Juvenile salmon smolt migrations through the Salish Sea: routes and survival of sockeye and steelhead

Steve Healy, Nathan Furey, Scott Hinch, Erika Eliason
Department of Forest and Conservation Sciences
University of British Columbia

Aswea Porter, Erin Rechisky, David Welch
Kintama Research

Stephen Vincent
Seymour Salmonid Society
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Salmon life stages

Smolt
Early marine behaviour and survival

• Little direct information on this life stage
• Thought to be important for productivity and poor returns of adults

Several large unknowns.....
• What are the specific migration routes?
• What is the role of currents or routes on survival?
• How do species differ?
• Are there mortality ‘hotspots’?
• What is the role of pathogens and fish condition?
1) **Multi-year acoustic tagging study:**

Routes of sockeye and steelhead smolts at one locale in the Strait of Georgia (Salish Sea) and the ramifications to survival

2) **Single year acoustic tagging study:**

Locale-specific survival of one population of steelhead smolts throughout the Salish Sea
1) Multi-year tagging study examining routes and ramifications to survival

~250 steelhead (2004-2008)

~600 sockeye (8 yrs; 2004-2013)
Detections grouped into “sequences” to represent distinct presences at the array.
~250 steelhead (2004-2008)
• 45-65% of steelhead move directly through the array
Lateral Distributions of Steelhead

- 45-65% of steelhead move directly through the array
~600 sockeye (8 yrs; 2004-2013)
Lateral Distributions of Sockeye

- 25-50% of sockeye move directly through the array.
Smolts possibly influenced by counterclockwise circulation patterns

- Steelhead smolts show much more counterclockwise behavior
- More surface oriented than sockeye
- Due to wind-driven currents?

(Foreman et al. 2012)
Smolts possibly influenced by counterclockwise circulation patterns

(FOREMAN ET AL. 2012)
What is the role of route on subsequent survival?
Migration route important for steelhead

Probability of Survival to QCS

Initial Position along NSOG array

Texada Island

Twice as likely to survive to QCS
Migration route less important for sockeye

- Sockeye survival to QCS more affected by timing
  - Chilko sockeye that arrived later to NSOG survived better to QCS

- The longer time spent milling near NSOG the poorer the survival

- Steelhead did not show these patterns
2) Single year tagging study examining locale specific survival in steelhead smolts through the Salish Sea

**Acoustic Tagging** (May, 2015)

- Seymour River Hatchery
- Steelhead smolts (n=274)
- Gill biopsies taken for genomic analysis (n=164)

Photo: Etovre Vese
Releases

West Vancouver (n=160)

Seymour River (n=83)
Releases

Legend
- Receivers
- Release sites

Kilometers
0 25 50 75 100

Queen Charlotte Strait
Johnstone Strait
Discovery Islands
Northern Strait of Georgia
Seymour
Derby
Mission
Fraser Mouth

West Van Labs
Above slide rock slide
Lower Seymour

Juan de Fuca Strait
CANADA
USA
• High mortality in Burrard Inlet
• Cumulative survival between release groups becomes more similar by final receiver array.
- Travel rates twice as fast through Discovery Islands
- Possible influence of currents and tides
SUMMARY

• Migration route differs between species
  - Northern Strait of Georgia: sockeye migrate more to the eastern side than steelhead
  - About half of smolts travel in counterclockwise loop here (particularly steelhead)

• Migration route effects survival
  - Steelhead that travelled on eastern side of NSOG had twice the survival rate to Queen Charlotte Strait (~250 km)

• Burrard inlet appears to be a mortality hotspot
  - 18 km of migratory area accounted for 50% of the loss in steelhead to NSOG
Next Steps

Influence of pathogens and fish condition:

• Non-lethal gill biopsies taken (Jeffries et al., 2014)

• Genomics to assess physiology and pathogen presence

• Relate to migration fate


contact: steve.healy2@gmail.com
Approach
- in 2012 half of our V7 tagged smolts had a small piece of gill removed prior to release
- gill tissue used for functional genomics assessment using high throughput qPCR
- no difference in survival between gill clipped and non-clipped fish

Results
- 15% of smolts that were never detected after release had gene expression profiles consistent with immune response to one or more viral pathogens
- the most commonly detected pathogen in the smolts was infectious haematopoietic necrosis virus (IHNV)
April 2016 – The return to Chilko lake:

(Clark et al. *Ecological Applications* accepted)

- Tracked over 1800s smolts for >1000 km (2010-2013)
- 63-90% survival over first ~14 km
- Upper Chilko = nocturnal movements
- Elsewhere = day and night movements
- Predation in the upper river?
- Data only from age-two smolts
Genomic Work

• qPCR using Biomark Fluidigm
• Assess up to 45 pathogens and 45 physiological biomarkers per sample
• Conducted on steelhead samples (2015) in March, 2016 at Pacific Biological Station (DFO) in Nanaimo, B.C.
## Genomic Work – example biomarkers and pathogens

<table>
<thead>
<tr>
<th>Name</th>
<th>Assay</th>
<th>Type or Function</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Renibacterium salmoninarum</em></td>
<td>Microbe</td>
<td>Pathogen</td>
<td>Balfry et al., 2011; Halpenny &amp; Gross, 2008</td>
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<tr>
<td><em>Aeromonas salmonicida</em></td>
<td>Microbe</td>
<td>Pathogen</td>
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<tr>
<td><em>Listonella anguillarum</em></td>
<td>Microbe</td>
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<td>Balfry et al., 2011</td>
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<tr>
<td><em>Flavobacterium psychrophilum</em></td>
<td>Microbe</td>
<td>Pathogen</td>
<td>Balfry et al., 2011</td>
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<tr>
<td><em>Infectious hematopoietic necrosis virus</em></td>
<td>Microbe</td>
<td>Pathogen</td>
<td>Hostetter et al., 2011; Jeffries et al., 2014</td>
</tr>
<tr>
<td>Interferon-induced GTP-binding protein Mx</td>
<td>Biomarker</td>
<td>Immune</td>
<td>Jeffries et al., 2014</td>
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<tr>
<td>Signal transducer and activator of transcription 1-alpha/beta</td>
<td>Biomarker</td>
<td>Immune</td>
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<tr>
<td>Immunoglobulin M</td>
<td>Biomarker</td>
<td>Immune</td>
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<tr>
<td>Complement factor C3</td>
<td>Biomarker</td>
<td>Immune</td>
<td>Jeffries et al., 2014</td>
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<tr>
<td>Heat-shock protein 90-beta</td>
<td>Biomarker</td>
<td>Stress</td>
<td>Jeffries et al., 2014</td>
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<tr>
<td>Phospholemman</td>
<td>Biomarker</td>
<td>Stress</td>
<td>Jeffries et al., 2014</td>
</tr>
<tr>
<td>Sodium Potassium ATPase</td>
<td>Biomarker</td>
<td>Osmoregulation/Stress</td>
<td>Kennedy et al., 2007; Stich, et al., 2015</td>
</tr>
<tr>
<td>Cold inducile RNA binding protein</td>
<td>Biomarker</td>
<td>Osmoregulation/Stress</td>
<td>Pan et al., 2004</td>
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<tr>
<td>Insulin-like growth factor 1</td>
<td>Biomarker</td>
<td>Growth; salinity tolerance</td>
<td>Beckman et al., 1998</td>
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