Homing and Straying, Part II

Mechanisms of Homing: Imprinting, Genetics, and Pheromones
Deepwater Bay sockeye experiment

- Olfactory nerve cut
- Tended to stay at release site
- Moved toward Fraser R. but did not ascend

Craigie 1926
Olfaction

Adult coho salmon were caught in the main and east forks of Issaquah Creek and then taken below the confluence. Controls were tagged and released; experimental fish made anosmic by plugging the nares with cotton.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Capture site</th>
<th>Issaquah</th>
<th>East Fork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>Issaquah</td>
<td>46 (100%)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>East Fork</td>
<td>8 (30%)</td>
<td>19 (70%)</td>
</tr>
<tr>
<td>Anosmic</td>
<td>Issaquah</td>
<td>39 (76%)</td>
<td>12 (24%)</td>
</tr>
<tr>
<td></td>
<td>East Fork</td>
<td>16 (84%)</td>
<td>3 (16%)</td>
</tr>
</tbody>
</table>

Imprinting

1. Takes place as a specific stage in development
2. Requires no rewards, punishment, or reinforcement
3. Is remembered for a long period of time
4. Elicits a response in a specific context
1. Rivers differ in chemistry (Rocks, soil, plants, etc.).
2. Differences are stable over seasons and years.
3. Salmon can learn these odors.
4. Salmon are attracted to the learned odors at maturity.
The anatomy of the olfactory area develops and sensory cells proliferate at maturation.

Water is funneled over the olfactory rosette as the fish moves through the water.
Experimental test of olfactory imprinting

Rear coho salmon in a hatchery that does not discharge into Lake Michigan

Expose fish to either of two artificial odors (or controls) as smolts

Release the smolts into the lake

At maturity, dribble each odor into a different stream and monitor those streams and also streams with no artificial odors

Which streams do the adults ascend?

Lake Michigan

Control – no odor

Morpholine odor

Control – no odor

PEA odor

Control – no odor
Experimental evidence of olfactory imprinting

Juvenile coho were exposed to PEA or Morpholine, then released into Lake Michigan. PEA and Morpholine were metered into streams to decoy adults.

<table>
<thead>
<tr>
<th>Recovery site</th>
<th>Morpholine</th>
<th>PEA</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Manitowoc River (Morpholine)</td>
<td>96.6</td>
<td>5.5</td>
<td>26.7</td>
</tr>
<tr>
<td>Two Rivers (PEA)</td>
<td>1.3</td>
<td>92.0</td>
<td>19.3</td>
</tr>
<tr>
<td>Release site</td>
<td>0.1</td>
<td>0.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Other sites</td>
<td>1.9</td>
<td>2.5</td>
<td>51.2</td>
</tr>
</tbody>
</table>

Given that adult salmon use odors that they learned as juveniles to identify home, how do they actually migrate up complex river systems?

Salmon do not seem to follow odor gradients. Rather, detection of the home odors triggers upstream swimming (positive rheotaxis).
Find River Mouth

Enter River

Home Odor Present?

Lateral Movements

Leave Home Odor?

Swim Upriver

Home?

Spawn

Find Bank: Odors Present?

Zig-Zag Upriver

Find Odors?

Backtrack

Leave River

Ocean

River

Quinn, based on Peter Johnsen
When do salmon learn?
Donaldson and Allen. 1957. T.A.F.S.

- Coho parr from Soos Creek hatchery brought to UW or Issaquah Creek for two months of rearing prior to release.
- Of those released at Issaquah 70 returned to Issaquah, 1 to UW, and 0 to Soos Creek.
- Of those released at UW, 124 returned to UW, 0 to Issaquah, and 0 to Soos Creek.

Conclusion?
Relationship between straying of coho, Chinook and steelhead, and the distance between rearing and release sites in the same river system (Lister et al. 1981)

<table>
<thead>
<tr>
<th>Rearing – release distance (km)</th>
<th>0</th>
<th>4-29</th>
<th>47-485</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of studies</td>
<td>10</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Avg. straying from release site</td>
<td>3%</td>
<td>74%</td>
<td>8%</td>
</tr>
<tr>
<td>Range</td>
<td>0-13%</td>
<td>37-100%</td>
<td>1-39%</td>
</tr>
<tr>
<td>% straying to rearing site</td>
<td>-</td>
<td>77%</td>
<td>55%</td>
</tr>
</tbody>
</table>

In 5 studies, smolts were released in other river systems; only 0 – 6% strayed from the release site.
Coho salmon commonly emerge in small streams, over-winter in side-channels or beaver ponds, and leave as smolts from large rivers.

Where and when do they imprint on home odors?
Sockeye salmon fry typically emerge in tributaries or lake beaches but leave as smolts from the lake’s outlet.
Do salmon imprint only once, as smolts, or sequentially during their lives in fresh water and their migrations to sea?
Straying by hatchery-produced coho salmon released on-site, downriver and at sea. All coho reared at Cascade Hatchery, near Bonneville Dam.

<table>
<thead>
<tr>
<th>Release location</th>
<th>% escapement outside Columbia River basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Bonneville Dam</td>
<td>&lt; 0.1%</td>
</tr>
<tr>
<td>Tongue Point</td>
<td>3</td>
</tr>
<tr>
<td>River bar</td>
<td>4</td>
</tr>
<tr>
<td>River plume (19 km offshore)</td>
<td>6</td>
</tr>
<tr>
<td>Non-plume (19 km offshore)</td>
<td>21</td>
</tr>
<tr>
<td>Non-plume (38 km offshore)</td>
<td>38</td>
</tr>
</tbody>
</table>

Hypothesized relationship between thyroxine, olfactory imprinting, and migration by coho salmon

Light-Dark Cycle + Circannual Rhythm + Temp. → Elevated Thyroxine → Tendency or Propensity to Learn Odors → Tendency to Migrate → Likelihood of Experiencing New Odors

Source: Dickhoff and co-workers
Genetic vs. learned elements in homing

The vast majority of studies show that salmon transplanted as smolts return to the release site rather than their ancestral home. Thus it is generally assumed that homing is based entirely on learned information. However, spawning site selection must be innate rather than learned, so might there be innate aspects of homing as well?
Coho salmon strayed more when released from a non-natal river than when released from their river of origin.

<table>
<thead>
<tr>
<th>River of origin</th>
<th>Release site</th>
<th>Adults</th>
<th>Jacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trent River</td>
<td>Trent River</td>
<td>10.2</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>Rosewall Creek</td>
<td>27.7</td>
<td>13.9</td>
</tr>
<tr>
<td>Black Creek</td>
<td>Black Creek</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Rosewall Creek</td>
<td>24.1</td>
<td>0</td>
</tr>
<tr>
<td>Little Qualicum R.</td>
<td>Little Qualicum</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Rosewall Creek</td>
<td>8.3</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Labelle, M. 1990. PhD, University of B.C.
Genetic and Learned Components in Chinook Salmon Homing

1. = upriver controls: Priest Rapids Hatchery fish, released from Priest Rapids

2. = lower river controls: Bonneville Hatchery fish, released from Bonneville Hatchery

3. = upriver transplants: Upriver parents but reared and released at Bonneville Hatchery
## % recovery of three chinook salmon groups

<table>
<thead>
<tr>
<th>Recovery area</th>
<th>Upriver controls</th>
<th>Lower river controls</th>
<th>Upriver transplants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonneville Hatchery</td>
<td>0</td>
<td>99</td>
<td>84</td>
</tr>
<tr>
<td>Below BD</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Above BD</td>
<td>0</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Priest Rapids</td>
<td>98</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Upper basin</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
A pheromone hypothesis for homeward migration in anadromous salmonids


“...the descending smolt establish population-specific pheromone trails leading from their respective freshwater home localities out to the salmon at sea. The maturing salmon respond innately to the smolt pheromones...and start homewards...resident [parr] populations themselves may mark the end of the homeward routes.”
Pheromone hypothesis

Key elements:
1. Salmon produce population-specific odors
2. Salmon can detect population-specific odors
3. Population-specific odors guide the homing migration
Pheromone Hypothesis

Questions:

1. How do the fish distinguish among populations?
   1. Genotype matching? Innate attraction?
   2. Phenotype matching? Ability to learn odors?

2. Would these odors meet the definition of pheromones?
   1. Evolved for communication or by-products?
   2. What would the selective pressures be?

3. How could adults home if no juveniles were resident or migrating from natal stream (pinks)?

4. What chemicals would vary consistently among populations but be stable despite changes in diet?
Tests of the Pheromone Hypothesis

- Experiments have shown that salmonids can distinguish their population from others by odors alone.
- Salmonids can also distinguish their siblings from others in their population.
- However, experiments indicated that salmon will home to the natal site rather than a non-natal site with pheromones.
Home is where one starts from. As we grow older, the world becomes stranger, the pattern more complicated of dead and living.

T. S. Eliot, “East Coker”