A Salish Sea-wide anomaly

The Salish Sea

Pacific Ocean

Strait of Georgia

Juan de Fuca Strait

Puget Sound
Decline in Salish Sea Marine Survival

Puget Sound
Strait of Georgia
VS
Washington / B.C. Coast

Coho
Chinook
Steelhead
Other known significant changes in the Salish Sea
What are primary factors affecting juvenile Chinook, coho & steelhead survival in the Salish Sea marine environment?
Funding Status

<table>
<thead>
<tr>
<th>Budget</th>
<th>$10 M</th>
<th>$10 M</th>
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<tr>
<td>Raised</td>
<td>$5.5 M</td>
<td>$10 M</td>
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Highlights

- $5 M Southern Endowment Fund Pacific Salmon Treaty – split between US and Canada
- $1.6 M Washington State legislature
- 1:1 in-kind match by participating entities
Objectives

Advance wild salmon recovery and sustainable fisheries

• What happened since the 1980’s and can we improve the situation for juvenile Chinook, coho and steelhead?

• How do we improve the accuracy of adult return forecasting with early marine survival data: to better manage harvest, hatcheries and natural spawning?
Hypotheses

A. **Bottom-up processes** that drive Chinook, coho and forage fish prey availability have changed, and salmon aren’t able to compensate.

B. **Top-down processes contributing** – More predators making situation worse. Eating larger juvenile steelhead, resident salmon and forage fish.

C. **Other factors may compound the problem:**
   - Microbes & disease
   - Toxics
   - Habitat degradation (role of estuaries?)

Ultimately, must weigh the contribution of:

- Local, human influence (water quality, predator management, hatchery management)
- Regional or global impacts (climate change, ocean acidification, natural cycles)
Research Highlights

• Survival analyses nearly complete
• Improving physical>biological connection

• Growth & survival studies underway
• Citizen Science in Strait of Georgia
• Sound-wide zooplankton program implemented

• Sound-wide contaminants assessment complete
• New tech - Seal head mounted PIT tag reader
• 9 Puget Sound steelhead studies
Growth & Survival: Building out from rivers

The Salish Sea
Salish Sea-wide Sampling Regime

Sampling directly affiliated with Project
- Buoys
- Zooplankton
- Juv. Salmon
Upgraded Acoustic Receiver Arrays
Puget Sound Steelhead
9 Puget Sound steelhead studies to:

1. Assess correlations between survival and ecosystem & fish characteristics

2. Identify locations, rate and timing of mortality

3. Evaluate disease, toxic contaminants, genetics, and predator-prey interactions to reveal the direct and underlying causes of mortality
Abundance trends – South to North

Declines increase from North to South Puget Sound

Kendall et al. (WDFW)
Environmental indicators & survival

Indicators “with long-term data-sets”

Kendall et al. (WDFW)

Disease
Contaminants
Etc.
Smolt migration & survival

Rapid migration (~20%)

Moore et al. (Mar. Ecol. Prog. Ser. In review)
Freshwater and Marine Factors

Green = urban | hatchery

Nisqually = undeveloped | wild
Key Findings

✓ Migration rate is very rapid - about 2 weeks

✓ Survival of Puget Sound steelhead smolts to the Pacific Ocean is low
  Green – 17%, Nisqually – 6%

✓ No apparent effects of population, translocation, or body size

✓ Release date was moderately important

✓ Highest mortality rates in the first marine segment

✓ Longer migrations through Puget Sound are associated with higher mortality

Moore et al. (in prep)
Where is mortality most acute?
Abnormal tag ‘behavior’ patterns

Nisqually River

Tidal height (ft)

15813

RKM -1.4
RKM 0.2
RKM 1.1
RKM 4.0


14
12
10
8
6
4
2
0
-2
-4
Identifying potential predators

**Top**
- Harbor seal
- Double-crested & Brandt’s cormorants
- Caspian terns

**Secondary**
- Harbor porpoise
- Common murre

Pearson et al. (WDFW)
Steelhead and Seals

Graph showing the Inland Washington stock of Steelhead and Harbor Seals from 1975 to 2000.

- Blue line = Steelhead
- Black line = Harbor Seals

Image of Harbor Seals.
Warning: Correlation ≠ Causation
Steelhead and Seals
Berejikian, Moore, and Jeffries (in prep)
What is the role of fish condition?
Sampling Design

5 Puget Sound watersheds
- Hatcheries
- Traps
- Lower River / Estuary

3 Offshore Areas
- Whidbey Basin
- Green / Duwamish
- Nisqually
Steelhead **PCB levels** generally low: 1.4 – 2.2x lower than Chinook at same locations.

16.7% Central and 25% South Puget Sound samples exceeded PCB adverse effects threshold.

Steelhead **PBDE levels** high in Nisqually, and 1.1 to 3 times higher than Chinook at same locations.

25% Central and South Puget Sound, and 33% Nisqually River samples = increased disease susceptibility

33% Nisqually estuary samples = altered thyroid production

O’Neil et al (WDFW)
Nanophyetus (parasite)

Key = 0, medium, high, very high

- Infection prevalence
- Parasite load

Findings

☑ No Nanophyetus in Skagit, Snohomish, Tahuya, Whidbey Basin

☑ Prevalence and parasite loads increase from trap to estuary in Green.

☑ Prevalence and parasite loads in Nisqually extremely high.

Chen (NWIFC) and Hershberger (USGS)
Prevalence of other features

Key = 0-20%, 20-40%, 40-60%, >60%

☐ Nanophyetus

△ Kidney Myxosporean

☆ Sanguinicola

⊆ Gill inflammation

❤ Heart inflammation

Findings

✓ Many fish from Green and Nisqually with Nanophyetus exhibit gill & heart inflammation.

✓ Heart & gill inflammation could be indication of compromised swimming performance.

Chen (NWIFC) and Hershberger (USGS)
Genome-Wide Association Study
Survivors vs Non-survivors (Methods)

• Genome-wide association studies (GWAS) ask:
  – Is there an significant correlation between genetic “fingerprints” and phenotype, behavior, life history . . . ?
  – For this specific study: between steelhead smolt genotypes and their fate (survival v. mortality) in Puget Sound?

• Acoustically tagged smolts

• Mortality = no detections in Puget Sound

• Survival = detection at last (SJF) array

• Genomic sequencing (~ 5700 “genes”)

• Six analyses with different grouping factors

Warheit (WDFW)
Genome-Wide Association Study
Survivors vs Non-survivors (samples and detection locations)
Genome-Wide Association Study
Survivors vs Non-survivors (Are there genetic differences?)

Expected $-\log_{10}(p\text{-value})$ – assuming uniform distribution and no association
Sequence Alignment with NCBI (NIH) database using BLAST

1. Morphogenesis. Possibly involved with fin development. Swim performance?
2. Possibly immunological
3. No alignment with salmonid sequences in NCBI database
4. Immunological or morphogenesis
Conclusions - Steelhead

- **Worse South – Better North** abundance (and survival) trends help hone in on mortality drivers.

- **Reciprocal transplant suggests marine mortality driver** and illustrates increased death by distance traveled through Puget Sound.

- **Disease prevalence and associated fish condition** (compromised gills, heart) may make South to Central Sound Puget Sound populations more vulnerable to predation. PBDE levels may contribute in Nisqually.

- Smolts in some populations with particular genetic fingerprints may be **compromised by their morphology (fin development) or immunological responses** making them sick or more vulnerable to predation.

- **Predation occurring and may include multiple predators.** Pop. increase, distribution, prey range, presence during steelhead outmigration, encounters, abnormal tag behavior, and stationary tag detection locations suggest harbor seals a likely predator. Harbor porpoises, cormorants, loons, common murres not studied. Of those, harbor porpoises w/ significant increase in population presence/distribution in Puget Sound.

- Correlational relationships may help put current findings in **ecosystem change context** and suggest potential drivers: + herring, - hatchery coho releases, + harbor seal.
Thank You!

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