Smolting
Maneuvering around enormous obstacles
Smolting: the developmental process that stimulates juvenile salmon to migrate to the ocean and prepares them for seawater existence once in the ocean.

A key component contributing to “salmonyness”

Behavior

Morphology

Physiology (endocrinology)
Are pink fry smolts?

• Seawater tolerant upon emergence
• Move immediately to estuary/nearshore habitat

Photo: Bill Heard
Lake trout in Nunavut, Canada

- First migration age 13-29
- Anadromous until age 50

- Large body size required for salt tolerance in charr?

Web of Science Title search (2010):

smolt* and

Atlantic salmon 587
Coho salmon 138
Chinook salmon 62
Brown (sea) trout 30
Steelhead trout 24
Sockeye salmon 26
Charr (Brook, Arctic, Dolly) 17
Cutthroat trout 2
Chum salmon 2
Pink salmon 1
Salmon smolting flowchart

Summer (age 0)
- Evaluate lipid stores
  - low: Stay in stream as parr
  - high: Re-evaluate next fall
  - very-high: Don’t go to sea. Mature now!

Winter (age 0)
- Continue feeding at high rate
- Condition factor drops
- Catabolic processes

Spring (age 1)
- Final silvering of body
- Increase lipid stores
- Osmoregulation
- Enter ocean

Smolting “types” based on age/size @ seawater entry:

pink (seawater tolerant at emergence)

chum/sub-yearling Chinook (seawater tolerant within 30 days)

coho/sockeye/Chinook/steelhead/Atlantics (sw tolerant at age 1-2)

cutthroat/brown(sea)/charr (sw tolerant at age 1 – 6+)

Rousenfell 1958
Smolting “models”: Atlantic and coho salmon (important in aquaculture).

Similar: yearling chinook and sockeye salmon, steelhead

Fish are yearlings, > 70 mm but typically 90 – 120 mm

2 - 3 years old in north

Occurs in the spring - photoperiod dependent

narrow window (weeks)

fish migrate quickly downstream

spend little time (days - weeks) in estuaries.
Variations (1):

- Under-yearling smolting: chum, 0-age chinook salmon

Occurs in spring/summer - size/age dependent

Fish are young and small (< 70 mm).

“Leisurely” downstream migration (more time spent feeding).

Weeks - months in estuary.
Variations (2):

- “over-yearling” smolting: brook, Arctic and Dolly Varden charr, cutthroat trout.

Occurs in spring - summer.

Fish are old (2 - 6 years) and large (> 200 mm).

Migrational characters relatively undescribed.

Seasonal oceanic residence (3 - 6 months) then return to freshwater (smolt multiple times)
Parr
Solitary
Territorial
Benthically oriented
Positive rheotaxis
Day Active

Smolts
Mid-water
Schooling
Negative rheotaxis
Night active
Restlessness
Both parr and smolt face osmoregulatory problems.

Problem: too much water not enough salt

Problem: too much salt not enough water

Gill is very permeable.

Parr - freshwater

34‰ water
14‰ salt
~0‰ water

Smolt - Ocean

14‰ water
14‰ salt
Solution: don’t drink freshwater, excrete water. Active uptake of salt.

Solution: drink saltwater, excrete salt.
Chloride cells are active “salt pumps”
Moving ions against their concentration gradient

Chloride cells

Freshwater

Seawater

\[ \text{Na}^+ \]

\[ \text{Na}^+ \text{ K}^+ \text{ ATPase} \]
• Non-lethal biopsy of several gill filaments
Gill ATPase changes seasonally and is correlated with changes in seawater tolerance.

Beckman et al. NOAA-NWFSC
Na⁺ K⁺-ATPase Physiology

Central California steelhead

Hayes et al. NOAA-SWFSC Unpublished
Migration Timing

• Downstream movement is photoperiod and flow dependent

Number of fish per day

- Why go to sea in the spring?
  - Use spring flows for efficient migration
  - Maximize productive marine summer

Data: NOAA - SWFSC
Smolting occurs within a seasonal window

Median date of chum salmon fry emigration (± 50%)

Median date of coho salmon smolt emigration (± 50%)

Carnation Creek
West Coast of Vancouver Island
Blair-Holtby et al. 1989
Two distinct mechanisms regulate smolt timing

Coho:
- Little variation median date (photoperiod)
- More individual variation (growth)

Chum:
- More variation median date (size/growth - temperature)
- Less individual variation
Growth

- Smolts may have a higher growth rate than non-smolt conspecifics

Central California steelhead

![Graph showing growth rates for non-smolts and smolts from May to March with significant differences marked by asterisks.](image-url)
Changes in condition factor

\[ K = \left( \frac{\text{Mass}}{\text{Length}^3} \right) \times 10^5 \]

- In summer fish with high K begin the process of smolting
- By spring, smolts have a lower K than non-smolts

Condition factor (K) of hatchery fish

• K declines through winter

• K reaches minimum just prior to downstream migration in spring
Smolts look different

- Addition of purines (guanine and hypoxanthine) to skin
- Melanin addition to fin margins
- Lowering of condition factor
Summary

Smolting is transitional and preparatory

Energy intensive physiological changes

Smolt timing is variable between species, within species but generally occurs in spring

Smolting is key to the uniqueness of salmon