Upriver Migration and Energetics

- Timing
- Patterns
- Speed
- Energetics
- Hell’s Gate Slide and Fishway
But before we dive into the details, let’s take a moment to consider the athletic performance accomplished by at least some populations…
“As regards the rate at which [Chinook salmon] ascend the river, we have more reliable and complete data for the Yukon than have been secured in any other stream. Records were obtained of their first appearance at a large number of localities. … The first king salmon to reach Dawson in the middle of July, 1920, had been traveling against a consistently rapid current for 29 days, at the rate of 52 miles per day, and during this period, as always within the river, had taken no food.”
“[The chums] entered the river about a week later than the kings, at Tanana they were not more than 10 days behind the latter, and at Dawson they were some 14 days behind the kings. The lower 800 miles of the river, as far as Tanana, were traversed at the rate of 50 miles per day and the next 700 miles, between Tanana and Dawson, were covered at the rate of 35 miles per day.”
An experimental “endless fishway” was built in which salmon jumped up a series of pools and then slid back down, to test swimming performance to aid design of dams.

In five days a 50 cm sockeye salmon ascended day and night, 2025 m (6648 feet) in 415 circuits of the fishway. It was still climbing when the staff let it go. Not until the fifth day did it show signs of slowing down, and blood lactate levels did not indicate muscular fatigue.
Migration timing between and within species (some patterns and a lot of variation)

1) Sockeye and Chinook tend to migrate and spawn early
2) Coho tend to migrate and spawn late
3) In Puget Sound pink salmon tend to spawn earlier than chum salmon but farther north this is not the case
4) Chinook and steelhead display extreme variation in migration timing among populations, and also considerable variation within populations (especially steelhead)
Estimated daily counts of adult salmon ascending the Ballard Locks in 2007

- Sockeye
- Chinook
- Coho
Estimated cumulative counts of adult salmon ascending the Ballard Locks in 2007

Median (50%) dates:

- 7 July
- 20 Aug
- 18 Sept
Monthly entry of chinook salmon as inferred from catches at Rio Vista, including winter, spring, summer, fall and late fall runs

Seasonal changes in the percentage of stream and ocean-type chinook to the total run in the Fraser River (data from Rich 1942)
Arrival patterns of Chinook salmon destined for parts of the Fraser River basin

Migratory timing of Fraser River sockeye salmon populations and pink salmon to the Strait of Juan de Fuca.)

Area 20 Date

18-Jun  03-Jul  18-Jul   02-Aug  17-Aug  01-Sep  16-Sep

100       200       300       400       500       600

Abundance (thousands)
Odd and even year pink salmon can differ in timing: Sashin Creek, Alaska

Counts of upstream migrating (ripe) and spent wild steelhead in two tributaries of the Siuslaw River, Oregon in 1991-1992 and 1992-1993

(ODFW data, complied by McMillan 2001)
Steelhead are commonly referred to by the season when they return to freshwater (summer or winter) but are more properly referred to by the environment where maturation takes place.

Ocean maturing (= winter) steelhead arrive in late winter and spawn shortly thereafter.

River maturing (= summer) steelhead arrive in late summer and spawn the following spring.
Entry of adult winter and summer steelhead into the Kalama River, Washington

Winter: mean spawning: 15 April
Summer: mean spawning: 1 Feb
Daily escapement of sockeye salmon into Iliamna Lake and estimated daily total run in 1983

Caveat: Counts in rivers may be affected by fishing...
Changes in fish traits over the run

- There are often systematic changes in the life history traits of salmon over the course of the migration.
- Sometimes these reflect differences in timing of discrete populations that differ in those traits.
- However, sometimes there are also systematic differences within populations.
Older salmon tend to arrive before younger ones (Tuluksak River, Alaska)
(Molyneaux and DuBois 1998)
Larger salmon of a given age may arrive before smaller ones (Tuluksak River chum)

- **Mean chum salmon length**
  - age 5 males: diamond symbols
  - age 4 females: square symbols

**Sampling date**
- 18-Jun
- 8-Jul
- 28-Jul
- 17-Aug
Male salmon typically precede females (chum salmon)

% males

Sampling date

18-Jun  8-Jul  28-Jul  17-Aug

Why might older/larger fish and males migrate and arrive before younger/smaller fish and females?

1) **Migratory performance**: bigger fish swim faster and so arrive sooner, even though they leave at the same time.

2) **Feeding ecology**: the optimal duration of time at sea depends on how big you are – smaller fish have a greater need to grow than larger fish.

3) **Spawning ground dynamics**: smaller fish cannot compete, and so arrive after bigger fish; breeding dynamics favors early arrival by males.
What time of day do salmon migrate upstream?

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Species</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primarily at night:</strong></td>
<td>kokanee</td>
<td>Lorz and Northcote 1965</td>
</tr>
<tr>
<td><strong>Primarily in the day:</strong></td>
<td>Sockeye, chinook, steelhead</td>
<td>Columbia River</td>
</tr>
<tr>
<td><strong>At night if the water is clear, in the day if turbid:</strong></td>
<td>Atlantic salmon</td>
<td>Hellawell et al. 1974</td>
</tr>
<tr>
<td><strong>At night in moderate flows, in the day on floods:</strong></td>
<td>Atlantic salmon</td>
<td>Potter 1988</td>
</tr>
<tr>
<td>Slightly more at night than during the day:</td>
<td>Atlantic salmon</td>
<td>Allan 1966</td>
</tr>
<tr>
<td></td>
<td>Brown trout</td>
<td></td>
</tr>
</tbody>
</table>
What is the relationship between flow and migration?

<table>
<thead>
<tr>
<th></th>
<th>Increases in flow stimulate migration:</th>
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<tbody>
<tr>
<td>rainbow trout</td>
<td>Davies and Sloane 1987</td>
</tr>
<tr>
<td>coho salmon</td>
<td>van den Berghe and Gross 1989</td>
</tr>
<tr>
<td>pink salmon</td>
<td>Hunter 1959</td>
</tr>
</tbody>
</table>
What is the relationship between flow and migration?

Increased or high flows retard migration:

<table>
<thead>
<tr>
<th>Fish Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>pink salmon</td>
<td>Davidson et al. 1943</td>
</tr>
</tbody>
</table>
Relationship between pink salmon migration and flow in Hooknose Creek, AK

Hunter (1959) JFRBC
Salmon movement can occur without pulses of stream flow: Skutz Falls, B.C.

Neave (1943) JFRBC
Upriver travel can be very rapid

• **Chinook**
  – Yukon River = 36 km/day (radio tagging)
  – Yukon tag/recovery ~ 40 to 77 km/day
  – Columbia River: 1134 km at 26 km/day (pre-dam)

  **Chum** - Amur River: 1193 km at 45 km/day
Jumping ability

Steelhead > Chinook > coho > chum = pink

Reiser et al. 2006 TAFS
Components of Research

1. Estimate travel rate (tagging, counts)
2. Estimate rate of energy consumption as a function of activity (lab)
3. Determine rate of energy depletion during migration
4. Estimate actual swimming speed
Energetics of Fraser River Sockeye

Analogy: Car

1. Determine Seattle to Olympia distance and time of travel
2. Determine the fuel consumption rate
3. Measure the gas used
4. Estimate the driving pattern
Fraser River system, B.C.
Speed of upriver travel

- **Sockeye**
  - Based on run peaks at different sites:
    - Stuart, Bowron, Horsefly = **48 km/day**
    - Chilko and Stellako = **34 km/day**
    - Adams = **27 km/day**
  - Stuart Lake: Lummi Island to Forfar Creek:
    - 1152 km in 27 days = **43 km/day** (tagging)
Relationship between percent body fat and migratory distance
Gilhousen 1980

![Graph showing the relationship between percent body fat and distance upriver.](image-url)
Energy remaining (% of initial) for Fraser River sockeye from entry to death on spawning grounds

<table>
<thead>
<tr>
<th>Race</th>
<th>Sex</th>
<th>Fat</th>
<th>Protein</th>
<th>Distance (km)</th>
<th>Elevation (m)</th>
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<tbody>
<tr>
<td>Stuart</td>
<td>M</td>
<td>9</td>
<td>64</td>
<td>1152</td>
<td>693</td>
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<tr>
<td></td>
<td>F</td>
<td>5</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chilko</td>
<td>M</td>
<td>17</td>
<td>61</td>
<td>725</td>
<td>1170</td>
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<tr>
<td></td>
<td>F</td>
<td>7</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adams</td>
<td>M</td>
<td>15</td>
<td>70</td>
<td>483</td>
<td>347</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>13</td>
<td>61</td>
<td></td>
<td></td>
</tr>
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Gilhousen. 1980. IPSFC Bull 22
Populations and species of salmon with more arduous migrations have more fat when they leave the ocean.

Sockeye salmon were placed in a swimming tunnel, water velocity and temperature were controlled, body size was measured, and oxygen consumption and energy use were recorded after determining the swimming capacity of the fish.
Energetics of migrating sockeye

For a 2.27 kg, 61 cm sockeye, the least energetic cost is 1.8 km/h. River Speed: equivalent to 4.3 km/h

Fraser River sockeye salmon catch

Note: 4-year cycle, and drop in catch after 1913
Fraser River at Hell's Gate, 1897, looking upstream before the railway was built on the East Bank
At Hell’s Gate the river is so constricted that it varies by nearly 30 m during a year.

Jackson. 1950. IPSFC Bull. III
Hell’s Gate

• The Fraser River was probably always hard for salmon to ascend at Hell’s Gate (and other locations).

• 1913 - dumping of rock material from railway construction virtually blocked passage of fish; millions died unspawned

• 1914 Feb. 23: a huge rockslide, caused by Canadian Northern Railway tunneling, again greatly restricted flows
Sockeye salmon blocked at Hell's Gate, 1913

www.saxvik.ca
Hell's Gate, February, 1914, after the collapse of the rock cliff above the Great Northern Railway Tunnel
Hell’s Gate: 1915

- After the slide it was virtually impassable to fish from levels 25 to 40 feet and difficult from 10 to 60.
- Vertical drop: 9 feet (after rocks removed).
- Velocity: 5.0 to 6.75 meters per second
Hell's Gate, 1914, looking upstream, temporary fishway built on the east bank to aid adult salmon migrating up-river.

Hell's Gate, 1915, excavated rock from slide on east bank deposited onto rock shelf on west bank.
Hell’s Gate

- Fishways now designed to pass 26,000 fish per hour in daylight. At the peak of the migrations they may pass over 500 salmon per minute.
- Aid passage at 10 to 70 feet elevations.
Correlation between mortality of sockeye salmon and temperature (Gilhousen 1990)

- Raft River: \( R^2 = 0.49 \)
- Early Stuart Lake: \( R^2 = 0.36 \)
Water temperatures (e.g., August means) have been getting warmer...
One response by salmon has been to avoid the warmer water. Columbia River sockeye are migrating earlier than in the past; steelhead are migrating later.
Future effects of climate change?
Estimated swimming speeds of migrating sockeye salmon (Hinch, Quinn data)

150 cm/sec = 5.4 km/h
or 2.5 body lengths/sec for a 60 cm fish
Temperatures (e.g., the Columbia River at Bonneville Dam) have been getting warmer.

$\text{r}^2 = 0.42$, $p < 0.001$
Hell’s Gate
Cross section at reference line station 20

Depth in Feet

Downstream view

1912 to 1948
Max: 93 ft
Min: 8 ft

Jackson, 1950. IPSFC Bull. III
Steelhead and chinook salmon counts at the fish ladder as a function of time of day: Lower Granite Dam, Snake River, in 1992.
Timing of Atlantic salmon ascending the Le Havre River, Nova Scotia

Hayes (1953)
B.F.R.B.C.