May 1st, 1:30 PM - 3:00 PM

**Marine Survival of Puget Sound Chinook salmon-New studies on size-selective mortality and critical growth periods**

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Marine Survival of Salmon: Size-selective Mortality and Critical Periods

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University of Washington
WA Cooperative Fish & Wildlife Research Unit

Washington Sea Grant
Pacific Salmon Commission
Salmon Recovery Fund Board
Nisqually, Tulalip, Skagit Coop. & Lummi Tribes
NOAA, WDFW, Kwiaht, DFO-Canada, Pac. Salmon Foundation
Study Objectives

• Use Size-selective mortality to identify critical periods of growth that influence survival to adulthood
  – Which life stages & associated habitats?
  – FW, estuarine delta, marine nearshore, offshore?
• Diagnose what factors limit growth or survival during critical periods
  – Food supply or quality
  – Temperature
  – Competition
  – Predation
  – Approach & example of pilot results
Survival Linked to Size & Growth at Specific Life Stages

Size at release & Marine entry NOT Correlated to Surv.

Marine survival Strongly linked to Wt after 1 month Epi-pelagic feeding In Puget Sound through July

2-3 fold Wt gain during 1° pelagic feeding

Weaker pattern In Sept.

Do critical periods vary among stocks? (Nisqually, Snohomish, Skagit, Nooksack) Critical periods in FW, estuarine, nearshore or offshore life stages?

Duffy & Beauchamp 2011 CJFAS 68:232-240
Hatchery: pre-release size structure & scales release date & abundance

**Outmigrant Trap**
Timing, Abundance
Size, Scales, (~Diet & Otoliths from morts)
Weekly Feb/Mar to ~July

**Estuarine Channels (trap or B Seine) & Nearshore Beach Seine**
Timing, Abundance
Size, Scales, Otoliths, Diet
2x per month

**Offshore Purse seining**
Timing, Abundance
Size, Scales, Otoliths, Diet
~2x per month
Including predatory fish
mid-Apr to mid-Oct

**Offshore Midwater Trawl**
Depth-stratified 15-m depths
Timing, Abundance
Size, Scales, Diet
Including predatory fish
July & Sept

**Returning Adults**: Scales & Otoliths & Residents
Track Specific Populations thru Early marine life stages

Methodical near/offshore sampling For selected watersheds

Size structure
Timing & duration
Total/relative abundance
Diet & Body Condition
Environmental Conditions

**Freshwater:**
Hatchery Release
Smolt traps

**Estuarine & nearshore Marine:**
Estuarine Tide channel traps 2x/mo
Beach seining 2x/mo Mar-Sep/Oct

**Offshore:**
Zooplankton 2x/mo Apr-Oct
Purse seining 1-2x/mo May-Sep
DFO Midwater Trawl: Sep

Grants approved, no funding, DFO
Timing of Life Stage Pulses: Downriver Migrants

<table>
<thead>
<tr>
<th>Date</th>
<th>Relative Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar</td>
<td>0.0</td>
</tr>
<tr>
<td>Apr</td>
<td>0.2</td>
</tr>
<tr>
<td>May</td>
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<td>Jun</td>
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<td>Jul</td>
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<tr>
<td>Aug</td>
<td>0.6</td>
</tr>
<tr>
<td>Sep</td>
<td>0.4</td>
</tr>
<tr>
<td>Oct</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Timing of Life Stage Pulses: Estuarine Delta & Nearshore

Relative Abundance

River Migrants

Estuarine Delta & Nearshore

Mar  Apr  May  Jun  Jul  Aug  Sep  Oct
Timing of Life Stage Pulses:
Offshore (within Puget Sound)

<table>
<thead>
<tr>
<th>Date</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
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<td>0.8</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

- Estuarine Delta & Nearshore
- Offshore w/in Puget Sound
- River Migrants
Size-Selective Mortality by Life Stage

Relative Abundance

River Migrants

Estuarine Delta & Nearshore

Offshore w/in Puget Sound

Fork Length (mm)

Avg. Juvenile in field samples
SSM: Scales used to back-calculate growth history of known-origin Juveniles & Adults

Circuli from Same Growth Region for Juv. & Adult from same brood year

Age-0 Chinook
BY 2001, June 2002 in PS
**Size-Selective Mortality by Life Stage**

- **Relative Abundance**
  - River Migrants
  - Estuarine Delta & Nearshore
  - Offshore w/in Puget Sound

- **Fork Length (mm)**
  - Avg. Juvenile in field samples

- **Surviving adults**
  - Size or Growth diverge during:
    - Offshore growth
    - Delta-Nearshore Growth
    - River growth
Size Selective Mortality (SSM)

For each life stage: SSM Inferred by comparing Size distributions (scale radius at specific circuli) for juveniles to:
- Juveniles at later life stages
- Adult survivors from that same group

Larger individuals survived at a Disproportionately higher rate.

In this hypothetical example:
- The Smaller 50% of juveniles contribute only 5% of the surviving adults

If significant SSM observed between periods,

Then diagnose factors affecting growth within these periods based on bioenergetics modeling

Examine scale-based size distributions at circuli #s corresponding to:

- Hatchery release
- Smolt outmigration
- Delta & Nearshore Marine rearing
- Offshore rearing
- Returning Adults
Higher Feeding Rate = Higher Growth & Survival

Hatchery PS Chinook (CWT groups)

**High Survival (0.8%) 2001**

- North: S = 0.7%
- Central: S = 0.6%
- South: S = 1.0%

**Low Survival (0.4%) 2002**

- North: S = 0.5%
- Central: S = 0.5%
- South: S = 0.3%

Body Mass (g)

- 97 mm (134 mm)
- 96 mm (120 mm)
- 86 mm (124 mm)

Release

Nearshore  Offshore

5/7  5/21  6/4  6/18  7/2  7/16

**20% higher avg feeding rate 2001**

- Insects: 66-90% $C_{max}$, 90% $C_{max}$, 88% $C_{max}$, g.e. = 16%
- Crab Larvae: 64% $C_{max}$, g.e. = 16%

**Consumption (g/period)**

- North: 90% $C_{max}$, g.e. = 16%
- Central: 90% $C_{max}$, g.e. = 16%
- South: 90% $C_{max}$, g.e. = 16%

20% higher avg feeding rate

S=0.6-1.0%

66-90% $C_{max}$

2002

- North: S=0.3-0.5%
- Central: 55-64% $C_{max}$

Low & Variable Feeding rates
Suggest food limitation
Prerequisite for competition

Duffy 2009 Dissertation
Temperature Effects on Metabolism, Feeding & Growth

Temperature has Less effect on Summer Growth than feeding rate for PS Chinook

Thermal effects are Likely more important In Strait of Georgia

10-g Chinook salmon
2800 J/g diet

Temperature has Less effect on Summer Growth than feeding rate for PS Chinook

Thermal effects are Likely more important In Strait of Georgia

Beauchamp & Duffy 2011. PSC Rept
Summary Approach

• Identify Critical Periods: “Let the fish tell us what’s happening!”
  – Critical periods can vary among Spp & Stocks
  • Methodical Sampling: Hatchery & smolt traps in FW, estuarine & nearshore marine, local epi-pelagic, open ocean, Adult returns
  – Use SSM to identify critical periods and associated habitats (lengths, scales &/or otoliths)
  – Diagnose factors affecting growth & survival within critical periods
  – Can Inform restoration efforts & priorities
Size-Selective Mortality

• Size-selective Mortality (SSM) is Prevalent
  – Stage-specific size positively correlated to survival
• Can be used to identify critical periods of mortality or growth which influences mort
  – SSM differs among Spp, stocks, life stages
• Shifts in size-at-age distribution among life stages reflects timing & magnitude of SSM
  – Need to account for stock origin & migration
• SSM doesn’t rely on serial abundance est.
• SSM can link top-down & bottom-up factors affecting Survival & Growth
Marine survival of hatchery Chinook in the Salish Sea region declined 1980s & remained low-but not adjacent regions.
BACKGROUND: Puget Sound Hatchery Chinook Salmon Marine Survival Rates (smolt-adult) by release year

Ruggerone & Goetz 2004
Duffy 2009

0.2-1.0% 21/23 yrs
Back-calculated size-at-age of juvenile & adult Puget Sound Chinook

SSM & Critical period approach:
Compare size-specific contributions of different life stages to adult returns & diagnose limits to growth & S in Critical periods

Questions for 2014-2015:
- Timing of life stages pulsing through specific habitats
- Size-specific contribution to later stages
- Identify critical life stages & assoc. habitat
- Growth performance w/in life stage/habitat
- Diagnose factors limiting growth:
  - Food supply (production, competition)
  - Food quality (energy content)
  - Thermal effects on metabolism
- SSM Predation impacts by resident salmon

Size of Juv Chinook Offshore approximates Size & G for Surviving Adults

Growth period (Circulus interval)

Growth rate of Juv Chinook Offshore approximates that for Surviving Adults.
Size Selective Mortality (SSM)

For each life stage: SSM Inferred by comparing Size distributions (scale radius at specific circuli) for juveniles to:
- Juveniles at later life stages
- Adult survivors from that same group

Larger individuals survived at a Disproportionately higher rate in Both hypothetical examples A & B

B, 2\textsuperscript{nd} mode of smaller juveniles did not survive to Adulthood.

This mode could represent growth trajectories from an alternative life history strategy that’s unsuccessful under prevailing conditions
Rapid Early Marine Growth Improves Survival

1997-2005: 4-fold difference in ocean survival

Similar relationship for all offshore juvenile Chinook during July (but ~80% hatchery)

2x difference in July Wet Weight
Potential Pelagic Competitors During Critical Period:
Biomass & Spatial Temporal Overlap

Pacific Herring dominate the biomass of epi-pelagic planktivores

Shallow: 0-15 m

Herring: smaller aggregations at greater depth (scattering layer)

July 2004

Mean Catch/hr

Depth (m)

Chinook
Other Salmon
Herring
Other

DFO Canada Midwater trawl
Modeling Process

Temporal Diet Composition

Thermal Experience

Consumer Growth

Predator Energy Density

Prey Energy Density

Bioenergetics Model

Fork length (mm)

Length frequency

0 20 40 60 80 100 120

Population Consumption by Herring & Chinook

Consumer Size Structure & Abundance

Compare Consumption Demand by Herring & Chinook for Key Prey During Critical Growth Period (May-July)
Potential Inter-specific Competition for Food

Herring remove 10-47x more Biomass of key shared prey than H+W Chinook during Critical May-July period

CONCLUSION:
On average, Competition driven 1° by Herring in pelagic Habitats of Puget Sound.

But-Competition should be Considered across the entire Epi-pelagic planktivore community

Intensity of competition will likely Vary among regions & months, based on relative abundance & diet of each species