Salmon Estuarine Residence
GENERAL QUESTIONS

What roles do estuaries and nearshore marine ecosystems play for salmon, trout and charr?

Is there evidence for “estuarine dependence”?

What attributes of estuaries are important?

What life history characteristics are important?

How have Pacific Northwest estuaries changed in their capacity to support salmon?

Can this knowledge help salmon recovery efforts?
Underlying question: What controls individual and population tendencies to migrate or reside?

- Internal condition
- External environment
- Genetic predisposition
TAKE-HOME MESSAGES (up front)

Estuaries are inherently difficult habitats in which to work, and in which to quantify aspects of salmon ecology.

Salmonid species and life history variants differ in their use and “dependence” on estuaries and nearshore marine environments.

Diversity of temporal and spatial distributions of habitats may be important to population resilience.
Salmon in Estuaries

Role: Haven, Highway, or Trap?

Estuary definition and types
Residence Patterns by species
Functional Significance
Transition to Seawater
Problems in Estuaries
Estuaries as Havens

- Abundant food sources
- Safety from predators – Turbidity
- Physiological transition for smolts
Estuaries as Highways

Area that salmon must pass through *en route* to the really important habitats at sea.
Estuaries as Traps

- Stressful salinity changes
- Tides create confusion
- Predators are waiting
- High salmonid density
Introduction to Estuaries:

- Definition
- Examples
- Types
- Tides
- Circulation and stratification
- Sediment transport
“An estuary is a semi-enclosed coastal body which has a free connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage.” (Pritchard 1967)
Regions of an estuary:

1. Marine or lower estuary, with a free connection to the ocean
2. Middle estuary: strong salt-fresh water mixing
3. Fluvial or upper estuary: water is fresh but subject to tidal changes in elevation
Coastal plain, drowned river valley

Fjord

Bar-built

Tectonic
Kennedy Creek, Totten Inlet, Puget Sound
Nisqually River delta, Puget Sound
Coastal Oregon bar-built estuary
Fresh water starts higher in elevation than the ocean, and is much lighter. (Salinity has a much stronger influence on density than temperature). The extent to which the estuary remains stratified varies greatly, being influenced by wind and topography.
Salinity (ppt)

Depth (m)

1 km

Chehalis River, Grays Harbor estuary, Washington
Unlike coastal plain estuaries, fjords can be very steep-sided, like this site in Dean Channel, B.C.
The sharpness of the halocline (and thermocline) decline with distance from the river mouth in a fjord-type estuary at Dean Channel, B.C.
Difficulties in studying estuaries

• It is comparatively easy to count fish coming in but often impossible to count them going out of an estuary
• There are fewer estuaries than streams, and so “replicates” are hard to find
• Many estuaries have already been altered
• Complex patterns seasonal, diel, tidal and lunar cycles complicate sampling (salinity, water depth, substrate, velocity, etc.)
How do we assess the importance of estuaries for salmon?

(use does not equal dependence)

1) Are alternative nursery habitats available?
2) What proportion of the population uses the estuary?
3) What is the duration of residence in the estuary?

Healey (1982)

Other considerations:

1) How fast do they grow, relative to other habitats?
2) What is their survival rate, relative to other habitats?
Estuary Residence by Species

- **Timing of estuary entrance and exit**
  - Pink/chum: peak late March to mid May
  - Coho: peak mid-May
  - Sockeye (Lake Washington, Quinalult): April to June
  - Chinook: racial structure prevents generalizations

- **Location within the estuary**
  - Tendency to move offshore as they grow

- **Duration of estuarine residence**
  - Chum: 2-4 weeks
  - Pinks: data weak but probably brief
  - Coho smolt: 1-2 weeks, fry may reside much of summer
  - Sockeye: move rapidly through estuary
  - Chinook: ocean-type may reside for over a month
  - Steelhead: very brief

Charr and cutthroat trout – extensive (?)
Variation in estuarine and nearshore dependence by Pacific salmon

- High dependence:
  - Ocean type chinook
  - Chum
  - Ocean type coho (?)
- Low dependence:
  - Stream type chinook
  - Stream type coho
  - Steelhead
  - Sockeye
Juvenile Chinook salmon entering the Columbia River estuary (1969)

N.B. Sampling stopped in September

Columbia River Estuary
Catches of ocean type Chinook in upper and lower regions of the Columbia River estuary in littoral and offshore habitat (McCabe et al. 1986).

<table>
<thead>
<tr>
<th>Month</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
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<tbody>
<tr>
<td>Upper intertidal</td>
<td>18</td>
<td>26</td>
<td>171</td>
<td>260</td>
<td>379</td>
<td>484</td>
<td>406</td>
<td>111</td>
<td>145</td>
<td>20</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Lower intertidal</td>
<td>0</td>
<td>5</td>
<td>25</td>
<td>55</td>
<td>297</td>
<td>602</td>
<td>380</td>
<td>28</td>
<td>25</td>
<td>10</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Upper pelagic</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>38</td>
<td>657</td>
<td>380</td>
<td>587</td>
<td>316</td>
<td>177</td>
<td>17</td>
<td>9</td>
<td>24</td>
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<tr>
<td>Lower pelagic</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>7</td>
<td>257</td>
<td>441</td>
<td>598</td>
<td>215</td>
<td>116</td>
<td>29</td>
<td>12</td>
<td>13</td>
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</tbody>
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- Light yellow = 0 to 25
- Orange = 26 to 100
- Green = 101 to 300
- Blue = >301
# Beach seine and purse seine catch rate (mean # of fish caught per set) at Jones Beach, OR

<table>
<thead>
<tr>
<th>Fishing gear</th>
<th>Catch per set</th>
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<tbody>
<tr>
<td>Beach seine</td>
<td></td>
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<tr>
<td>Ocean-type chinook</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>178</td>
</tr>
<tr>
<td>June</td>
<td>164</td>
</tr>
<tr>
<td>July</td>
<td>497</td>
</tr>
<tr>
<td>Average</td>
<td>274</td>
</tr>
<tr>
<td>Purse seine</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>15.7</td>
</tr>
<tr>
<td>June</td>
<td>24.9</td>
</tr>
<tr>
<td>July</td>
<td>14.1</td>
</tr>
<tr>
<td>Average</td>
<td>17.9</td>
</tr>
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</table>
Weekly catch per set averages for yearling chinook, steelhead, coho, and sockeye salmon

**Purse seine: beach seine**

- **Steelhead**
  - April: 58:1
  - July: 1

- **Coho salmon**
  - April: 3:1
  - July: 1

- **Sockeye salmon**
  - April: 26:1
  - July: 1

- **Yearling chinook salmon**
  - April: 4:1
  - July: 1
Catch per set averages for sub-yearling chinook at Jones Beach

1:3.5

- Purse seine
- Beach seine
Percent fish caught at mid-water trawl catches of juvenile fall chinook salmon in the Columbia River estuary, 1966.

<table>
<thead>
<tr>
<th>Fishing depth</th>
<th>Jones Beach</th>
<th>Tongue Point</th>
<th>Clatsop Spit</th>
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<tbody>
<tr>
<td>0-3 m</td>
<td>96.3</td>
<td>95.2</td>
<td>97.9</td>
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<tr>
<td>3-6 m</td>
<td>3.6</td>
<td>4.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Below 6 m</td>
<td>0.1</td>
<td>0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Catch represents 10 trawl hauls at each depth at each location
Growth and Feeding in Estuaries

Rapid growth:

- Chum in Hood Canal: 5.7 - 8.6% body weight per day, 10% in first four days.
- Chum in Skagit River Salt Marsh: 6% body weight per day
- Chinook in Duwamish River: 2.6 mm/week

N. B. The expression of growth is tricky – small fish grow faster on a relative basis but slower on an absolute basis than large fish.
Feeding in Estuaries

Feeding

1. Marshes with emergent plants: larval insects, mysids, amphipods
2. Mudflats: epibenthic copepods, amphipods
3. Eelgrass beds: amphipods, isopods
4. Open water: drift insects, larval crabs and fishes, pelagic copepods
Detritus-based food web in estuary marshes

Amphipods
Isopod
Mysid
Copepod
Juvenile Salmon
Leptocottus
Chironomid

Adapted from Dorcey et al. 1978. Westwater Res. Rept. UBC.
Chum fry weight in relationship to time in the Nanaimo River, B. C.

Chum fry mean weight (g)

- inner
- outer

Early March, late March, early April, late April, early May, late May, early June, late June, early July
Mason (1974) pointed out that chum fry were regularly found in habitat inundated by high tides but de-watered on low tides. The presence of fry in these habitats and their size distribution indicated active use of these areas rather than passive movement through the estuary.
Growth of wire-tagged chinook fry released and recaptured in the Sacramento – San Joaquin estuary or upper Sacramento River

How can we tell if growth or residence in the estuary is important?

• Measure the scales of salmon smolts of different sizes to define the relationship between scale size and fish size.

• Measure a lot of juvenile salmon for length.

• Collect salmon that survival to adulthood and measure their scales. Then, “back-calculate” how big that fish was as a smolt.

• Compare the distributions; were the survivors bigger as smolts than the population at large?
Scales record growth history

Individual circuli
Length of adult and juvenile salmon leaving freshwater, Sixes River, OR

% of the sample

Length (mm) leaving freshwater

- adults
- juveniles
Estimated estuarine growth of adult and juvenile salmon Sixes River, OR

% of the sample

Estimated estuarine growth (mm)

- adults
- juveniles
Transition to seawater

Smolting is a transition process, and estuaries may provide a region where fish can _behaviorally osmo-regulate_. This may be especially important for salmon that enter the estuary at a small size (e.g., chum fry) because their surface to volume ratio makes water retention difficult.

Iwata and Komatsu 1984 CJFAS
Problems in Estuaries

• Pollution - Urban human population centers
• Freshwater flow changes – human uses
• Land-use changes in upland areas
• Habitat loss in the estuary itself
• Dredging and other in-water activities

Estuaries are natural areas of deposition, so the concentration of toxic materials is not surprising
Commencement Bay and the estuary of the Puyallup River, WA.

The development of coastal cities as ports greatly affected many estuaries.
Is loss of estuary habitat important?

Estuary use is difficult to pin down, and the benefits are intuitive but hard to quantify. Magnusson and Hilborn (2003) reported that the post-release survival of Chinook (but not coho) salmon from hatcheries increased with the % of the estuary in natural condition. This is consistent with the greater apparent dependence of Chinook than coho on estuaries.

Estuaries 26: 1094-1103