Effects of large infrastructure on the underwater visual environment and heightened predation on salmon in the Salish Sea

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Infrastructure Impacts on the Underwater Visual Environment & Salmonid Predation

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Hood Canal Bridge

Photo credit: Hans Daubengerer
Human Impacts on Visual Environment

• Change in land & water use

• Nutrient input/diversion (Ag & Urban)
  – Productivity & Organic turbidity

• Turbidity Change:
  – Increased by erosion (Land Development, Ag)
  – Decreased by dams (sediment traps, altered spring run-off patterns)

• Urbanization-Artificial Lighting
Skyglow can increase light by ecologically significant levels 10s of km from source, creating light halos around cities.

- Increases light in pelagic waters far from the source.

Artificial Light At Night (ALAN)

1- Direct spillover of light into aquatic habitats
   - Localized effects (1-100 m)

2- Skyglow is light reflected from the atmosphere or clouds back to earth at high levels around cities
   - Far-reaching effects (10-80 km from source)

Mexico City at night

By Fernando Tomás from Zaragoza, Spain - Flickr, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=348732
Why Focus on Visual Environment?

- Vision is the primary sensory mechanism used by predators in Pelagic (openwater) habitats.
- Vision essential for Foraging & Predator Avoidance:
  - **Planktivores** (eat zooplankton)
  - **Piscivores** (eat fish)
- Visual conditions are dynamic through time & space, and vary widely among waters.
- Food webs function differently as visual conditions change.
- Land-Water Use & Infrastructure have changed the underwater visual environment (artificial lighting, dams, ag/urban run-off).
Night Satellite Imagery

Salish Sea & Coastal Wa-BC

Link change in light environment to visual capabilities of predators to assess how predation risk has changed

Threshold Effects on Visual Prey Detection

Characteristic response to Light

Characteristic response to Turbidity

**Prey Size:**
RD reduced for Prey < 45-50 mm
-Pigmentation important

RD constant for Prey > 50 mm
-Schools no easier to detect than Single prey fish > 50 mm!

Functions for piscivorous:
- Chinook Salmon
- Coastal Cutthroat trout
- Inland Cutthroat trout
- Rainbow trout
- Lake Trout

Apply functions to Ambient Visual conditions to predict Foraging capability at:
-any depth
-any time of day or night
-any time of year
Artificial Light Pollution is shifting Night toward twilight conditions that increase predators’ efficiency.
Effect of Urban Light Pollution on Predation Risk:
- Nocturnal Migratory Corridors & Feeding Habitat
- Dark Nocturnal Refuge in Early Marine Life

Resident Chinook & Coho overlap with depths of juvenile salmon
Sufficient light penetration at night to support effective nocturnal predation

7x increased risk

Depth of Ship Canal
Depth of juvenile salmon
In Puget Sound
0-15 m thru July
0-30~45 m after July

50% reduction in light = Predation risk reduction to 25% of present
Depth integrated chlorophyll, a proxy for sub-surface phytoplankton biomass has been declining.

**Puget Sound Water Quality Trends**

**Chlorophyll declining**

\[ y = -6.5713x + 132.00 \]
\[ R^2 = 0.5932 \]

**“Transparency” Increasing**

\[ y = 0.5973x - 119.83 \]
\[ R^2 = 0.7608 \]

**Bottom-up processes affect Magnitude of predation mortality Via prey growth & detection**

Increasing *Noctoluca*: Gelatinous dinoflagellate Feeds on Diatoms

Decline in edible phytoplankton (Diatoms)

Increased transparency & Predation risk
Elwha River Plume

Juvenile salmon:
Feeding on
Zooplankton
& Surface Insect
w/out impediment

Piscivores:
Foraging Ineffective for:
-Pelagic Fish
-Some Birds & Mammals

Piscivores effective

Photo Credit: Tom Roorda
Mechanistic Integration Needed

Important to recognize mechanistic interplay among water quality-quantity with bottom-up and top-down processes as they affect salmon productivity & ecosystem health

Mechanistic Guide for Restoration
- Identify & target critical life stages & habitats
- Prioritize restoration of habitat function to enhance Growth & Survival
- Calibrate expectations to goals and actions targeting short- versus long-term restoration
Summary: Top-Down Processes

• Piscivorous Fish exhibit size-selective predation
  • Size-selectivity likely more variable for mammals & birds
  • Harbor seals implicated in marine mortality of steelhead, but their effects on Chinook and Coho less understood

• Visual foraging conditions have shifted in favor of predators
  • All major salmon predators primarily use vision to feed
  • Artificial lighting & skyglow have significantly increased nocturnal threat environment throughout Puget Sound
  • Increasing subsurface transparency increases efficiency of visual predators (shifting plankton dynamics, timing and duration of turbidity plumes: dams, erosion)
ALAN: Artificial Light At Night  
Known & Potential Impacts

- Increase predation on juvenile salmon & forage fish during rearing & migration

- Aggregation of fish under lighted piers or bridges intensifies predation.

- Suppress zooplankton diel vertical migration by artificial skyglow.

- Disrupt larval invert. settlement site selection in Sessile spp.

- De-synchronize broadcast spawning-Lunar cycle cues

- Extend nocturnal foraging by wading birds


-Increased skyglow increases chronic nocturnal predation on smaller fish
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Light Effects:

- RD increases rapidly until reaching saturation intensity threshold (SIT)

- Max RD for Piscivores ~5x higher than for Planktivores

Turbidity Effects:

- RD for Piscivores declines after threshold of 1.5 NTU

- Minimal turbidity effect in Oligo-mesotrophic lakes (0-2 NTU)

- Proportional declines steeper for Piscivores (Confer et al. 1978, O'Brien 1987, Link & Edsall 1996)
Predicted Pelagic Piscivore-Planktivore Dynamics as Productivity Increases

Planktivores: go from Lo Growth & Hi Risk to Hi Growth & Hi Risk
Piscivores impose Heavy Predation: go from Lo Growth to High Growth

Planktivores: Risk declines rapidly & Growth Improves; Less DVM & Schools
Piscivores: Predation impacts decline, High Growth supported by Inverts

Piscivores: Shift to Benthic feeding &/or more inverts. Benthic & Littoral Predators dominate

Planktivores-Growth declines w/ inedible phytoplankton to support zooplankton
Shift to benthic & Surface feeding behavior/spp.

Foraging Behavior: Pelagic Cruising → Benthic Ambush/Sweep
Sensory Mechanism: Visual → Tactile-Chemo-Electro reception