**Evaluating Cumulative Ecosystem Response of the Columbia River Estuary Ecosystem to Past and Current Restoration Efforts**

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If ecosystem restoration is to continue to be pursued, we need to know if restoration efforts are effective in meeting their goals. In the Columbia River estuary (CRE), there are three basic questions relative to the effectiveness of restoration, as follows: 1) Are individual projects meeting their local performance objectives? 2) Is the multitude of efforts adding up to produce an improvement in the broader estuarine ecosystem? 3) Are the local and cumulative ecosystem improvements helping salmon? Obviously, the complexity and uncertainty associated with answers to these questions increases as one moves from question #1 to question #3, as does the importance of the answer relative to salmon in the CRE.

An ecosystem-based approach for restoration was developed in 2003, which formed the basis for a framework employed since 2007 to prioritize proposed restoration projects. The prioritization framework is under further development to improve its ability to incorporate the latest science to better inform decisions based on issues such as which genetic stocks most benefit from estuarine habitats. A reference site program and habitat monitoring program are underway, which both help in the design of projects as well as assess factors contributing to natural variation in project outcomes. Finally, there is a draft adaptive management plan for ecosystem restoration that can be used to capture learning, and inform plans for new restoration projects and conservation actions. This plan is also effective in capturing results of new research findings and immediately putting those findings into action.

Over the past five to 10 years or so, the focus has grown on the estuary as a place where salmon populations could benefit from restoration. There is a developing suite of activities that, when taken together, form the genesis of an integrated estuarine restoration program that should have direct benefits to salmonid populations. These activities include:

- Studies providing the scientific underpinnings of the role of estuarine habitats in supporting early-life history stages of salmon,
- Technologies to track the movement of very young salmon,
- Site specific studies on salmon occurrence and feeding in restored systems,
- Studies on changes in factors that salmon respond to such as temperature, and prey production and availability in restored systems,
- Development of a framework to quantify the role of the cumulative effect of restored sites on the broader estuary ecosystem and salmon.

The goal of the Corps-funded research during 2004-2009 was to develop and begin to implement an evaluation of the cumulative effects of multiple habitat restoration actions in the lower Columbia River and estuary. Because we could find no studies that

explicitly attempted to assess cumulative effects of restoration projects on an ecosystem benefitting fish, we developed a "levels of evidence" approach. In this approach, field-collected and modeled data are analyzed additively for net ecosystem improvement; hydrodynamic model outputs and meta-analyses are examined for synergistic effects; and predictive ecological relationships between structure and function are developed relative to hydrology, vegetation, and fish. Synthesis of these three lines of evidence forms the basis for the cumulative effects evaluation. The program requires input from multiple projects and practitioners in the system. Thus, to facilitate comparison of monitoring data across restoration projects, we established a protocols manual for standardized monitoring of physical and biological metrics. Monitored indicators include water depth and temperature, channel geometry, vegetation and elevation surveys, above-ground biomass, fish species composition and abundance. During 2005 through 2009 field studies, baseline and post-restoration data were collected on restoration sites and associated reference sites, including brackish marsh and tidal freshwater swamp habitats that have sustained substantial areal losses due to flood control, hydropower and water withdrawals. Information on the cumulative effects of ecosystem restoration actions will provide the Region with predictive capabilities to help design the best projects to meet program goals, as well as highlight uncertainties and ways to modify approaches within an adaptive framework.

As an example from our research, we examined linear and synergistic relationships in dike-breach restoration scenarios on the tidal portion of the Grays River, a tributary of the Columbia River estuary. The purpose was to improve the efficacy of suites of projects designed to provide habitat for endangered anadromous fishes. We used data from a hydrodynamic model to test the hypothesis that the cluster size of hydrological reconnection projects has a nonlinear effect on the area of floodplain inundation and available habitat, under both even and uneven spatial configuration scenarios.

Findings and products to date developed in the cumulative effects studies are:

1. An estuary-wide habitat monitoring protocol that can be used by all restoration projects to collect similar data sets on their performance
2. Proof of frequent and prolonged juvenile salmonid use of restored systems
3. Proof of salmonid prey production in restored systems
4. Evidence of improved water quality (i.e., lower temperature) in restored systems
5. Evidence of production and export of marsh macrodetritus from the restored systems to the broader estuary (thus restoring a major process lost over the past century)
6. Evidence of initiation of nutrient processing and dissolved organic matter export from restored systems
7. Evidence of reformation of natural tidal channel morphology
8. Evidence of resumption of sediment accretion process to enhance the rate of habitat recovery
9. Data indicating the rate of habitat change is rapid over the first five years for emergent wetland systems, but full recovery of tidal forest swamps will take many decades

10. Establishment of full tidal hydrology reconnection is generally more effective than muted reconnection
11. Development of a method to predict cumulative effects now and in the future
12. Modeling proof of potential synergistic effects and optimization of multiple restoration projects on wetted area
13. Development of a draft adaptive management plan for ecosystem restoration in the CRE.

At the recent National Conference on Ecosystem Restoration, the CRE was listed as among the top seven or eight ecosystem-based restoration programs in the country. The CRE program is under scrutiny by the Chief of the USACE as well as the Office of Management and Budget, and the Administration. The message from the Administration through OMB is that programs that are both ready and 'good' will receive continued funding. The rarely stated working hypothesis is "restoring historical, and conserving existing, shallow water habitats and landscapes will result in the increased fitness and survival of young salmon and thus increase salmon populations." In smaller systems it has been demonstrated that restoring the ecosystem components that salmon utilize does benefit populations. However, the scale of the CRE is large and complex making the resolution of the response of salmon populations to multiple small actions difficult. To resolve the response requires:

- A more concentrated and coordinated effort which includes effectiveness monitoring of restored sites,
- Quantification of the realized function of these sites to young salmon,
- Monitoring of adult returns in a strategic manner, and
- Focused, feasible adaptive management to validate and improve predictive models and thus maximize the effectiveness of future efforts, and produce 'good' projects worthy of continued investment.

There is an opportunity for the CRE to demonstrate to the country how ecosystem restoration can successfully and efficiently recover endangered species.