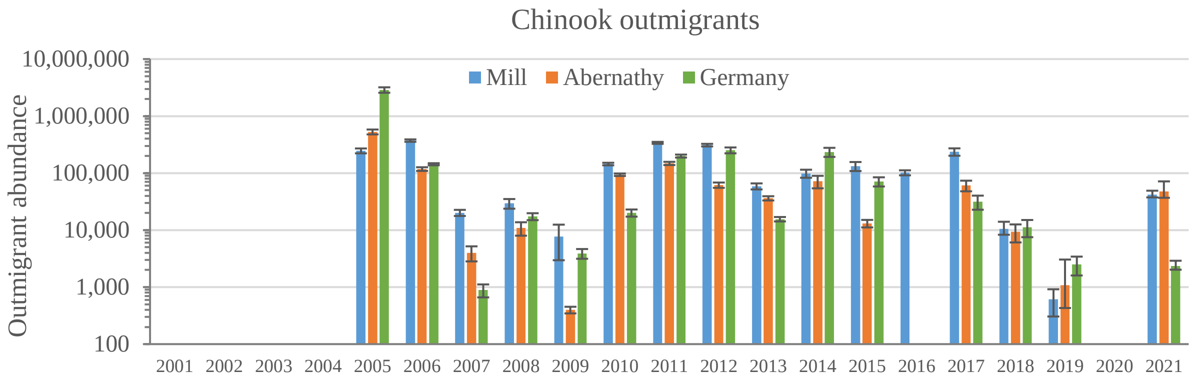


Figure 16. Time series of steelhead smolt abundance in Mill, Abernathy, and Germany creeks, 2001-2021. Top graph shows best available annual estimates and 95% confidence intervals. Bottom graph shows the 3-yr running median of abundance and the cumulative amount a stream length treated in Abernathy Creek.



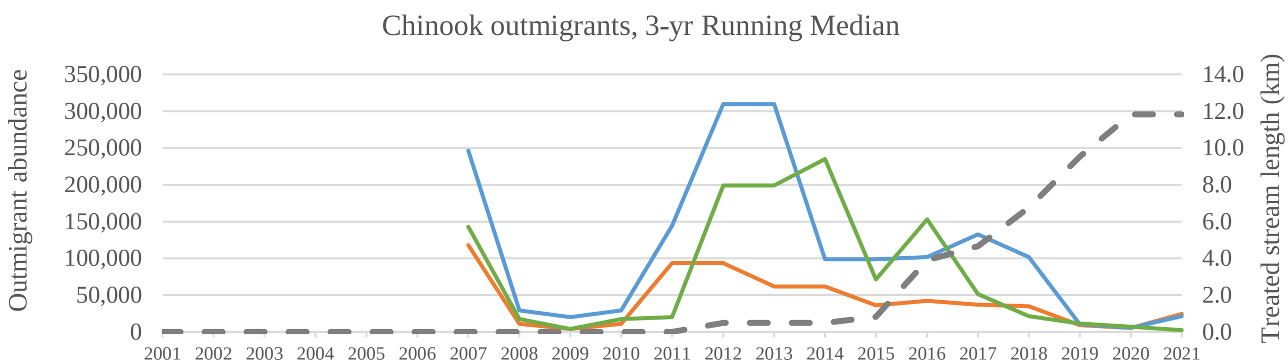
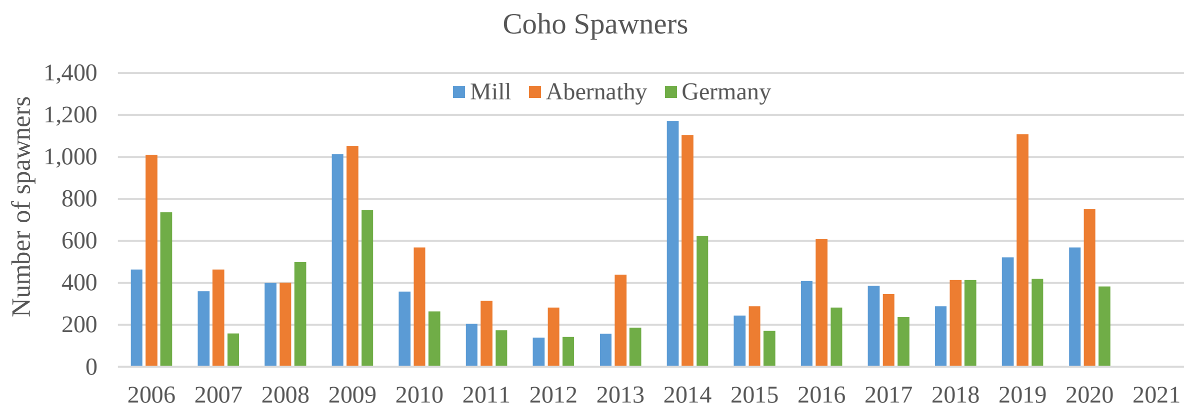


Figure 17. Time series of Chinook outmigrant abundance in Mill, Abernathy, and Germany creeks, 2005-2021. Top graph shows best available annual estimates and 95% confidence intervals. Note, the logarithmic scale on the y-axis. Chinook outmigration estimates are not available for 2001-2004 (the trap did not operate during outmigration period), 2016 (due to ESA take permit restrictions), and 2020 (missed the majority of the outmigration due to restrictions related to the COVID-19 pandemic).Bottom graph shows the 3-yr running median of abundance and the cumulative amount a stream length treated in Abernathy Creek.



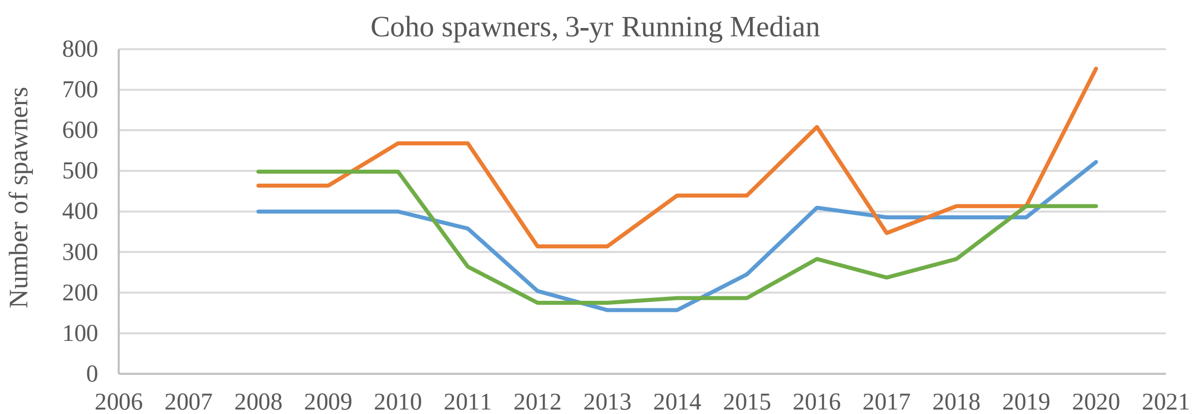
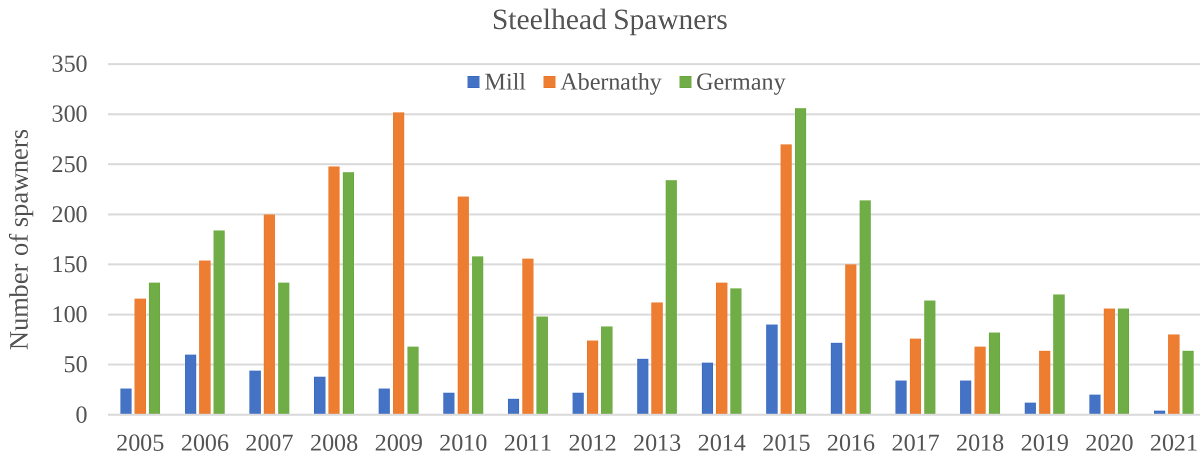


Figure 18. Time series of coho spawner abundance for Mill, Abernathy, and Germany creeks (2006-2020). Top graph shows best available point estimates. Bottom graph shows the 3-yr running median of abundance.



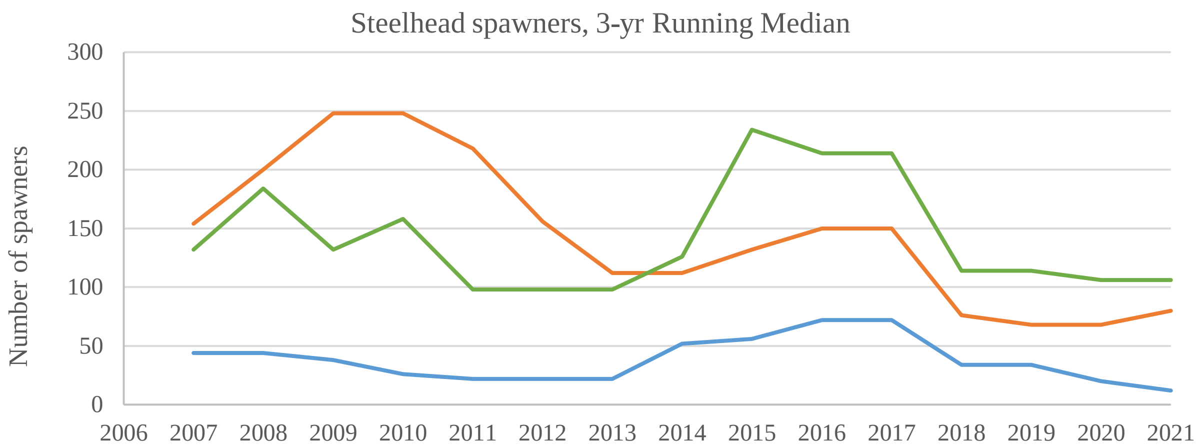


Figure 19. Time series of steelhead spawner abundance for Mill, Abernathy, and Germany creeks (2005-2021). Top graph shows best available point estimates. Bottom graph shows the 3-yr running median of abundance.

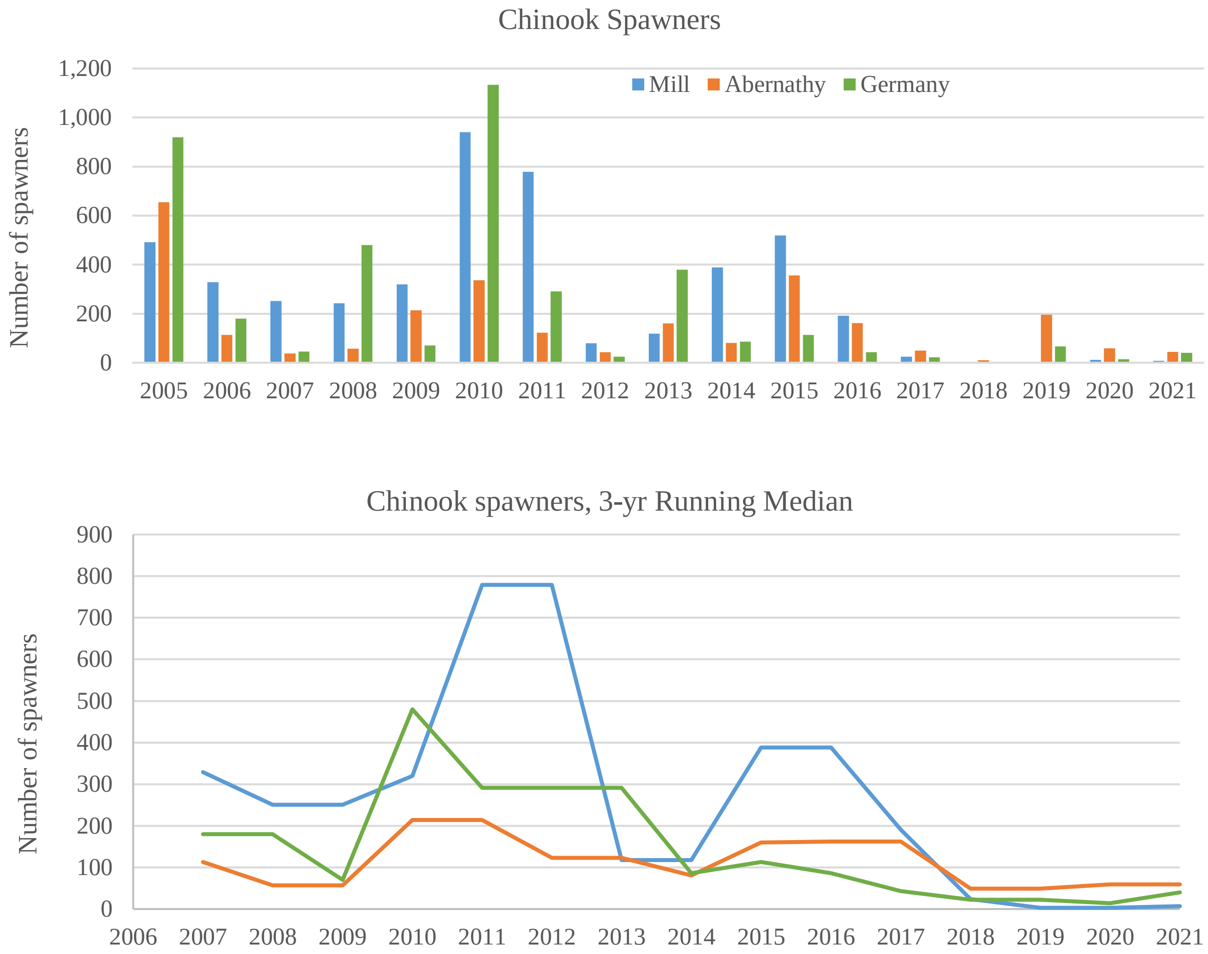


Figure 20. Time series of Chinook spawner abundance for Mill, Abernathy, and Germany creeks (2005-2021). Top graph shows best available point estimates. Bottom graph shows the 3-yr running median of abundance.

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Appendix A: Removed

Appendix A was entitled: Monitoring Panel Questions to be Addressed in Annual Reports. The 2020 report was reformatted and the information in Appendix A was moved to the body of the report.

Appendix B: Detailed Summary of Restoration Projects

Table B- 1. Detailed summary of nutrient enhancement projects. Table includes goals, years completed, actions, and detailed description of the watershed-scale application of salmon carcass analogs Germany and Abernathy creeks. Analog and distance calculations are the total coverage summed over all treatments during a season. Density (kg/m^2) is calculated using a 6-m bankfull width based on annual habitat surveys in these watersheds.

				Action Detail			
Watershed	Goal	Year	Action	Analog (kg)	Distance (m)	Density (kg/m^2)	Comments
Germany	Increase marine-derived nutrients available to stream food web during fall months	2010	Fall	9,630	12.1	0.13	Disintegrated
		2010	Spring	5,987	12.2	0.08	Disintegrated
		2011	Fall	11,567	18.7	0.12	Two treatments (Sept, Oct)
		2012	Fall	10,206	18.7	0.11	Two treatments (Sept, Oct)
		2013	Fall	7,257	18.7	0.12	One treatment (Oct)
Abernathy	Increase marine-derived nutrients available to stream food web during spring months	2013	Spring	5,126	9.3	0.09	Two treatments (May, June)
		2014	Spring	6,532	11.5	0.10	Two treatments (May, June)
		2015	Spring	18,144	22.5	0.13	Two treatments (May, June)

Table B- 2. Detailed summary of instream habitat projects completed in Abernathy Creek[a]. Table includes goals, years completed, actions, and detailed description of the action. Primary treatments (actions) are Off-Channel/Side Channel (OF/SC), Floodplain Reconnection (FR), Instream Habitat Complexity (IHC), Fish Passage (FP), and Riparian Planting/Management (RP).

Project	Goal	Year	Action	Action Detail
Abernathy Creek Bridge Removal	Increase connectivity	2012	FR, RP	Removed one bridge, placed root wads over 100 feet of off-channel habitat, and planted 0.1 riparian acres.
Abernathy Creek Two Bridges	Increase complexity	2012	FR, IHC	Removed 1200 feet of abandoned roadbed from the floodplain, re-meandered and placed large wood, rootwad and boulder structures over 1500 feet of stream channel, and planted 1.5 riparian acres.
Abernathy 5A Side Channel	Increase connectivity	2015	OC/SC, IHC	Connected and placed root wad and large wood structures over 600 feet of side-channel habitat, and planted 1.7 riparian acres.
Abernathy Sitka Spruce	Increase complexity	2015	IHC, FR	Placed large wood structures over 500 feet of stream channel and planted 0.1 riparian acres.
Abernathy Creek Wisconsin Site	Increase complexity	2016	IHC	Placed large wood structures over 1300 feet of stream channel, and connected 580 feet of off-channel habitat.
Abernathy Creek Cameron Site	Increase complexity	2016	IHC, FR, RC	Placed large wood structures through 6400 feet of stream channel and planted 1.8 riparian acres.
Abernathy Creek Midway	Increase complexity	2016	IHC, OC/SC	Removed one bridge, placed large wood structures over 1800 feet of stream channel, and planted 0.1 riparian acres

Abernathy Creek Davis Site	Increase complexity	2017	OC/SC, IHC	Placed large wood structures through 1800 feet of stream channel, reconnected 720 feet of off-channel/side-channel habitat, and planted 1.0 riparian acres.
Abernathy Creek Headwaters Implementation	Increase complexity	2018 – 2020	IHC	Placed large wood structures through 6,864 feet of stream channel and planted and thinned riparian habitat to promote habitat diversity along 6,864 feet of stream bank for a total of 8 acres of riparian habitat.
Sarah Creek Habitat & Passage Enhancement	Increase complexity and fish passage	2019	IHC, FP	Placed large wood and boulders through 2,580 feet of stream channel to address 1 fish passage barrier at a bedrock falls. This should improve access to 9,080 feet of habitat. Riparian habitat was planted and thinned across 9.1 acres and 5,170 feet of stream bank to promote habitat diversity.
Erick Creek Instream Habitat Restoration	Increase complexity	2020	IHC	Placed large wood structures through 4,220 feet of stream channel. Reconnected 0.4 acres of off-channel habitat and removed 0.3 acres of relict road grade material from the floodplain. 14 acres of riparian habitat was also planted to promote habitat diversity along 8,450 feet of streambank.
Abernathy Creek Mainline Restoration	Increase complexity	2021	IHC	3,330 feet of stream habitat was treated with large wood structures. Riparian habitat restoration is planned for 2021.

[a]Projects listed in this table were located upstream of the smolt trap location and are in ‘Completed’ status.

Appendix C: Recommended Habitat Treatment in Germany Creek to support the Lower Columbia Intensively Monitored Watershed

This appendix was first included in the 2017 annual report and is retained here as a record of the approach to implementing restoration within the Lower Columbia Intensively Monitored Watersheds.

Lower Columbia Fish Recovery Board

Memorandum

Date: December 7, 2017

To: Salmon Recovery Funding Board Monitoring Panel

From: Steve Manlow, Executive Director

Subject: Recommended Habitat Treatment in Germany Creek to support the Lower Columbia Intensively Monitored Watershed (IMW)

This memo is in response to the May 2017 Salmon Recovery Funding Board (SRFB) Monitoring Panel annual review recommendations. Specifically, this memo responds to the Monitoring Panel's condition requiring identification of remaining restoration projects in Abernathy and Germany creeks, along with associated cost estimates and priority for implementation[1].

The Lower Columbia Intensively Monitored Watershed (IMW) addresses the subbasin complex that includes Mill, Abernathy and Germany Creeks. The 2009 restoration treatment plan identified potential restoration projects in Abernathy and Germany Creeks. Mill Creek serves as the control stream. The treatment plan calls for three phases of restoration project implementation, with each phase composed of 20 projects. Given inadequate funding to fully implement all 60 of the identified restoration projects from the treatment plan, as well as statewide implementation challenges, the SRFB made a decision to allocate up to $2 million per year from 2014 through 2016 to accelerate implementation of IMW projects in the Lower Columbia, Hood Canal and Straits complexes[2]. To ensure sufficient restoration work occurs in a focused and timely manner, the SRFB and Lower Columbia Fish Recovery Board (LCFRB) also made the decision to focus habitat restoration work in the Lower Columbia IMW complex in Abernathy Creek, and focus efforts in Germany Creek on nutrient enhancement.

In 2017, dedicated IMW funding for restoration projects via a SRFB allocation was discontinued. The LCFRB is not advocating for reestablishing dedicated SRFB funds for restoration projects in IMW complexes. Remaining treatment plan projects in Abernathy Creek will therefore need to be funded through other competitive, region-wide grant round processes. To be competitive, project proposals must address regional restoration needs for high priority populations. However, the region also recognizes the broader importance of completing necessary treatments in Abernathy Creek, and will work to move remaining high priority projects forward. Currently, there are two remaining projects in Abernathy Creek that have completed designs, but need to be implemented to address detectable response estimates for coho salmon. These are the Erick Creek Culvert Replacement and Abernathy Creek Reach 9B projects.

The IMW treatment plan was updated in 2016. The plan update included recommendations for future treatment prioritization, with highest priority placed on implementing the remaining projects in Abernathy Creek that target coho salmon life history bottlenecks. The plan update also includes the recommendation

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[1] See May 2017 SRFB Monitoring Panel Recommendations. Cost estimates for project implementation are found in the 2009 Abernathy and Germany Creeks Intensively Monitored Treatment Plan.
[2] See August 2012 SRFB Briefing Memo and March 2014 SRFB Meeting Minutes.

that habitat restoration work in Germany Creek be reconsidered, as long as it does not negatively impact the ability to measure responses in Abernathy Creek. It is important to note that as with future treatments in Abernathy Creek, any additional work in Germany Creek would need to occur through existing or new competitive grant processes. While efforts will be made to align any future work in Germany Creek with IMW study goals, the primary focus will be on ensuring high priority salmon and steelhead recovery needs and priorities are met. This is consistent with the SRFB and LCFRB's direction of focusing funding on completing the necessary restoration treatments for the IMW study in Abernathy Creek. The following is therefore presented within this context.

Implementing treatment actions in Germany Creek could address different habitat restoration questions than actions in Abernathy Creek. The Abernathy Creek watershed is lower gradient with numerous tributaries, and treatment is primarily focused on coho rearing needs. In contrast, the Germany Creek watershed is higher gradient with few tributaries and off-channel areas, and habitat conditions are more conducive to the rearing needs of winter steelhead. With these differences in mind, the LCFRB IMW Technical Oversight Group (TOG) brainstormed priorities for treatment options in Germany Creek during two meetings in 2017. Identified priorities include:

- Identifying and treating sediment point sources in the headwaters of Germany Creek;
- Increasing habitat complexity in the upper watershed mainstem and side-channels of Germany Creek; and
- Increasing habitat complexity in high priority stream reaches[3] that are situated on rural residential and agriculture parcels.

Sediment input from the mid to upper reaches of Germany Creek is high, and multiple slope failures have been identified during the duration of the IMW study. These inputs affect habitat conditions throughout the watershed. Addressing excessive headwater sediment sources is therefore essential to habitat treatments. Some sediment point sources in the headwaters of Germany Creek may already be identified through the Washington Department of Natural Resources (DNR) Road Maintenance and Abandonment Plan (RMAP) program, and it will be important to review available data to determine if sources are negatively impacting anadromous fish habitat both locally and downstream. It is also recommended that projects focus on adding complexity to simplified, mainstem and side channel habitat throughout watershed. The structural design of projects that increase mainstem habitat complexity may be difficult due to high stream power. However, increased habitat complexity could increase flow heterogeneity, leading to improved rearing and spawning conditions via the retention of sediment and conversion of plane-bed to forced pool-riffle channel type.

The majority of high priority (Tier 1 and Tier 2) stream reaches occur in the middle and lower portions of the Germany Creek watershed, where the creek flows adjacent to the primary access road and through small, privately owned parcels. Treatment actions through these stream reaches should address habitat complexity needs, but must also incorporate current and anticipated land uses. Given these constraints, the types and scale of treatments may differ from currently implemented IMW projects, especially those conducted on state-owned forest land in Abernathy Creek. For these reasons, projects implemented in Germany Creek can provide valuable information on how habitat treatment in transitional and constrained landscapes may benefit watersheds and focal populations.

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[3] Stream reaches are identified in the regional Habitat Strategy: https://www.lowercolumbiasalmonrecovery.org/landingpage#b

SRFB funds can be used to design and implement habitat projects in Germany Creek, but as noted above, proposals must compete with others across the Lower Columbia region. To be competitive under the LCFRB and SRFB review process, projects must address restoration needs for high priority populations and stream reaches, which are typically Tier 1 and 2 reaches supporting multiple Primary populations (see the LCFRB Project Evaluation Criteria). The limited length and number of Tier 1 reaches, combined with the lack of multiple species in the middle to upper portions of the watershed, may reduce competitiveness of project proposals in Germany Creek. Absent a non-SRFB funding source, and given the above constraints and policy direction, restoration work in Germany Creek may occur on a protracted schedule with less spatial intensity than work already completed and planned for Abernathy Creek. Given this reality, the IMW monitoring plan for Germany Creek should be updated and adaptively managed to identify approaches that will evaluate this potentially protracted strategy of treatment in an effective and timely manner.

References

HDR Inc, and Cramer Fish Sciences. 2009. Abernathy and Germany Creeks Intensively Monitored Treatment Plan. Prepared for the Lower Columbia Fish Recovery Board, Longview, Washington.

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Appendix D: Evaluation of Salmon Carcass Analogs

This appendix was first included in the 2017 annual report and is retained here as a record of the findings associated within the Lower Columbia Intensively Monitored Watersheds. This master's thesis is currently being prepared as a peer-review manuscript.

Effectiveness of Salmon Carcass Analogs as a Form of Nutrient Enhancement for Juvenile Coho Salmon (*Oncorhynchus kisutch*) In Three Lower Columbia Watersheds

Matthew Sturza, Western Washington University
Masters of Science, 2017

ABSTRACT: Adult Pacific salmon exhibit a form of parental care after spawning and perishing by depositing a subsidy of marine derived nutrients (MDN) that may be incorporated into the stream food web and feed juvenile salmon. Adult salmon populations have significantly declined since the late 19th century, thereby reducing the amount of MDN within Pacific Northwest Streams. This loss in nutrients within stream food webs may be limiting the growth and survival of juvenile salmon and therefore reducing the population sizes of adult salmon. One strategy to mitigate for nutrient deficiencies within a stream is the use of salmon carcass analogs (SCA), pellets composed of pulverized and pasteurized marine forage fish. We investigated the effectiveness of SCA in enhancing the size and abundance of juvenile coho salmon within a complex of three watersheds (Abernathy, Germany, and Mill Creek) that empty into the lower Columbia River near Cathlamet, WA. SCA applications occurred in the fall (2010-2013) on Germany Creek and in the spring (2013-2015) on Abernathy Creek, while Mill Creek served as a reference watershed and did not receive SCA applications. We periodically gathered samples of periphyton, macroinvertebrates, and juvenile coho (fin clips) before and after SCA application at approximately two month intervals. Juvenile coho were also sampled for fork length and weight. Samples were taken at three sites at the lower, middle, and upper extent of adult coho spawning within each watershed. During the final sampling event of each year, while juvenile coho were outmigrating, fin clips were taken at smolt traps located near each river's confluence with the Columbia River. Data from smolt traps were used to estimate the average fork length and abundance of juvenile coho during each year of this project. To evaluate the timing and extent of nutrients from SCA being incorporated into the stream food web, samples were processed and analyzed for δ15N, a measure of the abundance of the heavier isotope of nitrogen that occurs more abundantly in the marine environment. Seasonal trends of δ15N in periphyton, macroinvertebrates, and juvenile coho, as well as seasonal trends of juvenile coho fork length and weight were compared between fertilized and unfertilized watersheds. We detected SCA effects on seasonal trends of macroinvertebrate and juvenile coho δ15N for the fall and spring treatments, indicating SCA nutrients were incorporated by these communities. We detected SCA effects on the seasonal trends of juvenile coho fork length and weight for the spring treatment, but not for the fall treatment. We could not detect SCA effects on seasonal trends of periphyton δ15N for either the fall or spring treatment, potentially due to smaller than needed sample sizes. Overall the effect of fall SCA application was to disrupt the seasonal trend of δ15N values among trophic levels by causing an increase in δ15N during the late fall/early winter when values are normally decreasing. The effect of spring SCA application was to enhance the seasonal trend, causing increases in δ15N values greater than those seen in the absence of SCA applications. Comparing juvenile coho sizes and abundances between years with and without SCA application and between fertilized and unfertilized watersheds indicated that neither the fall or spring treatment had a significant effect on coho growth and survival. Where SCA are to be used as a salmonid

recovery tool, we recommend that careful watershed selection and subsequent monitoring be employed to ensure investments are worthwhile.

Full thesis available at: http://cedar.wwu.edu/wwuet/597/

Appendix E: Standardizing the Juvenile Time Series

Prepared by Thomas Buehrens and Jamie Lamperth, WDFW

December 2018

Background

Smolt abundance estimates in LC-IMW streams are generated from data collected under a mark-recapture design (e.g., BTSPAS; Bonner and Schwarz 2011; Bonner and Schwarz 2014). This is accomplished by releasing marked smolts upstream of traps throughout the entire trapping season and using recaptures of marked smolts to determine their catchability. The raw catch of unmarked smolts is expanded by the catchability (i.e., trap efficiency) to obtain estimates of total smolt abundance passing the trap. A crucial requirement of this study design is that catchability be the same for unmarked smolts and marked smolts released upstream. Previous work in other watersheds has demonstrated that the distance that marked fish are released upstream affects whether the catchability of marked and unmarked fish are similar. In particular, the larger smolts (e.g., Coho and Steelhead) may need to be released substantial distances upstream (e.g., 1 km or greater) from traps in order for the catchability of marked fish to be similar to unmarked fish (Tattam et al. 2013).

The understanding that release locations too close to the trap may result in biased estimates of smolt abundance posed a particular challenge for the LC-IMW smolt time series since the release locations for the LC-IMW traps historically were 0.1 – 0.2 km upstream of the traps (a relatively close distance). Correcting this issue required adjusting both the release location (moving the release location farther upstream) and adjusting the historical estimates to account for any bias. To do this, equivalent numbers of Coho and Steelhead were released from the historical release location and a new site ~ 1.6 km upstream from the trap in each stream. Releases occurred throughout the outmigration period with equivalent numbers of smolts released from the historical and upstream sites on each stream. Paired release trials were conducted for four consecutive years (2014 to 2017), providing the data necessary to generate unbiased estimates of smolt abundance across the time series.

Analysis Approach

A hierarchical state-space model was developed to relate abundance estimates made using lower release sites to abundance estimates made using upper release sites. The state space framework enabled partitioning of variance due to observation error from variance due to imperfect predictions of the upper trap abundance using the lower trap abundance based on the regression model (e.g., process errors).

Log-Normal Moment Matching

Abundance estimates were assumed to be log-normally distributed and their point estimates and uncertainty were converted into log-normal shape parameters.

First, the coefficient of variation of each abundance estimate was converted into a log-normal standard deviation:

$$sd = \sqrt{\log(1 + CV^2)}$$

Next, the posterior means (2017-2018) and modes (maximum likelihood; 2014-2015) were converted to log-normal means using the following equations, respectively:

$$\mu = \log(mode) + sd^2$$

$$\mu_{log} = \log(mean) - \frac{sd^2}{2}$$

Observation Model

The observed log-mean abundance μ in watershed *w* for species *s* in year *y* based on efficiency releases made at release site *r* (upper or lower) was assumed to be normally distributed around the log of the true abundance in that year *N*.

$$\mu_{w,s,y,r} \sim \text{lognormal}\left(\log(N_{w,s,y,r}),\, sd_{w,s,y,r}\right)$$

Process Model

The abundance at the upper trap $N_{w,s,y,upper}$ was equal to the abundance at the lower trap $N_{w,s,y,lower}$ multiplied by estimated bias *b*.

$$N_{w,s,y,upper} = N_{w,s,y,lower} * b_{w,s,y}$$

Several models of bias were compared using k-fold cross validation to minimize mean absolute prediction error to determine which model best predicted upper trap site abundance using lower trap site abundance across all species, years, and watersheds. Various models performed similarly, and the following model of bias was chosen where bias was a function of a global mean bias (b_μ) and several random effects, including watershed *W*, species *S*, and a species by watershed interaction *Int_SW* plus a residual ε.

$$b_{w,s,y} = b_\mu + W_w + S_s + Int\_SW_{s,w} + \varepsilon_{w,s,y}$$

Priors

The mean bias b_μ was given a vague normal prior centered on zero. The true abundance *N* at the lower trap was given a very vague gamma prior. The residual process errors $\varepsilon_{w,s,y}$ were drawn from a normal distribution with mean zero and process error standard deviation. The process error standard deviation σ_ε was drawn from a vague Cauchy distribution. Random effects were drawn from normal distributions, and their standard deviations (hyperpriors) were drawn from vague Cauchy distributions (Gelman 2006). All priors and hyper priors were chosen with the intent of allowing the likelihoods to dominate the prior in determining the posterior

Appendix E-1. Priors and hyper priors.

Parameter	Prior Distribution
b_μ	$\text{normal}(0, 5)$
$N_{w,s,y,upper}$	$\text{gamma}(1E-06, 1E-06)$
$\varepsilon_{w,s,y}$	$\text{normal}(0, \sigma_\varepsilon)$
σ_ε	$\text{half Cauchy}(0, 2.5)$
Random effects	
W_w	$\text{normal}(0, \sigma_W)$
S_s	$\text{normal}(0, \sigma_S)$
$Int\_SW_{s,w}$	$\text{normal}(0, \sigma_{SY})$
Hyperpriors	
σ_W	$\text{half Cauchy}(0, 2.5)$
σ_S	$\text{half Cauchy}(0, 2.5)$
σ_{SW}	$\text{half Cauchy}(0, 2.5)$

Results

On average, the point estimates of trap efficiency for Coho and Steelhead increased by 36.2% (range;-7.5% to 86.4%) and 41.3% (range; 11.5% to 60.0%), respectively. The precision of the estimates prior to 2014 decreased significantly. Mean CV of the original estimates was 9.47% while the mean CV of the standardized estimates was 30.0%. The reduction in the precision of the estimates is due to the combined uncertainty of the original estimate and the uncertainty in the model predictions. However, the benefit of this adjustment is that data points are comparable throughout the entire time series, allowing for future analysis of trends.

The estimates generated by the model represent the portion of the migration that occurred from mid-April to the end of the trapping season; this is the time period in which the calibration data were collected. To calculate a total standardized estimate, the point estimate and variance from the beginning of trapping (typically sometime between mid-January and early February) to mid-April, as derived from the original estimate, was added to the modeled point estimate and variance. After combining the two time periods, the median proportion of the estimate that occurred prior to mid-April was 0.239 and 0.034 for Coho and Steelhead, respectively. For Coho, the mean proportion by basin was 0.268 (Mill), 0.239 (Abernathy), and 0.228 (Germany). Standardized estimates are shown in Figure 3.

Appendix F: Data Management

The overall IMW program is comprised of one federal agency, two state agencies, two tribal organizations, and one private company. From the beginning we chose to use each entity's existing data management system(s) rather than construct a single system unique to the IMW program. As a result the data quality control elements identified by the ISP are in varying formats, distributed among participating entities, and are specific to a particular data stream (i.e. there is no single document that contains all this information). As described below, data for the Lower Columbia IMW Study are maintained by the Washington Department of Ecology (ECY), Washington Department of Fish and Wildlife (WDFW), Weyerhaeuser (WEYCO). The Pacific States Marine Fisheries Commission maintains the PTAGIS database which stores all tag data from this study.

WATER QUALITY

Finalized water quality and quantity data are publicly available:

- https://apps.ecology.wa.gov/continuousflowandwq/StationDetails?sta=25D050

ANNUAL ADULT SPAWNERS

Reach-scale and georeferenced spawner data are housed in the WDFW Traps-Weirs-Survey (TWS) database. Final adult spawner estimates are publicly available through the Salmon Conservation Reporting Engine:

- https://fortress.wa.gov/dfw/score/score/species/species.jsp

ANNUAL SUMMER PARR

Reach-scale parr and habitat data are maintained by WEYCO in a project database.

PIT tag data are publicly available through the PTAGIS database:

- http://www.ptagis.org/

ANNUAL SMOLTS

Field data, final estimates, and protocols are archived by WDFW in the Juvenile Migrant System (JMS) database. Final smolt estimates are currently available through the data.wa.gov website. In the future, these data will be publicly available through the WDFW Salmon Conservation Reporting Engine:

- https://data.wa.gov/Natural-Resources-Environment/WDFW-Juvenile-Population-Abundance/cqra-s74n

ANNUAL HABITAT

Habitat data are maintained by WDFW in a project database.

PROJECT MONITORING

PROJECT monitoring data are maintained by WDFW in a project database.

Appendix G: Reports

Presented in reverse chronological order

Lamperth, J., M. Litz, A. Johnson, K. Krueger, W. Dezan, B. Ehinger, and M. Zimmerman. 2021. Lower Columbia Intensively Monitored Watershed Annual Report for 2020. Report to the Washington State Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

Lamperth, J., W. Ehinger, A. Johnson, M. Litz, W. Dezan, M. Zimmerman. 2019. Lower Columbia Intensively Monitored Watershed Study: 2019 Annual Report. Report to the Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

Zimmerman, M. S., J. Lamperth, W. Ehinger, A. Johnson, K. Krueger, and N. Pittman. 2018. Lower Columbia Intensively Monitored Watershed Study: 2018 Annual Report. Report to the Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

Zimmerman, M. S., W. Ehinger, A. Johnson, K. Krueger, and T. Quinn. 2017. Lower Columbia Intensively Monitored Watershed Study: 2017 Annual Report. Report to the Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

Sturza, M. T. 2017. Effectiveness of Salmon Carcass Analogs as a Form of Nutrient Enhancement for Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Three Lower Columbia Watersheds. M. Sc. Thesis, Western Washington University, Bellingham, Washington http://cedar.wwu.edu/wwuet/597/.

Zimmerman, M. S., K. Krueger, and W. Ehinger. 2016. Lower Columbia Intensively Monitored Watershed Study: 2016 Annual Report. Report to the Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

Zimmerman, M. S., K. Krueger, T. Johnson, W. Ehinger, and A. Johnson. 2016. Lower Columbia Intensively Monitored Watershed Study: 2016 Progress Report. Report to the Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

Bennett, S., G. Pess, N. Bouwes, P. Roni, R. E. Bilby, S. Gallagher, J. Ruzycki, T. Buehrens, K. Krueger, W. Ehinger, J. Anderson, C. Jordan, B. Bowersox, and C. Greene. 2016. Progress and Challenges of Testing the Effectiveness of Stream Restoration in the Pacific Northwest Using Intensively Monitored Watersheds. Fisheries **41**:92-103.

Zimmerman, M. S., K. Krueger, B. Ehinger, R. E. Bilby, J. Walter, and T. Quinn. 2015. Intensively Monitored Watersheds Program: Lower Columbia River Study Plan Update. Report to the Salmon Recovery Funding Board Monitoring Panel, Olympia, Washington.

IMW Scientific Oversight Committee (IMWSOC). 2013. Intensively Monitored Watersheds Synthesis Report 2013. Prepared for the Salmon Recovery Funding Board.

Zimmerman, M. S., K. Krueger, B. Ehinger, P. Roni, R. E. Bilby, J. Walter, and T. Quinn. 2012. Intensively Monitored Watersheds program: an updated plan to monitor fish and habitat responses to restoration actions in the Lower Columbia watersheds, FPA 12-03, Washington Department of Fish and Wildlife, Olympia, Washington. Available online: http://wdfw.wa.gov/publications/01398/.

Krueger, K. L., K. Pierce, E. Pittman, K. Samson, R. Nauer, D. Price, and T. Quinn. 2012. Intensively monitored watersheds: habitat monitoring report 2012.

Krueger, K. L., K. Pierce, E. Pittman, K. Samson, R. Nauer, D. Price, and T. Quinn. 2010. Intensively monitored watersheds: habitat monitoring report 2010.

Kinsel, C., P. R. Hanratty, M. S. Zimmerman, B. Glaser, S. Gray, T. Hillson, D. Rawding, and S. Vanderploeg. 2009. Intensively Monitored Watersheds: 2008 fish population studies in the Hood Canal and Lower Columbia stream complexes, FPA 09-12, Washington Department of Fish and Wildlife, Olympia, Washington. Available online: http://wdfw.wa.gov/publications/00783/.

Bilby, R., W. Ehinger, T. Quinn, G. Volkhardt, K. Krueger, D. Seiler, G. Pess, C. Jordan, M. McHenry, and D. Poon. 2005. Study evaluates fish response to management actions. Western Forester **50**:14-15.

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Bilby, R. E., W. J. Ehinger, C. Jordan, K. Krueger, M. McHenry, T. J. Quinn, G. Pess, D. Poon, D. E. Seiler, and G. C. Volkhardt. 2004. Evaluating watershed response to land management and restoration actions: Intensively Monitored Watersheds (IMW) progress report. Submitted to the Washington Salmon Recovery Funding Board.

Appendix H: Conferences

2021

PNAMP Intensively Monitored Watersheds Workshop, Online Meeting, November 16 – December 7, 2021

2021 Salmon Recovery Conference, Online Meeting, April 28-30, 2021

- M. Litz and J. Lamperth. 2021. Fish responses to habitat treatments in the Lower Columbia IMW complex

2020

PNAMP Intensively Monitored Watersheds Workshop, Online Meeting, May 28, 2020

SRFB RCO IMW Workshop, Online Meeting, November 4, 2020

- Lamperth, J. and M. Litz. 2020. Lower Columbia IMW

2019

2019 Salmon Recovery Conference, Tacoma, Washington, April 8-9, 2019

- Asher, E. 2019. MAGA: Make Abernathy Great Again.
- Lamperth, J. 2019. Fish and In-Stream Habitat Responses to Habitat Restoration Treatments in the Lower Columbia IMW complex.

2018

PNAMP Intensively Monitored Watersheds Workshop, Portland, OR, November 1-2, 2018

2017

2017 Salmon Recovery Conference, Wenatchee, Washington, April 25-27, 2017

- Ehinger, W. 2017. Lower Columbia Intensively Monitored Watershed: Study Design and Challenges
- Johnson, A. 2017. Developing and Updating the Lower Columbia IMW Treatment Strategy
- Zimmerman, M.S. 2017. Restoration in Abernathy Creek: Have We Done Enough? 2016

2016

PNAMP Intensively Monitored Watersheds Workshop, Portland, OR, November 1-2, 2016

Workshop - RESEARCH IN THE MILL, ABERNATHY, GERMANY CREEK WATERSHEDS. Abernathy Fish Technology Center, Longview, Washington, July 21, 2016

- Zimmerman, M.S. 2016. Overview of adult and juvenile time series (Chinook, coho and steelhead)
- Johnson, T. 2016. Snorkel survey evaluation of steelhead passage at electric weir/Abernathy falls

2015

Workshop - RESEARCH IN THE MILL, ABERNATHY, GERMANY CREEK WATERSHEDS. Vancouver, Washington, July 22, 2015

- Zimmerman, M.S. 2015. Overview of the Lower Col IMW Program
- Ehinger, W. 2015. Water quality/quantity monitoring
- Johnson, T. 2015. Lessons from baseline monitoring
- Sturza, M. 2015. Response to Salmon Carcass Analog – preliminary results

2013

PNAMP Intensively Monitored Watersheds Workshop, Portland, OR, March 20-21, 2013

- Zimmerman, M.S. 2013. Lower Columbia Intensively Monitored Watershed Study
- Using Existing Data and Models to Understand Restoration Effectiveness Workshop, Ellensburg, WA, February 8, 2013