Chehalis basin watershed analysis and life-cycle modeling

Tim Beechie, Jeff Jorgensen, Colin Nicol, Caleb Fogel, Gus Seixas, Jamie Thompson, Britta Timpane-Padgham

NOAA Fisheries, Northwest Fisheries Science Center, Seattle, WA
Overview

- Overview of the NOAA model
  - Conceptual model
  - Habitat analysis overview
  - Life cycle model overview

- Diagnostic scenarios
  - Assumptions
  - Results

- ASRP scenarios
  - Assumptions
  - Results
Conceptual Model

Drivers
- Barriers
- Road density
- Floodplain habitat
- Wood
- Beaver ponds
- Riparian shade

Habitat conditions
- Temperature
- Fine sediment
- Rearing area
- Spawning area

LCM inputs
- Productivity

LCM outputs
- Capacity

Salmon response

See examples in Bartz et al. 2006, Scheuerell et al. 2006
Coho Salmon Life Cycle Model

Need capacity and/or productivity for each life stage and subbasin
Influences on Life-Stage Parameters

- Fine sediment
- Shade
- Wood
- Barriers
- Beaver ponds
- Floodplain habitat

- Spawners/Eggs
  - Egg-to-fry survival (density independent)
  - Pre-spawn mortality
  - Harvest

- Age 3 adults + jacks
- Age 3
- Age 2
- Age 1

- Emergent Fry
- Fry Colonization
- Mainstem Fry
- Natral Basin Fry
- Natal Basin Parr
- Mainstem Parr
- Mainstem Smolts
- Natal Basin Smolts

- b2
  - Ocean survival

- Winter rearing (Beverton-Holt)
- Summer rearing (Beverton-Holt)

- Delta-bay survival (density-independent)
NOAA Model Structure

**Raw data layers:**
- USGS 10-m DEM
- C-CAP land cover raster
- PRISM mean annual precip
- Washington roads
- Ecological Diversity Regions
- SWIFD streamlines
- WDFW Migration barriers
- WDFW Thermalscape
- Riparian files
- Floodplain habitat polygons
- Large river edge habitat
- Large river backwaters
- Spawning riffles

**Final habitat layers:**
- Large river edge habitat
- Large river backwaters
- Large river spawning riffles
- Floodplain habitats
- Attributed streamline

**Diagnostic scenarios:**
- Migration barriers
- Fine sediment
- Wood loading
- Shade (temperature)
- Bank armor
- Channel straightening
- Beaver ponds
- Floodplain habitats

**LCM results:**
- Coho
- Spring Chinook
- Fall Chinook
- Steelhead

**Restoration scenarios:**
- Restoration actions
- Climate change effects
- Future development
Spatial Analysis Steps

- Assign attributes to 200-m stream reaches
  - e.g., slope, wetted width, land cover, fine sediment, temperature

- Generate stream habitat data layers
  - e.g., small stream habitats (<20 m bankfull width), large river habitats (>20 m bankfull width), floodplain habitats
Spatial Analysis Outputs

- Large river bank edge habitat length
- Large river backwater habitat areas
- Large river spawning riffle areas
- Floodplain habitat areas
- Attributed stream lines (slope, land cover, fine sediment, temperature, etc.)
Habitat Analysis Steps

- Estimate habitat areas by reach
  - e.g., area of pools, riffles, beaver ponds, floodplain habitats, large river edge habitats

- Summarize current and historical habitat areas and attributes by sub-basin and EDR

- Create diagnostic and restoration scenarios
  - LCM input files of life stage capacities and productivities by sub-basin
Habitat Analysis Outputs

- Output files from the habitat analysis are input files for the life-cycle models
  - Include life stage capacities and productivities for each sub-basin
  - One file for each species and scenario (current, historical, 9 diagnostic, 4 ASRP)

<table>
<thead>
<tr>
<th>Subbasin number (1-63)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
</tr>
<tr>
<td>Egg to fry productivity</td>
</tr>
<tr>
<td>Adult capacity</td>
</tr>
<tr>
<td>Egg capacity</td>
</tr>
<tr>
<td>Summer capacity</td>
</tr>
<tr>
<td>Summer productivity</td>
</tr>
<tr>
<td>Winter capacity</td>
</tr>
<tr>
<td>Winter productivity</td>
</tr>
<tr>
<td>Prespawn productivity</td>
</tr>
</tbody>
</table>
Floodplain Habitat Change
Floodplain Habitat Change

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Fish Density (fish/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coho (summer)</td>
</tr>
<tr>
<td>Marsh</td>
<td>0</td>
</tr>
<tr>
<td>Pond</td>
<td>1.8</td>
</tr>
<tr>
<td>Side Channel</td>
<td>0.9</td>
</tr>
<tr>
<td>Slough</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Large River Habitat Change

- Habitat types from Beechie et al. (2005) and Beamer and Henderson (1998)
- Fish densities from Beamer and Henderson (1998)
Large River Habitat Change
# Small Stream Habitat Change

<table>
<thead>
<tr>
<th>Slope class</th>
<th>Reference</th>
<th>Forest</th>
<th>Wetland</th>
<th>Agriculture</th>
<th>Developed</th>
<th>Bare</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2%</td>
<td>81</td>
<td>75</td>
<td>89</td>
<td>92</td>
<td>74</td>
<td>83</td>
</tr>
<tr>
<td>2-4%</td>
<td>66</td>
<td>48</td>
<td>53</td>
<td>60</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>&gt;4%</td>
<td>35</td>
<td>34</td>
<td>--</td>
<td>31</td>
<td>54</td>
<td>34</td>
</tr>
</tbody>
</table>

Based on 339 field survey sites from WDFW; reference site data from other studies.
## Small Stream Habitat Change

**Current Condition**

<table>
<thead>
<tr>
<th>Slope class</th>
<th>Reference</th>
<th>Forest</th>
<th>Wetland</th>
<th>Agriculture</th>
<th>Developed</th>
<th>Bare</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2%</td>
<td>81</td>
<td>75</td>
<td>89</td>
<td>92</td>
<td>74</td>
<td>83</td>
</tr>
<tr>
<td>2-4%</td>
<td>66</td>
<td>48</td>
<td>53</td>
<td>60</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>&gt;4%</td>
<td>35</td>
<td>34</td>
<td>--</td>
<td>31</td>
<td>54</td>
<td>34</td>
</tr>
</tbody>
</table>

Based on 339 field survey sites from WDFW; reference site data from other studies
## Small Stream Habitat Change

### Historical Condition

<table>
<thead>
<tr>
<th>Slope class</th>
<th>Reference</th>
<th>Forest</th>
<th>Wetland</th>
<th>Agriculture</th>
<th>Developed</th>
<th>Bare</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2%</td>
<td>81</td>
<td>75</td>
<td>89</td>
<td>92</td>
<td>74</td>
<td>83</td>
</tr>
<tr>
<td>2-4%</td>
<td>66</td>
<td>48</td>
<td>53</td>
<td>60</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>&gt;4%</td>
<td>35</td>
<td>34</td>
<td>--</td>
<td>31</td>
<td>54</td>
<td>34</td>
</tr>
</tbody>
</table>

Based on 339 field survey sites from WDFW; reference site data from other studies
Riparian Condition

- Current shade inventory using lidar and aerial photos
- Reference tree heights for historical shade
- Change in shade and temperature model
Fine sediment

- Percent fine sediment based on forest road density
- Incubation productivity related to percent fine sediment (Jensen et al. 2009)
## Habitat effects on LCM parameters

### Coho and Steelhead

<table>
<thead>
<tr>
<th></th>
<th>Egg capacity</th>
<th>Egg-to-fry productivity</th>
<th>Summer rearing capacity</th>
<th>Summer rearing productivity</th>
<th>Winter rearing capacity</th>
<th>Winter rearing productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barriers</strong></td>
<td>X</td>
<td></td>
<td>X¹</td>
<td>X</td>
<td>X¹</td>
<td>X</td>
</tr>
<tr>
<td><strong>Fine sediment</strong></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wood loading</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Shade</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Channel length</strong></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Bank condition</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Beaver pond area</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Floodplain</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Wood + floodplain</strong></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

1. Effect expressed only when barrier is 100% blocking
## Habitat effects on LCM parameters

### Spring and Fall Chinook

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Pre-spawn productivity</th>
<th>Egg capacity</th>
<th>Egg-to-fry productivity</th>
<th>Subyearling rearing capacity</th>
<th>Subyearling rearing productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine sediment</td>
<td>X</td>
<td></td>
<td></td>
<td>X¹</td>
<td>X</td>
</tr>
<tr>
<td>Wood loading</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Shade</td>
<td>X²</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Channel length</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Bank condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Beaver pond area</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Floodplain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Wood + floodplain</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

1. Effect expressed only when barrier is 100% blocking
2. Spring Chinook only
Chinook Life Cycle Model

1. Spawners/Eggs
   - Prespawn mortality
   - Harvest

2. Age 2-6 adults
   - Ocean survival
   - $b_5$

3. Age 5
   - Ocean survival
   - $b_4$

4. Age 4
   - Ocean survival
   - $b_3$

5. Age 3
   - Ocean survival

6. Natal Basin Fry
   - Emergent Fry
   - Incubation productivity (density independent)

7. Fry colonization (Beverton-Holt)

8. Mainstem subyearling rearing (Beverton-Holt)

9. Movement to mainstem

10. Mainstem subyearling rearing (Beverton-Holt)

11. Fry rearing/migration (density independent)

12. Fry Migrants

13. Delta-bay survival

14. Age 1
   - Ocean survival

15. Age 2
   - Ocean survival


17. Subbasin subyearling rearing (Beverton-Holt)
Life Cycle Model Outputs

- Spawner abundance ($N_{eq}$ by subbasin, EDR, or basin)

- Intrinsic productivity ($P_n$, empirical fit of Beverton-Holt slope at origin)

- Cumulative capacity ($C_n$, calculated based on $N_{eq}$ and $P_n$)
Diagnosis and Restoration

Drivers:
- Barriers
- Road density
- Floodplain habitat
- Wood
- Beaver ponds
- Riparian shade

Habitat conditions:
- Temperature
- Fine sediment
- Rearing area
- Spawning area

LCM inputs:
- Productivity
- Capacity

LCM outputs:
- Salmon response

Life-cycle model:
- Landscape and habitat analysis

Drivers and habitat conditions are connected to the Life-cycle model, influencing the Salmon response.
Diagnosis and Restoration

Drivers
- Barriers
- Road density
- Floodplain habitat
- Wood
- Beaver ponds
- Riparian shade

Habitat conditions
- Temperature
- Fine sediment
- Rearing area
- Spawning area
- Productivity
- Capacity
- Salmon response

LCM inputs

LCM outputs

Landscape and habitat analysis

Life-cycle model
## Diagnostic scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>Current conditions for all habitat variables</td>
</tr>
<tr>
<td>No barriers</td>
<td>Current conditions for all habitats, no migration barriers</td>
</tr>
<tr>
<td>Historical fine sediment</td>
<td>Historical fine sediment levels</td>
</tr>
<tr>
<td>Historical wood</td>
<td>Historical wood loading</td>
</tr>
<tr>
<td>Historical shade</td>
<td>Historical shade and temperature</td>
</tr>
<tr>
<td>Historical large river length</td>
<td>Historical large river channel length multiplier</td>
</tr>
<tr>
<td>Historical bank condition</td>
<td>Historical bank condition (no rip-rap in large river)</td>
</tr>
<tr>
<td>Historical beaver</td>
<td>Historical beaver pond areas</td>
</tr>
<tr>
<td>Historical floodplain</td>
<td>Historical marsh, pond, and side-channels in floodplains</td>
</tr>
<tr>
<td>Historical wood + floodplain</td>
<td>Historical wood loading and historical marsh, pond, and side-channels in floodplains</td>
</tr>
</tbody>
</table>
Coho Diagnostic Results
Summary: Coho

- Loss of overwinter habitat has likely had the largest effect on coho populations
  - Beaver ponds
  - Floodplain habitat

- Other effects are also important
  - Migration barriers
  - Loss of shade and increased temperature
  - Loss of wood

- Fine sediment may have a modest effect
  - High uncertainty
Spring Chinook Diagnostic Results

Graph showing the results of different conditions on spring chinook spawning.

- Current: +0%
- Current, w/ historical fine sediment: +54%
- Current, w/ historical wood loading: +33%
- Current, w/ historical shade: +40%
- Current, w/ historical large river bank conditions: +4%
- Current, w/ historical large river length: +7%
- Current, w/ historical beaver ponds: +3%
- Current, w/ historical floodplain, habitat: +40%
- Historical conditions: +81%
- Historical conditions: +259%
Summary: Spring Chinook

- Largest modeled effects from
  - Increased temperature
  - Increased fine sediment

- Wood loss has also had a significant effect

- Uncertainty:
  - Fine sediment model does not identify specific locations or actions for restoration
Fall Chinook Diagnostic Results

![Bar chart showing the comparison of spawners across different conditions.
- Current
- Current, w/ no barriers
- Current, w/ historical fine sediment
- Current, w/ historical wood loading
- Current, w/ historical shade
- Current, w/ historical large river bank conditions
- Current, w/ historical large river length
- Current, w/ historical beaver ponds
- Current, w/ historical floodplain habitat
- Historical conditions

The chart indicates an increase in spawners under historical conditions by +134%, suggesting a significant improvement in environmental conditions for these species.]
Summary: Fall Chinook

- Largest modeled effects from:
  - Loss of wood
  - Increased fine sediment

- Smaller effects from:
  - Floodplain habitat loss

- Uncertainty:
  - Fine sediment model does not identify specific locations or actions for restoration
ASRP Restoration Scenarios

• No action baseline
  • Includes climate change (temperature increases 1°C by 2045 and 2°C by 2085, Isaak et al. 2017)
  • Includes future development (impervious area increase)

• Three ASRP restoration scenarios
  • Scenario 1: 200+ miles treated
  • Scenario 2: 300+ miles treated (adds to Scenario 1)
  • Scenario 3: 400+ miles treated (adds to Scenario 2)
ASRP Restoration Assumptions

Inside managed forest:
• Wood placement (scalar of 1.0, 75th percentile of natural loading)
• Barrier removal (includes all barriers in a selected GSU)
• Passive beaver recovery (scalar of 0.1)

Outside managed forest:
• Wood placement (scalar of 1.0)
  • Small streams: include beaver dam analogs (scalar of 1.0)
• Barrier removal (includes all barriers in a selected GSU)
• Riparian restoration: scalar of 0.75 (accounts for roads and structures)
• Within riparian corridor floodplain is also reconnected, which could include side channels, oxbows, floodplain wetlands (scalar of 1.0)
Coho Salmon

Scenario 1:  
13% of coho stream length is treated

Scenario 2:  
21% of coho stream length is treated

Scenario 3:  
28% of coho stream length is treated
Spring Chinook

Scenario 1: 28% of Sp. Chin. stream length is treated

Scenario 2: 28% of Sp. Chin. stream length is treated

Scenario 3: 44% of Sp. Chin. stream length is treated
Scenario 1:
20% of F. Chin. stream length is treated

Scenario 2:
27% of F. Chin. stream length is treated

Scenario 3:
35% of F. Chin. stream length is treated
Restoration Scenario Summary

- **Coho salmon**
  - Sensitive to increasing temperature
  - Positive restoration effect by 2040s, near current levels by 2080s

- **Spring Chinook**
  - Very sensitive to increasing temperature
  - Positive restoration effect by 2040s, but population decline by 2080s

- **Fall Chinook**
  - Less sensitive to increasing temperature
  - Positive restoration effect by 2040s and 2080s
Next steps

- Complete 2019 report
  - Review comments received, editing now
  - Final report due December 30, 2019

- Complete steelhead model QA/QC

- 2020 updates
  - Updates to habitat data, restoration scenarios?
  - Add stochastic effects of peak flows
  - Complete chum salmon model