Hatchery rearing duration effects on reproductive behavior and breeding success of steelhead trout

Barry Berejikian
Chris Tatara
Don Van Doornik
Michael Humling¹
Jeff Atkins

¹/US Fish and Wildlife Service
US Fish and Wildlife Service, Winthrop National Fish Hatchery

[Map showing the location of Winthrop National Fish Hatchery in the Columbia Basin]

[Images of the Winthrop National Fish Hatchery facility]
Age-at release effects on post-release performance of hatchery reared steelhead

- **Age-1 release (S1)**
  - Most hatchery programs
  - Challenging for local broodstock programs and cold rearing temperatures
  - High residualism rates in slower growing fish

- **Age-2 release (S2)**
  - Can reduce size-selective mortality
  - Can improve migration speed and survival
  - Residualism from early male maturation

References:
Objectives

• Estimate the effects of hatchery rearing duration (S1 vs S2) on breeding success

• Estimate the breeding success of precociously mature male parr from S2 programs

• Identify mechanisms causing variation in breeding success

• Examine implications of different rearing strategies on hatchery and natural populations
Measuring breeding success

Image: Chris Tatara
Spawning studies at Winthrop NFH

~100 m²

Location within each sector

Image: Michael Humling

Image: Michael Humling
Experimental Design

- Six breeding populations
  - Two stream channels stocked 1 week apart
  - Reflects natural spawn timing
  - Three years (2015-2017)
- 11-13 males & females in each breeding population
  - Approx. equal numbers of S1 & S2 adult steelhead (males skewed towards S1)
  - 6 mature S2 parr into each breeding population
- Unique external tag
- Fin clip for pedigree analysis
Observe and quantify behavior (dawn to dusk)
Fry produced per female (top) and male (bottom)
Female offspring production and fecundity

- **Population Size**
- **Fecundity**

<table>
<thead>
<tr>
<th>Year (Channel #)</th>
<th>Fry produced</th>
<th>Total fecundity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015 (1)</td>
<td>40,000</td>
<td></td>
</tr>
<tr>
<td>2015 (2)</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>2016 (1)</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>2016 (2)</td>
<td>20,000</td>
<td></td>
</tr>
<tr>
<td>2017 (1)</td>
<td>40,000</td>
<td></td>
</tr>
<tr>
<td>2017 (2)</td>
<td>15,000</td>
<td></td>
</tr>
</tbody>
</table>
Female breeding success

Analysis of Covariance

<table>
<thead>
<tr>
<th>Effect</th>
<th>Type III SS</th>
<th>df</th>
<th>Mean Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear Type</td>
<td>0.038</td>
<td>1</td>
<td>0.038</td>
<td>0.120</td>
<td>0.730</td>
</tr>
<tr>
<td>Body Mass</td>
<td>1.702</td>
<td>1</td>
<td>1.702</td>
<td>5.413</td>
<td>0.023</td>
</tr>
<tr>
<td>Error</td>
<td>20.757</td>
<td>66</td>
<td>0.314</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing mean percent fry produced over years and channels](image1)

![Graph showing ln(fry produced) vs. body mass](image2)

R² = 0.0765
Male breeding success (S1, S2, parr)

### Analysis of Variance (S1, S2, Parr)

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>Mean Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear type</td>
<td>45.760</td>
<td>2</td>
<td>22.880</td>
<td>9.782</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>240.917</td>
<td>103</td>
<td>2.339</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean (±SE) fry produced by year and channel:

- **2015 (1)**: 14.5% ± 0.5%
- **2015 (2)**: 13.5% ± 0.6%
- **2016 (1)**: 17.2% ± 0.7%
- **2016 (2)**: 16.8% ± 0.8%
- **2017 (1)**: 15.3% ± 0.6%
- **2017 (2)**: 14.9% ± 0.7%

---

[Image of bar chart showing mean fry production by year and channel with error bars for S1, S2, and parr, along with average.]
Male breeding success (S1, S2 only) ANCOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>Mean Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear type</td>
<td>13.67</td>
<td>1</td>
<td>13.67</td>
<td>4.900</td>
<td>0.030</td>
</tr>
<tr>
<td>Body mass</td>
<td>2.77</td>
<td>1</td>
<td>2.77</td>
<td>0.995</td>
<td>0.322</td>
</tr>
<tr>
<td>Error</td>
<td>186.92</td>
<td>67</td>
<td>2.79</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ R^2 = 0.0304 \]

\[ R^2 = 0.0006 \]
Male breeding success ANCOVA (S1 and S2 < 2.8 kg)

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III SS</th>
<th>df</th>
<th>Mean Squares</th>
<th>F-Ratio</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear type</td>
<td>11.27</td>
<td>1</td>
<td>11.27</td>
<td>5.778</td>
<td>0.021</td>
</tr>
<tr>
<td>Body mass</td>
<td>3.35</td>
<td>1</td>
<td>3.35</td>
<td>1.719</td>
<td>0.197</td>
</tr>
<tr>
<td>Error</td>
<td>76.08</td>
<td>39</td>
<td>1.95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Male body size vs breeding success (parr only)

\[ R^2 = 0.1793 \]
Male dominance hierarchies
Dominance vs fry production (by breeding group)

4 of 6 regressions are significant

R² = 0.609
R² = 0.3372
R² = 0.4269
R² = 0.3847
R² = 0.4517
R² = 0.1316
First to enter nest at time of spawning

Proportion of fry produced vs. first to enter frequency. The graph shows a positive correlation with a coefficient of determination ($R^2$) of 0.8361. The linear model for s1 is indicated by the dotted line.

- parr
- s1
- s2

Linear (s1)
### Sex-bias in relative fitness estimates?

<table>
<thead>
<tr>
<th>Species</th>
<th>Male RRS</th>
<th>Female RRS</th>
<th>Comments</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic salmon</td>
<td>0.51</td>
<td>&lt; ~1.0</td>
<td>Breeding success</td>
<td>Fleming et al. 1997</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0.32</td>
<td>&lt; 0.51</td>
<td>Adult to juvenile</td>
<td>Williamson et al. 2010</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0.64</td>
<td>&lt; 1.00</td>
<td>Lifetime</td>
<td>Hess et al. 2012</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0.48</td>
<td>&lt; 1.2</td>
<td>Adult to Juvenile</td>
<td>Sard et al. 2015</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>0.83</td>
<td>&lt; 1.48</td>
<td>Lifetime</td>
<td>Anderson et al 2012</td>
</tr>
<tr>
<td>Steelhead</td>
<td>0.60</td>
<td>&lt; 0.63</td>
<td>Lifetime $H_{hw}$ v. $H_{ww}$</td>
<td>Araki et al. 2007</td>
</tr>
<tr>
<td>Steelhead</td>
<td>0.31</td>
<td>&lt; 0.42</td>
<td>Lifetime $W_{hh}$ v. $W_{ww}$</td>
<td>Araki et al. 2009</td>
</tr>
<tr>
<td><strong>Steelhead</strong></td>
<td><strong>0.60</strong></td>
<td>&lt; <strong>1.15</strong></td>
<td><strong>Adult to juvenile (nn broodstock)</strong></td>
<td><strong>Ford et al. 2016</strong></td>
</tr>
<tr>
<td>Steelhead</td>
<td>0.32</td>
<td>&lt; 0.50</td>
<td>Adult to juvenile (hn broodstock)</td>
<td>Ford et al. 2016</td>
</tr>
<tr>
<td>Steelhead</td>
<td>0.14</td>
<td>&gt; 0.13</td>
<td>Adult to juvenile (hh broodstock)</td>
<td>Ford et al. 2016</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0.62</td>
<td>&lt; 0.82</td>
<td>Breeding success</td>
<td>Fleming and Gross 1993</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0.62</td>
<td>&lt; 0.84</td>
<td>Lifetime</td>
<td>Theriault et al. 2011</td>
</tr>
<tr>
<td>Chum salmon</td>
<td>0.99</td>
<td>&gt; 0.73</td>
<td>Adult to juvenile</td>
<td>Berejikian et al. 2009</td>
</tr>
<tr>
<td>Chinook salmon</td>
<td>1.1</td>
<td>&gt; 1.0</td>
<td>Lifetime $H_{hh}$ v. $H_{ww}$</td>
<td>Ford et al. 2012</td>
</tr>
<tr>
<td>Coho salmon</td>
<td>0.97</td>
<td>&gt; 0.74</td>
<td>Lifetime</td>
<td>Ford et al. 2006</td>
</tr>
<tr>
<td>Steelhead</td>
<td>0.48</td>
<td>&gt; 0.40</td>
<td>Lifetime</td>
<td>Berentson et al. 2011</td>
</tr>
</tbody>
</table>
Summary

• Female breeding success
  • Somewhat influenced by body size and fecundity
  • Similar between S1 and S2
  • Up to 73% of eggs converted to fry
  • Productivity should be unaffected by rearing strategy

• Male breeding success
  • Success highly skewed towards a few of the larger males
  • Otherwise body size has little influence
  • S1 > S2; possibly influenced by competitive asymmetries
  • Precocious males contribute substantially (~10% of the fry produced)
Acknowledgements

- Chris Pasley
- Bill Gale
- Matt Cooper
- Jon Box
- Natalie Schiebel
- Teresa Fish

- BPA, Project #: 1993-056-00