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Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary, Annual Report 2011

DRAFT REPORT

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March 2012

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Draft Report

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Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Preface

This research was performed under the auspices of the U.S. Army Corps of Engineers (USACE) Columbia River Fish Mitigation Program, Anadromous Fish Evaluation Program. The study code is EST-P-09-1) and the study title is Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary. The study was funded by the U.S. Army Corps of Engineers Portland District (CENWP) (Ref. No. W66QKZ10249512) under agreements with the U.S. Department of Energy and the U.S. Department of Commerce for work by Pacific Northwest National Laboratory (PNNL). Subcontractors to PNNL included the University of Washington and Mr. Earl Dawley (National Marine Fisheries Services-retired). Ms. Cynthia Studebaker was the CENWP's technical lead for the study.

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Acknowledgments

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 measurement and indexing methods. Accordingly, we 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 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, an Army Corps of Engineers Portland District 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 Bonneville Power Administration, especially Amy Borde (PNNL). In addition, we thank Susan Ennor and Mike Parker for editing and formatting the report.

Acronyms and Abbreviations

ATIIM	Area-Time Inundation Index Model
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CEERP	Columbia Estuary Ecosystem Restoration Program
cm	centimeter(s)
DNA	deoxyribonucleic acid
ELHD	Early Life History Diversity
ERTG	Expert Regional Technical Group
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
GIS	geographic information system
HIS	habitat suitability index
LCRE	lower Columbia River and estuary
LCREP	Lower Columbia River Estuary Partnership
LiDAR	Light Detection and Ranging
MSL	Marine Sciences Laboratory
NOAA	National Oceanic and Atmospheric Administration
PNNL	Pacific Northwest National Laboratory
RME	research, monitoring, and evaluation
RNA	ribonucleic acid
RPA	Reasonable and Prudent Alternative
RSF	resource selection functions
SBU	survival benefit unit
SDM	Species Distribution Model
USACE	U.S. Army Corps of Engineers or Corps
USFWS	U.S. Fish and Wildlife Service

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1.0 Introduction

This report describes the 2011 research conducted under the U.S. Army Corps of Engineers (USACE or Corps) project EST-P-09-1, Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary. The research was conducted by the Pacific Northwest National Laboratory (Marine Sciences Laboratory [MSL], Hydrology Group, and Ecology Group), in partnership with the University of Washington, School of Aquatic and Fishery Sciences/Columbia Basin Research, and Mr. Earl Dawley. This Columbia River Fish Mitigation Program project, informally called "Salmon Benefits," was started in fiscal year 2009 to evaluate and advance the state of the science regarding the ability to quantify the benefits of habitat restoration actions in the lower Columbia River and estuary to listed salmonids[1].

1.1 Relevance to Columbia Estuary Ecosystem Restoration Program Goal

The goal of the Columbia Estuary Ecosystem Restoration Program (CEERP) is to understand, conserve, and restore ecosystems in the lower Columbia River and estuary (LCRE). Four key management questions underlying the CEERP program (Action Agencies 2012) are as follows:

1. What are the limiting factors or threats, i.e., stressors and controlling factors, in the estuary preventing the achievement of desired habitat or fish performance?
2. Which actions are most effective at addressing the limiting factors preventing achievement of habitat, fish, or wildlife performance objectives?
3. Are the estuary habitat actions achieving the expected biological and environmental benefits, e.g., survival benefit unit (SBU) targets?
4. What adjustments should be made, if any, to improve the ability of the SBU crediting method to predict benefits to Endangered Species Act (ESA)-listed fish from ecosystem protection and restoration in the LCRE??

Research, monitoring, and evaluation (RME) includes compliance monitoring, implementation monitoring, status and trends monitoring, action effectiveness monitoring and research, and critical uncertainties research (Johnson et al. 2008). This study predominantly addresses management questions 3 and 4 (above) by developing science-based methods to use for status and trends monitoring, action effectiveness research and monitoring, and project prioritization. Methods and indices have the capacity to compare pre- to post-project and program conditions at varying landscape scales, as appropriate. Results are transferrable to restoration practitioners for project planning and design and to managers for program evaluation. Results of analyses using the methods we developed may inform the Expert Technical Regional Group's assignment of SBUs.

1.2 Study Research Goal and Objectives

The primary goal of this study is to establish scientific methods to quantify benefits from habitat restoration to listed salmon and trout in the LCRE, from Bonneville Lock and Dam to the mouth of the

[1] Listed salmon include Chinook, coho chum, sockeye, steelhead, and trout.

river, through indices for three required areas (see the Biological Opinion (BiOp) on operation of the Federal Columbia River Power System (FCRPS)): habitat connectivity, early life history diversity, and survival. The CEERP's working hypothesis of this research is that habitat restoration in the LCRE benefits outmigrating, listed juvenile salmon and trout. Ancillary hypotheses are that these benefits can be measured by indices of 1) habitat connectivity, 2) early life history diversity, and 3) survival. In addition, this study supports the Corps in its ecosystem restoration actions in the LCRE under multiple Water Resources Development Act authorities.

Based on recommendations from the 2009-2010 study (Diefenderfer et al. 2010), the objectives of the 2011 study were as follows:

1. 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.
2. Early Life History Diversity (ELHD) Index: Perform a retrospective analysis of historic juvenile fish catch data to assess multi-decadal trends in the binary ELHD index, develop an ELHD index that incorporates fish density, test the new ELHD index, and solicit peer review of the ELHD index
3. Survival Benefits: Review literature on physiology of outmigrating salmonids in the LCRE with the intent to evaluate the applicability of common physiological measures to use for assessing the benefits to juvenile salmon from restoration in estuaries, assess the use of fish growth measures as an indicator of fish response to habitat restoration, and recommend the best measures to pursue in future research on indexing habitat benefits. The final element of the survival objective is to explain terms and concepts relevant to modeling the relationships between habitat characteristics and species distribution and the use and capabilities of the primary approaches (statistical vs. mechanistic) in species-habitat modeling, and develop the basis for a conceptual model of restoration benefits.

1.3 Study Background and Approach

The approach of this project is to develop and apply quantitative methods for statistical analysis and spatial data processing to evaluate the three subject indices: habitat connectivity, ELHD, and survival. This study began with a comprehensive literature review in 2009 to specifically define each of the three subject areas, evaluate relevant existing methods, and assess the feasibility of indexing or otherwise measuring the three subject topics, as detailed in the 2009 Annual Report (Diefenderfer et al. 2010). In particular, this study was initiated to address gaps in coverage of BiOp Reasonable and Prudent Alternative (RPA) Actions 58, 59, and 60: habitat connectivity, life history diversity index, and restoration-associated survival benefits. Pilot testing, begun in 2009, continued with the addition of a field data collection element in 2010, described in the 2010 Annual Report (Diefenderfer et al. 2011). In 2011, a survival benefits conceptual modeling effort was introduced, and development and testing of quantitative habitat connectivity and ELHD indices continued, with no field work conducted in this current project year. Also in 2011, a coordinated laboratory-field data collection element was designed to build on the findings of the 2010 field effort and further inform survival benefits metric development, although the focus of the study remains on quantitative method development and testing.

1.4 Study Rationale

A goal of the 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 that have important functions in the ecosystem. Habitat connectivity is affected directly by passage barriers, such as dikes, levees, tidegates, 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. 2009). 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 for quantifying and periodically monitoring habitat connectivity has not been developed and applied in the LCRE as required by RPA Action 59. Action 59 addresses the following management question: What is the extent of habitat connectivity by reach and is it increasing? This project is developing 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.

Early 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 ELHD of salmonid populations in the Columbia 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 LCRE is to reverse this trend (Johnson et al. 2008). Fresh et al. (2005) stated that maintenance of ELHD 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 (Sobocinski et al. 2008; Sather et al. 2009; Johnson et al. 2010). Therefore, an understanding of trends in ELHD is important for assessing the performance of restoration projects. As called for by RPA Action 58, a quantitative method is needed to index and periodically monitor the ELHD of salmonids in the LCRE. Action 58 addresses a key management question: What is the level of ELHD in salmonid species in the LCRE and is it increasing? This project is developing a method for determining the status and trends of species-specific ELHD indices in the LCRE for Chinook and other species as data permit.

The 2008 BiOp included an assessment of the *survival benefits* of habitat restoration actions in the LCRE proposed in the Biological Assessment. The assessment was necessarily based on professional judgment using the best available knowledge, because data on incremental benefits to juvenile salmon survival associated with specific restoration projects are not available. Direct measurements of survival rates would require telemetry methods (e.g., Perry and Skalski 2006; Skalski and Griswold 2006) such as those pilot tested at the site scale during 2010 research under this project (Diefenderfer et al. 2010, 2011). However, acoustic-tag technology would need to be miniaturized to holistically estimate survival of salmon and trout through the estuary (Diefenderfer et al. 2010), because beach seine catches indicate that the size structure is skewed toward smaller salmon nearer to shorelines (Fresh et al. 2005; Sather et al. 2009, 2011; Johnson et al. 2010; Diefenderfer et al. 2011) and smaller fish generally have longer residence times (Campbell 2010).

Given these limitations, survival benefits may be assessed indirectly through measures such as fish habitat usage and fish condition, as noted in the literature review in the first annual report of this project (Diefenderfer et al. 2010, Table 4.1) and subsequently pursued in this project's research. Under this approach, measures may include growth of marked fish, diet, residence time, foraging success, or physiology (Fresh et al. 2005; Bottom et al. 2005). 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), reach and estuary scales, integrated into a single index (Diefenderfer et al. 2010, Table 4.1). This approach is fundamentally based on the food web, particularly the direct contribution of primary productivity in wetland habitats on islands and the floodplain to macrodetritis-based salmonid prey production as well as the indirect effect on environmental conditions such as temperature in the main stem river, which in turn affects phytoplankton, zooplankton, and insects (ISAB 2011, p.183-189; Diefenderfer et al. in preparation). Because the majority of wetland habitats in the lower river and estuary have been eliminated over the last 150 years, with a concomitant 82% decrease in macrodetritus mass, the restoration of this food-web function is a primary rationale for the habitat restoration effort in the region (Sherwood et al. 1990; ISAB 2011, p.186).

Despite the importance of salmonid growth rates to habitat and population models, and spatial management, sensitive measurements of growth rates are not well documented in the Columbia River estuary. While otolith microstructure has been successful at estimating growth (e.g., Campbell 2010), it is a lethal method and thus not desirable for use with many ESA species. Subsequently, a renewed interest has occurred in using physiological and biochemical measures, such as RNA/DNA ratios, protein and lipid concentrations, as a nonlethal approach to growth indices. An understanding of the effects of restoration actions on habitat properties and, in turn, juvenile salmon condition is needed for an ecosystem conceptual model of the LCRE, a foundational tool for successful, systematic implementation of ecological restoration (Thom et al. 2010) that is being updated in Salmon Benefits project work. The research need regarding survival or other benefits pertains to RPA Action 60, which called for the evaluation of habitat restoration actions and 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 tidal wetland habitat area use by salmonids, measures of the benefits to salmonids that use those areas, and measures of the benefits from the effects of these areas on habitats in the main stem river that are encountered by all outmigrating salmon and trout.

1.5 Report Contents and Organization

Formal annual reports were submitted for the 2009 and 2010 project years (Diefenderfer et al. 2010, 2011). In this interim project year, the Corps has requested that a brief summary of key findings and activities be submitted in lieu of a formal report for project study code EST-P-09-1, Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary. At the conclusion of the project in 2013, a formal report covering multi-year activities 2009−2012 will be submitted and will include well-developed chapters and technical appendices describing all research conducted for the study. The 2013 final project report will be suitable for regional review. This report summarizing key findings is organized around the three primary research topic areas and their integration; the organization is modeled after Chapter 3.0, "Key Results" of Diefenderfer et al. (2011).

2.0 Methods and Results

Key findings of research activities conducted during the 2011 project year are presented in a succinct format in this section. Findings from habitat connectivity research include developments in site-scale wetted area modeling (Section 2.1) and computer-assisted dike layer extraction (Section 2.2). Key results of early life history diversity research include a retrospective analysis, further development of the index, sensitivity testing and peer review (Section 2.3). Research in the survival benefits area included literature reviews in physiology (Section 2.4) and species-habitat modeling (Section 2.5). Integration occurred through a conceptual modeling effort focused on juvenile salmon-habitat relationships relative to estuarine habitat restoration (Section 2.6). The summary of each key finding includes the problem statement and background, research objectives, methods and key results of the research.

2.1 Site Area Modeling for Restoration Project Planning

Prepared by Andre Coleman

2.1.1 Problem Statement and Background

Restoration project proponents need to be able to measure area affected by the project prior to submitting ERTG Project Templates. However, the relevance of key hydrologic indicators of area to ecological response, particularly benefit to salmon, has not been conclusively determined. Thus, of the many ways to define area, none is known to be most useful for planning. In addition, the relevance of key hydrological area measurements may be different in portions of the LCRE dominated by fluvial, rather than by tidal influences.

2.1.2 Research Objectives

The objectives of the research were to develop and disseminate a geographic information system (GIS)-based model to predict the inundation of restoration project sites by integrating topographic and hydrologic data. The model should be cost-effective and suitable for preliminary screening of restoration alternatives to assist planners in prioritizing which sites to restore. The model is not intended to substitute for a hydrodynamic model in final project engineering.

2.1.3 Methods

The PNNL-developed, Area-Time Inundation Index Model (ATIIM), is designed to address the need for rapid site assessment and characterization within an estuarine environment. This model was originally developed as part of the Corps-sponsored “Cumulative Effects” study (EST-P-02-04) and more recently was further developed through the Salmon Benefits study. It has appeared in the peer-reviewed literature as well as project annual reports (Diefenderfer et al. 2008; Thom et al. 2011b; Coleman et al. in preparation). ATIIM integrates 1) advanced terrain processing of Light Detection and Ranging (LiDAR) elevation data; 2) in situ, modeled, or synthesized hourly water surface elevation data; and 3) a wetted area algorithm to determine two- and three-dimensional inundation extent and a series of landscape and structural site metrics.

2.1.4 Key Results

ATIIM produces three types of data output: 1) spatial data including raster and vector representations of the site under different flow states and restoration designs (Table 1); 2) tabular data providing site characteristics and metrics (Table 2); and 3) graph data derived from the analysis and post-processing of the spatial data (Coleman et al. in preparation).

Table 1. Spatial data output from the ATIIM model.

1. Processed and merged LiDAR and bathymetry data with channel enforcement (where LiDAR elevation was missing due to standing water at the time of data collection)
2. Microtopographic flow accumulation
3. Microtopographic flow direction for channel routing
4. Microtopographic channel network
5. Flow path length
6. Horizontal and vertical distance to channel
7. Site drainage boundary and sub-basins within primary site
8. Data series of two-dimensional wetted area inundation polygons at 10-cm increments through the min/max range of water surface elevation record
9. Data series of three-dimensional volumetric area inundation at 10-cm increments through the min/max range of water surface elevation record (provides basis for calculating nutrient fluxes in the tidal exchange)
10. Raster-based normalized frequency of inundation
11. Raster-based Topographic Roughness Index (index can be used as a metric for restoration progress and habitat opportunity)
12. Raster-based Topographic Wetness Index (index can be used to determine high soil-saturation zones and existing/potential restoration wetlands based on natural topography)

Table 2. Tabular data output produced by the ATIIM model.

Total Time Steps	The total number of hourly time-steps used in the analysis. This value is based on the length of record available from observed water surface elevations.
Days Verification	Number of days used in the analysis
Auto-Determined Site Bankfull Elevation	Using an automated graph-based slope-change algorithm, the site average bankfull elevation is determined.
Time Steps < Inundation Elevation of X	The number of time-steps where water exists below the bankfull elevation (X).
Time Steps >= Inundation Elevation of X	The number of time-steps where water exists at or above the bankfull elevation (X).
Percent Time of Overbank Inundation	The percent time (from the total time-series) where water is at or above the bankfull elevation.
Total Site Area	The total drainage area of the site in square feet.
Total Area-Hectares	Total drainage area of the site measured in hectares.
Total Hectare Hours	The total number of hectares inundated at each time-step through the study period. Evaluation of inundation is occurring at every 10 cm of elevation.

Table 2. (contd)

Hectare Hours < X	The number of hectare-hours below the bankfull elevation (X).
Percent Hectare Hours < X	The percent (from the total time-series) of hectare-hours below the bankfull elevation.
Hectare Hours >= X	The number of hectare-hours at or above the bankfull elevation (X).
Percent Hectare Hours >= X	The percent (from the total time-series) of hectare-hours at or above the bankfull elevation.
Maximum Possible Hectare Hour Inundation	The theoretical maximum hectare-hour value at the site, basically assuming the entire site is inundated for the entire time-series.
Percent Time Inundation for Site Comparison	The percent time inundation, or area-time inundation index, is calculated as the actual number of hectare-hours of inundation, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum hectare-hours for the site.
Time Volume Inundation Index	The percent time of volumetric inundation is calculated as the actual volume of water, including both in-channel and floodplain area, summed at 10-cm increments of elevation, and divided by the theoretical maximum acre-feet-hours for the site.
Surface-Area to Volume Ratio	Ratio of the planimetric surface area to the three-dimensional volume at each 10-cm increment of elevation.
Maximum Water Surface Elevation Frequency (MFWSE)	Most frequently observed water surface elevation in the period of record.
Habitat Opportunity	Data-series of channel-edge length based habitat availability at 10-cm increment of elevation.
Percent Habitat Opportunity	Data-series of percent habitat availability at each 10-cm increment divided by the total possible habitat availability.
Habitat Opportunity at MFWSE	The habitat opportunity percentage and length at the most frequently observed water surface elevation in the period of record.
Water Surface Elevation Percent Frequency at Bankfull Elevation	WSE frequencies greater than or equal the mean bankfull elevation provides an indicator of the potential frequency that fish could access the marsh edge for feeding.
Total Site Channel Density	Stream channel length per unit area calculated by dividing the total center-of-channel length at the site by the total site area.
Inundated Channel Density	Stream channel length per unit area calculated at each 10-cm increment of elevation providing a measure of density in the aquatic/terrestrial interface over varying tidal/flow levels.
Inundation Perimeter	Data series of the total perimeter length of inundated area at each 10-cm increment in the WSE data record. This measure of the aquatic-terrestrial interface provides information about site characteristics and the potential for habitat opportunity and nutrient/biomass flux.
Inundation Perimeter at MFWSE	The inundation perimeter length at the most frequently observed water surface elevation in the period of record.

Table 2. (contd)

Elevation-Area Relationship (Hypsometric Curve)	Quick assessment metric of the landform shape at a site, opportunity for inundation, and habitat opportunity.
Site Mean Topographic Roughness Index	See description under Spatial Data.
Site Standard Deviation Roughness Index	See description under Spatial Data.
Site Mean Topographic Wetness Index	See description under Spatial Data.
Site Standard Deviation Wetness Index	See description under Spatial Data.

2.2 Computer-Assisted Dike Layer Extraction

Prepared by Jerry Tagestad and Yinghai Ke

2.2.1 Problem Statement and Background

A comprehensive GIS layer of dikes in the LCRE floodplain is widely recognized as an essential missing tool for habitat connectivity assessments or indices.

2.2.2 Research Objectives

To support an effort by the Oregon Department of Land Conservation and Development, the National Oceanic and Atmospheric Administration (NOAA), the Lower Columbia River Estuary Partnership (LCREP) and Bonneville Power Administration (BPA) to produce a dike layer, by developing and delivering a computer-assisted extraction of dikes in the region. Our 2011 analysis of the outputs of manual delineation methods identified the following potential gaps, which could in part be addressed by including a LiDAR data feature extraction in the process: structures that appear to be dikes may be omitted; the delineated length of breached dikes may underestimate the length of breached dike visible in the LiDAR data; non-dike structures that may or may not restrict flow (i.e., railroads, roads, etc.) appear in the LiDAR data, but are not delineated in the sample dike inventory; space between some elevated structures may be erroneously delineated as connected structures. This research is critical because instances of omission, mis-delineation or mis-classification in a dike inventory can compromise a passage barrier assessment, potentially resulting in gross over- or under-estimation of passage barrier presence and length in the LCRE. A combination of manual and semi-automated techniques has the potential to produce a superior layer.

2.2.3 Methods

PNNL staff created a dike layer using computer-assisted feature extraction techniques and 1-m LiDAR elevation data. Dikes are generally conspicuous in high-resolution LiDAR data as flat-topped, linear features with steeply sloping sides. The extraction methodology relied on feature extraction software, Feature Analyst 4.2, from Overwatch Systems in the ArcGIS work environment. Feature analyst workflow requires the user to identify examples of the feature of interest, adjust extraction settings, and (optionally) refine initial results by identifying correct and incorrect extractions. For each LiDAR tile, the analyst delineated 4 to 8 dike segments 30 to 100 m in length, taking care to distribute examples over dikes of varying width and height. Because dikes exhibit unique cross-sectional characteristics (generally steeply sloped on both sides and flat on the top), slope data, derived from the LiDAR data, was used in the extraction along with the LiDAR elevation data.

In some instances where the initial Feature Analyst results for a tile were extremely cluttered, Feature Analyst Hierarchical Learning was run to improve the results. Once the results were sufficiently complete, polygons were rasterized on the score attribute. In general, the features with higher scores better match the characteristics of training data. To further refine the results, with more control than is afforded by the Feature Analyst work flow, a cleanup model was created in ERDAS Imagine. The cleanup model compared each candidate dike pixel to a score criterion, slope criteria, and elevation above the mean-high high water level.

To smooth results, the retained pixels were then subjected to a Dilate-Erode process and clumps smaller than 35 pixels were removed from the layer. The smoothed, cleaned candidate pixels were converted to polygon and skeletonized to a line using Feature Analyst post-processing function “Polygon to Line.” Some dangles remained as an artifact of the skeltonization process. These were removed using ArcGIS Ver. 10 command “Trim” with a threshold of 75 m. Finally to remove excess vertices, dike lines were generalized using the Arc10 “Generalize” function with a 5-m tolerance.

2.2.4 Key Results

The PNNL-developed prototype, rapid extraction, dike mapping for the estuary (Figure 1) was delivered to the LCREP team in November 2011. These data were derived from LiDAR data via a computer-assisted, GIS approach and are intended to provide an independently derived layer to be refined by a human analyst.

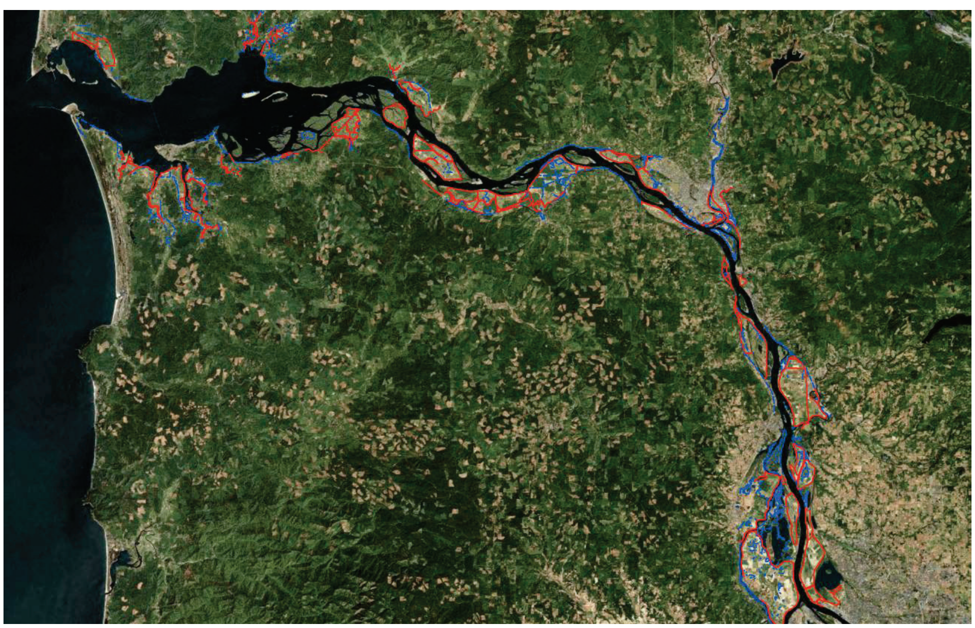

Figure 1. Estuary-wide view of the extraction results (in blue) compared to existing dike layer (in red)

2.3 Early Life History Diversity Index

Prepared by Gary Johnson and Nikki Sather

2.3.1 Problem Statement and Background

The 2008 FCRPS BiOp called for the Action Agencies (primarily BPA and USACE) to develop an index of life history diversity for juvenile salmon in the LCRE (NMFS 2008, Reasonable and Prudent Alternative 58.2). In previous work, we reviewed literature and developed and tested a binary approach based on the presence/absence of juvenile salmon of various size classes over various time periods and habitats (Diefenderfer et al. 2010, 2011). The binary approach, however, did not incorporate fish density, a key variable in life history diversity, and there could be more to learn from application of the ELHD index to past data sets.

2.3.2 Research Objectives

1. Perform a retrospective analysis of historic juvenile fish catch data to assess multi-decadal trends in the binary ELHD index.
2. Develop an ELHD index that incorporates fish density.
3. Test the new ELHD index.
4. Solicit peer review of the ELHD index in general.

2.3.3 Methods

1. Retrospective Analysis − Endeavored to extract empirical data including catch data from historical reports and assessed the applicability of the available data.
2. Index Development − Revisited the literature on existing diversity indices.
3. Test – Performed a case study applying a modified Shannon index using the beach seine catch data from Cottonwood Island during 2010 for three habitat types over 10 months (Diefenderfer et al. 2011).
4. Peer-Review − Solicited review and comments from Dr. Roy Kropp, MSL ecologist, on the index-based approach for quantifying ELHD of juvenile salmon.

2.3.4 Key Results

Retrospective Analysis − The application of the ELHD index to other data sets in LCRE was unsuccessful. We intended to examine multi-decadal trends in early life history diversity using a retrospective analysis of data from others over the past 30 years, but the analysis was not possible because the appropriate data were not available or data simply were not physically available. Appropriate in this case meant the data included fish sizes and frequency distribution, and sampling was periodic over several years. We used catch data from Jones Beach (Dawley et al. 1986) in the 2010 report (Diefenderfer et al. 2011), but other data were not available or amenable to analysis given our methodologies.

Index Development − To incorporate salmon density into the ELHD index, we modified Shannon's diversity index using the proportion of individuals in salmon size classes instead of species.

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where, p_i is the fraction of individuals belonging to the i-th species, or, in the case of ELHD for Chinook salmon, the fraction of total density belonging to the i-th size class. The size classes, derived from catch data (Sather et al. 2011), were <50 mm, 51-90 mm, 91-120 mm, >120 mm.

Test – The index test using Cottonwood Island catch data shows the sensitivity of the Shannon diversity index to evenness (see Figure 2 and Table 3). This approach for salmon ELHD requires further investigation.

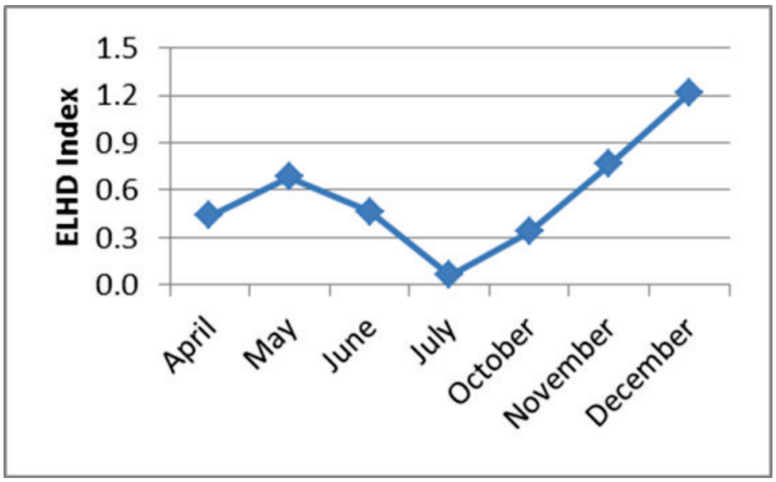

Figure 2. Early life history diversity index, April−December.

Table 3. Unmarked Chinook salmon count data.

Month	<50	51-90	91-120	>120
April	3894	701	0	8
May	706	1195	6	1
June	196	1089	9	0
July	1	214	1	0
October	0	2	17	0
November	0	29	30	1
December	6	1	8	4

A comparison of ELHD index values among three habitat types at Cottonwood Island revealed a serious drawback in applying the ELHD index as an indicator of the relative importance of habitat types to juvenile salmon. Namely, the index value relied on the presence of multiple size classes sampled at a given site; this implied direct habitat use does not reflect indirect benefits of habitats to fish such as prey and nutrient export. The occurrence of various size classes of fish with the estuary or a given habitat may reflect trends in population attributes, but the subsequent index values generated as a result of catch data should not be used to evaluate ecological benefits between sites and habitat types.

Peer-Review – Dr. Kropp's review comments included, "Regardless of the metrics, as long as there is not a biological rationale for them, you will not truly be able to understand and evaluate the effects of the restoration efforts on the system… You need to have a defined way of determining when values differ versus when they don't. This should be based on biology, not math... The farther the index value travels from scientist to management, and probably eventually to the public, the more likely it will be that the underlying data get lost. Once those data are lost, explanatory power and understanding are gone." We agree with these comments and intend to incorporate them into present and future work. Examples include clarifying the attributes associated with how the ELHD index is calculated and its subsequent intended use for management applications. Furthermore, we continue to make refinements with regard to coupling biotic information into a condensed and quantitative format.

2.4 Physiology Literature Review[1]

Prepared by Christa Woodley

2.4.1 Problem Statement

Many existing physiological methods for measuring benefits to juvenile salmon of habitat restoration are variable with life stage and time of year, and thus are not reliable indicators of habitat quality. New approaches are needed to measure and evaluate habitat restoration benefits on juvenile salmon.

2.4.2 Research Objectives

1. Evaluate the applicability of common physiological measures to use for assessing the benefits to juvenile salmon from restoration in estuaries.
2. Assess the use of fish growth measures as an indicator of fish response to habitat restoration.
3. Recommend the best measures to pursue in future research on indexing habitat benefits.

2.4.3 Methods

We examined over 30 years of peer-reviewed literature pertaining to juvenile salmon physiological measures, both common and novel, used in fisheries to monitor growth, condition, populations and habitat-provided benefits. This involved about 250 journal articles and reports.

2.4.4 Key Results

We identified characteristics or factors related to working in the LCRE with juvenile salmon that helped to determine the appropriateness of reviewed physiological measures. Measures should pertain to parr, smolting, and smolted juvenile salmon; be quantifiable and repeatable on several biological levels (cellular through population); have low variability among individuals, be easily monitored across space and time; have fine-scale temporal resolution; not require recapture for serial sampling; not be confounded by other physiological processes; and be responsive to habitat conditions.

[1] Katie Wagner, Amanda Bryson, Nichole Sather, and Gary Johnson contributed to this review.

The neuro-endocrine-based measures we reviewed are not appropriate measures of restoration benefits unless one understands seasonal/photoperiod, habitat or environmental quality, genetic differences (e.g., run or stream origination), life stage, and baseline along with strict adherence to capture and collection protocol to limit experimental variability. This makes them difficult to use as habitat-related responses by juvenile salmon in the LCRE.

Somatic growth is dependent upon food intake and composition as well physiological processes, such as assimilation of nutrients. The best growth measures to pursue for the purpose of indexing habitat benefits are related to tissue synthesis and degradation. This is because they indicate actual tissue synthesis, are not easily confounded by stressors like handling, are responsive to habitat conditions including prey accessibility and water quality, and have low statistical variability.

2.5 Species-Habitat Modeling Literature Review

Prepared by Kate Buenau

2.5.1 Problem Statement

As part of developing a numerical model to link the restoration of estuarine habitat to survival benefits for juvenile salmonids, we need to understand existing types of species-habitat models and how they are used. The development of species-habitat models includes several types of modeling approaches with a range of terminology and definitions. Because terms have not always been used consistently, they create challenges in communicating and understanding the key differences between models and choices to be made while developing one.

2.5.2 Research Objective

This research sought to explain terms and concepts relevant to modeling the relationships between habitat characteristics and species distribution in order to provide a common vocabulary for discussing such models, and to explain the use and capabilities of the primary approaches (statistical vs. mechanistic) in species-habitat modeling.

2.5.3 Methods

We reviewed literature that explained the types of species-habitat models available and their development, including critiques of major modeling approaches. We summarized the key dichotomy between statistical and mechanistic species-habitat models.

2.5.4 Key Results

The U.S. Fish and Wildlife Service (USFWS) originally defined habitat suitability index (HSI) models broadly as a means of relating measurable habitat characteristics (physical, chemical, biological) to the carrying capacity of a species (USFWS 1981). The USFWS suggested several approaches to model development, including mechanistic and statistical models and expert opinion. In practice, most HSI models developed under these guidelines use a combination of literature references on habitat suitability and expert opinion. A major criticism of these HSIs is that they generally do not include estimates of uncertainty. This deficiency and a general lack of data and funding mean few HSI models have been validated. Further research and development of the HSI model structure outlined by the USFWS has been limited despite the continued use of HSI models by resource managers.

Another modeling approach, resource selection functions (RSF), statistically relates species presence to habitat characteristics via multiple regression. These models inherently include estimates of uncertainty and can be validated, but the data needs are intensive. The limited ability to extrapolate results beyond the conditions in which data were collected constrains the utility and interpretation of these models.

Other terms for species habitat models have been used ambiguously: the phrase "Habitat Suitability Model" is sometimes used to refer to HSI models and sometimes to RSF models, often with different usage within and outside of the United States. "Species Distribution Model" (SDM) is a broad term that can include models such as those described above or others, such as large-scale models of species distribution relative to climate change.

Two primary approaches to modeling species-habitat relationships are mechanistic and statistical models. Mechanistic models focus on the physiological relationships between organisms and characteristics of the environment, explaining why a species can live where it does. Statistical models (such as RSF models) need not explain why a species occupies a location, only describe the characteristics of sites where the species is present. A well-constructed, *statistical* SDM would thoroughly describe the habitat where species *were observed* at a given time; whereas a well-constructed *mechanistic* SDM would describe the extent of where species *could live* given their physiological requirements. Both approaches have strengths and limitations; some recent research provides suggestions for combining aspects of both.

2.6 Conceptual Model of the Benefits of Estuarine Habitat Restoration for Juvenile Salmon

Prepared by Kate Buenau

With contributions to the conceptual model made by PNNL staff Lara Aston, Amy Borde, Jill Brandenberger, Heida Diefenderfer, Erin Donley, Gary Johnson, Roy Kropp, Nikki Sather, Ron Thom, Christa Woodley, and Dana Woodruff

2.6.1 Problem Statement

Developing a numerical model for juvenile salmon survival benefits gained from estuarine habitat restoration requires the establishment of a conceptual model basis, prioritization of components to include, and collection of specific information for use in the model.

2.6.2 Research Objectives

1. To develop the conceptual basis for a numerical model of habitat units for juvenile salmon present in estuarine habitats by identifying key components of the linkages between the physical habitat, biotic community, and salmon population processes.

2. To collect and consolidate information about these components, including literature and expertise held by researchers at PNNL.

2.6.3 Methods

A group of 10 MSL researchers met to identify key components and linkages to include in the conceptual model. After developing and refining the conceptual model diagram, team members collected key literature and wrote summaries for their subject areas of expertise explaining the significance of model components and relationships.

2.6.4 Key Results

At the highest level, we have organized the model into three tiers: physical, biotic, and salmon, reflecting our goal of relating alterations to the hydrogeologic environment to salmon density and survival through both the direct effects of the physical environment and indirect effects mediated by the biotic community (Figure 3).

We grouped components of the physical tier into three categories: hydrogeologic, water, and soil and sediment profile. The hydrogeologic environment includes the physical structure and hydrodynamics of a site. It is the model component directly affected by hydrological reconnection and must pass on the effects to other model components for restoration to be successful. The water category includes water properties such as temperature, dissolved oxygen, and turbidity. The third physical category is the soil and sediment profile, including structure and composition. These physical categories interact with each other, influence the biotic community at the site, and in some cases directly affect salmon (e.g., wetted area, water properties).

The biotic community consists of primary producers, both macro- and microscopic, whose composition and abundance are determined by the physical environment. The microbial loop connects the biotic community and physical environment through the breakdown of detritus and organic material. The prey category includes the invertebrate taxa, whose food web is based upon the primary producers and microbial loop, and which are themselves food sources for juvenile salmon.

The salmon tier of the model includes states and processes that link salmon survival and density to the biotic and physical environment. Biotic interactions directly affect juvenile salmon health or survival. Salmon behavior includes predator avoidance, foraging, and residence time at a site and is affected by prey availability, water quality, and the hydrogeologic environment. Key to linking all these factors are the physiological responses of salmon to their physical environment, namely the stress response and growth, which respond to many other components, interact with each other, and drive salmon density and survival.

The full conceptual model shown here applies to the effects of hydrological reconnection on juvenile salmon which have some physical presence at a reconnected site. A subset of the relationships shown also applies to cases where salmon do not enter the site, but benefit from resources exported from the site in the form of detritus and prey. In such cases, the direct connections between the physical tier and salmon and the feedback from salmon to the biotic component would not apply. Rather, the links between the physical tier through prey, as mediated by flow, would benefit fish through the exported benefits of hydrological reconnection.

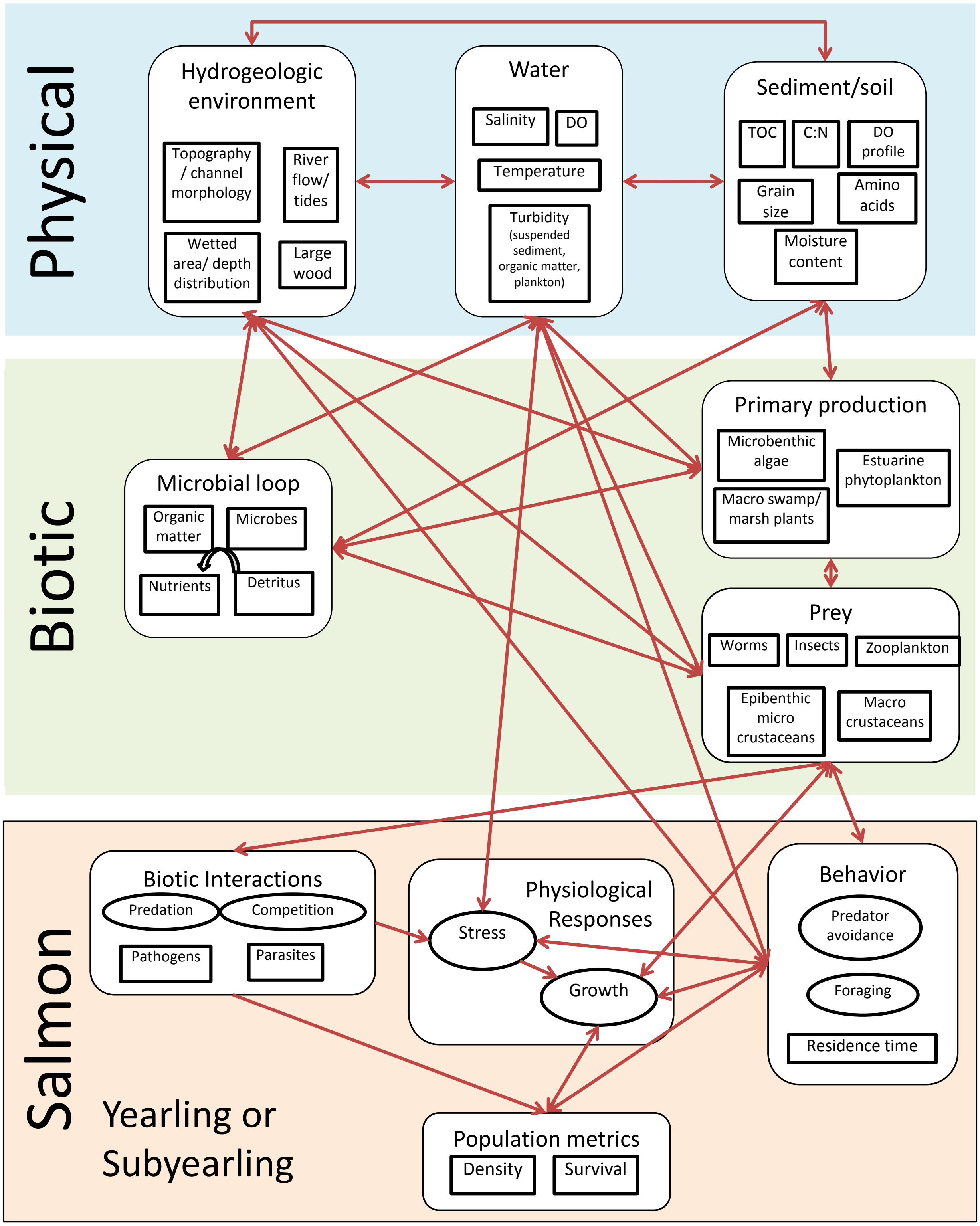

Figure 3. Preliminary conceptual model of direct and indirect juvenile salmon survival benefits from habitat restoration in the lower Columbia River and estuary.

3.0 Management Implications and Recommendations

The facets of this research, while originally brought together in this project to address three individual gaps in BiOp coverage, can be theoretically integrated through the conceptual model (Figure 3). Habitat connectivity, as an example, is primarily controlled by the hydrogeologic environment area of the model. Early life history diversity can be both a behavioral response to environmental conditions and a population response over longer time frames.

3.1 Management Implications

3.1.1 Habitat Connectivity

The ATIIM can produce numerous hydrologic metrics that describe different aspects of site area (e.g., maximum frequency wetted channel area versus maximum floodplain area inundated), as detailed in the appendix to this report. Hydrologic process metrics such as inundation frequency and duration can inform the evaluation of proposed restoration sites, e.g., determine trade-offs between water-surface elevation and habitat opportunity, compare alternative restoration designs, predict impacts of altered flow regimes, and understand nutrient and biomass fluxes. In an adaptive management framework, this model can be used for effectiveness monitoring of changes in the developmental trajectories of restoration sites and to provide standardized site comparisons.

3.1.2 Early Life History Diversity

A high-level indicator of early life history diversity is under development that can be used to track progress in the CEERP conducted by the Action Agencies. The premise is that increased life history diversity will lead to increased population resilience and recovery. As it has evolved, the creation of an ELHD index has proven to be a challenging endeavor. Efforts have been made to capture the key elements associated with the complex nature of the data, but efforts have not fully transitioned from development phase, and utility of this evaluation tool has yet to be determined.

3.1.3 Survival Benefits

The species-habitat literature review explains the type of modeling approaches and the language used to describe them, providing a basis for discussion of models used to achieve specific goals. It summarizes the strengths, weaknesses, data needs, and applications of different model types to help guide the development of habitat unit models according to their goals, requirements, and the types of information available.

The conceptual model identifies key components of the relationship between the physical habitat that juvenile salmon may use and salmon growth and survival, including intermediate physical and biotic components that connect restoration actions to the response of salmon benefitting from the restoration at that site. The conceptual model combines literature review, input from multiple projects, and the knowledge of subject matter experts and provides newer research and information than previously developed conceptual models. The conceptual model as currently developed is directed at the scale of sites affected by hydrologic reconnection. It also includes information on data availability, both conceptual and numerical and whether data is available for the LCRE or only for other regions. In doing so, it identifies data gaps overall or for the LCRE specifically and can therefore be used to guide further research.

3.2 Recommendations

3.2.1 Habitat Connectivity

Under the “habitat connectivity” objective of the Corps-sponsored “Salmon Benefits” project (study code EST-P-09-1), the proposal for 2012 work addresses the need to make the above-described model available to project proponents. This will be accomplished by creating an easy-to-use ArcGIS extension of the ATIIM. The extension and accompanying user’s manual would be housed in the ESRI ArcGIS Resource Center available for free public download. Suitable water level inputs to the ArcGIS extension would be provided by field-collected time-series pressure data (e.g., from a HOBO level logger), nearby tide gage, hydrodynamic models such as the Corps’ Adaptive Hydraulics Model or the U.S. Geological Survey Delft 3-D model, or through the input of a synthetic time-series of water surface elevations if the user is interested in running hypothetical scenarios. Additional data requirements to run the tool would be only topographic data and bathymetric data; e.g., the terrain model of the LCRE released by the Corps in 2010. This tool would permit project proponents with commonly available GIS capabilities to predict metrics such as maximum inundated area, maximum frequency inundated area, water volume fluxes, and habitat opportunity for use in restoration project planning. With guidance from the ERTG and the Action Agencies on a reference elevation, e.g., 2-year flood, a standard measurement method and application tool would be available to restoration practitioners to use for the wetted-area measurement in project templates of the ERTG review process.

3.2.2 Early Life History Diversity

The Shannon ELHD index may be refined by adding dimensions such as time and genetic stock. Approaches to ELHD based on statistical uniformity may be investigated, and ramifications of resolution of the data discussed. We may consider integration of catch data from multiple gear types from various studies, e.g., shallow-water beach seines and main channel purse seines. Finally, the findings and development of the ELHD index work from 2009 through 2012 should be synthesized to make final recommendations for an ELHD index and its applicability.

3.2.3 Survival Benefits

In physiology research, determine on a species-specific basis the relationship between fish tissue synthesis/degradation and habitat conditions as reflected in various levels of quality and quantity of food. This will require a formal experimental design and laboratory/field research. The strongest inference of survival benefits in the LCRE, however, will be gained by using multiple measurement methods, including site or reach specifics with fish condition and telemetry in a single index. This research is critical to meaningful evaluation of the effectiveness of habitat restoration actions in the CEERP.

From the species-habitat literature review, we recommend that the approach to habitat unit modeling for juvenile salmon in the LCRE be primarily mechanistic, due to the nature of data available on the use of habitat by salmon and the goal of modeling changes to growth and survival rather than simply presence/absence. Statistical analysis of existing data sets may still be useful for parameterizing aspects of a mechanistic model. Based upon the literature on the application of species-habitat models, we recommend that estimates of uncertainty be explicitly included in all aspects of the model to allow for the rigorous application and any future testing or validation of the model.

The next steps for the use of the conceptual model are the prioritization of elements for inclusion in a numerical salmon-habitat model and the formal gathering of quantitative relationships and parameters for use in a numerical model, using sources identified during the course of conceptual model development. During this process it is possible that there may be aspects of the conceptual model identified for additional or more in-depth research, either through further literature surveys or as suggestions for future empirical study.

3.3 Relevance to the 2008 Biological Opinion on FCRPS Operations

This investigation has implications relevant to the entire adaptive management cycle of the CEERP (Thom et al. 2011a). The corollary to establishing our ability to *measure* habitat restoration benefits upon project completion is developing the ability to *predict* habitat restoration benefits during the Corps' ecosystem restoration planning process. Therefore, the project addresses BiOp RPA Actions 2 and 3, 36 and 37, and 58, 59, and 60 (NMFS 2008; 2010). The following RPA subactions are specifically addressed:

- RPA 58.2 – develop an index and monitor and evaluate life history diversity of salmonid populations at representative locations in the estuary
- RPA 59.3 – develop an index of habitat connectivity and apply it to each of the eight reaches of the study area
- RPA 60.3 – evaluate the effects of selected individual habitat restoration actions at project sites relative to reference sites and evaluate post-restoration trajectories based on project-specific goals and objectives.

In addition, the region, i.e., Action Agencies[1] , 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 as 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 ESA. The Action Agencies will submit to NOAA Fisheries, Annual Progress Reports in September each year except 2013 and 2016; in these 2 years, comprehensive evaluations of multi-year implementation activities are due by the end of June.

[1] The Action Agencies comprise the Corps, BPA, and the Bureau of Reclamation (Reclamation).

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