Developmental rate and survival of embryos

- Temperature and rate of incubation
- Survival of embryos
  - Disturbance by other females
  - Gravel quality – water flow
  - Dissolved oxygen
  - Scour and physical shock
The number of days from fertilization to hatching or emergence is fundamentally controlled by temperature, but also varies between species.
Temperature Units and development

There is a general equivalence between time and temperature, such that embryos achieve about the same stage of development after

10 days at 5 degrees or
5 days at 10 degrees

Temperature Units = number of days x temperature

\[ 10 \times 5 = 50 \]
\[ 5 \times 10 = 50 \]
Ecological importance of temperature

Normal spawning times of two populations

Straying to a warmer creek would lead to premature emergence

Straying to a cooler creek would delay emergence

Cool = spawn early
Warm = spawn late

Sheridan 1962. Pink Salmon Symposium
Temperature Units and development: Part II

Overall, development is faster in warmer water than colder water, but the difference is not as great as would occur if development required a fixed number of temperature units.

Cold water: embryos require fewer TUs to develop that at warmer water

The ecological effect is to allow embryos that start late (in cold water) to “catch up” a bit, and to “slow down” those that started early (in warm water).
Variation in TUs needed for development at different temperatures: Nadina River sockeye salmon

Temperature units to yolk absorption

Degrees C

TU to yolk absorption

constant 800 TU

Brannon 1987
Nadina River sockeye salmon yolk absorption rate in relation to temperature

Simulated, if 800 TUs were required at all temperatures

Days to yolk absorption

Actual rate

Temperature

Brannon 1987
Survival to emergence: average and sources of variation

**Density Dependent Factors**
1. Redd “superimposition” (digging up)
2. Water Quality
   - Dissolved oxygen
   - Disease

**Other Mortality – Biotic**
1. Egg predation

**Physical Factors**
1. Suffocation:
   - Low D.O. Delivery rate
   - Removal of metabolic wastes
2. Scour from high flow:
   - physical shock, especially at about 100 TUs.
## Percent Survival to Emergence

<table>
<thead>
<tr>
<th>Species</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pink</td>
<td>11.5%</td>
</tr>
<tr>
<td>Chum</td>
<td>12.9%</td>
</tr>
<tr>
<td>Sockeye</td>
<td>12.7%</td>
</tr>
<tr>
<td>Coho*</td>
<td>25.3%</td>
</tr>
<tr>
<td>Steelhead*</td>
<td>29.3%</td>
</tr>
<tr>
<td>Chinook*</td>
<td>38.0%</td>
</tr>
</tbody>
</table>

* Percentages are averages of data for wild populations.

* = weak data

These values reflect densities that had been reduced by fishing, so are probably higher than “natural”.
Density-dependence: Chilko River sockeye

![Graph showing the relationship between spawning adults and fry production.](image)
Density-dependence: Weaver Creek Spawning Channel

Note high survival rates at low density
Effects of temperature on survival from fertilization to emergence (Murray and McPhail 1988)
Relationship between coho survival to emergence and % fine sediment

Cederholm et al. 1981. Salmon Spawning Gravel Symposium
Survival of coho salmon embryos to emergence in relation to % fine material

- Coho redds (Cederholm)
- Coho redds (Koski)
- Coho (lab)

Percent fines < 0.85 mm

Chart showing the relationship between percent fines and survival of coho salmon embryos.
Survival to emergence in relationship to particle size for salmonids

- Steelhead
- Chinook
- Sockeye
- Coho

Percent survival vs. Particle diameter (mm)
Gravel particle size is important for embryo survival, but how do we sample it?

1) Pebble count: measure the median axis of a random sample of particles from the surface of the stream (quick but superficial)

2) McNeil cylinder: collect, dry and weigh a bulk sample of gravel including surface and deeper material (more effort)

3) Freeze-core: collect a sample revealing the vertical profile of gravel sizes (most time-consuming and costly)
McNeil Cylinder: gravel sample
Freeze core sampling
Low dissolved oxygen levels reduce survival: rainbow and steelhead trout

Sowden & Power
Coble
Estimated critical levels of dissolved oxygen* for chum salmon embryos: older embryos need more DO

* Critical oxygen levels are those at which respiratory demand is just satisfied

Alderdice et al. (1958)
Chronic low oxygen levels slow development and reduce alevin weight

Shumway et al. (1964)
Concentrations of carotenoid pigments in eggs of different salmonid species (Craik 1985)

Concentration (micro-grams/gram)

- Sockeye
- Coho
- Pink
- Chum
- Steelhead
- Rainbow
- Cutthroat
- Dolly Varden
- Arctic charr
- Atlantic

The chart shows the concentration of carotenoid pigments in the eggs of different salmonid species. Sockeye and Coho have significantly higher concentrations compared to the other species.
Fertilization success and survival of embryos and alevins may be enhanced by carotenoid concentration (Craik 1985).

Rainbow and brown trout

Rainbow and brown trout

Micrograms of carotenoid per gram of egg

% fertilization and embryo/alevin survival

Fertilization success

Survival of embryos and alevins
At moderate temperatures (4 – 8 C), rainbow trout embryo mortality was associated with reduced carotenoid pigment concentration (Craik 1985)
Fine sediment does not reduce DO levels, only the transport rate of the water.
DO levels in chum salmon redds declined from spawning to emergence.

Spawning

Emergence

Dissolved Oxygen mg/l

Percent
Egg to fry survival is reduced by high flows during incubation.

Graph showing the relationship between Cedar River peak flow (m$^3$/s) and Egg to fry survival (%). The data points indicate a decreasing trend in survival with increasing flow. The graph is labeled for Sockeye Salmon.
Sliding ball scour monitors
Sliding ball scour monitors

a) Before scour.

b) After scour.

streambed surface

before scour

4 cm

after scour
Scour and egg burial depth: Kennedy Creek chum salmon reds
The depth of scour varies among habitat types: Kennedy Creek

% monitors scoured to 0.2m

- **Site A**
- **Site B**

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Site A</th>
<th>Site B</th>
<th>All Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riffle</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Lower Riffle</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Glide</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Pool Tailout</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Pool Lat.Bar</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Note: The values for each habitat type are not provided in the image.
What is the cause of mortality from flooding?

- Dislodgement of embryos that drift downstream, get eaten, etc.
- Crushing of embryos within the gravel
- Disruption of normal development from mechanical shock at sensitive periods
- Sedimentation of the egg pocket and smothering of the embryos after the flood
Salmon embryos are very vulnerable to handling or other mechanical disturbance during a period in their development. Johnson et al. (1989)
Winter flows in Carnation Creek in relationship to coho egg to fry survival

R² = 0.71

Holtby and Healey (1986)
Egg to fry survival in relation to an index of gravel quality: Carnation Creek coho

Holtby and Healey (1986)
Complex effects of flooding

• Gravel mobilizes during high flows, crushing and dislodging embryos in vulnerable habitats
• As flood waters recede, fine sediment transported by the flood settles into the gravel, finding its way into the interstitial spaces of the redds.
Sources of Embryo Mortality

- Low ambient DO
- Predation
- Dig up
- Desiccation or freezing
- Suffocation
- Scour
- High flows
- Low flows
- Fine sediment
- Fishes
- Birds
- Density
- Female size
- Female timing