**Estuarine Habitats for Juvenile Salmon in the Tidally-Influenced Lower Columbia
River and Estuary**

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Context

This work focuses on the numerical modeling of Columbia River estuarine circulation and associated modeling-supported analyses conducted as an integral part of a multi-disciplinary and multi-institutional effort led by NOAA's Northwest Fisheries Science Center. The overall effort is aimed at: (1) retrospective analyses to reconstruct historic bathymetric features and assess effects of climate and river flow on the extent and distribution of shallow water, wetland and tidal-floodplain habitats; (2) computer simulations using a 3-dimensional numerical model to evaluate the sensitivity of salmon rearing opportunities to various historical modifications affecting the estuary (including channel changes, flow regulation, and diking of tidal wetlands and floodplains); (3) observational studies of present and historic food web sources supporting selected life histories of juvenile salmon as determined by stable isotope, microchemistry, and parasitology techniques; and (4) experimental studies in Grays River in collaboration with Columbia River Estuary Study Taskforce (CREST) and the Columbia Land Trust (CLT) to assess effects of multiple tidal wetland restoration projects on various life histories of juvenile salmon and to compare responses to observed habitat-use patterns in the mainstem estuary. From the above observations, experiments, and additional modeling simulations, the effort will also (5) examine effects of alternative flow-management and habitat-restoration scenarios on habitat opportunity and the estuary's productive capacity for juvenile salmon.

The underlying modeling system is part of the SATURN¹ coastal-margin observatory [1]. SATURN relies on 3D numerical models [2, 3] to systematically simulate and understand baroclinic circulation in the Columbia River estuary-plume-shelf system [4-7] (Fig. 1). Multi-year simulation databases of circulation are produced as an integral part of SATURN, and have multiple applications in understanding estuary/plume variability, the role of the estuary and plume on salmon survival, and functional changes in the estuary-plume system in response to climate and human activities.

Progress in 2008/2009

- Advances in SATURN were presented [8, 9] at an international workshop on the use of modern ocean observatories. The by-invitation workshop was attended by many of the leading observatory efforts in Western Europe, and by selected leading efforts in the US. SATURN was selected to showcase the role of observatories in PNW coastal margin research in general, and estuary and plume-focused salmon research in particular.
- Decade-long simulation databases for the Columbia River estuary are at the core of our contribution to the overall project. The reference simulation database is currently DB16. Based on the 3D numerical circulation code SELFE [3], DB16 uses ocean boundary conditions from a companion river-to-ocean database (DB14), which we use as reference for plume studies in a separate (but related) BPA project.

¹ The observatory was originally known as "CORIE". SATURN stands for Science And Technology University Research Network, and is operated by the NSF Science and Technology Center for Coastal Margin Observation and Prediction (CMOP). CORIE is now a sub-system within SATURN. SATURN is a multi-institutional effort, with overall scientific direction of Antonio Baptista, and supported by multiple sources of funding.

In 2008/09, a year of simulations (2007) was added to DB16, which now covers 1999-2007. Simulations are in progress to extend the DB16 through the end of 2008. Note that circulation forecasts equivalent to DB16 are conducted daily, and extend through the present; however, forecasts are based on predicted forcing (as opposed to observed or hindcasted forcing), hence are typically less skilled than the actual simulation databases.

Recent CMOP data sets (e.g., the profiling station SATURN-01 and two Remus-100 autonomous underwater vehicles) offer the opportunity to assess and further improve skill of the circulation simulation databases in areas that have been traditionally data poor. Fig. 2 shows an example of model-data comparison for SATURN-01, in this case providing insight into the vertical structure of salinity in the North Channel, and associated modeling skill. Fig. 3 shows an example of model-data comparison for a REMUS-100, deployed during flood tide in the North Channel, to examine salinity intrusion dynamics. Both figures suggest significant modeling skill, but also point to the opportunity for further improvement.

Based on the experience acquired with DB16, supporting calibration and validation are in progress to create a higher skill simulation database for the estuary. Differences relative to DB16 range from a newer version of SELFE to choices of internal parameters. Our main objective is to further improve the representation of the vertical structure of density in the lower estuary, which has substantial implications on upstream salinity intrusion (an estuarine indicator with major significance for physical habitat opportunity).

- DB16 was used to characterize the state and variability of estuarine circulation through the creation of climatologies and anomalies of physical variables and indicators that integrate/simplify complex estuarine dynamics. Examples are shown in Fig. 4, in the form of maps of variables and of a time series of salinity intrusion length anomalies. Additional climatologies and anomalies are available on the web: <http://ambwd02.stccmop.org/climatology/climatology.php?interval=yearly&db=14>, map-based representations, and <http://www.stccmop.org/datamart/columbiariver-climatologies> for indicators.

The characterization of state and variability is an essential precursor to understanding estuarine changes. Using salinity intrusion length as an indicator, we have in 2008/09 investigated estuarine change from pre-development to contemporary conditions, and to conditions associated with climate-induced sea level change as well as earthquake-induced subsidence of the lower Columbia River bottom topography. An example is shown in Fig. 5, which suggests a consistent trend for progressive increase of salinity during Spring.

- Long-term variability and abrupt changes in the physics of the Columbia River estuary-plume-shelf ecosystem are believed to modulate salmon survival and life histories. Flow regulation, navigational improvements, and diking and filling have profoundly modified the estuary over the past century, with extensive loss of wetland habitat. Using the high-resolution modeling capabilities of SATURN, we have been investigating the impact of natural variability and anthropogenic change on estuarine physical habitat opportunity (PHO) for salmon.

This work expands on Bottom et al. [10] in a variety of ways, including (a) the use of 3D (rather than 2D) circulation models, (b) insights into the role of salinity and temperature (not considered by [10]) on PHO in different regions of the contemporary and predevelopment estuary, and (c) inclusion of both human-associated impacts and impacts from large-scale processes (sea level rise and Cascadia Zone Subduction).

In a dissertation to be defended July 31, 2009, Burla [7] summarizes part of our findings. In particular, she suggests that strategies aimed at re-establishing connectivity between the river and its floodplain (e.g., through modification of both flow and bathymetry) are likely to be most effective in significantly restoring PHO in the CR estuary.

- In a separate but related project, both DB11 and DB14 were used to address the question of whether the intraseasonal variability in smolt-to-adult survival rates (SARs) for steelhead (*Oncorhynchus mykiss*) and Snake River spring/summer chinook salmon (*O. tshawytscha*) are related to conditions in the Columbia River plume when the juvenile migrants enter the ocean [6]. Results suggest that steelhead (but not Chinook) salmon benefit from the plume environment at a narrow window of time around their ocean entry.

We have in 2008/09 shown that there are meaningful correlations between important physical indicators of plume and estuary behavior. For instance, plume area (defined by the 28 psu contour) and estuarine salinity intrusion length, are clearly inter-related (Fig. 6; correlation factor: 87%).

Both of the above results suggest the possibility, which we are starting to investigate, that indicators of estuarine conditions (such as salinity intrusion length or residence times) may offer additional useful insights into smolt-to-adult survival rates.

- The need to understand the impact of local restoration projects on physical habitat opportunity has led in 2008/09 to the refined modeling of the circulation in the Grays River system. This modeling has been conducting using DB16 for “estuary” boundary conditions (Fig. 7). Thanks are due to Dr. Zhaoqing Yang of the Marine Sciences Laboratory, Pacific Northwest National Laboratory for supplying the original grid used in [11], which we extended and adapted in our study. This is a continuing effort.

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Figure 1: The SATURN modeling system includes multiple special scales, across the broadly defined Columbia River coastal margin (top left panel). The emphasis of this study is in the estuary, for which the bottom panels show the grid and bathymetry, respectively. A separate but related study focuses on the plume (top right panel shows grid overlaid on bathymetry)

Figure 2: Model-data comparison of the vertical structure of salinity at profiling station SATURN-01 (see http://www.stccmop.org/corie/observation_network/fixedstation?station=saturn01 for station location). The top panel shows observations, middle panel shows simulations (from a DB16-analog daily forecast) and bottom panel shows the differences.

Figure 3: Model-data comparison for observations from a REMUS-100, during flood, at the North Channel. Top (bottom) left panel shows simulations (observations). Model results are from a calibration run, being conducted in preparation for the creation of a simulation database of higher skill than DB16. Top right panel shows period of deployment against simulations of salinity structure at SATURN-01. Top bottom panel correlates simulated and observed salinity. All results are from a blind comparison (observations not available at the time of the simulation).

Figure 4: Climatology for the bottom salinity of the Columbia River estuary (1999-2006, top left), and selected annual climatologies and associated anomalies (right panels). For more climatologies and anomalies, see <http://ambwd02.stccmop.org/climatology/climatology.php?interval=yearly&db=14>. Bottom left panel shows the annual anomalies for an integrative indicator (salinity intrusion length, SIL) derived from the same simulations that generated the map-based climatologies.

Figure 5: Integrative indicators (such as salinity intrusion length) offer the ability to understand variability (each line) and change (differences between lines). Here, results suggest a trend for increased salinity intrusion in the estuary in Spring, from pre-development to contemporary conditions, and into anticipated future scenarios (sea level rise; post an anticipated Cascadia Subduction Zone event, leading to deep subsidence in the Columbia River lower estuary)

Figure 6: There is a strong correlation between near-field plume area (as defined by the 28 psu contour) and salinity intrusion length in the estuary (correlation factor: 87%). Correlation decreases substantially for plume areas defined by larger salinity contours (not shown), because of increasing ocean influences.

Figure 7: Grays River grid and its nesting in the DB16 grid. The small scale of the Grays River region poses challenges for grid building due to fine resolution source bathymetry requirements and the sensitivity to small grid errors. Nesting in the DB16 grid allows the Grays River model to be run with more natural boundary conditions.