Summary of a Technical Workshop held April 4-5, 2012: Developing an Estuarine Indicator System for the Lower Columbia River and Estuary

Workshop Sponsors:

Lower Columbia Estuary Partnership
U.S. EPA Office of Water
Bonneville Power Administration

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[1] The Biological Condition Gradient information (section I.B) was copied, almost verbatim, from several sources, including Cicchetti and Pryor (2008), Cicchetti (2010), Davies and Jackson (2006) and USEPA (2011).

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Executive Summary

The lower Columbia River and estuary is designated an "estuary of national significance" under Section 320 of the Clean Water Act, making it one of 28 National Estuary Programs. All NEPs are encouraged by the U.S. Environmental Protection Agency to develop and implement an estuary condition indicator system to guide monitoring and research efforts, and regional partners are also interested in creating an indicator system for the lower Columbia. The overarching goal of the indicator system is to allow NEP partners to track ecosystem condition over time and to track the effectiveness of the implementation of actions listed within their Comprehensive Conservation and Management Plan (CCMP). Additionally, we feel an estuary condition index would enable monitoring and research results to be more easily translatable to the public, scientists and managers and garner support for long term data collection efforts. Finally, this effort overlaps well with features of Oregon and Washington salmon recovery efforts, including developing a monitoring strategy for the lower river.

The Estuary Partnership has been working with regional partners through the Science Work Group and a two-day workshop in April to begin developing the estuarine indicator system. Through these groups, we have developed goals, objectives, and focus questions that the indicator system will address. The U.S. EPA has collaborated with our effort by providing guidance on the use of their Biological Condition Gradient (BCG) framework as a basis for the indicator system. The BCG uses a conceptual model describing how a series of identified ecological attributes respond to a gradient of increasing stress, providing a context for the current condition of the lower river with respect to our management goals and its historical condition, whether the lower river is continuing to degrade or on a recovery trajectory.

This document describes the overall process for developing the estuarine condition index and outlines the steps accomplished and results to date. Specifically, this report provides a summary of the results from the April 4-5, 2012 workshop and describes recommended next steps. Smaller focus groups targeting specific tasks will be hosted in the future to move this work forward with periodic updates to the Science Work Group.

I. Introduction

A. Purpose of the Document

The purpose of this document is to provide a summary of the April 4-5, 2012 workshop and the conceptual framework for developing and implementing an indicator system of ecosystem condition for the lower Columbia River and estuary (LCRE), using U.S. Environmental Protection Agency's (U.S. EPA) Biological Condition Gradient (BCG). The document is intended primarily to summarize the workshop and assist workshop participants and Indicator Steering Committee members with future work.

B. Organization of the Document

The document is organized into four sections: 1) introduction; 2) background on the general BCG approach; 3) process for developing the estuarine indicator system within the BCG framework; 4) results of the April 4-5 workshop and next steps and 5) appendices.

C. Key Terms

Bioassessment: the use of biological indicators to evaluate ecological condition.

Biological Condition Gradient (BCG) framework: a method developed by EPA's Office of Water (Office of Science and Technology) to evaluate the extent of biological alteration using a common scale (the BCG) that is anchored in a baseline condition of "as naturally occurs" or "minimally disturbed."

Biological Condition: the biological structure, extent, function and biophysical processes within a waterbody. Biological Condition can be evaluated at any scale, and is not limited to "condition' in the strict sense of organism fitness.

Biotope: Area that is relatively uniform in physical structure and that can be identified by the dominant biota (Cicchetti and Greening 2011)

Estuarine BCG Framework: an evolving method for applying the general principles of the BCG framework to organize estuarine biological structure, condition, function, and connectivity at the scales of a single habitat, an entire estuary, or a set of estuaries. The BCG was originally tested for hard bottom, temperate streams (Davies and Jackson 2006).

II. Background of the Biological Condition Gradient Approach

A. Estuarine Indicator System

The lower Columbia River and estuary is designated an "estuary of national significance" under Section 320 of the Clean Water Act, making it one of 28 National Estuary Programs. NEPs are administered by U.S. EPA, and U.S. EPA strongly encourages all NEPs to develop and implement an estuary condition indicator system to guide status and trends monitoring. Aspects of the indicator system are a requirement under the 1993 Government Performance and Results Act (GPRA), for example. The overarching goal of the indicator system is to allow stakeholders to track ecosystem condition over time as well as track the effectiveness of the NEP's implementation of actions listed in their Comprehensive Conservation and Management Plan (CCMP). Additionally, an estuary condition index would enable status and trend results to be easily translatable to the public, scientists and managers. Finally, the Northwest Power Conservation Council (NPCC) and Bonneville Power Administration (BPA) have also recently requested we create an estuarine condition index for the lower river, and this effort overlaps well with features of Oregon and Washington salmon recovery efforts.

The Lower Columbia Estuary Partnership (Estuary Partnership) has been working with regional partners through the Science Work Group to develop the estuarine indicator system. The Science Work Group developed goals, objectives, and focus questions that the indicator system will address. These are as follows:

- **Program Goal:** The goal of the Program is to track the status and trends of ecosystem condition to inform decisions for the purpose of conserving and restoring the lower Columbia River and estuary.

- **Program Objective:** Use estuarine quality and condition index to track changes in LCRE; provide context for results of other RME efforts.

- **Focus Questions to be addressed by Estuarine Condition Index:**

    1. What is the biological integrity[2] of the LCRE and is it improving or declining? Are Columbia River Basin ecosystems healthy? (Estuary Partnership, 1999a, b; NPCC, 2010)
    2. What is juvenile salmon performance (i.e., life history strategy diversity, spatial structure, growth, foraging success) in the lower river, and is it improving or declining? What are the limiting factors and threats that affect the status of an ESU within the estuary and are they improving or declining? (NMFS, 2011a, b)
    3. What are the pollutants of concern, and are their concentrations increasing or decreasing? Are pollutant levels increasing or decreasing? Are concentrations of toxics in sediment and biota impair native species? (from Estuary Partnership 1999a, b)
    4. What are the ecosystem (biological, chemical and physical) processes and are those processes improving or degrading? (NMFS, 2011b)
    5. What are the effects of climate change on estuary ecosystem condition and are they increasing or decreasing? How are the components adapting to stressors of climate change and how resilient are the components? Is climate change affecting fish and wildlife in the Columbia River Basin? (Estuary Partnership, 1999 a, b; NPCC, 2010)

As part of this effort, the Estuary Partnership is collaborating with the U.S. EPA on using the biological condition gradient framework for the indicator system to provide a scientifically defensible index that is easily translatable to the general public. This is explained in more detail in the next section, while the process for developing the indicator system is outlined in section III.

B. Biological Condition Gradient (BCG)

Overview of bioassessments

Bioassessment (the use of biological indicators to evaluate ecological condition, includes Indices of Biologic Integrity) allows managers to consider the cumulative impacts of many anthropogenic stressors. Bioassessment in estuaries integrates many of the upstream stressors in the larger watershed, and is therefore a vital contribution to holistic management at the waterbody and watershed level. Bioassessments tie directly to our goal of protecting the lower

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[2] USEPA definition of biological integrity: capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization that is comparable to representative natural habitat in the region (Karr and Dudley, 1981; Frey, 1977).

Columbia River's biological integrity (using EPA's definition: the ability of an aquatic ecosystem to of support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization that is comparable to representative natural habitat in the region) (Karr and Dudley, 1981; Frey, 1977).

Data from bioassessments have been used to:

- ***Define goals for a waterbody*** – provide information on the composition of a naturally occurring aquatic community for use as reference sites for similar waterbodies and a benchmark against which to measure the biological integrity of surface waters.
- ***Report status and trends*** - provide information on the status of the expected aquatic biota in a waterbody and, with continued monitoring over time provide information on long-term trends.
- ***Identify high-quality waters and watersheds*** - to identify high-quality waters and watersheds and support implementation of antidegradation policies.
- ***Document biological response to stressors*** - provide information to develop biological response signatures (e.g., a measurable, repeatable response of specific species to a stressor or category of stressors).
- ***Complement pollutant-specific ambient water quality criteria*** – complement water quality standards (WQS) by providing field information on the cumulative effects on aquatic life from multiple pollutants, as well as detecting impacts from pollutants that do not have recommended numeric criteria.
- ***Address water quality impacts of climate change***- used in concert with physical, chemical, and land use data to help identify baseline biological conditions against which the effects of climate change on aquatic life can be studied and compared.

Overview of the Biological Condition Gradient (BCG) Approach

The BCG (Figure 1) is a conceptual model developed by EPA's Office of Water (Office of Science and Technology) to describe six stages of increasing alteration of biological structure and function along a gradient of response anchored in a baseline condition of "as naturally occurs" or "minimally disturbed." The central components of the generalized BCG framework as developed by EPA's Office of Water are as follows:

1. One or more biological indicators are used to assess biological condition and ecological state.
2. The BCG defines up to six levels of biological responses to increasing stress (Figure 1; Table 1), from the highest state of condition (least stress) to the lowest condition (most stress).
3. The highest level of condition is anchored in "as naturally occurs" or "minimally disturbed."
4. Expert best professional judgment is used to define the thresholds at each level.

The BCG levels provide a consistent "common language" that can facilitate comparisons among biological assessments at multiple spatial scales, across habitats, or between waterbodies. These levels provide a way to interpret biological assessments and use these data for management decisions in a way that is easily communicated to the public and that enables a more meaningful and effective evaluation of environmental improvements.

The descriptive model of the BCG is based on a body of empirical science demonstrating that ecological response follows a predictable trajectory in response to generally increasing anthropogenic stress. The intent of the BCG is to use this trajectory to define a scientific framework for consistent bioassessment, meaningful goal-setting, and coordinated management decision-making. The intent of a BCG is to assist with the steps of:

> 1) Determining the environmental conditions that exist (assessment). The BCG defines an anchored and consistent baseline of "as naturally occurs" and communicates current ecological condition relative to that baseline as a "common language" that applies across different biological metrics and scales.
> 2) Deciding what environmental conditions are desired (goal-setting). The BCG is a scientific framework that can be used with expert groups and stakeholders to set easily communicated environmental goals.
> 3) Planning for how to achieve these conditions (management). The BCG provides a scientific basis for planning, restoration, protection, and monitoring by providing a common language and shared quantitative goals (see Davies and Jackson 2006 for further information).
> 4) Communicate with stakeholders—When biological and stress information is presented in this framework, it is easier for the public to understand the status of the aquatic resources relative to what high-quality places exist and what might have been lost.

The goal of BCG applications are tools and guidance that improve understanding and communication of estuarine condition and lead to improved management decision-making, e.g., by improving the ability to diagnose a problem, identify stressors, estimate recovery potential, and set anti-degradation thresholds.

Importantly, the BCG approach is not an attempt to return ecological systems to a rigid conceptualization of a minimally disturbed previous historic state. The BCG is a flexible communications and goal-setting tool. The BCG approach uses the concept of "minimally disturbed" or "as naturally occurs" to anchor our understanding of ecological degradation, but these conditions are used to *inform* goal setting, and are not considered a "default" environmental outcome or goal. While "minimally disturbed" or "as naturally occurs" can be idealized as the conditions that existed prior to European colonization, it is clear that we will not return the lower Columbia River to these conditions.

The BCG is a tool to incorporate our understanding of where our waterbodies have been into a stakeholder vision of what conditions we want for our estuaries. Cairns et al. (1993) conceptualized this within a hypothetical waterbody as a trajectory of degradation, described by BCG tiers, followed by a set of alternate restoration strategies and associated restoration trajectories, none of which assume that restoration will be a direct return along the path of degradation (Figure 2). The BCG approach recognizes that recovery is not the reverse of degradation - the model helps organize our thinking about what critical ecological attributes must be restored in order to maintain or restore ecologically sustainable systems.

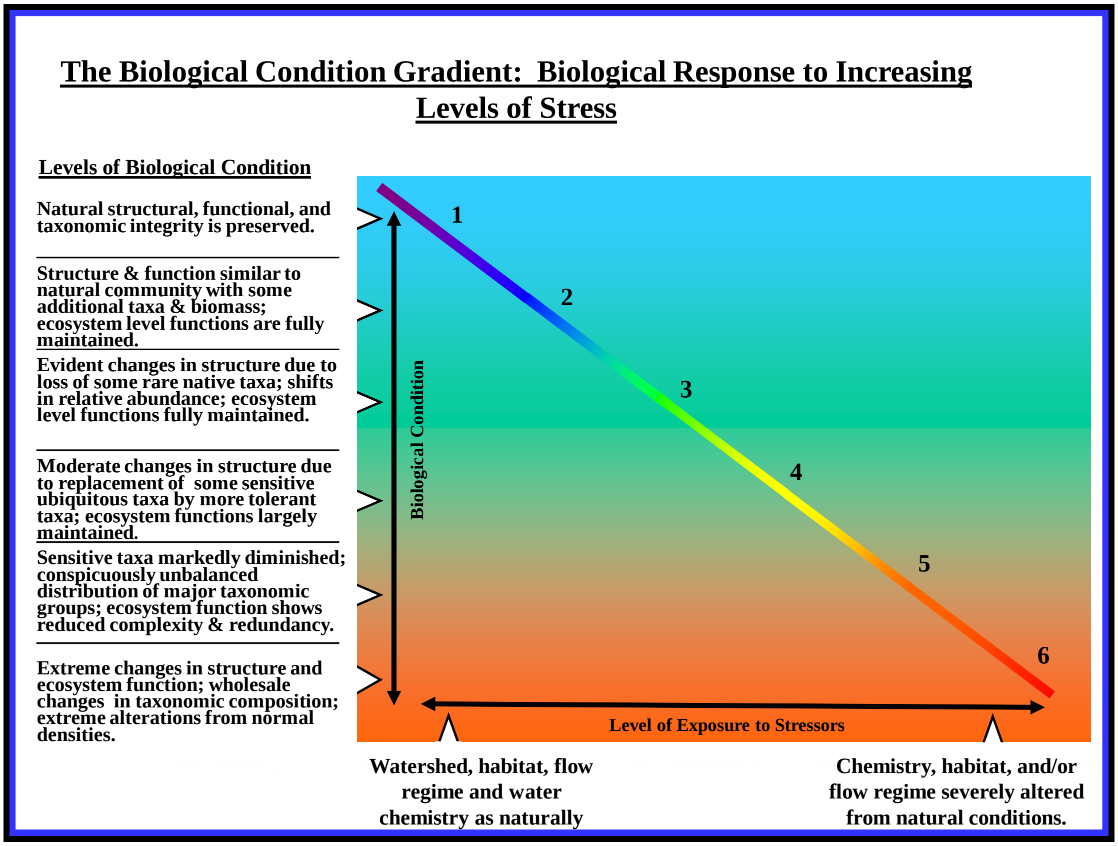

Figure 1. The conceptual model of the Biological Condition Gradient.

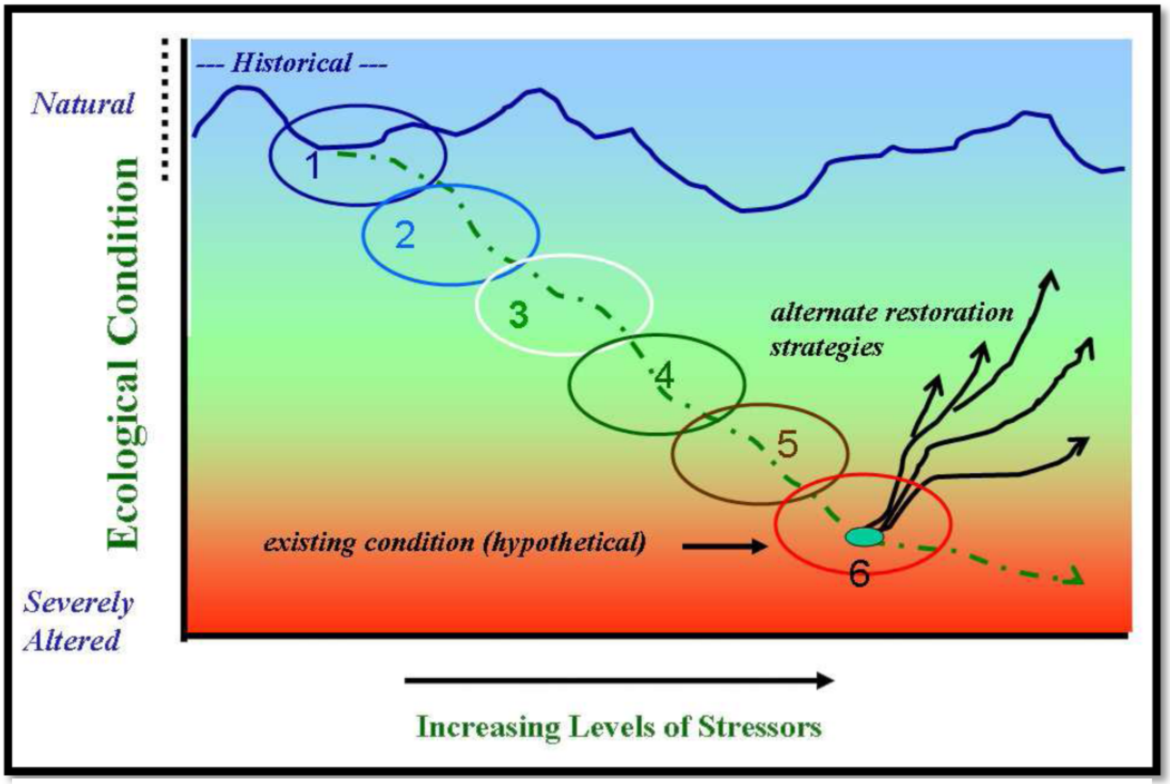

Figure 2. A hypothetical trajectory of degradation in a waterbody, also showing possible trajectories of recovery under alternate restoration strategies. Modified from Cairns et al. (1993).

BCG application in streams

The original BCG, which was developed for hardbottom temperate streams, describes how 10 ecological attributes change in response to increasing levels of stressors (Table 1). The stressors follow a gradient of biological condition and are broken into six tiers. The model was then tested by determining how consistently a regionally diverse group of biologists assigned samples of macroinvertebrates or fish to the six tiers (Davies and Jackson 2006). This model has been applied and adapted for streams in eight states in the Midwest and along the East Coast; there are several other efforts planned or under development in over 12 other states.

Table 1. Stream BCG (from Davies and Jackson, 2006).

Ecological Attributes	**Biological Condition Gradient Tiers or Levels**					
	1	**2**	**3**	**4**	**5**	**6**
I. Historically documented, sensitive, long-lived or regionally endemic taxa	As predicted for natural occurrence except for global extinctions	As predicted for natural occurrence except for global extinctions	Some may be absent due to global extinction or local extirpation	Some may be absent due to global, regional or local extirpation	Usually absent	Absent
II. Sensitive–rare taxa	As predicted for natural occurrence, with at most minor changes from natural densities	Virtually all are maintained with some changes in densities	Some loss, with replacement by functionally equivalent *Sensitive-ubiquitous* taxa	May be markedly diminished	Absent	Absent
III. Sensitive–ubiquitous taxa	As predicted for natural occurrence, with at most minor changes from natural densities	Present and may be increasingly abundant	Common and abundant; relative abundance greater than *Sensitive-rare,* taxa	Present with reproducing populations maintained; some replacement by functionally equivalent *taxa of intermediate tolerance.*	Frequently absent or markedly diminished	Absent
IV. Taxa of intermediate tolerance	As predicted for natural occurrence, with at most minor changes from natural densities	As naturally present with slight increases in abundance	Often evident increases in abundance	Common and often abundant; relative abundance may be greater than *Sensitive-ubiquitous* taxa	Often exhibit excessive dominance	May occur in extremely high OR extremely low densities; richness of all taxa is low
V. Tolerant taxa	As naturally occur, with at most minor changes from natural densities	As naturally present with slight increases in abundance	May be increases in abundance of functionally diverse tolerant taxa	May be common but do not exhibit significant dominance	Often occur in high densities and may be dominant	Usually comprise the majority of the assemblage; often extreme departures from normal densities (high or low)

VI. Non-native or intentionally introduced taxa	Non-native taxa, if present, do not displace native taxa or alter native structural or functional integrity.	Non-native taxa may be present, but occurrence has a non-detrimental effect on native taxa	Sensitive or intentionally introduced non-native taxa may dominate some assemblages (e.g., fish or macrophytes)	Some replacement of sensitive non-native taxa with functionally diverse assemblage of non-native taxa of intermediate tolerance	Some assemblages (e.g., fish or macrophytes) are dominated by tolerant non-native taxa	Often dominant; may be the only representative of some assemblages (e.g., plants, fish, bivalves)
VII. Organism Condition (especially of long-lived organisms)	Any anomalies are consistent with naturally occurring incidence and characteristics	Any anomalies are consistent with naturally occurring incidence and characteristics	Anomalies are infrequent	Incidence of anomalies may be slightly higher than expected	Biomass may be reduced; anomalies increasingly common	Long-lived taxa may be absent; Biomass reduced; anomalies common and serious; minimal reproduction except for extremely tolerant groups
VIII. Ecosystem Functions	All are maintained within the natural range of variability	All are maintained within the natural range of variability	Virtually all are maintained through functionally redundant system attributes; minimal increase in export except at high storm flows	Virtually all are maintained through functionally redundant system attributes though there is evidence of loss of efficiency (e.g., increased export or decreased import)	There is apparent loss of some ecosystem functions manifested as increased export or decreased import of some resources, and changes in energy exchange rates (e.g., P/R; decomposition)	Most functions show extensive and persistent disruption
IX. Spatial and temporal extent of detrimental effects	N/A A natural disturbance regime is maintained	Limited to small pockets and short duration	Limited to the reach scale and/or limited to within a season	Mild detrimental effects may be detectable beyond the reach scale and may include more than one season	Detrimental effects extend far beyond the reach scale leaving only a few islands of adequate conditions; effect extends across multiple seasons	Detrimental effects may eliminate all refugia and colonization sources within the catchment and affect multiple seasons
X. Ecosystem connectance	System is highly connected in space and time, at least annually	Ecosystem connectance is unimpaired	Slight loss of connectance but there are adequate local recolonization sources	Some loss of connectance but colonization sources and refugia exist within the catchment	Significant loss of ecosystem connectance is evident; recolonization sources do not exist for some taxa	Complete loss of ecosystem connectance in at least one dimension (i.e., longitudinal, lateral, vertical, or temporal) lowers reproductive success of most groups; frequent

						failures in reproduction & recruitment; most major living habitats are eliminated

Purpose for using the BCG approach - it provides a common language across waterbodies

The “levels” or “tiers” (1 - 6 in Figure 1; Table 1) of biological condition of the BCG serve as a “common language” for assessment, to relate different biological metrics such as benthic IBIs, seagrass maps, chlorophyll concentrations, etc. These levels have the same inherent definitions for any biological measure in any setting, so that “Tier 1” carries the same basic meaning in (for example) phytoplankton in a Vermont stream, benthos in a California lake, or fish communities in a New Jersey estuary.

The descriptive gradient of biological response to stressors (e.g., Table 1, as used in freshwater) is the scientific underpinning behind a consistent estuarine BCG, with the assumption that biological structure, condition, and function will follow a predictable trajectory in response to generally increasing anthropogenic stress. The narrative of Figure 1 defines this trajectory, and provides a consistent platform for assignment of BCG tiers/levels.

Further, the TALU document (US EPA 2005) and Davies and Jackson (2006) provide a detailed process for using expert consensus and available data (stressor-response relationships from comprehensive monitoring programs) to calibrate the BCG and consistently assign biological metric scores to BCG levels 1 - 6. The BCG levels are designed to align with Tiers under evolving management approaches, to be used as targets for protection and restoration.

III. Process for developing an LCRE Estuarine Indicator System within the BCG Framework

A. Overview of the “Habitat Mosaic” approach to bioassessment

Productive estuaries in a natural state are composed of a mosaic of living habitats or *biotopes*, including submerged aquatic vegetation beds, emergent marshes, tidal forests, clam flats, and specific soft-bottom benthic communities. The “Habitat Mosaic” approach in bioassessment is a first-order evaluation of the biological condition of a waterbody based on the recognition that anthropogenic stress to an estuary leads to destruction of these living habitats. This method considers the distribution of these living habitats to be a central part of estuarine biology. A further assumption is that a mosaic of biotopes which most resembles the mosaic that would naturally occur in an estuary will provide greatest benefit for the native communities of organisms that have evolved in that setting over millennia. A first-order assessment using this approach compares acreage data from a time period of interest to acreage data from one or more time periods in the past. Ecological priorities are to “Restore the Historic Balance” of critical habitats in percent compositions of biotope mixes relative to an undisturbed historic benchmark, as well as to restore total acres of all living habitats, to the extent possible. The Tampa Bay Estuary Program (TBEP) has been working successfully with these concepts for many years (see

Lewis and Robison 1995). We propose that this method can be used together with other approaches as an important component in the management of the lower Columbia River, and could provide many advantages by linking environmental goals to biotope acres and biotope metrics under the BCG framework.

B. Example application of the BCG approach in other estuaries

The TBEP has been managing their estuary based on a management approach and an ecological framework they call “restore the historic balance”. Briefly, this involves visioning with stakeholders to set habitat coverage goals (acres or hectares) representative of a less impacted condition (based on habitat ratios from an earlier time period) and then enacting management programs to restore the estuary to that more ecologically balanced state. Tampa Bay developed an ecological vision derived from habitat ratios that existed in 1950, then used that vision as guidance and motivation to dramatically reduce nutrient loads to the estuary and enact bay-wide programs to identify, protect, and restore valued habitats. These actions led to greatly improved water quality, and to gains of over 2,200 hectares of high-value estuarine habitat, including over 1,700 hectares of seagrass habitat that had been lost, and almost 100 hectares of a valued and scarce high-marsh habitat that had been lost at a more rapid rate than other habitats. Public awareness was a central component of TBEP’s successes. This is further described in Lewis and Robison (1995) and in Greening and Janicki (2006).

The TBEP approach can generally be described as follows:

1. Identified faunal guilds of importance (estuary-dependent species)
2. Identified their ecological needs (i.e., key estuarine habitats, habitat mosaic)
3. Identified datasets that could be used for creating targets
    - Used historic habitat maps, compared to current habitat coverage for floodplain and aquatic habitats (i.e., seagrass)
4. Developed numeric targets for habitats important to faunal guilds
    - Targeted subset of historic floodplain habitat mosaic
        - protect the remaining stands of intact habitats through conservation lands
    - Targeted 1950s coverage of seagrass
5. Determined resource needs of seagrass:
    - Improve water clarity (by reducing phytoplankton levels)
    - Reduce nutrient loads, specifically nitrogen, to reduce phytoplankton concentrations
6. Created numeric management targets:
    - Numeric seagrass coverage goals by bay segment
    - Numeric nitrogen load reduction goals by year
7. Created decision support framework and tools for implementation:
    - Coordinated with agencies, citizens and industries to implement voluntary nitrogen load reduction actions
    - Established a Nitrogen Management Consortium to guide implementation and provide feedback
    - Developed comprehensive monitoring program to assess effectiveness of actions and status of resources
        - Monthly monitoring for water clarity, concentrations of nutrients, phytoplankton concentrations

        - Inter-lab split samples and other Quality Assurance steps
        - Atmospheric deposition monitoring for nutrients and modeling to predict spatial/temporal inputs
        - Annual seagrass condition monitoring (e.g., fixed transects including bed deep edge, density, epiphytes, blade length)
        - Biennial seagrass coverage monitoring (i.e., aerial mapping)
        - Landcover/landuse data every five years (i.e., aerial mapping)
        - **Note:** The monitoring is undertaken by partners including local and state agencies; the role of the TBEP to coordinate, resolve issues, compile and analyze data, report results to wider audience, facilitate management and monitorign actions
    - Report out to public on trends and progress in meeting targets every 2-3 years
    - Partners undertake diagnostic studies on identified uncertainties (wave energy effects on seagrass, seagrass "donut" phenomena, grazing impacts, effectiveness of Best Management Practices on nutrient load reductions, etc)
8. Result - region has met nitrogen load reduction goals, shown significant increases in seagrass coverage and is on recovery trajectory to meet seagrass coverage goals (see Tomasko et al., 2005)

C. Process for LCRE Estuarine Indicator System

Overall Process

The Estuary Partnership's Science Work Group (SWG) has established the following process for developing the estuary indicator system using the BCG framework and its application in Tampa Bay as an example:

1. Identify goal, objective, actions and assessment questions of interest to resource managers. (*Completed by SWG; March 27, 2012*)
2. Describe "minimally disturbed" LCRE, identify ecosystem attributes for protection or restoration. (*Completed by April 4-5 workshop participants*)
3. Define the key ecological needs of attributes and quantifiable targets for ecosystem attributes (*Initiated by April 4-5 workshop participants; Continued work by Indicator Steering Committee and Focus Groups for Individual Attributes; Anticipated to be completed in fall 2012)*
4. Determine core indicators and metrics (*Initiated by April 4-5 workshop participants; Continued work by Indicator Steering Committee and Focus Groups for Individual Attributes; Anticipated to be completed in fall 2012*)
5. Determine population of interest (using Columbia River Estuary Ecosystem Classification) for each core indicator and minimum number of sites (*Future Work by SWG, Indicator Steering Committee; Anticipated to be completed in fall 2012*)
6. Determine what specifically we measure (metrics), frequency of sampling and sampling period (*Future Work by SWG, Indicator Steering Committee; Anticipated to be completed in fall/winter 2012*)
7. Establish analysis methods, quality control and data management (*Future Work by SWG, Indicator Steering Committee; Anticipated to be completed in fall/winter 2012*)
8. Match available funding and projects to list of core indicators (*Future Work by SWG, Indicator Steering Committee*)

    a. Define roles and responsibilities for collection of individual metrics, quality control and data management
    b. Incorporate results from other estuary RME into index as relevant

9. Develop decision support tools, incorporate targets and monitoring results into management activities of lower river (*Estuary Partnership staff, SWG, Indicator Steering Committee*)
10. Monitor and provide results, provide periodic updates to stakeholders (*Ecosystem Monitoring Program, AFEP research projects, other programs as applicable*)
11. Provide recommendations for diagnostic /BACI studies to better understand uncertainties, variability and reasons behind trends/results (*SWG, SRWG, CREC*)
12. Update to reflect new findings and emerging issues as necessary.

We hope to accomplish steps 1 through 8 in 2012, with step 3 being the key for developing long term management goals and undertaking subsequent steps. We accomplished key aspects of steps 2 through 4 at the April 4-5 workshop, whereas developing quantifiable targets (step 3) will require detailed discussions and data analysis. We expect this to largely be accomplished through an overall Indicator Steering Committee and multiple focus groups after the April workshop. The results of this effort should provide focus to steps 4 and subsequent tasks.

Objectives of April 4-5, 2012 workshop
This workshop was set up as a first step towards developing a better understanding of biological condition in lower Columbia River: defining where the river "was", as historic condition, so that we can better understand where the river "is", in present condition. This would then inform a stakeholder vision for where we want the river to be and management goals.

First steps:

- Define a concept and qualitative description of "minimally disturbed" in the Columbia estuarine system, considering biology and ecological function along the environmental gradients that occur in the lower river.
- Identify the key changes and patterns of biological changes with increasing anthropogenic impact or stress (departures of biological condition and ecological function from minimally disturbed conditions).
- Identify what we want as target conditions for the future, based on current constraints that are unlikely to significantly improve (hydropower and urbanization)
    - Identify attributes that are important to recover or protect (for example: Pacific salmonids, waterfowl/birds using Pacific migratory flyway)
- Describe the biological and ecological needs of these attributes (diversity of habitats distributed throughout lower river, food sources, migratory pathway safe from predation, low disease)

Follow up steps:

- Identify and assess the existing historical and current data that are available for these key indicators that can be used in developing targets (e.g., landcover, macroinvertebrate composition, water temperature, mortality estimates from predation).

- Review datasets and develop realistic, numeric targets (for example: X acres of emergent marsh habitat in Reaches A-E, Y acres in Reaches F-H, <35% cover of reed canary grass per site, <19 degrees Celsius water temperature in months July-August in Reaches F-H)
- Identify indicators to measure to determine if we are meeting targets (for example: landcover, vegetation cover, water temperature), etc. (steps 4-12).

IV. Outcomes of the April 4-5, 2012 Workshop

A. Definition of a "minimally disturbed" LCRE

Workshop participants were broken into three groups and requested to develop qualitative descriptions of a "minimally disturbed" LCRE. The goal of this exercise was to qualitatively define baseline conditions in the lower river and those ecological attributes that stand out as important to workshop participants. The results of this discussion provided a framework for comparisons with current ecological conditions and subsequent discussions focused on identifying which ecological attributes are important to restore or protect into the future...ultimately our management objectives. This description was not meant to be inclusive but to provide an overall conceptual basis.

The notes from the three break out groups were compiled and synthesized into the following description. The author followed one group's organization of the descriptions by largely categorizing items using an ecosystem process framework; the following categories were used: natural hydrologic processes and sediment dynamics; food web and trophic processes; habitat and habitat forming processes; and species. It is interesting to note that participants essentially identified a series of indicators for each ecosystem process. These were integrated in subsequent discussions.

Synthesis Description[3] - All three groups used the time period for "minimally disturbed" as before large scale, anthropogenic effects, pre-industrialization, mid 1800s.

Natural Hydrologic Processes and Sediment Dynamics

- Timing, magnitude, *duration, frequency, rate of change*
- Recurrent, frequent flooding of floodplain, including freshet
- Sufficient bed material transport to facilitate bar formation and channel migration; dynamic channel migration, wider mouth, more sediment transport to the nearshore ocean
- Sufficient suspended material transport to enable widespread floodplain deposition
- Sufficient material transport of large woody debris (LWD) and organic matter
- Connectivity between ecosystem types to mainstem, floodplain; fish opportunity
- *Plume dynamics*
- *Natural stream bank processes such as erosion*

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[3] Bullets in normal font were mentioned by 2 or more groups, while bullets in italics were mentioned by 1 group only. Group 3 used a slightly different framework for their notes (i.e., controlling factors, stressors, processes and functions) as well as including some information on present day stressors. They felt the author's system missed the intent of aspects of their descriptions; their notes are included as additional information in Appendix I.

Food web and trophic processes

- Local production of macrodetritus, transported by flows/connectivity to mainstem; vascular plants/macrodetritus – based food web
- *Natural trophic cascades (wolves in Yellowstone example: wolves preying on elk, allows riparian vegetation to recover, affects river morphology)*
- Natural habitat capacity
- Natural water properties such as nutrients, pH, DO, chlorophyll, turbidity
- Little invasive species impact on food web
- Natural inter and intra competition and predation amongst species

Habitats and habitat forming processes

- Natural habitat distribution and abundance - balance
- Habitat diversity -- high diversity, presumably
- Wetland marshes, swamps, etc. -- see historical condition in Keith's maps
- Shallow water sloughs and channels -- high productivity, cold water refugia.
- *LWD trapping sediment, seeding, nurselogs*
- Beaver dams/ponds – prevalent
- *Natural barriers*
- *Natural stream bank processes such as erosion*
- *Abundance of riparian for nearshore cooling*

Species

- Salmon diversity of size, age class, life history types, species, natural r*esidence time of salmonids*
- Lamprey, sturgeon, resident fish or sensitive species
- Little invasive species or little impact on native species or ecosystems
- *Columbian white-tailed deer*

Overall

System resilience to acute and recurrent disturbances

Water quality with minimal chemical contamination - Erosion introduces naturally occurring contaminants.

Natural temperature regime – annual maximum water temperatures and time distribution of temperature (maximum temperatures later in summer and not as high as now).

Energy flux - marine derived nutrients to upstream watersheds

Questions and comments from Groups

- *Should we define "minimally disturbed" on smaller scale than entire lower river; spatial and temporal differences too great?*
- *Use existing work to define "minimally disturbed"*
- *Ensure indicators are measurable and reflect biologic, chemical and physical processes*

B. Identification of Key Ecological Attributes for Protection and Restoration

Workshop participants were then broken into two different break-out groups to undertake a data exercise "pilot" so they would understand the next steps of developing a BCG framework. The exercise was to use juvenile salmon as an example ecosystem attribute and by using example datasets (photo point, water quality time series, water elevation time series, sediment grain size, vegetation composition, etc.), begin identifying supporting components and processes that define juvenile salmon biological requirements. The ultimate objective of this was twofold: 1) allow participants a more "hands on" understanding of the components of a BCG framework and 2) identify key supporting components and indicators for this attribute.

As part of a larger work session, workshop participants were then requested to identify ecological attributes of importance. Attributes were defined as those components of the ecosystem we want to protect or restore such as focal species (e.g., salmonids) or natural habitat diversity. Participants listed the following potential attributes:

- Dungeness crabs
- Salmon
- Sturgeon
- Eulachon
- Lamprey
- Resident fish
- Birds that use Pacific flyway
- Bald eagles, ospreys
- Beavers
- Columbia White-tailed deer
- Butterflies
- Red legged frog
- Turtles
- Native mussels
- Wapato
- Spike rush
- Water quality
- Natural habitat mosaic

Participants then came to a consensus on the following as the five key attributes for the lower Columbia River and estuary:

1. Natural habitat mosaic, including water column
    - Native biological communities
2. Pacific salmonids
3. Resident fish
4. Water quality
5. Ecosystem processes

C. Supporting Components and Indicators for Identified Attributes

Attribute 1 – Habitat Mosaic - participants reviewed the approach by the Estuary Partnership in undertaking a historic versus current habitat change analysis. To undertake the comparison, a cross-walk was created between the two datasets so that we could do a true comparison (compare "apples to apples"). Habitats were lumped into the following classes:

- Forested
- Non-tidal forested wetland
- Tidal forested wetland
- Herbaceous
- Non-tidal herbaceous wetland
- Tidal herbaceous wetland
- Shrub scrub
- Non-tidal shrub scrub
- Tidal shrub scrub
- Tidal flats
- Deep water
- Other (bare ground)

Workshop participants recommended including additional indicators under this attribute:

- Aquatic areas that support specific life stages:
    - Spawning habitats
    - Cold water refugia

    - Rearing habitats
    - Shallow, slow velocity
- Site or landscape specific mosaic, gradient along channel/slough; channel complexity, elevation gradient; description of this per reach;
- Landscape metrics, patch size, across lower river, averages

Next Steps: Consider creating numeric management targets per habitat or ratio of habitats per geographic area. Consider creating qualitative site and landscape specific mosaic targets.

Previous related work: In 2011 the Science Work Group identified those habitats that represented >10% of the cover for an individual reach. For those, the SWG prioritized habitats that suffered significant decreases in coverage (>25%), and further prioritized the habitats by severity of loss (i.e., the greater % loss, the higher the ranking). The SWG gave even greater weight to those habitats if there was a total loss or very little remaining habitat, as shown in the 2010 landcover dataset. Finally, the SWG reviewed "rare" habitats (i.e., those habitats that had <10% cover for an individual reach), and prioritized those habitats that suffered significant relative decreases (e.g., shrub scrub). Based on these considerations, the SWG identified the following habitats as priority by location (in order):

Table 2. Habitats identified as priority for protection and restoration by River Reach (top) and for which River Reaches the habitat is a priority (bottom).

River Reach	Priority Habitats
A	1. Tidal herbaceous wetland, 2. Tidal wooded wetland
B	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
C	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
D	1. Tidal herbaceous wetland, 2. Tidal wooded wetland, 3. Forested, 4. Herbaceous
E	1. Herbaceous, 2. Forested, 3. Shrub scrub, 4. Tidal herbaceous wetland
F	1. Forested, 2. Herbaceous, 3. Non-tidal herbaceous wetland, 4. Shrub scrub
G	1. Forested, 2. Herbaceous, 3. Tidal herbaceous wetland
H	Non-tidal wooded wetland

Priority Habitat	Relevant River Reaches
Tidal herbaceous wetlands	A – E, G
Tidal wooded wetland	A - D
Forested	A, D - G
Herbaceous	D - G
Shrub scrub	E, F
Non-tidal herbaceous wetland	F
Non-tidal wooded wetland	H

The SWG identified tidal herbaceous wetland, forested, tidal wooded wetland and herbaceous classes as priority for protection for the entire lower river (see Estuary Partnership 2012, Sections 2 and 6, for more details).

Attribute 2 – Pacific salmonids – in the data exercise break out, small groups were requested to identify supporting components and indicators of biological requirements for salmonids in the estuary. One group categorized their indicators into the following components: access to good quality habitat; food availability and quality; safety (health, fitness, survival, etc). When reconvened, workshop participants considered this and modified it into the following components: habitat opportunity; habitat capacity (food availability and quality); safety; and realized function. Indicators for each component are listed in Table 3.

Table 3. Supporting components and indicators for Pacific salmonid attribute.

Habitat opportunity	Capacity - food availability & quality	Safety	Realized function
Connectivity: to site for most ESUs	WQ: T, DO, pH, salinity, velocity, depth, contaminants, prey, other fish composition, vegetation composition & cover	WQ: T, DO, pH, salinity, velocity, depth, contaminants, other fish composition, vegetation composition & cover	Survival, residence time, growth, foraging success
Inundation	Complexity: Natural channel edge riparian habitats, LWD, pool ratio, Mix, natural habitat mosaic at site and landscape scale	Health – few parasites and pathogens	Fitness – genetic diversity
Coverage and distribution of habitats across landscape	Size of habitat (stability, resilience)	Refuge from predators	
	Indirect benefits from habitats (shading, LWD, predation, OM)		

Invasive species	Invasive species	Invasive species	

One aspect that participants wanted to capture for the indicators was the concept that these likely are of equal importance and we might not want to prioritize them. Any one of these could be a limiting factor that precludes access to habitats. In other cases, such as the capacity or safety components, salmonids might have access to habitats that decrease or threaten their fitness or performance.

Next Steps: Revisit “safety” indicator category. Consider integrating habitat opportunity and capacity indicators into management targets for Attribute 1. Consider using OR and WA recovery plans for identifying numerical targets when applicable. Consider state standards for not-to-exceed water quality thresholds with temporal considerations as targets. Others?

Previous related work: See Attribute 1. State standards have been developed for temperature, dissolved oxygen and other water quality metrics. See Attributes 3 and 4.

Attributes 3 and 4 – Resident Fish and Water Quality – Due to time constraints, these attributes were not fleshed out at the workshop. The Estuary Partnership will host follow up focus groups to define these in more detail. A lot of work for the Water Quality attribute has been accomplished through the EPA Toxics Reduction Working Group and will be integrated as appropriate, whereas the Northwest Power and Conservation Council (NPCC) sub-basin plan (NPCC 2004) can be used as a foundation for the resident fish attribute.

Attribute 5 – Ecosystem Processes – workshop participants identified key ecosystem processes and indicators in the first break out session. These are as follows:

Natural Hydrologic Processes and Sediment Dynamics

- Timing, magnitude, duration, frequency, rate of change
- Recurrent, frequent flooding of floodplain, including freshet
- Sufficient bed material transport to facilitate bar formation and channel migration; dynamic channel migration, wider mouth, more sediment transport to the nearshore ocean
- Sufficient suspended material transport to enable widespread floodplain deposition
- Sufficient material transport of large woody debris and organic matter
- Connectivity between ecosystem types to mainstem, floodplain; fish opportunity
- Plume dynamics
- Natural stream bank processes such as erosion

Food web and trophic processes

- Local production of macrodetritus, transported by flows/connectivity to mainstem; vascular plants/macrodetritus – based food web
- Natural trophic cascades
- Natural habitat capacity
- Natural water properties such as nutrients, pH, DO, chlorophyll, turbidity
- Little invasive species impact on food web

- Natural inter and intra competition and predation amongst species

Habitats and habitat forming processes

- Natural habitat distribution and abundance - balance
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- Shallow water sloughs and channels -- high productivity, cold water refugia.
- LWD trapping sediment, seeding, nurselogs
- Beaver dams/ponds – prevalent
- Natural barriers
- Natural stream bank processes such as erosion
- Abundance of riparian for nearshore cooling

Next Steps: Consider threshold ranges for optimal timing, magnitude, frequency, duration, rate of change for flows in mainstem at 3 locations (Bonneville, Vancouver and Beaver Army Terminal). Consider integrating floodplain inundation targets for habitat mosaic in Attribute 1. Consider creating not-to-exceed water quality thresholds, with temporal considerations as in Attribute 2. Others?

Previous related work: Review hind cast model predictions for historic flows in Bottom et al. (2005) and other work (D. Jay) for use in developing optimal flow thresholds (see Appendix II for examples). See Attributes 1 and 2.

D. Discussion

Several participants recommended that we build upon previous work of the NPCC in the sub-basin plans. In 2004, the Estuary Partnership and Lower Columbia Fish Recovery Board (LCFRB) developed a lower Columbia River sub-basin plan for the NPCC which includes the identification of indicator species and broad categories for their use (see LCREP and LCFRB 2004). The plan identifies focal species, species of ecological interest, species of management interest and species of recreational interest (Table 4). The plan primarily focuses on the focal species and their habitat needs but discusses the other three categories as important to track as indicators to assess ecosystem condition, represent specific habitats and integrate in resource management programs. Revisiting these and integrating the work previously accomplished by the NPCC with the indicators identified above should be an important next step.

According to NPCC 2004, focal species in the sub-basin plan were selected based on:

- Status under the Endangered Species Act
- Cultural, ecological and local importance of the species
- Level of information available about the species allowing an effective assessment
- Life history strategies representative of the *use* of the mainstem lower Columbia River Subbasin

Table 4. Focal Species and Other Indicator Species Identified through NPCC Sub-basin Plan (adapted from NPCC 2004)

Species	**ESA**	**Ecological**[1]	**Cultural**	**Economic**[2]	**Recreation**[3]
Species of Primary Interest (Focal Species)					
Chinook	X	X	X	X	

Chum	X	X	X	X	X
Steelhead	X	X	X	X	X X
Coho	X	X	X	X	X
Pacific Lamprey	X	X	X		
Bald Eagle	X	X	X		
Columbia White-Tailed (CWT) Deer	X	X	X[4]		
Green Sturgeon		X	X		
White Sturgeon		X	X	X	X
Species of Ecological Significance					
N. Pikeminnow		X		X[8]	X
Shad		X[7]		X	X
River Otter		X[9]			
Eulachon		X	X	X	X
Caspian Tern		X[6]		X	
Osprey		X			
Yellow Warbler		X[10]			
Red-eyed Vireo		X[10]			
Species of Management Interest					
Dusky Canada Goose				X[5]	
Sandhill Crane	X			X[5]	
Species of Recreational Significance					
Walleye		X[7]			X
Smallmouth Bass		X[7]			X
Channel Catfish		X[7]			X

[1] May be positive or negative ecological impact; this column only indicates relative significance.
[2] May be positive or negative economic impact; this column only indicates relative significance.
[3] Active recreation potential (e.g., harvest).
[4] Likely ecologically important historically.
[5] Seasonal crop damage.
[6] Historically not present in estuary at current numbers.
[7] Non-native species.
[8] Some economic importance for control program.
[9] Indicator of ecosystem health.
[10] Indicator of habitat type.

The definitions and uses of the four categories of species were defined as follows (see NPCC 2004: Chapter 2)

- ***Species of Primary Interest (Focal Species):*** This category receives the highest level of attention. The ocean-type and stream-type salmonids play a major role in structure and content of the subbasin assessment because of their importance to all of the selection criteria, the absence of management plans in the estuary/mainstem, and the far-reaching implications of their life cycle requirements to various landscape-level processes and habitat conditions within and outside of the subbasins. Well-developed recovery or management plans exist for bald eagle, CWT deer, Pacific lamprey, and green/white sturgeon.

- ***Species of Ecological Interest:*** This category is intended to represent the general health of the mainstem in terms of quality of the environment, habitat diversity, or management issues. Native species include: Northern pikeminnow, river otter, eulachon, Caspian terns, osprey, yellow warbler, and red-eyed vireo; non-native species include shad.
- ***Species of Management Interest:*** This category of species is important from a management perspective and is indicative of a habitat type that is not represented elsewhere (e.g., agricultural lands).
- ***Species of Recreational Interest:*** This category of non-native species has recreational interest in the mainstem, as well as poorly understood ecological interactions with salmonids.

NPCC 2004 also describes habitat needs of the focal species and identifies biological and physical objectives and numerical targets in some cases. For the relevant attributes identified through this workshop, NPCC 2004 should be used as a basis for developing numerical targets under this indicator process and updated where appropriate.

Additionally, no upland or terrestrial attributes were identified through this workshop, although these habitats and associated species are important for assessing ecosystem condition. Focal and other species identified through the NPCC 2004 process should be used as a starting point to identify an upland/terrestrial attribute(s) for inclusion in the indicator system.

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1. Are Columbia River Basin fish and wildlife abundant, diverse, productive, spatially distributed, and sustainable?
2. Are Columbia River Basin ecosystems healthy?
3. Is climate change affecting fish and wildlife in the Columbia River Basin?

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Appendix I

Breakout Group 3 Notes

Time frame for non-anthropogenic effects = pre-industrialization, mid 1800s.

Do the parameters have to have been measured in the min disturbed state? Not nec. Need to know what they probably were in the min disturb state.

Stressors
Flow regulation -- pre-dam
Dredging - no dredging.
Barriers -- all natural, no manmade
Invasive spp - few
Toxics -- minimal
Oc cond's -- sea level not static, ocean not acidifying,

Ecosystem Controlling Factors
Flow regime/hydrograph -- pre-dam hydrograph. Grand Coulee piece on OPB. Unregulated flow. No water withdrawals.
Thermal regime/water temperature -- max water temperatures on a yearly scale and time distribution of temp. Max temp's later in summer and not as high as now.
Water quality -- pH is less acidic, D.O. good, chlorophyll lower, turbidity lower
Contaminant/pollutants/toxics regime -- minimal or none. Erosion introduces naturally occurring contaminants.

Ecosystem structures
Wetland marshes, swamps, etc. -- see historical condition in Keith's maps
Habitat diversity -- high diversity, presumably.
Invasive plant species -- few and far between
Shallow water sloughs and channels -- high productivity, cold water refugia.
Beaver dams/ponds -- prevalent

Ecosystem processes
Sediment regime -- more floodplain deposition, more sediment transport to the nearshore ocean. Less stream bank erosion.
Channel dynamics regime - restricted from moving around because of hardened shorelines and levees, undisturbed is unrestricted.
Flux regime -- Nutrient and organic matter flux from floodplain to main stem-- undisturbed is a macro-detritus based food web.
Landform regime -- unrestricted a, pre-Corps, no channelization, no pile structures, levees, rip-rap.
Competition -- no hatchery fish
Fish and animal community structure -- fewer invasives, xxx
Primary production -- vascular plant prod'n more than phyto

Ecosystem functions
Energy flux -- marine derived nutrient to u/s watersheds
Salmon ELHD -- high ELDH

Appendix II

Introduction to the lower Columbia River and estuary

A. Processes and patterns that drive ecosystem structure and function

The geographic scope of the lower Columbia River study area includes the tidally influenced portion of the mainstem; from Bonneville Dam (River Mile [RM] 146) to the mouth of the Columbia River. The study area includes the lower portion of the Willamette River up to Willamette Falls (RM 26.6), along with the tidally influenced portions of all tributaries below Bonneville Dam.

The Columbia River estuary is a drowned river estuary, the dominant type of estuary along the Pacific coast. It was formed by the river valley flooding during sea level rise after the last ice age, and differs from the fjord-type estuaries formed through glaciation (e.g., Puget Sound), lagoonal estuaries resulting from flat topography and low freshwater inflows (e.g., Humboldt Bay) or rare, bar-built (Tillamook Bay) estuaries (Emmett et al., 2000). The historical surface area is estimated to have been approximately 186 square miles, while the current surface area is approximately 159 square miles (NMFS, 2011).

The Pacific Northwest has a Mediterranean climate (i.e., wet, cool winters and warm, dry summers). Most precipitation falls from October thru May, while June thru September months are dry. Mountain and glacier snow melt from interior B.C. and U.S. cause high freshwater inflows to the estuary in May and June and moderately high flows can also occur between November and March, caused by heavy winter precipitation. Columbia River discharge now typically ranges from 100,000 to 500,000 cubic feet per second (cfs), while unregulated historical flows ranged between 79,000 to 1 million cfs (NMFS, 2011).

Much of the Pacific Northwest geomorphology results from the North American Plate moving north-northwest against Juan De Fuca and other Plates, producing a subduction zone and the rugged topography including the Olympic, Coast Range, Klamath and volcanically active Cascade Mountains (Emmett et al., 2000). This rugged topography then creates the orographic precipitation patterns of a relatively wet coastal region and dry, desert conditions east of the mountain ranges.

Finally, the California Current is a slow moving southerly current off the Pacific coast. It is most dominant in summer when northwest winds are typical, while in winter, southwesterly winds cause an inshore counter-current to develop. The summer ocean upwelling carries cool, deep, nutrient-rich water to the surface. With the addition of sunlight, the nutrient-rich waters stimulate growth of phytoplankton populations (primarily diatoms); primary production is then closely linked to the ocean upwelling conditions. Tidal exchange transports associated flora and fauna into the lower Columbia River estuary where organisms such as Dungeness crab and salmonids take advantage of these conditions. For example, Dungeness crab spawn in the winter, larvae are retained nearshore, and juveniles move into the estuary to rear. Many salmonid stocks spawn in the tributaries during fall or winter, and juveniles migrate to sea in spring/summer just before or during the productive upwelling period (Emmett et al., 2000).

B. Historical Changes to the Lower Columbia River

The Columbia River is the 4th largest watershed in the U.S., draining 259,000 square miles and traveling 1,200 miles from its headwaters in the Canadian Rockies to its outlet at the Pacific Ocean. Since the 1930s anthropogenic impacts include the construction of >30 mainstem dams and more than 45 smaller flow control structures on tributaries for hydropower, flood control, irrigation and transportation. Freshwater is also diverted to irrigate arid lands in eastern Washington and Oregon for large-scale agricultural production. Water management through dams and maintenance of the navigation channel through dredging and pile dike construction allow deep-water ports inland as far as Lewiston, Idaho.

River flow, a primary factor affecting juvenile salmon performance and habitat use patterns in the estuary and plume, has been significantly modified by operations of the Federal Hydropower System, including reducing the mean annual flow, reducing the size of spring freshets, almost completely eliminating overbank flows, and changing the timing of ecologically important flow events as well as habitat forming processes (Bottom et al., 2005; Fresh et al., 2005). These hydrological changes, along with floodplain diking and navigation channel maintenance, represent a fundamental shift in the physical state of the lower Columbia River ecosystem, and have resulted in a loss of vegetated and shallow water habitats and changes in the size, seasonality, and behavior of the plume (Bottom et al., 2005; Fresh et al., 2005). Changes include significant losses of emergent marsh, tidal swamp, and forested wetlands; shifts in organic matter important to estuarine food webs; and changes in features of the plume. Large scale floodplain diking has severed the historic connection of habitat with the river, eliminating any direct use ("habitat opportunity") and reducing indirect (e.g., export of organic matter for food webs) benefit to the fish (Fresh et al., 2005). Low velocity, peripheral bay habitats and the mid-estuary estuarine turbidity maximum are locations in the lower river where organic matter is concentrated and where invertebrate prey production and fish and macroinvertebrate feeding are higher than many other locations (Bottom and Jones, 1990; Jones et al., 1990; Simenstad et al., 1990). Researchers hypothesize that the loss of these historic wetlands and macro-algal habitats (e.g., mud and sand flats) within the estuary may have shifted estuarine food chains from macrodetrital to microdetrital sources (Sherwood et al., 1990). Such a shift would likely benefit food chains supporting pelagic-feeding fishes such as American shad (*Alosa sapidissima*) with corresponding loss of food webs supporting epibenthic-feeding fishes such as juvenile salmon (Bottom et al., 2005). Shallow water-dependent life history strategies ("ocean-type") will have been most affected by these changes within the estuary, while larger life history strategies (i.e., "stream-type") will have been most affected by changes in the plume (Fresh et al., 2005). These changes could have significant consequences for both the expression of salmonid diversity and productivity.

Additionally, exposure to waterborne and sediment-associated chemical contaminants has the potential to affect survival and productivity of all anadromous stocks in the estuary (Fresh et al., 2005; Johnson et al., 2007; LCREP, 2007). The type and extent of exposure may vary with life-history type. For "stream-type" salmonids that move through the estuary quickly, short-term exposure to waterborne contaminants such as current use pesticides and dissolved metals may be the greatest threat, as these chemicals can disrupt olfactory function and interfere with behavior such as capturing prey, avoiding predators, imprinting, and homing for stream-type ESUs (Fresh et al., 2005). Stocks that use the estuary extensively (i.e., ocean-type ESUs) may be exposed to these types of contaminants as well as persistent, bioaccumulative toxicants such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and DDTs that they may absorb through feeding and rearing in the estuary (Fresh et al., 2005; LCREP, 2007; Johnson et al., 2007; Sloan et al., 2010). Chronic exposure to and accumulation of these chemicals in tissues can lead to effects such as reduced growth, immune dysfunction, and metabolic disorders that may lessen an outmigrant's chance of survival (Meador et al., 2002; Arkoosh et al., 2001; Arkoosh and Collier 2002; Arkoosh et al., 2010).

Limiting factors and threats to juvenile salmonids (from Estuary Recovery Plan Module [NMFS, 2011]):

Limiting factors include the following:

1. **Habitat-Related Limiting Factors**
    - Reduced in-channel habitat opportunity
        - Flow-related estuary habitat changes
        - Sediment/nutrient-related estuary habitat changes
    - Reduced off-channel habitat opportunity
        - Flow-related changes in access to off-channel habitat
        - Bankfull elevation changes
    - Reduced plume habitat opportunity
        - Flow-related plume changes
        - Sediment/nutrient-related plume changes
    - Water temperature
    - Stranding
2. **Food Web-Related Limiting Factors**
    - Food Source Changes
        - Reduced macrodetrital inputs
        - Increased microdetrital inputs
    - Competition and Predation
        - Native fish
        - Native birds
        - Native pinnipeds
        - Exotic fish
        - Introduced invertebrates
        - Exotic plants
3. **Toxic Contaminants**
    - Bioaccumulation toxicity
    - Non-bioaccumulative toxicity

Threats include the following categories:

- flow, including climate change;
- sediment, including entrapment of fine sediment in reservoirs, impaired transport of coarse sediment and dredging; structures such as pilings, dikes and filling;
- reservoir-related temperature changes and over-water structures such as docks and jetties;

- food web (including species relationships), including increased phytoplankton production, altered predator/prey relationships and ship ballast practices that introduce exotic invasive species;
- water quality, including those resulting from agricultural, urban and industrial practices;
- riparian practices and
- ship wakes

In order of priority, threats are listed as follows:

- Flow regulation
- Dikes and filling
- Altered predator/prey relationships
- Urban and industrial practices
- Agricultural practices
- Impaired transport of coarse sediment
- Pilings and pile dike structures
- Reservoir-related temperature changes
- Riparian practices
- Climate cycles and global climate change
- Water withdrawal
- Dredging
- Entrapment of fine sediment in reservoirs
- Ship wakes
- Increased phytoplankton production
- Over-water structures
- Ship ballast practices

C. Considerations for target habitat mosaic conditions

The following figures and table are for illustrative purposes and for consideration in discussions at the workshop. We have not contacted authors for permission to reprint.

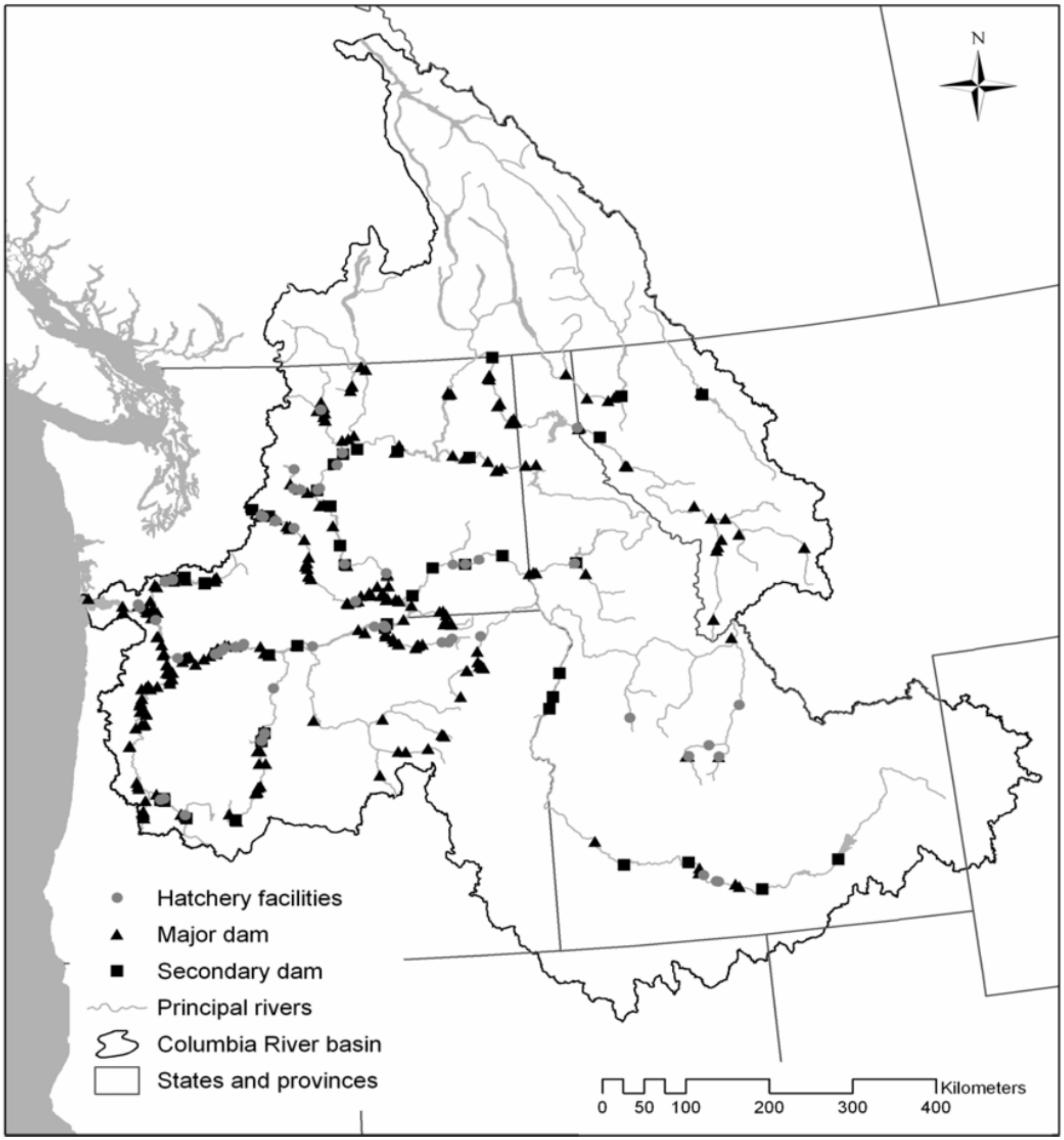


Figure 3. Present distribution of salmon hatcheries and mainstem and secondary dams (StreamNet 2003) (copied from Bottom et al., 2005)

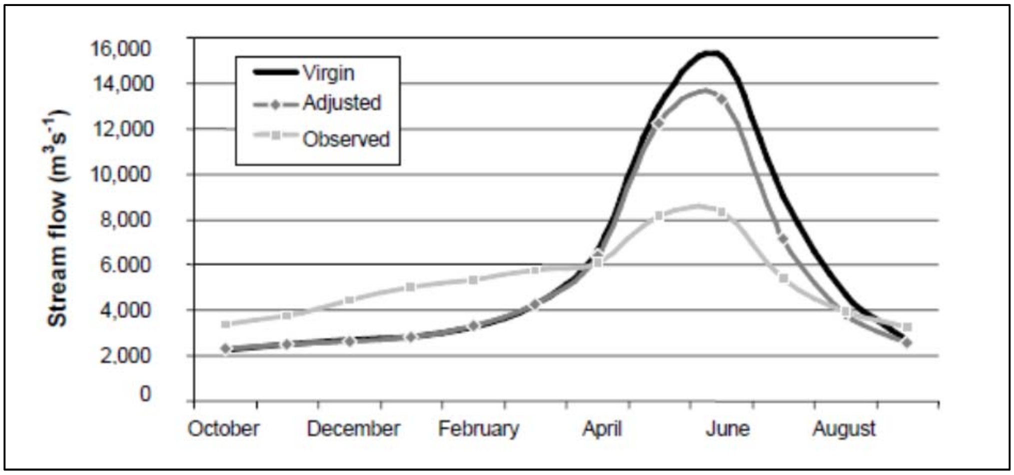


Figure 4. Comparison of the monthly averaged Columbia River eastern subbasin virgin, adjusted, and observed river-flow estimates from 1970 to 1999. Flow regulation and irrigation depletion decreased spring and summer flows (May to August), while fall and winter flows (September to March) increased. (copied from Bottom et al. 2005.)

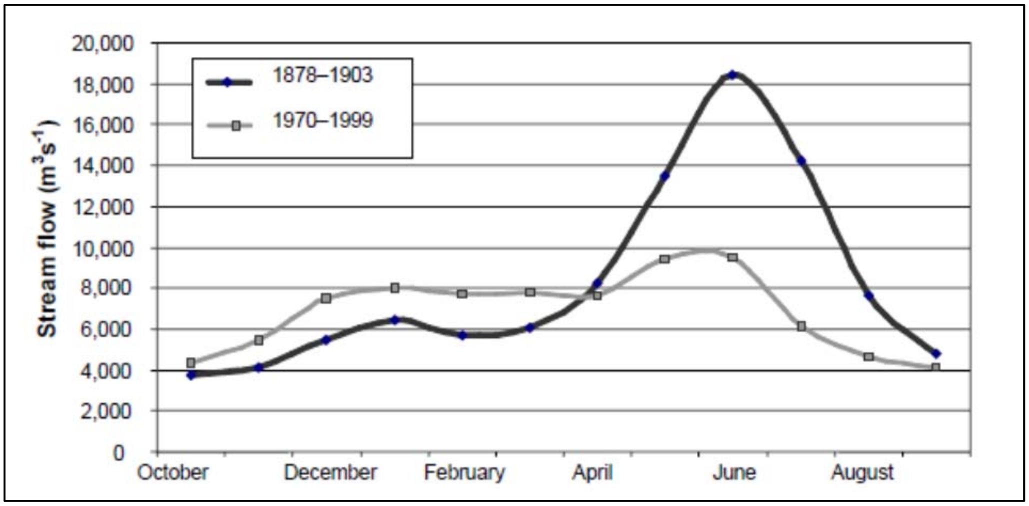


Figure 5. Changes in the annual Columbia River flow at Beaver Army Terminal, near Quincy, Oregon, 1878–1903 versus 1970–1999. (copied from Bottom et al. 2005.)

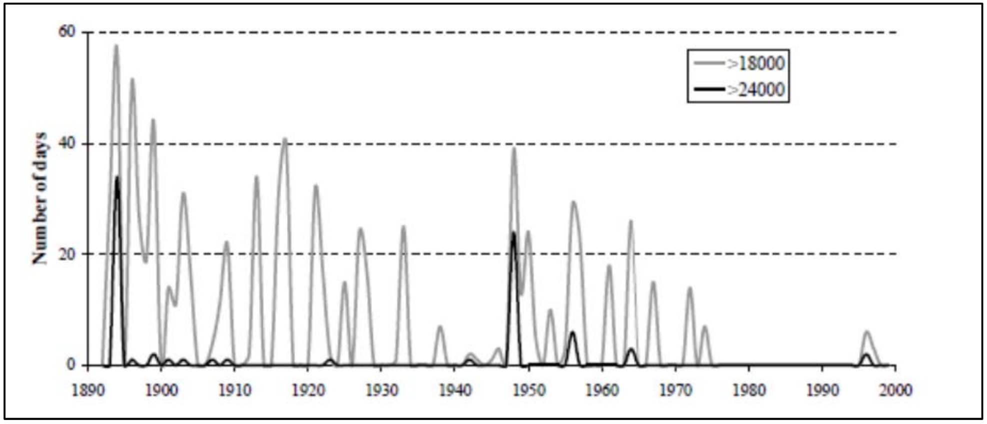


Figure 6. The incidence of flows above 18,000 m3s-1 (the pre-1900 estimated bankfull flow level) and above 24,000 m3s-1 (the present bankfull flow level). The present bankfull flow level has been exceeded only five times (twice in 1956) in four years since 1948. (copied from Bottom et al., 2005)

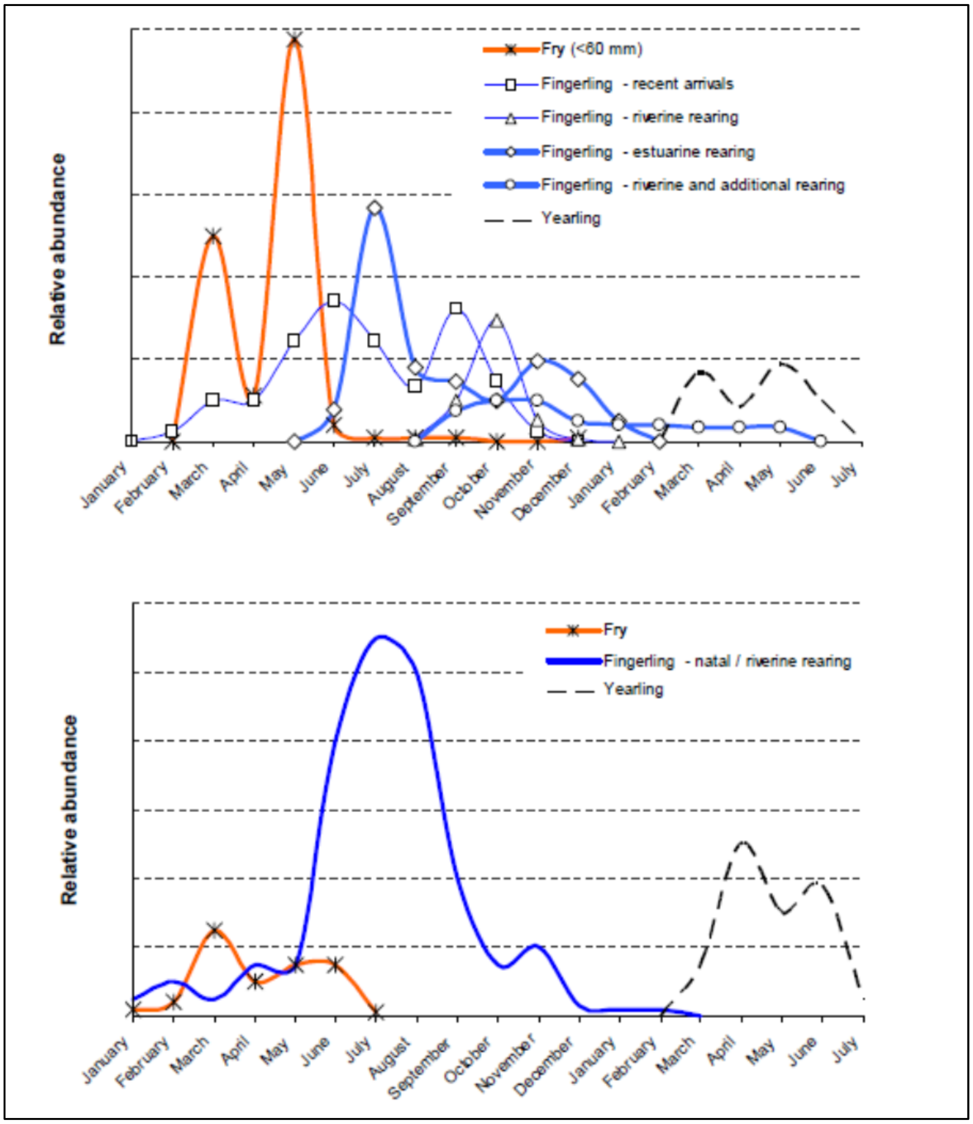


Figure 7. Historical and contemporary early life history types for one broodyear of Chinook salmon in the Columbia River estuary. Historical timing and relative abundance (top) inferred from historical sampling throughout the lower estuary (Rich 1920). Contemporary timing and relative abundance (bottom) derived from Dawley et al. (1985) sampling at Jones Beach. (Adapted from Burke 2005.) (copied from Fresh et al., 2005)

Habitat Opportunity

Bottom et al. defined habitat opportunity as the capability of juvenile salmon to access and benefit from occupying a habitat (Table 2 lists factors encompassing opportunity).

Table 5. Factors affecting estuarine-habitat opportunity for juvenile salmon (taken from Bottom et al., 2005)

Physical	**Physiological/ behavioral**	**Water characteristics and quality**	**Ecological**
Tidal flooding Depth Duration Fluvial flooding	Water velocity Turbidity	Temperature Salinity Dissolved oxygen Turbidity	Proximity to disturbance (e.g., noise, movement, etc.)

Frequency Depth Duration Timing Distributary and tidal channel structure		Toxicants	Refugia from predation (e.g., extent of overhanging vegetation, marsh vegetation height, proximity to deepwater habitats)

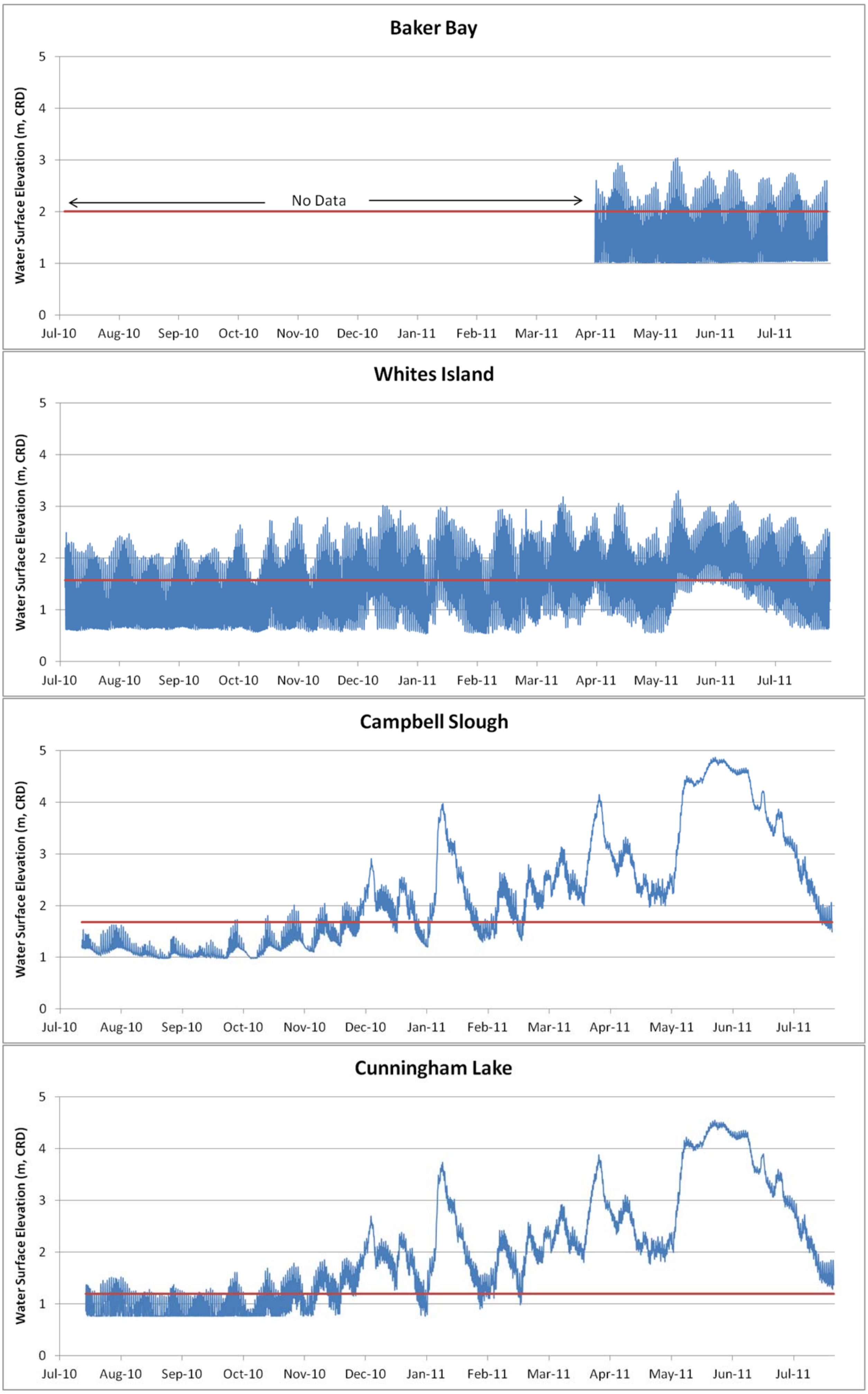
Habitat capacity

Bottom et al. defined habitat capacity as “those habitat qualities that promote juvenile-salmon production, including conditions necessary for feeding, growth, growth efficiency, and eluding predators…” These include:

- “productivity of selected invertebrate prey, including quantity and availability,
- physicochemical and ecological conditions that maintain prey production,
- salinities and temperatures that promote high assimilation efficiencies, and
- predation levels as affected by habitat structure and relative vulnerability of salmon (e.g., refugia in vegetation or shallow water) as well as the habitat attributes of predators”. (Bottom et al., 2005)

Tidal Freshwater Wetland Habitats Water Elevation Data

(from Ecosystem Monitoring Program)



Baker Bay

Whites Island

Campbell Slough

Cunningham Lake

Water surface elevation data from the study sites where sensors were deployed 2010-2011.
Red line marks the average marsh elevation at each site.