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PNNL-20295

Prepared for the U.S. Army Corps of Engineers, Portland District,
under an Interagency Agreement with the U.S. Department of Energy
Contract DE-AC05-76RL01830

Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, Annual Report 2010

Final Report

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October 2011

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[3] U.S. Fish and Wildlife Service, Abernathy Fish Technology Center

Preface

The research reported here was performed under the auspices of the U.S. Army Corps of Engineers (USACE) Anadromous Fish Evaluation Program (study code EST-P-09-1). The study was funded by the U.S. Army Corps of Engineers Portland District (CENWP) (Ref. No. W66QKZ00065578) under an agreement with the U.S. Department of Energy for work by Pacific Northwest National Laboratory (PNNL). Subcontractors to PNNL were the University of Washington and Mr. Earl Dawley (National Marine Fisheries Service, retired). The U.S. Fish and Wildlife Service was funded separately by the USACE to collaborate on this project. Mr. Blaine D. Ebberts and Ms. Cindy A. Studebaker were, in turn, the CENWP's technical leads for the study. PNNL's project manager was Dr. Heida L. Diefenderfer, who is also custodian of the data.

This report is the second annual report of a 4-year project (2009–2012) to develop quantitative methods for evaluating the effectiveness of salmon habitat restoration in the lower Columbia River and estuary. In addition to the main body of the report, data summary appendices by particular authors address specific topics of research under this project.

Report Citation:

Diefenderfer, H.L., G.E. Johnson, N.K. Sather, J.R. Skalski, E.M. Dawley, A.M. Coleman, K.G. Ostrand, K.C. Hanson, D.L. Woodruff, E.E. Donley, Y. Ke, K.E. Buenau, A.J. Bryson, and R.L. Townsend. 2011. *Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, Annual Report 2010.* PNNL-20295, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by the Pacific Northwest National Laboratory, U.S. Fish and Wildlife Service, and University of Washington, Richland, Washington

Recommended Citation for a Chapter or Appendix in the Report:

Diefenderfer, H.L., N.K. Sather, G.E. Johnson, J.R. Skalski, E.M. Dawley, K.G. Ostrand, K.C. Hanson, B. Kennedy and B.D. Ebberts. 2011. "2010 Experimental Design and Field Work Plan." Appendix A, in *Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, Annual Report 2010,* Diefenderfer, HL and 13 others. PNNL-20295, prepared for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by the Pacific Northwest National Laboratory, U.S. Fish and Wildlife Service, and University of Washington, Richland, Washington.

Executive Summary

This report describes the 2010 research conducted under the U.S. Army Corps of Engineers (USACE) project EST-P-09-1, titled Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, and known as the "Salmon Benefits" study.

ES.1. Salmon Benefits Project Overview

The primary goal of the study is to establish scientific methods to quantify habitat restoration benefits to listed salmon and trout in the lower Columbia River and estuary (LCRE) in three required areas: habitat connectivity, early life history diversity, and survival (Figure ES.1). The general study approach was to first evaluate the state of the science regarding the ability to quantify benefits to listed salmon and trout from habitat restoration actions in the LCRE in the 2009 project year, and then, if feasible, in subsequent project years to develop quantitative indices of habitat connectivity, early life history diversity, and survival.

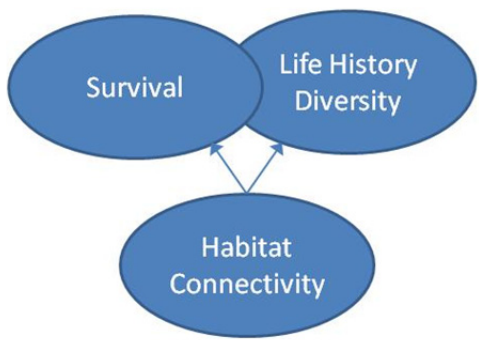


Figure ES.1. Interrelationships Among Habitat Connectivity, Life History Diversity, and Survival in the Context of LCRE Ecosystem Restoration

Based on the 2009 literature review, the following definitions are used in this study. Habitat connectivity is defined as a landscape descriptor concerning the ability of organisms to move among habitat patches, including the spatial arrangement of habitats (structural connectivity) and how the perception and behavior of salmon affect the potential for movement among habitats (functional connectivity). Life history is defined as the combination of traits exhibited by an organism throughout its life cycle, and for the purposes of this investigation, a life history strategy refers to the body size and temporal patterns of estuarine usage exhibited by migrating juvenile salmon. Survival is defined as the probability of fish remaining alive over a defined amount of space and/or time.

The objectives of the 4-year study are as follows: 1) develop and test a quantitative index of juvenile salmon habitat connectivity in the LCRE incorporating structural, functional, and hydrologic components; 2) develop and test a quantitative index of the early life history diversity of juvenile salmon in the LCRE; 3) assess and, if feasible, develop and test a quantitative index of the survival benefits of tidal wetland habitat restoration (hydrologic reconnection) in the LCRE; and 4) synthesize the results of investigations into the indices for habitat connectivity, early life history diversity, and survival benefits.

ES.2 2010 Methods

The geographic scope of the project includes the LCRE from Bonneville Dam to the mouth of the river. However, in 2010, a substantial portion of the study effort was devoted to implementation of a field study in the Cottonwood Island area of the lower Columbia River, near Longview. Elements of the field study design addressed objectives 1–3, increasing our body of knowledge about and our ability to effectively index habitat connectivity, life history diversity, and survival benefits. Three salmon habitat strata were studied: main channel, off-channel, and wetland channel.

The project passive integrated transponder (PIT)-tagged and released 9,945 juvenile fall Chinook salmon originating from the Kalama Falls Hatchery, the Kalama River screw trap, or from unknown origins (captured in beach seines at Cottonwood Island). PIT-tag detection arrays were installed at locations at and near Cottonwood Island in an effort to track movements of and habitat access by these fish. All sampling methods and metrics are summarized in Table ES.1, with references to the specific appendix of this report in which complete objectives, methods, and results of each portion of the field study are presented.

Table ES.1. Salmon Benefits Project Multi-Metric Sampling at Cottonwood Island

Metric/Method	Category	2010 Report Appendix	April 2010	May 2010	June 2010	July 2010	Aug. 2010	Sept. 2010	Oct. 2010	Nov. 2010	Dec. 2010	May 2011
Density, fork length/beach seine	Salmon Presence	B	X	X	X	X			X	X	X	
Tagged fish origin, residence time/PIT-tag antenna arrays	PIT-Tag Detections	I		X	X	X	X	X	X	X	X	
Water level and temperature (HOBO U20 level logger) [(a)]	Water Quality, Habitat Capacity		X	X	X	X	X	X	X	X	X	
Plasma protein and triglyceride, bioelectrical impedance analysis	Salmon Physiology (Nutritional Condition)	J	X	X	X	X						
RNA:DNA ratio	Salmon Physiology (Growth Potential)	J	X	X	X	X						
Plasma cortisol, whole-blood glucose and lactate, plasma ions, osmolality	Salmon Physiology (Stress Response)	J	X	X	X	X						
Gill Na+,K+ -ATPase activity	Salmon Physiology (Osmoregulatory Capacity)	J	X	X	X	X						
Phytoplankton abundance and classification, chlorophyll_*a*	Water Properties (biological)	C		X				X		X		X
Total organic carbon (particulate, dissolved), nutrients (NO_3, NO_2, NH_4, TN, PO4, TP, SiO_4)	Water Properties (organic matter and nutrients)	C		X				X		X		X
Temperature, salinity, DO; suspended sediments (total, organic, inorganic fractions)	Water Properties (physical)	C		X				X		X		X

(a) April-August; the complete data set will be downloaded when water levels permit.
DO = dissolved oxygen; NO_3 = nitrate; NO_2 = nitrite; NH_4 = ammonia; PO_4 = phosphate; SiO_4 = silicate; TN = total nitrogen; TP = total phosphate.

While most of the effort in the 2010 study year concerned field sampling and analysis, work on the development of quantitative indices of habitat connectivity, life history diversity, and survival benefits also continued. In accordance with the efficiency principle of the Salmon Benefits project, existing data sets from other projects were used in development of the indices. Key results of the field research and non-field work are summarized in the following paragraphs. (One-page summaries of the problem statements, research objectives, and methods associated with these results may be found in Chapter 3.0 of this report, and comprehensive presentations of each are available in the appendices.)

ES.3 2010 Research Results

Field Research Results:

Cottonwood Island Juvenile Salmon Densities. Unmarked Chinook salmon were the most abundant salmon captured at Cottonwood Island from April to December 2010 (>67% total salmon catch). Over all sampling months, mean density for juvenile salmon was greatest in the off-channel (~0.26 fish/m^2), followed by the wetland-channel (~0.18 fish/m^2), and finally the main-channel (~0.07 fish/m^2) habitat stratum. Salmon density was highest in the wetland during April (~0.6 fish/m^2), the off-channel during May (~1.0 fish.m^2), and the main channel during June (~0.1 fish/m^2). There were few differences in the mean size of unmarked Chinook salmon among habitat strata, except in December 2010 when mean fork length in the wetland channel stratum (~42 mm) was noticeably less than that in the main- and off-channel strata (~100 mm). Mean length of juvenile salmon steadily increased from ~40 mm in April to ~100 mm in October–December. Marked Chinook salmon were larger than unmarked Chinook salmon within the three habitat strata on Cottonwood Island from April through July; notably, the length difference decreased from ~100% to ~5% from April through July at the off-channel and main-channel strata.

Northern Pikeminnow in the Vicinity of Cottonwood Island. Twenty-two northern pikeminnow (*Ptychocheilus oregonensis*) were detected in the vicinity of wetland channels on or near Cottonwood Island during the time of operation of PIT-tag detection arrays from May through December 2010. All 22 fish were verified to have been captured, tagged, and subsequently released for the Northern Pikeminnow Management Program, a multi-agency effort administered by the Pacific States Marine Fisheries Commission.[1] Northern pikeminnow had an average residence time of 9.9 days (SE = 31.4 days). Most of the 22 fish were detected between May and June. This time period typically corresponds to high abundances of salmonids within the LCRE, consistent with the beach seine data collected at Cottonwood Island.

Organic Matter, Nutrient, and Plankton Associations for Wetland-Channel, Off-Channel, and Main-Channel Habitat Types at Cottonwood Island. For the water properties measured (i.e., temperature, organic and inorganic suspended sediments, total organic carbon [TOC], nutrients, chlorophyll_*a*, phytoplankton abundance and diversity), results indicate statistically significant differences between months (i.e., seasonal variability) for all habitat strata. However, there were no statistically significant differences noted between sites or habitat strata, with the exception of the Kalama wetland-channel site sampled in September, which exhibited eutrophic characteristics in the water column. The temporal differences were driven largely by phytoplankton abundance, chlorophyll_*a* content, and nutrients.

[1] Personal Communication, December 9, 2010, Erick Van Dyke, Oregon Department of Fish and Wildlife, 17330 SE Evelyn Street, Clackamas, Oregon, 97015; available URL: http://www.pikeminnow.org.

Chlorophyll_*a* and phytoplankton abundance were highest during May of each year, with a decrease in September and an additional reduction in November at all habitat strata. Conversely, nutrient concentrations were generally greater during September (nitrate and phosphate) and November (nitrate), with lower concentrations during the months when phytoplankton abundance was highest. Suspended sediments were composed primarily of the inorganic fraction, and were generally similar between habitat strata and seasons. TOC samples were composed primarily of the dissolved fraction with some variability between strata and season.

<u>PIT-Tag Detections of Salmon and Trout in the Estuary.</u> The single largest source of PIT-tag detections at the study area came from run-of-the-river tagged fish. The PIT-tagged salmonids came from a wide range of release locations including North Toutle River, Little White Salmon River, Deschutes River, Nez Perce Tribal Hatchery, Clearwater River, Rapid River, Sawtooth and Imnaha traps, Lake Wenatchee, Methow River, and Winthrop Hatchery. The results suggest a wide range of species and stocks are associated with shallow-water habitats of the LCRE during their early life phases. The fact that upriver juvenile salmon were in shallow, off-channel habitats of the LCRE implies that they could be available to restored sites in these areas of the landscape. Recoveries of PIT-tagged hatchery and screw trap fish in the Cottonwood Island vicinity wetland channels, purposefully tagged and released for our study, were disappointing with only six fish detected throughout the summer and fall. Tagged hatchery fish were released according to the Kalama Falls Hatchery management schedule, on June 28 and July 13, 2010. No data are available on the physiological condition (e.g., smoltification) of the released fish at the time of release to support interpretations regarding their subsequent migration timing. Kalama Falls fish are reared in relatively cold water and the June 28 through July 13 releases coincided with relatively high water temperatures in the Columbia River. Water temperatures in the Cottonwood off-channel and wetland-channel habitat strata during that time were >16 °C and >19 °C, respectively, at the time of beach seining, which may explain why we detected few tagged salmonids during the period following the Kalama Falls fish releases.

<u>Physiological Correlates of Juvenile Chinook Salmon Habitat Use.</u> Plasma-based (protein and triglyceride concentrations) and composition-based (bioelectrical impedance analysis) indicators of nutritional condition fluctuated both between habitat types and across the sampling period, suggesting a correlative relationship between habitat use and fish condition and pointing to the usefulness of measures of organismal condition for measuring habitat-based benefits associated with restoration activities. Growth potential (RNA:DNA ratio) did not vary temporally or by habitat, and would not be a useful variable for measuring habitat-based benefits associated with restoration activities. Measurements of the primary (plasma cortisol) and secondary (whole-blood glucose and lactate, plasma ions and osmolality) stress response were confounded by capture procedures as well as water temperature, and it is unlikely that any measurement of chronic stress based on environmental conditions could be made dependent on capture protocols. Measurement of reproductive hormones served little value in determining habitat-specific differences because 11-keto testosterone (11-KT) concentrations were homogeneous between habitat types, and no fish had elevated plasma 11-KT concentrations indicative of precocial maturation. The gill Na^+,K^+ -ATPase (NKA) activity of fish indicated that all individuals were undergoing smoltification and actively emigrating, but there were no differences between habitats, which constrained the usefulness of this measurement for determining benefits of habitat use.

Development of Indices for Habitat Connectivity, Life History Diversity, and Survival Benefits:

Expansion of Passage Barrier Accounting for a Habitat Connectivity Index to the Estuary Scale. The passage barrier accounting method is the simplest element of the suite of metrics composing the habitat connectivity index proposed in the first year of this study. The method involves subtraction of passage barriers that have been reduced or removed through restoration activities, from the set of previously existing barriers (i.e., from the baseline set in place at the time of the 2000 Biological Opinion). Expansion of the passage barrier accounting assessment to the reach and estuary scales was more difficult than expected. Obtaining the required data was time-consuming and ultimately not wholly successful because in some cases data needed for the accounting do not exist or cannot be found. Typically, cross-sectional surveys are included in implementation and compliance monitoring requirements associated with restoration activities; therefore, we expected that these data would be available. In fact, two significant obstacles to obtaining the data were discovered during our 2010 effort. First, we found that no single list of all on-the-ground completed restoration projects in the LCRE existed, and thus we needed to create one for this task. Second, data on project-specific restoration activities, and particularly the specifications of passage barrier changes that occurred, are not readily available and we learned from implementers that to date, collection of these data has not always been funded. The project inventory we compiled for dike breaches and other tidal reconnection restorations during the 2000–2010 time frame based on available data is presented in Appendix D.

Improvement of Early Life History Diversity (ELHD) Indices for Juvenile Salmon in the LCRE. After the creation of an innovative ELHD index on this project in 2009, it was necessary to refine the preliminary analyses by incorporating multiple data sets and investigating the applicability of the index under various spatial and temporal scenarios. The 2010 effort focused on the development and investigation of ELHD indices to strengthen and advance the concept of an ELHD index as a high-level monitoring indicator for juvenile salmon. Based on the size and timing of unmarked migrating Chinook salmon, four size categories were designated for the purpose of calculating life history diversity indices: <61 mm, 61–90 mm, 91–120 mm, and >120 mm. Our analyses found that ELHD indices were typically higher for unmarked than marked Chinook salmon, e.g., 0.19 and 0.08, respectively, at Sandy River Delta (SRD) 2008–2009. ELHD indices for the Cottonwood Island area generally were two to three times higher than those for the SRD. At both the Cottonwood Island and SRD areas, ELHD indices for off-channel habitats were higher than those for main-channel habitats, which were higher than wetland channels. For approximately the same time of year, the ELHD for Jones Beach in 1978 (0.63) was comparable to a main-channel site at Cottonwood Island in 2010 (0.71), and was twice that for an SRD 2009 site (0.29). A protocol for the collection of fish data to support ELHD calculations was drafted, which covers study design, data collection, data processing, calculations and analysis, and caveats. Detailed instructions are presented for data collection equipment, deployment, fish handling, catch processing, subsampling, fin tissue for genetic stock identification, ancillary data, and field data sheets.

Retrospective Analysis to Support Development of the Survival Benefits Index. In 2009, it was determined to be unknown whether upstream use of off-channel habitats by juvenile salmon during the outmigration is related to subsequent use of off-channel habitats downstream in the LCRE. Therefore, we undertook a retrospective analysis of 2008 Juvenile Salmon Acoustic Telemetry System (JSATS) studies acoustic-telemetry data from multiple sites in the LCRE to evaluate the proclivity of juvenile salmon to use off-channel migration routes. We found that the numbers and proportions of main-channel and off-channel SRD fish were similar for detections at downstream main-channel and off-channel arrays. There was no relationship between main-channel and off-channel distribution in the SRD and subsequent use of main-channel or off-channel habitat downstream in the Cathlamet Bay and Grays Bay areas.

ES.4 Management Implications

Tools that produce reliable and informative data to assess the effectiveness of restoration are essential to stakeholders and funding agencies in the Columbia Estuary Ecosystem Restoration Program (CEERP). Action-effectiveness data at scales from the site (project) to the entire estuary are required to measure the effects the multi-million dollar restoration effort is having on juvenile salmon and the ecosystems they use in the LCRE. The CEERP's adaptive management process is fueled by action-effectiveness data that are analyzed and evaluated to inform program strategy and action plans. On the Salmon Benefits project, we are developing indices of habitat connectivity, early life history diversity, and survival at the site scale for the most part. The intention, however, is that the index tools be applied estuary-wide, along with data from other monitoring and research projects, to provide information to CEERP decision-makers.

Study Relevance to Existing Management Activities

This study is fulfilling the requirements of Reasonable and Prudent Alternative (RPA) subactions 58.2 and 59.3 in the 2008 Federal Columbia River Power System BiOp:

- Subaction 58.2 – "Develop an index and monitor and evaluate life history diversity of salmonid populations at representative locations in the estuary."
- Subaction 59.3 – "Develop an index of habitat connectivity and apply it to each of the eight reaches of the study area."

Our research also has application to the Expert Regional Technical Group (ERTG) for estuary habitat restoration. The ERTG uses the best available field data on "optimal" salmon densities by habitat type in its method to assign survival benefit units for prospective restoration projects. Based on our beach seine data from Cottonwood Island, optimal fish densities would be ~1.0, 0.5, and 0.1 fish/m^2 for off-channel, wetland-channel, and main-channel habitats, respectively. Over the long-term, the ERTG may examine and contemplate new approaches for assigning survival benefit units to restoration projects. Such work should be informed by the research we are conducting to develop indices for habitat connectivity, early life history diversity, and survival.

Furthermore, our PIT-tag detection results indicate that, contrary to widespread prior understanding, CEERP restoration activities are relevant to upriver stocks. Through our PIT-tag detection results, we noted the presence of upriver (above Bonneville Dam) Columbia River basin stocks in shallow-water habitats off the main channel of the lower Columbia River. This suggests that they could use restored sites in these areas of the landscape despite previously available information suggesting that these migrants tend to move to the Pacific Ocean more quickly than their counterparts from downriver (below Bonneville Dam). This finding generally points to the applicability of CEERP restoration activities to upriver stocks, but further research is needed to determine the proportion of these fish that will use tidal freshwater and estuarine habitats in the LCRE, the potential duration of use of these habitats, and the effects of such habitat use on upriver salmon at individual and population levels.

Future Monitoring and Research

Our research is designed to complement and be integrated with other ongoing monitoring and research studies in the LCRE. These studies, funded mostly by the USACE and Bonneville Power Administration, include Multi-scale Action Effectiveness Research (PNNL/Oregon Department of Fish and Wildlife/U.S. Fish and Wildlife Service [USFWS]/University of Washington [UW]), Tidal Fluvial Research (National Marine Fisheries Service/UW), Julia Butler Hanson (USFWS), Ecosystem Monitoring and Reference Sites (Lower Columbia River Estuary Partnership), and various project-specific action-effectiveness studies. We will continue to coordinate and exchange information with these researchers through the "monitoring and research coordination" meetings within the CEERP process and in meetings for the Anadromous Fish Evaluation Program.

The methods we are developing to index habitat connectivity, early life history diversity, and survival benefits of restoration actions are at different levels of maturity and have various strengths, weaknesses, and areas for improvement. To summarize, indices for habitat connectivity and early life history diversity are maturing and show promise to graduate for regional use in the next year or two. Indexing the survival benefits of restoration is a more challenging endeavor, but near-term research is underway to continue development of the conceptual base and utility of the survival benefits index.

Restoration of connectivity to quality, productive wetland habitats is hypothesized to promote increased life history diversity and survival, and diverse life history patterns promote resilience to environmental perturbations. Restoring reconnections to rearing and refuge habitats in the LCRE to increase life history diversity and the probability that juvenile salmon survive and return as adults will support the resiliency and sustainability of Columbia River basin salmon populations. To do this biologically and cost-effectively, restoration managers need applied research such as indices of habitat connectivity, early life history diversity, and survival. Therefore, the development of methods to measure ecosystem restoration effectiveness in terms of habitat connectivity, life history diversity, and survival by this study is germane.

Acknowledgments

Additional contributors to field data collection included Ron Kaufmann (PNNL) and Richard Glenn, Benjamin Kennedy, Ashley McNamee, James Samagaio, and Will Simpson (USFWS). PIT-tag antenna arrays were engineered by Kurt Steinke and Jerone Anderson (USFWS). Additional data reduction and analysis was performed by Val Cullinan, Kenneth Ham, Jina Kim, and Bill Pratt (PNNL). Fish-tagging operations were greatly assisted by staff from the Washington Department of Fish and Wildlife and the Kalama Falls Hatchery. Erick Van Dyke and Michele Weaver, of the Oregon Department of Fish and Wildlife, provided information about the northern pikeminnow detected at Cottonwood Island and previously tagged by the Northern Pikeminnow Management Program.

Parts of the research reported herein did not include field data collection, and instead relied on collaborative efforts with other concurrent projects to provide the data used for pilot testing. Accordingly, we would like to thank the staff involved with the following projects: 1) Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats in the Lower Columbia River, a Bonneville Power Administration (BPA) project begun in 2007 (BPA 2005-001-00), now transitioned to a USACE Columbia River Fish Mitigation Program project (EST-P-11-NEW); 2) Evaluating Cumulative Ecosystem Response to Habitat Restoration Projects in the Lower Columbia River and Estuary, a CENWP project begun in 2004 (EST-02-P-04); and 3) the Ecosystem Monitoring and Reference Sites projects of the Lower Columbia River Estuary Partnership, funded by the BPA, especially Amy Borde (PNNL). We are grateful for the personal communications by Ian Sinks (Columbia Land Trust), April Cameron and Micah Russell (Columbia River Estuary Study Taskforce), Mike Ott and Amy Gibbons (Corps of Engineers Portland District), and Catherine Corbett, Keith Marcoe, and Evan Hass (LCREP) providing restoration project monitoring data in support of the passage barrier assessment effort during this study year.

The authors appreciate peer review of the report by Dick Ecker, and of an earlier version of Appendix J by Patty Crandell. We thank Susan Ennor, Rose Zanders, Kathy Neiderhiser, and Mike Parker for editing and formatting the report.

Acronyms and Abbreviations

ANOVA	analysis of variance
ArcGIS	ArcInfo Geographic Information System
ATP	adenosine triphosphate
BIA	bioelectrical impedance analysis
BiOp	Biological Opinion
BPA	Bonneville Power Administration
°C	degree(s) Celsius or Centrigrade
CB	Cathlamet Bay
CCC	Carroll's Channel (wetland) channel
CEERP	Columbia River estuary restoration program
CENWP	U.S. Army Corps of Engineers Portland District
CIC	Cottonwood Island wetland channel
CLT	Columbia Land Trust
cm	centimeter(s)
Corps	U.S. Army Corps of Engineers
CRD	Columbia River Datum
CRE	Columbia River estuary
CREST	Columbia River Estuary Study Taskforce
CRITFC	Columbia River Inter-Tribal Fish Commission
DART	Data Access in Real Time
DEM	Digital Elevation Model
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DOC	dissolved organic carbon
DOQ	digital orthophoto quadrangles
D/S	downstream
EDTA	Ethylenediaminetetraacetic acid ($C_{10}H_{16}N_2O_8$)
ELHD	early life history diversity
ERTG	Expert Regional Technical Group
EVA	ethylene vinyl acetate
FCRPS	Federal Columbia River Power System
ft	foot(feet)
g/dL	gram(s) per deca liter

GB	Grays Bay
GIS	geographic information system
GPS	global positioning system
h	hour(s)
ha	hectare(s)
HSD	"Honestly Significantly Different" (Tukey's test)
HUC	Hydrologic Unit Code
ISO	International Organization for Standardization
JB	Jones Beach
JSATS	Juvenile Salmon Acoustic Telemetry System
K^+	potassium
11-KT	11-keto testosterone
kHz	kilohertz
km	kilometer(s)
km^2	square kilometer(s)
µL	microliter(s)
lb	pound(s)
LCR	lower Columbia River
LCRE	lower Columbia River and estuary
LiDAR	Light Detection and Ranging
LRR	Lower River Reaches
m	meter(s)
m^2	square meter(s)
MC	main channel
MDS	multi-dimensional scaling
mg	milligram(s)
mg/dL	milligram(s) per deca liter
mg/L	milligram(s) per liter
mL	milliliter(s)
mm	millimeter(s)
mM	millimolar
mmol/L	millimole(s) per liter
µmol	micromolar

N	nitrogen
NA	not applicable
Na^+	sodium
NAVD88	North American Vertical Datum of 1988
ND	no data
ng/mL	nanogram(s) per milliliter
NH_4	ammonia
NKA	Na+,K+ -ATPase activity
NMFS	National Marine Fisheries Service
NO_2	nitrite
NO_3	nitrate
NOAA	National Oceanic and Atmospheric Administration
NWR	National Wildlife Refuge
OC	off channel
ODLCD	Oregon Department of Land Conservation and Development
OHWM	ordinary high water mark
oz	ounce(s)
P	phosphorus
PDO	Pacific decadal oscillation
PIT	passive integrated transponder
PTAGIS	PIT-Tag Information System
PNNL	Pacific Northwest National Laboratory
PO_4	phosphate
POC	particulate organic carbon
psu	practical salinity unit(s)
PVA	population viability analysis
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
RNA	ribonucleic acid
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
SB	Salmon Benefits
SD	standard deviation
SE	standard error
SiO_4	silicate
SPM	suspended particulate matter
SR	Snake River

SRD	Sandy River Delta
TBD	to be determined
TFM	Tidal Freshwater Monitoring (project)
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended sediments
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
UW	University of Washington
WC	wetland channel
WDFW	Washington Department of Fish and Wildlife
WRDA	Water Resources Development Act

Contents

Figures

Tables

1.0 Introduction

Prepared by Heida Diefenderfer and Gary Johnson

This report describes the 2010 research conducted under the U.S. Army Corps of Engineers (USACE or Corps) project EST-P-09-1, titled Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary. The research in 2010 was conducted by the Pacific Northwest National Laboratory (PNNL), Marine Science Laboratory and Hydrology Group in partnership with the University of Washington (UW), School of Aquatic and Fishery Sciences, Columbia Basin Research; Earl Dawley (NOAA Fisheries, retired); and the U.S. Fish and Wildlife Service (USFWS), Abernathy Fish Technology Center. This research, referred to as the Salmon Benefits project (or study), was started in fiscal year 2009. The primary goal of the study is to establish scientific methods to quantify habitat restoration benefits to listed salmon and trout in the lower Columbia River and estuary (LCRE) in three required areas: habitat connectivity, early life history diversity, and survival. The general study approach was to first evaluate the state of the science regarding the ability to quantify benefits to listed salmon and trout from habitat restoration actions in the LCRE in the 2009 project year, and then, if feasible, in subsequent project years develop quantitative indices of habitat connectivity, early life history diversity, and survival.

1.1 Study Rationale

Restoration of connectivity to quality, productive wetland habitats is hypothesized to promote increased life history diversity and survival (Bottom et al. 2005a; Williams 2006). This was concluded for life history diversity based on studies of marsh restoration in the Salmon River estuary on the central Oregon coast (Bottom et al. 2005b). Diverse life history patterns promote resilience to environmental perturbations (Waples et al. 2009). On this basis, it is thought that restoring reconnections to rearing and refuge habitats in the LCRE to increase life history diversity and the probability juvenile salmon survive and return as adults will support the resiliency and sustainability of Columbia River basin salmon populations. However, to accomplish this biologically and in a cost-effective manner, restoration managers need applied research that is specific to the LCRE in the areas of habitat connectivity, early life history diversity, and survival indices.

This study is fulfilling the following requirements of Reasonable and Prudent Alternative (RPA) subactions 58.2 and 59.3 in the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) (NOAA Fisheries 2008):

- Subaction 58.2 – "Develop an index and monitor and evaluate life history diversity of salmonid populations at representative locations in the estuary."
- Subaction 59.3 – "Develop an index of habitat connectivity and apply it to each of the eight reaches of the study area."

Tools that produce reliable and informative data to assess the effectiveness of restoration are essential to stakeholders and funding agencies in the Columbia Estuary Ecosystem Restoration Program (CEERP). Action-effectiveness data at scales from the site (project) to the entire estuary are required to measure the effects the multi-million dollar restoration effort is having on juvenile salmon and the ecosystems they use in the LCRE (Johnson et al. 2003, 2008). The CEERP's adaptive management process is fueled by action-effectiveness data that are analyzed and evaluated to inform program strategy and action plans (Thom et al. 2011).

We are developing indices of habitat connectivity, early life history diversity, and survival at the site scale for the most part. The intention, however, is that the index tools be applied estuary-wide, along with data from other monitoring and research projects, to provide information to CEERP decision-makers. Our research has application to the Expert Regional Technical Group (ERTG) for estuary habitat restoration, which uses the best available field data on "optimal" salmon densities by habitat type in its method to assign survival benefit units for prospective restoration projects (ERTG 2010). Over the long-term, the ERTG may examine and contemplate new approaches to assign survival benefit units to restoration projects. Such work should be informed by the research we are conducting to develop indices for habitat connectivity, early life history diversity, and survival.

1.2 Study Objectives

The overall objectives of the 4-year study are as follows:

1. Develop and test a quantitative index of juvenile salmon habitat connectivity in the LCRE incorporating structural, functional, and hydrologic components.
2. Develop and test a quantitative index of the early life history diversity of juvenile salmon in the LCRE.
3. Assess and, if feasible, develop and test a quantitative index of the survival benefits of tidal wetland habitat restoration (hydrologic reconnection) in the LCRE.
4. Synthesize the results of investigations into the indices for habitat connectivity, early life history diversity, and survival benefits.

1.3 Background

1.3.1 Study Area

The geographic scope of the project includes the LCRE from Bonneville Dam to the mouth of the river. The entrance propensity study design, developed to assess salmon usage of estuarine habitats (Perry and Skalski 2008) and recommended for assessing survival benefits to outmigrating juvenile salmonids in the 2009 Annual Report for this project (Diefenderfer et al. 2010a), was implemented in 2010 in the Cottonwood Island area of the lower Columbia River, near Longview (Figure 1.1).

Figure 1.1. The Location of Cottonwood Island in the Lower Columbia River

The study area is in tidal freshwater habitat on the Washington side of the river. It was selected based on its representativeness of a variety of habitat strata defined by environmental characteristics, structural connectivity, and perceived functional connectivity, and its proximity to a source of fall Chinook salmon that could be tagged to test the entrance propensity design. Three habitat strata were studied for the effects of habitat connectivity, both structural and functional (water properties and physiological metrics) on salmonid usage: main channel, off-channel, and wetland channel.

1.3.2 Definitions

Based on the 2009 literature review, the following definitions are used in this study:

Habitat connectivity. A landscape descriptor concerning the ability of organisms to move among habitat patches, including the spatial arrangement of habitats (structural connectivity) and how the perception and behavior of salmon affect the potential for movement among habitats (functional connectivity).

Life history. The combination of traits exhibited by an organism throughout its life cycle, and for the purposes of this investigation, a life history strategy refers to the body size and temporal patterns of estuarine usage exhibited by migrating juvenile salmon.

Survival. The probability of fish remaining alive over a defined amount of space and/or time.

Main-channel habitat. A habitat located along the main stem of the lower Columbia River and estuary.

Off-channel habitat. A habitat along channels that does not front directly on the main stem of the L, and instead must be reached by passing behind other landforms such as islands.

Wetland-channel habitat. A habitat along channels that are more confined than off-channel habitats and occur within tidally influenced wetlands (swamps and marshes) of the lower Columbia River and estuary.

Entrance propensity. The proportion of smolts present in the near-field that enter a habitat of interest, in this case off-channel tidally influenced wetlands.

Passage barrier accounting method. Subtraction of the number of passage barriers removed by ecosystem restoration, from the number of passage barriers in the original year-2000 set.

1.3.3 Previous Project Activities and Findings

In January 2009, this study began with the principle that if acceptable methods for indexing habitat connectivity, early life history diversity, or survival benefits existed in the literature, then we would apply the methods to the particular scope of the problem in this region and the target species and age class. If no such methods existed, we would examine the feasibility of the desired measurement or index and, if possible, develop and test new quantitative methods and subject them to independent peer review. Fundamentally, this project is guided by the need to develop and apply quantitative methods for statistical analysis and spatial data processing to evaluate the three subject topics: habitat connectivity, early life history diversity, and survival. The study began with a literature review to specifically define each of the three subject areas. After the review of the state of the science, the study proceeded with an evaluation of relevant existing methods, an assessment of the feasibility of indexing or otherwise measuring the three subject topics, and pilot testing of existing or development of new methods where feasible.

Activities in 2009 included first, a literature review and development and pilot testing of a preliminary index of habitat connectivity. This effort included modification of existing measurement methods for two elements of structural connectivity: passage barrier assessment accounting and nearest-neighbor distance. Second, a literature review and development and pilot testing of a preliminary index of early life history diversity were completed. Binary, matrix-based mathematical methods to index early life history diversity were developed and tested with existing lower Columbia River beach seine data. The early life history diversity index includes three elements: All-Salmon-Length-Month, Species-Month-Length-Habitat, and Stock-Month (for Chinook only). Third, we conducted a literature review and adapted a near-field model statistical design capable of estimating intra-site survival and the probability of site entry for near-shore fish. We completed a comprehensive assessment, summary, and ranking of survival benefit measurement methods, including the strength of inference to salmon survival benefits, potential for results to be confounded, technical feasibility, and cost.

In summary, in 2009, we found that while the measurement of habitat connectivity is a tractable problem, indexing early life history diversity is more challenging, and there are numerous constraints on our ability to measure or index survival benefits associated with habitat restoration in the LCRE, as detailed in the 2009 Annual Report (Diefenderfer et al. 2010a). We recommended a pilot field study to assess the habitat connectivity, life history diversity, and survival or other benefits for juvenile salmonids associated with a habitat restoration action at a tidal wetland site in the lower Columbia River and estuary. On this basis, in 2010, the pilot testing begun in 2009 continued with the addition of a field data collection element, as described in the 2010 Experimental Design and Field Work Plan (Appendix A). Cottonwood Island was selected as the study site, in part because at the time a restoration project was being planned there, and it was thought that before and after data would strengthen the findings; however, at present it appears that those plans have been cancelled. In addition, the Cottonwood Island site had been monitored by other Corps and Bonneville Power Administration (BPA) studies, thereby strengthening the database contributing to our understanding of ecosystem structures and processes there.

1.4 2010 Project Objectives

Based on recommendations from the 2009 study (Diefenderfer et al. 2010a; http://www.nwp.usace.army.mil/pm/e/finalreports.asp), the objectives of the 2010 study were as follows:

1. Develop methods and perform a pilot field and geographic information system (GIS) study to assess the structural and functional habitat connectivity for juvenile salmon of key estuarine habitats associated with habitat restoration actions in the LCRE.
2. Develop methods and perform a pilot field study to assess the early life history diversity of juvenile salmon associated with habitat restoration actions in the LCRE.
3. Develop methods and perform a pilot field study to assess the survival or other benefits for juvenile salmon associated with habitat restoration actions in the LCRE.

1.5 Management Applications

The U.S. Army Corps of Engineers Portland District (CENWP) is involved in ecosystem restoration actions in the LCRE under multiple Water Resources Development Act (WRDA) authorities, and in response to the 2008 BiOp on operation of the FCRPS (NOAA 2008). The region—i.e., USACE, BPA, National Oceanic and Atmospheric Administration (NOAA) Fisheries, resource management agencies, and the research community—will use action-effectiveness data from restoration projects to assess how well the habitat actions are working. This approach is called for in the BiOp, the Northwest Power and Conservation Council's Fish and Wildlife Program, and recovery plans for salmonid populations listed under the Endangered Species Act. Quantitative evaluation methods produced by the study will also inform decisions under other the Corps' WRDA ecosystem restoration authorities applicable to the LCRE. The Action Agencies for the 2008 BiOp are the USACE, BPA, and the Bureau of Reclamation. The Action Agencies submit Annual Progress Reports to NOAA Fisheries in September each year, except 2013 and 2016 when comprehensive evaluations of multi-year implementation activities are required.

The management applications of this project concern the evaluation of salmon habitat restoration project effectiveness in the LCRE (RPA actions 58, 59, and 60), prioritization of new habitat restoration projects and programs (RPA actions 36 and 37), and BiOp reporting, including the first comprehensive reporting due in June 2013 (RPA actions 2 and 3).

1.6 Report Contents and Organization

The ensuing chapters of this report provide a brief synopsis of the methods from field data collection and non-field research (Chapter 2.0). The findings from the appendices are summarized in a short format in Chapter 3.0, Key Results. They are integrated and synthesized relative to management implications in Chapter 4.0, which includes both discussion and recommendations. References for the literature cited in the four chapters of the body of the report are then listed in Chapter 5.0. Each appendix contains a unique reference list for literature cited in the appendix. The abbreviated format of the main body of this report is intended to encourage increased readership, and enable readers to peruse particular appendices that may be of interest depending on their backgrounds and purposes.

In 2010, we investigated uncertainties concerning each of the three indices falling under the purview of this research: habitat connectivity, early life history diversity, and survival benefits. The diversity of this research argued for independent presentation of each piece as a line of evidence in 10 separate appendices, B through K. The rationale, methods, results, and implications of each of these investigations are presented categorized by main topic—habitat connectivity, early life history diversity, and survival benefits. Appendix A contains the 2010 Experimental Design and Field Work Plan developed and finalized by the project team in April 2010 and implemented in April through December 2010. It provides the basis for much of the data analyzed in the subsequent appendices:

- Appendix B – Cottonwood Island Beach Seine Data Collection Report
- Appendix C – Organic Matter, Nutrients, and Plankton Associations for Wetland, Off-Channel, and Main-Channel Habitat Types
- Appendix D – Habitat Connectivity Index Progress Report
- Appendix E – Early Life History Diversity Indices for Juvenile Salmon in the LCRE
- Appendix F – Protocol for Early Life History Diversity Indices
- Appendix G – Retrospective Analysis of 2008 LCRE Acoustic-Telemetry Data to Evaluate the Proclivity of Juvenile Salmon to Use Off-Channel Migration Routes
- Appendix H – Adult and Juvenile Salmonid Abundance and Migration Timing at Bonneville Dam: Estimated Trends, 1980–2009
- Appendix I – Analysis of Estuary PIT-Tag Detections
- Appendix J – Physiological Correlates of Juvenile Chinook Salmon Habitat Use in the Lower Columbia River Estuary
- Appendix K – Review of Estuarine Habitat Inclusion in Salmon Life History Modeling.

2.0 2010 Methods Synopsis

Prepared by Heida Diefenderfer

The primary focus of Salmon Benefits project activities in 2010 was to design a field protocol and perform a pilot field study to assess the survival or other benefits to juvenile salmonids, their early life history diversity, and habitat connectivity associated with key estuarine habitats and habitat restoration actions. Additional research involved continuing theoretical development and pilot testing of quantitative indices of habitat connectivity and early life history diversity.

2.1 The Field Study

The field study was conducted at a long-term, intensively monitored area: Cottonwood Island at Columbia rkm 113 near Longview, Washington, located approximately 6 km downstream of the confluence with the Kalama River (Figure 2.1). The Cottonwood Island site, owned by four Washington ports, is located immediately adjacent to privately owned Howard Island; the channel between the two islands was filled in with emergency disposal of dredged material from the Cowlitz River after the eruption of Mt. St. Helens and the filled channel is now owned by the Washington Department of Natural Resources (personal communication, Steve Vigg, February 23, 2011, Washington Department of Fish and Wildlife, 2108 SE Grand Blvd, Vancouver, WA 98661).

Figure 2.1. Cottonwood Island, Just Upstream (south) of the Confluence of the Cowlitz River and the Columbia River near Longview, Washington

With the extent of past and current sampling that has occurred on Cottonwood Island--and future planned sampling—it may be referred to as an "intensively monitored site." Habitat characteristics of the wetland channel at Cottonwood Island were monitored by the Reference Sites project of the Lower Columbia River Estuary Partnership (LCREP), funded by the BPA, in 2010 and 2011. Beach seining and rapid habitat assessment were conducted at multiple sites on the island by the BPA project, Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats in the Lower Columbia; this project has continued sampling the site into 2011. In addition, beach seining by the CENWP project, Contribution of Tidal Fluvial Habitats in the Columbia River Estuary to the Recovery of Diverse Salmon Evolutionarily Significant Units (EST-P-10-1), began in 2010, and seining and prey data collection by the BPA-funded Ecosystem Monitoring project of the LCREP is expected to begin in 2011.

The Salmon Benefits project team efforts began in 2010 with production of the 2010 Experimental Design and Field Work Plan (completed on March 11, 2010; see Appendix A). The PIT-tag statistical design for survival benefits as reflected by entrance propensity, recommended by J.R. Skalski in the first year of the study (Diefenderfer et al. 2010a), was developed and applied to the Cottonwood Island study area, including fish captured at beach seining sites and fall Chinook salmon from the Kalama Falls Hatchery and Kalama River screw trap. Monthly beach seining at Cottonwood Island began in April, and six paired PIT-tag antenna arrays were deployed at Cottonwood Island in May. Tagged fish were released both from the Kalama Falls Hatchery and in lesser numbers at Cottonwood Island sites to assess entrance propensity (Table 2.1); the total number of tagged hatchery Chinook salmon released at the hatchery was 8,990. Water properties sampling, described in Appendix C, began in May on a seasonal basis and was coordinated with the beach seining activities when possible.

The configuration of Cottonwood Island offered three habitat strata: main channel (Figure 2.2), off-channel (Figure 2.3), and wetland channel (Figure 2.4). The wetland channel, an emergent marsh on the north side of the island, is a historical habitat that was present in the 1800s, but in terms of habitat connectivity this habitat stratum yields the lowest degree of structural connectivity (e.g., distance between habitat patches). The off-channel habitat is also on the north side of the island and is vegetated; it is one step removed in connectedness from the main channel. The main channel is along the south side of the island, barren of vegetation, and composed of recently deposited dredged material; this stratum maintains the greatest degree of structural connectivity.

Table 2.1. PIT-Tagged Chinook Salmon Releases During the 2010 Salmon Benefits Study

Tag/Release Title	Tagging Location(s)	Release Location(s)	Number of Fish/Date
1a. First Hatchery Release	Hatchery	Hatchery	4,491 (6/28/2010)
1b. Second Hatchery Release	Hatchery	Hatchery	4,499 (7/13/2010)
2. Dispersal Release	Hatchery	Cottonwood Is. Seine Sites	100 Hatchery (7/2/10;7/6/10)
3. Direct Wetland Release (2:1 ratio)	Hatchery and Screw Trap	Cottonwood Is. Wetland Channel	111 Hatchery & 49 Screw Trap (6/30/10)
4. Kalama Screw Trap	Screw Trap	Hatchery (below screw trap)	401 (various)
5. Beach Seine	Cottonwood Island	Habitat strata (main channel, off-channel, wetland channel)	291 Monthly Beach Seine

Figure 2.2. The Wetland-Channel Habitat Sampled at Cottonwood Island

Figure 2.3. The Off-Channel Habitat Sampled at Cottonwood Island

The field study plan (Appendix A) integrates multiple metrics measuring the habitat, fish density, and fish condition (Figure 2.3). In addition, complete methods used in developing each type of fish and habitat data are described in associated appendices: beach seine data collection (Appendix B), water properties and plankton (Appendix C), analysis of PIT-tag detections (Appendix I), and physiology (Appendix J).

Figure 2.4. The Main-Channel Habitat Sampled at Cottonwood Island

2.2 Indices

The 2010 research concerned indexing habitat connectivity, early life history diversity, and survival benefits. While pilot-scale testing of these indices for the most part is being conducted at the site scale, all indices have the potential for future application at reach or estuary scales.

2.2.1 Habitat Connectivity

Habitat connectivity index research in 2010 focused on the passage barrier accounting method of assessing changes in habitat connectivity produced by restoration actions in the LCRE (Appendix D). The passage barrier accounting method represents a simple subtraction of the number of passage barriers removed through restoration activities from the total set of passage barriers originally present. For example, using this method we can measure change in passage barriers using four metrics: width of restored passage, area of restored passage, area of habitat made available by the new passage, and percent channel/floodplain habitat area increase. Incorporating the above four metrics into our analysis permitted better resolution of potential change in structural and functional habitat connectivity conditions resulting from ecosystem restoration actions.

The 2010 research expanded the initial 2009 pilot study of passage barriers, which we undertook using readily available data from the Grays River complex (Diefenderfer et al. 2010a), to larger reach and estuary scales in the LCRE. We focused on measurement of the set of passage barriers in existence in 2000 (the year of the original BiOp), and measurement of changes in them as a result of restoration projects funded by the Action Agencies since then, at the estuary scale. While this method is a simplified approach to measuring changes in habitat connectivity, its measurement remains intractable in some ways because of the state of data available about the estuary, as described in Appendix B.

Table 2.2. Salmon Benefits Project Multi-Metric Sampling at Cottonwood Island

Metric/Method	Category	2010 Report Appendix	April 2010	May 2010	June 2010	July 2010	Aug. 2010	Sept. 2010	Oct. 2010	Nov. 2010	Dec. 2010	May 2011
Density, fork length/beach seine	Salmon Presence	B	X	X	X	X			X	X	X	
Tagged fish origin, residence time/PIT-tag antenna arrays	PIT-Tag Detections	I		X	X	X	X	X	X	X	X	
Water level and temperature (HOBO U20 level logger)	Water Quality, Habitat Capacity	(a)	X	X	X	X	X	X	X	X	X	
Plasma protein and triglyceride, bioelectrical impedance analysis	Salmon Physiology (Nutritional Condition)	J	X	X	X	X						
RNA:DNA ratio	Salmon Physiology (Growth Potential)	J	X	X	X	X						
Plasma cortisol, whole-blood glucose and lactate, plasma ions, osmolality	Salmon Physiology (Stress Response)	J	X	X	X	X						
Gill Na+,K+ -ATPase activity	Salmon Physiology (Osmoregulatory Capacity)	J	X	X	X	X						
Phytoplankton abundance and classification, chlorophyll_*a*	Water Properties (biological)	C		X				X		X		X
Total organic carbon (particulate, dissolved), nutrients (NO_3, NO_2, NH_4, TN, PO_4, TP, SiO_4)	Water Properties (organic matter and nutrients)	C		X				X		X		X
Temperature, salinity, DO; suspended sediments (total, organic, inorganic fractions)	Water Properties (physical)	C		X				X		X		X

(a) The complete data set will be downloaded later in 2011, when water levels permit.
DO = dissolved oxygen; NO_2 = nitrate; NO_2 = nitrite; NH_4 = ammonia; PO_4 = phosphate; SiO_4 = silicate; TN = total nitrogen; TP = total phosphorus.

2.2.2 Early Life History Diversity

Continuing research on development of an early life history diversity (ELHD) index for juvenile salmon (Appendix E) involved additional review of the size classes and trials of the draft quantitative indices developed during the first study year, 2009 (Diefenderfer et al. 2010a). The intent of the size class reevaluation effort was to examine the existing literature to determine whether the previously selected size classes accurately represent different life history strategies, or cohorts, of migrating fish in the LCRE. The intent of further trials of the ELHD index was to test various spatial and temporal scenarios to further examine the robustness, sensibility, and usefulness of the indices. For example, four scenarios that incorporated differing elements of space and time are analyzed using the Chinook-Length-Month Index. We also developed an ELHD index protocol to encourage standardized application of this new method throughout the LCRE (Appendix F). The intent of the protocol is to recommend methods to sample, process, and analyze data pertaining to juvenile salmonids that will facilitate calculation of the ELHD indices.

2.2.3 Survival Benefits

Following recommendations of Diefenderfer et al. (2010), we conducted three additional non-field analyses during 2010 using existing data developed by other research projects and programs for cost-efficiency. Using 2008 LCRE acoustic-telemetry data, we evaluated the proclivity of juvenile salmon to use off-channel migration routes, a variant on the entrance propensity model tested in the field, to test the hypothesis that a tendency to enter upper estuary habitats would be predictive of actual entry into lower estuary habitats, to help inform development of methods to evaluate the survival benefits of restoration (Appendix G). Using data from the Columbia River Data Access in Real Time (DART) website, we estimated 1980–2009 trends in adult and juvenile salmonid abundance and migration timing at Bonneville Dam. Finally, we conducted a literature review of the history of inclusion of estuarine habitat in salmon life history modeling, to inform efforts to model effects of restoration of estuary habitats on salmon populations (Appendix K).

3.0 Key Results

The diversity of the research conducted to investigate habitat connectivity, early life history diversity, and survival benefits guided the separate presentation of each line of evidence (detailed in Appendices B through K of this report). The problem statement, research objectives, methods, key results, and management implications associated with the appendices are summarized in the following sections for a quick overview of the contents of this report. The multi-year study objectives (Section 1.2) to which each research effort corresponds are also called out. Key results cover juvenile salmon densities, water properties, passage barrier accounting for habitat connectivity, early life history diversity indices and protocol development, analysis of acoustic-telemetry data relative to off-channel migration routes, PIT-tag detections, and physiological correlates.

3.1 Cottonwood Island Juvenile Salmon Densities

Prepared by Nikki Sather

Problem Statement: Site-specific patterns associated with temporal and spatial densities of juvenile salmon as defined by discrete habitat strata are poorly understood in tidal freshwater portions of the LCRE. The Cottonwood Island site served as a location for developing methods to index habitat connectivity, early life history diversity, and survival benefits of restoration. Specifically, we sought to increase understanding of the patterns associated with the distribution of juvenile salmon within habitat strata of different quality and distance from the main channel.

Multi-Year Study Objectives: 1, 2, 3

Research Objectives: Characterize juvenile salmon species composition, length-frequency distribution, density (#/m^2), and temporal and spatial distributions at wetland-, off-channel, and main-channel habitats of Cottonwood Island.

Methods: Beach seine in shallow-water habitats within three strata: main channel, off-channel, and wetland channel monthly from April through December 2010. Methods were similar to those of Sather et al. (2011).

Key Results:

- Unmarked Chinook salmon were the most abundant salmon captured at Cottonwood Island from April to December 2010 (>67% total salmon catch).
- Over all sampling months, the mean density for juvenile salmon was greatest in the off-channel (~0.26 fish/m^2), followed by the wetland-channel (~0.18 fish/m^2), and finally the main-channel (~0.07 fish/m^2) habitat stratum.
- Salmon density was highest in the wetland during April (~0.6 fish/m^2), the off-channel during May (~1.0 fish.m^2), and the main channel during June (~0.1 fish/m^2).
- There were few differences in the mean size of unmarked Chinook salmon among habitat strata, except in December 2010 when mean fork length in the wetland channel (~42 mm) was noticeably

less than that in main- and off-channel strata (~100 mm). Mean length of juvenile salmon steadily increased from ~40 mm in April to ~100 mm in October–December.

- Marked Chinook salmon were larger than unmarked Chinook salmon within the three habitat strata on Cottonwood Island from April through July; notably, the length difference decreased from ~100% to ~5% from April through July at the off-channel and main-channel strata.

Management Implications and Recommendations: Data collected via direct capture techniques such as beach seining provide key information about the spatial and temporal patterns associated with fish communities in shallow-water habitats. In addition to providing general information about the size and abundance of juvenile salmon, these data provide the foundation for several key elements of the Salmon Benefits research program, including analysis of the ELHD index, inquiry into functional connectivity relative to hydrology and specific water properties, and provision of samples for physiological analysis. Given the useful application of beach seine data to multiple elements of the Salmon Benefits research program, we recommend that beach seine techniques continue to be used, as needed, in subsequent project years.

Reference: Appendix B.

3.2 Organic Matter, Nutrients, and Plankton Associations for Wetland-Channel, Off-Channel, and Main-Channel Habitat Types at Cottonwood Island

Prepared by Dana Woodruff

Problem Statement: A key component in determining diversity in food and habitat quality for juvenile salmon is developing a better understanding of metrics associated with functional connectivity, including those related to water properties that support the base of the food web (e.g., organic matter, nutrients, plankton). In the LCRE, critical gaps remain in the understanding of food web structure and function as they relate to juvenile salmonid growth, fitness, and survival (ISAB 2011).

Multi-Year Study Objectives: 1, 3

Research Objective: Develop and refine collection methods, and collect preliminary data on selected water properties that support the base of the food web (organic matter, suspended sediments, nutrients, and plankton) in three habitat strata (main channel, off-channel, wetland channel).

Methods: Water properties were collected from the Cottonwood Island area at three habitat strata: main channel, off-channel, and wetland channel. Samples were collected seasonally during May, September, and November 2010, and May 2011. Sample analysis methods were similar to those of Woodruff et al. (2011).

Key Results:

- Temporal Scale. Significant differences were observed between the four synoptic sampling events, for most of the water-property metrics. This was particularly evident for temperature, chlorophyll_*a* concentration, phytoplankton abundance, and selected nutrients, and represents the seasonal change in primary production in the estuary.

- Spatial Scale. No significant differences were observed in most of the water-property metrics between the three habitat strata of Cottonwood Island (main channel, off-channel, wetland channel) for any of the four synoptic sampling events (May, September, and November 2010; and May 2011). The metrics analyzed included temperature, salinity, total suspended sediments, chlorophyll_*a*, phytoplankton abundance, and nutrients; and particulate, dissolved and total organic carbon (TOC).

Management Implications and Recommendations: These data can be used to inform project prioritization for restoration efforts in the LCRE. From a temporal perspective, the differences noted between seasons have implications for the timing of peak primary production and its relationship to prey resources and juvenile salmon growth and fitness, which remain to be elucidated through future research. The similarity in results observed between habitat strata—in this case all strata were located around one island in a single reach—illustrates the importance of spatial scale when considering the collection location of water property data. That is, water appears to be well-mixed at this scale despite the presence of different land cover types and plan-form channel morphometry in the three habitat strata; at larger scales, gradients in water properties would be expected, (e.g. salinity, nutrients, organic matter quality) and could be used to inform restoration effectiveness.

Reference: Appendix C.

3.3 Passage Barrier Accounting for a Habitat Connectivity Index

Prepared by Heida Diefenderfer

Problem Statement: Increasing the connectivity of wetland habitats available to juvenile salmon in the LCRE is an objective of the habitat restoration program (Johnson et al. 2003). Measurement methods are needed to assess the effectiveness of the program at achieving increased habitat connectivity.

Multi-Year Study Objective: 1

Research Objective: Conduct a "passage barrier accounting" assessment at the reach and ultimately the estuary scale. In the 2009 first-year annual report of the Salmon Benefits study, we developed this method and successfully pilot-tested it for a single tributary to the LCRE: the lower Grays River floodplain, a tidal freshwater area.

Methods: The passage barrier accounting method is the simplest element of the suite of metrics composing the habitat connectivity index proposed in the first year of this study (Diefenderfer et al. 2010a). The method involves subtraction of passage barriers that have been reduced or removed, through restoration activities, from the set of previously existing barriers (i.e., from the baseline set in place at the time of the 2000 BiOp). Trends in various metrics describing passage barriers were calculated during the pilot test, including change in cross-sectional area of channels, change in top-width of dikes, and change in available connected wetted habitat area in the channels and on the floodplain. Eventually, it is hoped that availability of historical data will be sufficient to calculate the amount of change since an 1800s historical baseline. For instance, it is expected that the 16.4% increase in habitat area from a year-2000 baseline shown by our pilot study of restoration actions at two sites at Grays River is only a small percentage of the historically available wetted area. In 2010, we sought and compiled available data on passage barriers at the estuary scale and passage barrier reduction for all restoration projects in the estuary.

Key Results: Expansion of the passage barrier accounting assessment to the reach and estuary scales was more difficult than expected. Obtaining the required data was time-consuming and ultimately not wholly successful because in some cases data needed for the accounting do not exist or cannot be found. Typically, cross-sectional surveys are included in implementation and compliance monitoring requirements associated with restoration activities; therefore, we expected that these data would be available. In fact, several obstacles to obtaining the data were discovered during our 2010 effort. We found that the record of projects implemented since the 2000 BiOp is structured based on funding. That is, a "project" is a funding instance, not an on-the-ground activity. Thus, in our initial project inventory, we found records of multiple projects associated with single restoration sites. For example, pre-restoration assessments during which no restoration activities occurred were recorded as projects. After reviewing materials from all major sponsors and implementers involved in the restoration program, we found that no single list of all on-the-ground completed restoration projects in the LCRE existed. This finding necessitated a substantial effort to interview project sponsors and implementers individually, to determine where and when restoration actions occurred. Restoration project implementers at Columbia Land Trust, Columbia River Estuary Study Taskforce, and the USACE were very helpful in reorganizing and submitting the requested available data on project-specific restoration activities, and particularly the specifications of passage barrier changes that occurred. However, these data are not readily available and required significant effort on the part of project implementers and the study team to develop. In addition, these data were available for only 29 out of 53 identified passage barrier changes. We learned from implementers that to date, collection of these data has not always been funded. The project inventory we compiled for dike breaches and other tidal reconnection restorations during the 2000–2010 time frame based on available data is presented in Appendix D.

Management Implications and Recommendations: The passage barrier assessment is a straightforward measurement of the expected increase in habitat availability or opportunity for juvenile salmonids resulting from habitat restoration actions undertaken by the Action Agencies in the LCRE. It relies only on data that are produced from the most basic, least expensive type of restoration site monitoring: implementation and compliance surveys. However, these data are not uniformly available in the LCRE. To assess LCRE restoration effectiveness at the estuary scale, a list of completed restoration projects and associated physical dimensions of altered project structures should be systematically collected, co-located, and made readily accessible at the programmatic level. Multiple entities are implementing habitat restoration and programmatic assessment is hindered by the lack of a process for centralized implementation and compliance survey data or higher-order data concerning action effectiveness; e.g., the change in wetted area resulting from habitat restoration actions.

Reference: Appendix D

3.4 Early Life History Diversity Indices for Juvenile Salmon in the LCRE

Prepared by Gary Johnson

Problem Statement: Initial calculations of the ELHD indices (Diefenderfer et al. 2010a) indicate that the approach, which simplifies a suite of metrics into a single numerical value, is reasonable for the purpose of a high-level indicator. Peer-review comments on the concept were supportive of further development of the ELHD indexing approach. However, after the 2009 effort to create an ELHD index, it was necessary to refine the preliminary analyses by incorporating multiple data sets and investigating the applicability of the index under various spatial and temporal scenarios. The 2010 effort focused on the development and investigation of ELHD indices in addition to those originally offered by Diefenderfer et al. (2010a) to strengthen and advance the concept of an ELHD index as a high-level monitoring indicator for juvenile salmon.

Multi-Year Study Objective: 2

Research Objectives: Our first 2010 objective was to reevaluate published literature sources in the context of size classes exhibited by migrating juvenile salmon in shallow-water habitats. This effort was intended to either confirm our original size groupings or provide an empirically based reason for modifying the size classes applied in the length-month ELHD index. Our second objective was to calculate ELHD indices for various scenarios to test the robustness, sensibility, and usefulness of ELHD indices.

Methods: By retaining the overall framework and approach for calculating the ELHD index that was created during the 2009 study effort, we were able to focus on refining key elements included in the calculations as well as applying the indices to an array of spatial and temporal conditions. We reviewed appropriate literature sources, compiled data from the Jones Beach, Tidal Freshwater Monitoring, Salmon Benefits, and other studies, and performed ELHD index calculations. ELHD analysis scenarios were chosen and analyzed using multiple data sets at various spatial and temporal scales.

Key Results: After the results of the size-class assessment, we presented ELHD indices for Chinook salmon from various analytical scenarios:

- Based on the size and timing of unmarked migrating Chinook salmon, four size categories were designated for the purpose of calculating life history diversity indices: <61 mm, 61–90 mm, 91–120 mm, >120 mm.
- ELHD indices were typically higher for unmarked than marked Chinook salmon, e.g., 0.19 and 0.08, respectively, at Sandy River Delta (SRD) 2008–2009.
- ELHD indices for the Cottonwood Island area generally were two to three times higher than those for the SRD.
- At both the Cottonwood and SRD areas, ELHD indices for off-channel habitats were higher than those for main-channel habitats which were higher than wetland-channel habitats.
- For approximately the same time of year, the ELHD for Jones Beach 1978 (0.63) was comparable to a main-channel site at Cottonwood Island 2010 (0.71), and was twice that for an SRD 2009 site (0.29).

Management Implications and Recommendations: A fundamental premise of the LCRE ecosystem restoration effort is that increasing habitat access, quality, and diversity will lead to increased early life history diversity and thereby increase the resiliency of salmon populations to environmental perturbations and aid recovery of depressed stocks (Bottom et al. 2005). The ELHD indices offer a quantitative approach to long-term tracking of life history diversity—over the course of the restoration effort. The estuary-wide effort to restore juvenile salmon habitat requires high-level indicators that managers and decision-makers can use to track progress and adjust strategies. The ELHD indices provide such an indicator for salmon life history diversity.

The ELHD indices are not intended to be used as a tool for evaluating the importance of habitats; however, a study design that incorporates a diversity of habitat types will likely capture the gamut of traits expressed by migrating juvenile salmon. In addition, the scale of ELHD analysis should be considered within the context of specific research needs. Site-scale determination of an ELHD index may have relevance under certain research programs. We, however, recommend a multi-scale approach to monitoring the ELHD of juvenile salmon by determining index values at several locations within the LCRE (e.g., reach and estuary-wide) and through time (e.g., monthly, seasonally, annually) (see Appendix F).

We were able to normalize historic data for applicability in calculating the ELHD index that was created within the context of contemporary data collection methodologies. We recommend incorporating other data collected within the LCRE, while recognizing that disparate sampling techniques may have the potential to introduce confounding factors in ELHD indices. Implementation of ELHD index calculations across sampling programs in the LCRE may require minor modifications to the algorithm.

Reference: Appendix E.

3.5 Protocol for Early Life History Diversity Indices

Prepared by Nikki Sather

Problem Statement: Standardized application of ELHD indices requires a protocol for data collection, processing, and analysis.

Multi-Year Study Objective: 2

Research Objective: Develop a protocol for early life history diversity indices.

Methods: The monitoring protocol was structured based on the protocols of Roegner et al. (2009). Detailed methods for collecting and processing juvenile salmon samples were modified from Sather et al. (2011). The analysis method was based on Diefenderfer et al. (2010a).

Key Results: A protocol was drafted that covered study design, data collection, data processing, calculations and analysis, and caveats. Detailed instructions were presented for data collection equipment, deployment, fish handling, catch processing, subsampling, fin tissue for genetic stock identification, ancillary data, and field data sheets.

Management Implications and Recommendations: The ELHD protocol will ensure comparability of results at multiple spatial and temporal scales. As mentioned above, the ELHD indices provide a high-level indicator that managers and decision-makers can use to track progress and adjust strategies in the estuary-wide effort to restore juvenile salmon habitat. We suggest concurrent application of ELHD protocols and the ELHD index, as indicated above, at multiple scales to monitor the ELHD of juvenile salmon in the LCRE. In addition, we recommend dissemination of the protocol via regional outreach (e.g., research coordination meetings, science workgroups, etc.).

Reference: Appendix F

3.6 Retrospective Analysis of 2008 LCRE Acoustic-Telemetry Data to Evaluate the Proclivity of Juvenile Salmon to Use Off-Channel Migration Routes

Prepared by Gary Johnson

Problem Statement: It is unknown whether upstream use of off-channel habitats by juvenile salmon during the outmigration is related to subsequent use of off-channel habitats downstream in the LCRE.

Multi-Year Study Objectives: 1, 3

Research Objective: Perform a pilot analysis of a landscape-scale approach to evaluate the proclivity of juvenile salmon to use off-channel migration routes.

Methods: Data were obtained from JSATS studies in the LCRE conducted during 2008 at the SRD (~rkm 196), Grays and Cathlamet bays (GB and CB at ~rkm 38), and associated main-channel areas. We calculated proportions of the total number of SRD main-channel fish detected in downstream main-channel and off-channel areas (CB and GB). Analogously, we calculated the proportions of the total number of SRD off-channel fish detected in downstream main-channel and off-channel areas.

Key Results: The numbers and proportions of main-channel and off-channel SRD fish were similar for detections at downstream main-channel and off-channel arrays. There was no relationship between main-channel and off-channel distribution in the SRD and subsequent use of main-channel or off-channel habitats downstream in the CB and GB area.

Management Implications and Recommendations: This information will inform development of methods used to evaluate the survival benefits of restoration. The limited nature of the results may be attributed to the acoustic-tag technology currently in use. We recommend engineering next-generation acoustic tags to monitor subyearling salmon movements in and survival through the estuary.

Reference: Appendix G

3.7 PIT-Tag Detections in the Estuary

Prepared by John Skalski

Problem Statement: Little is known about which fish stocks use the estuary environment during smolt migration, or their origins in the Columbia River basin. This information is needed to substantiate the value of ecosystem restoration in the LCRE to upriver stocks.

Multi-Year Study Objectives: 1, 2, 3

Research Objective: Evaluate the feasibility of using PIT-tag detection arrays to passively detect outmigrants as they move through and use the near-shore, shallow-water environments in the lower Columbia River.

Methods: Six autonomous 40-ft PIT-tag detection arrays were placed in an off-channel habitat in the vicinity of Cottonwood Island. These arrays were used to continuously monitor for PIT-tag detections from May to 13 December 2010.

Key Results: The single largest source of PIT-tag detections at the study area came from run-of-the-river tagged fish. A total of 56 such fish were detected. Of these fish, 30 were salmonids, 22 northern pikeminnows, and four were without PIT-Tag Information System (PTAGIS) release records. Salmonids were detected between May and the middle of August. Northern pikeminnow presence overlapped the occurrence of salmonid smolts. The salmonids had an average residence time of 8.9 hours (SD = 26.1 hours), while northern pikeminnow had an average residence time of 9.9 days (SE = 31.4 days). All northern pikeminnow were tagged and released in the vicinity of the study area. The PIT-tagged salmonids came from a wide range of release locations including North Toutle River, Little White Salmon River, Deschutes River, Nez Perce Tribal Hatchery, Clearwater River, Rapid River, Sawtooth and Imnaha traps, Lake Wenatchee, Methow River, and Winthrop Hatchery. The results suggest a wide range of species and stocks are associated with shallow-water habitats of the LCRE during their early life phases.

Management Implications and Recommendations: This study suggests the feasibility of using PIT-tag detection arrays in the LCRE to monitor relative usage over time, as ecosystem restoration progresses, during which time salmonid stocks are expected to recover. However, to implement the entrance propensity design we recommend that the low detection probabilities and the environmental challenges of implementing PIT-tag antenna arrays in tidal wetlands of a large river (tides, turbidity, channel span, seasonal hydrograph, and salinity) be considered.

Reference: Appendix I.

3.8 Physiological Correlates of Juvenile Chinook Salmon Habitat Use in the Lower Columbia River Estuary

Prepared by Kyle Hanson

Problem Statement: Diefenderfer et al. (2010a) suggested that physiological metrics might be useful indicators of survival benefits to juvenile salmon from habitat restoration within the LCRE. However, there is a paucity of research on physiological measurements from juvenile salmon collected in the LCRE.

Multi-Year Study Objective: 3

Research Objectives: Determine whether suites of physiological indicators representative of organismal condition, stress response, and smoltification can indicate benefits to emigrating juvenile Chinook salmon greater than 80 mm in length (and mostly of hatchery origin) conferred by LCRE habitat use (main channel vs. off-channel).

Methods: To determine the physiological correlates of habitat use within the estuary, Chinook salmon were collected from three habitats (wetland channel, off-channel, and main channel) at Cottonwood Island in the LCRE. Due to an inability to capture fish of a sufficient size for physiological sampling (more than 80 mm in length) in the wetland channel, analyses were restricted to only fish from the off-channel and main-channel habitats. Blood samples and a small gill biopsy were taken from fish of a sufficient size for physiological sampling (more than 80 mm in length) over a 3-day period each month from April through July. A subset of fish in May and June were subjected to lethal sampling for bioelectrical impedance analysis (BIA) to determine overall body composition and muscle biopsy for RNA:DNA ratio analysis of growth potential. Samples were then analyzed to evaluate the usefulness of suites of physiological indicators representative of organismal condition (plasma triglycerides, plasma protein, condition factor, BIA, RNA:DNA ratio), stress response (whole blood glucose, whole blood lactate, plasma cortisol, plasma ions, plasma osmolality, hematocrit), precocial maturation (plasma 11-keto testosterone [11-KT]), and smoltification (gill Na^{+},K^{+} -ATPase activity [NKA]).

Key Results: Plasma-based (protein and triglyceride concentrations) and composition-based (BIA) indicators of nutritional condition fluctuated both between habitat types and across the sampling period, suggesting a correlative relationship between habitat use and fish condition and pointing to the usefulness of measures of organismal condition for measuring habitat-based benefits associated with restoration activities. Growth potential (RNA:DNA ratio) did not vary temporally or by habitat, and would not be a useful variable for measuring habitat-based benefits associated with restoration activities. Measurements of the primary (plasma cortisol) and secondary (whole-blood glucose and lactate, plasma ions and osmolality) stress response were confounded by capture procedures as well as water temperature, and it is unlikely that any measurement of chronic stress based on environmental conditions could be made dependent on capture protocols. Measurement of reproductive hormones served little value in determining habitat-specific differences because 11-KT concentrations were homogeneous between habitat types, and no fish had elevated plasma 11-KT concentrations indicative of precocial maturation. The gill NKA activity of fish indicated that all individuals were undergoing smoltification and actively emigrating, but there were no differences between habitats, which constrained the usefulness of this measurement for determining the benefits of habitat use.

Management Implications and Recommendations: This study showed that physiological monitoring may be used to evaluate habitat quality in juvenile salmonids, although there is still the need to further clarify the causal mechanism that links habitat characteristics to organismal condition in juvenile salmonids. To monitor habitat quality through physiological status, managers should focus on the deployment of handheld meters such as BIA analyzers to the field because the use of these devices requires little training and they produce data in real time. While future research is required to elucidate the functional mechanism by which the quality of restored habitats can increase organismal condition in juvenile salmonids, integration of physiological monitoring into ecological restoration plans could provide Action Agencies with quantitative measurements of the success of restoration activities.

Reference: Appendix J.

4.0 Discussion and Recommendations

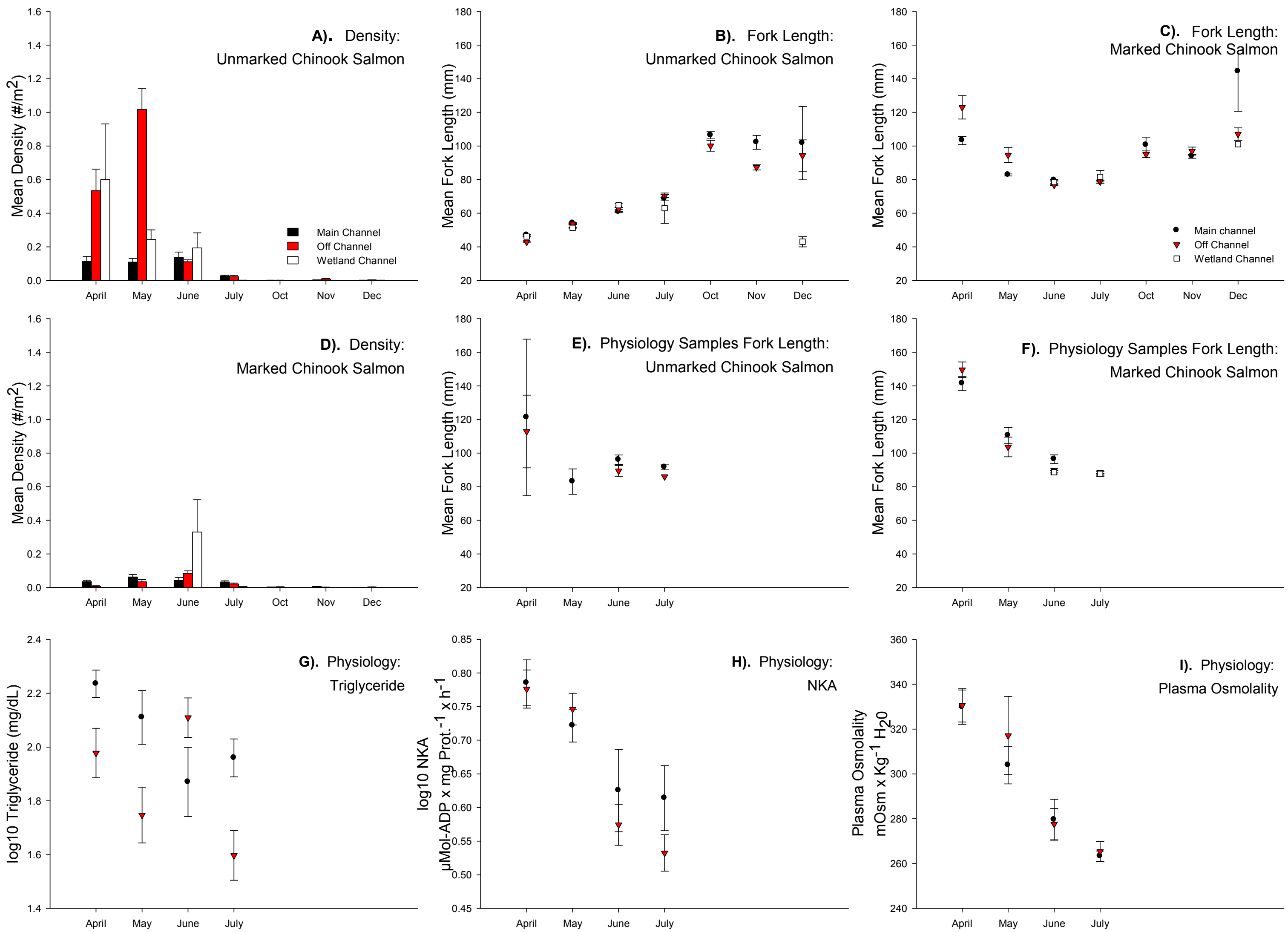
Prepared by Heida Diefenderfer, Gary Johnson, Earl Dawley, and Nikki Sather

This chapter discusses the field and non-field research into the development of standard indices for the effects of ecosystem restoration on improvement of salmon habitat connectivity, early life history diversity, and survival, which was conducted by the Salmon Benefits project in 2010. This chapter integrates findings from multiple appendices to provide a greater synthesis of the results and their implications. It concludes with recommendations and management implications.

4.1 The Field Study

During 2010, we collected a coordinated, intensive suite of measurements of juvenile salmon and their ecosystems in the Cottonwood Island area (rkm 113) of the lower Columbia River to help build the scientific foundation for assessment of the benefits of ecosystem restoration. The study was designed to compare metrics across three distinct habitats types—wetland channel, off-channel, and main channel—with the intent to inform development of high-level indices of restoration effectiveness that managers can use to make restoration program decisions. Even though the study site at Cottonwood Island was not itself being restored, the results and experiences gained from the research will be applicable to restoration effectiveness research methodologies because of their basis in restoration ecology. The 2010 data are synthesized in Figure 4.1.

We found that, overall, mean density for juvenile salmon was greatest in the off-channel, followed by the wetland-channel, and finally the main-channel habitat strata (Appendix B). There were few differences in the mean size of unmarked Chinook salmon between habitat strata. However, the distribution of unmarked Chinook salmon differed in that a higher proportion of small sizes (e.g., <60 mm) were captured in the wetland and off-channel habitats compared with the main channel. The ELHD index was comparable between the off-channel and main-channel habitats (0.57–0.66), which was about three times higher than the index for the wetland-channel habitat (0.21–0.27) (Appendix E). Fish physiology metrics generally declined from spring to summer 2010 with no discernable patterns between the off-channel and main-channel sites (Appendix J). The wetland-channel sites were excluded from the physiological analyses because fish captured in this habitat stratum were not large enough to be used for the selected metrics. Water temperature was comparable among the sites (except for higher temperatures in the wetland in summer), and showed the typical increase in spring and early summer, and a summertime peak followed by a decline in later summer and fall (Figure 4.1M). Water properties (organic and inorganic suspended sediments, TOC, chlorophyll_*a*, phytoplankton abundance and diversity) were not statistically different among the habitat types, with the exception of one eutrophic wetland channel in September (Appendix C).


A). Density:
Unmarked Chinook Salmon
Mean Density (#/m^2)
Main Channel
Off Channel
Wetland Channel
B). Fork Length:
Unmarked Chinook Salmon
Mean Fork Length (mm)
C). Fork Length:
Marked Chinook Salmon
Mean Fork Length (mm)
Main channel
Off Channel
Wetland Channel
D). Density:
Marked Chinook Salmon
Mean Density (#/m^2)
E). Physiology Samples Fork Length:
Unmarked Chinook Salmon
Mean Fork Length (mm)
F). Physiology Samples Fork Length:
Marked Chinook Salmon
Mean Fork Length (mm)
G). Physiology:
Triglyceride
log10 Triglyceride (mg/dL)
H). Physiology:
NKA
log10 NKA
µMol-ADP x mg Prot.$^{-1}$ x h^{-1}
I). Physiology:
Plasma Osmolality
Plasma Osmolality
mOsm x Kg^{-1} H$_2$0
April
May
June
July
Oct
Nov
Dec

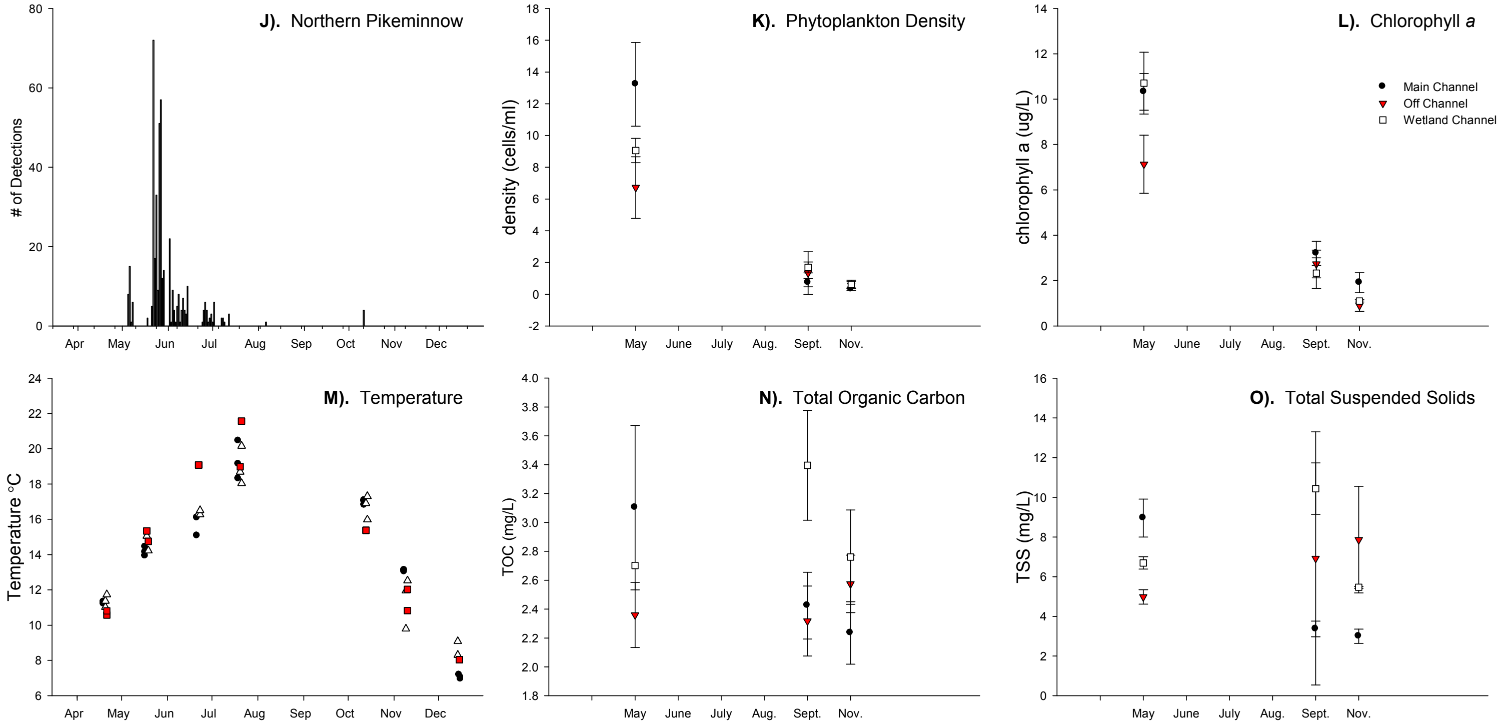


Figure 4.1. Monthly Results of Cottonwood Island Multi-Metric Sampling. (a) Beach seine collections of unmarked Chinook salmon at three habitat strata (with standard error) indicate decreasing use of the wetland channel from April through June, relatively consistent and low use of the main channel, and a use pattern for the off-channel habitat that peaked in May. (b) Unmarked Chinook salmon fork length increased from spring through winter months. (c) Marked Chinook salmon were larger than their unmarked counterparts as indicated by mean fork lengths from April through July. (d) Beach seine collections of marked Chinook salmon yielded densities that were smaller compared to unmarked Chinook salmon, except during the month of June in the wetland channel. (e) Unmarked Chinook salmon fork length of physiology samples. (f) Marked Chinook salmon fork length of physiology samples. Physiology measures of marked salmon captured in beach seines between April and July (with standard error) include (g) triglycerides, (h) NKA, and (i) plasma osmolality. (j) Detected numbers of northern pikeminnow were concentrated between May and July with a peak in June. For water properties (with standard deviation), there was a significant difference in phytoplankton density (k) and chlorophyll_*a* concentration (l) between May and the fall months of September and November. (m) Temperatures in all habitat strata showed consistent trends upward from April through August and downward in the fall, and exceeded 16 °C in all strata in mid-summer. No clear seasonal patterns were observed in (n) total organic carbon or (o) total suspended solids. The Kalama wetland site exhibited significantly higher concentrations of all water property metrics shown here during the month of September, characteristic of eutrophic conditions, and for this reason is not included in this figure (see Appendix C).

The trends observed from the beach seine data collection effort at Cottonwood Island during 2010 were similar to those reported by others within various locations of the LCRE. Large abundances of small (<60 mm), unmarked Chinook salmon typically dominate catches from spring through early summer in tidal freshwater habitats (Roegner et al. 2008; Sather et al. 2011). Densities of marked, hatchery Chinook salmon were lower than unmarked Chinook salmon at most Cottonwood Island strata, a trend that has also been reported by Sather et al. (2011) within various shallow-water habitats of the LCRE. In terms of size (as measured by fork length) Chinook salmon captured in shallow-water habitats typically exhibit a pattern of increased growth that begins during late winter as fry migrate through the LCRE (Roegner et al. 2008; Sather et al. 2011). The mean fork length for unmarked Chinook salmon captured at Cottonwood Island follows this general trajectory; however, the sizes of marked Chinook salmon follow a much different pattern. In addition to being less abundant in shallow-water habitats near Cottonwood Island, marked Chinook salmon were larger during the spring and summer sampling periods, compared with unmarked Chinook salmon. Differences in size between marked and unmarked Chinook salmon were generally less apparent during fall months. The co-occurrence of larger hatchery fish with smaller unmarked salmon during winter and spring has been observed by others sampling similar habitats within the LCRE (Sather et al. 2009, 2011).

Water temperature increased at the Cottonwood Island beach seine sites from April through July and decreased from October through December. This seasonal trend emulates the overall trend in water temperature within the main-stem Columbia River (Columbia River DART 2010). The higher temperatures recorded during June and July corresponded with a precipitous decrease in the abundance of unmarked Chinook salmon captured at Cottonwood Island. Storch et al. (2011) noted that modeled growth of unmarked Chinook salmon was reduced in shallow-water habitats in the vicinity of the SRD during sustained periods of high temperature. Increased water temperatures (>19 °C) likely caused unsuitable habitat conditions for juvenile salmon, which may explain the reduced abundance observed at Cottonwood Island during summer months.

4.1.1 Detections of PIT-Tagged Kalama Falls Hatchery Salmon

Recoveries of PIT-tagged hatchery and screw trap fish in the Cottonwood Island vicinity wetland channels (Figure 4.2), purposefully tagged and released for our study, were disappointing with only six fish detected throughout the summer and fall (Appendix I). Tagged hatchery fish were released according to the Kalama Falls Hatchery management schedule on June 28 and July 13, 2010. No data are available on the physiological condition (e.g., smoltification) of the released fish at the time of release to support interpretations regarding their subsequent migration timing. Kalama Falls fish are reared in relatively cold water and the June 28 through July 13 releases coincided with relatively high water temperatures in the Columbia River. Water temperatures in the Cottonwood off-channel and wetland-channel habitat strata during that time were >16 °C and >19 °C, respectively, at the time of beach seining (Figure 4.1B). Likely as a result, we detected few tagged salmonids during the period following the Kalama Falls fish releases. Thus, the test of the entrance propensity study design using PIT-tagged fish was inconclusive. Tag recoveries at the East Sand Island bird colonies (personal communication, Scott Sebring, Pacific States Marine Fisheries Commission, P.O. Box 155, Hammond OR. 97121) provided the largest number of detections from this study—373 from the first 4,491 fish hatchery release, 220 from the second 4,499 fish hatchery release, and 20 yearling Chinook from the 547 fish tagged from the Kalama River screw trap. These data indicate most Kalama hatchery fish may have moved readily downstream with only a few using shallow-water habitats in the Cottonwood Island study area. Also, low PIT-tag detection rates could be explained by the poor detectability of the PIT-tag antenna arrays due to their location, orientation, and relatively large expanse of area to sample.

Figure 4.2. PIT-Tag Antenna Arrays at (a) Cottonwood Island (CIC) and (b) Carroll's Channel (CCC)

4.1.2 Detections of PIT-Tagged Salmon Beach-Seined at Cottonwood Island

Of the 291 fish captured in beach seines at Cottonwood Island, tagged, and subsequently released, 13[1] were detected again at the PIT-tag antenna arrays (4.5%). Nine Chinook salmon were detected at the Cottonwood Island array (3%), and four Chinook salmon were detected at the mainland array (1%). Seven of the 13 detected fish were limited to a single detection event. The remaining six Chinook salmon were detected over a time period that ranged from 4 to 11 days. Of these fish, most of detection events occurred during the month of June. The longest residence time for a Chinook salmon occurred during July (11 d), which was exhibited by a single fish. Evaluation of residence time, directionality, and movement of PIT-tagged Chinook salmon was challenging due to low detection rates as well as the spatial arrangement of the PIT-tag antenna arrays that did not span the entire width of the channels. One explanation of the lack of detections of PIT-tagged fish known to be in the study area is the poor detectability of the PIT-tag antenna arrays mentioned above.

4.1.3 Detections of PIT-Tagged Salmon from Upriver Release by Others

The proportions of endangered juvenile salmonids from the interior Columbia basin (upriver from Bonneville Dam) observed to use shallow-water habitats in the Columbia River estuary are smaller than proportions from salmon populations west of the Cascades (Dawley et al. 1986; Roegner et al. 2009; Johnson et al. 2010; Sather et al. 2011). On this basis, during development of the research plan to assess use of shallow-water environments by juvenile salmonids and the study design for entrance propensity (Appendix A), we surmised that too few PIT-tagged juvenile fish from the interior would be observed in a study of this scale to draw substantive conclusions about interior-origin salmon. Therefore, we selected juvenile fall Chinook salmon from Kalama Falls Hatchery as the target because of a known history of long-duration use of the estuary prior to entering the ocean as subyearlings (Reimers and Loeffel 1967; Dawley et al. 1986). With rather modest numbers of marked fish we assumed there would be sufficient detections of PIT-tagged fish to provide statistically significant observations of shallow-water habitat use; however, as described above, water temperatures in the wetland channels in the vicinity of Cottonwood Island at the time of Kalama Falls Hatchery releases and PIT-tag antenna array detectability may have influenced the resulting exceedingly low detection rates.

In contrast, during the springtime, the water temperature did not inhibit salmonid residence at sites with the PIT-tag detectors (Figure 4.1M) and a noticeable number of salmonids from above Bonneville Dam were detected. Of all the juvenile salmonids detected at the two shallow-water wetland sites in the Cottonwood Island vicinity, we observed that 13.5% (seven[2]) were from the Snake River basin (one spring, two summer, two fall, and two unknown). Snake River juvenile Chinook salmon, as determined by genetic stock identification, have also been detected by other studies within shallow-water areas of the estuary. These detections have included a range of sampling locations spanning several reaches (ie. reaches A-E, and G) within the LCRE. The genetic analysis has indicated Snake River juvenile Chinook salmon collected within estuarine habitats comprised approximately three percent of the samples collected for each study (LCREP/LCRFRB 2004, Roegner et al. 2009, Sather et al. 2011).

[1] One of the tags in this category of fish received secondary handling and therefore was not included in the analysis in Appendix I.

[2] Two Snake River basin adults were also detected and are included in the analysis in Appendix I.

To better understand the observed difference between PIT-tag detection percentages (13.5%) and genetics data (~3%), we partitioned numbers of PIT-tagged fish released in four river reaches: Lower-, Mid-, and Upper-Columbia, and the Snake River. The Upper Columbia and Snake river releases were adjusted for survival to Bonneville Dam (NOAA Fisheries 2010). We then assessed differences of detection percentages for the four reaches (Table 4.1). It became clear that the distribution of PIT tags released was heavily skewed, and that the difference between genetics analysis and PIT-tag detections was an artifact of tagging practices. We calculate that the greatest percentages of detections in relation to releases were lower river fish from the Bonneville Pool and downstream of Bonneville Dam as was observed by Sather et al. (2011) and Roegner et al. (2009).

4.1.4 Detections of PIT-Tagged Northern Pikeminnow

Twenty-two northern pikeminnow were detected in the vicinity of wetland channels on or near Cottonwood Island during the time of operation of PIT-tag detection arrays from May through December 2010. Nearly equal numbers of these fish were detected at the two primary detection array sites: 13 at Cottonwood Island Channel and 12 at Carroll's Channel on the mainland (three fish were detected at both sites). There were a total of six arrays, one in the Cottonwood Island wetland channel and two immediately outside, and two in the Carroll's wetland channel and one immediately outside (Figure 4.2). At Cottonwood Island, 7 unique tag detections occurred in the wetland channel and 13 in the off-channel habitat outside it. At Carroll's channel, no northern pikeminnow were detected in the wetland channel and 14 unique detections occurred in the off-channel habitat outside it. All 22 fish were verified to have been captured, tagged, and subsequently released for the Northern Pikeminnow Management Program, a multi-agency effort administered by the Pacific States Marine Fisheries Commission (personal communication, Erick Van Dyke, December 9, 2010, Oregon Department of Fish and Wildlife, 17330 SE Evelyn Street, Clackamas, Oregon, 97015; available URL: http://www.pikeminnow.org). This program tags northern pikeminnow longer than 200-mm fork length.

Information provided by the Northern Pikeminnow Management Program (personal communication, Erick Van Dyke, December 9, 2010) indicates that the northern pikeminnow identified in the Cottonwood Island wetland channel were all captured below Bonneville Dam in the month of April during four sample years: 1 fish in 2006, 3 fish in 2008, 3 fish in 2009, and 15 fish in 2010 (Table 4.2). Furthermore, while the combined group of northern pikeminnow was released after tagging from a fairly wide area of the main-stem Columbia River, ranging from Abernathy Creek (River mile 54) to The Fishery Boat ramp (River mile 134), most (45%) were released in the area between Cottonwood Island and lower Sandy Island.

Most of the 22 fish were detected between May and June (Figure 4.1J). This time period typically corresponds to high abundances of salmonids within the LCRE, consistent with the beach seine data collected at Cottonwood Island (Figure 4.1A). It appears that northern pikeminnow had primarily moved out of the wetland channels by August, with a single additional detection in the fall; however, the PIT-tag antenna arrays were operated from the island and did not entirely cover the mouth of the channels, so only fish movements nearer to the shore were recorded.

Table 4.1. PIT-Tag Releases of Juvenile Salmonids in Columbia River Subbasins for 2010, Compared to Detections in Two Shallow Water Embayments in the Vicinity of Cottonwood Island (rkm 113); with Adult Salmonid Detections

Lower Columbia rkm 0-233		Mid-Columbia rkm 234-470		Upper Columbia rkm 471-875		Snake River rkm 522 plus SR km	
Release no.	Detections @ rkm 113	Release no.	Detections @ rkm 113	Release no.	Detections @ rkm 113	Release no.	Detections @ rkm 113
Chinook Spring							
28,481	0	101,022	0	139,067	0	395,061	1
Chinook Summer							
0	0	4	0	173,848	1	117,759	2
Chinook Fall							
21,348[(a)]	30[(a)]	46,050	12	42,760	0	591,475	2
Chinook Unknown							
12,586	0	11,812	1	1,429	0	193,828	2
Coho							
9,369	0	428	0	58,127	0	185	0
Steelhead							
7,136	0	47,280	0	160,229	1	328,695	0
Sockeye							
910	0	3,779	0	31,573	0	65,441	0
Total juvenile releases and detections							
58,482	30	210,375	13	607,033	2	1,692,444	7
% detected in relation to release no.							
	0.0513		0.0062		0.0002[(b)]		0.0002
Adult Steelhead							
			1		1		2
Adult Sockeye							
					1		

(a) Kalama Falls Hatchery, Kalama River, and Cottonwood Island beach-seined fish are the origin of the 9,945 fish released and 27 of the detections.
(b) Release numbers adjusted for transport and in-river survival (NOAA Memo 2010).

Table 4.2. Northern Pikeminnow Tagged by the Northern Pikeminnow Management Program and Detected in the Wetland Channel at Cottonwood Island. (Courtesy of the Pacific States Marine Fisheries Commission Northern Pikeminnow Management Program and the Oregon Department of Fish and Wildlife)

CIC:	Date PIT-Tagged	River Mile	Fork Length (mm)
1BF229903D	4/17/2006	54	354
1C2C3208D6	4/21/2009	70	340
1C2C37EB0F	4/22/2009	84	295
1C2C3CB933	4/22/2009	84	234
1C2CFE881B	4/21/2010	70	294
1C2CFE4AC6	4/21/2010	73	386
1C2CFE8669	4/21/2010	71	359
1C2CFE785A	4/21/2010	74	335
1C2CFDF865	4/22/2010	70	344
1C2CFD869D	4/21/2010	71	277
CCC:			
1C2C3CF768	4/22/2008	133	461
1C2C2FCD07	4/21/2008	78	310
1C2C3392FC	4/14/2008	61	460
1C2CFE6A4B	4/26/2010	132	450
1C2CFDFFBC	4/26/2010	134	387
1C2CFE9494	4/3/2010	122	505
1C2CFE903D	4/21/2010	71	323
1C2CFD6DD6	4/22/2010	84	301
1C2CFE5F13	4/21/2010	70	334
1C2CFE9F4B	4/22/2010	70	335
1C2CEF97CD	4/20/2010	64	360
1C2CF0CA02	4/20/2010	64	441

4.2 Indices

This study focused on the benefits of LCRE ecosystem restoration to juvenile salmon using three interrelated subjects: habitat connectivity, early life history diversity, and survival (Figure 4.3). Following the strategy put forth by Simenstad and Cordell (2000), it is key that connectivity to quality habitats be restored to support salmon functionality; i.e., the habitat access-quality-function linkage. The CEERP is applying this basic strategy (Thom et al. 2011). In our view, habitat connectivity is the foundation upon which increased early life history diversity and survival are built. A diversity of habitats should help foster a diversity of life history types and improve chances of surviving to adulthood and population resiliency (Waples et al. 2009). Therefore, methods to measure ecosystem restoration effectiveness in terms of habitat connectivity, life history diversity, and survival are germane.

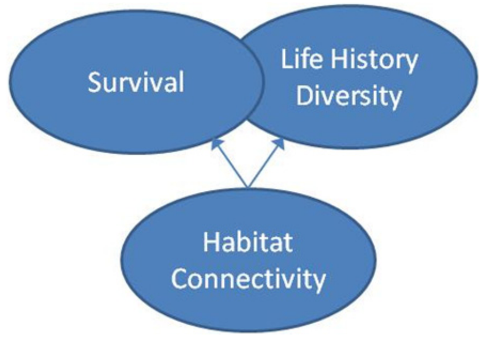


Figure 4.3. Interrelationships Among Habitat Connectivity, Life History Diversity, and Survival in the Context of LCRE Ecosystem Restoration

The methods we are developing to index habitat connectivity, early life history diversity, and survival benefits of restorations are at different levels of maturity and have various strengths and weaknesses and areas for improvement (Table 2.1). To summarize, indices for habitat connectivity and early life history diversity are maturing and show promise to graduate for regional use in the next year or two. Indexing the survival benefits of restoration is a more challenging endeavor.

Table 4.3. Summary of Status, Strengths and Weaknesses, and Recommendations for Indices of Habitat Connectivity, Life History Diversity, and Survival

	Habitat Connectivity	Life History Diversity	Survival
Status	Potential methods evaluated and priority identified; needs further technical development and testing; release to region in 2012	Method developed; results from trial scenarios presented in this report need peer-review; release to region in 2012	Potential methods still being investigated; both indirect and direct approaches are being scrutinized; release to region unknown at this time
Strengths	Quantitative; comparable across sites; can be applied estuary-wide; potential to become a high-level indicator	Simple, straightforward; comparable over space and time (carefully); high-level indicator useful to managers	TBD
Weaknesses	Requires savvy GIS user; availability of elevation data; availability of historical baseline; availability of shallow-water habitat model to assess flow conditions; more data on juvenile salmon behavior is needed	Does not account for fish density; lack of available juvenile salmon data collected in accordance with ELHD protocol (Appendix F)	TBD
Recommendations	Complete the prototype; beta test with new users; convene a workshop to disseminate	Peer-review 2010 results; account for fish density; use a multi-scale approach to monitor the ELHD at several locations within the LCRE (e.g., reach) and times (e.g., monthly for multiple years); consider establishing sentinel site(s) where data for ELHD index would be collected long-term; encourage adoption of the ELHD protocol (Appendix F)	Based on 2010 results, step back and refine investigations of fish physiology and entrance propensity as approaches to index survival benefits of restoration

4.3 Conclusions

The 2010 research conducted under the auspices of the Salmon Benefits study provided conclusions generated by both the field, and non-field, components:

- Site-scale passage barriers, dike breaches, and wetted area can be extracted using remote-sensing and modeling techniques for passage barrier change assessment.
- Standard nearest-neighbor distance methods can be modified for salmon using hydrologic routing and directional thresholds for applications at reach or estuary scales.
- Analysis of beach seine data at the Cottonwood Island site scale suggests that structural habitat connectivity (Diefenderfer et al. 2010a) alone is insufficient to explain observed salmon densities; functional parameters (e.g., juvenile salmon migration ecology) need further testing in a statistically robust experimental design.
- Analysis of the water property data at Cottonwood Island suggests that structural habitat differences between strata (main channel, off-channel, wetland channel) are not reflected as differences in the immediately adjacent waters. However, seasonal differences are evident and represent changes in primary production with implications for food web structure that need further study.
- ELHD indices provide a means to quantify life history diversity to serve as a high-level indicator of ELHD in the estuary for use by regional managers.
- PIT-tag detections showed salmon from the Columbia River basin above Bonneville Dam, as well as lower Columbia and Willamette river systems, were present in two shallow tidal freshwater habitats; this has implications for other sites throughout the estuary.
- A statistical design for entrance propensity at site or larger geographic scales that involves PIT-tag technology must consider the environmental challenges of implementing PIT-tag antenna arrays in tidal wetlands (tides, turbidity, channel span, salinity), and low detection probabilities. Other technologies may be required.
- Pilot ecophysiological sampling at the Cottonwood Island site scale did not conclusively show a potential to consistently differentiate habitat strata.

4.4 Recommendations

In summary, recommendations relative to each of the four areas of salmon benefits research based on the 2010 field and non-field research components are provided below.

- **Habitat Connectivity Index**: Extend spatial and temporal (trends) scope of structural/hydrologic metrics, including passage barrier accounting metric and nearest-neighbor distance, and continue development of salmon-specific functional component.
- **ELHD Index**: Perform retrospective analysis of life history diversity to assess multi-decadal trends, adapt the ELHD indices produced by the project for particular management questions, and coordinate with relevant research, monitoring, and evaluation (RME) work groups.
- **Survival Benefits Index**: 1) Develop a formal conceptual model of restoration benefits. 2) Specify the application space for microacoustic tags to apply to small juvenile salmon (up to 60 mm) for the

purpose of action-effectiveness monitoring and research to develop a survival benefits index for restoration evaluations in the LCRE. This will also inform the development of a functional habitat connectivity index. 3) Coordinate a laboratory-field study with concurrent juvenile salmon methodologies being developed for the Corps' research program, Acoustic Telemetry Evaluation of Dam Passage Survival and Associated Metrics at John Day, The Dalles, and Bonneville Dams, 2011, also known as the 3-Dam Study, to assess baseline physiology of 45- to 90-mm salmon in shallow tidal LCRE habitats.

- **Synthesis**: Assess relationships between habitat connectivity, early life history diversity, and survival benefits; prepare a summary integrating the results of the three lines of evidence; and develop habitat unit models for juvenile salmon in the LCRE to link biological response to habitat use.

4.5 Management Implications

Tools that produce reliable and informative data to assess the effectiveness of restoration are essential to stakeholders and funding agencies in the CEERP. Action-effectiveness data at scales from the site (project) to the entire estuary are required to measure the effects the multi-million dollar restoration effort is having on juvenile salmon and the ecosystems they use in the LCRE (Johnson et al. 2003, 2008). The CEERP's adaptive management process is fueled by action-effectiveness data that are analyzed and evaluated to inform program strategy and action plans (Thom et al. 2011). We are developing indices of habitat connectivity, early life history diversity, and survival at the site scale for the most part. The intention, however, is that the index tools be applied estuary-wide, along with data from other monitoring and research projects, to provide information to CEERP decision-makers.

Our research is designed to complement and be integrated with other ongoing monitoring and research studies in the LCRE. These studies, funded mostly by the USACE and BPA, include Multi-scale Action Effectiveness Research (PNNL/Oregon Department of Fish and Wildlife/USFWS/UW), Tidal Fluvial Research (National Marine Fisheries Service/UW), Julia Butler Hanson (USFWS), Ecosystem Monitoring and Reference Sites (LCREP), and various project-specific action-effectiveness studies. We intend to coordinate and exchange information with these researchers through the "monitoring and research coordination" meetings within the CEERP process, as well as in meetings for the Anadromous Fish Evaluation Program. This will identify areas of potential duplication of effort and ensure that corrective adjustments will be made.

Through our PIT-tag detection results, we noted the presence of upriver (above Bonneville Dam) Columbia River basin stocks in shallow-water habitats off the main channel of the lower Columbia River (Appendix I). These migrants tend to move to the Pacific Ocean more quickly than their counterparts from downriver (below Bonneville Dam) (Dawley et al. 1986). The fact that upriver juvenile salmon were in shallow, off-channel habitats of the LCRE implies that they could be available to restored sites in these areas of the landscape. This finding generally points to the applicability of CEERP restoration activities to upriver stocks, but further research is needed to determine the proportion of these fish that will use tidal freshwater and estuarine habitats in the LCRE, the potential duration of use of these habitats, and the effects of such habitat use on upriver salmon at individual and population levels.

This study is fulfilling the requirements of RPA subactions 58.2 and 59.3 in the 2008 FCRPS BiOp (NOAA Fisheries 2008), as follows:

- Subaction 58.2 – "Develop an index and monitor and evaluate life history diversity of salmonid populations at representative locations in the estuary."
- Subaction 59.3 – "Develop an index of habitat connectivity and apply it to each of the eight reaches of the study area."

Our research has application to the ERTG for estuary habitat restoration. The ERTG uses the best available field data on "optimal" salmon densities by habitat type in its method to assign survival benefit units for prospective restoration projects (ERTG 2010). Based on our beach seine data from Cottonwood Island, optimal fish densities would be ~1.0, 0.5, and 0.1 fish/m^2 for off-channel, wetland-channel, and main-channel habitats, respectively. Over the long-term, the ERTG may examine and contemplate new approaches to assign survival benefit units to restoration projects. Such work should be informed by the research we are conducting to develop indices for habitat connectivity, early life history diversity, and survival.

Restoration of connectivity to quality, productive wetland habitats is hypothesized to promote increased life history diversity and survival (Bottom et al. 2005a; Williams 2006). This was concluded for life history diversity based on studies of marsh restoration in the Salmon River estuary on the central Oregon coast (Bottom et al. 2005b). Diverse life history patterns promote resilience to environmental perturbations (Waples et al. 2009). Restoring reconnections to rearing and refuge habitats in the LCRE to increase life history diversity and the probability juvenile salmon survive and return as adults will support the resiliency and sustainability of Columbia River basin salmon populations. To do this biologically and cost-effectively, restoration managers need applied research, such as habitat connectivity, early life history diversity, and survival indices.

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Technical Appendices

Part I: Field Research Methods – Appendix A

Part II: Habitat Connectivity – Appendices B through D

Part III: Life History Diversity – Appendices E and F

Part IV: Survival Benefits – Appendices G through K

Part I: Field Research Methods

Appendix A

2010 Experimental Design and Field Work Plan: Estimating Estuary Usage and Survival Benefits

Appendix A

2010 Experimental Design and Field Work Plan: Estimating Estuary Usage and Survival Benefits[1]

Prepared by Heida Diefenderfer, Nikki Sather, Gary Johnson, John Skalski, Earl Dawley, Ken Ostrand, Kyle Hanson, Benjamin Kennedy and Blaine Ebberts

The extent to which juvenile salmonids use lower Columbia River estuary (LCRE) environments is assumed to be high, but is not actually known. The purpose of the study reported here is to quantify the propensity of subyearling Chinook salmon smolts to use natural or mature restored or created estuary environments during their outmigration. However, capturing sufficient numbers of run-of-river subyearling Chinook salmon to perform a release-recapture investigation can be problematic. Therefore, this study will use both passive integrated responder (PIT)-tagged hatchery and naturally reared subyearling Chinook salmon from the Kalama River to provide a large number of marked smolts.

For the hatchery-released and naturally reared subyearlings, entrance propensity[2] and estuary residence times will be determined on a site-specific basis. Estimated entrance propensity, residence time, and within-estuary survival will be compared between hatchery and wild subyearlings. This task will assess whether hatchery release can serve as a surrogate for wild fish when assessing the salmon benefits of estuarine habitats and by proxy estuarine restoration activities. In addition, we will compare the residence times in shallow-water habitats of smolts that volitionally entered sites and those directly released within a site. Direct releases have been proposed as a means of quantifying estuary residence time and survival. This task will determine whether direct releases can provide reliable measures of estuary residence time and estuary survival.

Another element of the study will compare physiological performance measures between hatchery and wild subyearlings to determine survival benefits. The mechanisms relating how the restoration of tidal wetlands improves or benefits fish populations remain poorly understood, despite numerous demonstrated benefits. Tidally influenced wetlands (marshes, swamps, and riparian forests) are especially well suited for studying the survival benefits of habitat restoration actions given their regular disturbance cycles, high productivity, and geomorphic heterogeneity. These controlling factors result in a high degree of floristic and structural diversity that have been demonstrated to regulate the climatic microhabitat, channel morphology, nutrients, and energy inputs of streams and rivers.

In particular, allochthonous inputs are a primary source of organic matter in streams and serve as food and habitat for aquatic macroinvertbrates. The diverse structure of riparian vegetation provides an array of habitats for terrestrial and lotic organisms and research suggests that terrestrial invertebrates that fall into streams from riparian vegetation provide an extremely important food source for salmonid populations (Wipfli 1997; Baxter et al. 2005). Across global regions, previous research has shown that

[1] This appendix contains the plan that was finalized on March 11, 2010, and implemented during the remainder of that calendar year. It has been edited and reformatted for inclusion as an appendix in this document.
[2] "Entrance propensity" is the proportion of smolts in the near-field that enter a habitat of interest, in this case off-channel tidally influenced wetlands.

terrestrial invertebrates contribute about 50% of the biomass (range 30–86%) in diets of stream salmonids (Baxter et al. 2005). In addition, experimental reductions in terrestrial invertebrate input have been shown to reduce fish growth and increase fish emigration out of sites poor in terrestrial invertebrates (Baxter et al. 2004). Shade provided by canopy cover mediates light and temperature. Plant roots and downed riparian trees and vegetation also supply inputs of woody and vegetative debris that regulate water flows and sediment as well as alter and diversify aquatic habitat. The investigation of physiological performance measures in juvenile salmonids provides quantitative support for examining the effects of tidal estuarine marshes on biota and biological processes more directly than previous studies in the estuary.

The objectives of this field study, and primary associated sampling methods, are as follows.

1. Estimate the propensity of subyearling Chinook salmon to use off-channel[3] habitats, either natural or mature restoration or creation sites. (Passive integrated transponder (PIT) tag)
2. Compare the residence time of subyearlings that volitionally enter off-channel habitats to that of smolts directly released into those sites. (PIT tag)
3. Compare the entrance propensity of hatchery vs. wild subyearling Chinook salmon smolts. (PIT tag)
4. Compare the residence time of hatchery vs. wild subyearling Chinook salmon smolts in estuary environments. (PIT tag)
5. Evaluate residence time, physiological response, and survival benefit metrics to determine if they can accurately and precisely measure presumed survival benefits associated with specific restoration activities. (PIT tag and beach seine)
6. Compare and evaluate the physiological performance of hatchery and wild Chinook salmon smolts that reside within estuarine habitats. (Beach seine and laboratory)
7. Develop site-specific information about the relative presence of salmonids in strata of different quality and distance from the main channel to support the habitat connectivity index. (PIT tag and beach seine)

These objectives will be addressed using hatchery-released and wild in-river-captured, PIT-tagged subyearling Chinook salmon smolts during spring–summer 2010.

A.1 Methods

In the past, fish from hatcheries on the Kalama and nearby Lewis rivers were not PIT-tagged because all major detection sites are upriver. We will PIT-tag large numbers of subyearlings at the Kalama Falls Hatchery and at Washington Department of Fish and Wildlife (WDFW) screw trap locations on the river. We will install stream-type PIT-tag antennas at channel openings and along off-channel habitats near the main stem of the Columbia River to detect the movements of downstream migrants. Selected estuary sampling sites will be a relatively short distance below the river confluence to maximize the number of PIT-tagged smolts available for detection. This study proposes to monitor PIT-tag detections at two

[3] By off-channel habitat, we mean those tidally influenced wetlands that do not front directly on the main stem of the Columbia River estuary, and instead must be reached by passing behind other landforms such as islands.

different estuary sites in the vicinity of Cottonwood Island, to begin understanding factors affecting estuary usage.

Beach seining will also be used to examine the role of habitat connectivity on the dispersal of juvenile salmon. We have identified three habitat strata on Cottonwood Island: wetland channel, off-channel, and main channel. In addition to examining the role of connectivity (i.e., access) to various habitat strata, we will be evaluating physical habitat conditions (e.g., water quality, vegetation characteristics, and substrate) at each of the sampling sites.

A.1.1 Study Sites

The sampling location is specific to the particular goals and objectives of the field study component of the Salmon Benefits project. The location and frequency of sampling associated with each task is also inherent to the field study goals and objectives, which are described in further detail in the following sections.

A.1.1.1 PIT-Tagging

PIT-tagged hatchery subyearling fall Chinook salmon smolts will be released from a hatchery on the Kalama River (Figure A.1) and two off-channel sites on or near the dredge-spoil created habitat on Cottonwood Island approximately 6 km downstream of the Kalama River mouth in the main stem Columbia River will receive PIT-tag detection equipment to measure subyearling use of the wetland-channel habitat (Figure A.2).

The off-channel estuarine site will receive six PIT-tag antenna arrays (Figure A.3). A pair of PIT-tag antenna arrays will be placed at the mouth of the off-channel site to detect PIT-tagged smolt presence and direction of movement. Another pair of PIT-tag antennas will be situated upstream of the off-channel opening and perpendicular to the shoreline to identify migrants susceptible to entrance in the vicinity of the mouth of the off-channel site. A third set of antenna arrays will be situated downriver of the off-channel opening and perpendicular to the shoreline to monitor the fish passing the entrance into the restoration site and the direction of movement once fish have left the site (Figure A.3). PIT-tag antenna arrays will be installed prior to fish tagging in April and maintained through December.

A.1.1.2 Beach Seining

Beach seining efforts will be partitioned among three habitat strata on Cottonwood Island: wetland channel, off-channel, and main channel (Figure A.4). Sample sites were selected from those previously identified by the Tidal Freshwater Monitoring (TFM) project, now Corps' project EST-P-11-01 (Sather et al. 2009; Johnson et al. 2010). Sites include four potential off-channel sites (OC-Is-21, OC-Is-23, OC-Is-28, OC-Is-29), two wetland channels (WC-1, WC-2), and four potential main-channel sites (MC-Is-20, MC-Is-22 MC-Is-24 MC-Is-26). Sampling will occur over a 3-day period each month from April through December 2010.

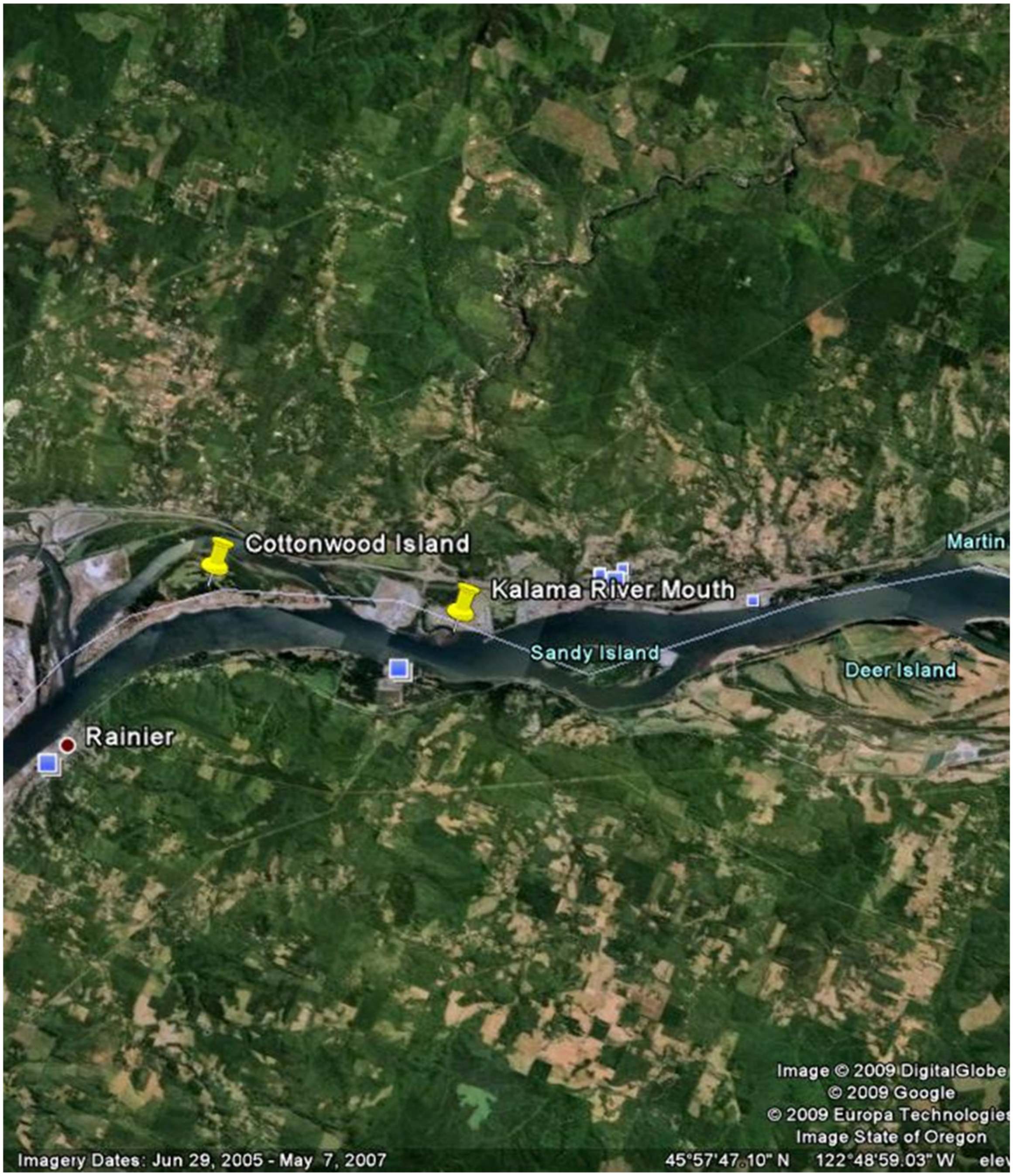

Figure A.1. Locations of the Kalama River and Proposed Estuary PIT-Tag Monitoring at Cottonwood Island

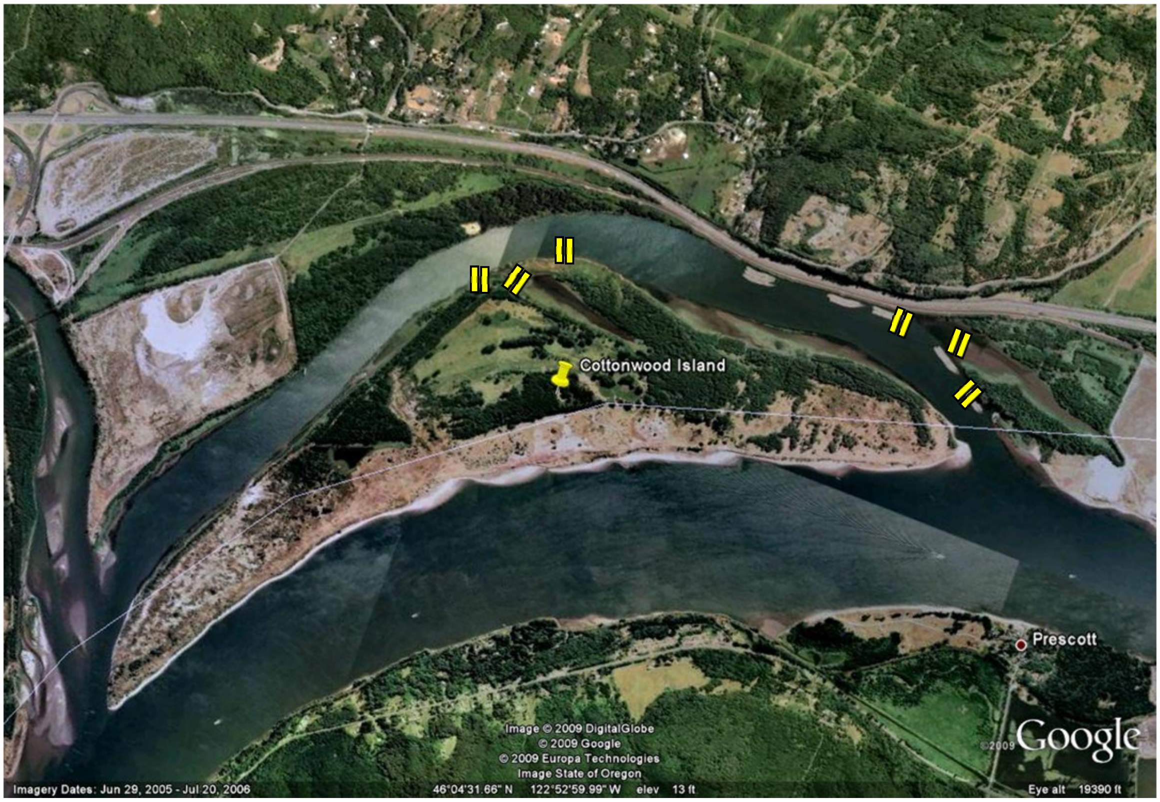

Figure A.2. Schematic of PIT-Tag Detection Arrays (yellow bars) Proposed for Two Channels near Cottonwood Island, Downstream of the Kalama River Confluence

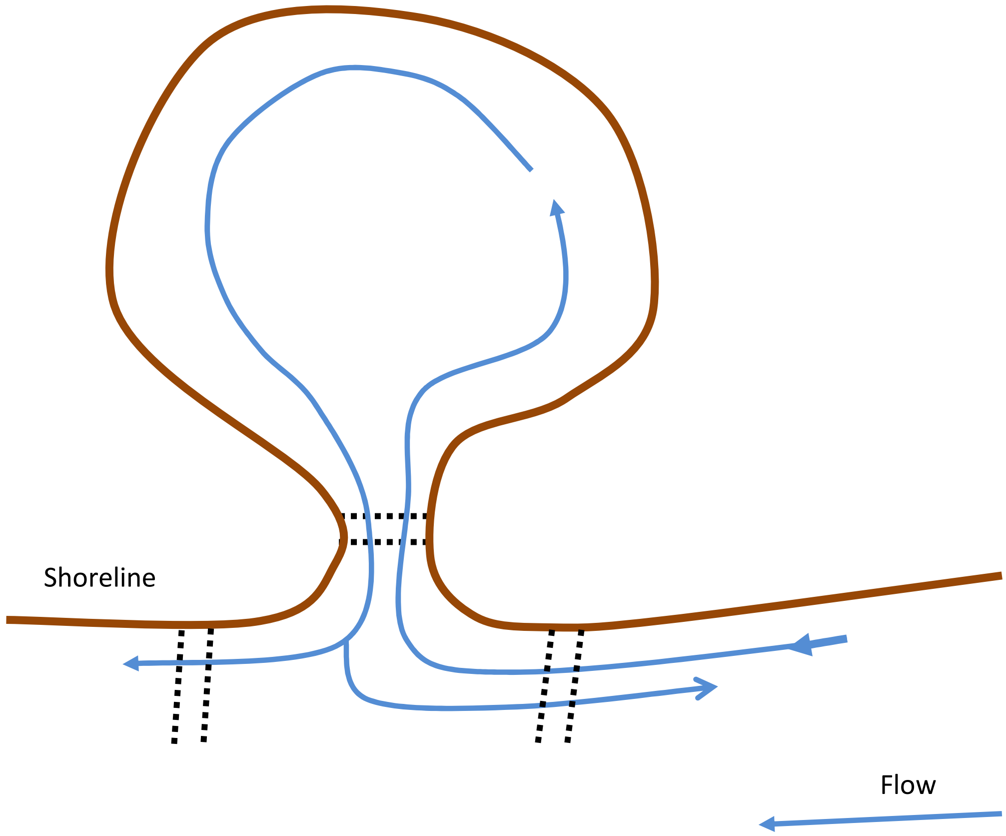

Figure A.3. Schematic of PIT-Tag Antenna Arrays Upstream, Downstream, and at the Estuary Entrance Used to Estimate Estuary Residence Time, Estuary Survival, and Entrance Propensity of Subyearling Chinook Salmon

A.2 Fish Capture and Tagging

A.2.1 Hatchery and Screw Trap Tagging

Using the 8.5-mm PIT tag (134.2 kHz ISO; Destron Fearing Inc.), subyearlings of length 50 mm $\leq x \leq$ 80 mm will be tagged to best represent the fish population. We propose to PIT-tag 9,500 subyearling Chinook salmon at Kalama Falls Hatchery in ponds up to 2 weeks prior to fish release.[4] We expect fish to be released between April and May, depending on hatchery densities, at a size of 75–80 mm (80–100 fish/lb).

A.2.2 Screw Trap and Beach Seine

We also propose using a screw trap near the mouth of the Kalama River to capture, mark, and release wild subyearling Chinook salmon of length 50 mm $\leq x \leq$ 80 mm. The screw trap will be operated beginning in April or May, at a minimum for 1 week prior to the time of the PIT-tag hatchery releases, and through September. Wild subyearlings will be PIT-tagged using the same 8.5-mm PIT tag. The goal

[4] Ken Ostrand and Kyle Hanson, USFWS-Abernathy, have secured permission to tag and to transport fish for direct release from Washington Department of Fish and Wildlife hatchery managers Sean Collins and Mike Johnson.

will be to mark and release up to 500 wild subyearlings back into the Kalama River; however, the WDFW estimates the maximum number of fish coming through the trap may be ~200. All tagging will follow standard protocols and wild Chinook smolts will be held up to 48 hours between time of tagging and release to monitor for handling mortality and tag shedding. The fish will be held in fish pens near the tagging sites until release. Up to 1,500 subyearling Chinook salmon will also be tagged during beach seine efforts in the vicinity of the Cottonwood Island study site.

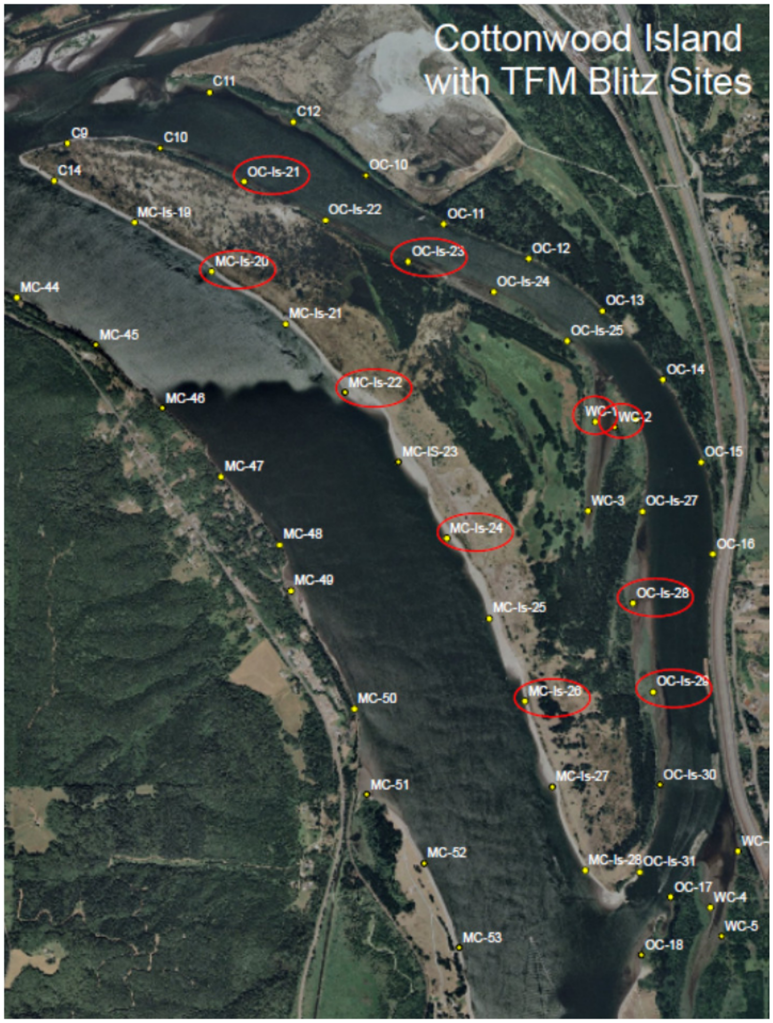

Figure A.4. Cottonwood Island Study Site. The habitat strata identified for sampling include off-channel, wetland channel, and main channel. Potential sites selected for beach seining efforts include the red circled site names.

A.2.3 Direct Releases

To complement the information about residence time and estuary survival of volitionally entered smolts, PIT-tagged hatchery and wild subyearlings will be directly released. Near the peak of the hatchery fish migration in May or June, 100 hatchery subyearlings will be directly released into the sampling sites around Cottonwood Island (i.e., 10 fish/site), to study their dispersal. In addition, throughout wild fish migration, wild fish captured at the screw trap will be tagged and for each wild fish tagged, two hatchery fish held at the hatchery for this purpose will be tagged; these small groups of wild and hatchery fish at a 1:2 ratio will be released into the wetland-channel site at Cottonwood Island after holding up to 48 hours, throughout the migration period. Up to 50 wild and 100 hatchery fish will be directly released in this manner. Due to anticipated low capture rates, hatchery vs. wild comparisons will only be performed at one location.

A.2.4 Beach Seining

Beach seining will sample multiple sites in three habitat strata: 1) off-channel wetland channel (two sites due to the time limitations of the tidal cycle in a small channel); (2) off-channel (four sites); and (3) dredge disposal/main channel (four sites). The minimum size requirement for a site is 500 m and is measured as a linear distance along the shoreline. In each stratum, three non-overlapping hauls will be made at each site; these will be used to calculate fish density. In addition, beach seine hauls will provide fish for physiological sampling (see Section A.4). Therefore, it may be necessary to complete more than three hauls per site to achieve the minimum sample size of 15 fish per stratum.

Gear type and set techniques will be similar to those described by Sather et al. (2009); the seine is 46 m long and 3 m deep at the center with wings that taper to 1.5 m. The wings are constructed of 13-mm stretch black knotless netting. This seine is fit with a bag constructed of 3.2-mm knotless mesh netting dyed green, and measures 2.4 m wide by 1.5 m deep. The seine is fit with 17-oz buoyancy, ethylene vinyl acetate (EVA) floats on 46-mm centers and a solid core lead line with a poly sleeve sewed to the base. A 15-m-long haul line will be affixed to a bridle at the tapered ends of each wing. One end of the haul line will be held to the shore while the boat moves toward the deep end of the channel. Once the end of the line is reached, the boat will turn 90 degrees and begin deploying the net (Figure A.5). After the full length of the net has been set, the haul lines will be used to bring the wings to the shore.

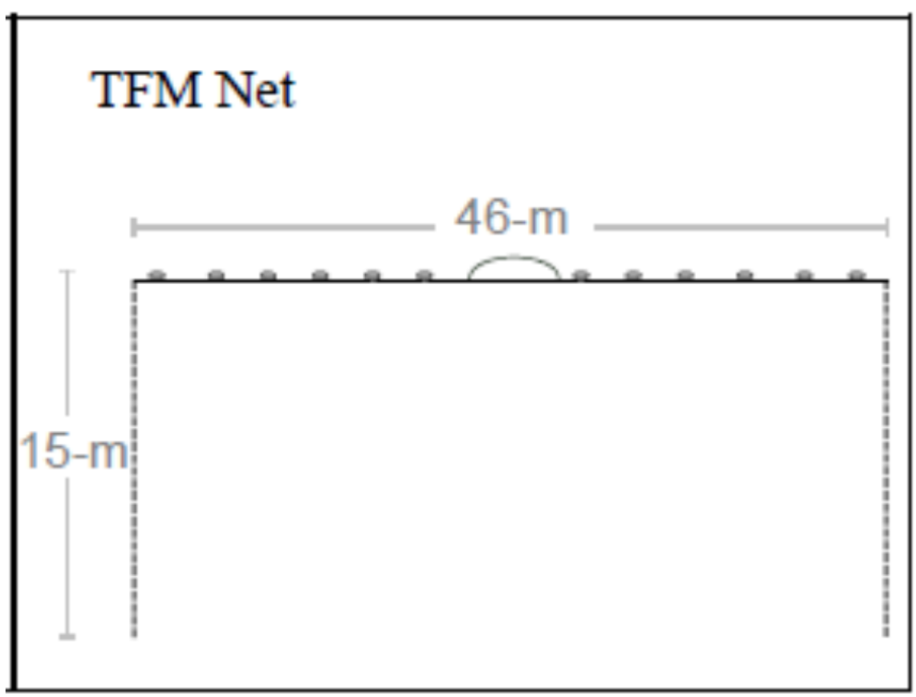

Figure A.5. Seine Deployment Schematic

After retrieval of the beach seine, all fish captured will be transferred to 5-gal buckets filled with river water. All salmon will be processed first and will therefore be segregated into buckets separate from the non-salmon catch. Aerators will be used to maintain adequate levels of dissolved oxygen in the buckets. The catch will be processed by enumerating all taxa and measuring to the nearest millimeter up to 20 individuals within each size class for a given species.

Salmon will be processed in accordance with physiological methods outlined in Section A.4 below. After the individual fish devoted to the physiological variables have been processed, the remainder of the salmon catch will be available for PIT-tagging. This effort will complement the tagging effort scheduled to occur at the Kalama Falls Hatchery as well as the tagging efforts scheduled for the Kalama River screw trap. Fish captured and PIT-tagged at Cottonwood Island will be held and released at the site of capture, with the exception of fish captured at the main channel sites, which will be released near site OC-18 just upstream of Cottonwood Island (Figure A.4). Four live boxes (live cars) will be used for holding 24 to 48 hours: one for main-channel sites, one for upstream off-channel sites, one for downstream off-channel sites, and one for wetland-channel sites. Biological samples such as fin clips, scales, and otoliths will be collected where possible and preserved for future analysis.

Within each site, ancillary data collection will include obtaining information about water properties as well as habitat assessments. Water property data will be measured with the YSI-556 and will include water temperature, salinity, dissolved oxygen, and conductivity. Water velocity will also be measured at each site. Additional water properties that may be measured include nutrients, total organic carbon, and dissolved organic carbon. These metrics may elucidate differences between the connectivity of habitats and may serve as an indicator of ecosystem function. The evaluation of site-specific habitat conditions will be done in accordance with rapid habitat assessments developed by Sather et al. (2011) Metrics include estimates of percent cover and distance between the water's edge and vegetative features such as emergent vegetation, shrubs, and tress.

A.2.5 PIT-Tagging Summary

There will be five separate PIT-tagging efforts between April and December:

- PIT-tag 9,500 Kalama Falls Hatchery Chinook in one batch, April to May depending on growth and development; hold and hatchery release as normal.
- PIT-tag up to 500 wild Chinook at the Kalama River screw trap and re-release them to the river; estimate 200 total.
- PIT-tag up to 50 wild Chinook, and double that number of hatchery fish (1:2 ratio), to be directly released at wetland channel on Cottonwood Island in "dribbles" April through May as wild fish are caught in screw trap.
- PIT-tag and direct release 100 Kalama Falls Hatchery fish in May or June; 10 per site, to the Cottonwood Island sampling sites.
- PIT-tag up to 1,500 Chinook caught in beach seine effort at all 10 Cottonwood Island (estimate 1,000-1,300 total) from April to December, to be released at the site of capture (after holding), except for fish captured at main-channel sites, which will be released at OC-18, just upstream of Cottonwood Island.

A.3 Physiological Sampling

To complement the information about the residence time and estuary survival of tagged juvenile salmon, physiological sampling of growth, stress, condition, development, and performance will be performed on hatchery smolts. We will first determine differences in growth potential among individuals at each site by sacrificing whole fish (N = 30 fish per site) for analysis of RNA:DNA ratio (Buckley and Bulow 1987). These fish will be sampled using beach seine techniques as described in Appendix B. Supplemental sampling of fish using a different collection method (e.g., electrofishing) may be required if the condition of fish is significantly altered by beach seine collection to the point where physiological indices may be affected by handling stress. This will be determined by physiological measurements of fish onsite during the initial beach seine sampling effort. If electrofishing is required, transects adjacent to beach seine sites will be sampled following standard protocols and collected fish will be tissue sampled using the methods described above.

Multiple indicators of the primary and secondary stress response will be measured from blood samples (taken via caudal venipuncture) from live fish (Table A.1). Using portable field analyzers, whole blood samples from 30 fish per site will be analyzed to determine circulating lactate and glucose levels, which are indicative of the secondary stress response (Morgan and Iwama 1997; Wendelaar Bonga 1997). A second subset of fish (N = 30 per site) will have blood samples analyzed for indicators of the primary stress response. Circulating levels of the primary stress hormone cortisol will be determined by lab analysis using commercially available enzyme-linked immunosorbent assay kits (Barton 2002). These plasma samples will also be analyzed for concentrations of ions and osmolality, which are indicative of stress-induced osmoregulatory disruption (Morgan and Iwama 1997; Wendelaar Bonga 1997).

Differences in nutritional condition and proximate composition of fish between sites will be assessed using a number of complementary methods. All fish that will be physiologically sampled will be measured for length and weight to determine their condition factor (K). Circulating levels of protein and triglycerides, which are indicative of recent feeding behavior (Wagner and Congleton 2004), will be determined from plasma samples (N = 30 fish per site) using commercially available assays. These fish will also be sampled using bioelectrical impedance analysis (BIA)—a nonlethal technique that passes a slight electrical current through the body—to assess proximate body condition (total body water, ash, protein and somatic energy reserves; Cox and Hartman 2005).

Multiple physiological measurements of development along two distinct life history paths (outmigration vs. residualism) will be measured in fish collected from each site. To determine smoltification and osmoregulatory preparedness for outmigration, gill Na^{+},K^{+} -ATPase (NKA) activity will be measured on a subset of fish (N = 30 per site) following the standard protocols detailed by McCormick (1993). These fish will also be blood sampled to measure precocial maturation rates determined from plasma samples that will be analyzed for circulating levels of sex hormones (11-ketotestosterone and estradiol; Larson et al. 2004).

Table A.1. Physiological Variables to Be Measured Across Four Sampling Sites Representing Habitat Restoration Activities in the Main Stem of the Columbia River

Variable	Measurement Type	Sample Type	N per Site	N Total
RNA:DNA ratio	Growth	Whole fish	30	120
Lactate, glucose	Stress response	Whole blood	30	120
Cortisol, ions, osmolality	Stress response	Plasma	30	120
Protein, triglycerides, BIA	Condition	Plasma	30	120
NKA activity, sex hormones	Development	Gill, plasma	30	120
Total Study				**600**

A.4 Statistical Analysis

A.4.1 Residence Time

Residence time of PIT-tagged smolts that entered the off-channel site volitionally will be measured from the last detection into the off-channel site to the time of the first detection out of the off-channel site. The double-detection arrays will provide information about the direction of movement. For smolts directly released into the off-channel site, residence time will be measured from release to the time of the first detection out of the estuary.

Mean residence time will be estimated by the arithmetic mean:

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n},$$

where t_i is the residence time for the *i*th smolt $(i = 1, \ldots, n)$ with associated variance:

$$\widehat{\text{Var}}(\bar{t}) = \frac{\sum_{i=1}^{n} (t_i - \bar{t})^2}{n(n-1)}.$$

Comparison of mean residence times of volitional entry hatchery, direct-released hatchery and direct-released wild subyearling Chinook salmon smolts will be based on a one-way analysis of variance (ANOVA).

A.4.2 In-Estuary Survival (S_E)

A.4.2.1 Directly Released Smolts

The double-antenna area at the mouth of the off-channel site will provide four unique capture histories that can be used to estimate in-site survival (S_E). A multinomial model will be used to calculate the maximum likelihood estimate of survival based on the capture histories and parameterization shown in Table A.2.

Table A.2. Parameterization for the Multinomial Model

History	Probability of Occurrence
11	$S_E p_1 p_2$
01	$S_E(1-p_1)p_2$
10	$S_E p_1(1-p_2)$
00	$(1-S_E)+S_E(1-p_1)(1-p_2)$

p_i = Probability of detection at the *i*th antenna array.

A.4.2.2 Volitional Entry Smolts

For smolts with a confirmed unidirectional entrance into the off-channel habitat, the estimate of in-site survival will be analogous to that for direct-released smolts. Fish with an antenna detection sequence of line 1, followed inward by line 2, will form the sample size for subsequent survival estimates.

A.4.3 Entrance Propensity

For fish traveling close to shore, an entrance propensity can be calculated. The double-detection array upshore of the mouth will be used to identify fish available for entry. (The analysis can be further refined, if desired, to just consider the fish detected at both arrays and moving toward the mouth.)

A joint likelihood model will be used to estimate the proportion of smolts in the near-field that 1) enter the site (i.e., Ψ_1); 2) do not enter the site but move offshore (i.e., $(1-\Psi_1)(1-\Psi_2)$; and 3) do not enter the site but move past the mouth and continue downshore (i.e., $(1-\Psi_1)\Psi_2$) (Figure A.6).

The joint likelihood model consists of three separate components:

$$L = L_{\text{Capt hist}} \cdot L_{P_1} \cdot L_{P_2}$$

where $L_{\text{Capt hist}}$ describes the alternative capture histories at the mouth or downshore array, L_{P_1} describes the probability of detection at the double array at the mouth, and L_{P_2} describes the probability of detection at the double array at the downshore array.

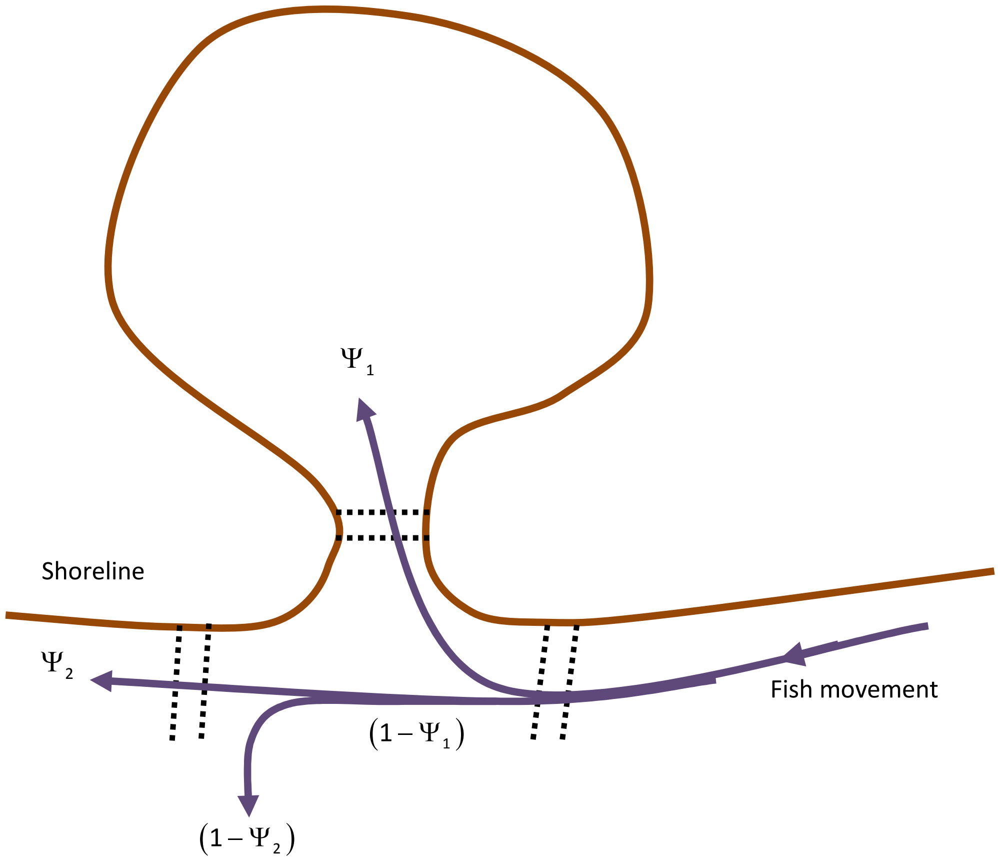

Figure A.6. Schematic of Transition/Movement Probabilities for Smolt Known to Have Been Detected at the Upshore Dual-Detection Array. Smolts can move into the site (i.e., Ψ_1), move offshore (i.e., $(1-\Psi_1)(1-\Psi_2)$), or move downshore (i.e., $(1-\Psi_1)\Psi_2$).

The capture histories consist of three possibilities (Figure A.6):

- detection at the mouth (n_1)
- detection downshore (n_2)
- not detected

for fish identified (*N*) to have arrived at the upshore array. The probability of these occurrences can then be modeled as

$$L_{\text{Cap Hist}} = \binom{N}{n_1, n_2} (\Psi_1 P_1)^{n_1} \left((1-\Psi_1)\Psi_2 P_2\right)^{n_2} \left(\Psi_1(1-P_1) + (1-\Psi_1)\left[(1-\Psi_2) + \Psi_2(1-P_2)\right]\right)^{N-n_1-n_2}$$

where P_1 is reparameterized as $P_1 = 1-(1-p_{11})(1-p_{12})$ and $P_2 = 1-(1-p_{21})(1-p_{22})$.

The likelihood describing the detection process at the mouth can be written as

$$L_{P_1} = \binom{a_\bullet}{a_{11}, a_{10}, a_{01}} \left(\frac{p_{11} p_{12}}{1-(1-p_{11})(1-p_{12})} \right)^{a_{11}} \left(\frac{(1-p_{11}) p_{12}}{1-(1-p_{11})(1-p_{12})} \right)^{a_{10}} \cdot \left(\frac{p_{11}(1-p_{12})}{1-(1-p_{11})(1-p_{12})} \right)^{a_{01}},$$

where a_{11} = number of fish detected at both arrays,

a_{10} = number of fish detected at array 1 but not array 2,

a_{01} = number of fish detected at array 2 but not array 1,

and where p_{11} = probability of detection at array 1 for the mouth dual array,

p_{12} = probability of detection at array 2 for the mouth dual array.

The likelihood L_{P_2} is analogous to L_{P_1} but for the dual array downshore of the mouth.

Profile likelihood confidence intervals will be calculated for the three alternative movement decisions (i.e., Ψ_1, $(1-\Psi_1)\Psi_2$, and $(1-\Psi_1)(1-\Psi_2)$). Likelihood ratio tests will test whether movement parameters (Ψ_i) are equal for hatchery and wild smolts.

A.4.3.1 Onshore vs. Offshore Use of the Off-Channel Site

Of the fish identified as entering the off-channel site, the individuals can be classified as either being detected previously at the onshore arrays or not. The classifications can be interpreted as fish moving along the nearshore (onshore) that entered the off-channel site or fish that entered the off-channel site from the offshore. This onshore:offshore ratio can be calculated for each site according to the formula

$$\hat{R} = \frac{x}{y}$$

where *x* is the number of onshore fish entering off channel site, and *y* is the number of offshore fish entering off-channel site.

The variance of $\hat{R}$ can be calculated as follows:

$$\widehat{\text{Var}}(\hat{R}) = \frac{\hat{R}(1-\hat{R})^2}{(x+y)}$$

A.4.4 Habitat Connectivity

Fish density data from beach seining will be normalized by water surface area or volume associated with each site, prior to comparison of the three strata. If structural connectivity is dominant, i.e., if distance swum has the largest affect on salmon habitat selection, then we would expect to see densities as follows: wetland channel < off-channel < main channel. In contrast, if habitat quality is dominant, then we would expect to see densities as follows based on wetland productivity: main channel < off-channel < wetland channel. Dispersal will also be quantified by the direct release of 100 PIT-tagged hatchery fish into the 10 beach seine sites.

A.4.5 Physiological Sampling

Differences will be assessed between PIT-tagged hatchery and wild fish and among sites for each response variable (i.e., physiological parameter). We will use Levene's Test for heterogeneous variances to evaluate survival benefit metrics. The distribution of untransformed errors among each response variable will be determined and ANOVA will be used to test for significant differences ($P < 0.05$) among the treatment errors. In addition, we will use a completely randomized design where each individual fish will be considered our experimental unit, and rearing types and sites will be considered our treatment. Kruskal-Wallis tests will be used to test for differences among physiological variables. Significant ($P < 0.05$) Kruskal-Wallis tests will be followed by Tukey-type mean separation tests for pair-wise comparisons.

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Part II: Habitat Connectivity

Part II: Habitat Connectivity

A goal of the lower Columbia River and estuary (LCRE) habitat restoration effort is to increase habitat connectivity—a measure of the degree to which habitats in a landscape matrix are physically connected or spatially continuous and the ability of one or more target species or populations to access these habitats. Increased habitat connectivity may benefit salmon populations by increasing the opportunity for juvenile salmonids to access shallow-water, off-channel habitats where they can forage in suitable environmental conditions and find refuge from predators during their migration to the ocean (Simenstad and Cordell 2000). At the landscape scale, habitat connectivity is an indicator of the linkages between habitats with important functions in the ecosystem. Habitat connectivity is affected directly by passage barriers, such as dikes, levees, tide gates, and culverts (Kukulka and Jay 2003). These structures are stressors in the LCRE because they restrict access by salmon to wetland habitats, and in some cases, have also significantly altered the environmental conditions of the habitats behind them (Simenstad and Feist 1996).

Habitat restoration actions in the LCRE are expected to improve habitat opportunity for listed salmonids, and more specifically, to increase tidal wetland habitat currently accessible within a given geographic area (NMFS 2008; Roegner et al. 2008). However, these length and area values vary temporally with water level in an estuary, which in turn varies with the regulated flow of the Columbia River, sea level, and tides (Diefenderfer et al. 2008) and are further modified by reach-specific conditions such as large woody debris (Diefenderfer and Montgomery 2009). A method to quantify and periodically monitor habitat connectivity has not been developed and applied for the LCRE as required by Action 59 of the Biological Opinion on operation of the Federal Columbia River Power System (www.salmonrecovery.gov). Action 59 addresses the following management question: What is the extent of habitat connectivity by reach and is it increasing? This report describes current work in the development of a habitat connectivity index based on hydrographic, topographic, and fish presence data to provide a way to track status and trends of habitat connectivity after restoration actions within major reaches of the lower Columbia River.

Appendix B and Appendix C contain results from the Cottonwood Island field sampling that are particularly related to habitat connectivity, although the habitat strata on which the entire study design were based ensure that all findings of the field study are in fact relevant to connectivity. Appendix B presents the results of beach seine data collection and Appendix C the results of water properties sampling. Appendix D contains a progress report on non-field elements of habitat connectivity index development, with a focus on passage barrier accounting.

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Appendix B

Cottonwood Island Beach Seine Data Collection Report

Appendix B

Cottonwood Island Beach Seine Data Collection Report

Prepared by Nikki Sather

A growing body of research in the lower Columbia River and estuary (LCRE) indicates juvenile salmon are present in a diversity of shallow-water habitat types throughout the year (Johnson et al. 2008; Roegner et al. 2008; Sather et al. 2011). The study design of this research program differs from current LCRE research efforts in that the design is intended to elucidate the distribution of juvenile salmonids among discrete habitat strata. The intent of Appendix B is to convey results of juvenile salmon density in shallow-water habitats of Cottonwood Island within the context of habitat connectivity (see methods, results, and discussion below). The 2010 beach seine effort provided an opportunity to address multiple objectives of the Salmon Benefits study. The beach seine data collected as part of this effort have also been integrated into the life history diversity, survival benefits, and physiology appendices (Appendices E, I, and J).

B.1 Methods

Details pertaining to the study design, and sampling techniques are provided in the 2010 Experimental Design and Field Work Plan (Appendix A).

B.2 Results

We captured five species of salmon and trout during the 2010 beach seine effort at Cottonwood Island. Chinook salmon (*Oncorhynchus tshawytscha*) were the most abundant salmon species encountered at Cottonwood Island. The remaining salmon and trout species captured in the beach seine composed less than 1% of the total catch within each of the respective habitat strata (Table B.1). Mean densities of juvenile salmon were greatest in the off-channel followed by the wetland channel. The main-channel habitat yielded the lowest mean densities of juvenile salmon (Figure B.1).

Table B.1. Proportion of Salmon Captured Within Each Habitat Stratum at Cottonwood Island. Unless otherwise noted, all fish are unmarked.

Taxon	Common Name	Main Channel	Wetland Channel	Off-Channel
Oncorhynchus tshawytscha	Chinook salmon	0.67	0.72	0.90
O. tshawytscha	Chinook salmon (marked)[(a)]	0.32	0.27	0.09
O. kisutch	Coho salmon	0.002	0.01	0.01
O. keta	Chum salmon	0.01	0.001	0.004
O. clarkii clarkii	Cutthroat trout	0	0	0.0004
O. clarkii clarkii	Cutthroat trout (marked)[(a)]	0	0	0.001
O. mykiss	Steelhead trout	0.001	0	0.0001
O. mykiss	Steelhead trout (marked)[(a)]	0.0006	0	0.001

a. Known hatchery fish are denoted in the field via a clipped adipose fin or a coded wire tag and are reported as marked in the table.

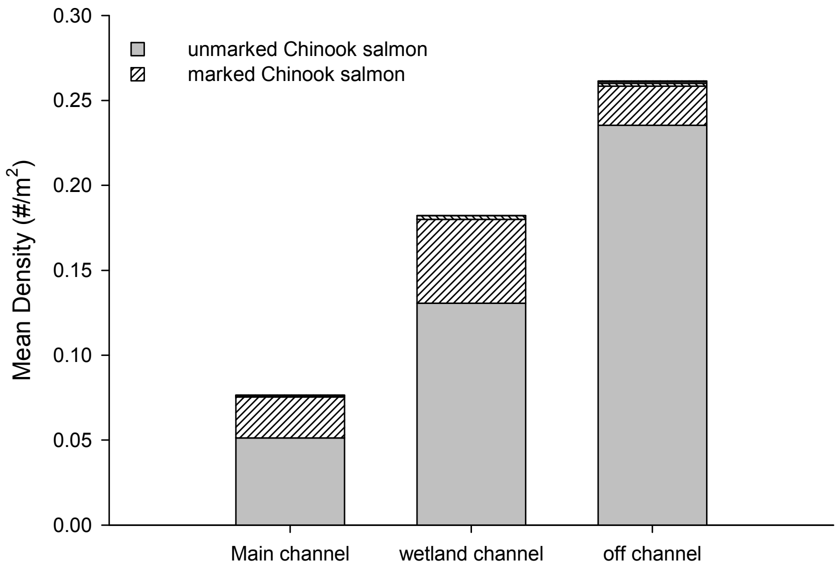

Figure B.1. Mean Density of Juvenile Salmon Captured Within Each Habitat Stratum at Cottonwood Island During 2010. Coho salmon, chum salmon, cutthroat trout, and steelhead trout account for minor portions of the catch (<1%) represented by the narrow band at the top of each bar.

The mean density of unmarked Chinook salmon was greatest during spring and early summer months followed by a sharp decline during fall and early winter (Figure B.2). The mean size of unmarked Chinook salmon increased from April through December. There were few differences in the mean size of unmarked Chinook salmon between habitat strata (Figure B.3). However, the distribution of unmarked Chinook salmon differed in that a higher proportion of small sizes (e.g., <60 mm) were captured in the wetland and off-channel habitats compared with the main channel. In addition, within habitat strata, the mean size of marked Chinook salmon was larger than unmarked Chinook salmon with differences in size between the groups decreasing from April through July (Figure B.4).

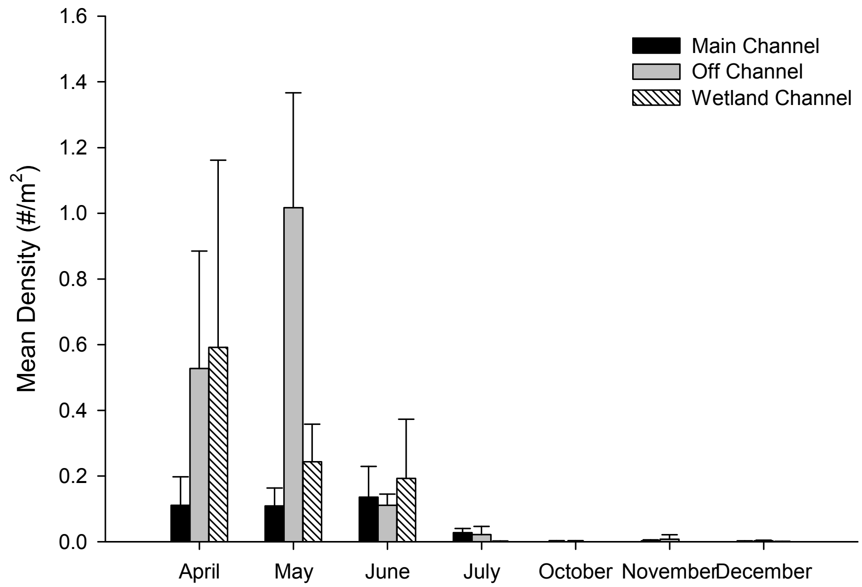

Figure B.2. 2010 Unmarked Chinook Salmon Density Captured in Three Habitat Strata (main channel, off-channel, wetland channel) at Cottonwood Island in the Lower Columbia River. Error bars represent the standard error of the mean.

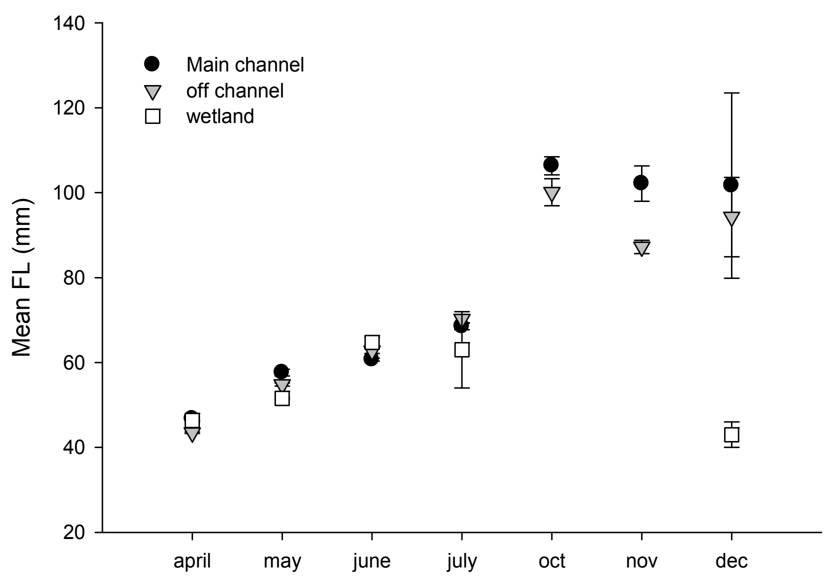

Figure B.3. Mean Fork Length (mm) for Unmarked Chinook Salmon Captured Within the Three Habitat Strata at Cottonwood Island in the Lower Columbia River. Error bars represent the standard error of the mean.

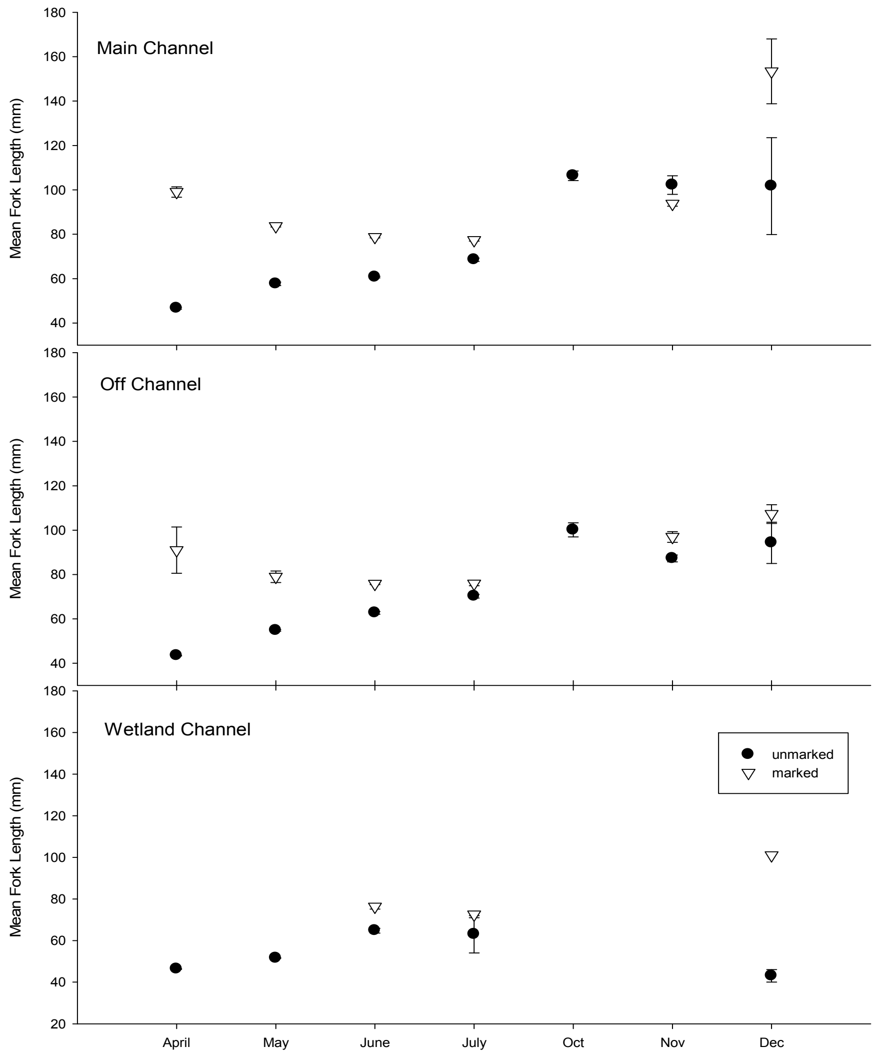

Figure B.4. Mean Fork Length for Unmarked and Marked Chinook Salmon Captured at Cottonwood Island from April Through December 2010. Error bars represent the standard error of the mean.

B.3 Discussion

The general patterns of species composition, size, and timing of migration associated with juvenile salmon at Cottonwood Island mimic those noted by other research efforts within the LCRE (e.g., Roegner et al. 2008; Sather et al. 2011). The implementation of a stratified design in this study provides an opportunity to explore the role of hydraulic connectivity related to the abundance of juvenile salmon in shallow-water habitats. In applying the framework of Lasne et al. (2007) to the Cottonwood Island study, hydraulic connectivity is greatest within the main channel, followed by the off-channel, and finally the wetland channel. However, fish assemblages are constrained by a combination of structural and functional attributes operating at multiple spatial scales.

In addition to yielding the lowest mean densities of juvenile salmon, the main channel differed from other strata with respect to structural differences. The main-channel sites were dominated by sandy sediments and vegetation along the beach face was sparse. The wetland channel was dominated by emergent vegetation, little bare ground, and fine sediments. The off-channel stratum, which yielded the highest overall densities of juvenile salmon, had habitat characteristics that were intermediate to the main-channel and wetland-channel strata. Off-channel habitats had a high proportion of emergent vegetation mixed with shrubs, trees, and bare ground. Compared with the other strata, the off-channel habitats were also noted to have a high occurrence of submerged aquatic vegetation. Similar to the wetland channel, the substrate was composed of fine sediment.

Differences in habitat characteristics among the strata may be correlated with differences in salmon densities. There appeared to be few differences in the mean size of unmarked Chinook salmon captured in the different strata, yet there were differences between strata in the proportion of size classes captured. The predominance of small size classes (e.g., <60 mm) of juvenile salmon in shallow backwater areas may indicate functional differences when compared with main-channel sites. However, functional attributes, such as prey resources and refuge, were not specifically examined as part of this study. Research focused on characterizing functional conditions between habitat strata may help elucidate questions centering on important habitats for juvenile salmon.

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Appendix C

Organic Matter, Nutrients, and Plankton Associations for Wetland-Channel, Off-Channel, and Main-Channel Habitat Types

Appendix C

Organic Matter, Nutrients, and Plankton Associations for Wetland-Channel, Off-Channel, and Main-Channel Habitat Types

Prepared by Dana Woodruff, Val Cullinan, and Bill Pratt

C.1 Problem Statement

Significant data gaps remain in our understanding of the food web structure and function as it relates to juvenile salmon use of various habitat types in the lower Columbia River and estuary (LCRE) (ISAB 2011). There is a need to characterize components that support the base of the food web, including biogeochemical properties of the water column (e.g., organic matter, nutrients, and plankton) in order to develop a better understanding of the mechanistic linkages between the base of the food web, prey resources, habitat use, and juvenile salmon.

C.2 Research Objectives

This supplement to the Salmonid Benefits study for fiscal year 2010 provided for the collection of selected water property data at each habitat type (i.e., main channel, off-channel, wetland channel) in association with beach seining activities for juvenile salmon at Cottonwood Island. This study component complements the habitat connectivity and survival benefits tasks for the 2010 reporting year with the following objectives:

1. Collect selected biogeochemical properties (temperature, dissolved oxygen, nutrients, organic carbon, suspended sediments, and chlorophyll_*a*), seasonally in association with each habitat type (i.e., wetland channels, off-channel, and main channel) and concurrent with beach seining activities.
2. Develop and refine collection methods for phytoplankton at each habitat type, concurrent with Objective 1 above, and develop estimates of abundance and taxonomic classifications.
3. Characterize the water-property metrics for each habitat type and evaluate differences with respect to each habitat strata, for each time period sampled.

This task was initiated as a pilot study to refine water-property field collection methods that would complement beach seining fish collection activities, and to acquire preliminary biogeochemical water properties data in close proximity to the three habitat strata at Cottonwood Island. The original design called for four seasonal sampling events conducted concurrently with beach seine activities. Due to weather and permitting issues, only two of the four water sampling events were conducted with beach seine activities. Water samples were collected in May, September, and November 2010, and May 2011.

C.3 Methods

C.3.1 Sample Design and Data Collection

Water-property samples were collected from the Cottonwood Island area at nine sites, segregated into three habitat strata with three sites per strata (Figure C.1). The habitat strata were: main channel (MC), off-channel (OC), and wetland channel (WC).

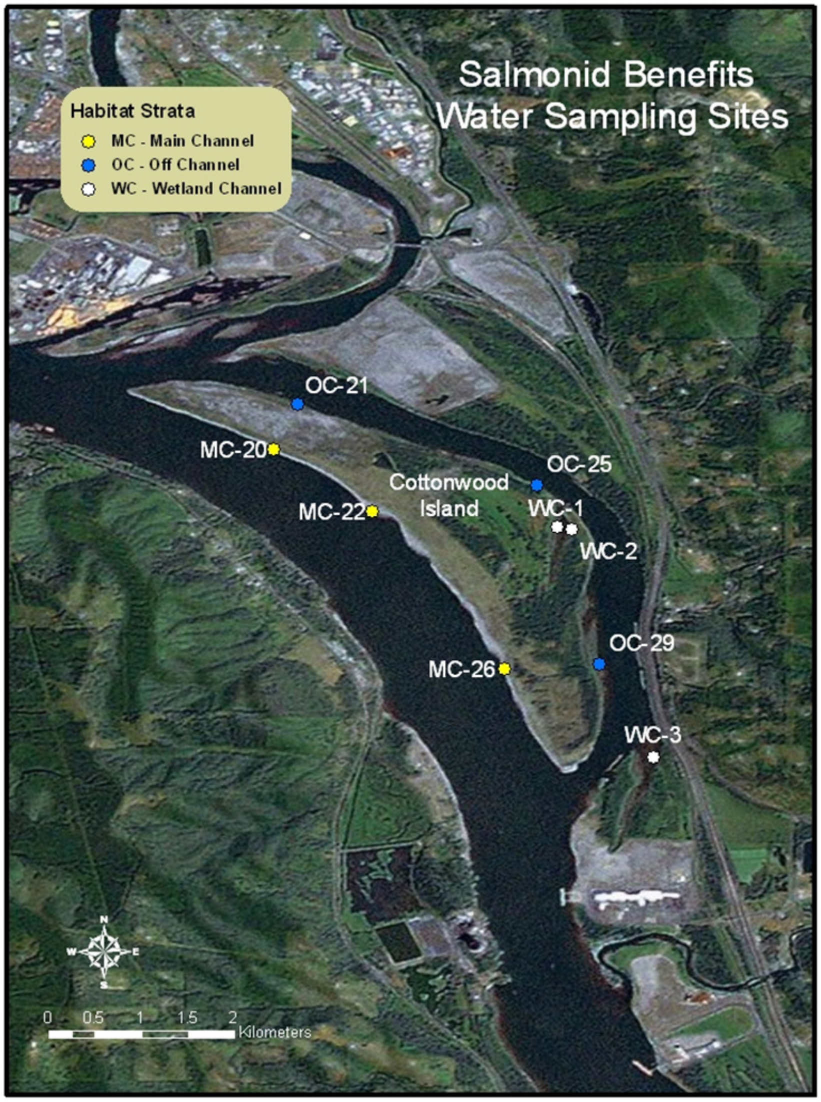

Figure C.1. Sampling Site Locations for Collection of Water-Property and Phytoplankton Metrics in Three Habitat Strata: Main Channel (MC), Off-Channel (OC), and Wetland Channel (WC)

Table C.1. Water-Property Sampling Sites in Habitat Strata Located Near Cottonwood Island

Habitat Strata	Site Codes
Main channel	MC-20, MC-22, MC-26
Off-channel	OC-21, OC-25, OC-29
Wetland channel	WC-1, WC-2, WC-3 (Kalama)[(a)]

(a) The WC-3 site is also referred to as the Kalama wetland site, located on the mainland near Cottonwood Island.

Three habitat strata and sites were selected (see Chapter 2.0 and Appendix A). The Kalama wetland (WC-3) site was also selected because it was associated with a set of passive integrated transponder (PIT)-tag antenna arrays, and data from the wetland channel could help explain the presence or absence of PIT-tagged fish. For data presentation, some graphics separate the WC-3 from the other wetland-channel sites.

Sampling was scheduled to occur on a seasonal basis within several days just prior to or after regularly scheduled beach seining activities, in order to not disturb fish in the immediate vicinity or compromise ambient water conditions by seining activities. Tentatively scheduled sample dates were in May, August, November 2010, and February 2011. The first sampling occurred on May 16, followed by beach seining on May 17–19. The second trip occurred on September 13, with no concurrent beach seining due to permitting issues. The third trip occurred on November 16, with beach seining occurring November 8–10. The fourth trip occurred on May 12th with no concurrent beach seining.

A total of nine base sites were accessed during the day by boat, with the wetland channels sampled during a higher tide when the sites could be accessed readily. Navigation to the sites occurred using global positioning system software. Water sampling occurred close to shore in approximately 0.5- to 3.0-m-deep water, depending on the beach slope and the presence of fringing emergent vegetation. Sites with emergent vegetation were sampled on the offshore side of the vegetation.

Water-quality parameters were measured near the surface (~0.25 m depth) using a handheld multi-probe YSI Model 85 or 556 (YSI Incorporated, Yellow Springs Ohio) lowered by hand from a boat. When practical, measurements were also taken near the bottom of the water column. A secchi depth measurement was taken when possible at the site, or just offshore in water deep enough to acquire a reading. Ancillary notes regarding sea state and weather conditions were recorded. Surface grab samples were collected using a clean bucket for bulk water processing of nutrients, organic matter, and suspended sediments. These samples were field processed to the extent possible, as described below, and placed on ice until returning to the laboratory later in the day. Nutrient samples (phosphate [PO_4] and nitrate [NO_3]) were filtered in the field using a surfactant-free cellulose acetate syringe filter. Samples for chlorophyll_*a* were passed through Whatman™ Grade GF/F filters and stored in the dark. Samples for particulate organic carbon (POC) and dissolved organic carbon (DOC) were passed through carbon-cleaned GF/F filters with the filter stored for POC and the filtrate saved for DOC in ashed glass vials. Samples for total suspended sediments (organic and inorganic fraction) were collected in 1-L polypropylene containers and stored on ice. Bulk water samples were preserved in 10% formalin for later analysis of phytoplankton abundance and taxonomic classification.

At the Marine Sciences Laboratory, nutrient, organic carbon, and chlorophyll_*a* samples were stored in a freezer (-10 °C) until further analysis. Suspended sediment samples were analyzed within 48 hours.

Table C.2 lists the water properties measured and analysis methods used. All samples were analyzed at the Marine Sciences Laboratory or the University of Washington.

Phytoplankton samples were enumerated on a Palmer-Maloney slide following the methods of Horner (2002) using a Leica™ DM IRB inverted microscope. Phytoplankton were classified into major taxonomic groupings.

Table C.2. Salmon Benefits Water Property Metrics, Collection, and Laboratory Analysis Methods, and Sampling Scheme

Parameter	Field Method	Laboratory Method	Sampling Frequency	Schedule
Long-term data loggers (2 stations)				
Depth	Onset logger	NA	Hourly	Through present
Temperature				
Surface-water sample collection at nine sites				
Temperature (°C)	YSI Model 85 or 556 handheld multi-probe	NA	One sample per site, including three field replicates collected in each strata per sample event	Seasonal
Salinity (psu)				
DO (mg/L)				
Chlorophyll *a*	Surface Grab Sample	EPA method 445.0 (EPA 1992)		
TOC, POC, DOC		Sugimura and Suzuki (1988)		
Total suspended sediments (inorganic and organic fraction)		APHA Standard Methods 2540 C & E (APHA 2005)		
Secchi depth	Secchi meter	NA		
PO_4-P	Surface Grab Sample	Bernhardt and Wilhelms (1967)		
NO_3-N		Armstrong et al. (1967)		
DO = dissolved oxygen; TOC = total organic carbon; POC = particulate organic carbon; DOC = dissolved organic carbon ; PO_4 = phosphate; NO_3 = nitrate; psu = practical salinity units, NA = not applicable.				

C.3.2 Data Analysis

A generalized linear model was used to examine statistical significance of the water-property metrics with respect to the month of sample collection (season), habitat stratum, and site. A nearest-neighbor cluster analysis of selected standardized variables examined similarity between the sample month, habitat strata, and site.

C.4 Results

Total suspended sediments (TSS) were dominated by the inorganic fraction (Figure C.2), and ranged from 57% inorganic matter in May at OC-25 to a high of 87% inorganic matter in November at OC-29. The TSS concentrations ranged between 3 and 10 mg/L with the exception of WC-3 site, which reached 64 mg/L in September.

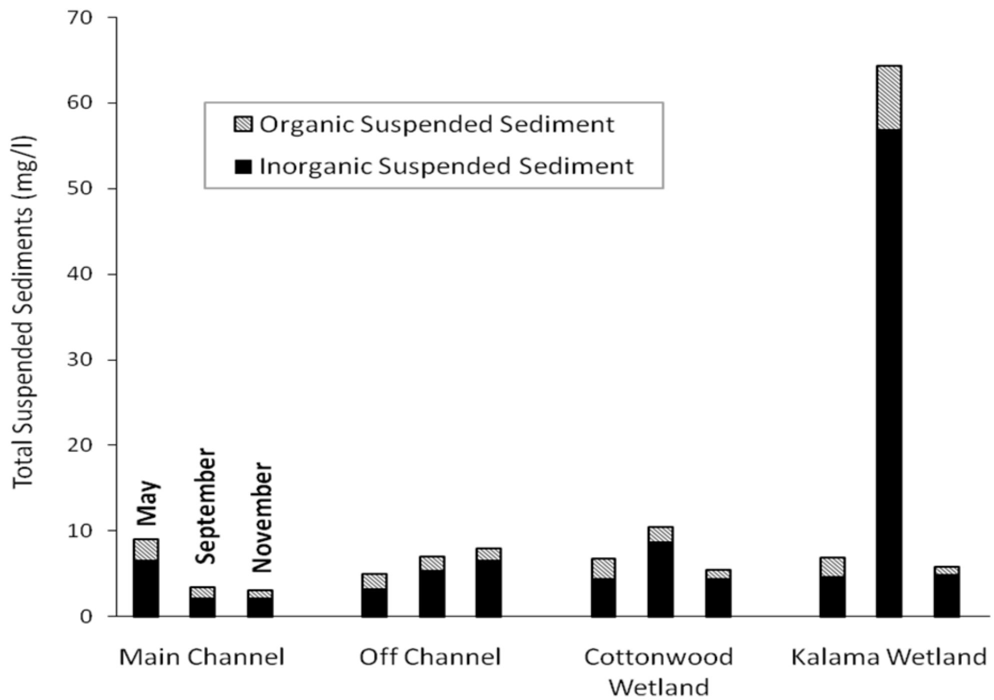

Figure C.2. Monthly Mean Organic and Inorganic Fraction of Total Suspended Sediments at Sites: Main Channel, Off-Channel, and Wetland Channel Separated into Cottonwood and Kalama

TOC ranged from a low of 2.2 mg/L in the main channel in November to a high of 3.4 mg/L in the wetland channel (WC-3) during September (Figure C.3). The dissolved component was dominant at all sites with the exception of the WC-3 site in September where particulate carbon increased relative to the dissolved fraction. Particulate organic carbon (POC) expressed as a percentage of total suspended particulate matter (SPM), ranged between 7 and 19% through the seasons and habitat strata. This range is typical for river systems with lower turbidity such as the Columbia (~10 mg SPM), and a similar POC/SPM ratio has been shown previously in the LCRE (Sullivan et al. 2001; Prahl et al. 1998).

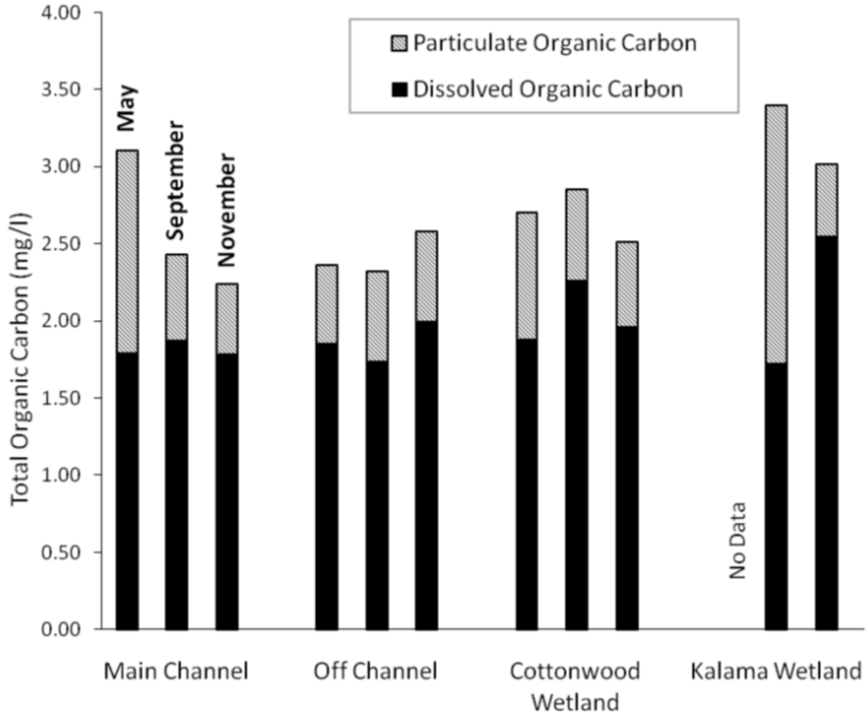

Figure C.3. Mean Particulate and Dissolved Fraction of Total Organic Carbon from the Main Channel, Off-Channel, the Wetland and Kalama Channels During Each Month Sampled

Chlorophyll_*a* concentrations ranged from a low of 0.9 mg/L at the off-channel sites during November 2010 to a high of 10.7 mg/L at the Cottonwood wetland sites during May 2010 (Figure C.4). Chlorophyll_*a* concentrations were significantly higher at the main-channel, off-channel, and Cottonwood wetland-channel sites during the spring seasons in May of 2010 and 2011, with a decrease shown in the early fall (September 2010) and a further decrease in November. The exception was the WC-3 site with an elevated chlorophyll_*a* concentration during September 2010, similar to the spring concentrations.

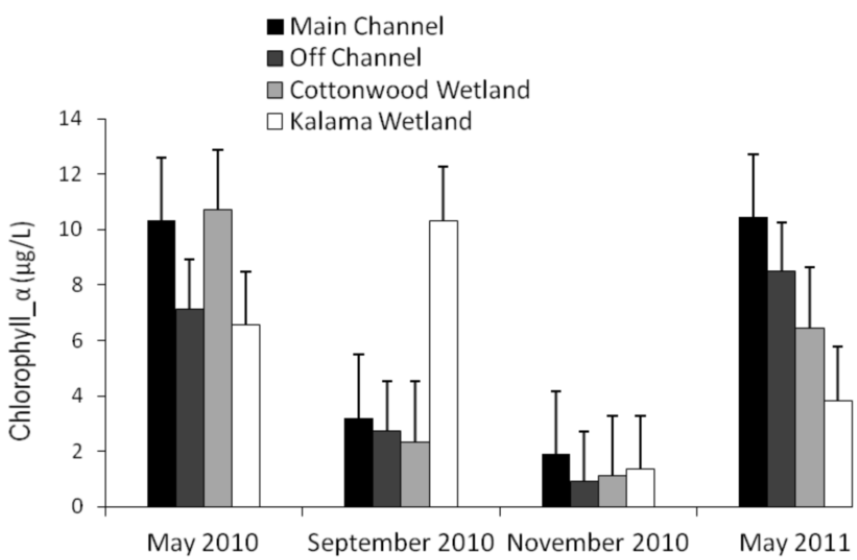

Figure C.4. Mean Chlorophyll_*a* Concentration (± 1 SD) from the Main Channel, Off-Channel, and the Wetland and Kalama Channel During Each Month Sampled

Phytoplankton abundance followed a pattern similar to the chlorophyll_*a* concentration with a spring density of 13,000 to 14,000 cells/mL during May of 2010 and 2011 in the main channel and a reduction in the early fall and late fall to 300 cells/mL in the main channel (Figure C.5). The exception again was the WC-3 site during September with the highest density of 15,000 cells/mL. These overall densities are similar to those found by Haertel et al. (1969) in the LCRE over a 16-month period and Frey et al. (1984) over a 13-month period. During the entire study, phytoplankton species were dominated by freshwater diatoms. A similar distribution was noted by Haertel et al. (1969), Frey et al. (1984), Lara-Lara et al. (1990), and Sullivan et al (2001). Dominant taxa included *Asterionella*, *Melosira* and *Fragilaria.* The diversity of taxa was similar between all habitat strata and was greatest during the spring sample collections. Diversity decreased in September with a further decrease in November.

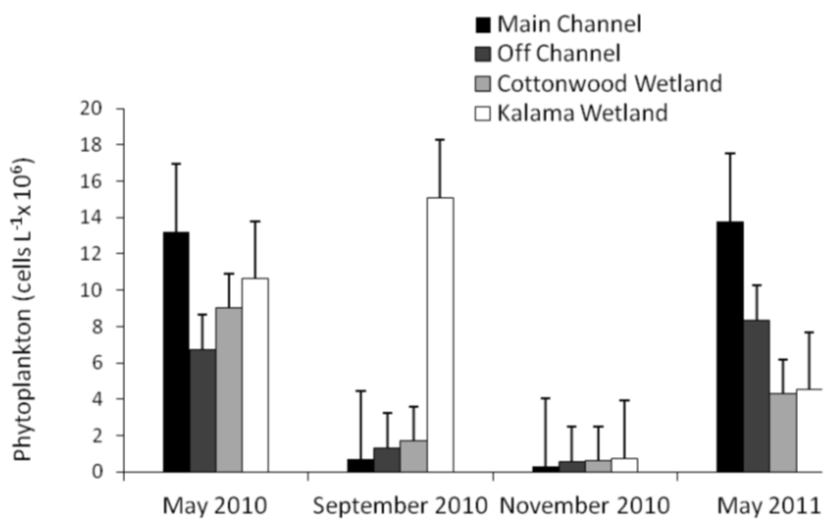

Figure C.5. Mean Phytoplankton Abundance (± 1 SD) from the Main Channel, Off-Channel, and the Cottonwood and Kalama Wetland Channel Sites During Each Month Sampled

In general, nitrate concentrations were lower in May and September for most sites and highest in November (Figure C.6). Although sampling did not occur at regular seasonal intervals, the data appear to follow a typically distinct seasonal variation for nitrate and phosphate that has been observed in the lower Columbia River, with the greatest concentrations appearing in the winter and the lowest concentrations occurring in the summer (Haertel et al. 1969; Dahm et al. 1981; Sullivan et al. 2001). Phosphate concentrations (Figure C.7) were lowest in May 2010 and 2011 with the exception of higher values at the WC-3 site (Kalama wetland) in May 2011 and higher but variable concentrations in September and November. Statistically, analysis of the data demonstrate significant differences between sampling periods (e.g., season), but show no statistically significant difference between habitat strata. However, several site specific differences are noted (e.g., lower nitrate at Cottonwood wetland and higher phosphate at the WC-3 site (Kalama wetland) in 2011).

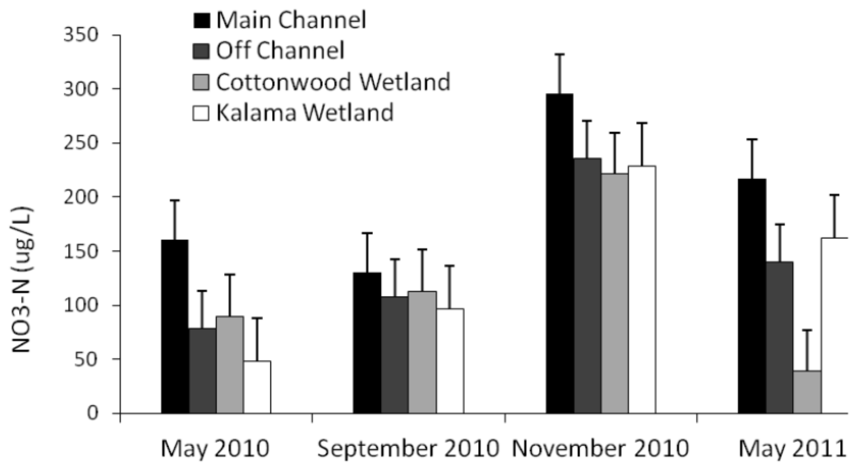

Figure C.6. Nitrate Concentration (± 1 SD) from the Main Channel, Off-Channel, and the Cottonwood and Kalama Wetland-Channel Sites During Each Month Sampled

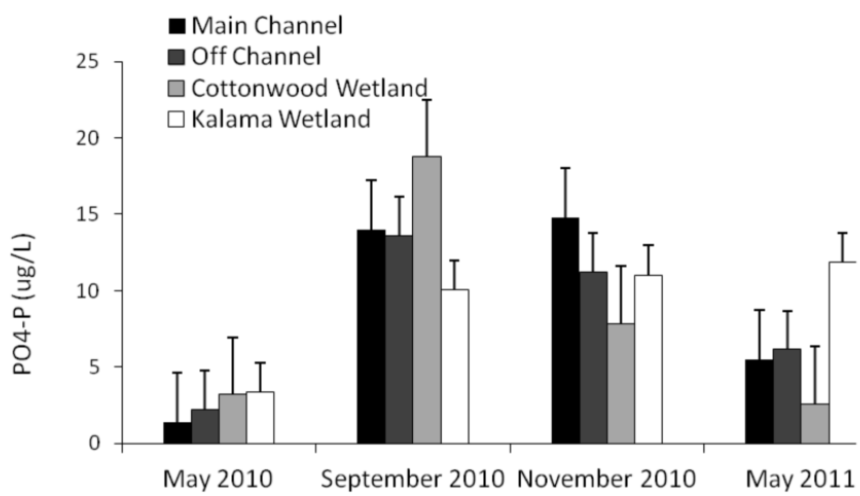

Figure C.7. Phosphate Concentration (± 1 SD) from the Main Channel, Off-Channel, and the Cottonwood and Kalama Wetland-Channel Sites During Each Month Sampled

The temporal patterns observed for phytoplankton, chlorophyll_*a*, and nutrients are likely linked through a combination of river flow rates, and timing of the spring freshet affecting inter-annual variability. Flow rates are known to exert influence on the mixing in the water column, influencing control of available light for phytoplankton growth. Light availability has been identified as a primary controlling factor for phytoplankton production in the estuary and river (Lara-Lara et al. 1990; Frey et al. 1983). Flow rates also control the retention time of water in the estuary, thereby influencing the growth and retention of phytoplankton in the estuary. Similarly, nutrient presence and availability, based on previous studies has shown a reduction in the estuary in the summer as phytoplankton production increases and nutrients are drawn down during low flows (Sullivan et al. 2001; Lara-Lara et al. 1990; Frey et al. 1983; Haertel et al. 1969). Although our data represent only four time periods, the temporal patterns shown are not dissimilar to those shown in previous studies.

Non-metric, multi-dimensional scaling (MDS) plots summarize the relative differences and similarities in biogeochemical properties between habitat strata and season. Figure C.8 shows the similarity and clustering for all sites and dates using a selected suite of biogeochemical attributes. Variables represented in this analysis are temperature, TSS, POC, nutrients, and cell abundance. Generally, the data are clustered by season, rather than by habitat stratum. The WC-3 site in May and September 2010 (upper left and upper right in plot) show the least similarity to the other groupings, as evidenced in previous plots. May samples for both years are represented as green-colored symbols; unfilled symbols represent May 2010 and filled symbols represent May 2011. For May sampling, both years are discrete yet related when compared to the other seasons. When the two samples from the WC-3 site (Kalama wetland, May and September) are removed, the seasonal differences are more apparent (Figure C.9).

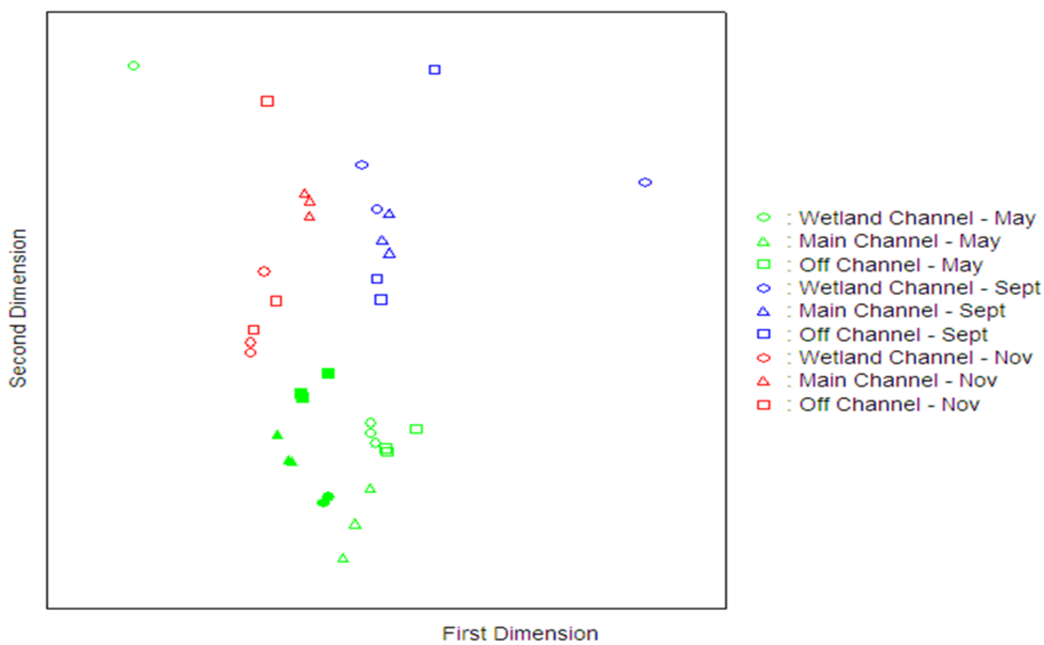

Figure C.8. Multi-Dimensional Scaling Plot of Selected Attributes (temperature, TSS, POC, nutrients, cell abundance) for All Sites and Dates. May 2010 shown as green unfilled symbols; May 2011 shown as green filled symbols.

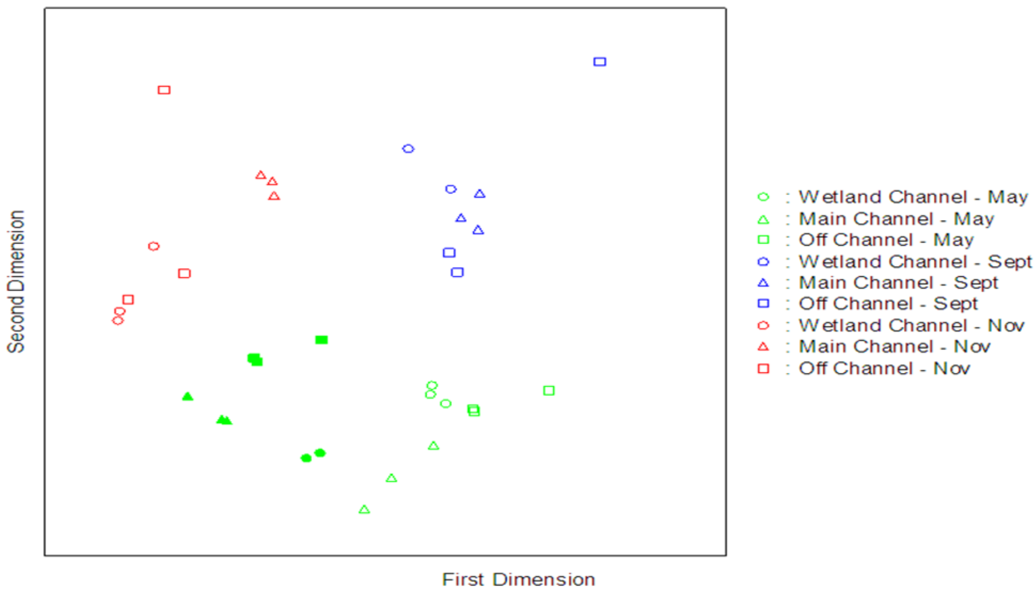

Figure C.9. Multi-Dimensional Scaling Plot of Selected Attributes (temperature, TSS, POC, nutrients, cell abundance) for All Sites and Dates, with WC-3 (Kalama Wetland) May and September 2010 Removed. May 2010 shown as green unfilled symbols; May 2011 shown as green filled symbols.

C.5 Summary

This pilot study was designed to provide a preliminary collection of water- biogeochemical parameters in support of the development of habitat connectivity and survival benefits indices. As a preliminary study, the sampling was restricted in terms of the number of samples collected and the timing and duration of sample collection, thus limiting the interpretation of the data beyond a cursory level. However, the data show distinct temporal differences of selected water properties associated with primary production (chlorophyll_*a*, phytoplankton abundance, nutrients), which relate to the food web structure and prey resources for juvenile salmon. From a spatial perspective, the lack of significant differences in water properties between habitat strata that surround Cottonwood Island are notable in that the water appears to be well-mixed at this scale despite the presence of different land cover types and channel morphology representing the three habitat strata; at larger spatial scales within the LCRE, gradients in salinity, nutrients, organic matter, and primary production would be expected.

Nutrients and organic matter constitute the basic fuels for the estuarine food web, and varying the quantity and quality of these water properties can significantly affect food web productivity and resilience (ISAB 2011). In addition, seasonal, annual, and spatial drivers (e.g., flow discharges, flooding, tides) to the base of the food web change the composition, availability, and timing of prey resources for juvenile salmonids. Research is needed to develop a quantitative and functional understanding of the linkages between key components of the estuarine food web (e.g., organic matter, nutrients), prey resources, and juvenile salmon habitat use. In the larger picture, prioritization of restoration activities in the Columbia River estuary, and indices currently being developed to measure restoration effectiveness in terms of habitat connectivity and survival can be informed and strengthened by research directed toward the food web linkages described above.

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Appendix D

Habitat Connectivity Index Progress Report

Appendix D

Habitat Connectivity Index Progress Report

Prepared by Heida Diefenderfer, Erin Donley, Yinghai Ke, Andre Coleman, and Nikki Sather

The overall goal for habitat connectivity research in 2010 was to "develop methods and perform a pilot field and [geographic information system] study utilizing a long-term, intensively monitored area to assess the structural and functional habitat connectivity for juvenile salmonids of key estuarine habitats associated with habitat restoration actions in the lower Columbia River and estuary." These results, derived from beach seine, fish physiology, and water properties data collected in three habitat strata at Cottonwood Island with differing levels of habitat connectivity, are reported in Appendices B, C, and J.

Thus, non-field research continued, but was de-prioritized during 2010. Research in 2011 will compose the final year of research on the habitat connectivity topic under the Salmon Benefits project, so a comprehensive report on the subject will be provided in the 2011 annual report. This progress report summarizes non-field results for 2010 that achieved final conclusions that can inform management decisions and upon which future research can be based. Of the preliminary multi-metric index developed in the 2009 study year, the primary research effort in 2011 was on passage barrier accounting. As described in the 2009 literature review (Diefenderfer et al. 2010, reduction of barriers to salmonid passage and hydrologic flows is a primary goal of the habitat restoration program in the lower Columbia River and estuary (LCRE). The passage barrier accounting method is the most straightforward metric in the habitat connectivity index, providing a simple estimate of the reduction in barriers achieved through ecosystem restoration (e.g., tide gate installation, dike breaching). Thus, this progress report is focused on the passage barrier accounting method of assessing changes in habitat connectivity produced by restoration actions in the LCRE.

The passage barrier accounting method, in essence, represents a simple subtraction of the number of passage barriers removed from the original set of passage barriers. The challenges, therefore, involve measurement of the set of passage barrier in existence in 2000 (the year of the original Biological Opinion [BiOp] for the Federal Columbia River Power System), and measurement of changes in them as a result of restoration projects funded by the Action Agencies since then. We contend that the underlying premise associated with quantifying the change in passage barriers provides a tangible value with which managers can begin to evaluate the potential for increased habitat connectivity between the main-channel and floodplain habitats. This is because an increase in habitat connectivity has the potential to provide direct benefits to juvenile salmon through provisions of habitat access and may also lead to improved ecosystem conditions or indirect benefits by restoring the structural and functional integrity of formerly disconnected sites. While this is a simplified approach for measuring changes in habitat connectivity, its measurement remains intractable in some ways because of the state of data available on the estuary, as described in this appendix.

We began our 2010 research by conducting an inventory of available data, then, based on the identified gaps, we continued with exploration of alternative methods to develop the data needed to perform the simple passage barrier assessment calculation. This appendix describes the results of these efforts and progress on structural and functional connectivity analyses. It begins with a brief synopsis of the previous pilot study on passage barrier accounting, and then details the progress made to gather existing data and develop new measurement methods to expedite filling data gaps in the passage barrier accounting assessment.

D.1 Background

In the first year of the Salmon Benefits study, we conducted a pilot study of passage barrier accounting (Diefenderfer et al. 2010). The selected complex of restoration projects was located on the Grays River and Deep River, tributaries to Grays Bay on the Washington side of the LCRE. These restoration projects were implemented by the Columbia Land Trust and partners, and were funded by the Bonneville Power Administration (BPA) through the Lower Columbia River Estuary Partnership (LCREP). In that pilot study, we measured change in passage barriers using four metrics: width of restored passage, area of restored passage, area of habitat made available by the new passage, and percent of habitat area increase (percent of the tidal floodplain of the Grays River). Six dike breaches and one double culvert installation were assessed. Existing survey data from the U.S. Army Corps of Engineers' (USACE's or Corps') cumulative effects project were used for the calculations (Johnson et al. 2008; Diefenderfer et al. 2008, Table II); these surveys evaluated cross sections in channels at the former location of the dike (for breaches), or immediately inside the dike (for culverts).

The results of the pilot study showed that the Grays River project complex produced a 16.4% increase in combined channel and floodplain habitat area: 6.7% by implementation of dike breaches and 9.7% by culvert installation. The remaining three metrics showed that the combined Grays River and Deep River complex produced a passage barrier decrease (potential fish passage increase) of 226.25 m (width of channel cross sections); a passage area increase of 221.26 m^2 in total area of channel cross sections; and a potential habitat area increase of 1.754 km^2.

In the pilot study, calculations of wetted area were made possible by previous Corps-funded research to develop wetted area models for habitat restoration and reference sites (Diefenderfer et al. 2008; Coleman et al. in preparation). Such models are not available at the LCRE scale or at individual LCRE reach scales. Thus, to expand the geographic scope of the passage barrier accounting method to reaches and the entire estuary required development of a new method for calculating habitat area, a method that is described in this appendix.

D.2 Spatial Inventory of Dike Data

The first term in the passage barrier accounting equation is the total existing passage barriers. During 2010, as detailed in this section, we inventoried existing spatial data and data source on dikes in the LCRE and floodplain for the purpose of passage barrier accounting, and we assessed the accuracy of these data sources. Through this process, we determined that future work is needed to update and create digital dike data. The existing spatial data includes "LCREP Levee Fill Database" by the University of Washington (UW) (called "UW dike data" in this report) and "diking.shp" developed from the Pacific Northwest National Laboratory (PNNL) prioritization framework created for the LCREP (Evans et al. 2006, referred to as "prioritization dike data" in this appendix). The data sources available at present for updating and/or creating dike data include high spatial resolution Light Detection and Ranging (LiDAR) data acquired in 2005 and 2009.

D.2.1 Comparison of UW Dike Data and Prioritization Dike Data

The major difference between the UW dike and prioritization dike data sets, are that UW dike data represent the location of dikes using lines in ArcInfo Geographic Information System (ArcGIS), while prioritization dike data are polygons representing the affected area of dikes (Table D.1). Visual assessment of the two data sets showed that the UW dike lines were missing and not complete compared to the prioritization dike data (Figure D.1). However, the polygon-based representation of the prioritization dike data is not suitable for dike-breaching analysis, an analytical method requiring measurements of the linear features of dikes on the landscape.

Table D.1. Comparison of UW Dike Data and Prioritization Dike Data

	UW Dike Data	Prioritization Dike Data
Data source	2005 LiDAR DEM, Google Earth imagery, Diking District Records	Mainly acquired from Jen Burke and Si Simenstad, UW (assume created from 10-m DEM).
Generation method	Manual delineation	UW layers "were edited to create a master polygon layer representing diked areas in the LCR. Additional diking data not present in the UW layer were added from USACE diking file. All lines were converted to polygons representing the estimated area behind the dike (i.e., potential hydrologic reconnection area). This was estimated using floodplain boundaries and DOQs. The master diking file was then post-processed to create a clean and consistent dataset." (Evans et al. 2006, Appendix A)
Data representation	Polylines	Polygons
Ground validation	None	Unknown

DEM = Digital Elevation Model; DOQ = Digital Orthophoto Quadrangles ; LCR = lower Columbia River

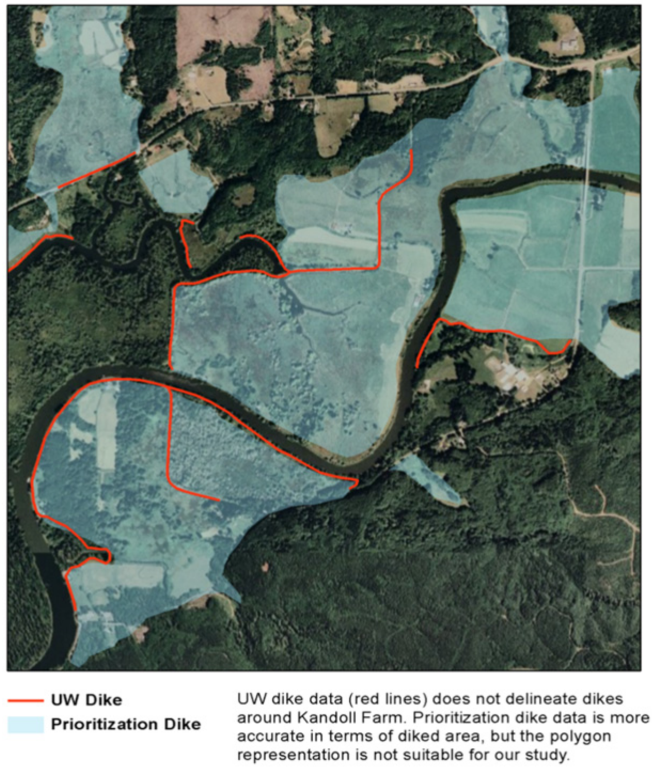

Figure D.1. Visual Comparison of UW Dike Data and Prioritization Dike Polygons

D.2.2 Comparison of 2005 LiDAR Data and 2009 LiDAR Data

2005 LiDAR data were acquired in the January-February 2005 time frame with vertical accuracies of ±15 to 25 cm on soft/vegetated surfaces in flat to rolling terrain and ±25 to 40 cm in hilly terrain (LiDAR Bare Earth DEM 2005). The post-processed data have a spatial resolution of 1 m. The 2009 LiDAR data were collected between December 2009 and February 2010, and, on average, collected over 8 points per square meter (Columbia River Survey 2010). The post-processed data have a spatial resolution of 1 m. Higher accuracies were achieved in the 2009 data set, with around 4-cm mean vertical errors.

Both data sets exhibited distinguishing differences between dike elevations and the elevations in other areas in the example sites (Figure D.2). However, the 2009 LiDAR elevation is superior to the 2005 LiDAR elevation because it reveals more detailed terrain variation (Figure D.2).

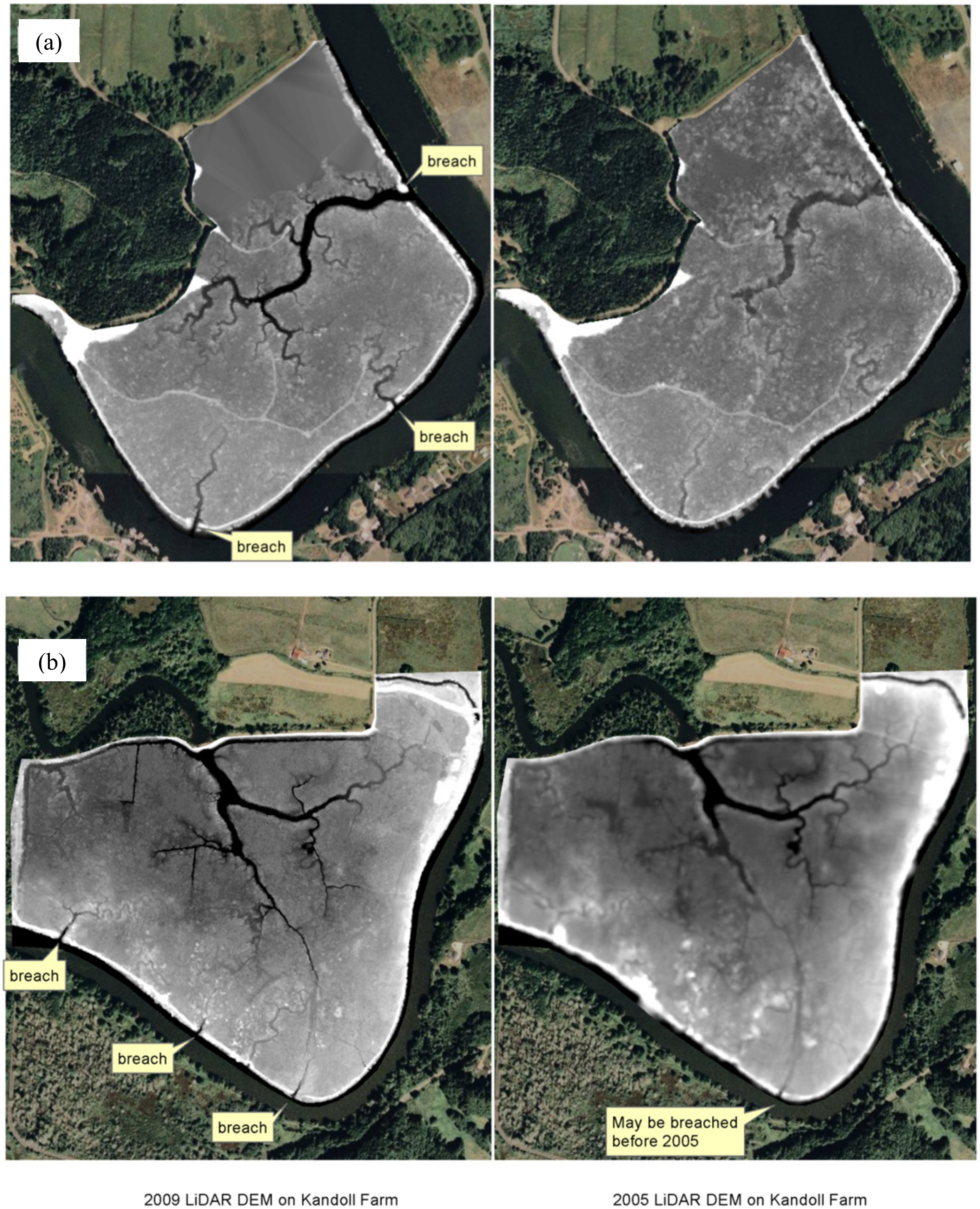

Figure D.2. Comparison of 2009 and 2005 LiDAR Elevation on the (a) Kandoll Farm and (b) Deep River Sites

D.2.3 Automatic Method to Extract Dike Lines

Several methods were examined to extract dike lines automatically, including elevation and landform classification, valley bottom flatness index, plan/profile curvature classification, computer-assisted feature extraction, etc. Among these methods, the Feature Analyst tool in ArcGIS has the best capability to extract the linear patterns of a dike. Figure D.3 demonstrates the dike lines generated using Feature Analyst at a site scale for existing Columbia Land Trust restoration sites Deep River and Johnson Property in the vicinity of Grays Bay, Washington. The elevation data were first clipped based on the site polygon; the Feature Analyst was trained to the type of feature that needed to be extracted and then applied to extract the linear patterns. The resulting polygons were used to create centerlines that represent the estimated dike lines. With post-processing such as manual editing or selection by line length in ArcGIS, extraneous data can be removed. Although the tool performs well at the site scale, it can extract redundant features such as subtle changes in terrain if the elevation in the whole tile was analyzed (Figure D.4).

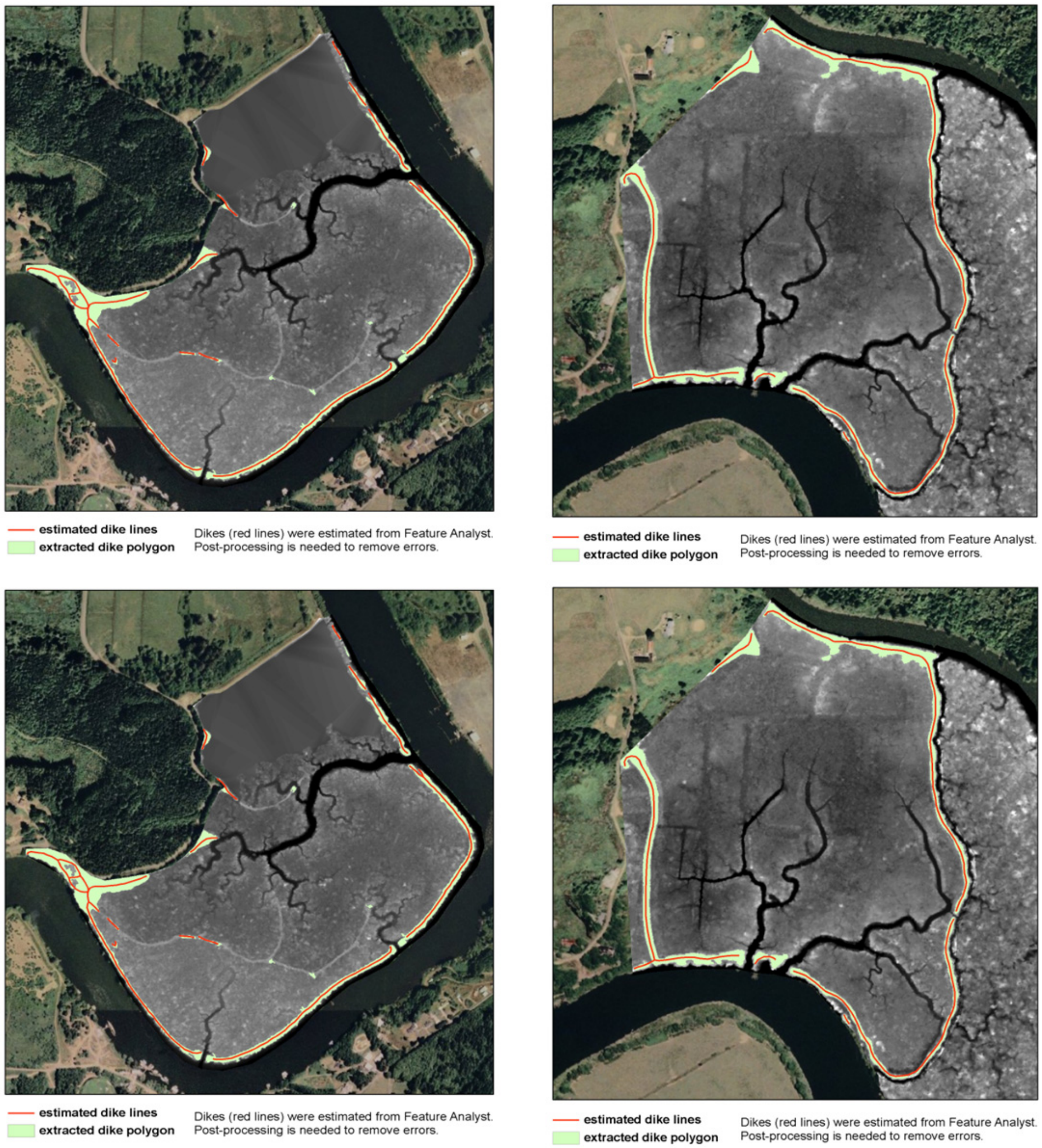

Figure D.3. Dike Lines Extracted from Feature Analyst at Deep River (left) and Johnson Property – West (right)

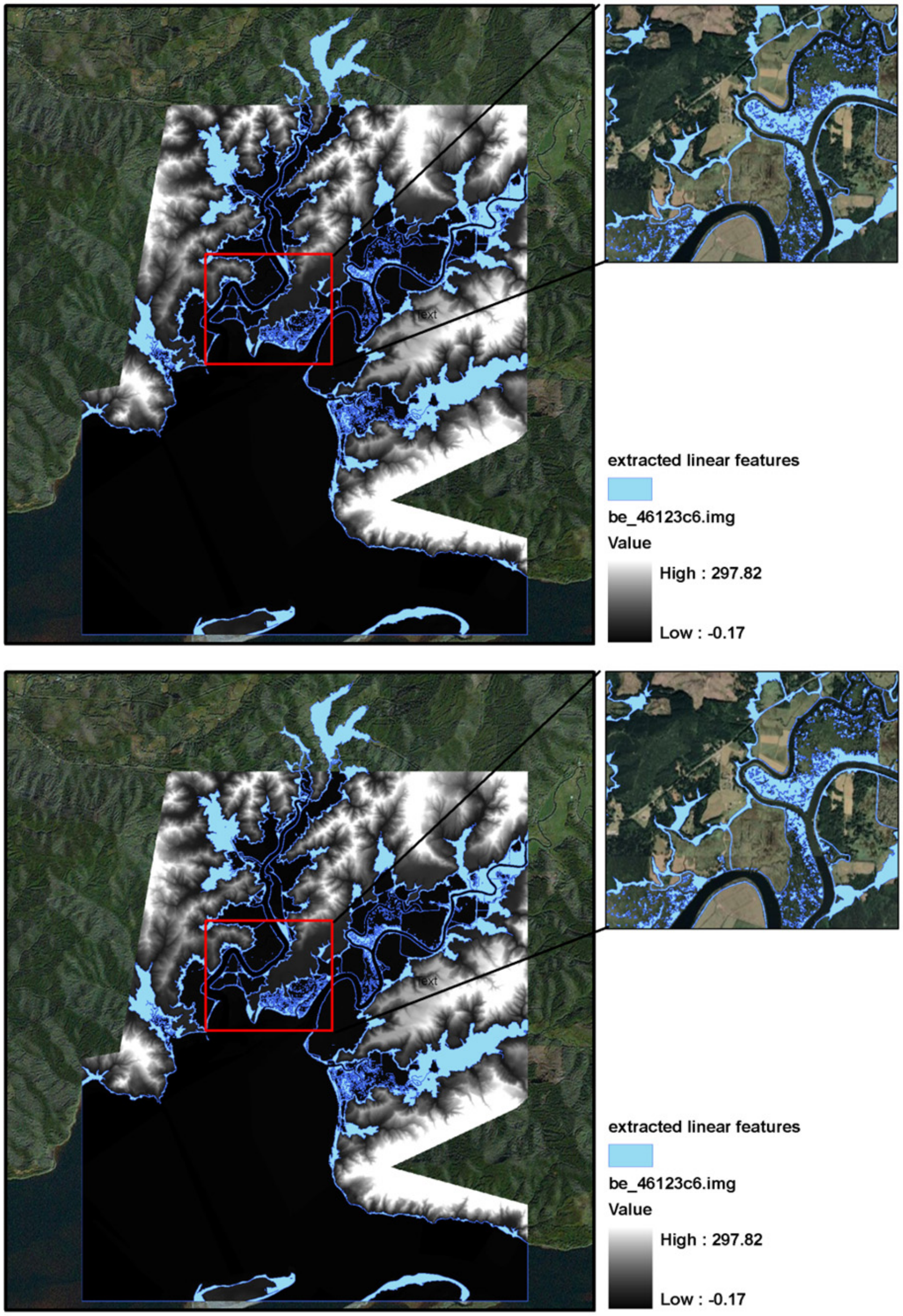

Figure D.4. Features Extracted for a LiDAR Tile

D.2.4 Summary of Dike Data Evaluation

Neither UW dike data nor prioritization dike data can be directly used for dike-breaching evaluation purposes. Feature Analyst provides an automatic tool for extracting dikes at an individual site scale, but post-processing will be required to remove linear features incorrectly classified as dikes and to add dike segments that were missed or removed via GIS cleanup techniques. For a larger region, or over the whole estuary, we recommend further exploration of the potential of Feature Analyst to extract a dike layer.

D.2.5 Oregon Department of Land Conservation and Development), Oregon Estuarine Levees Inventory, 2009–2011 (In progress)

In the course of our 2010 dike data evaluation, we learned of a simultaneous effort sponsored by the Oregon Department of Land Conservation and Development (ODLCD) and the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center Fellowship (Mattison 2010). Through subsequent meetings with the NOAA Coastal Fellow and the LCREP, it became clear that the NOAA/ODLCD effort had the potential to fill the data gap we had identified relative to a linear-feature diking layer in the LCRE. However, because the fellowship began with research in southern Oregon and worked to the north, work on the LCRE—the largest estuary in the study area—did not begin until 2011. Therefore, the Salmon Benefits project team committed to providing assistance to the NOAA/ODLCD effort.

To date, the Salmon Benefits project team (“team”) has coordinated the delivery of the Washington State ownership information for the LCRE historical floodplain, by the USACE; and provided our initial assessment of the ability of automated feature-extraction tools to improve the efficiency of the process. The team has compiled spatial data pertaining to the location of tide gates and diking improvement districts, and has made these data available to the Oregon Estuarine Levees Inventory team. The team is also providing technical support to the NOAA/ODLCD effort by ensuring access to spatial data coverage of the entire historical floodplain. The fellowship’s effort is scheduled for completion in September 2011, at which time the diking layer will be publicly available at a forthcoming website (http://www.coastalatlas.net/index.php?option=com_wrapper&Itemid=28&map=estuarymap&cps=-10416.666666666744,940972.222222222,3000000&layers=__base__,Estuaries). We may use it to update the passage barrier accounting assessment for the Salmon Benefits study.

D.3 Inventory of Passage Barrier Removal Data

The second term in our passage barrier accounting equation is passage barrier removal, which was measured by four metrics in the pilot study (Diefenderfer et al. 2010). Early in the 2010 estuary-scale inventory process, we learned that no single database of passage barrier removal with Action Agencies BiOp funds exists. Therefore, it became clear that the essence of this task would be to collate existing data from multiple sources and identify data gaps. In recognition of the fact that data available for all projects that have occurred in the LCRE since 2000 were likely to be more highly variable than the data that we ourselves had collected in the Grays River and Deep River areas and used in the pilot study, we developed a slightly larger set of potential passage barrier removal metrics for the estuary-scale inventory, with the hope that at least one of the metrics would have been collected on all projects. The metrics included in the query table that we developed to interview project managers (Table D.2, Figure D.5) were as follows:

- agency/organization
- restoration activity
- project name/location
- project dates

- number of dikes removed/modified
- dike top-width
- channel cross-sectional area
- number of culverts removed/modified
- total increase in passage area from culverts/tide gates
- available spatial data
- latitude and longitude.

These metrics are essentially basic implementation and compliance survey metrics, not action-effectiveness metrics (Thom and Wellman 1996; Busch and Trexler 2003). With the query tables in hand, we queried restoration practitioners and managers operating throughout the estuary and receiving Action Agency BiOp funds, in order to develop the most complete available data set to date on passage barrier removal.

Table D.2. Hydrologic Reconnection Restoration Projects for Which Dimensions for Altered Flow-Restricting Structures Are Available

Agency/Organization	Activity[a]	Project Name/Location[b]	Dates[c]	Number of DikeModifications[d]	Dike Top-width (meters)[e]	Channel Cross-sectional Area (m^2) (if known)[f]	Number of Culverts Removed/Modified[g]	Number of Tide Gates Removed/Modified[h]	Total Increase in Passage Area from Culverts/Tide Gates (m^2)[i]	GIS Polygon/Map Available? (Y/N)[j]	Latitude	Longitude
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWR - Brooks Slough	2009to 2010	-	-	2.32	0	3	6.96	Y	46.2578	-123.417964
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWR - Duck Lake Slough	2010	-	-	2.67	0	1	2.67	Y	46.2385	-123.412689
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWR - Hampson Slough	2009	-	-	2.67	1	1	2.67	Y	46.2593	-123.425187
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWR - Indian Jack Slough	2010	-	-	2.67	1	1	2.67	Y	46.2314	-123.399096
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWR – (W-259) Unnamed Slough 2	-	-	-	-	1	-	2.32	Y	46.268	-123.447177
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWR - Winter Slough	2009	-	-	2.67	1	1	0.65	Y	46.255	-123.435654

Table D.2. (contd)

Agency/Organization	Activity[a]	Project Name/Location[b]	Dates[c]	Number of DikeModifications[d]	Dike Top-width (meters)[e]	Channel Cross-sectional Area (m^2) (if known)[f]	Number of Culverts Removed/Modified[g]	Number of Tide Gates Removed/Modified[h]	Total Increase in Passage Area from Culverts/Tide Gates (m^2)[i]	GIS Polygon/Map Available? (Y/N)[j]	Latitude	Longitude
USACE	Tide Gate Modifi-cation	Julia Butler Hanson NWRH – (W-201) Unnamed Slough 1	-	-	-	-	-	-	0.65	Y	46.2597	-123.440058
LCREP	Culvert Removal	Alder Creek Fish Passage Restoration	2005 to 2006	-	-	-	3	-	-	Y	45.8319	-122.954309
LCREP	Culvert Removal	Conyers Creek	2007	-	-	-	4	-	2.99	Y	46.1004	-123.2009
LCREP	Culvert Removal	Mirror Lake Phase 1 Young Creek Culvert restoration	2005	-	-	-	2	-	9.29	Y	45.5454	-122.207251
LCREP	Culvert Removal	Oaks Bottom Restoration	2007	-	-	-	1	-	1.82	Y	45.4762	-122.657684
CREST	Tide Gate Modifi-cation	Barrett Slough	2005	-	-	-	-	1	1.82	Y	46.1369	-123.867811
CREST	Culvert Installa-tion	Brownsmead - Blind Slough Restoration	2003to 2006	-	-	-	7	-	18.94	Y	46.2146	-123.529439
CREST	Tide Gate Modifi-cation	Brownsmead - Blind Slough Restoration	2003to 2006	-	-	-	-	4	7.28	Y	46.2146	-123.529439
CREST	Culvert Installa-tion	Fort Clatsop, Phase 1	2007	-	-	-	1	-	0.66	Y	46.1285	-123.88052
CREST	Tide Gate Modifi-cation	Johnson Slough	2003	-	-	-	-	1	1.82	Y	46.3169	-123.661267
CREST	Tide Gate Modifi-cation	Larson Slough	2004	-	-	-	-	1	1.82	Y	46.1213	-123.874793
CREST	Dike Scrapedo wn	Lewis and Clark River Dike Breach, Phase 1	2004to 2005	3	1) 1.74 2) 1.74 3) 1.07	-	-	-	7.91	Y	46.0914	-123.84762
CREST	Dike Removal	Lewis and Clark River Dike Breach, Phase 2	2005to 2006	6	1)30.48 2)30.48 3)15.24 4)27.43 5)24.38 6)12.19	-	-	-	261.99	Y	46.0939	-123.849495
CREST	Culvert Removal	Perkins Creek Restoration and Enhancement	2009	-	-	-	1	-	0.66	Y	46.1298	-123.913565
CREST	Culvert Installa-tion	Perkins Creek Restoration and Enhancement	2009	-	-	-	1	-	21.08	Y	46.1298	-123.913565

Table D.2. (contd)

Agency/Organization	Activity[a]	Project Name/Location[b]	Dates[c]	Number of DikeModifications[d]	Dike Top-width (meters)[e]	Channel Cross-sectional Area (m^2) (if known)[f]	Number of Culverts Removed/Modified[g]	Number of Tide Gates Removed/Modified[h]	Total Increase in Passage Area from Culverts/Tide Gates (m^2)[i]	GIS Polygon/Map Available? (Y/N)[j]	Latitude	Longitude
CREST	Channel Exca-vation	Skipanon River	2002	-	-	-	-	-	8.04	Y	46.1799	-123.909719
CREST	Tide Gate Modifi-cation	Vera Slough	2005	-	-	-	-	2	4.64	Y	46.1642	-123.889726
CLT	Dike Removal	Grays Bay - Devil's Elbow Acquisition and Restoration	2004	2	32.5	-	-	-	20.26	Y	46.313	-123.66906
CLT	Levee Removal	Grays Bay - Deep River Phase 2: Campbell Acquisition and Restoration	2004	3	43.9	-	-	-	62.4	Y	46.3184	-123.699282
CLT	Tide Gate Removal	Grays Bay - Deep River Phase 2: Campbell Acquisition and Restoration	2004	-	-	-	-	1	0.66	Y	46.3184	-123.699282
CLT	Dike Removal	Grays Bay - Kandoll Farm Phase 2 Acquisition and Restoration	2003 to 2005	-	23	-	-	-	20.82	Y	46.3239	-123.653281
CLT	Levee Removal	Grays Bay - Johnson Farm Restoration	2003 to 2004	-	30.65	-	-	-	15.8	Y	46.3169	-123.661267
CLT	Natural Dike Breach	Haven Island	-	-	26.0	54.5	-	-	-54.5	Y	46.1165	-123.808419

"-" = Data not available; CREST = Columbia River Estuary Study Taskforce; CLT = Columbia Land Trust

(a) Restoration activity documented by the Lower Columbia River Estuary Partnership (LCREP).
(b) Name and location of the project documented by LCREP.
(c) Years during which the restoration activity took place.
(d) Number of dike modifications that took place at the restoration site.
(e) Width of top of dike (in meters; see Figure D.5)
(f) Channel cross-sectional area (in m^2). NOTE: please feel free to attach cross-section data for calculation purposes. Channel cross-sectional area can be estimated using the formula for area of a trapezoid: (Area = ½ (top width + width bottom) x depth).
(g) The number of culverts removed or modified at the restoration project site.
(h) The number tide gates removed or modified at the restoration project site.
(i) Increase in area (m^2) of passage resulting from culvert/tide gate modification or removal. NOTE: please feel free to attach before and after specifications of culverts/tide gates for the purpose of calculating total change in area. The area of passage can be estimated using the formula for the area of a circle: $A= \prod r^2$
(j) Are you able to provide GIS polygons or maps of the restoration projects?

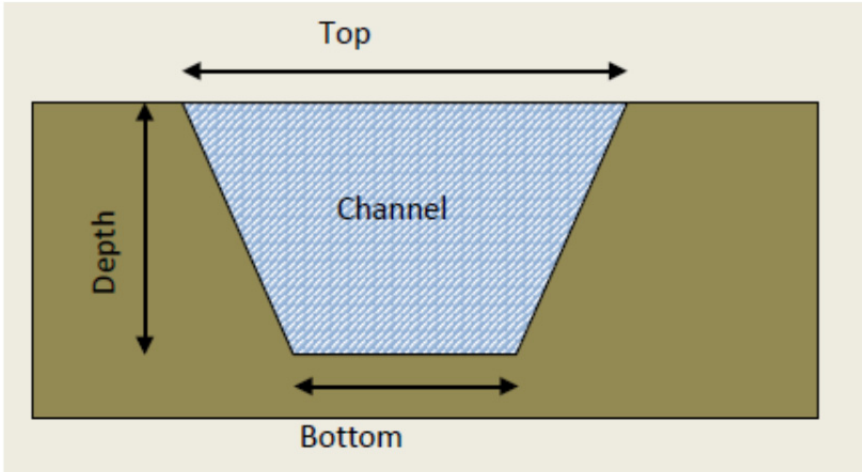

Figure D.5. Graphical Explanation of Dike Breach Dimension Used for Top-Width and Area Calculations. Blue cross-hatched area represents cross-sectional area.

D.3.1 Inventory of Hydrologic Reconnection Projects

We began by compiling a master table of all past and present restoration projects involving hydrologic reconnection in the LCRE. The primary source for this table was the LCREP's online Program Database (http://maps.lcrep.org/). Currently, LCREP's online database is the only comprehensive inventory of restoration projects in the LCRE that is publicly available. Other sources included the Conservation Registry (http://www.conservationregistry.org/); information products of the Estuary and Ocean Research, Monitoring, and Evaluation Subgroup; and personal communication with project managers at various organizations and agencies. We discovered a significant barrier to this seemingly simple effort in the different uses of the term "project" by key participants in the Columbia Estuary Ecosystem Restoration Program: the BPA, Corps, LCREP, Columbia Land Trust (CLT), and Columbia River Estuary Study Taskforce (CREST). We found that in many cases, a single on-the-ground restoration project was counted multiple times in agency tracking systems because it had been funded incrementally; i.e., the term "project" was linked with a funding installment rather than a location in the LCRE being restored. This made tracking of project actions and accomplishments much more difficult than anticipated.

Rather than reproduce the master table herein, subsequent sections of this inventory provide tables for 1) the projects we were able to obtain implementation and compliance survey information about (Table D.2) and 2) projects for which we were not able to obtain information (Table D.3). We are grateful for the personal communication from individuals throughout the region, as cited in the acknowledgements of this report. These individuals helped ensure that we were provided with all relevant information from the on-the-ground restoration projects that is currently available from their respective agencies and non-governmental organizations.

D.3.2 Collection of Survey Data

D.3.2.1 Description of Passage Barrier Data from LCREP

We identified 21 restoration sites for which LCREP was the primary contact where hydrologic reconnection restoration actions had been implemented. Of those 21 restoration sites, LCREP was able to provide 8 project reports with varying degrees of detail regarding project actions and specifications. Three of the eight project reports contained detailed information about project site restoration actions, including physical dimensions of flow-restricting structures that had either been removed or modified. One of the eight project reports contained information about the number of flow-restricting structures that had been removed or modified at the project location. However, that report did not contain details about the physical dimensions of the structures at the site. The information in the remaining four reports was not detailed enough to be relevant to our passage barrier assessment. Ultimately, we were able to obtain physical dimensions for flow-restricting structures at 3 of the 21 restoration sites for which LCREP was the primary contact.

D.3.2.2 Description of Passage Barrier Data from CREST

CREST was able to provide detailed physical dimensions for structures at all of the sites for which we requested data (12 sites).

D.3.2.3 Description of Passage Barrier Data from CLT

CLT provided us with detailed project information for all sites for which CLT was the primary contact, except the Walluski River restoration site. Physical dimensions for flow-restricting structures at Walluski River restoration site are not available because the water level was too deep to measure the structures at the time of the site visit. All other data requests were fulfilled. In sum, we requested information about 10 sites and received information about 7 sites, because it was impossible to collect structure dimensions at the remaining 3 sites.

D.3.2.4 Description of Passage Barrier Data from USACE

We identified 14 restoration sites for which USACE was the primary contact where hydrologic reconnection restoration actions had been implemented. The Corps' staff, including Amy Gibbons and Mike Ott, who were involved with many of the restoration actions at the time they were implemented, provided physical dimension data for the structures at 7 of the 14 sites.

D.3.3 Project Survey Data and Projects Without Survey Data

This section contains a table of the hydrologic reconnection restoration projects that we identified through review of documentation from the Action Agencies and primary ecosystem restoration implementing organizations in the LCRE, but for which implementation and compliance survey data could not be obtained from project sponsors.

Table D.3. Hydrologic Reconnection Restoration Projects for Which Dimensions for Flow-Restricting Structures Are not Available

Agency/ Org	Activity	Project Name/Location	Dates	GIS Polygon/ Map Available? (Y/N)	Latitude	Longitude
USACE	Tide Gate Modification	Green Slough	2002	Y	46.13318	-123.8731
USACE	Tide Gate Modification	Hanson Creek	2002	Y	46.14505	-123.8674
USACE	Tide Gate Modification	Julia Butler Hanson NWR – Tenasillahee Island	2003	Y	46.25993	-123.4317
USACE	Tide Gate Modification	Julia Butler Hanson NWR – Risk Creek	2009	Y	46.25143	-123.4002
USACE	Tide Gate Removal	Crims Island Restoration	2005 to 2007	Y	46.17193	-123.1421
LCREP	Tidal Reconnection	Anunde Island	2002	Y	46.13126	-123.2314
LCREP	Culvert Modification	Birnie Creek	2000	Y	46.20458	-123.3811
LCREP	Culvert Modification	Breeze Creek	1999	Y	45.8597	-122.6695
LCREP	Tidal Reconnection	Deer Island Slough Restoration Assessment	2009	Y	45.96048	-122.8512
LCREP	Culvert Removal	Duck Creek	2002	Y	46.26084	-123.3221
LCREP	Tidal Reconnection	Lower Washougal Restoration, Phase 1	2005	Y	45.57981	-122.3979
LCREP	Tide Gate Modification	Nikka Creek Tide Gate Improvement	ND	Y	46.32943	-123.6374
LCREP	Dike Removal	Port of Astoria Dike Breach	2002	Y	46.1569	-123.8635
LCREP	Culvert Removal	Scappoose Bay – Malarkey Ranch Barrier #261	2004	Y	45.80412	-122.8485
LCREP	Culvert Removal	Scappoose Bay – Malarkey Ranch Barrier #294	2004	Y	45.79962	-122.8467
LCREP	Dike Modification	Shillapoo NWR	2004	Y	45.71014	-122.7534
LCREP	Levee Removal	Steigerwald NWR	2006	Y	45.56367	-122.303
LCREP	Culvert Modification	Teal Slough	2003	Y	45.81659	-122.8385
LCREP	Dike Removal	Wallacut River	2005	Y	46.31898	-124.0097
LCREP	Tide Gate Modification	Warren Slough	2002	Y	46.18849	-123.5837
LCREP	Dike Removal	Westport Slough Levee Removal	2000	Y	46.12712	-123.2425
CLT	Dike Removal	Walluski River Kerr Property Acquisition and Restoration	2003 to 2004	Y	46.13112	-123.7805
CLT	Levee Removal	Walluski River Acquisition & Restoration	2006	Y	46.13112	-123.7805
CLT	Tide Gate Removal	Walluski River Kerr Property Acquisition and Restoration	2003 to 2004	Y	46.13112	-123.7805

NWR = National Wildlife Refuge ND = No Data

D.3.4 Method Development: Remote Dike Breach Detection

Because of the significant percentage of restoration projects implemented since 2000 for which no implementation and compliance survey information was available, at the Corps' direction, we undertook an effort to determine whether it would be cost-effective to measure dike breaches using remote-sensing imagery. The alternative would be on-the-ground surveys at multiple locations throughout the estuary, some requiring access by boat and most with periods of access highly restricted by tidal cycles in combination with seasonal daylight hours. It was clear, from the outset, that culverts and tide gates could not be measured from imagery collected from above the Earth.

Comparison of the 2005 and 2009 LiDAR elevations on dikes at the Kandoll Farm and Deep River restoration sites demonstrates the potential of using two data sets to detect dike breaches. For example, compared to the elevation profile along the dike in 2005, the elevation along the dike in 2009 shows an abrupt drop in elevation at the location where the dike was breached (Figure D.6). Once dike lines are established, an analysis such as this is straightforward and allows for an easy determination of dike breaches at a site and even considering whether breaches occurred since 2005 or were pre-2005. In summary, using 2009 LiDAR alone for comparison of 2005 and 2009 LiDAR elevations could have potential to extract dike and detect dike breach locations.

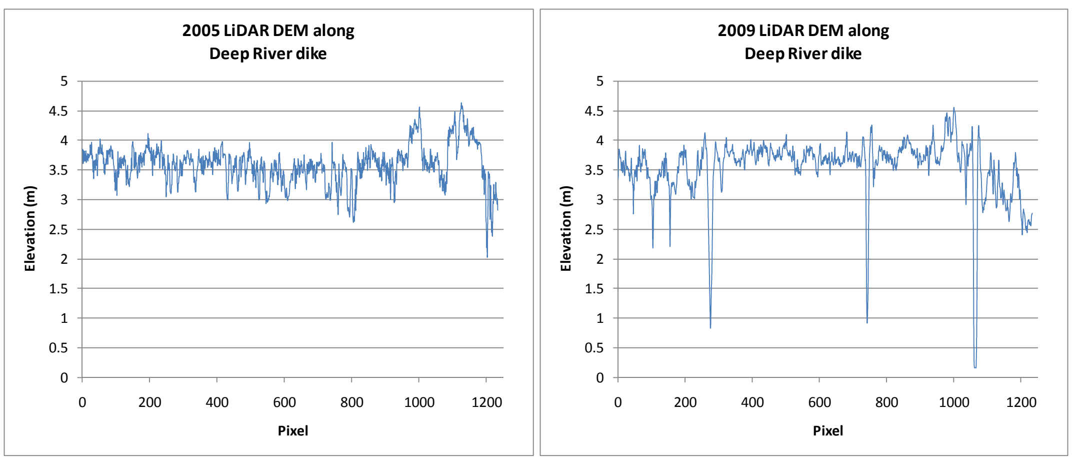

Figure D.6. Comparison of an Elevation Profile on the Dike Top for 2005 and 2009 at the Deep River Site. The abrupt drops in elevation profile indicate three dike breaches in the right panel.

D.3.5 Method Development: Wetted Area Estimation Method for Juvenile Salmon Habitat Area

The goal of this effort was to develop and demonstrate a method for estimating potential wetted area of project restoration sites in the LCRE. Our primary objective was to map the ordinary high water mark (OWHM) at each project restoration site and calculate the estimated potential wetted area within the OHWM for the purpose of identifying and quantifying the potential connected habitat area for outmigrating juvenile salmon.

Our methods were as follows:

1. Obtain polygons from project sponsors delineating acquisition area or project area, as available.
2. Determine the river kilometer in which the restoration site is located using spatial data for river kilometer.
3. Determine the OHWM (in feet above the Columbia River Datum) for the river kilometer in which the project site is located from the Corps' "Columbia River Datum Elevations" (15 Aug 1978). This determination required two steps:
   a. Convert the OHWM from feet to meters.
   b. Subtract the "NAVD88 to CRD Conversion" factor (a negative number) from the OHWM to obtain the OHWM relative to NAVD88 (North American Vertical Datum of 1988).
4. Using a GIS, map the contour line for the OHWM relative to NAVD88.
5. Calculate the total area in hectares within the potential wetted area polygon using the 10-m Digital Elevation Model (DEM) (Evans et al. 2006, Appendix A).

For this demonstration, we preliminarily assessed sites within Grays River and Deep River, the tributaries to Grays Bay on the Washington side of the LCRE, for which we had previously acquired spatial data and restoration site polygons through the Corps' cumulative effects project. Below, we provide the preliminary results of applying the wetted area estimation method at Deep River–Svenson Landing and Grays River Mill Road.

Deep River–Svenson Landing (Figure D.7) is located at rkm 37.01, where the published OHWM is 9.4 ft (2.86512 m). Relative to NAVD88, the OHWM is 2.98386 m. According to this method, the estimated potential wetted area below the OHWM at Deep River–Svenson Landing is 5.0952 ha. The estimated potential wetted area represents 8.3% of the land area at the Deep River–Svenson Landing restoration site.

Grays River Mill Road (Figure D.8) is located at rkm 40.23, where the OHWM is 9.4 ft (2.86512 m). Relative to NAVD88, the OHWM is 3.01434 m. According to this method, the estimated potential wetted area below the OHWM at Grays River Mill Road is 2.5160 ha. The estimated potential wetted area represents 11% of the land area at the Grays River Mill Road restoration site.

These preliminary findings are indicative of the wide range of variation between reported restoration site area measurements, typically the parcel ownership boundaries, and actual potential wetted area that may serve as 1) directly accessible salmon habitat or 2) a source of wetland plant-based prey that is injected into the food web via overland flows on the Columbia River floodplain. As an example, the Corps' cumulative effects project has documented the wetted area at Crims Island (Johnson et al. 2011, Appendix A; Coleman et al. in preparation), and it is approximately one-sixth (35.1/209.8 ha) of the total restoration area identified by the LCREP interactive map (www.lcrep.org). To accurately portray restoration program effectiveness, in our view, it is critically important to distinguish between potential salmon habitat and ownership boundaries as these two values may be substantially different.

Figure D.7. Wetted Area Estimation at Deep River–Svenson Landing. The polygon in purple is the restoration site polygon for Deep River–Svenson Landing. The magenta lines indicate the elevation of the OHWM at 2.98386 m relative to NAVD88. The teal polygon represents the potential wetted area below the OHWM at Deep River–Svenson Landing.

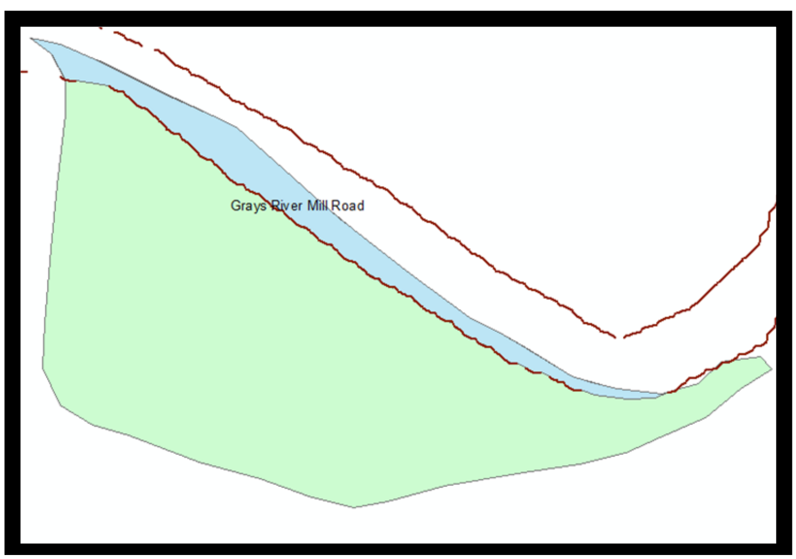

Figure D.8. Wetted Area Estimation at Grays River Mill Road. The polygon in green is the restoration site polygon for Grays River Mill Road. The brown lines indicate the elevation of the OHWM at 3.01434 m. The blue polygon represents the potential wetted area below the OHWM at Grays River Mill Road.

D.4 Nearest-Neighbor Distance Evaluation

On the basis of the 2009 habitat connectivity literature review (Diefenderfer et al. 2010), we implemented a nearest-neighbor algorithm, a structural connectivity measurement method. We used this method to calculate the distances between reference wetlands in the LCRE and the decrease in those distances brought about by restoration projects for which information was available in the first year of this study. The project inventory necessitated by the passage barrier assessment (detailed above) ensured that in 2010, we inventoried additional information about restoration projects implemented since 2000 (Figure D.9). In addition, we updated the nearest-neighbor distance calculations at the estuary scale based on this new information (Table D.4).

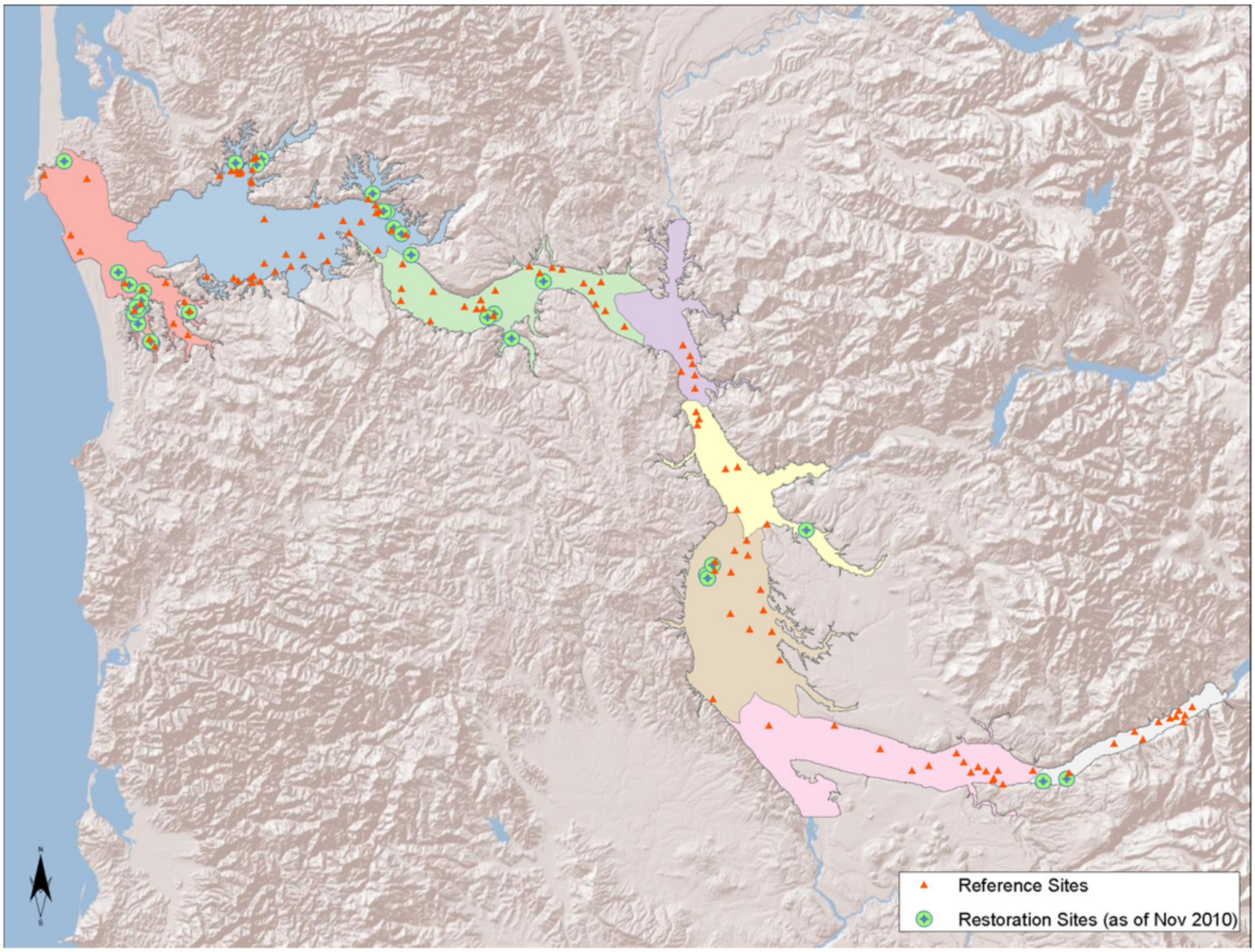

Figure D.9. Identified Reference and Restoration Sites in the LCRE as of November 2010. These sites were the basis of the reported nearest-neighbor distance calculations.

Table D.4. Updated Nearest-Neighbor Distances for Reference Wetlands (using a multiple nearest-neighbor distance band method)

Metric	Restoration & Reference Sites	Restoration Sites
Minimum Distance (m)	485.1	772.5
Average Distance (m)	3139.1	10264.6
Maximum Distance (m)	11883.7	57257.9

From the baseline of 127 identified reference sites, the 36 verified hydrologic reconnection restoration sites produced a nearest-neighbor distance reduction of approximately 24%. (Restoration "projects" with duplicate coordinates were removed from these calculations, so that only restoration "sites" on which actions were implemented were included.) These types of nearest-neighbor distance calculations may be used to help to prioritize restoration actions in the estuary, e.g., by addressing the "long tail" on the histogram, where distances between floodplain wetlands are the greatest (Figure D.10). This approach must also consider historical conditions controlled by topography, however; that is, long stretches in the outmigration by juvenile salmon may naturally exist without suitable estuarine wetland habitats, particularly in the Columbia River Gorge region.

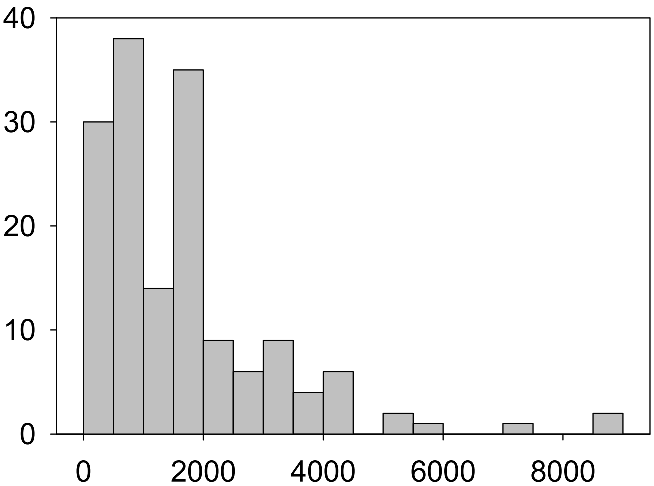

Figure D.10. Histogram of the Nearest-Neighbor Distances (in meters) Between All Identified and Verified Restoration and Reference Sites in the LCRE

Our continuing refinement of available nearest-neighbor distance calculation methods will be reported in the final habitat connectivity report in the 2011 annual report of the Salmon Benefits project. Ongoing methods development includes hydrologic routing of nearest-neighbor distance, multiple nearest-neighbor analytical methods, and directional constraints. In addition, when the LCREP land-cover data product becomes available in 2011, the original reference site data set used in this calculation will be reevaluated against the new data with the goal of analyzing discrete plant communities and landforms.

D.5 Summary

In summary, in 2010 we found it unexpectedly challenging to find complete, high-quality data sets for existing dikes and passage barriers, or for passage barrier removal since 2000. Because these two data sets are essential to the passage barrier accounting equation, we were unable to produce estuary-scale estimates in 2010. We plan to do so in 2011 based on existing data set development. First, at the Corps' direction, we are supporting the effort by a NOAA Coastal Fellow to develop a diking layer (Mattison 2010) instead of duplicating efforts, and plan to use the results at the conclusion of that data development effort in September of 2011. Second, we found significant obstacles to measurement of the effects of passage barrier removal. At the simplest level, implementation and compliance monitoring of passage barrier removal is not conducted at all projects, and therefore we investigated remote-sensing methods to offset the costs of site visits. We found 1) that dike breaches may be measured from LiDAR data while of course tide gates and culverts cannot be, and 2) that LiDAR data and ordinary high-water mark information may be used to coarsely estimate wetted area. However, these methods will require ground-truth verification in 2011, and it is likely that changes in shallow-water habitat area as a result of the LCRE restoration program would be more successfully predicted and measured by a hydrodynamic model that is effective at geographic scales between the estuary and the project site.

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Part III: Life History Diversity

Part III: Life History Diversity

Life history diversity is a measure of different spatial and temporal patterns of migration, habitat use, spawning, and rearing displayed within a species of Pacific salmon (from Johnson et al. 2008), which likely contributes to the resilience of salmonid populations in a fluctuating environment. The life history diversity of salmonid populations in the Columbia River basin is believed to have decreased in the last 100 years (Bottom et al. 2005), and one of the goals of habitat restoration in the lower Columbia River and estuary (LCRE) is to reverse this trend (Johnson et al. 2008). Fresh et al. (2005) stated that maintenance of life history diversity is an "especially critical portion of the role of the estuary." For example, the Columbia River below Bonneville Dam may provide important overwintering areas for subyearling Chinook salmon, a hypothesis that is currently under investigation (Johnson et al. 2011).

An understanding of trends in life history diversity is, therefore, important for assessing the performance of restoration projects. As called for in RPA 58 of the Federal Columbia River Power System Biological Opinion, a quantitative method is needed to index and periodically monitor life history diversity of salmonids in the LCRE. Action 58 addresses a key management question: What is the level of life history diversity in salmonid species in the LCRE and is it increasing? This project is developing a method to determine the status and trends of species-specific early life history diversity indices in the LCRE for Chinook and other species as data permit.

Two appendices are presented in this section. Appendix F presents an examination of the literature behind size class selection, and further trials of the life history diversity indices this project developed in 2009. To date, this project has primarily used data collected by other projects for other purposes to evaluate potential life history diversity indices, which is not entirely satisfactory because of spatial and temporal sampling limitations. Therefore, Appendix G contains a field protocol designed to maximize the benefits of beach seine data collection for the evaluation of life history diversity.

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Appendix E

Early Life History Diversity Indices for Juvenile Salmon in the LCRE

Appendix E

Early Life History Diversity Indices for Juvenile Salmon in the LCRE

Prepared by Nikki Sather, Gary Johnson and Earl Dawley

An early life history diversity (ELHD) index provides a high-level indicator of coalescing attributes of salmon life history strategies in the lower Columbia River and estuary (LCRE). Diefenderfer et al. (2010) outlined an approach for calculating an ELHD index for juvenile salmon. This work provided example calculations using existing catch data for juvenile salmon in the LCRE, but additional refinement of ELHD indices for juvenile salmon is necessary to advance the concept. The objectives of the effort reported in this appendix were as follows:

1. Examine the literature to confirm or modify the size classes for juvenile salmon that are applied in the calculation of the length-month ELHD indices.
2. Calculate ELHD indices under various spatial and temporal scenarios to assess the robustness, sensibility, and usefulness of the indices.

E.1 Juvenile Salmon Size Classes

During 2010, we revisited the juvenile salmon size classes that are applied in the length-month ELHD index calculation. The intent of the reevaluation was to determine whether the size classes accurately represent different life history strategies, or cohorts, of migrating fish in the LCRE. The initial size classes were based on findings described by Beamer et al. (2005) for juvenile Chinook salmon in the Puget Sound region. However, in light of recent data collection and reporting efforts in the lower Columbia River, we felt it appropriate to establish size class criteria based on data derived from our specific region of interest. The initial size classes applied in the ELHD index calculation were limited to four categories: <40 mm, 41–60 mm, 61–100 mm, and >100 mm.

We examined reported sizes and length frequency distributions of juvenile salmon collected from shallow-water habitats in the LCRE. Roegner et al. (2008) reported composite length frequency data collected with beach seines from 2002 through 2004 in the Columbia River estuary; modes were present at 40 mm and 100 mm. These data, however, were not directly applicable to addressing our inquiries because the temporal synopsis of the size data for juvenile salmon were too condensed. Regardless, the information summarized by National Marine Fisheries Service researchers does provide an additional context for validating the sizes of migrating juvenile salmon in the LCRE. Campbell (2010) characterized residence time of juvenile Chinook salmon within the saline portion of the estuary by depicting data into four size categories: <45 mm, <60 mm, 61–90 mm, and <90 mm.

Length frequency data from the Tidal Freshwater Monitoring study (Sather et al. 2011) indicate the size categories described by Campbell (2010) in the LCRE are similar to those for fish captured in upstream tidal freshwater habitats. Based on the size and timing of unmarked migrating Chinook salmon (Figure E.1) four size categories were selected for the purposes of calculating a life history diversity index: <61 mm, 61–90 mm, 91–120 mm, >120 mm.

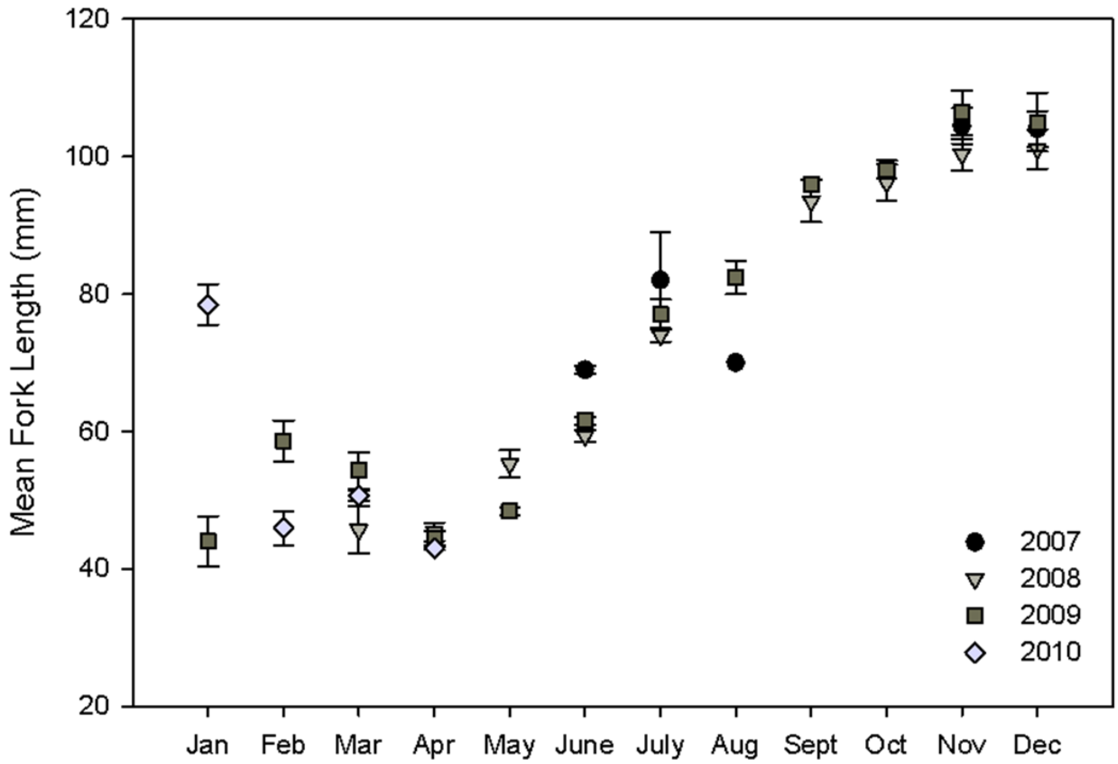

Figure E.1. Mean Fork Length of Unmarked Chinook Salmon Sampled at the Sandy River Delta Study Area During 2007–2010 (figure from Sather et al. 2011). Error bars represent the standard error of the mean.

E.2 Scenario Comparison of ELHD Indices

The following analyses examine the ELHD index for Chinook salmon at multiple spatial and temporal scales in the LCRE. Scenarios include comparisons of ELHD between sites, habitat strata, and when available, across years.

E.2.1 ELHD Indices

Diefenderfer et al. (2010) presented new indices to describe aspects of the early life history characteristics of juvenile salmon in the LCRE. The Length-Month Index (Eq. E.1),

$$LengthMonthIndex = \frac{\sum_{j=1}^{m} \sum_{k=1}^{s} w_{jk}}{m * s} \tag{E.1}$$

where

w_{jk} = fish presence (=1)/absence (=0) for Chinook salmon for the jth month and kth size.

j = 1,….,m (#months)
k = 1,…,s (#size classes)

and the Stock-Month Index (Eq. E.2).

$$StockMonthIndex = \frac{\sum_{j=1}^{m} \sum_{m=1}^{t} v_{jm}}{m*t} \qquad (E.2)$$

where,

v_{jm} = fish presence (=1)/absence (=0) for the jth month and mth stock.

j = 1,….,m (#months)
m = 1,…,t (#stocks)

E.2.2 ELHD Index Scenarios

The scenarios for ELHD indices incorporated new data for calculations of the Length-Month Index for Chinook salmon, Jones Beach fish catch data, and the Stock-Month Index (Table E.1).

Table E.1. ELHD Index Scenarios for Chinook Salmon

Scenario	Index	Project(s)	Year	Origin	Site(s)
A	Length-Month	TFM	2008, 2009, combined	u, m	SRD (A,B,C,D,E,N); combined and separately
B	Length-Month	TFM	2008, 2009, combined	u, m	D, E, and N
C	Length-Month	SB	2010 (Apr-Jul)	u, m,	OC, MC, WC
D	Length-Month	SB	2010 (Apr-Jul)	u, m,	OC-25, OC-21, OC-29 MC-20, MC-22, MC-26 WC-1, WC-2
J1	Length-Month	JB,TFM	1978 (JB), 2009 (TFM), 2010 (SB)	either	JB, TFM Site E, SB Site MC-20
S1	Stock-Month	TFM	2009 (blitz months)	u, m	LRR, SRD
S2	Stock-Month	TFM	2009	u, m	SRD

U = unmarked
M = marked, hatchery
TFM = Tidal Freshwater Monitoring
SB = Salmon Benefits
JB = Jones Beach

OC = off channel
MC = main channel
WC = wetland channel
LRR = Lower River Reaches
SRD = Sandy River Delta

Chinook-Length-Month Index. These index calculations used the revised fish size classes (Section E.2.1). Analysis scenarios for this index are as follows:

- Scenario A – Calculate ELHD indices for unmarked and marked Chinook salmon using Tidal Freshwater Monitoring (TFM) data collected during 2008 and 2009. This calculation will show the performance of the index.
- Scenario B – Examine ELHD indices for different habitat types sampled near the Sandy River Delta (SRD). Analysis will include a main-channel/confluence site (e.g., D), an off-channel site (e.g., E), and a wetland-channel site (e.g., N).

- Scenario C – Examine ELHD indices for Chinook salmon sampled in different habitat strata near Cottonwood Island during the Salmon Benefits (SB) 2010 study. Analysis will examine differences between main-channel, off-channel, and wetland-channel habitats.
- Scenario D – Examine site scale ELHD indices for Chinook salmon captured at Cottonwood Island during the SB 2010 study.

Jones Beach Data. We quantitatively evaluated the ability of the indices to incorporate data sets derived from different capture methods by performing calculations for the ELHD indices using data collected at Jones Beach (JB; rkm 75) during 1978. Using a beach seine to collect juvenile salmon, Dawley et al. (1986) conducted monthly sampling that often spanned several weeks each month. This study documented length frequency distributions of fish according to 5-mm size class increments for the first 100 to 200 juvenile Chinook salmon encountered. This effort, which focused on accounting for sizes of Chinook salmon, did not distinguish between marked and unmarked fish. As a result of the differences in sampling protocols between the JB study and the SB and TFM studies, we attempted to normalize the data sets to the extent possible. Because the JB data encompass a richer temporal sampling scheme compared to the contemporary data sets, the JB ELHD index was calculated by selecting time periods that were similar to those sampled in the TFM and SB studies. In addition, the ELHD indices for TFM and SB were calculated by examining the presence and/or absence of either marked or unmarked fish.

We calculated an ELHD index for one scenario using the JB data as follows:

- Scenario J1 – Length-Month Index for JB vs TFM Site A (2009) vs SB Site MC-20 (2010)
- Stock-Month Index. For the new Stock-Month Index, landscape-scale differences in genetic stock composition for juvenile Chinook salmon were evaluated using the TFM data from two regions; Lower River Reaches (LRR; rkm 110-141) and SRD (rkm 188-202). We calculated Stock-Month Index for the following scenarios:
  - Scenario S1 – The Stock-Month Index to compare LRR and SRD for six sampling periods for unmarked juvenile Chinook salmon.
  - Scenario S2 – The Stock-Month Index to evaluate differences between marked and unmarked juvenile Chinook salmon during 2008 and 2009 captured at the SRD.

E.3 ELHD Index Results

The calculated ELHD index values for the scenarios described above are presented in Tables E.2 through E.4. To be clear, using the Length-Month Index for Chinook salmon as an example, the indices of early life history diversity simply reflect the proportion of the total number of size class and month combinations in which juvenile Chinook salmon were present. Additional factors and salmon species are incorporated into other indices (Diefenderfer et al. 2010). The scenario results that follow are only for Chinook salmon and include ELHD indices for unmarked vs marked. Spatial, temporal, and habitat type comparisons are also made depending on the scenario.

E.3.1 Scenarios A and B

Comparing two off-channel sites in the vicinity of the SRD with an index value derived from combining all sites (e.g., Scenario A) in the same area yielded both spatial and temporal differences.

Index values were higher during 2009 at Site E (Gary Island) and for all SRD sites combined compared with 2008. However, there were no differences in index values at Site A between the 2 years (Table E.2). In a comparison of ELHD index values across habitat types at the SRD (e.g., Scenario B), the wetland channel yielded the lowest value during 2008 and 2009. In 2008, the confluence site had a higher index value compared to an off-channel site, but this pattern was reversed during 2009 (Table E.2). The only consistent trend resulting from analyzing index values at different spatial scales in 2008 and 2009 was higher ELHD values for unmarked Chinook salmon compared with marked Chinook salmon.

Table E.2. ELHD Index Results for Scenarios A and B Using Data from the TFM Project to Calculate the Chinook-Length-Month Index

		2008		2009		Combined	
Scenario	Site(s)	Unmarked	Marked	Unmarked	Marked	Unmarked	Marked
A	Base (combined A,B,C,D,E,N)	0.184	0.125	0.198	0.035	0.191	0.080
	A	0.292	0.167	0.292	0.063	0.292	0.155
	E	0.146	0.104	0.250	0.042	0.198	0.073
B	D – confluence	0.229	0.167	0.208	0.021	0.219	0.094
	E – off-channel	0.146	0.104	0.250	0.042	0.198	0.073
	N – wetland channel	0.042	0.000	0.083	0.000	0.063	0.000

E.3.2 Scenarios C and D

Similar to Scenario B, Scenario C uses data collected as part of the SB study from April through December 2010 to examine differences in ELHD index values across habitat types. While sampling techniques between the two studies are analogous, these scenarios differ with respect to when and where the samples were collected (Appendix A). For unmarked Chinook salmon sampled at Cottonwood Island, the off-channel habitat strata yielded the highest ELHD index value followed by the main channel, and wetland habitats (Table E.3). The ELHD index value for marked Chinook salmon sampled at Cottonwood Island was greatest for the main-channel habitat strata followed by the off-channel and wetland-channel habitats. A site-scale analysis (Scenario D) of the data indicates a similar range of ELHD index values for unmarked and marked Chinook salmon in the off-channel and main-channel sites. The range of values for unmarked and marked Chinook salmon is similar between sites and the values are markedly smaller than values derived from off-channel and main-channel sites (Table E.3).

Table E.3. ELHD Index Results for Scenarios C and D Using Data from the Salmon Benefits Project to Calculate the Chinook-Length-Month Index

Scenario	Project(s)	2010 (Apr-Dec)	Unmarked	Marked
C	SB	Off-Channel	0.607	0.571
		Main Channel	0.583	0.655
		Wetland Channel	0.268	0.214
D	SB	OC-25	0.643	0.571
		OC-21	0.679	0.643
		OC-29	0.500	0.500
		MC-20	0.500	0.536
		MC-22	0.679	0.679
		MC-26	0.571	0.750
		WC-1	0.286	0.250
		WC-2	0.250	0.179

E.3.3 Scenario J1

Analysis of multiple data sets provides a means for evaluating the ELHD index within a broader spatial and temporal context. The ELHD index was highest for marked and unmarked Chinook salmon at Cottonwood Island during 2010 (site MC-20) followed by the index calculated from data collected at Jones Beach during 1978. The index derived from data collected at an off-channel site (site A) within the vicinity of the SRD during 2009 was more than twice as low as the indices from the two main-channel sites at Cottonwood Island and Jones Beach.

Table E.4. ELHD Index Results for Scenario J1 Using Data from the Jones Beach, TFM, and Salmon Benefits Projects to Calculate the Chinook-Length-Month Index

Scenario	Project(s)	Site(s)/Year(s)	Unmarked and Marked Combined[a]
J1	JB,TFM, SB	JB (1978)	0.625
		TFM Site A (2009)	0.292
		SB Site MC-20 (2010)	0.714

(a) Unmarked and marked Chinook salmon were combined to facilitate comparisons across multiple data sets due to differences in sampling methodologies.

E.3.4 Scenarios S1 and S2

Applying the Stock-Month Index to genetic data collected from juvenile Chinook salmon across portions of the tidal freshwater landscape of the LCRE (Scenario S1) indicated samples collected from upriver sites had a higher index compared with those collected from sites farther downriver. Unmarked Chinook salmon had higher index values from the SRD vicinity than unmarked Chinook salmon in 2008 and 2009 (Scenario S2; Table E.5).

Table E.5. ELHD Index Results – Scenarios S1 and S2 – Index S-M, TFM Project

Scenario	Year	Site(s)	Unmarked	Marked
S1	2009-10	LRR	0.583	--
		SRD	0.625	--
S2	2008	SRD	0.472	0.222
	2009	SRD	0.510	0.083

E.4 Discussion

Partitioning sites to incorporate a diversity of distinct habitat types provides an opportunity to evaluate the ELHD of juvenile salmon throughout the LCRE. Densities of juvenile Chinook salmon were highest in off-channel, followed by wetland-channel and main-channel habitats during the 2010 SB sampling effort (Appendix B). However, the trend for Chinook salmon densities in these three habitat strata deviated from the trend in ELHD index values such that off-channel and main-channel strata yielded similar values and the wetland channel yielded a much lower value. While the overall densities of juvenile Chinook salmon were higher in the wetland-channel sites compared to those sampled in the main channel, the salmon we captured in the wetland-channel site were present over a short duration and occupied a narrow range of sizes.

The ELHD index is not intended to be a tool for evaluating the importance of habitats. It can be used to compare and contrast differences in the size, timing of migration, and genetic diversity of migrating juvenile salmon at various scales (e.g., site, strata, reach). Depending on the particular question being asked, site-scale comparisons of the ELHD indices may be useful. However, due to the patchy nature of migrating juvenile salmon, and inter-annual variability, it may be necessary to examine indices over multiple years before deriving conclusions about differences in ELHD at limited spatial scales. Furthermore, inquiries intended to discern site-scale differences relevant to juvenile salmonid ecology should include an ecosystem-based approach that evaluates a combination of structural and functional conditions of habitats within the LCRE.

Most of the scenarios we examined yielded clear differences in index values between marked and unmarked Chinook salmon. These differences are consistent with findings from other research in the LCRE indicating differences in the timing and sizes of migrating marked salmon. Based on data derived from beach seine collection techniques, which sample shallow-water habitats, marked Chinook salmon were present over shorter time periods, occupied narrower ranges of sizes, and were typically larger than their unmarked counterparts (Sather et al. 2011; Appendix B). The results of the ELHD index values reflect these conditions.

Incorporating historic data sets such as the Jones Beach study into the comparison of ELHD indices of contemporary data collection efforts provides a means for evaluating the trends of ELHD through time. Beach seine samples at Jones Beach and Cottonwood Island display a broader representation of migrating juvenile salmon compared with the off-channel site at Gary Island near the SRD. Differences in catches and subsequent ELHD index calculations are related to the geomorphology, hydrology, and location within the riverine landscape of particular sampling locations. Hydraulic connectivity is greater at the two main-channel locations (Jones Beach and Cottonwood Island) with both being located much farther downriver than the off-channel Reed Island site near the SRD. At Jones Beach and Cottonwood Island, the river width was relatively narrow, which may have resulted in higher densities of migrating salmonids. The seining sites were unobstructed by vegetation and the beach was characterized by a shallow slope, well suited for efficient capture of fish with a seine. The TFM study did not include a main-channel habitat with comparable characteristics to those described at Jones Beach and Cottonwood Island. Thus, we are unable to determine if differences in ELHD index values are correlated with elements of hydraulic connectivity, position of the sites within the riverine landscape, inter-annual variability, or some combination of all attributes.

When using the ELHD index to compare multiple data sets, differences in sampling methodologies (e.g., gear type, sampling intensity, protocols) should be thoroughly evaluated. For the Jones Beach study, the net size (triple that used by other researchers) in addition to frequent and repetitive sampling (often 10 hauls per day, 7 days per week) resulted in large catches of fish, which likely provided a better representation of fish characteristics compared to less intensely monitored beach seine sites that deploy smaller nets for capturing fish in shallow-water habitats. To facilitate the incorporation of the JB data into our analyses, we normalized the data and modified our approach to account for an analysis that included both marked and unmarked Chinook salmon. As more data are collected within the LCRE they will provide a means to evaluate the past and present conditions of ELHD of juvenile salmon, thereby providing a tool for assessing the response of habitat restoration.

E.5 Management Implications and Recommendations

A fundamental premise of the LCRE ecosystem restoration effort is that increasing habitat access, quality, and diversity will lead to increased early life history diversity and thereby increase the resiliency of salmon populations in responding to environmental perturbations and aid the recovery of depressed stocks (Bottom et al. 2005). The ELHD indices offer a quantitative approach to track life history diversity over the long-term—over the course of the restoration effort. The estuary-wide effort to restore juvenile salmon habitat requires high-level indicators that managers and decision-makers can use to track progress and adjust strategies. We have the following recommendations to further development of ELHD indices.

- Develop a more integrative ELHD index than the simple presence/absence approach from which to incorporate information, and to allow expansion and constriction of the index across space and time. For example, analyses assimilating species densities may strengthen the inferences used in evaluating ELHD of juvenile salmon in the estuary.
- Collaborate with other research programs in the LCRE to expand the spatial and temporal breadth ELHD index. Incorporating data sets from multiple river locations, habitat types, and across multiple years may elucidate long-term trends in life history diversity and provide better resolution between baseline and post-restoration conditions.

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Appendix F

Protocol for Early Life History Diversity Indices

Appendix F

Protocol for Early Life History Diversity Indices

Prepared by Gary Johnson, Nikki Sather, and Earl Dawley

The ELHD index protocol was modeled after Roegner et al. (2009). Detailed methods for collecting and processing juvenile salmon samples were modified from Sather et al. (2011).

Diefenderfer et al. (2010) developed indices for early life history diversity (ELHD) of juvenile salmon in the lower Columbia River and estuary (LCRE). Standardized application of ELHD indices requires a protocol for data collection, processing, and analysis to ensure comparability of results at multiple spatial and temporal scales. The intent of this appendix is to establish a protocol for sampling, processing, and analyzing data pertaining to juvenile salmonids that will facilitate calculation of the ELHD indices described herein. To this end, we evaluated salmonid species composition, fish size, and temporal distribution patterns at selected monitoring sites in the LCRE within the context of collecting data to be used for calculating the ELHD indices.

F.1 Study Design

Site Selection. Selection of sampling site(s) should consider the following criteria:

- Ensure that accessibility is possible during all months of the year.
- Avoid spatial overlap of sites that are being sampled by other research programs. If a particular site or area is integral to multiple research programs, attempt to share data and streamline protocols to meet the needs of all. Coordinate efforts to collect data throughout the LCRE.
- Ensure the same equipment can be used at all times of the year and from year to year.
- Ensure that physical features of the site can be measured/evaluated.
- Make sure the history and origin of the site is known.
- Incorporate sites that are representative of a diversity of habitat conditions. At the coarsest scale, we recommend selecting main-channel, off-channel, and wetland-channel habitats.

Sampling Periodicity. The minimum effort includes two replicate samples per site. Frequency of sampling should be monthly for a minimum of 1 year.

F.2 Data Collection

F.2.1 Equipment

Depending on the site and habitat to be sampled, various types of gear may be used to collect fish for the ELHD index. The site selection criteria will also influence choice of equipment. In many instances in the LCRE, a beach seine will be most useful for the purposes of ELHD indices. Regardless of the selected gear type, the key is to remain consistent in the application of gear and techniques through time.

For beach seining in the LCRE, the following net, called the TFM (Tidal Freshwater Monitoring) net, or similar is recommended. The TFM net was designed to sample juvenile salmon within shallow-water habitats of the LCRE. It is 46 m long and 3 m deep at the center with wings that taper to 1.5 m. The wings are constructed of 13-mm stretch black knotless netting. The bag is constructed of 3.2-mm knotless mesh netting dyed green, and measures 2.4 m wide by 1.5 m deep. The seine is fitted with 17-oz buoyancy ethylene-vinyl acetate floats on 46-mm centers and a solid core lead line with a poly sleeve sewed to the base. A 15-m-long haul line is affixed to a bridle at the tapered ends of each wing.

F.2.2 Deployment

One end of the haul line is held to the shore while the boat moves perpendicular toward the deep end of the channel. Once the end of the line is reached, the boat is turned 90 degrees and the net is deployed parallel to the shore (Figure F.1). After the full length of the net has been set, and the second haul line is brought to the shore, the lines are used to bring the wings to the shore. Care must be taken to ensure the lead line remains in contact with the substrate.

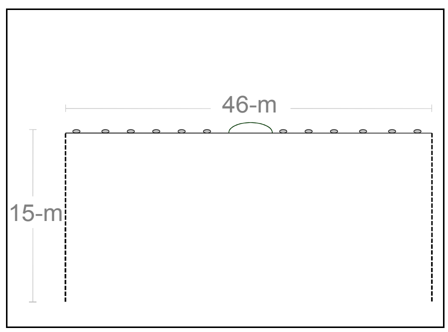

Figure F.1. Net Deployment (from Sather et al. 2011, Figure 2.4)

F.2.3 Fish Handling

After each haul, remove the fish from the net and place them in holding buckets filled with river water at ambient temperature. Separate all salmon from the catch and place them in buckets for immediate processing. Use aerators to maintain adequate levels of dissolved oxygen in the holding water.

F.2.4 Catch Processing

Process catches by enumerating all taxa and measuring length to the nearest millimeter for up to 20 individuals within each size class for a given species. The Stock-Month ELHD index uses the following size categories: <60 mm, 61–90mm, 91–120 mm, and >121 mm. Identify fish to the lowest taxonomic level practical. In addition to enumeration and length measurements of salmon, to help distinguish hatchery origin use a coded-wire tag wand and note if salmon have an intact adipose fin. A passive integrated transponder (PIT)-tag reader can also be used to identify PIT-tagged fish, which may provide additional information on origin and residence time of juvenile salmon.

F.2.5 Subsampling

When catches are large, a subsampling procedure may be implemented that allows rapid processing of the catch while providing a means for determining species composition and enumerate salmon. Keeping the catch in the bag and in the water, homogenize the catch and remove 1 to 2 aliquots using a standard aquarium net. Place the subsample in holding buckets for detailed processing. Quantify the volume of the remaining catch by enumerating the number of aliquots required to remove all fish from the bag. Although this approach introduces unknown bias in precision for quantifying taxa, it provides a standardized means of documenting thousands of fish over a short time period while also reducing handling stress and mortalities.

F.2.6 Fin Tissue for the Genetic Stock-Month Index

On a subsample of juvenile Chinook salmon, clip fin tissue for genetic stock identification and place it in a labeled vial. Preserve fin clips in ethanol for analysis later in the laboratory.

F.2.7 Ancillary Data

Collect additional information about environmental conditions and habitat features. Take photos at each site during the sampling. Maintain a record of the actual sampling locations by using a handheld global positioning system (GPS). Depending on the specific GPS unit, point data may need to be post-processed and later exported into ArcInfo Geographic Information System (ArcGIS) software for mapping. Collect data on physical habitat features, including vegetation characterization, land and water-level elevation, and an analysis of substrate grain size by following the protocols outlined by Roegner et al. (2009).

F.2.8 Field Data Sheets

The design and layout of field data sheets can be customized to fit specific project needs and/or meet personal preference. At minimum, data sheets need to include date, site name, sample time, and space for recording fishery data (e.g., species, length, weight, genetic sample numbers) and corresponding ancillary data (e.g., temperature, dissolved oxygen, flow). Information corresponding to land and water-level elevations, substrate grain size, and specific habitat conditions can be recorded separately on topic specific data sheets.

F.3 Data Processing

Data transfers from field to electronic data sheets must be subjected to independent review for quality assurance/quality control. We recommend that electronic data entry from field data sheets and notebooks receive a 100% quality assurance check by an individual not responsible for the original entry process. Subsequent electronic calculations and data manipulations should receive a 10% quality assurance check, again, by an independent reviewer. Errors and discrepancies in the data are resolved by working back through the data beginning with raw data and interviewing data custodians. Records of this process should be maintained and should include the raw data, the quality assured and quality controlled data, and the final version of the data.

F.4 Calculations and Analysis

Using the area swept for each beach seine haul, calculate fish density as the number of individuals per square meter. Currently, the ELHD index uses binary data for species occurrences, but fish densities may be incorporated into the calculation for future analyzes.

$$LengthMonthIndex = \frac{\sum_{j=1}^{m} \sum_{k=1}^{s} w_{jk}}{m * s} \qquad \text{(F.1)}$$

where,

w_{jk} = fish presence (=1)/absence (=0) for Chinook salmon for the j^{th} month and k^{th} size.

j = 1,….,m (#months)
k = 1,…,s (#size classes)

and the Stock-Month Index (Eq. F.2).

$$StockMonthIndex = \frac{\sum_{j=1}^{m} \sum_{m=1}^{t} v_{jm}}{m * t} \qquad \text{(F.2)}$$

where,

v_{jm} = fish presence (=1)/absence (=0) for the j^{th} month and m^{th} stock.

j = 1,….,m (#months)
m = 1,…,t (#stocks).

F.5 Data Caveats

In interpretation of the previous sections of this appendix, the following caveats should be kept in mind:

- Fish are captured with a particular beach seine in particular locations.
- Different habitats may necessitate implementing the use of different gear types (e.g., beach seine and fyke net). The sensitivity of the ELHD index has not been evaluated under these potential circumstances.
- The data collection period may be limited to less than monthly sampling efforts as recommended in this protocol.
- Different decades and years may be sampled.
- Collection efforts may occur in different longitudinal locations in the river with corresponding differences in fish populations and fish densities. These factors must be considered when interpreting the data.
- Different habitat types will have different physical conditions affecting the catch.
- Not all hatchery fish are marked.

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Part IV: Survival Benefits

Part IV: Survival Benefits

The 2008 Biological Opinion (BiOp) for the Federal Columbia River Power System included an assessment of the survival benefits of habitat restoration actions in the lower Columbia River and estuary (LCRE) proposed in the Biological Assessment (www.salmonrecovery.gov). The assessment was necessarily based on professional judgment using the best available knowledge, because data on incremental benefits to juvenile salmonid survival associated with specific restoration projects are not available. Direct measurements of survival rates would require telemetry methods (e.g., Perry and Skalski 2008; Skalski and Griswold 2006) such as those pilot tested at the site scale in 2010 research of this project.

In addition, "survival benefits" may be assessed indirectly through other measures such as fish habitat usage and condition, as detailed in the first annual report of this project (Diefenderfer et al. 2010, Table 4.1) and pilot tested in 2010 research. Such measures may include growth of marked fish, diet, residence time, foraging success, or physiology (Fresh et al. 2005; Bottom et al. 2005). It is expected that the strongest inference of survival benefits from habitat restoration in the LCRE would be gained by using multiple measurement methods, including fish condition and telemetry at the site (residence time) and reach and estuary scales integrated into a single index (Diefenderfer et al. 2010, Table 4.1). However, the smallest outmigrants use shallow-water estuarine habitats more than larger outmigrants (Fresh et al. 2005; Campbell 2010; Sather et al. 2009; Johnson et al. 2011), and technology development is required to successfully tag salmonids of this size for estuary-scale survival studies (Diefenderfer et al. 2010).

The research need regarding survival or other benefits pertains to BiOp RPA 60, which called for evaluation of habitat restoration actions. It is not certain that changes in life history diversity or habitat connectivity produced by estuarine habitat restoration can be measured in terms of increased survival, but an evaluation of the potential is necessary given the requirements of the BiOp. Action 60 addresses a third key management question: What are the survival benefits from LCRE habitat restoration efforts and are they increasing? This project is developing estimators of restored area use by salmonids and measures of the benefits to salmonids that use those areas and benefits to the overall population.

The appendices in this section are presented according to the level of data development, e.g., existing, new, and none. Appendix G and Appendix H reanalyze existing data to support the objectives of this project: acoustic tag data and fish passage data, respectively. Appendices I and J analyze data field-collected by the project team according to the methods described in Appendix A. Appendix K looks toward the future objectives of the project, examining the survival modeling literature relevant to the estuary to date.

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Appendix G

Retrospective Analysis of 2008 LCRE Acoustic-Telemetry Data to Evaluate the Proclivity of Juvenile Salmon to Use Off-Channel Migration Routes

Appendix G

Retrospective Analysis of 2008 LCRE Acoustic-Telemetry Data to Evaluate the Proclivity of Juvenile Salmon to Use Off-Channel Migration Routes

Prepared by Gary Johnson, Jina Kim, and Kenneth Ham

Juvenile salmon migrate downstream through the lower Columbia River and estuary (LCRE) through the main-channel and off-channel habitats (e.g., Harnish et al. In Review; Johnson et al. 2010; McComas et al. 2009). Use of off-channel areas, as opposed to the main channel, is related to the size of migrating fish, watershed of origin, and other factors. In general, subyearling life histories, smaller fish, and fish originating in the lower Columbia River are more likely to use off-channel habitats than yearling life histories, larger fish, and fish from above Bonneville Dam (Dawley et al. 1986). This generality is important because one of the main approaches to restoring LCRE habitats to increase juvenile salmon performance is to reconnect off-channel areas with the main-channel Columbia River (Johnson et al. 2003; 2008). Developing methods to measure or assess the benefits to juvenile salmon of such restoration actions is a goal of the Salmon Benefits project.

Existing Juvenile Salmon Acoustic Telemetry System (JSATS) data for 2008 are available from acoustic receiving nodes placed in three non-main-channel habitats: Sandy River Delta (SRD), Cathlamet Bay (CB), and Grays Bay (GB) (Figure G.1). The hypothesis is that previous use of off-channel habitat during the outmigration (SRD) has no relationship with subsequent use downstream (CB and GB) (Diefenderfer et al. 2010). The objective was to use existing acoustic-telemetry data to perform a pilot analysis of a landscape-scale approach to evaluate the proclivity of juvenile salmon to use off-channel migration routes. This information will help inform development of methods for evaluating the survival benefits of restoration.

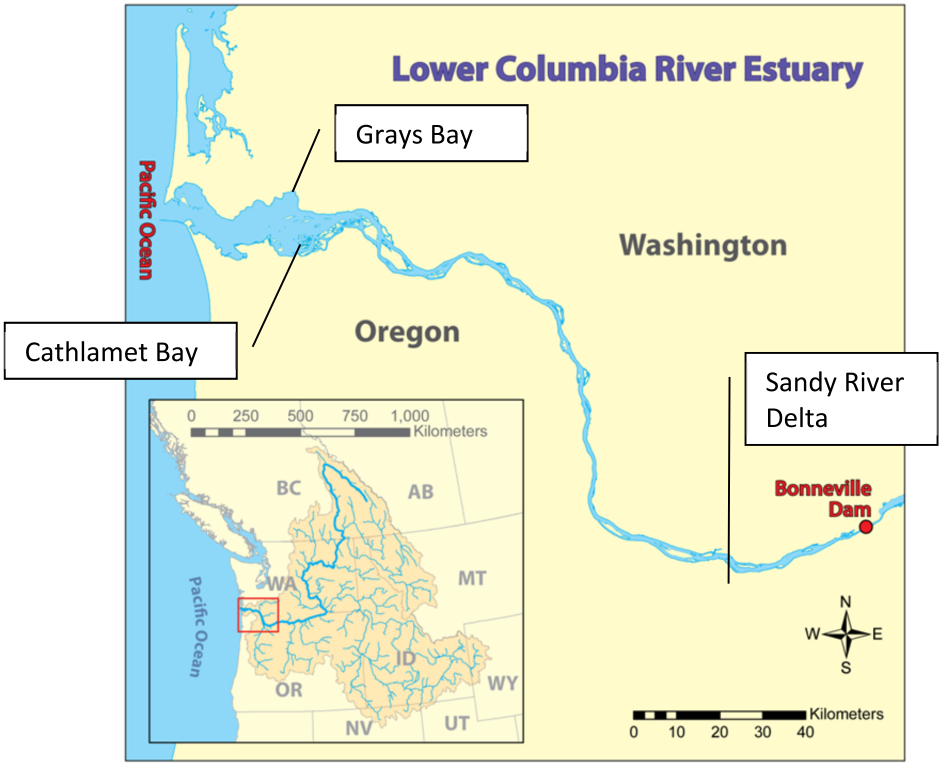

Figure G.1. Map of LCRE showing the Sandy River Delta, Grays Bay, and Cathlamet Bay

G.1 Methods

The data used for this analysis were derived from JSATS studies in the LCRE conducted during 2008 by Ploskey et al. (2009), Sather et al. (2009), and the National Marine Fisheries Service/Pacific Northwest National Laboratory (acoustic telemetry study; report not available). The analysis was conducted separately for yearling Chinook salmon, steelhead, and subyearling Chinook salmon. The methodology entailed five steps:

Step 1 Identify applicable JSATS tag codes from the main-channel and off-channel areas of the SRD, the most upstream area of interest (Sather et al. 2009, Section 4.2.5).

Step 2 Extract detections of the SRD tag codes from receiver arrays downstream at CB, GB, and the main channel.

Step 3 Tabulate the SRD fish detected downstream in main-channel and off-channel (CB and GB) arrays.

Step 4 Calculate proportions of the total number of SRD main-channel fish detected in downstream main-channel and off-channel areas (CB and GB). Analogously, calculate proportions of the total number of SRD off-channel fish detected in downstream main-channel and off-channel areas (CB and GB).

Step 5 Perform a Chi-square analysis of the actual versus the expected proportions.

G.2 Results

There were 16,825 detections of JSATS-tagged fish in the main-channel and off-channel areas of the SRD during 2008 (Table G.1). Of this total, 6.7% were in the off-channel areas of the SRD. The numbers and proportions of SRD main-channel fish and SRD off-channel fish were similar for detections at downstream main-channel and off-channel arrays (Table G.2). Of the tagged fish detected at either the SRD main-channel or off-channel areas, the highest proportions subsequently detected downstream in off-channel areas were subyearling Chinook salmon (0.27) and the lowest proportions were for steelhead (0.14) (Table G.2; Figure G.2). The downstream off-channel proportions are over twice as high as those at the SRD (Tables G.1 and G.2).

Based on the results of a Chi-square analysis, there was no relationship between main-channel and off-channel distribution in the SRD and subsequent use of main- or off-channel habitat downstream in the CB and GB area (Table G.3). That is, previous use of upstream off-channel migration routes was not related to subsequent use of off-channel areas downstream.

Table G.1. Applicable JSATS Tag Code Detections from the Main-Channel and Off-Channel Areas of the SRD During 2008 for Yearling Chinook Salmon (SPR_CHN), Steelhead (STH), and Subyearling Chinook Salmon (SUM_CHN). (The data set for this retrospective analysis is not identical to that reported by Sather et al. [2009] due to refinements of detection filter algorithms.)

2008	SPR_CHN	STH	SUM_CHN	Total
SRD Nodes	660	104	366	1,130
Main Channel	6,905	2,636	6,154	15,695

Table G.2. Numbers and Proportions of SRD Fish Detected Downstream (D/S) in Main-Channel and Off-Channel (CB and GB) Arrays, Including Yearling Chinook Salmon (SPR_CHN), Steelhead (STH), and Subyearling Chinook Salmon (SUM_CHN).

	SPR_CHN		STH		SUM_CHN	
	SRD	MC	SRD	MC	SRD	MC
	Number of Detections					
D/S Main Channel	293	3,801	55	1,498	158	2,761
D/S Off-Channel Bays	63	646	9	241	58	1,016
Total	356	4,447	64	1,739	216	3,777
	Proportion of Detections					
D/S Main Channel	0.82	0.85	0.86	0.86	0.73	0.73
D/S Off-Channel Bays	0.18	0.15	0.14	0.14	0.27	0.27

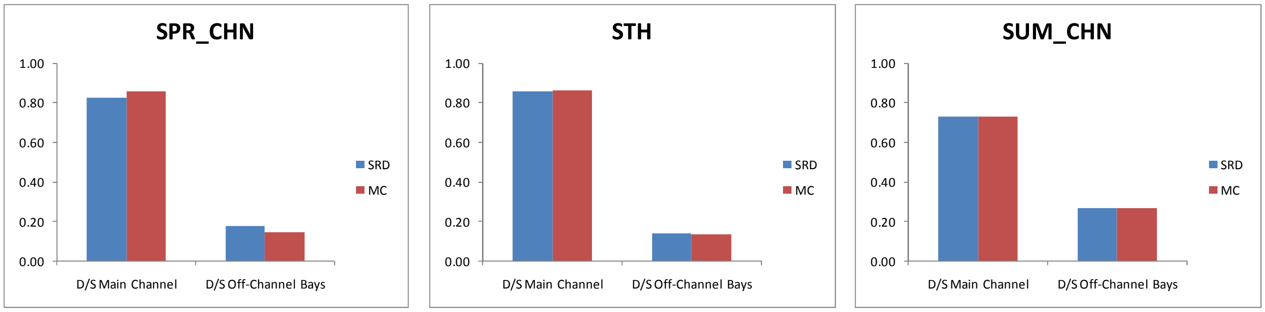

Figure G.2. Proportions of Tagged Yearling Chinook Salmon (SPR_CHN), Steelhead (STH), and Subyearling Chinook Salmon (SUM_CHN) Detected in the Vicinity of the SRD That Were Subsequently Detected in Downstream Main-Channel and Off-Channel Bay Locations

Table G.3. Chi-Square Test Results

	SPR_CHN-Observed			SPR_CHN-Expected		*(observed - expected)2*		
	SRD	MC	Subtotal	SRD	MC	*expected*		
D/S Main Channel	293	3,801	4,094	303	3,791	0.359780345	0.028802	
D/S Off-Channel Bays	63	646	709	53	656	2.077490455	0.166311	
Subtotal	356	4,447	4,803		*p* =	0.104704416	χ^2 =	2.632384
	STH-observed			STH-expected		*(observed - expected)2*		
	SRD	MC	Subtotal	SRD	MC	*expected*		
D/S Main Channel	55	1,498	1,553	55	1,498	0.000287544	1.06E-05	
D/S Off-Channel Bays	9	241	250	89	241	0.001786224	6.57E-05	
Subtotal	64	1,739	1,803		*p* =	0.963016103	χ^2 =	0.00215
	SUM_CHN-observed			SUM_CHN-expected		*(observed - expected)2*		
	SRD	MC	Subtotal	SRD	MC	*expected*		
D/S Main Channel	158	2,761	2,919	157	2,761	6.04146E-05	3.46E-06	
D/S Off-Channel Bays	58	1,016	1,074	58	1,016	0.0001642	9.39E-06	
Subtotal	216	3,777	3,993		*p* =	0.98770531	χ^2 =	0.000237

G.3 Management Implications

This analysis was performed on acoustic-telemetry data from tagged, actively migrating juvenile salmonids derived from sources at Bonneville Dam or upstream. The mean length of the tagged fish population was 144 mm for yearling Chinook salmon, 215 mm for steelhead, and 115 mm for subyearling Chinook salmon. Therefore, the results are not representative of smaller size classes of juvenile salmonids (40–100 mm) known to use shallow-water areas of the LCRE (Johnson et al. 2011). The analysis, however, does demonstrate the utility of retrospective analyses of LCRE acoustic-telemetry data. Such analyses will become even more useful to managers if acoustic transmitters and shallow-water hydrophones can be developed that allow reliable tagging and detection, respectively, of small juvenile salmon (> 50 mm). Perry and Skalski (2008) provided a statistical design for acoustic-telemetry methods to evaluate the survival benefits of restoration. Our retrospective analysis shows the potential of a landscape-scale approach to evaluate the proclivity of juvenile salmon to use off-channel migration routes. Future analyses should incorporate telemetry detections at selected off-channel restoration and reference sites.

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Appendix H

Adult Salmonid Passage and Juvenile Migration Timing at Bonneville Dam: Estimated Trends, 1980–2009

Appendix H

Adult Salmonid Passage and Juvenile Migration Timing at Bonneville Dam: Estimated Trends, 1980–2009

Prepared by Erin Donley, Gary Johnson, and John Skalski

This assessment of trends in estimated adult salmonid abundance and timing of juvenile salmonid migrations at Bonneville Dam was recommended by the Salmon Benefits team in its first-year research.

H.1 Problem Statement and Objective

The Salmon Benefits team hypothesized that trends in estimated adult salmonid abundance and timing of juvenile salmonid migration at Bonneville Dam might support interpretation of restoration monitoring metrics in the lower Columbia River and estuary (LCRE) because the primary purpose of habitat restoration is to restore depressed salmon populations. Such data are available via an on-line public database. Diefenderfer et al. (2010) suggested an examination of abundance trends as an indirect indicator of salmonid survival. In addition, trends in adult salmonid abundance and juvenile salmonid migration timing may potentially support other Anadromous Fish Evaluation Program Salmon Benefits efforts, including past assessments of fish stock composition, life-history diversity, and residence time in Lower Columbia River segments. The objective of the research reported here was to estimate overall trends in adult salmonid passage and juvenile salmonid migration timing using monitoring data collected at Bonneville Dam.

This appendix also provides estimates of percentage composition for returning adult Columbia River Chinook salmon.

H.2 Methods

H.2.1 Adult Salmonid Passage and Abundance

Data on adult salmonid abundance were collected from the Columbia River Data Access in Real Time (DART) website.[1] Columbia River DART focuses on the Columbia River basin dams and fish passage. All data included in this document were generated at Bonneville Dam.

The estimated adult salmonid abundance summary data described below include:

- estimated annual species totals for Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), and steelhead (*O.mykiss*)
- estimated annual species totals by run for Chinook salmon.

[1] http://www.cbr.washington.edu/dart/dart.html

Calculations were based on DART data, which include adult passage at Bonneville Dam estimated using daily visual counts. Chinook runs were identified based on run schedules as established by the U.S. Army Corps of Engineers (USACE) and Yakima Klickitat Fisheries Project.[2] An important caveat related to the data is the fact that data collection periods did not span the total length of time in which the specified Chinook salmon run times occur. For example, the USACE Chinook "run schedule" indicates that fish passing the dam between March 15 and May 31 are considered spring Chinook salmon for the purposes of DART analysis. However, data are only being collected from March 26 through May 31. In addition, inter-annual variability in the run timing of this group of Chinook salmon may occur outside of the dates identified by the USACE run schedule. Therefore, the spring Chinook salmon run abundance reported via DART may underestimate the number of adult Chinook salmon that actually passed Bonneville Dam during the naturally occurring spring Chinook run timing.

H.2.2 Juvenile Migration Timing

The estimated juvenile salmon migration timing information described below includes annual species index totals for subyearling and yearling Chinook salmon, coho salmon, sockeye salmon, and steelhead. Calculations were based on DART data, which include juvenile passage at Bonneville Dam estimated using a daily smolt passage index.

H.2.3 Percent Age Composition

Over a period of 11 years, the Columbia River Inter-Tribal Fish Commission (CRITFC) conducted a series of field studies at Bonneville Dam in which they assessed the age, length-at-age, and stock composition of adult Pacific salmon. Each year, CRITFC sampled adult salmon at the dam and examined the scales of sampled fish to estimate age composition of returning adults. The annual age composition estimates are reported in a series of reports from the years 1998–2009 (Hooff et al. 1999a, b; Kelsey and Fryer 2001, 2002, 2003; Miranda et al. 2004, 2005; Whiteaker et al. 2006, 2007, 2008; Torbeck et al. 2009; Whiteaker and Fryer 2009). We averaged the reported CRITFC age composition percentages for adult Chinook salmon for each annual run (spring, summer, and fall) over the 11 years for which data are available.

H.3 Total Estimated Adult Salmonid Passage Bonneville Dam, 1980–2009

Adult Chinook salmon are generally estimated to have the greatest abundance of all the adult salmonids monitored at Bonneville Dam. As indicated in Table H.1 and Figure H.1, Chinook population numbers were greatest between the years 2001 and 2005, fell during 2006 and 2007, and show an upward trend toward the end of the period monitored. Steelhead are estimated to have the second greatest abundance of the adult salmonids monitored at Bonneville Dam. The trends in the steelhead population follow those of the Chinook population, with the greatest steelhead abundance occurring between 2001 and 2005. Between 1980 and 1993, adult sockeye abundance oscillated around 100,000 individuals. However, in 1994 and 1995 the sockeye population declined precipitously to 8,774 individuals. After the initial decline, the sockeye population rose and fell between approximately 100,000 and 15,000 individuals until the year 2008, when the population reached its maximum abundance for the period

[2] http://www.cbr.washington.edu/dart/adult.html

monitored, 213,607 individuals. Similar to sockeye salmon, the coho salmon population at Bonneville Dam is generally estimated to have a lower abundance relative to other adult salmonid populations monitored at the dam. The lowest coho salmon abundance occurred in the year 1983 (8,402 individuals) and the greatest abundance occurred in the year 2001 (259,772 individuals).

Table H.1. Estimated Adult Passage at Bonneville Dam from 1980Through 2009 for Chinook Salmon, Steelhead, Sockeye Salmon, and Coho Salmon. Data were obtained from the DART website.[a]

Year	Chinook Salmon	Steelhead	Sockeye Salmon	Coho Salmon
1980	207,967	129,315	58,905	12,844
1981	232,299	159,270	56,037	21,935
1982	247,911	157,640	50,219	55,816
1983	186,214	218,419	100,542	8,402
1984	216,469	316,066	152,540	16,604
1985	296,613	344,136	166,369	38,646
1986	370,738	379,986	58,152	108,651
1987	467,966	303,055	116,993	17,923
1988	409,751	279,226	79,721	27,038
1989	373,218	287,813	41,908	27,425
1990	296,551	183,054	49,597	11,637
1991	226,427	274,564	76,488	58,876
1992	218,689	310,814	84,985	14,335
1993	259,344	188,386	80,178	10,642
1994	208,197	161,821	12,496	20,291
1995	189,426	202,348	8,774	10,395
1996	272,895	203,583	30,252	15,727
1997	356,717	258,509	46,926	23,969
1998	248,839	184,887	13,219	46,290
1999	306,868	206,046	17,863	40,684
2000	401,779	275,806	93,398	85,847
2001	868,429	636,460	114,934	259,772
2002	871,763	483,956	49,610	88,570
2003	921,314	365,821	39,326	125,759
2004	845,950	313,378	123,291	115,042
2005	569,038	314,681	73,002	83,200
2006	493,703	338,859	37,066	102,110
2007	272,474	322,253	24,376	88,552
2008	518,944	357,841	213,607	135,535
2009	480,284	604,939	177,823	224,899
Average	394,559.2	292,097.7	74,953.2	63,247.2
Standard Deviation	219,294.8	120,701.9	51,968.8	62,739.2
Maximum	921,314.0	636,460.0	213,607.0	259,772.0
Minimum	186,214.0	129,315.0	8,774.0	8,402.0

a. http://www.cbr.washington.edu/dart/adult.html

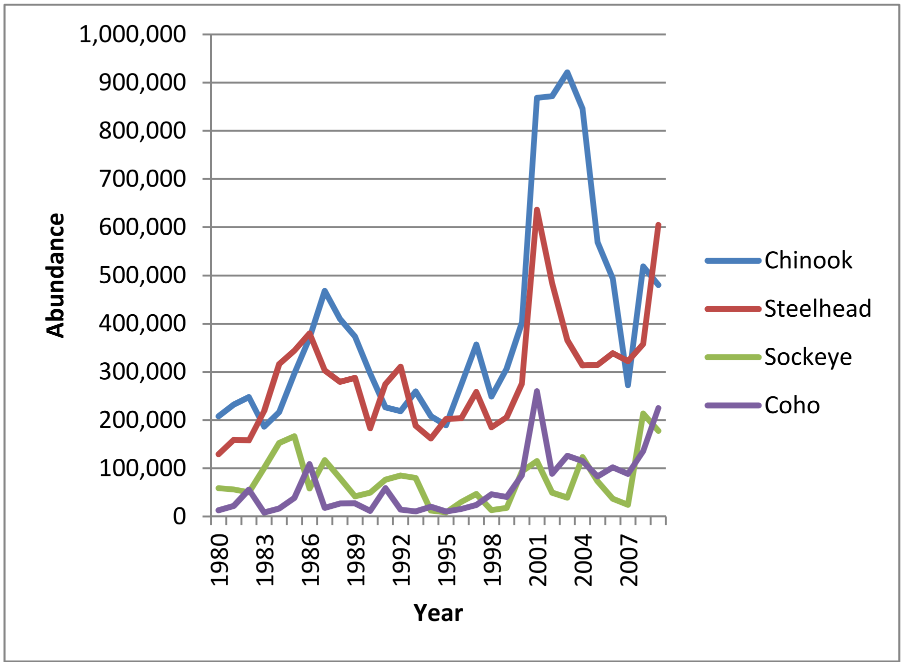

Figure H.1. Estimated Adult Passage at Bonneville Dam from 1980 Through 2009. Data were obtained from the DART website.[3]

H.4 Estimated Adult Chinook Passage by Run at Bonneville Dam, 1980–2009

Adult fall-run Chinook salmon are estimated to have the greatest abundance of all adult Chinook salmon monitored at Bonneville Dam. For the period monitored, fall-run Chinook abundance was greatest in the year 2003 with 610,075 individuals (see Table H.2 and Figure H.2). The lowest fall-run Chinook abundance occurred in the year 1983 with 113,270 individuals. Adult spring-run Chinook salmon are estimated the have the second greatest abundance of the three groups of Chinook salmon monitored at Bonneville. The spring-run population abundance trends generally follow those of the fall-run Chinook salmon, with the greatest spring-run abundance occurring in the year 2001 (391,818 individuals) and the lowest abundance occurring in the year 1995 (10,194 individuals). The summer-run Chinook salmon population is estimated to have the lowest overall abundance of the three groups of Chinook salmon adults monitored at Bonneville Dam. For the period monitored, the greatest summer-run Chinook abundance occurred during the year 2002, and the lowest abundance occurred during the year 1992. Unlike the fall-run and spring-run Chinook salmon populations, the summer-run Chinook salmon did not experience drastic dips in population throughout the period monitored.

[3] http://www.cbr.washington.edu/dart/adult.html

Table H.2. Estimated Adult Chinook Salmon Passage by Run at Bonneville Dam from 1980 Through 2009. Data were obtained from the DART website[(a)]

Year	Fall Total	Spring Total	Summer Total
1980	127,880	53,072	27,003
1981	147,109	62,827	22,363
1982	157,771	70,011	20,129
1983	113,270	54,898	18,046
1984	147,278	46,870	22,321
1985	189,007	82,788	24,489
1986	226,695	118,074	26,447
1987	336,936	97,596	33,033
1988	290,011	88,209	31,315
1989	263,979	80,885	28,301
1990	177,887	93,934	24,730
1991	150,300	57,171	18,952
1992	115,201	88,425	15,063
1993	126,479	110,820	22,045
1994	170,397	20,169	17,631
1995	164,202	10,194	15,030
1996	205,368	51,493	16,034
1997	214,710	114,071	27,936
1998	189,064	38,342	21,433
1999	242,124	38,574	26,170
2000	192,793	178,336	30,616
2001	400,205	391,818	76,156
2002	473,786	269,428	127,436
2003	610,075	195,671	114,808
2004	583,269	170,291	92,143
2005	415,684	74,038	79,208
2006	299,161	96,456	97,519
2007	157,784	66,624	47,882
2008	314,995	125,545	78,271
2009	283,691	114,525	81,936
Grand Total	7,487,111	3,061,155	1,284,446
Average	249,570	102,039	42,815
Standard Deviation	132,159	77,414	33,012
Max	610,075	391,818	127,436
Min	113,270	10,194	15,030

a. http://www.cbr.washington.edu/dart/adult.html

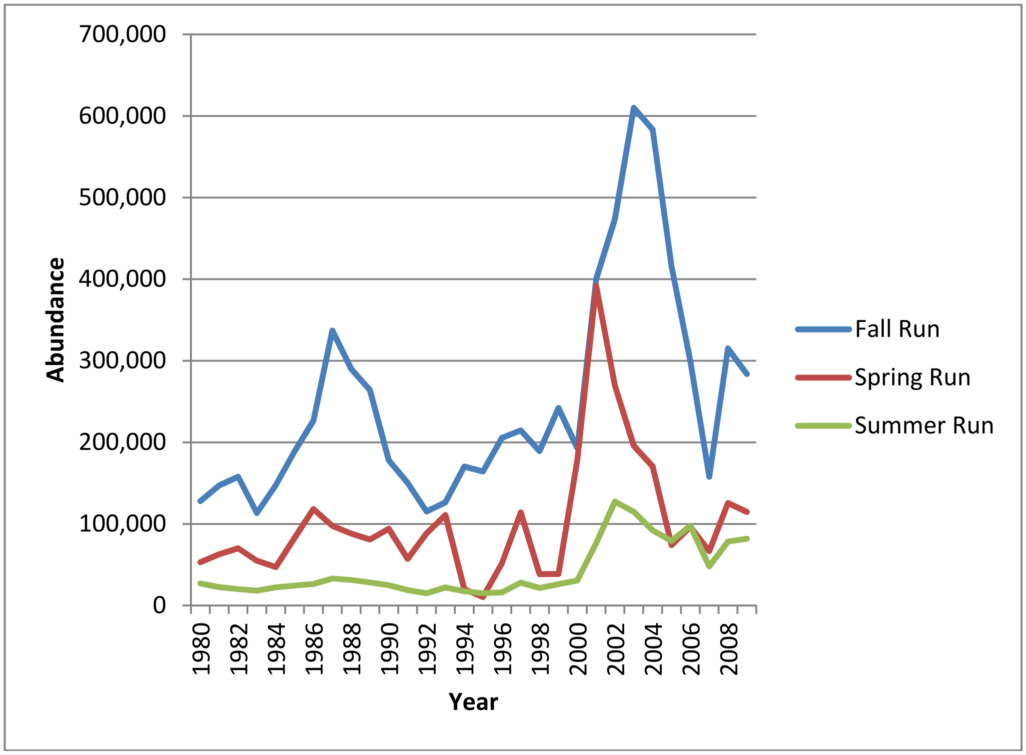

Figure H.2. Estimated Adult Chinook Passage by Run at Bonneville Dam from 1980 Through 2009. Data were obtained from the DART website[4].

H.5 Juvenile Passage Indices at Bonneville Dam, 1986–2009

The following is an explanation of juvenile salmonid index values reported through DART by the Fish Passage Center, which was established by the Northwest Power and Planning Council Fish and Wildlife Program. The index value information reported below includes a combination of hatchery and wild juvenile data. It is useful for interpretation of juvenile salmonid migration timing only. The data are *not* useful for the purpose of deriving overall juvenile salmonid population abundance. Several characteristics of the juvenile salmonid index values make the data inappropriate for daily or inter-annual comparison. For example, while juvenile salmon migrate during all months, the juvenile bypass system at Bonneville Dam does not operate year-round. In addition, index values are generated under conditions of differential reservoir spill flow and turbine flow. These complications preclude the use of these data for comparison between days, years, or species. Annual juvenile salmonid passage index values generated at Bonneville Dam are provided in Table H.3 and Figure H.3.

[4] http://www.cbr.washington.edu/dart/adult.html

Table H.3. Annual Juvenile Passage Index Values at Bonneville Dam from 1986 through 2009.[(a)] Data were obtained from the DART website.[5]

Year	Chin0	Chin1	Coho	Sock	Stlhd
1986	175,228	150,819	169,162	47,449	62,962
1987	427,306	191,388	188,032	29,875	67,911
1988	724,096	365,812	599,194	77,921	103,703
1989	1,756,758	435,451	491,615	138,308	206,225
1990	1,219,786	337,787	677,407	81,403	202,891
1991	1,257,383	609,417	575,107	147,176	230,199
1992	2,320,366	723,652	388,807	10,835	108,585
1993	4,339,391	2,168,048	1,250,712	538,861	790,024
1994	3,607,433	779,720	626,437	87,143	199,211
1995	3,406,406	1,776,322	1,104,448	263,673	483,444
1996	1,921,838	470,112	863,814	37,412	436,835
1997	1,499,549	286,142	706,544	31,145	780,841
1998	1,591,880	346,280	513,645	114,568	397,210
1999	1,692,673	638,607	375,644	118,207	351,309
2000	3,814,911	2,535,055	1,977,556	65,608	657,064
2001	2,940,641	1,688,673	2,164,026	106,961	489,392
2002	7,075,267	3,349,185	2,341,191	849,129	1,462,261
2003	7,903,922	4,043,776	2,116,570	1,261,379	1,635,181
2004	4,577,937	1,449,398	918,385	183,774	153,204
2005	3,822,582	1,528,366	771,692	41,903	186,605
2006	3,856,912	2,256,238	657,542	407,725	271,628
2007	4,072,828	1,949,995	628,618	171,273	267,163
2008	3,769,357	1,291,085	358,756	145,402	450,291
2009	4,310,847	1,717,031	503,313	74,964	677,048
Average	3,003,554	1,295,348	873,676	209,671	444,633
Standard Deviation	1,934,926	1,046,904	636,436	293,727	403,797
Maximum	7,903,922	4,043,776	2,341,191	1,261,379	1,635,181
Minimum	175,228	150,819	169,162	10,835	62,962

a. Chin0 represents subyearling Chinook salmon, Chin1 represents yearling Chinook salmon, Sock represents sockeye salmon and Stlhd represents steelhead.

5 http://www.cbr.washington.edu/dart/pass_com.html

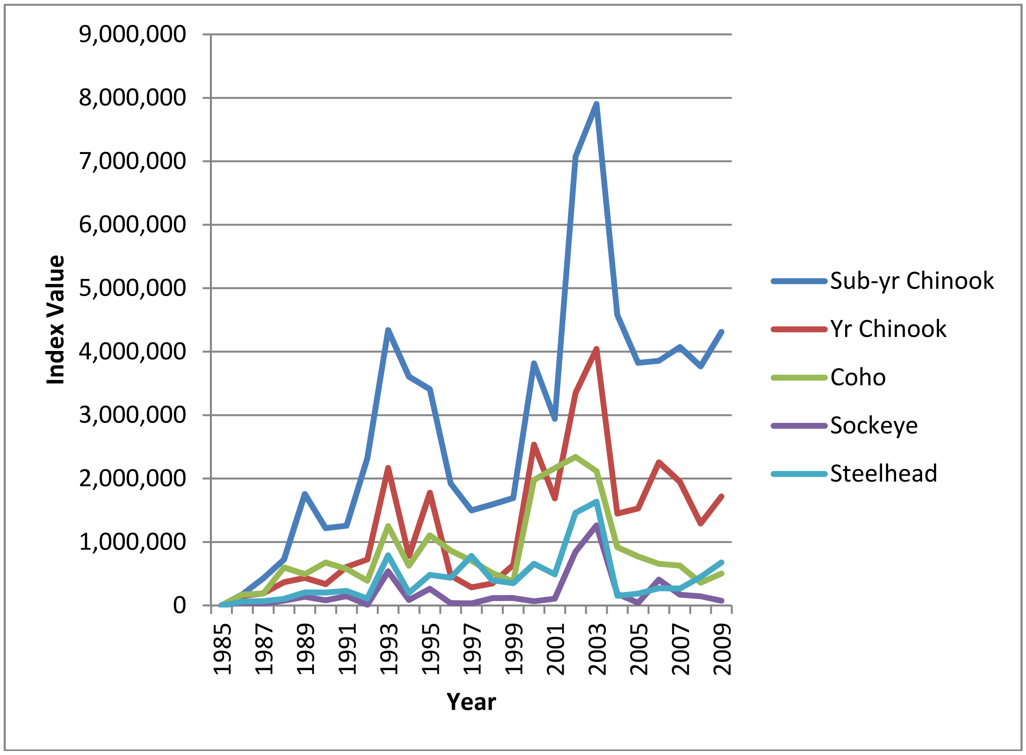

Figure H.3. Estimated Juvenile Salmonid Passage Index Values at Bonneville Dam from 1985 Through 2009. Data were obtained from the DART website[6].

H.6 Adult Age Composition

The numbers listed in Table H.4 are the estimated percentage of fish in each age class. For example, of the adult spring-run Chinook salmon counted in the year 2006, 2% were 3-year-olds, 80% were 4-year-olds, 17% were 5-year-olds, and 1% were 6-year-olds. These estimations are based on Columbia River Chinook salmon age composition studies performed at Bonneville Dam (Hooff et al. 1999a b; Kelsey and Fryer 2001, 2002, 2003; Miranda et al. 2004, 2005; Whiteaker et al. 2006, 2007, 2008; Torbeck et al. 2009; Whiteaker and Fryer 2009).

[6] http://www.cbr.washington.edu/dart/pass_com.html

Table H.4. Estimated Percent Age Composition of Returning Adult Chinook Salmon at Bonneville Dam from 1998 Through 2009.[(a)] The average and standard deviation for the entire data series of percent age compositions for spring, summer and fall Chinook salmon are highlighted.

Species	Run	Year Assessed	2 Years Old	3 Years Old	4 Years Old	5 Years Old	6 Years Old
Chinook salmon	sp	1998	0%	4%	50%	46%	0%
Chinook salmon	su	1998	0%	11%	33%	52%	4%
Chinook salmon	f	1998	1%	32%	24%	39%	3%
Chinook salmon	sp	1999	0%	23%	70%	7%	0%
Chinook salmon	su	1999	0%	21%	39%	37%	3%
Chinook salmon	f	1999	1%	28%	63%	8%	0%
Chinook salmon	sp	2000	0%	14%	83%	3%	0%
Chinook salmon	su	2000	1%	43%	30%	26%	0%
Chinook salmon	f	2000	11%	17%	32%	40%	0%
Chinook salmon	sp	2001	0%	3%	88%	9%	0%
Chinook salmon	su	2001	0%	15%	68%	14%	3%
Chinook salmon	f	2001	7%	39%	43%	10%	1%
Chinook salmon	sp	2002	0%	1%	86%	13%	0%
Chinook salmon	su	2002	0%	5%	52%	43%	0%
Chinook salmon	f	2002	5%	33%	51%	11%	0%
Chinook salmon	sp	2003	0%	7%	39%	54%	0%
Chinook salmon	su	2003	1%	13%	33%	50%	3%
Chinook salmon	f	2003	3%	10%	60%	27%	0%
Chinook salmon	sp	2004	0%	5%	89%	6%	0%
Chinook salmon	su	2004	1%	18%	32%	45%	4%
Chinook salmon	f	2004	2%	33%	25%	39%	1%
Chinook salmon	sp	2006	0%	2%	80%	17%	1%
Chinook salmon	su	2006	2%	6%	34%	53%	5%
Chinook salmon	f	2006	8%	21%	33%	36%	2%
Chinook salmon	sp	2007	0%	25%	52%	23%	0%
Chinook salmon	su	2007	2%	37%	22%	33%	6%
Chinook salmon	f	2007	11%	18%	46%	23%	2%
Chinook salmon	sp	2008	0%	17%	75%	8%	0%
Chinook salmon	su	2008	1%	24%	59%	14%	2%
Chinook salmon	f	2008	9%	50%	30%	11%	0%
Chinook salmon	sp	2009	0%	49%	45%	6%	0%
Chinook salmon	su	2009	1%	37%	35%	26%	1%
Chinook salmon	f	2009	12%	16%	58%	14%	0%
Chinook salmon	sp	Average	0.00%	13.64%	68.82%	17.45%	0.09%
Chinook salmon	su	Average	0.82%	20.91%	39.73%	35.73%	2.82%
Chinook salmon	f	Average	6.36%	27.00%	42.27%	23.45%	0.82%
Chinook salmon	sp	Standard Deviation	0.75	12.84	16.19	14.17	2.06
Chinook salmon	su	Standard Deviation	4.20	11.83	13.06	12.86	1.04
Chinook salmon	f	Standard Deviation	2.01	15.20	20.74	15.06	0.39

a. sp represents spring Chinook salmon; su represents summer Chinook salmon; f represents fall Chinook salmon.

H.7 Management Implications

This assessment of trends in estimated adult salmonid abundance and timing of juvenile salmonid migrations at Bonneville Dam fulfills a recommendation of the Salmon Benefits team resulting from its first-year research. However, as a consequence of the data caveats mentioned above, the trends in juvenile and adult salmonids at Bonneville Dam are not likely to be useful to support interpretation of Salmonid Benefits project data. It is possible that the estimated percent age composition of returning adults may be useful for consideration in future salmonid life history analyses.

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Appendix I

Analysis of Estuary PIT-Tag Detections

Appendix I

Analysis of Estuary PIT-Tag Detections

Prepared by John Skalski and Richard Townsend

I.1 Problem Statement

Little is known about the feasibility of conducting either qualitative or quantitative studies of juvenile salmon movement, residence time, or survival using passive integrated transponder (PIT)-tag technologies in the estuarine environment. Furthermore, little is known about juvenile salmon using the nearshore and estuarine environment of the lower Columbia River. It is unknown which fish stocks from which fish sources might be actively using restored habitats within the Lower Columbia River, estuary, and estuary tributary areas.

I.2 Research Objective

Evaluate the feasibility of using PIT-tag detection arrays to detect outmigrants as they move through and use the nearshore and estuarine environment of the lower Columbia River. This study will determine the feasibility of conducting both quantitative mark-recapture investigations and qualitative assessments of fish presence and residence time. In so doing, preliminary information about which fish stocks may be using this environment will also be gathered.

I.3 Methods

Six autonomous, 40-ft PIT-tag detection arrays were placed in an off-channel habitat in the vicinity of Cottonwood Island. These arrays were used to continuously monitor for PIT-tag detections from May 1 through December 13, 2010. The arrays picked up detections from run-of-river (ROR) PIT-tagged fish as well as fish tagged by this project.

This project tagged and released a total of 8,989[1] fall Chinook juvenile salmon from Kalama Falls Hatchery and also captured, tagged, and released 404 juvenile salmon from the Kalama River screw trap. In addition, this project released 160 juvenile salmon in the estuary, inland from the PIT-tag detectors, to estimate residence time.[2] All of these fish were tagged and released by this project to increase the number of tagged fish moving through the study area. Release files and PIT-tag detections were uploaded to the PIT-Tag Information System (PTAGIS) database operated by the Pacific States Marine Fisheries Council.

Final deployment of the six PIT-tag detection arrays did not permit using multi-state mark-recapture models to estimate smolt survival, use of, and movement in the estuary. Instead, the PIT-tag detection arrays were used to collect general information about which juvenile salmon stocks were using the nearshore and estuarine environment and when.

[1] One PIT-tagged fish released in the first hatchery release was subsequently beach seined, and was removed from analysis due to secondary handling.
[2] One hundred and sixty juvenile salmon were directly released in the vicinity of Cottonwood Island. This figure does not include “dispersal” or “beach seine” released fish as described in Chapter 4.0 of this report.

I.4 Results

Over the period from May 1 through December 13, 2010, when the shoreline PIT-tag detectors were in operation, a total of 81 unique PIT-tagged fish were detected (Table I.1). Releases of PIT-tagged fish from the Kalama Falls Hatchery (i.e., 8,989 fish) and from the Kalama River screw trap (i.e., 404 fish) proved ineffectual in producing tagged fish arrivals at the Cottonwood Island study area. Only 5 of the hatchery-released fish (i.e., 0.06%) and none of the screw-trap released fish (i.e., 0%) were ever detected at the PIT-tag detection arrays (Table I.1). Of 160 PIT-tagged fish released into the tidal freshwater, inland above the PIT-tag detectors, only 6 (i.e., 3.75%) were ever detected as they exited the area.

The single largest source of PIT-tag detections at the study area came from ROR tagged fish. A total of 56 such fish were detected. Of these fish, 30 were salmonids, 22 northern pikeminnows (*Ptychocheilus oregonensis*), and 4 without PTAGIS release records (Table I.2).

I.4.1 ROR PIT-Tag Detections

The single largest source of detection information came from the ROR PIT-tagged fish that were detected at the study area. These fish were tagged by a variety of groups ranging from public utilities to state, federal, and tribal organizations (Table I.3). The releases associated with these ROR PIT-tag detections occurred from 2006 through 2010 (Table I.4). The detected fish were from a total of 22 different release locations. Six of these locations were associated with northern pikeminnows, while the remaining 16 locations were associated with salmon releases (Table I.5). The releases associated with the detected northern pikeminnows all occurred in the general vicinity of the study area, between rkm 95 and 188. The detected salmonids came from a variety of locations, including the North Toutle River, Snake River, Clearwater River, Sawtooth and Imnaha rivers, Lake Wenatchee, and Methow River (Figure I.1, Table I.5).

The ROR salmonids were detected at the Cottonwood Island study area from May to mid-August (Figure I.2). The northern pikeminnow detections were concurrent with the timing of salmonid presence.

Mean residence times of ROR PIT-tagged fish were based on first and last detections of each fish with two or more detections. For Chinook salmon, mean residence time was 7.6 hours with a standard deviation (SD) between fish of 22.6 hours. The mean residence time for northern pikeminnows was much longer, 11.5 days (SD = 33.6 days). These data suggest that while the salmonids were active migrants through the area, the northern pikeminnows were temporary residents off and on during the salmonid migration (Table I.6).

Based on first and last detection locations for salmonids with two or more detections, 1 of 16 fish were detected moving upstream (6.25%), 0 were moving downstream (0%), and 15 were not moving out of the area (93.75%). These movements were based on detections between sites Carroll's Channel wetland channel (CCC) and Cottonwood Island wetland channel (CIC). Sample sizes were too small to associate movement direction with direction of tidal flow (Table I.6).

Table I.1. Origins of the 81 PIT-Tagged Fish Detected at Any PIT-Tag Array in the Study

Source	# Released	# Detected
Release 1 (fall Chinook)	4,490	4[1]
Release 2 (fall Chinook)	4,499	1
Dispersed	100	2
Direct	160	6
Kalama screw trap	404	0
Beach seine	286	12[1]
Non-study sources	--	56[3]
Total		81

Table I.2. Species Composition of the ROR Fish Detected at PIT-Tag Detection Arrays in the Study Area. (Codes used in PTAGIS were as follows: *species* 1 = Chinook salmon, 3 = steelhead, 4 = sockeye salmon, D = northern pikeminnow; *run* 1 = spring, 2 = summer, 3 = fall, 5 = unknown; *rear type* H = hatchery, W = wild, U = unknown.)

	Salmonids										
	Chinook Salmon						Steelhead		Sockeye Salmon	Northern Pikeminnow	
Detection site	11H	12H	12W	13H	15H	15U	32H	32W	45H	D0W	Total
CCC		2	1	5	2		1	2	1	9	23
CIC	1			11		1	1	1		10	25
CCC & CIC				1						3	4
Total	1	2	1	17	2	1	2	3	1	22	52

CCC = Carroll's Channel (wetland) channel; CIC = Cottonwood Island wetland channel

Table I.3. Organizations that Released the ROR PIT-Tagged Fish Detected in the Cottonwood Island Study Area

Organizations	Salmonid	Northern Pikeminnow	Total
Biomark	1		1
Chelan Public Utility District	1		1
Fish Passage Center	1		1
Idaho Department of Fish and Game	2		2
National Marine Fisheries Service	3		3
Nez Perce Tribe	3		3
Oregon Department of Fish and Wildlife	1		1
Pacific Northwest National Laboratory	1		1
Pacific State Marine Fisheries Council	3	22	25
RTR Consultants	1		1
US Fish and Wildlife Service	13		13
Total	30	22	52

[3] Four of the 56 non-study fish detected did not have PTAGIS records.

Table I.4. Years of Release for ROR Fish by Species Detected at PIT-Tag Arrays at the Cottonwood Island Study Area

Species	2006	2007	2008	2009	2010	Total
Chinook salmon					24	24
Steelhead			3	1	1	5
Sockeye salmon		1				1
Northern pikeminnow	1		3	3	15	22
Total	1	1	6	4	40	52

Table I.5. Release Sites Associated with the ROR PIT-Tagged Fish Detected at the Cottonwood Island Study Area

Species	Rkm	Release Site Code	Release Site Name
Northern pikeminnow	000.095	COLR2	Columbia River - Three Tree Point, WA, to Lewis River (rkm 49-140)
	000.107	COLR2	Columbia River - Three Tree Point, WA, to Lewis River (rkm 49-140)
	000.140	COLR2	Columbia River - Three Tree Point, WA, to Lewis River (rkm 49-140)
	000.186	COLR3	Columbia River - Lewis River to Bonneville Dam (rkm 140-234)
	000.188	COLR3	Columbia River - Lewis River to Bonneville Dam (rkm 140-234)
Salmonids	000.307	COLR4	Columbia River - Bonneville Dam to John Day Dam (rkm 234-347)
	111.032.028.018.001	TOUT	North Toutle Hatchery, Washington Department of Fish and Wildlife
	261.002	LWSH	Little White Salmon National Fish Hatchery
	269	SPRC	Spring Creek National Fish Hatchery
	328.140.006	TROU2C	Trout Creek, Deschutes River Watershed
	522.173	LGRRRR	Lower Granite Dam - Release below the PIT-Tag Diversion System Gate with Return to River
	522.224.038	NPTH	Nez Perce Tribal Hatchery
	522.254	SNAKE3	Snake River - Clearwater River to Salmon River (rkm 224-303)
	522.263	CJRAP	Captain John Rapids Acclimation Pond
	522.303.140.007.006	RPDTRP	Rapid River Trap
	522.303.215.118	KNOXB	Knox Bridge
	522.303.617	SAWTRP	Sawtooth Trap
	522.308.007	IMNTRP	Imnaha Trap
	730	RI2BYP	Rock Island Dam - Release into the PH2 Juvenile Facility Bypass flume/pipe
	754.09	WENATL	Lake Wenatchee
	843	METHR	Methow River
	843.081	WINT	Winthrop National Fish Hatchery

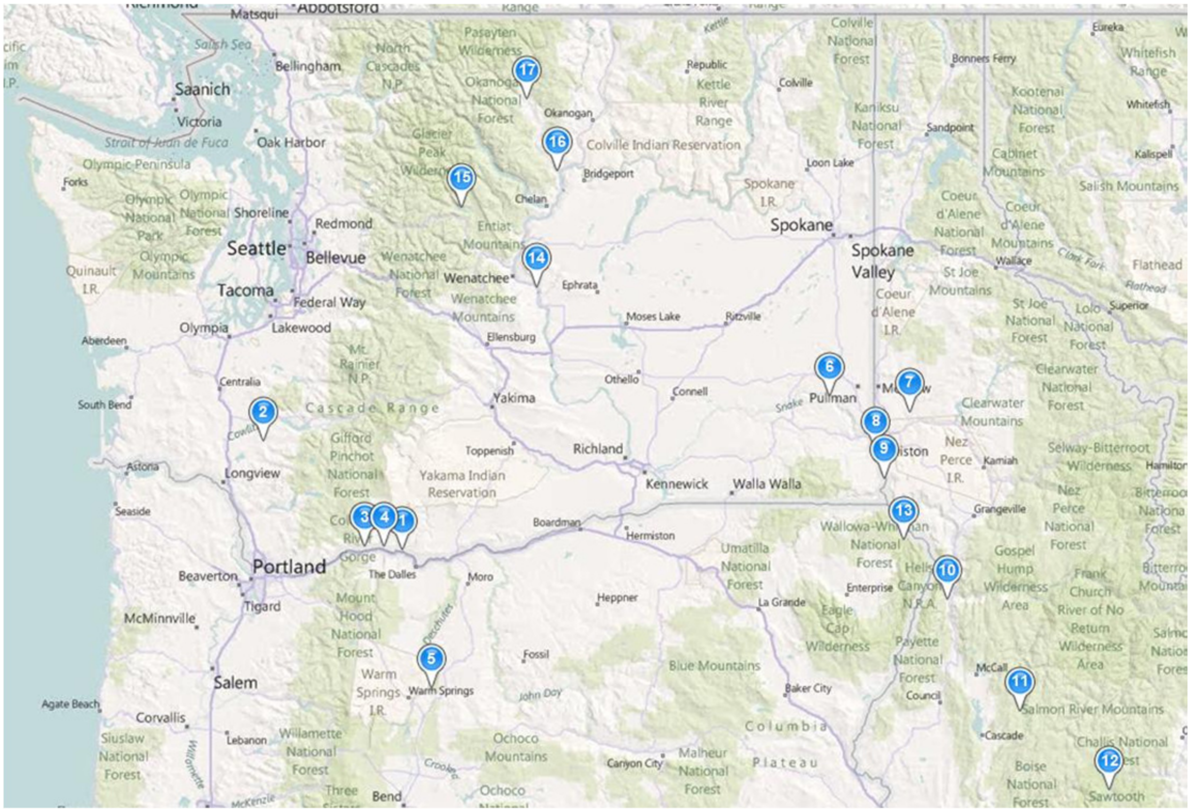
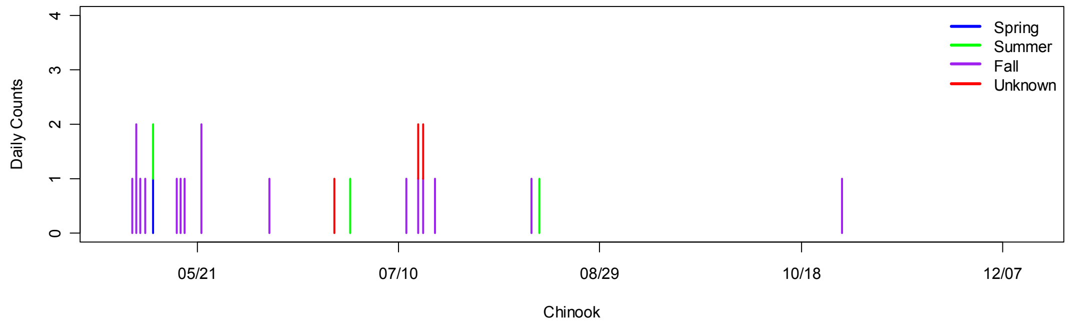


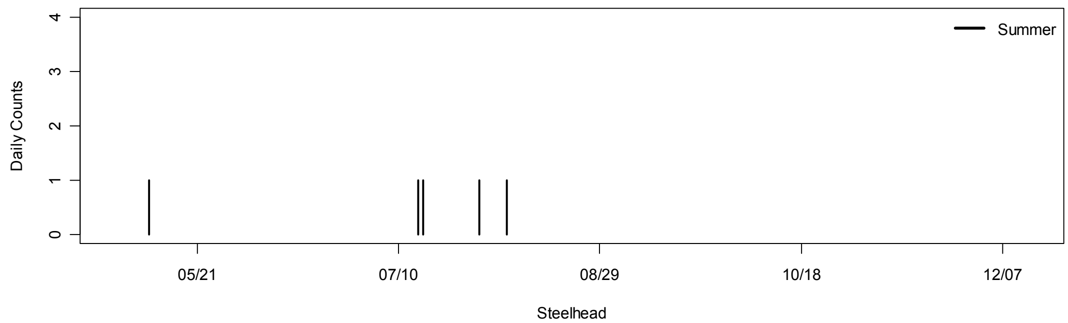
Figure I.1. Release Locations of Salmonid ROR PIT-Tagged Fish Detected at the Cottonwood Island Study Area. Site numbers are identified in the list below.

Figure I.1 Sites	Figure I.1 Locations
1	Columbia River between Bonneville and John Day dams
2	North Toutle Hatchery
3	Little White Salmon National Fish Hatchery
4	Spring Creek National Fish Hatchery
5	Trout Cree, Deschutes River Watershed
6	Lower Granite Dam
7	Nez Perce Tribal Hatchery
8	Snake River between Clearwater River and Salmon River
9	Captain John Rapids Acclimation Pond
10	Rapid River Trap
11	Knox Bridge
12	Sawtooth Trap
13	Imnaha Trap
14	Rock Island Dam
15	Lake Wenatchee
16	Methow River
17	Winthrop National Fish Hatchery

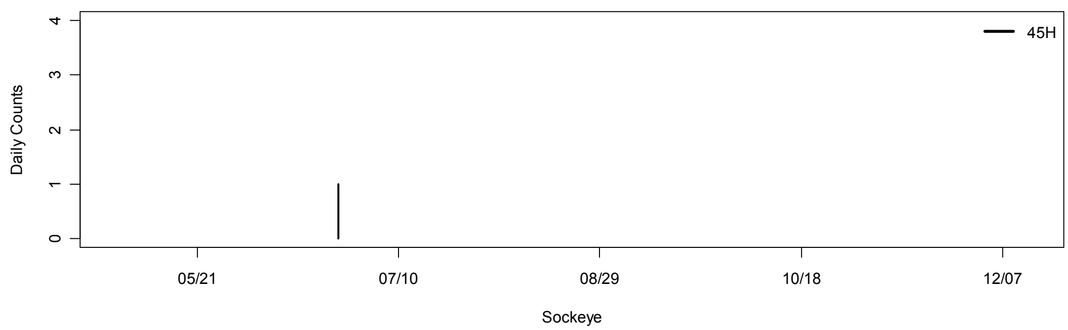
a. Chinook salmon



b. Steelhead



c. Sockeye salmon



d. Northern pikeminnow

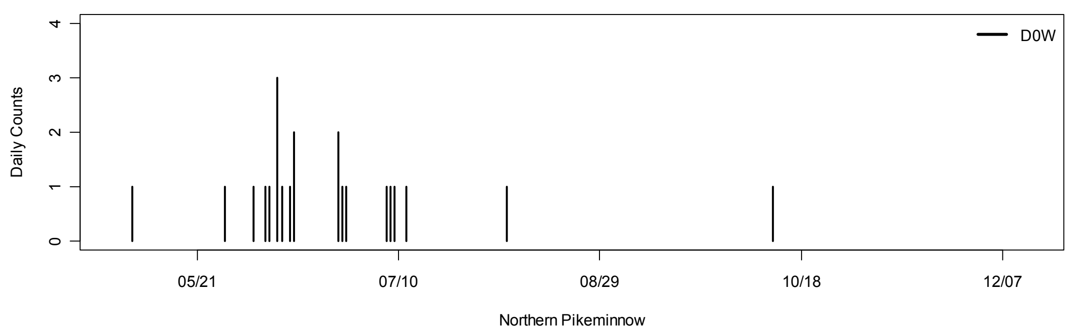


Figure I.2. Dates of First Detection of ROR PIT-Tagged Fish at the Cottonwood Island Study Area by Species

Table I.6. Summary of Mean Residence Time and Direction of Movement of ROR PIT-Tagged Fish Detected at the Cottonwood Island Study Area. Only fish with at least two detections were used in movement determination.

		Movement Direction			Average Residence Time	
Species	*n*	Upstream	Downstream	In Place	Time	SD
Chinook salmon	15	1		14	7.60 h	22.65 h
Steelhead	1			1	0.05 h	NA
Sockeye salmon	0				NA	NA
Northern pikeminnow	19		3	16	11.49 days	33.63 days

NA = not applicable

I.4.2 Directly Released Fish

One hundred and sixty Chinook salmon were PIT-tagged at the Kalama Falls Hatchery and directly released into the estuary sites inland from the PIT-tag detectors. Only 6 of these fish (3.75%) were detected as they apparently exited the study area. Their average residence time was 3.38 days (SD = 2.21 days), with a range from 1.16 to 6.98 days. The placement of the PIT-tag detector arrays in 2010 did not permit estimation of in-estuary (in wetland channel) survival, as described in Chapter 4.0 of this report.

I.4.3 Kalama Release Fish

Only 7 of 8,989 hatchery-released PIT-tagged Chinook salmon from the Kalama Falls Hatchery (i.e., 0.078%) were detected at the Cottonwood Island study area.[4] Of the 8,989 hatchery and 404 Kalama River screw-trap PIT-tagged fish, 9 and 2, respectively, were detected in the National Marine Fisheries Service (NMFS) mid-water trawl operated in the vicinity of rkm 118. None of the seven fish detected at the estuary PIT-tag detection arrays was detected at the mid-water array.

I.5 Management Implications

The field testing of PIT-tag detection arrays at the Cottonwood Island study area proved ROR PIT-tagged fish from a variety of sources and fish stocks were using the nearshore tidal freshwater environment. Furthermore, it demonstrated that northern pikeminnows also inhabit that environment during the time of the juvenile salmon outmigration. The study illustrated the feasibility of using PIT-tag detection technology to gather information about juvenile salmon presence and residence time. This feasibility study also revealed that more development will be needed before flat-plate PIT-tag detectors can be efficiently and effectively deployed in this environment. Changes in detection gear deployed will be necessary to cope with the seasonal and diel fluctuations in river flow.

This field effort also found that conducting studies to estimate salmonid movement, use of, and survival in the estuary environment would be very challenging using just PIT-tag capabilities. Despite specific efforts to make PIT-tagged fish available for movement studies, less than 1% of the fish tagged and released upstream of the study area at the Kalama Falls Hatchery were ever detected. We also discovered the 40-ft PIT-tag detection arrays that are currently available are too short in many instances to provide the detection coverage needed to perform quantitative studies of smolt survival and movement.

[4] Hatchery releases included in this calculation are “Release 1,” “Release 2,” and “Dispersed” (see Table I.1).

Given the current PIT-tag detection equipment available, this technology may be best suited to providing qualitative information about juvenile salmon presence in shallow-water habitats of the lower Columbia River and estuary. More development will be needed before this technology can be used to provide quantitative information about juvenile salmon survival and movements in all but very specific situations where the study area is small and well defined.

Appendix J

Physiological Correlates of Juvenile Chinook Salmon Habitat Use in the Lower Columbia River Estuary

Appendix J

Physiological Correlates of Juvenile Chinook Salmon Habitat Use in the Lower Columbia River Estuary

Prepared by Kyle C. Hanson, Kenneth G. Ostrand, Richard A. Glenn, and Ashley S. McNamee

J.1 Abstract

Habitat restoration projects in the lower Columbia River estuary (LCRE), aimed at increasing habitat connectivity, are commonly used for the conservation of Pacific salmonids (*Oncorhynchus* spp.). These projects rely on the assumption that juvenile salmonids benefit from access to diverse habitats leading to populations that are more resilient to disturbance. However, there has been little quantification of the physiological benefits of habitat restoration for juvenile salmon. Therefore, we evaluated a series of physiological indicators of nutritional condition, growth, the stress response, and smoltification to determine whether these variables could be used to show that habitat use (main channel vs. off-channel) conferred a benefit to juvenile Chinook salmon (*O. tshawytscha*) during emigration. Plasma-based (plasma protein and triglyceride) and composition-based (bioelectrical impedance analysis) indicators of nutritional condition fluctuated between habitat types and across the sampling period. This result suggests that there is a correlative relationship between habitat use and fish condition. Growth potential (RNA:DNA ratio) did not vary temporally or by habitat. Measurements of the primary (plasma cortisol) and secondary (whole-blood glucose and lactate, plasma ions and osmolality) stress response were confounded by capture procedures as well as water temperature. The osmoregulatory capacity (gill Na^+,K^+ -ATPase activity) of fish captured in the study indicated that all individuals were undergoing smoltification and actively emigrating. Future research should focus on establishing the mechanistic link between habitat characteristics and benefits to juvenile salmonid survival, most likely using physiological indicators of nutritional condition.

J.2 Introduction

Large-scale habitat restoration projects are increasingly used as a conservation tool to mitigate for declines in Pacific salmonid population numbers throughout the Columbia River basin (Bottom et al. 2005; Fresh et al. 2005). Particularly within the Columbia River estuary, restoration projects have focused on increasing the availability of side-channel habitats to emigrating juvenile salmonids (Bottom et al. 2005; Fresh et al. 2005). Implicitly, these projects rely on the assumption that juvenile salmonids that use these restored and reconnected habitats are conferred some benefit. At the population level, restoration projects focusing on increasing habitat connectivity have also been theorized to increase life history diversity of juvenile salmonids, which in turn leads to an increased resilience of salmonid stocks (Fresh et al. 2005). It follows that increased connectivity between habitat types may also confer a benefit to individual juvenile salmonids because fish should gain access to optimal areas for foraging (Simenstad and Cordell 2000; Sommer et al. 2001), predator avoidance (Simenstad and Cordell 2000), and overwintering (Giannico and Hinch 2003; Hurst 2007) during emigration to the ocean. However, to date, no explicit physiological benefit to individual fish has been documented.

Physiological indicators are commonly used to document the individual response of fish to habitat degradation and alteration. Functionally, physiological processes form the basis by which an individual organism or population interacts with abiotic factors (Ricklefs and Wikelski 2002), thereby constraining the ability of an organism to adapt to altered environmental conditions resulting from habitat degradation or restoration (Adolph 1956). Use of altered, suboptimal habitat induces acute and chronic stress within individuals in a population leading to a cascade of physiological alterations to organismal performance, including impairment to immune response, performance, and growth as well as alterations to behavior (Wedemeyer et al. 1990; Barton et al. 2002). If organisms are unable to adapt to the altered environmental characteristics, populations can suffer from decreased survival (Wedemeyer et al. 1991). Given that restoration projects aim to reverse habitat degradation, biological monitoring can be used to determine the survival benefit for individuals in restored habitats when compared to individuals in other areas, while also allowing for the effectiveness of habitat restoration activities to be quantitatively measured (Cooke and Suski 2008).

Prior to assessing habitat quality through physiological sampling, suites of biochemical variables must be evaluated to determine suitable indicators of habitat-specific benefits. Commonly, physiological studies use measurements of indicators of the primary (stress hormones) and secondary (metabolic and osmoregulatory changes) stress response to determine if an individual occupies degraded habitat (Wedemeyer et al. 1990; Barton et al. 2002; Barton 2002). Restored habitats may provide greater access to optimal foraging areas, thereby increasing the nutritional condition of juvenile salmonids (measured by plasma-borne biochemical constituents), which rapidly respond to alterations in feeding behavior (Wagner and Congleton 2004; Congleton and Wagner 2006), and potential benefits to growth (Sommer et al. 2001; Sommer et al. 2005). With access to restored habitats with a range of environmental conditions, juvenile salmon would also be able to avoid suboptimal areas that could impart chronic stress. Finally, access to a wider range of connected habitats would allow for expression of multiple life history types (Fresh et al. 2005) that may be characterized by differences in migration timing and osmoregulatory preparation for saltwater. As such, monitoring physiological indicators related to these biological processes could be used to determine the quality of habitat used by juvenile salmonids during emigration through the Columbia River estuary.

The goal of the study reported here was to assess the usefulness of physiological indicators for estimating survival benefits of differential habitat use by juvenile Chinook salmon within the lower Columbia River and estuary (LCRE). Fish were captured in three separate habitat types (main channel, off-channel, and wetland channel) representing various degrees of connectivity to the main stem of the Columbia River. Suites of physiological indicators representative of organismal condition, stress response, precocial maturation, and smoltification were evaluated to determine whether they could be used to determine differences in physiological condition based upon patterns of habitat use.

J.3 Materials and Methods

J.3.1 Study Site

To determine the physiological correlates of habitat use within the estuary, fish were collected from three habitat strata (wetland channel [WC], off-channel [OC], and main channel [MC]) at Cottonwood Island in the Columbia River estuary. Within the OC and MC strata, fish were collected at three sampling sites. Within the WC, fish were collected from two sampling sites. Physiological sampling occurred over a 3-day period each month from April through July (Table J.1), and sampling coincided with high tides during daylight hours to ensure that WCs had sufficient depth for fish capture.

Table J.1. The Number of Samples from Juvenile Chinook Salmon Captured During Four Months of Emigration During 2010 in the Lower Columbia River Estuary Listed by Habitat Type (MC = main channel, OC = off-channel, WC = wetland channel)

Sampling Period	Habitat	N_{Marked}	$N_{Unmarked}$	N_{Total}
April 19-20	MC	12	2	14
	OC	12	2	14
	WC	0	0	0
May 17-19	MC	14	0	14
	OC	13	1	14
	WC	0	0	0
June 21-23	MC	10	4	14
	OC	14	1	15
	WC	11	0	11
July 18-20	MC	12	2	14
	OC	14	0	14
	WC	3	0	3

Fish were captured via beach seine; the seine used for fish capture in this study was constructed of 13-mm stretch black knotless netting and measured 46 m long and 3 m deep at the center with wings tapering to 1.5 m. The bag of the seine was constructed of 3.2-mm knotless mesh netting and measured 2.4 m wide by 1.5 m deep. Flotation was provided by 0.48-kg buoyancy ethylene vinyl acetate floats on 46-mm centers, and the lead line was constructed from a solid core lead line in a poly sleeve sewed to the base of the net. For retrieval of the net, a 15-m haul line was affixed to a bridle at the tapered ends of each wing. During each capture event, one end of the haul line was held onshore while a boat moved into the channel perpendicular to shore. Upon reaching the end of the haul line, the boat turned parallel to the shore to deploy the net. After the full length of the net had been set, the haul lines were used to bring the wings to shallow water where captured fish were transferred to 18.9-L buckets filled with fresh river water. Any Chinook salmon of sufficient size (>80 mm in length) for physiological sampling (N = 126) were transferred directly to a physiological sampling station for immediate processing.

J.4 Physiological Sample Collection

Prior to sample collection, fish were kept in buckets filled with fresh river water (at ambient temperature) and supplied with aeration to maintain dissolved oxygen levels. Fish-holding time prior to blood sampling was less than 5 minutes. Fish of a sufficient size for physiological sampling (more than 80 mm in length) were anaesthetized (buffered tricaine methanesulfonate [MS-222] at 90 mg of MS-222/L of water) until loss of equilibrium, and then weighed (nearest tenth of a gram) and measured (nearest mm). Fish were placed supine on measuring board and a blood sample (0.1 – 0.3 mL, depending on fish size) was taken via caudal venipuncture using pre-heparinized syringes (1-mL syringe, 5/8-in., 25-gauge needle). Blood samples were then transferred to 1.5-mL tubes and stored in a water/ice slurry prior to centrifugation. An aliquot of whole blood was removed for glucose, lactate, and hematocrit analyses. The remaining whole blood was then centrifuged at 10,000 x gravity for 7 minutes and plasma was flash frozen in liquid nitrogen for transport to the lab and storage at -80 °C for future analysis. In addition, a small clip of gill tissue (half the length of 4 to 6 gill filaments) was collected following the methods of McCormick (1993). The gill clip was stored on ice cold sucrose-EDTA-Imidazole buffer (250 mM sucrose, 10 mM Na2-EDTA, 50 mM imidazole, pH = 7.3) and flash frozen in liquid nitrogen for transport to the lab and stored at -80 °C until analyses could be performed. Fish were then placed in a bucket of fresh river water to regain equilibrium prior to being released downstream from the capture site.

In addition to the physiological sampling described above, a subset of fish was lethally sampled in May and June for bioelectrical impedance analysis (BIA) to determine overall body composition (Cox and Hartman 2005; Hanson et al. 2010) and collection of muscle tissue for later RNA:DNA ratio analysis to determine growth potential (Buckley and Bulow 1987). After the blood and gill biopsies, the fish were euthanized by cerebral percussion, blotted dry, and placed laterally on a nonconductive measuring board with the left side of the fish facing up for BIA following the protocols by Hanson et al. (2010). Briefly, fish were connected to a tetrapolar BIA analyzer (Quantum II; RJL Systems, Detroit, Michigan) that measures resistance (Ω) and reactance (Ω) by introducing a slight electrical current through two sets (consisting of a signal and detecting electrode placed 1 cm apart) of modified needle electrodes inserted 2 mm into the musculature. One set of electrodes was placed in the anterior dorsal musculature (even with the anterior apex of the operculum), and the second set was placed in the medial musculature of the caudal peduncle region (even with the anterior insertion of the adipose fin) midway between the lateral line and dorsal midpoint. The distance (L) between detector electrode sets was measured for each fish. A biopsy of white muscle tissue (20 to 30 mg) was excised from the dorsal musculature midway between adipose and dorsal fin insertion above the lateral line. The muscle biopsy was placed in a 1.5-mL microcentrifuge tube and flash frozen in liquid nitrogen prior to storage at -80 °C until analyses could be performed.

J.5 Organismal Condition and Growth Potential Analyses

Analysis of biochemical parameters from plasma and gill tissue samples were conducted on a microplate spectrophotometer (Powerwave XS, BioTek Instruments Inc., Winooski, VT), and all samples were run in triplicate. Biochemical indicators of juvenile salmonid nutritional condition (Congleton and Wagner 2006), specifically plasma triglyceride concentrations (EnzyChrom Triglyceride Assay Kit, #EGTA-200, BioAssay Systems, Hayward, CA) and plasma protein concentrations (BCA Protein Assay, 23227, Thermo Scientific, Rockford, IL) were determined using commercially available colorimetric assay kits following standard protocols. Both plasma triglyceride and protein concentrations have been previously shown to reflect fasting and nutritional condition in juvenile salmonids (Congleton and Wagner 2006).

Additional measures of fish condition were generated from the BIA and length/weight data recorded at the time of capture. We determined a metabolic condition index indicative of body composition relating to nutritional condition, phase angle (°), from BIA data (Barbosa-Silva et al. 2003). Phase angle was calculated from the following equation (Willis and Hobday 2008):

$$\text{phase angle } (^\circ) = \left(\arctan\left(\frac{\text{resistance}}{\text{reactance}}\right)\right) \times \frac{180^\circ}{\pi}$$

Length and weight measurements were used to calculate condition factor (K) for each individual fish by the following equation (Anderson and Gutreuter 1983):

$$K = \left(\frac{W}{L^3}\right) \times 100{,}000$$

where K represents condition factor, W represents mass (g), and L represents fork length (mm).

To determine the RNA:DNA ratio (a surrogate for protein construction, active growth, and condition), frozen muscle samples were placed in a lysis buffer (Buffer RLT Plus, Qiagen, Valencia, CA) and disrupted and homogenized using the TissueLyser II (Qiagen, Valencia, CA). Simultaneous extraction of RNA and DNA from the supernatant from homogenized samples was performed using a commercially available kit (AllPrep DNA/RNA Mini Kit, Qiagen, Valencia, CA) and following kit protocols. Extracted DNA and RNA were then stained with ultrasensitive fluorescent nucleic acid stain reagents. DNA was stained using Quant-iT PicoGreen dsDNA (invitrogen, Molecular Probes, Inc., Eugene, OR), and RNA was stained using Quant-iT RiboGreen RNA (invitrogen, Molecular Probes, Inc., Eugene, OR). All samples and standards were analyzed within 24 hours of extraction using the PerkinElmer 2030 multilabel reader (Victor, Perkin Elmer Life and Analytical sciences, Wallac Oy, Turku, Finland), and results were reported as nanograms per milliliter (ng/mL) of both RNA and DNA. Subsequently, ratios were calculated by dividing total RNA concentration by DNA concentration.

J.6 Stress Response Analyses

In the field, whole blood glucose and lactate levels, commonly used indicators of stress and anaerobic activity in fish (Ferguson and Tufts 1992; Wendelaar Bonga 1997), were measured from blood samples using portable handheld meters. Portable glucose and lactate meters have been shown to produce results comparable to those of laboratory studies and are particularly useful for evaluating relative differences between treatments (Morgan and Iwama 1997; Venn Beecham et al. 2006). Whole blood glucose levels were measured by adding 10 µL of whole blood to a handheld glucose meter (Accu-Chek , Roche Diagnostics Corp., Indianapolis, IN), and whole blood lactate levels were measured in the field by adding 10 µL of blood to a handheld lactate meter (Lactate Pro LT-1710; Arkray, Inc., Kyoto, Japan). A small volume of whole blood was placed in a heparinized capillary tube and spun for 120 s using a hematocrit centrifuge to generate hematocrit values (% packed cell volume). Plasma cortisol (a primary stress hormone in fish [Barton 2002]) concentrations were determined in the laboratory using a commercially available kit (Cortisol EIA Kit, ADI-901-071, Enzo Life Sciences, Plymouth Meeting, PA) and following protocols included with the kit.

J.7 Reproductive Status Analysis

To determine whether male fish precocially matured (Larsen et al. 2010), plasma 11-keto testosterone (11-KT) (11-keto testosterone EIA Kit, #582751, Cayman Chemical, Ann Arbor, MI) concentrations were determined using commercially available kits.

J.8 Osmoregulatory Status Analysis

The activity of Na+,K+ -ATPase (NKA), an enzyme that aids in extrusion of salt across the gill membranes and is upregulated during smoltification (Hoar 1989; Evans et al. 2005), in gill tissue was determined using the technique described by McCormick (1993).

J.9 Statistical Analyses

All analyses were performed in the statistical package JMP v7.0 (SAS Institute, Cary, North Carolina) and the level of significance for all tests (α) was assessed at 0.05 (Zar 1999). All values presented represent mean ± SD unless otherwise noted. Prior to statistical analysis, variables were assessed for the assumption of univariate normality, and variables that did not meet this criterion were log10 (glucose, triglyceride, protein, NKA activity) or square root (cortisol, 11-KT) transformed (Zar 1999). Two-way analysis of variance, followed by Tukey's honestly significant difference (HSD) post hoc tests, was performed to test for differences in physiological variables among months, between habitats, and for all interactions (Day and Quinn 1989; Zar 1999).

J.10 Results

In total, physiological samples from 126 fish captured in all three habitats across the study period were analyzed (Table J.1). However, the number of samples analyzed for a single physiological variable varied due to limitations in the volume of plasma collected from an individual fish (Table J.2). Due to an inability to collect fish of sufficient size from the WC habitat during April and May as well as the low number of samples collected in July, statistical analysis of temporal trends could not be conducted from these samples. As a result, these values were not used in further statistical testing, and we discuss differences between MC and OC habitats from this point forward.

Table J.2. Biological Characteristics of Juvenile Chinook Salmon (N = 126) Captured in Three Estuarine Habitats Within the Lower Columbia River. The number of samples analyzed for each physiological parameter varied due to limitations in the volume of plasma available for analysis.

Variable	N	Mean ± SD (Min. – Max.)
Organismal condition and growth metrics		
Total Length (mm)	112	111.76 ± 30.73 (81.0 – 200.0)
Mass (g)	102	17.77 ± 16.35 (5.6 – 76.7)
Condition Factor (K)	102	1.08 ± 0.10 (0.83 – 1.36)
Plasma Triglyceride (mg/dL)	108	128.40 ± 94.97 (4.43 – 591.18)
Plasma Protein (g/dL)	110	2.72 ± 0.49 (0.63 – 3.82)
Plasma Cortisol (ng/mL)	108	79.55 ± 59.24 (1.11 – 299.60)
RNA:DNA ratio	55	3.07 ± 3.73 (0.18 – 20.04)
Resistance (Ω)	57	741.69 ± 88.72 (505 – 985)
Reactance (Ω)	57	174.50 ± 31.12 (111 – 264)
Phase Angle (°)	57	13.2 ± 1.8 (9.4 – 17.9)
Stress response metrics		
Whole Blood Glucose (mg/dL)	84	69.86 ± 21.20 (32.0 – 174.0)
Whole Blood Lactate (mmol/L)	76	8.07 ± 2.10 (3.0 – 12.7)
Hematocrit (%)	37	37.45 ± 7.27 (20 – 60)
Plasma Osmolality (mOsm x Kg^{-1} H_2O)	74	303.57 ± 37.60 (218 – 385)
Plasma Na^+ (mmol/L)	40	134.75 ± 12.84 (98 – 163)
Plasma Cl^- (mmol/L)	40	123.85 ± 8.40 (107 – 145)

Table J.2. (contd)

Variable	N	Mean ± SD (Min. – Max.)
Reproductive status metric		
Plasma 11-keto Testosterone (ng/mL)	101	0.17 ± 0.19 (0.01 – 1.14)
Osmoregulatory status metric		
Na^+,K^+ -ATPase activity (μmol-ADP x mg prot.$^{-1}$ x h^{-1})	110	4.01 ± 1.82 (0.68 – 9.74)

J.11 Organismal Condition and Growth Metrics

The condition factor of fish varied between the two habitats throughout the study period, although there were no differences in condition factor between months (Table J.3, Figure J.1A). Specifically, fish from the OC had higher average condition factor scores than fish from the MC (Table J.3, Figure J.1A). Plasma protein concentrations varied both between habitats and among months (Table J.3, Figure J.1B). Plasma protein levels were highest in April and then decreased to the lowest levels in May before increasing across the rest of the sampling period (Table J.3, Figure J.1B). Across the duration of the sampling period, fish from the OC had higher plasma protein levels than fish from the MC (Table J.3, Figure J.1B). There was also significant interaction between time period and habitat; plasma protein concentrations in fish from the OC increased throughout the study, whereas concentrations in fish from the MC decreased (Table J.3, Figure J.1B). Plasma triglyceride concentrations also varied by both month and habitat type. Triglyceride levels declined across the study months from a high in April to a low in July (Table J.3, Figure J.1C). Fish captured in the MC were measured to have higher triglyceride values than fish from the OC (Table J.3, Figure J.1C). In addition, there was significant interaction between time period and habitat type; plasma triglyceride concentrations of fish sampled in the MC decreased at a faster rate than those of fish sampled in the OC (Table J.3, Figure J.1C). In the two months that it was measured, phase angle was significantly lower in June when compared to April for all fish (Table J.3, Figure J.1D). However, there was an interaction between time period and habitat type. Fish from the MC showed an increasing phase angle between the sampling periods, whereas fish from the OC showed a significant decrease in average phase angle (Table J.3, Figure J.1D). Finally, the ratio of RNA to DNA content did not differ between habitat types or months in sampled fish (Table J.3).

Table J.3. Statistical Results from Two-Way Analysis of Variance Comparing Physiological Variables of Juvenile Chinook Salmon Captured in Two Habitat Types in the Lower Columbia River Estuary. Bolded and italicized text indicates statistical significance at α=0.05.

Variable	Source	d.f.	F-Value	P-Value
Organismal condition and growth metrics				
Condition Factor (K)	***Full Model***	***7, 94***	***3.16***	***0.005***
	Month		1.60	0.19
	Habitat		***9.20***	***0.003***
	Month*Habitat		2.64	0.06

Table J.3. (contd)

Variable	Source	d.f.	F-Value	P-Value
Stress response metrics				
[a] Plasma Protein (g/dL)	***Full Model***	***7, 102***	***4.50***	***<0.001***
	Month		***4.86***	***0.003***
	Habitat		***5.64***	***0.02***
	Month*Habitat		***4.05***	***0.01***
[a] Plasma Triglyceride (mg/dL)	***Full Model***	***7, 100***	***5.11***	***<0.001***
	Month		***4.60***	***0.005***
	Habitat		***8.25***	***0.005***
	Month*Habitat		***5.18***	***0.002***
Phase Angle (°)	***Full Model***	***3, 53***	***4.90***	***0.004***
	Month		***4.63***	***0.04***
	Habitat		0.73	0.40
	Month*Habitat		***9.27***	***0.004***
[a] RNA:DNA ratio	Full Model	3, 51	0.67	0.57
	Month		0.04	0.85
	Habitat		0.01	0.97
	Month*Habitat		1.98	0.17
[a] Whole Blood Glucose (mg/dL)	***Full Model***	***5, 78***	***4.70***	***<0.001***
	Month		***6.34***	***0.003***
	Habitat		0.73	0.40
	Month*Habitat		***4.83***	***0.01***
Whole Blood Lactate (mmol/L)	***Full Model***	***4, 71***	***4.30***	***0.004***
	Month		***5.19***	***0.003***
	Habitat		0.12	0.73
[b] Plasma Cortisol (ng/mL)	***Full Model***	***7, 100***	***18.65***	***<0.001***
	Month		***39.00***	***<0.001***
	Habitat		***4.13***	***0.04***
	Month*Habitat		***3.10***	***0.03***
Plasma Osmolality (mOsm x Kg^{-1} H_2O)	***Full Model***	***7, 66***	***9.16***	***<0.001***
	Month		***20.19***	***<0.001***
	Habitat		0.25	0.62
	Month*Habitat		0.25	0.86
Plasma Na^+ (mmol/L)	Full Model	3, 36	2.46	0.08
	Month		1.75	0.19
	Habitat		2.75	0.11
Plasma Cl^- (mmol/L)	Full Model	3, 36	1.92	0.14
	Month		2.11	0.14
	Habitat		0.86	0.36
Hematocrit (%)	Full Model	3, 33	2.82	0.06
	Month		1.78	0.19
	Habitat		0.30	0.60
	Month*Habitat		0.70	0.41
Reproductive status metric				
[b] Plasma 11-keto Testosterone (ng/mL)	Full Model	7, 93	0.53	0.81
	Month		0.38	0.76
	Habitat		0.76	0.38
	Month*Habitat		0.50	0.68
Osmoregulatory status metric				
[a] Na^+,K^+ -ATPase activity (μmol-ADP x mg $prot.^{-1}$ x h^{-1})	***Full Model***	***7, 102***	***7.17***	***<0.001***
	Month		***15.43***	***<0.001***
	Habitat		1.28	0.26
	Month*Habitat		0.81	0.49

Note: [a] denotes log_{10} transformed variables; [b] denotes square root transformed variable.

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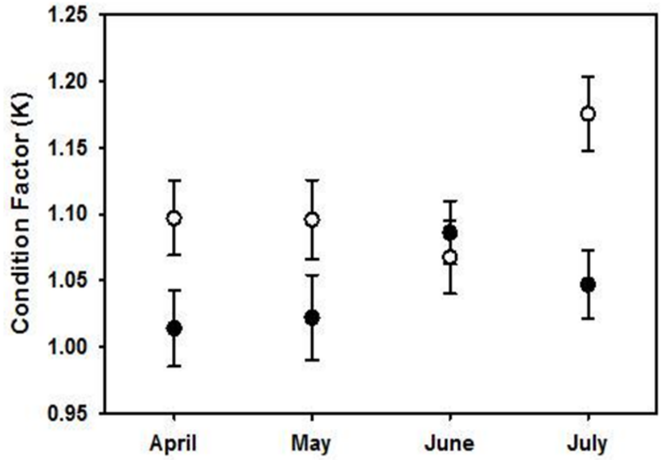
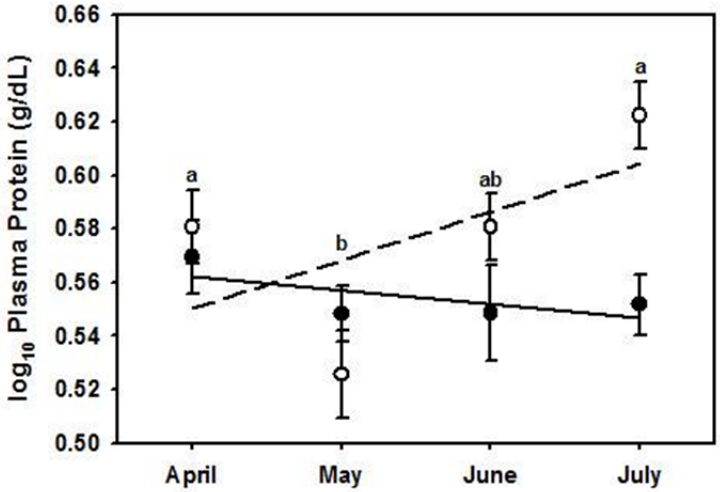
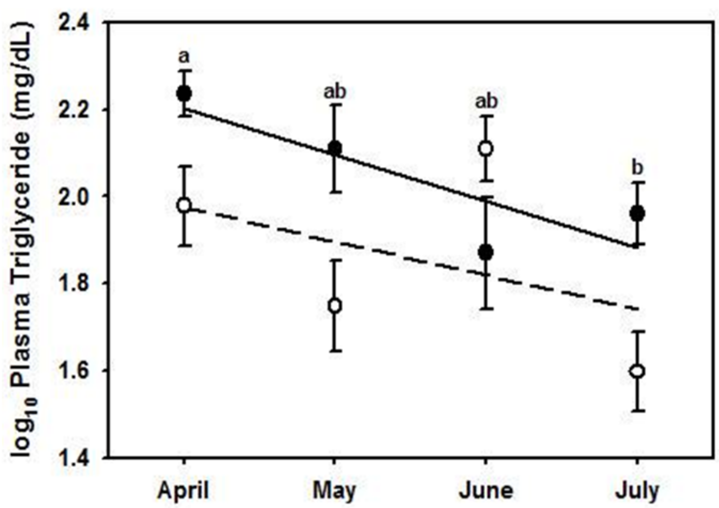

Condition Factor (K)
1.25
1.20
1.15
1.10
1.05
1.00
0.95
April
May
June
July

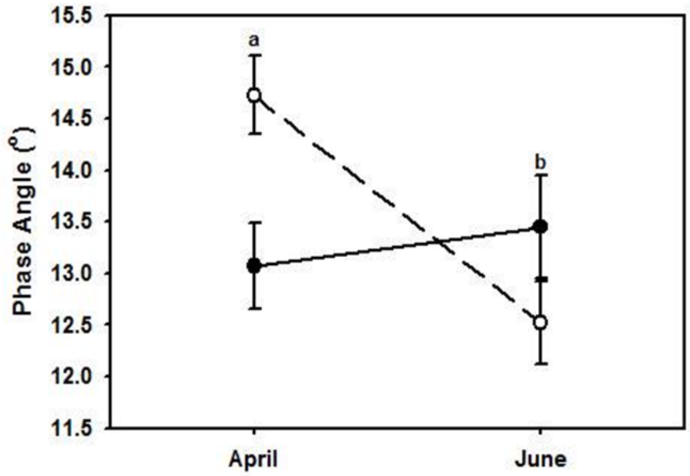
(A)


log10 Plasma Protein (g/dL)
0.66
0.64
0.62
0.60
0.58
0.56
0.54
0.52
0.50
a
b
ab
a
April
May
June
July

(B)


log10 Plasma Triglyceride (mg/dL)
2.4
2.2
2.0
1.8
1.6
1.4
a
ab
ab
b
April
May
June
July

(C)

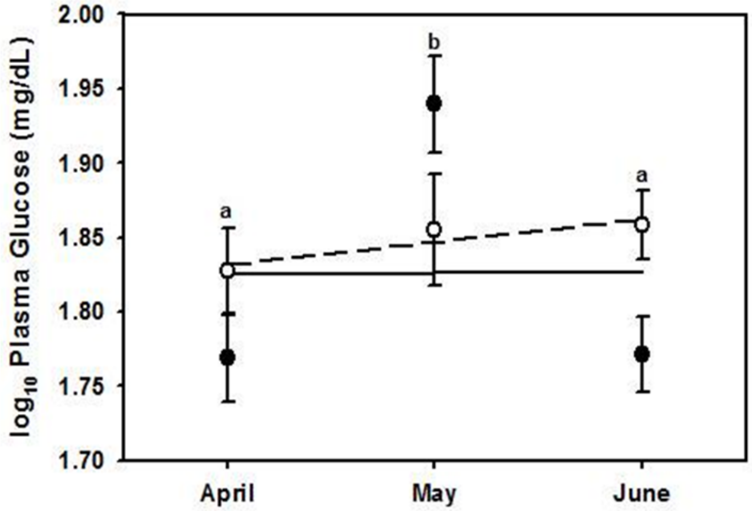


(D)

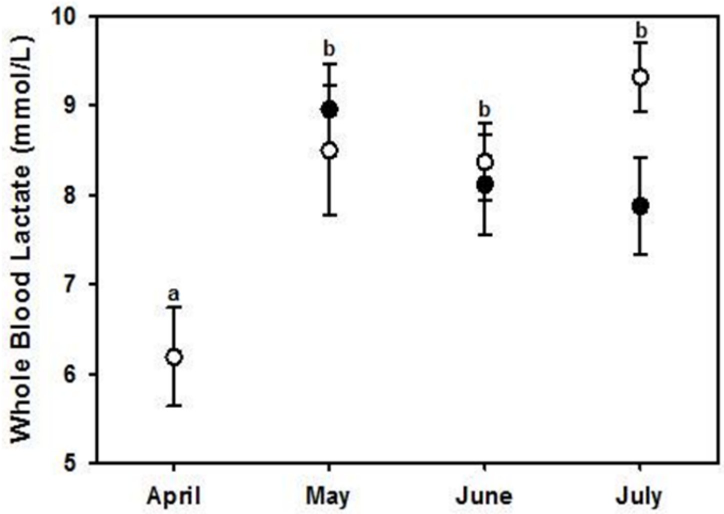
Figure J.1. Measurements of the Nutritional Condition of Juvenile Chinook Salmon Captured in Two Habitat Types in the Lower Columbia River Estuary. A) Condition factor (K), B) plasma protein (g/dL), C) plasma triglyceride (mg/dL), and D) phase angle (°). Filled circles represent values fish captured in the main channel (MC) and open circles represent values for fish captured in the off-channel (OC). Dissimilar letter groups represent differences between monthly means. Overlaying lines represent significant interaction terms between time and habitat type (dashed lines = OC, solid lines = MC).

J.12 Stress Response Metrics

In general, most physiological measurements of the stress response varied between habitats or across the sampling period. Glucose differed between months with fish captured in May having the highest average concentrations (Table J.3, Figure J.2A). In addition, there was significant interaction in glucose concentrations between habitat type and month; glucose concentrations significantly increased for fish in the OC across the sampling period, unlike conspecifics in the MC (Table J.3, Figure J.2A). Lactate concentrations did not differ by habitat but did vary across the sampling period with fish that were sampled in April having significantly lower concentrations of lactate than fish sampled in any other month (Table J.3, Figure J.2B). Plasma cortisol concentrations increased across the study period with fish sampled in April having the lowest values and fish sampled in July having the highest values (Table J.3, Figure J.3A). In addition, habitat-specific differences in cortisol content were noted with cortisol concentrations higher for fish sampled from the MC than for fish sampled from the OC (Table J.3, Figure J.3A). There was also significant interaction between habitat and time period; cortisol concentration increased at a faster rate between time periods for fish sampled in the OC than for fish sampled in the MC Table J.3, Figure J.3A). While plasma osmolality significantly decreased across the sampling period, there were no significant differences between fish sampled from each habitat (Table J.3, Figure J.3B).



(A)



(B)

Figure J.2. Field-Based Measurements of the Secondary Stress Response of Juvenile Chinook Salmon Captured in Two Habitat Types in the Lower Columbia River Estuary. A) whole blood glucose (mg/dL), and B) whole blood lactate (mmol/L). Filled circles represent values of fish captured in the main channel (MC) and open circles represent values for fish captured in the off-channel (OC). Dissimilar letter groups represent differences between monthly means. Overlaying lines represent significant interaction terms between time and habitat type (dashed lines = OC, solid lines = MC).

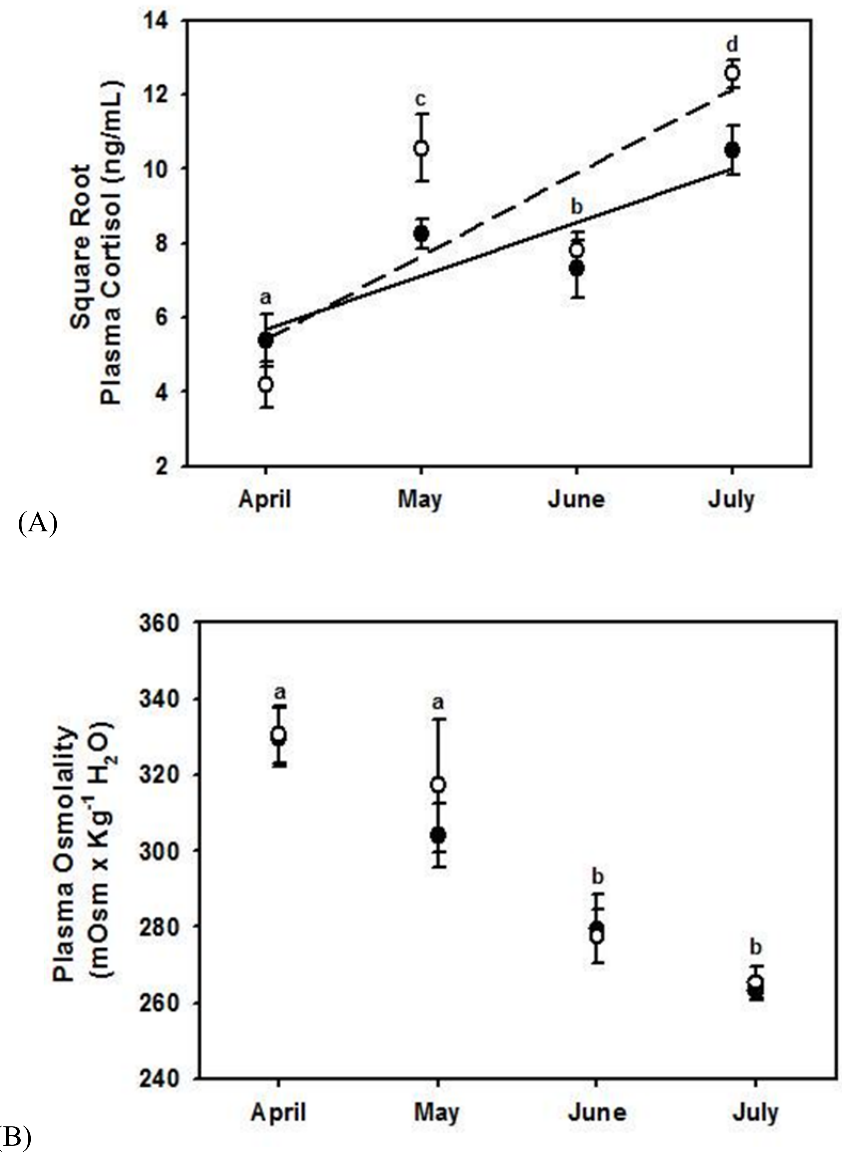


Figure J.3. Lab-Based Measurements of the Primary (A. plasma cortisol) and Secondary (B. plasma osmolality) Stress Response of Juvenile Chinook Salmon Captured in Two Habitat Types in the Lower Columbia River Estuary. Filled circles represent the values of fish captured in the main channel (MC) and open circles represent values of fish captured in the off-channel (OC). Dissimilar letter groups represent differences between monthly means. Overlaying lines represent significant interaction terms between time and habitat type (dashed lines = OC, solid lines = MC).

J.13 Reproductive Status Metrics

Measured 11-KT concentrations did not differ between habitat types or months (Table J.3). All 11-KT values were categorically low, indicating that none of these fish were undergoing precocious maturation. The equivalent female reproductive hormone, 17β-estradiol (E2), could not be assessed due to low plasma concentrations of the hormone in juvenile fish that required greater plasma volumes from each individual than were collected in a sample.

J.14 Osmoregulatory Status Analysis

While there were no differences in osmoregulatory status between habitats, there was a temporal pattern evident in NKA activity (Table J.3; Figure J.4). Specifically, NKA activity was highest in fish sampled in April and May in both habitats. Fish sampled in June and July, had significantly lower NKA activity regardless of habitat type.

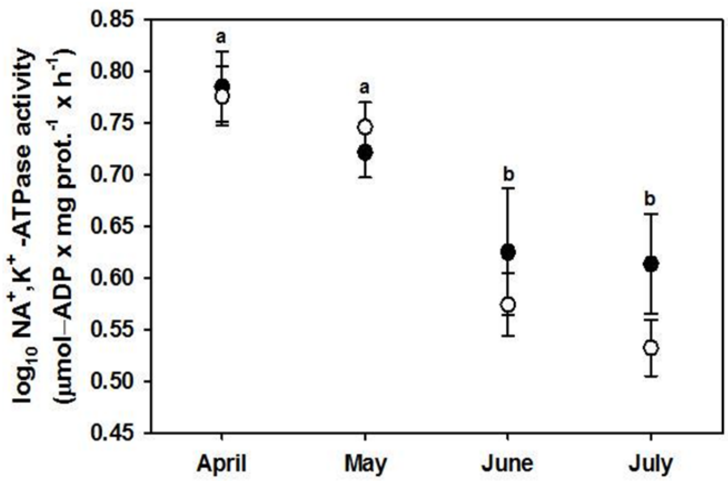


Figure J.4. Differences in Osmoregulatory Function as Measured by the Gill Na+,K+ -ATPase Activity of Juvenile Chinook Salmon Captured in Two Habitat Types in the Lower Columbia River Estuary. Filled circles represent values of fish captured in the main channel (MC) and open circles represent values of fish captured in the off-channel (OC). Dissimilar letter groups represent differences between monthly means.

J.15 Discussion

J.15.1 Organismal Condition and Growth Metrics

Overall, the physiological indicators of the condition of juvenile Chinook salmon varied both temporally and among habitats. These physiological measures may be quite valuable in measuring habitat-based benefits associated with restoration activities. At the most gross scale, the condition factor of captured fish was related to habitat-use patterns, with fish in the OC having higher overall condition factor scores indicating that fish of a given length were heavier in the OC. Because only measurements of weight and length are required to calculate the condition factor (Anderson and Gutreuter 1983), these measurements can easily be generated from data that are commonly and inexpensively collected during biological sampling. Similarly, BIA can be easily deployed in field settings with minimal training required for biological sampling staff, although a greater investment in equipment is required (Willis and Hobday 2008; Hanson et al. 2010). Previous work has shown that both the condition factor and BIA produce data that are analogous to proximate body composition analysis, an intensive and lethal method of determining organismal condition that is commonly used (Hanson et al. 2010). However, there are drawbacks to using the BIA methodology. To generate the maximum amount of data from BIA, species- or population-specific calibrations should be performed by lethally sampling individuals for proximate body composition analysis (Hanson et al. 2010). Unfortunately, this can be difficult when working with threatened and endangered species (Hanson et al. 2010). In addition, because four detecting needle electrodes must be inserted into the body of the target fish, this method has the potential to induce injury, stress, and delayed mortality in sampled animals (Cox and Hartman 2005; Hanson et al. 2010).

The RNA:DNA ratio, an indicator of growth potential in juvenile fish (Buckley and Bulow 1987), did not vary either temporally or between habitats. This result was influenced by the large amount of inter-individual variation in growth potential among sampled fish within each habitat and month. Furthermore, RNA:DNA ratio analysis required a lethal sampling effort because a muscle biopsy was removed from each fish. Sampling of this nature may be impossible when working with certain threatened and endangered populations. For these reasons, the RNA:DNA ratio is not a useful variable for measuring habitat-based benefits associated with restoration activities.

Plasma-based indicators of nutritional condition fluctuated both between habitat types and across the sampling period. In the current study, plasma protein content was typically higher in fish captured in the OC, and plasma protein levels increased in fish captured in the OC while decreasing in fish from the MC. Plasma triglyceride levels were lower for fish in the OC in all months, and plasma triglyceride levels decreased at a faster rate in fish from the MC relative to the OC across the sampling period. While it is impossible to determine whether changes in nutritional condition were causally related to habitat use, previous studies have linked changes in these variables to feeding and fasting in juvenile salmon (Congleton and Wagner 2006; Wagner and Congleton), indicating that there is a correlative relationship between habitat use within the estuary and fish condition.

During smoltification, energy reserves are depleted due to extensive mobilization and consumption of lipids from viscera and muscle tissue (Sheridan 1988). Within the plasma, this is reflected as an initial increase in plasma lipid levels (such as triglycerides) at the onset of smoltification followed by a decline in lipid content during the migration period regardless of feeding behavior (Congleton and Wagner 2006). Plasma protein levels are positively related to food consumption in juvenile salmonids (Love 1970; Storebakken et al. 1991; Navarro and Gutiérrez 1995), and are a long-term indicator of the nutritional condition of fish because protein concentrations recover at a slow rate after depletion during fasting (Congleton and Wagner 2006). In the current study, plasma triglyceride levels decreased across the study period, which corresponds to the mobilization of lipids during the onset of smoltification in early spring followed by consumption of lipid reserves across the summer migration period as fish moved through the estuary. Similarly, plasma protein concentrations also decreased across the sampling period for fish migrating through the MC, indicative of energy consumption during smoltification and migration.

However, concentrations of these indicators of nutritional condition were quite different between the study habitats across the summer. Lipid consumption may either be greatest for fish in the MC or partially mitigated for fish in the OC because the decline in plasma triglyceride occurred at the greatest rate in fish captured in the MC. In addition, plasma protein levels decreased across the study period for fish captured in the MC, but increased for fish using OC habitats. Cumulatively, these data on organismal condition indicate that a correlation exists, whereby fish that use OC habitats are in better nutritional condition as evidenced by increasing plasma protein content and at least partially mitigating plasma triglyceride consumption across the sampling period and higher overall condition factor scores. Habitat-specific benefits may be mediated through increased foraging opportunities in the OC, because previous studies have indicated that plasma lipid concentrations decrease across the smoltification and migration period regardless of food consumption (Sheriden 1988; Congleton and Wagner 2006), but that plasma protein content remains stable or increases when forage is consumed (Congleton and Wagner 2006). In addition, because the RNA:DNA ratio measurements did not indicate any differences between the habitat types, consumed forage may be used primarily to replenish depleted energy reserves rather than for growth.

J.15.2 Stress Response Metrics

In the current study, multiple indicators of the stress response were measured in sampled fish with the expectation that some variables would be more related to the primary stress of the capture event, while other variables would relate to ongoing chronic stress based upon environmental conditions in each habitat type. Fast-acting indicators of the primary stress response, such as plasma lactate, plasma glucose, and plasma cortisol, were primarily influenced by the capture event, and all measures of these variables exceeded baseline levels in fish that were not handled (Morgan and Iwama 1997; Wendelaar Bonga 1997). There was a temporal pattern in plasma cortisol, whereby fish captured in April and May had the lowest concentrations. Similarly, plasma osmolality and ion concentrations decreased across the sampling period, potentially indicating that fish faced chronic stress as water temperature increased. As a part of the stress response, the gills become perfused with blood, allowing ions and other solutes to passively transfer out of the fish and into the surrounding environment (Wendelaar Bonga 1997; Barton 2002). The patterns in plasma cortisol, osmolality, and ions across the sampling period likely reflect the stress of the capture event interacting with water temperature during each month. As water temperatures increase, the magnitude of the stress response to handling also increases (Barton et al. 2002).

Because beach seining is a relatively slow capture process (upwards of 30 minutes to deploy and retrieve the net) and the stress response would begin when an individual fish first encounters the net in the water column, it is unlikely that any measurement of chronic stress imparted by environmental conditions could be made while using this capture technique. In addition, while not the focus of this report, the increases in the magnitude of the stress response that are concomitant with increases in water temperature should be viewed with some concern by sampling crews. Across the study, mean water temperatures as measured at the MC (April = 11.2 ± 0.1 , May = 14.2 ± 0.2 °C, June = 15.6 ± 0.5 °C, July = 19.3 ± 0.6 °C), OC (April = 11.37 ± 0.2 °C, May = 14.6 ± 0.4 °C, June = 16.4 ± 0.1 °C, July = 19.0 ± 0.6 °C), and WC (April = 10.69 ± 0.1 °C, May = 15.1 ± 0.3 °C, June = 19.1 ± 0.0 °C, July = 20.3 ± 1.3 °C), increased during each month in a similar pattern to the increases measured in the magnitude of the stress response. High-stress, long-duration capture methods such as beach seining that also subject fish to crowding and processing in poor water quality (e.g., high temperatures, low dissolved oxygen concentrations) coupled with high ambient water temperatures are likely to induce higher delayed mortality rates during the warmer months. This situation becomes especially problematic given the indiscriminant nature of netting whereby Endangered Species Act listed species may also be subjected to capture stress prior to release that would induce delayed mortality. Directed techniques that target only focal species and require less time to capture individuals should be investigated to mitigate for capture stress.

J.15.3 Reproductive Status Metrics

Measurement of reproductive hormones served little value in determining habitat specific differences. Measured 11-KT concentrations were homogeneous between habitat types, and no individual fish had elevated plasma 11-KT concentrations (above 0.8 ng/mL) indicative of precocial maturation by male fish (Larsen et al. 2010). In addition, due to the very low concentration of estradiol in immature fish, no assays could be run on the amount of plasma collected in the field. In general, reproductive hormone values are exceedingly low in juvenile salmonids that are actively emigrating as smoltification and maturation are physiologically incompatible (Foote et al. 1991; Larsen et al. 2010). As such, measuring reproductive hormone concentrations would not be of much interest unless researchers presume there is a specific relationship between habitat characteristics and precocial maturation of juvenile fish that induce failure to emigrate (Larsen et al. 2010).

J.15.4 Osmoregulatory Status Metrics

While NKA activity did vary temporally, there were no differences in osmoregulatory status noted between habitat types, indicating that fish of this size were at the same stage of preparedness for emigration and residence in saltwater. NKA activity was highest in April and May before declining across June and July, although all measured values indicated that fish were likely to be prepared for saltwater entry. Because there were no differences between NKA activity between habitats, juvenile Chinook salmon are likely actively migrating through the area, and use of OC habitat is not related to osmoregulatory preparation. Due to the lack of differences in osmoregulatory capacity in fish captured from each habitat, NKA activity is not a variable that would be measured to determine a benefit to juvenile salmonids based upon habitat use. However, the strong temporal trend in data does provide an insight into the emigration processes that dictate movement of juvenile fish through the estuary and may elucidate key time periods that correspond to optimal physiological condition for peak emigration of various size classes of fish.

J.15.5 Management Implications

While the current study documented variation in fish physiological condition based upon temporal trends and habitat use, the causal mechanism that links habitat characteristics to organismal condition in juvenile salmonids needs to be further clarified. Given that physiological indicators of fish nutritional condition varied both temporally and between habitat types, in situ experiments should focus on manipulating habitat conditions and monitoring physiological responses. In addition, repeated sampling of individuals would likely shed light on the benefits to the nutritional status of fish conferred by inhabiting different habitats, because this sampling method would allow for the tracking of nutritional changes in individuals in specific habitats over time. Due to the interaction of capture technique with multiple physiological variables (primarily indicators of the stress response), sampling strategies and techniques must be evaluated during the study design phase to ensure that physiological variables are not artificially manipulated by capture and handling. However, this study has demonstrated the proof of concept that physiological monitoring can be used to evaluate habitat quality in juvenile salmonids. To monitor habitat quality through physiological status, managers should focus on the deployment of handheld meters such as BIA analyzers to the field for use during scheduled sampling, because these devices require little training or cost, and produce data in real time. While future research is required to elucidate the functional mechanism by which the quality of restored habitats can increase organismal condition in juvenile salmonids, integration of physiological monitoring into ecological restoration plans can provide action agencies with quantitative measurements of the success of restoration activities.

J.16 Literature Cited

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Appendix K

Review of Estuarine Habitat Inclusion in Salmon Life History Modeling

Appendix K

Review of Estuarine Habitat Inclusion in Salmon Life History Modeling

Prepared by Kate Buenau

This literature review of the history of estuarine components in salmon life history modeling was recommended by the Salmon Benefits study team in its first-year research, 2009.

K.1 Literature Review

The review examined the literature pertaining to Pacific salmon life history modeling for the Columbia River and tributaries as well as related models elsewhere in the Pacific Northwest. The first objective was to identify to what extent, if any, estuaries were included in salmon life history models. The second objective was to understand how habitat characteristics have been incorporated into salmon models. This process was intended to determine whether the Salmon Benefits team can apply the framework of existing models that include salmon habitat components to project-level assessments of salmon survival in the Columbia River estuary. We attempted to comprehensively review salmon modeling in the region, which includes a range of life history strategies. Due to the greater availability of data in the Columbia tributaries, most models focus on stream-type salmon. However, these models still provide insight into the types of models that could be developed for ocean-type salmon in the estuary. The literature review suggests that there is a lack of salmon life history modeling regarding salmon survival and estuarine habitat, which reflects the absence of field data to parameterize such models. The literature reviewed in the following sections is summarized in Table K.1, which appears at the end of this appendix.

K.1.1 Age-Structured Matrix Models

Kareiva et al. (2000) published the first of a series of age-structured Leslie matrix models[1] of Snake River spring/summer Chinook salmon. Kareiva et al.'s model is deterministic (no random variability in parameters between years or model replicates) and density-independent (survival and reproduction are constant regardless of the number of fish present in a given area). Survival in the Columbia River estuary is incorporated into second-year survival, and there are no explicit considerations of habitat quality or quantity. The analysis focused on the impacts of migration mortality and effects of harvest and Columbia River dams. Sensitivity[2] analysis determined that "modest" increases in first-year and estuary/early ocean survival could lead to population growth, and would be more effective at increasing the population than

[1] Leslie matrix models consist of information about age-specific vital rates (survival and reproduction) in the form of a matrix. In combination with the age structure of a population, such models can be used to project population sizes, age structures, and growth rates into the future, as well as determine how changes in specific vital rates will affect population growth. The mathematical properties of Leslie matrices are well understood and solvable without the use for computer simulation.

[2] Sensitivity analyses determine the effect of absolute changes in individual vital rates upon the growth rate of the population.

further modifications or removal of dams. Peters and Marmorek (2001) also analyzed Snake River spring/summer populations with a density-dependent (Ricker) model that was not stage structured. The authors focused on assessing uncertainties through decision analysis regarding mitigation for dam impacts on juvenile survival, and found that uncertainties about estuary and ocean survival had the greatest influence on the outcomes of proposed actions.

Wilson (2003) extended Kareiva et al.'s (2000) analysis with only minor modifications to the model, and compared historical to modern conditions to look for causes of population decline. Wilson's analysis concurred with Kareiva et al. in that changes in estuary and early ocean survival best explain modern declines in Snake River stocks. Zabel et al. (2006) extended the matrix model further by adding density-dependent recruitment, stochastic vital rates (growth and reproduction are assumed to vary within a given distribution from year to year), and correlated ocean survival to historical records of the Pacific decadal oscillation (PDO). Crozier et al. (2008) extended the Zabel et al. (2006) model to incorporate climate effects on juvenile survival through air and stream temperatures based on empirical studies on populations spawning in the Salmon River basin (Crozier and Zabel 2006) and atmospheric climate change models, along with variability in ocean conditions. These latter two studies focused on climate variability rather than the roles of habitat or particular life stages. The development of matrix models for Columbia River salmon is summarized in Figure K.1.

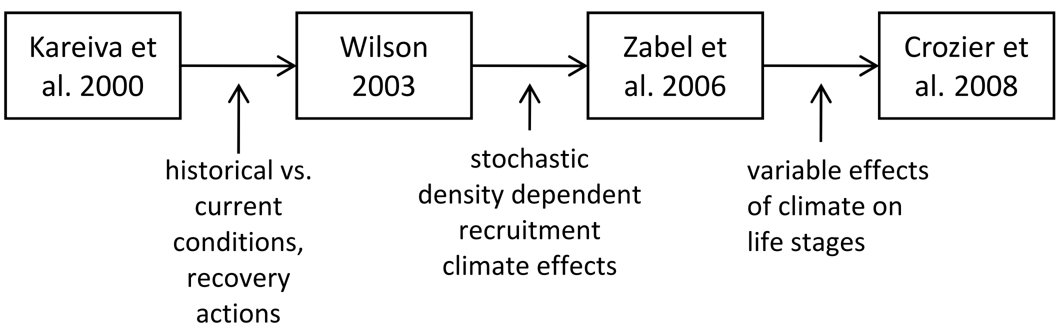

Figure K.1. Development of Published Age-Structured Matrix Models for the Columbia River and Tributaries

Matrix models of stocks outside of the Columbia River watershed include a stochastic population viability analysis[1] (PVA) of ocean-type Chinook in the South Umpqua River (Ratner et al. 1997). They implicitly based spawning and recruitment upon stream habitat quality to obtain viability estimates with and without further habitat degradation.

Based on the literature review conducted within the context of the Salmon Benefits project, the nonspatial matrix models developed for salmon may either indicate the importance of estuary survival in the life cycle (Kareiva et al. 2000; Wilson 2003) or link implicitly to habitat (Ratner et al. 1997), but not estuarine habitat specifically. These studies were limited to sensitivity/elasticity analysis[2] of demographic

[1] Population viability analysis is a process in which models are used to calculate metrics such as extinction risk or time to extinction for species of concern, and can include analysis of how population or habitat management actions affect extinction risk.

[2] In contrast to sensitivity analyses, elasticity analyses determine the effect of *proportional* changes, e.g. ± 5% of each vital rate, in order to allow direct comparison of the effect of rates that differ in scale or magnitude.

parameters and were not equipped to examine factors contributing to survival in the estuary. The matrix models examined for this review did not contain links between survival or recruitment and specific habitat conditions, with the exception of Crozier et al.'s (2008) which incorporated climate effects on flow and temperature in spawning grounds.

One model that does base survival upon habitat availability is a modified matrix model developed for ocean-type Chinook salmon in Puget Sound (Greene and Beechie 2004). This model can be set up to allow juveniles to spend different lengths of time (in weeks) in redds, streams, deltas, and nearshore habitat and incorporates their survival within those habitats as well as density dependence in some or all life stages. Greene and Beechie applied the model to the Skagit and Duwamish watersheds and four hypothetical watersheds in which one of the four habitats mentioned above is restricted in area. This allows for modeling of the effects of time spent and survival in each habitat and the effects of restoration of those habitats. Restoration is represented by an increase in habitat area, without including further detail (e.g., different types of estuary habitat). They concluded that population growth rates were most sensitive to mortality in nearshore and ocean habitats and least sensitive to mortality in stream and delta habitats. Although this model does not contain estuarine habitat types other than deltas, the structure of the model and general conclusions could be extended to more habitat types.

K.1.2 Models Explicitly Linking Salmon Populations to Habitat Type and Quality

Nickelson and Lawson (1998) connected a simulation-based[1] PVA of coastal Oregon coho salmon to a statistical model (Nickelson 1998) linking egg-to-smolt survival and juvenile carrying capacity to habitat quality. In these studies stream habitat quality was defined by channel morphology, such as riffles or rapids and different types of pools. The population models include density dependence, stochastic variability, climatic variability, genetic fitness, and straying of spawners from their natal streams. Sharma et al. (2005) used a similar approach with a stage-based density-dependent (Beverton-Holt) model of Lake Washington/Cedar River coho salmon. This model uses morphological classifications of stream habitat much as Nickelson did, but also relates those categories to types of land use (e.g., agriculture, urban, old growth, second growth.)

McHugh et al. (2004) developed a simulation model that uses habitat characteristics (sediments and temperatures) to define egg-to-smolt survival rates for Snake River spring-summer Chinook under several scenarios of habitat change. This model was limited to egg-to-smolt survival rather than the entire life cycle. The model was parameterized with laboratory data and tested against empirical data. The McHugh et al. (2004), Nickelson and Lawson (1998), and Sharma et al. (2005) models focus on attributes of habitat quality for spawners and juveniles up to the smolt stage, without mechanisms for exploring the role of estuary habitat.

The Shiraz model (Scheuerell et al. 2006) takes a further step in relating the effects of land-use actions on habitat quantity and quality (Bartz et al. 2006) to the life history of salmon (Scheuerell et al.

[1] Simulations numerically solve models that are too complex to have analytical solutions as matrix models do (i.e., by calculating numbers of fish in each age class each year, rather than using a formula to directly determine the population growth rate). They are generally used when models become too complex for the structure of matrix models, such as those that incorporate variable time frames spent in life stages or habitats, more complex survival and reproductive functions, etc. Simulation models of salmon generally still use age or stage classes (e.g., larvae, fry). Models with stochastic components usually require large numbers of replicate simulations in order to determine the distribution of model outputs when inputs vary randomly.

2006). The model framework (Figure K.2) is highly adaptable to many different populations; Scheuerell et al. (2006) applied it to Snohomish ocean-type Chinook. The habitat model focuses on four habitat quality metrics: stream temperatures during prespawning and egg incubation periods, peak stream flow during incubation, and fine sediment. The values of these metrics are determined by measurements of vegetated and impervious ground cover and geomorphologic characteristics within subbasins, in order to predict the effects of land-use change on habitat quality. Habitat quantity determines carrying capacity for adults and juveniles in a manner similar to that used by Nickelson and Lawson (1998) and Sharma et al. (2005). That information is then provided to the population model, which incorporates multiple stocks defined by their life history strategy and a specific set of habitat types that the fish pass through. Stocks can be defined at spatial scales from watersheds to streams. Scheuerell et al. (2006) model 62 subbasins in the Snohomish watershed. The model framework allows for various functional forms (e.g., linear, exponential, polynomial relationships) within the life history, harvest, and spatial components of the model and produces results in the form of abundance, productivity, spatial distribution, and diversity of the population.

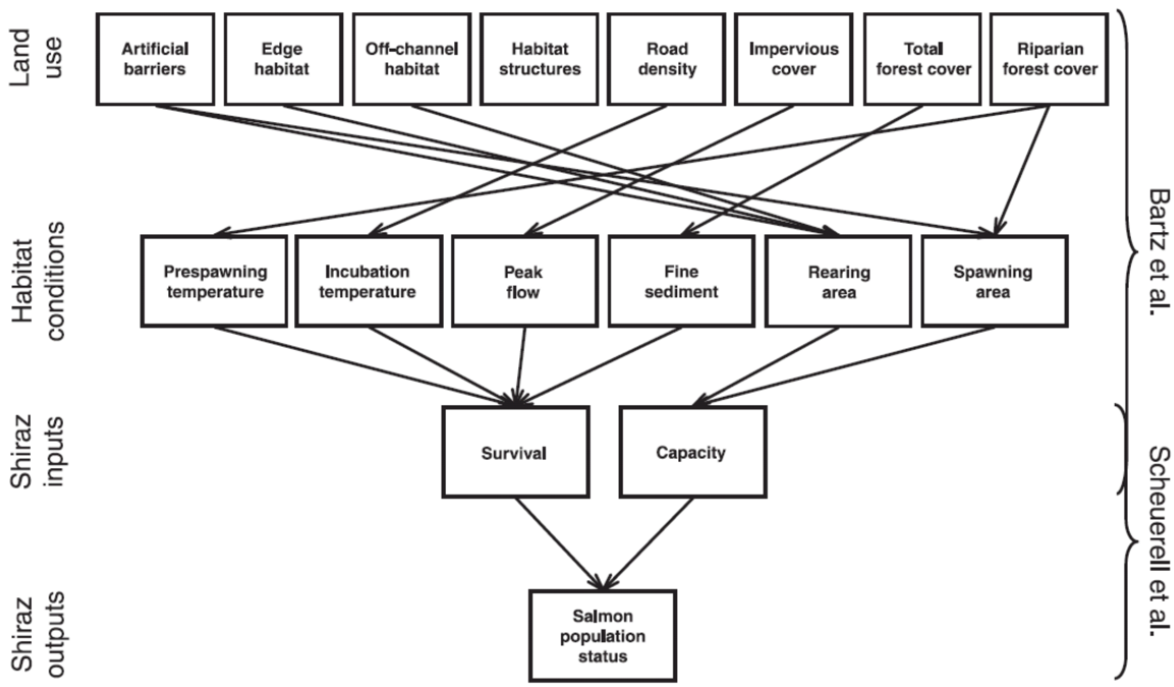

Figure K.2. From Bartz et al. (2006) Representing the Land-Use and Stream Habitat Conditions Input into the Shiraz Model

The model framework described by Bartz et al. (2006) and Scheuerell et al. (2006) was the first to combine detailed information about land cover and use with the population dynamics of multiple, interacting salmon stocks. The model requires a wide range of both physical and biological inputs, although individual components or life stages can be simplified to account for the amount of data available. The model allows for the specification of four estuarine habitat types and subdivision of estuarine habitats, although the example presented treats the estuary as a single unit due to lack of data. Scheuerell et al. (2006) found that the model was most sensitive to increases in survival or carrying capacity in the estuary and lower main stem compared to headwater and peripheral reaches.

Battin et al. (2007) used the Shiraz model to test the effects of restoration scenarios on Snohomish Chinook salmon under several climate change scenarios. Jorgenson et al. (2009) and Honea et al. (2009) adapted the Shiraz model for use with spring-run Chinook salmon in the Wenatchee River basin. Jorgenson et al. established the habitat inputs for the basin using an approach similar to Bartz et al. (2006), but with the addition of additional techniques to handle uncertainty and reduce bias in the estimation of parameters from empirical habitat data. Honea et al. (2009) describe the application of this habitat model to an adaptation of the Shiraz model for the Wenatchee stocks. These studies are examples of how large, complex models such as the Shiraz model are designed with the flexibility to adapt to different physical locations and even, to some extent, statistical and parameterization techniques.

K.2 Conceptual Model of Salmon Demography and Habitat

Determining the role of the Columbia River estuary in the viability of salmon populations—that is, to what extent improvements in estuary habitat will increase salmon stocks and reduce extinction risk—requires an explicit understanding of how habitat characteristics (e.g., area, connectivity, and quality) affect the salmon life cycle (Figure K.3). Habitat characteristics may not only influence survival rates or a particular life stage, but also the growth rates of individuals while they reside in a particular habitat, thus potentially affecting survival downstream and in the ocean. If the time spent in estuarine habitats is affected by habitat quantity and quality in conjunction with life history strategy, the interaction between residence time and survival and growth should also be considered.

The links between survival in the estuary and adult return and population viability have been included in most salmon life cycle models, with varying levels of specificity. Modeling studies that consider the sensitivity of the population growth rate to estuarine survival find this stage to be highly important to population viability, but cannot extend that analysis to the drivers of estuarine survival. The link between estuarine habitat and survival has been generally omitted in published models due to lack of information. The connections between residence time, growth rates, and survival in and below the estuary have not been explored aside from Greene and Beechie’s (2004) study, which includes residence time and survival in the delta as a function of area.

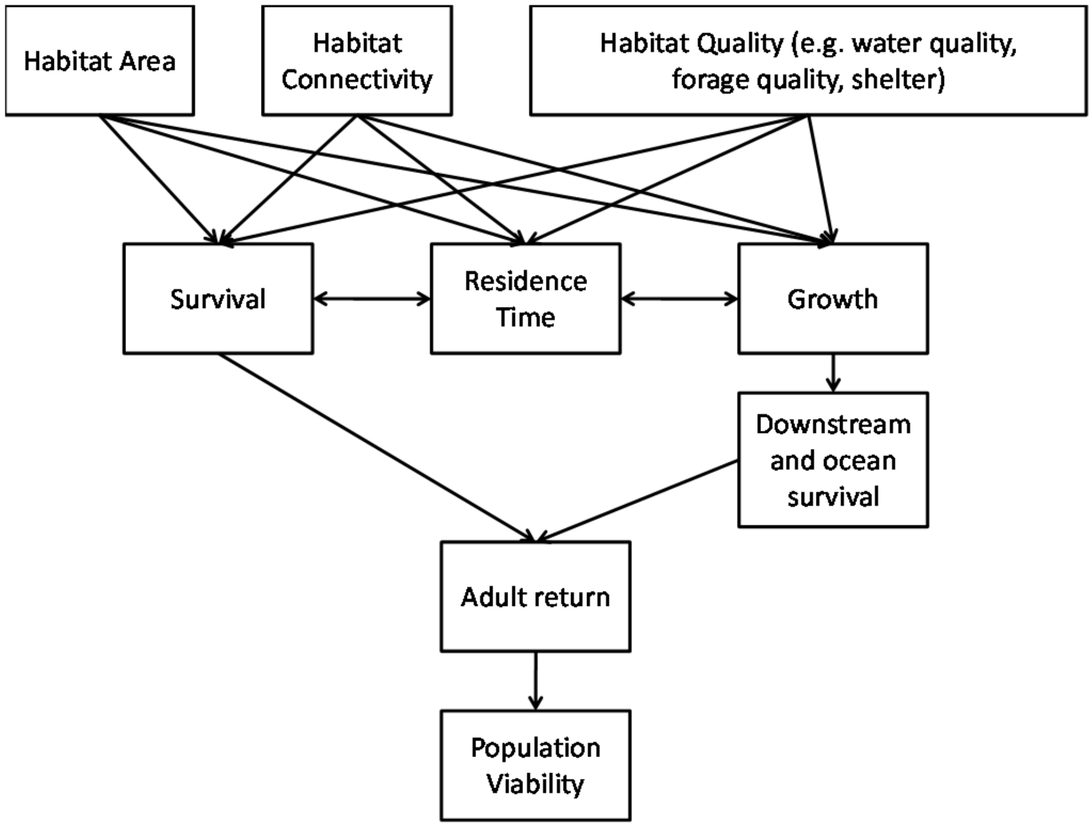

Figure K.3. Prototype Conceptual Model of the Relationship Between Estuarine Habitat and Salmon Population Viability

The body of empirical knowledge about interactions between salmon and habitat types in the Columbia River estuary is growing (Thom et al. 2004; Bottom et al. 2005; Johnson et al. 2011; Roegner et al. 2010), but data connecting estuarine habitat to juvenile salmonid survival is generally lacking due to the difficulty of measuring survival for smaller fish. Conceptual models such as the prototype in Figure K.3 can be used to synthesize the information available for each link, as well as to communicate how current and planned research will address information gaps. Conceptual models provide the basis for numerical models that further assess the level and quality of information. The literature review suggests that there is a lack of salmon life history modeling regarding salmon survival and estuarine habitat, which reflects the absence of field data to parameterize such models. Even when data for particular links are missing, basic models of salmon life history can quantify the importance of missing information for understanding and predicting population viability, and thus the potential value of information compared to the effort or cost of obtaining it. The process of filling information gaps through research will improve the ability of the model to predict the outcome of specific habitat restoration actions on salmon populations, and therefore the ability both to decide between alternative actions and to improve their implementation.

Table K.1. Review of Estuarine Habitat Inclusion in Salmon Life History Modeling

Authors	Kareiva, Marvier, McClure	Peters, Marmorek and Peters, Marmorek, Deriso	Wilson
Affiliation	NMFS	ESSA Technologies	USFWS
Year	2000	2001	2003
Model lineage			based on Kareiva et al. 2000
Type of model	Age-structured matrix, deterministic, no density dependence	Ricker with specific passage mortality, not stage-structured, used decision analysis/weights of evidence approach. Also used CRISP, FLUSH, and a hydrology model	Age-structured matrix, deterministic, no density dependence
Focal group	Snake River spring/summer Chinook	Snake River spring/summer Chinook in one paper, Snake River fall Chinook in other	Snake River spring/summer Chinook
Focal mechanisms	Migration mortality, dams. Impacts on populations of past actions involving harvest rates, juvenile transport and survival. Improved survival at other life stages.	Focus on hydrology, three actions: status quo, barging of juveniles, and drawdown/unimpoundment of lower Snake River dams	Dam breaching and habitat restoration
Spatial scale and resolution	7 index stocks from Snake River	8 index stocks from Snake River	7 index stocks from Snake River
Temporal scale	Focus on time-invariant growth rate	1997-2097	Time-invariant growth rate at historical and more recent conditions
Temporal resolution	Annual	Mixed, with passage model incorporated	Annual
Role of estuary	Estuarine survival incorporated into survival from age 1 to age 2, value of around 2%. Reductions in estuarine mortality of 1–9% would lead to population growth.	Two models: one indirectly estimated estuary and ocean survival, the other calculated estuary and ocean survival from climatic factors.	Incorporated as with Kareiva et al. 2000, also looked at historical data
Links to habitat	No	No	Restoration to implicitly affect egg-to-smolt and subbasin prespawning survival
Major findings	Dam removal probably would not reverse decline; recent actions haven't reversed declines but may have prevented extinction, and reductions in estuarine or first-year survival would have the biggest impact.	Uncertainties with the largest influence on relative outcomes of actions were patterns and causes of mortality in the estuary and ocean. Fall Chinook populations had less information available and it was difficult to distinguish well between actions for that population.	Sharp decline in estuarine and ocean survival, starting after last four dams completed, is primary reason for decline. Suggests this is mainly connected to oceanic regime shifts.

Table K.1. (contd)

Authors	Zabel, Scheuerell, McClure, Williams	Crozier, Zabel, Hamlet	Ratner, Lande, and Roper
Affiliation	NMFS	NWFSC, UW	U of Oregon and US Forest Service
Year	2006	2008	1997
Model lineage		Modified from Zabel 2006	
Type of model	Stochastic, density dependent age-structured matrix model, mechanistic PVA	Stochastic, density dependent age-structured matrix model	Age-structured matrix, stochastic, density dependent (Ricker)
Focal group	Snake River spring/summer Chinook	Snake River spring/summer Chinook in Salmon River basin	Spring Chinook in South Umpqua River, ocean-type population
Focal mechanisms	Density dependent recruitment, first-year oceanic survival and climate, specifically PDO	Effects of climate change on life stages and variability of effects between populations. Environmental effects on parr-to-smolt survival and early ocean survival.	Environmental and demographic stochasticity, increasing instream mortality prior to spawning, continued habitat degradation at historical rate.
Spatial scale and resolution	Snake River basin	Four populations	One Umpqua population
Temporal scale	Simulations from 1900-2002	88-year simulation	100- and 200-year PVA projections
Temporal resolution	Annual	Annual	Annual
Role of estuary	Estuarine survival grouped with early ocean survival and regressed to Pacific Decadal Oscillation index. Included in survival to third year.	Estuarine survival included with first-year ocean survival, that rate is mostly based on ocean conditions	Part of first-year survival, not further specified
Links to habitat	No	Habitat effects based on climate change, centered on flow and temperature	Implicit; degradation of habitat by actions such as logging represented by reduced spawning success
Major findings	Strong evidence for density-dependent recruitment, and for the relationship between 3-year survival and PDO. Climate important, different parameters important depending on the metric, hydro-related parameters not that important.	Effects of climate change on freshwater habitat will have a large impact on fish; variability in populations may buffer response	Population would be viable without habitat degradation, but may be optimistic because of factors (hatcheries, etc.) not considered. With habitat degradation at historical rate, probability of extinction is 1.

Table K.1. (contd)

Authors	Greene and Beechie	Nickelson and Lawson	Sharma, Cooper, Hilborn
Affiliation	NWFSC	ODFW	Columbia River Inter-Tribal Fish Commission, UW
Year	2004	1998	2005
Type of model	Age-structured matrix with adjustments to account for weeks of residence in specific habitats	Stochastic stage-based model with reach-specific production	Mechanistic PVA, Beverton-Holt with stages and harvest
Focal group	Puget Sound ocean type Chinook, four hypothetical watersheds and the Duwamish and Skagit rivers.	Oregon coho	Coho, habitat data from Lake Washington/Cedar River
Focal mechanisms	Contribution of various aquatic habitats to population dynamics –density dependence in all life stages. Includes mortality rates in redds, streams, tidal delta, and nearshore habitat.	Habitat quality, exploitation, cyclic marine survival	Synthesizing habitat, hatchery production, harvest and ocean rates mechanistically
Spatial scale and resolution	Two real and four hypothetical watersheds	Three basins on Oregon coast	Eight Watershed Administrative Units
Temporal scale	300 generations	30- and 99-year simulations	
Temporal resolution	Annual, but model accounts for time spent in different habitats in first year on week scale	Not specified	Annual, although some stages happen during part of a year
Role of estuary	Delta is one of four habitats, with amount of habitat and time spent in habitat variable	Mentioned that the basins have large estuaries, but no other mentioned of connection in the model	Nothing specific
Links to habitat	In hypothetical watersheds, limited habitat in redd/stream/delta/nearshore but not the others	Used reach-specific production parameters from a habitat limiting factors model described elsewhere	Capacity for each stage related to area of stream of each habitat type, productivity related to land use
Major findings	In model watersheds, reducing nearshore and ocean mortality had greater effects than reducing delta or stream mortality. Density- dependent migration reduced the number of fish using area-restricted habitats, so changes to survival in that habitat had less effect. Limited habitat would make downstream habitats more important because fish are forced to spend more time there.	Quality of habitat linked to whether populations could survive marine fluctuations.	Looked at habitat change scenarios, effects of hatcheries with and without domestication effects; the latter cause increases with later declines. Also looked at hatchery shutdowns. State that their mechanistic PVA with land management actions is unique. Give a table of policy objectives and how different options reach those objectives.

Table K.1. (contd)

Authors	McHugh, Budy, Schaller	Scheuerell, Hilborn, Ruckelshaus, Bartz, Lagueux, Haas, Rawson	Bartz, Lagueux, Scheuerell, Beechie, Hass, Ruckelshaus
Affiliation	Utah State University, USFWS	NMFS, UW	NMFS
Year	2004	2006	2006
Model lineage		Shiraz	Habitat model for Shiraz
Type of model	Simulation of egg-to-smolt survival based upon habitat characteristics, inc. future scenarios. Not life cycle model but may be first to model effect of habitat quality measurements.	Spatially explicit multistaged Beverton-Holt model, (density dependent)	Statistical habitat and land-use model
Focal group	Snake River spring-summer Chinook	Snohomish ocean-type Chinook	Snohomish ocean-type Chinook
Focal mechanisms	Egg-to-smolt survival as a function of field habitat measurements: three sediment and two temperature	Effect of historical, present, and proposed land use on spawning. Population response to restoration actions. Measures abundance, productivity, spatial distribution and life history diversity.	Four habitat quality attributes: prespawning stream temperature, incubation stream temperature and peak flow, fine sediment. Land use: roads, impervious and riparian cover, total forest. Elevation, drainage area, precipitation, gradient, alluvium.
Spatial scale and resolution	Six indicator stocks in Snake River watershed	62 subbasins in Snohomish watershed	62 subbasins in Snohomish watershed
Temporal scale	NA	Not specified	NA
Temporal resolution	NA	Annual time scale but include transitions within a single year	NA
Role of estuary	NA	Included as one spatial unit, though ocean-type salmon in the case study don't spend much time there.	Estuarine habitat considered separately with forest, scrub shrub, and emergent marsh habitats.
Links to habitat	Sediment and temperature to egg-to-smolt survival	User specifies habitat indicators, including physical factors or quantities of area types. Indicators can change over time but not stochastically. This study focused on spawning-habitat linkage.	Provides habitat quality attributes listed above and habitat quantity attributes in terms of potential juvenile and adult capacity.
Major findings	Model did reasonably well at predicting trend in survival rates between streams of different quality, but negatively biased. Uses habitat-survival links from laboratory studies, not regressions on data from actual habitats.	Improving juvenile rearing habitat in estuary and lower main stem reaches would have the best chance of improving overall population performance.	First study to link land use to habitat conditions at scales relevant to recovery planning, and link habitat to population status explicitly with both steps?

Table K.1. (contd)

Authors	Jorgenson, Honea, McClure, Cooney, Engie, Holzer	Honea, Jorgenson, McClure, Cooney, Engie, Holzer and Hilborn	Battin, Wiley, Ruckelshaus, Palmer, Korb, Bartz, Imaki
Affiliation	NMFS	NMFS	NWFSC
Year	2009	2009	2007
Model lineage	Adaptation of Bartz et al. (2006)	Adaptation of Shiraz	Adaptation of Shiraz
Type of model	Bayesian model averaging to link habitat quality with predictors	Spatially explicit, stage-structured Beverton-Holt model	Same as Scheuerell
Focal group	Wenatchee basin, spring run Chinook	Wenatchee basin, spring run Chinook	Snohomish Chinook
Focal mechanisms	Landscape and land use related to rearing and spawning habitat. Water temps and substratum. Altitude, gradient, roads, forest cover, drainage, precipitation, impervious and alluvium.	Habitat change to population change, individual habitat characteristics with substantial influence; do life stage-specific habitat influences determine which life stage has the largest population effect?	Effects of climate change on land-use scenarios (no restoration to full restoration)
Spatial scale and resolution	Wenatchee catchment, HUC6 subcatchment level	Wenatchee basin HUC6 subcatchments	Same as Scheuerell
Temporal scale	NA	100 years	Same as Scheuerell
Temporal resolution	NA	Annual	Same as Scheuerell
Role of estuary	Not considered	Estuary survival incorporated into first ocean year	Same as Scheuerell
Links to habitat	Provides link to habitat to supply to Honea et al. (2009) model	Habitat inputs and scenarios from Jorgenson (2009)	Same as Scheuerell
Major findings	Some similarities to Bartz et al. (2006), some differences probably tied to location. Model averaging approach helps deal with uncertainty.	Survival through egg stage most sensitive to restoration, because fines have a strong influence. First-year ocean survival (and thus estuary) not included in sensitivity analysis because don't know how modeled habitat improvements would change that stage.	Strong climate change effect on salmon. If the strongest effects are at higher elevations, and the restoration projects are at lower elevations, should end up with salmon shifting lower.

CRISP = Columbia River Salmon Passage model
FLUSH = Fish Leaving Under Several Hypotheses (passage model)
HUC6 = Hydrologic Unit Code 6
NA = not applicable
NMFS = National Marine Fisheries Service
NWFSC = Northwest Fisheries Science Center
ODFW = Oregon Department of Fish and Wildlife
PVA = Population Viability Analysis
USFWS = U.S. Fish and Wildlife Service
UW = University of Washington

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