A LANDSCAPE APPROACH TO PLANNING RESTORATION AND CONSERVATION OF ANADROMOUS FISH HABITAT ACROSS A COMPLEX ESTUARINE MOSAIC: APPLICATIONS TO LONG-TERM MONITORING AND SALMON RECOVERY

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Abstract: Most ecosystem restoration opportunities ostensibly fulfill a broad ensemble of desirable ecosystem goods and services. However, the urgency and efficacy required to restore threatened and endangered species habitat is not well served by ad hoc, opportunistic approaches to restoration and conservation. Strategic planning is critical, especially in the case of juvenile anadromous fishes that must adapt to estuarine landscape mosaics of varying spatial and temporal habitat availability and quality as they migrate to the coastal ocean from their natal watersheds. We are developing a landscape ecology-based, geospatial approach to enable strategic planning for restoration and preservation of juvenile Pacific salmon (Oncorhynchus spp.) habitat in the 233-km Columbia River estuary. The Landscape Planning Framework adapts the structure and geodatabase of the hierarchical Columbia River Estuary Ecosystem Classification (Classification) to identify and compare spatially-explicit restoration and preservation sites that would most likely benefit unique, at-risk genetic stocks of Columbia River salmon. We merge geomorphic and land cover data from the Classification to delineate aquatic habitat area, called fish habitat catena, based on the existing scientific data on estuarine habitat requirements of juvenile Chinook salmon (Oncorhynchus tshawytscha). Using landscape metrics to quantify the structure, composition, distribution and organization of existing and restorable fish habitat catena under different hydrologic regimes, the Framework will allow managers and practitioners to strategically identify and rank the types and locations for optimum habitat restoration and conservation of different genetic salmon stocks.

Keywords: Estuaries; Pacific Salmon (Oncorhynchus spp.); identifying appropriate conservation and restoration objectives; endangered species habitat

Introduction

Ecosystem restoration can often enhance ecosystem goods and services through opportunistic, dispersed deployment of actions, under the classic “build it and they will come” supposition (Palmer et al. 1987). However, restoration to address the habitat requirements of migratory species through complex landscapes requires a much more strategic approach, that is specifically designed to conserve populations or metapopulations of a species that display varying habitat requirements over space and time (Lambeck and Hobbs 2002). The Columbia River Landscape Planning Framework (LPF) is a landscape ecology-based, geospatial approach to enable strategic planning for restoration and preservation of juvenile Pacific salmon (Oncorhynchus spp.) habitat in the 233-km Columbia River estuary. It is designed as a Geographic Information System (GIS) framework to identify and rank areas of the estuary that do or could provide the most habitat benefit to diverse genetic stocks (Evolutionary Significant Units, ESU) of salmon migrating through and rearing in the estuary. The LPF is initially being designed to address juvenile Chinook salmon (O. tshawytscha) habitat because their ocean-type life history forms tend to be the most dependent on estuarine habitat and because their populations are depleted in the Columbia River basin to the point that five ESU are listed under the US Endangered Species Act (Bottom et al. 2005; Teel et al. 2014).

We analyze the Columbia River Estuary Ecosystem Classification (“Classification”; Simenstad et al. 2011) geospatial data to delineate fish habitat catena that are derived from the Classification’s geomorphic catenae (Level 5; Fig. 1). A fish habitat catena is a unique set of landscape features (i.e., geomorphic catenae) and other characteristics (such as landcover classes) that describes geomorphic and other characteristics of beneficial habitat for juvenile salmon. Fish habitat catenae have been defined by the project team based on current scientific understanding of how juvenile salmon use estuarine habitat and serve as the basis from which spatial attributes of habitat, such as size, shape, and edge density, are quantified. Quantification is possible because fish habitat catenae are derived largely from the digitized ecosystem classification.

Our objectives are to: (1) use established and emerging science on juvenile salmon habitat requirements in estuaries (“scientific principles”) to identify individual and combinations of geomorphic catena that as fish habitat catena constitute restoration and conservation targets; (2) apply scientifically-based landscape metrics to quantify the structure, composition, distribution and organization of fish habitat catena; (3) analyze characteristics of fish habitat catena that constitute the most beneficial estuarine habitat for juvenile salmon (initially focused on Chinook salmon, O. tshawytscha) of different ESU; and, (4) establish baseline (“benchmark”) metrics, from historic and current reference fish habitat catena, that strategically identify and rank the types and locations of fish habitat catena of highest priority for restoration and conservation.

Because the LPF quantifies the expected increase in desirable attributes (large habitat patches, high habitat complexity, etc.) in different areas, results can be used to compare potential restoration or protection opportunities to each other, to average values for the geographical area of interest, to reference sites, or to...
assigned target values. Output of the analysis is presented as maps showing areas that offer the highest restoration and protection value for juvenile salmon, along with statistical data for each area (e.g., change in the amount of edge habitat). The landscape planning framework is intended to inform management decisions about where to focus efforts to protect existing habitat, restore missing links in the distribution of habitat, and improve the quality and connectedness of existing habitat.

Figure 1. Illustration of the derivation of “fish habitat catena” from the Geomorphic Catena level of the Columbia River Estuarine Ecosystem Classification (“Classification”).

Materials and methods

We developed the framework by identifying sets of aquatic and wetland features in the estuary that are believed to represent the best habitat conditions and landscape setting for discrete genetic stocks of juvenile salmon, that can then be analyzed to quantify the occurrence, distribution, size, and complexity of those features at the desired spatial scale. Our first step was to apply GIS rules to the Classification (Simenstad et al. 2011) geodatabase to delineate aquatic fish habitat catenae that juvenile salmon can directly occupy, as well as adjacent wetland areas that directly (e.g., shading that reduces water temperature) or indirectly (e.g., drainage of drift prey organisms) influence the quality of the fish habitat catena (Fig. 2). Based on the Classification’s attribution of human cultural features, infrastructure, and modification, we also identify fish habitat catenae that are “tidally impaired” (as compared to “open”) where natural tidal-fluvial flooding is regulated or isolated from and thus have potential for future restoration or enhancement (Fig. 3). In the Columbia River estuary, we have delineated seven general categories and 21 unique fish habitat catenae, including two landscape features of importance—channel confluences and the head of tide in tributaries to the estuary. Eight different types of wetlands mediate the quality of that habitat which juvenile salmon occupy when migrating through or rearing in the estuary. We are also developing GIS rules to identify potential locations of American beaver (Castor canadensis) habitat, which is known to benefit juvenile salmon in tidal wetlands (Hood 2012) and is expanding throughout the former range of this “ecosystem engineer”.

Once the fish habitat catenae have been categorized, their structural characteristics can be described and compared over different scales. We use spatial metrics generated by GIS-based (i.e., ArcGIS®; https://www.arcgis.com/) or independent landscape analysis software (e.g., FRAGSTATS®; http://www.umass.edu/landeco/index.html) to qualify the fish habitat catenae, which we can then use to compare across four scales, among: (1) fish habitat catenae; (2) ecosystem complexes (the Classification’s level 5 landscape scale); (3) local landscapes (e.g., large areas of surge plains); and, (4) hydrogeomorphic reach (the Classification’s Level 3 landscape scale). Based on current information on the habitat requirements of juvenile salmon in estuaries, we calculate spatial metrics to compare the size, distribution, diversity and complexity of fish habitat catenae over different scales and conservation/restoration scenarios. By adjusting fluvial-tidal water levels in GIS according to different hydroperiod regimes, it is also possible to evaluate changes in fish habitat catenae to understand how the structure of juvenile salmon habitats may change as different genetic stocks pass through different reaches of the estuary under dissimilar hydrologic seasons.
Results and discussion

Results for application of the LPF to the Columbia River estuary are preliminary but provide some insight into the framework’s utility for conservation and restoration planning in estuarine settings. As one example, we are comparing the relative gain in the accessibility and capacity of fish habitat catenae that would accrue with restoring tidal-fluvial flooding to the currently altered catenae among the eight hydrogeomorphic reaches in the Columbia River estuary (Fig. 4). Initial analyses indicate that proportional increases in both direct fish habitat catenae and indirect wetland area would be greater in the upper five (tidal freshwater) reaches and the lowest (euhaline) reach of the estuary. Similarly, the proportional change in the number of channel confluences, as well as edge and confluence density, would also be maximally increased in these reaches; conversely, the greatest proportional increase of indirect drainage and 2-yr flood expansion of fish habitat catenae might be maximized in the central reaches of the estuary. Given the heterogeneous spatial and temporal concentrations of different genetic stocks of Columbia River salmon across the estuary, these results imply the need for multiple conservation strategies.
Although the foremost purpose of the LPF is to provide proactive guidance about where exceptional estuarine habitat of genetic stock-specific juvenile salmon most needs protection and restoration, it can also be applied as a conservation management tool. By using the GIS platform to simulate different designs and locations of estuarine protection and restoration, we are assessing and comparing the relative benefits potentially delivered to juvenile salmon by alternative actions in different regions of the estuary. Similarly, because the adjacent wetland influence on the direct fish habitat catenae is based on the general type of vegetation, the seral development of vegetation at restoration sites can also be simulated to predict long-term changes in those benefits.

**Figure 4.** Examples of analytical output from Landscape Planning Framework to illustrate change in landscape metrics when “altered” fish habitat catenae could be restored to more “open”, natural tidal-fluvial flooding in the Columbia River estuary (CRE); the head of tide is in Reach H and the mouth of the estuary in Reach A.

**Conclusions**

- Restoration of estuarine habitat for anadromous fish, such as juvenile Pacific salmon, needs to be more ‘strategic’ by linking variability in fish demographics with hydrogeomorphic variability in landscape structure and processes that influence fish habitat.
- Understanding the hierarchical scales of hydrological, geomorphic and ecological controls on fish habitat across the estuarine gradient can inform strategic restoration planning such as applied through the Landscape Planning Framework.
- Overlaying fish habitat requirements and genetic variability to existing and potential estuarine landscape mosaics would enable more targeted conservation actions befitting the variability in genetic and life history patterns of movement and rearing of anadromous fishes in an estuary.

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**References**


