Density-dependent and landscape effects upon estuary rearing in Chinook salmon: insights from long-term monitoring in four Puget Sound estuaries

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Chinook salmon and estuary habitat loss

ESA listing affects natural resources management:
• Critical habitat issues in US
• Potential to shut down fisheries
• Orca food – proposal to increase hatchery production to boost prey
• PSP Vital Sign – road to recovery by 2020

Extensive use of estuaries by juveniles

Current area = 1-55% of historical (PSNERP Change Analysis 2011)
Chinook in estuaries: Which life history types benefit?

**Subyearling hatchery (marked) populations**
- Emergent fry
- Rear in hatchery (months)
- Migrate through (days)
- Migrate through (days)
- Hatchery migrant

**Wild (unmarked) populations**
- Emergent fry
- Rear in freshwater
- Several months
- > 1 year
- Migrate downstream as fry
- Migrate through (days)
- Migrate through (days)
- Rear in natal estuary (wks to months)
- Migrate through (days)
- Rear in nearshore refuge habitats (wks to months)
- Fry migrant
- Nearshore refuge Rearing Fry migrant
- Tidal Delta Rearing migrant
- Parr migrant
- Yearling migrant
Questions

What landscape features influence distribution and abundance of fish?
- Estuary system
- Landscape connectivity
- Habitat types
- Channel types

Does estuary habitat limit population recovery?
- Evaluating density dependence among populations
- Possible hatchery interactions in estuaries
Landscape features

Estuary system

Landscape connectivity

Channel type

Wetland habitat type

Nooksack
Skagit
Snohomish
Nisqually
Landscape features

Estuary system

Landscape connectivity

Channel type

Wetland habitat type

Nooksack
Skagit
Snohomish
Nisqually

Distributary
Offchannel

Offchannel
Landscape features

Estuary system

Landscape connectivity

Channel type

Wetland habitat type

Nooksack
Skagit
Snohomish
Nisqually

Forested riverine tidal (FRT)

Estuarine emergent
marsh (EEM)

Estuarine forest transition (EFT)
Hatchery vs natural origin fish

**Migrant fry**

**Hatchery releases**

Outmigrants/ha of estuary channel

Outmigration year

- Nisqually
- Nooksack
- Skagit
- Snohomish
System differences

![Bar chart showing average Chinook 0+ density (fish/ha) for different systems: Skagit, Snohomish, Nooksack, and Nisqually. The chart compares total and unmarked fish densities.](image)
Channel & habitat types

FRT = Forested riverine tidal
EFT = Estuarine forest transition
EEM = Estuarine emergent marsh
Density-dependent relationships

![Graph showing the relationship between UM Chinook density and Fry outmigrants/channel area](image)
Testing for density dependence

Estuary productivity = Average annual estuary density
Migrant fry/channel area

\[ \log_e(d/f) = \log_e(a) + bf \]

Density-dependent

Density-independent
Density-dependent relationships

Outmigrant fry / channel area (ha)

$\log_e$ (Estuary productivity)

Other population traits exhibiting density dependence in the Skagit:

- Estuary growth and size
- Residence time in estuary
- Proportion of migrants entering Puget Sound as fry
- Smolt-adult return rate
Potential interactions with hatchery fish

Additional analyses indicate:
- Bioenergetic models – high consumption demand by hatchery fish in 3 estuaries
- Seasonal declines in unmarked fish after hatchery releases
Conclusions

What landscape features influence distribution and abundance of fish?
- Estuary system
- Landscape connectivity
- Habitat types
- Channel types
- Context-dependent effects

Does estuary habitat limit population recovery?
- Evidence for density-dependent interactions at large outmigrations
- These levels were not observed in 2 populations
- Densities of unmarked fish negatively tracked hatchery releases
- Hatchery releases regularly surpass estimated maximum densities

Relevant improving benefits of restoration
Thanks!
Statistical analysis

Question:
What landscape features influence annual densities of unmarked salmon?

Four main effects:
- Estuary System (Nooksack, Skagit, Snohomish, Nisqually)
- Landscape connectivity (covariate)
- Habitat type (Forested riverine tidal, estuarine forest transition, estuarine emergent marsh)
- Channel type (Off-channel, distributary)

Interactions of main effects:
- System * connectivity
- System * habitat type
- System * channel type
- Connectivity * habitat type
- Connectivity * channel type
Statistical analysis

Question:
Does estuary habitat limit population recovery?

Remove landscape effects:
- Landscape connectivity (covariate)
- Channel type (off-channel, distributary)
- Connectivity * channel type

Retain system and habitat-dependent variation to test for annual effects of:
- Migrant fry
- Hatchery releases
Density-dependent relationships

\[ \log_e(\text{Estuary productivity}) \]

Outmigrant fry / channel area (ha)
Prediction: if there is competition, fish should become less selective at higher fish densities

Test: Similarity of diet composition and prey availability

David et al. 2016
Potential interactions with hatchery fish

Possible causes

- “Pied-piper effect”: fish follow large migrations
- Pulsed competition for food during hatchery releases induces early migration
- Introgression of genotypes for rapid outmigration
- Down-river transmission of pathogens from hatcheries

Additional research needed
Consumption demand of hatchery fish

Nooksack

Skagit

Snohomish

Nisqually
Possible Decision Framework

Are migrations dominated by fry?

- Yes
  - Reduce mortality of adults
  - Improve FW habitat conditions
- No

Is estuary habitat limited during large migrations?

- Yes
  - Reconnect off-channel sites
  - Improve landscape connectivity
  - Increase FRT or EFT habitat conditions
- No

Do hatchery releases dominate migrations?

- Yes
  - Prioritize increasing capacity in multiple habitat types
  - Consider hatchery management and habitat restoration objectives jointly
    - Later releases
    - Releases from out-of-system hatcheries
- No

Skagit

Nooksack estuary

Nooksack

Snohomish

Nisqually