

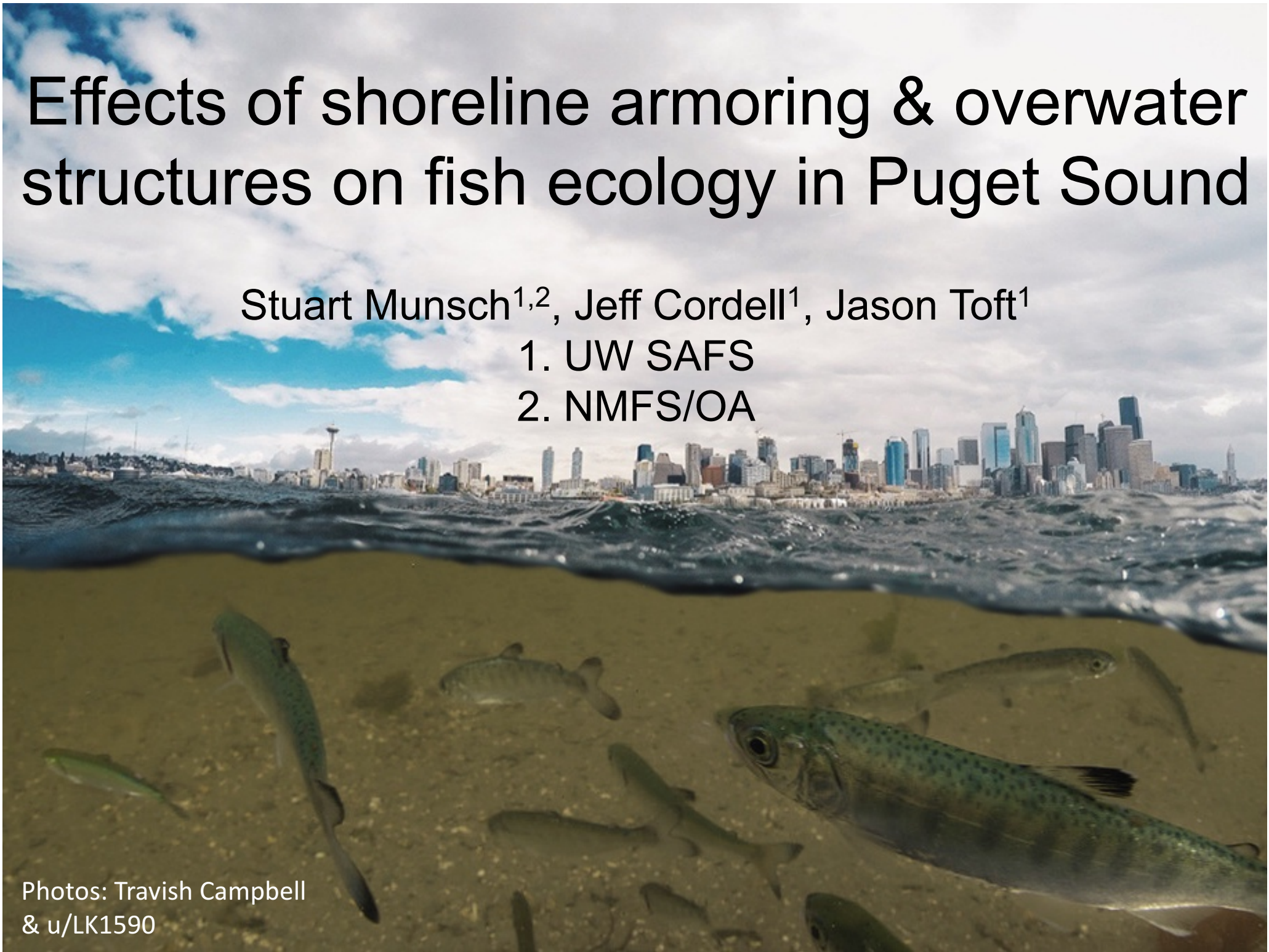
# Effects of shoreline armoring & overwater structures on fish ecology in Puget Sound

Stuart Munsch<sup>1,2</sup>, Jeff Cordell<sup>1</sup>, Jason Toft<sup>1</sup>

1. UW SAFS

2. NMFS/OA

Photos: Travish Campbell  
& u/LK1590



# PhD work w/Wetland Ecosystem Team



Stu Munsch



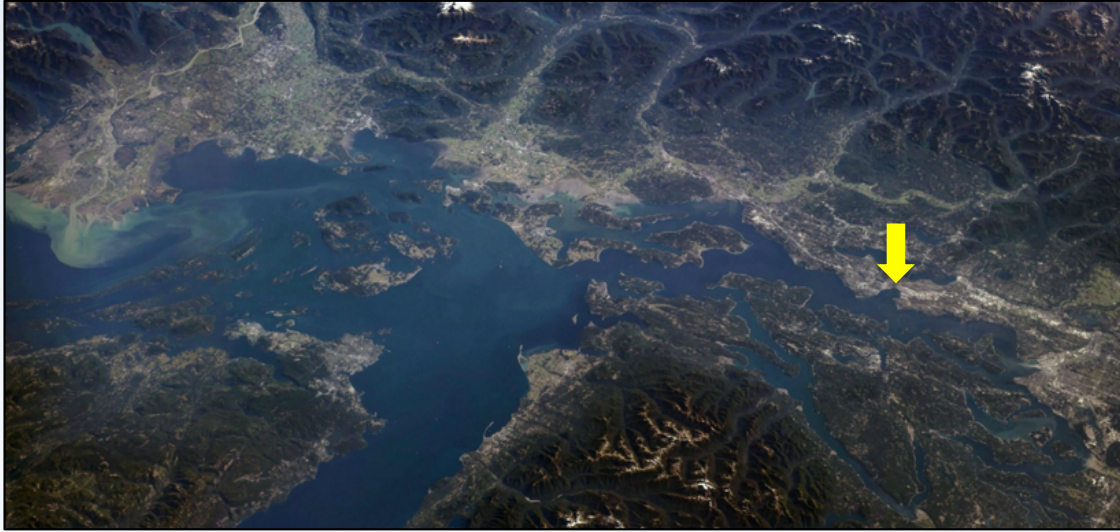
Jeff Cordell



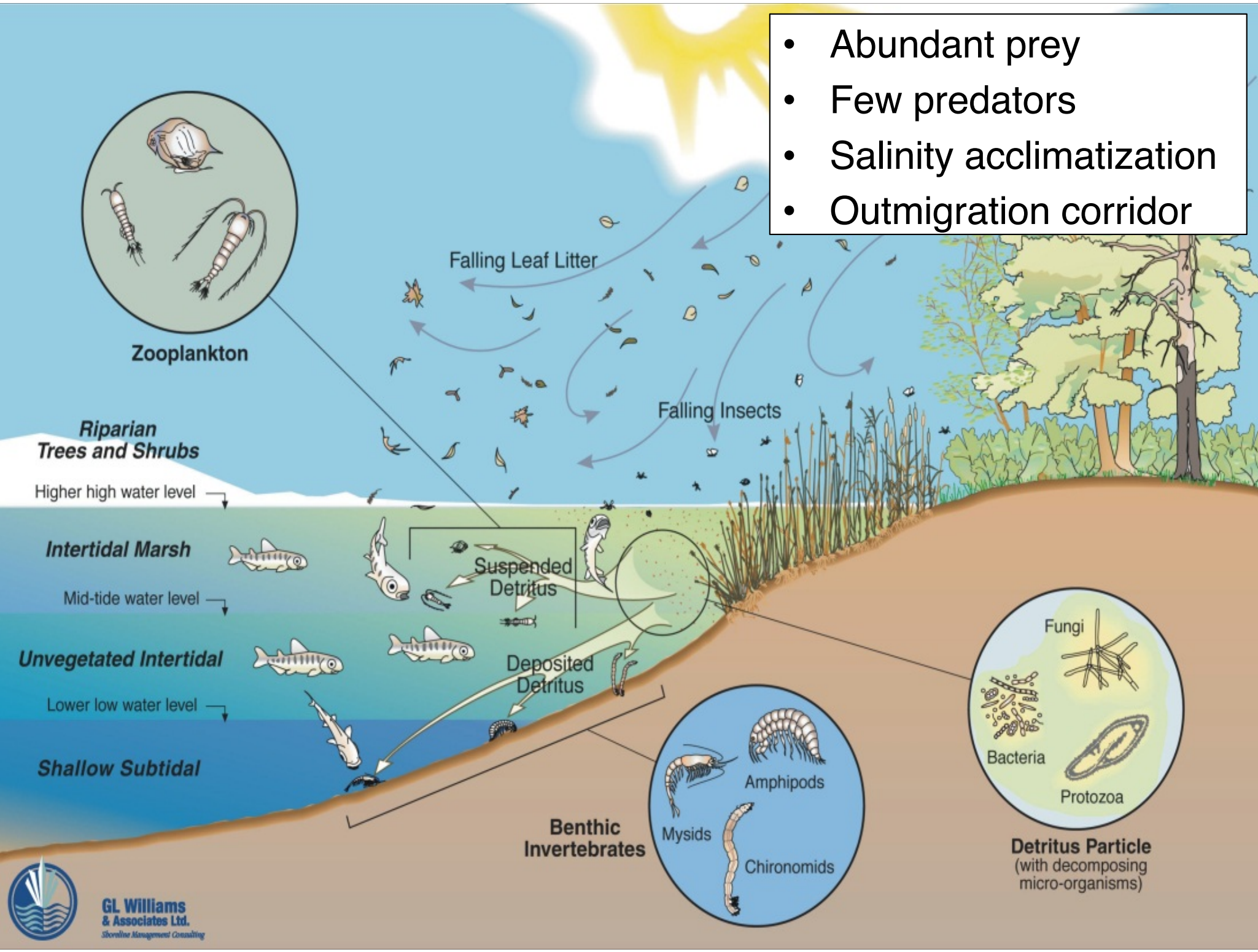
Jason Toft

School of Aquatic & Fishery Sciences  
University of Washington

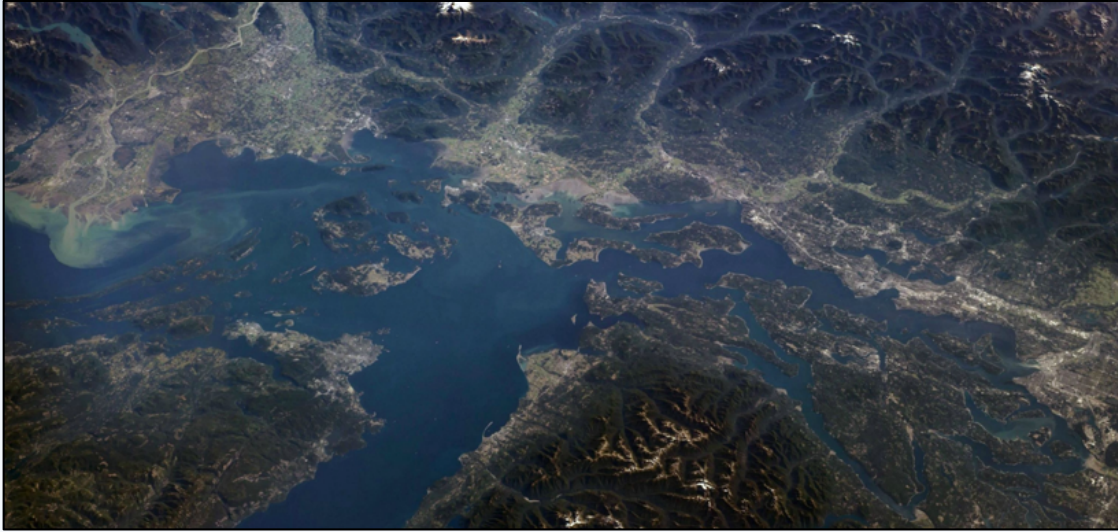
# Puget Sound



- Abundant prey
- Few predators
- Salinity acclimatization
- Outmigration corridor



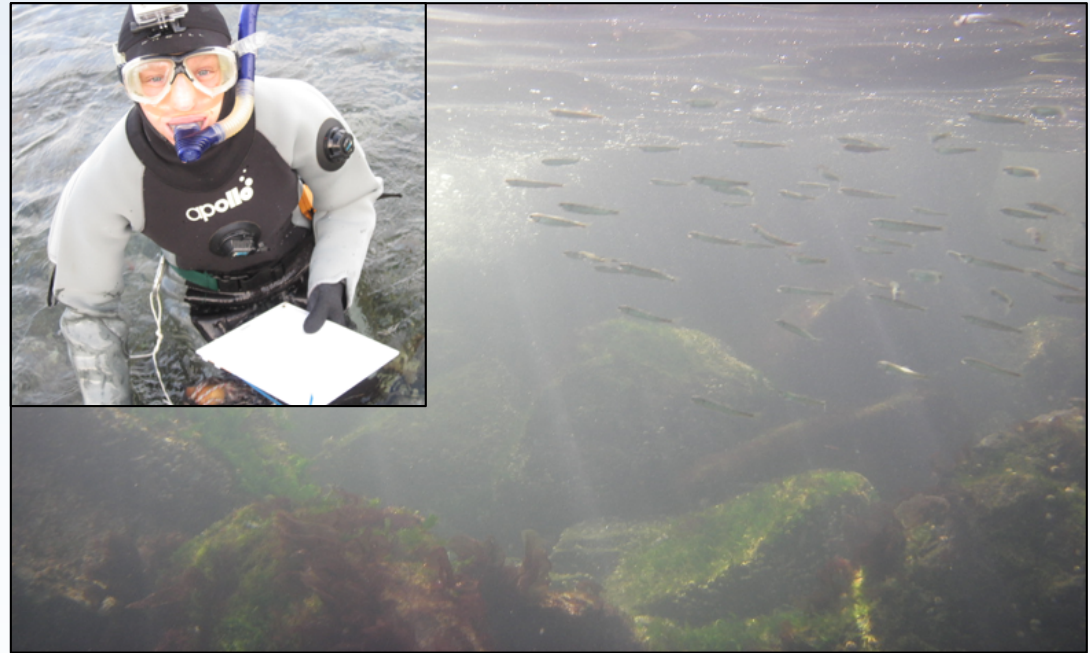
# Puget Sound, Armoring, & Overwater Structures



- 1/3 of Puget Sound's shorelines are armored<sup>1</sup>
- Overwater structures are common

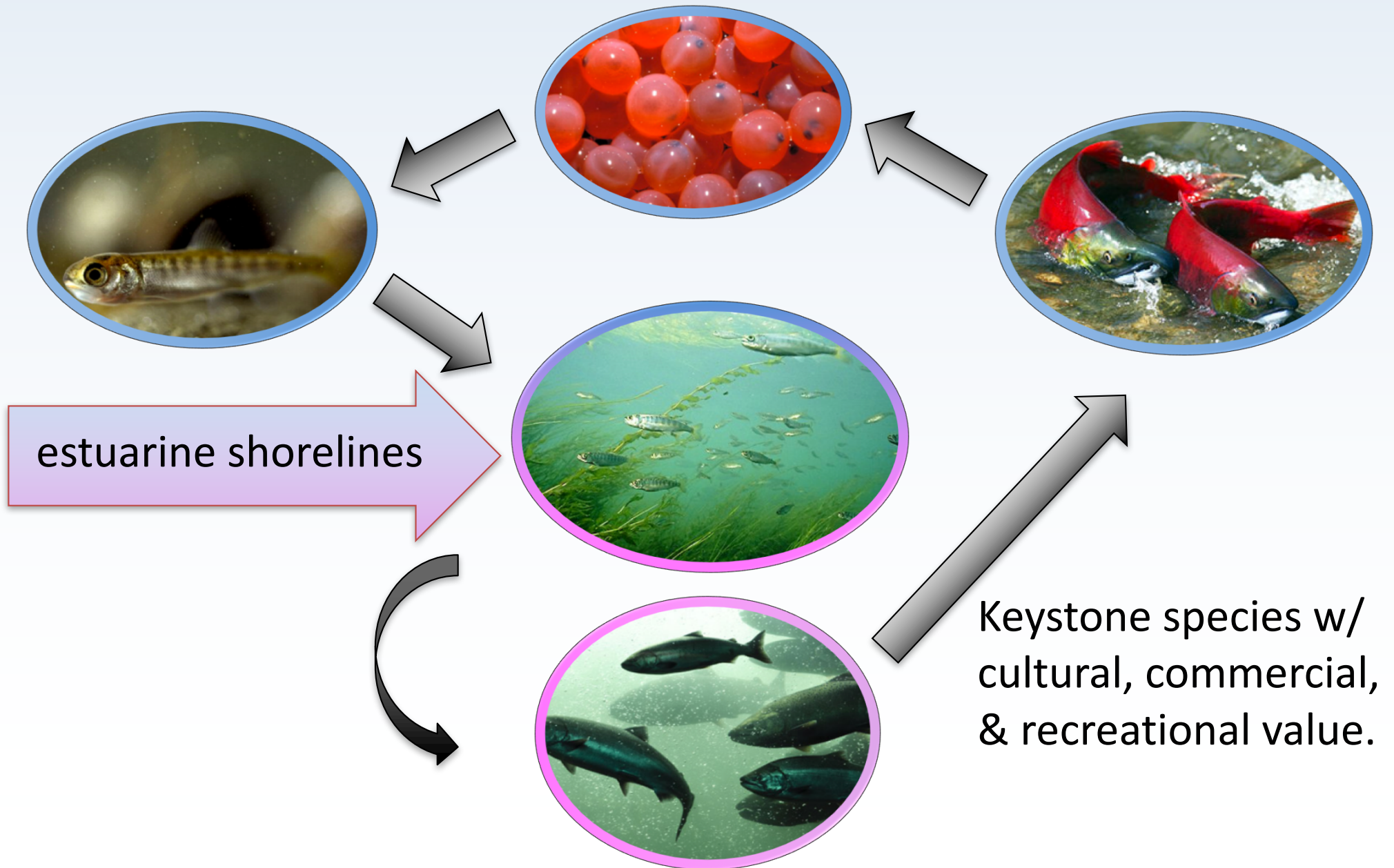
1. Simenstad et al. 2011

# Fish in Puget Sound occur and feed along highly modified shorelines



- Fish are trying to use modified habitats
  - Juvenile salmon are forced to use modified habitats along migratory routes
- How do shoreline armoring and overwater structures affect the function of nearshore fish habitats?

# Focal species: Pacific salmon



# Research & management opportunity: Reconstruction of a highly modified shoreline

1934



2014



- 2001 Nisqually Earthquake damaged the Elliott Bay seawall
- Waterfront needed reconstruction
  - Do armoring and overwater structures impair fish habitat?
  - Can we improve habitat along a highly modified waterfront?
- Elliott Bay has become a focal system for research examining effects of shoreline modifications on fish ecology



# Elliott Bay (WA)

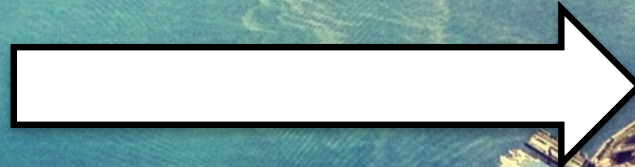
- 21 km<sup>2</sup> estuary bordering Seattle
  - Historical shores were beaches and mudflats
  - Presently 99% armored shoreline
- Economic center (restoration impractical & undesirable)
  - Commerce
  - Tourism
  - Recreation
  - Transportation
- Fish and crab habitat
  - Juvenile Chinook, chum, pink salmon are most abundant species
  - Chinook salmon listed as threatened under ESA
  - Species of cultural, ecological, and economic interest

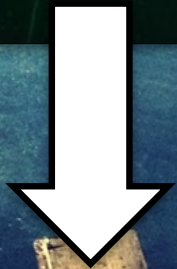


# An experimental system

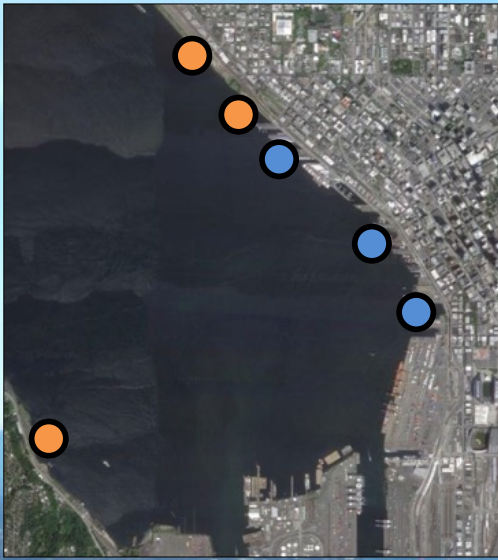








Can compare habitat use among sites with different modifications



# Data collection

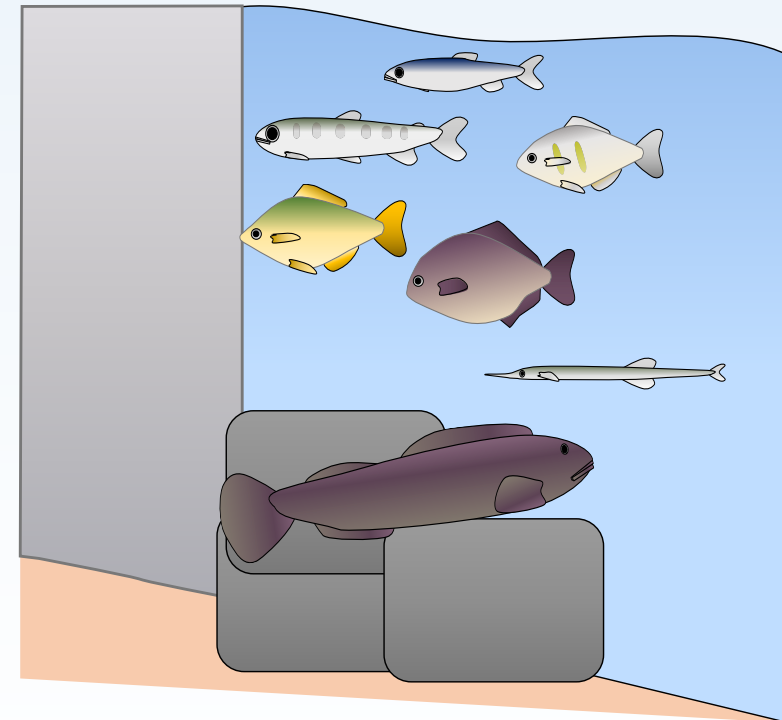
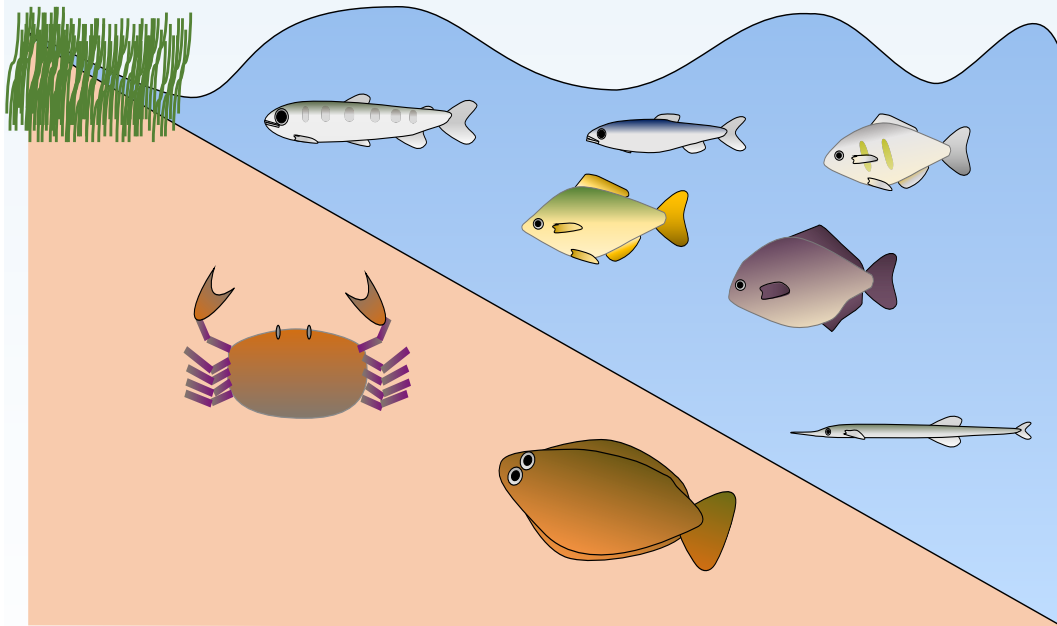


- Netting
- Snorkel observations
- Scuba observations
- Plankton sampling
- Diet sampling
- Egg monitoring



- Quantitative & empirical
- Observed hundreds of thousands of fish over about a decade

# Fish & crab assemblages differ between armored and unarmored shorelines

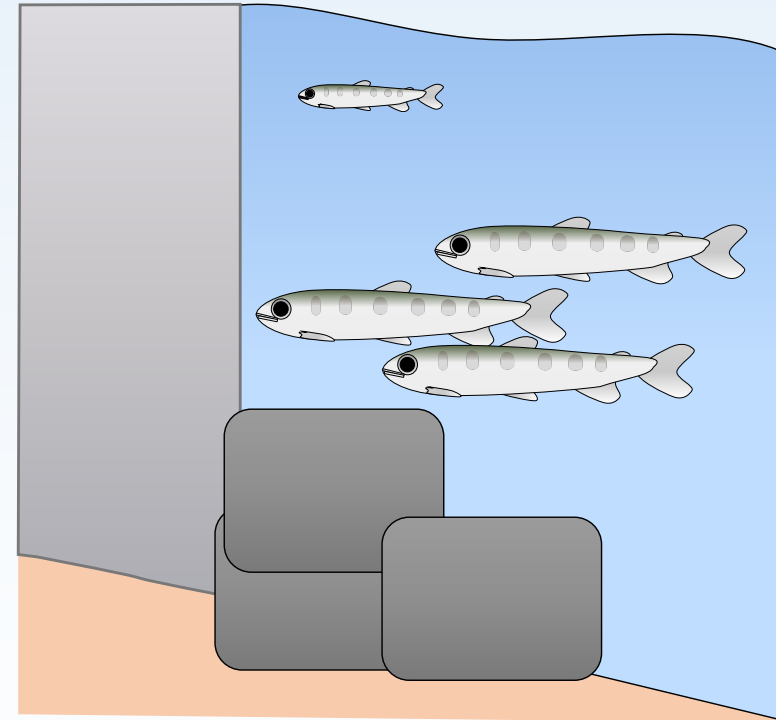
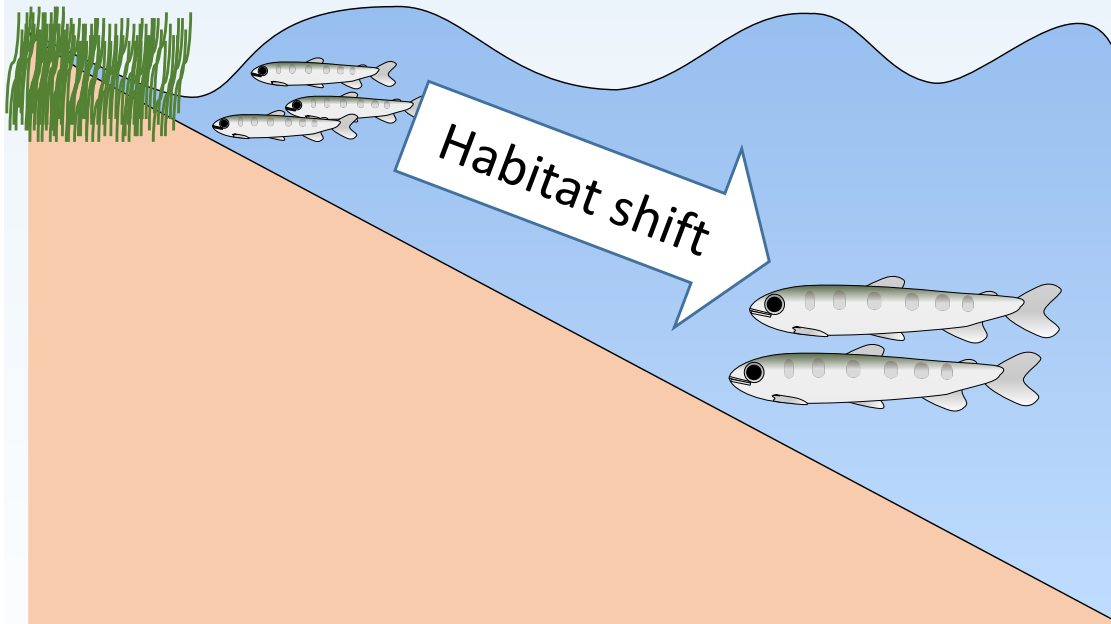


Presence of fish that select for sandy or rocky substrates is determined by shoreline structure<sup>3</sup>

1. Toft, Cordell, Simenstad, Stamatidou 2007 *NAJFM* (Snorkel surveys)
2. Morley, Toft, Hanson 2012 *Estuaries & Coasts* (Netting)
3. Munsch, Cordell, Toft 2015 *Ecological Engineering* (Scuba surveys)



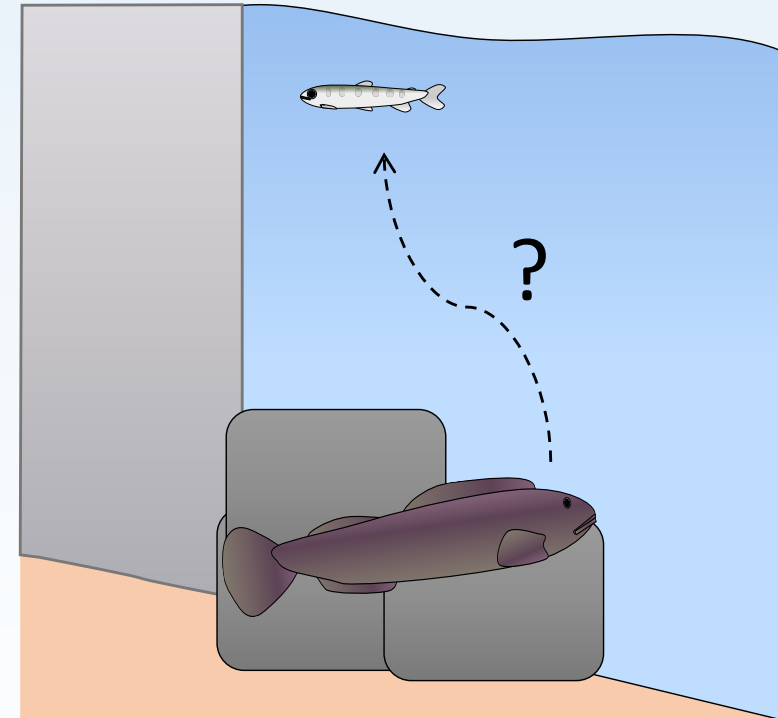
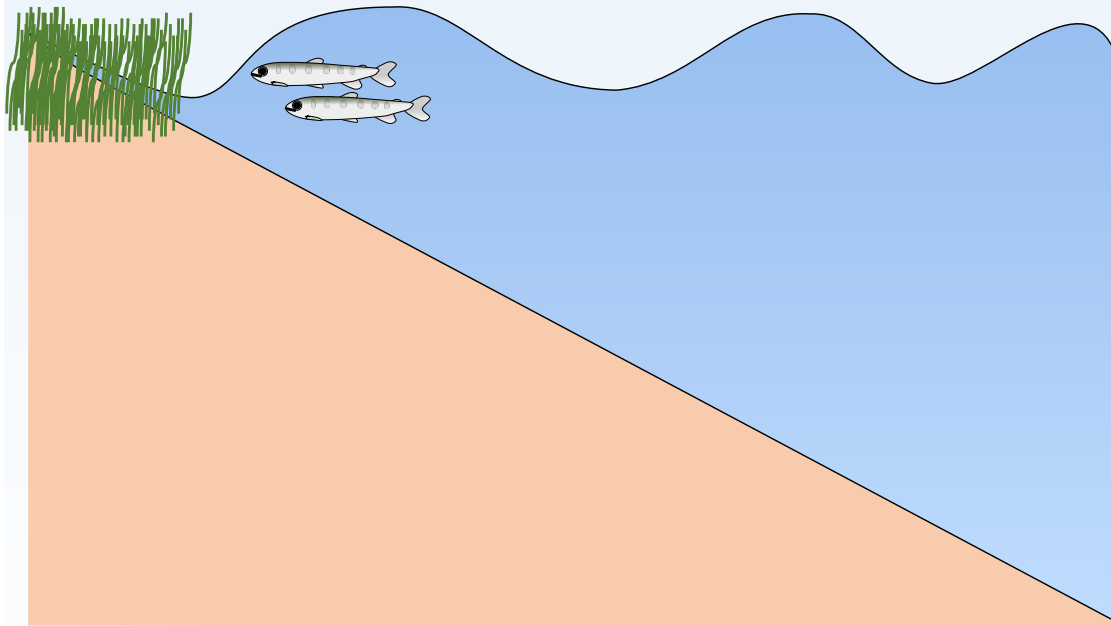
# Shoreline armoring that eliminates shallows prevents ontogenetic habitat shifts



- Juvenile salmon transition from extreme shallows to deeper waters as they grow
  - probably to balance safety of shallows with maximizing habitat use
- Armoring creates deep waters near shore inhabited by larger salmon

1. Munsch, Cordell, Toft 2016 *Marine Ecology Progress Series*

# Shoreline armoring exposes salmon to predators

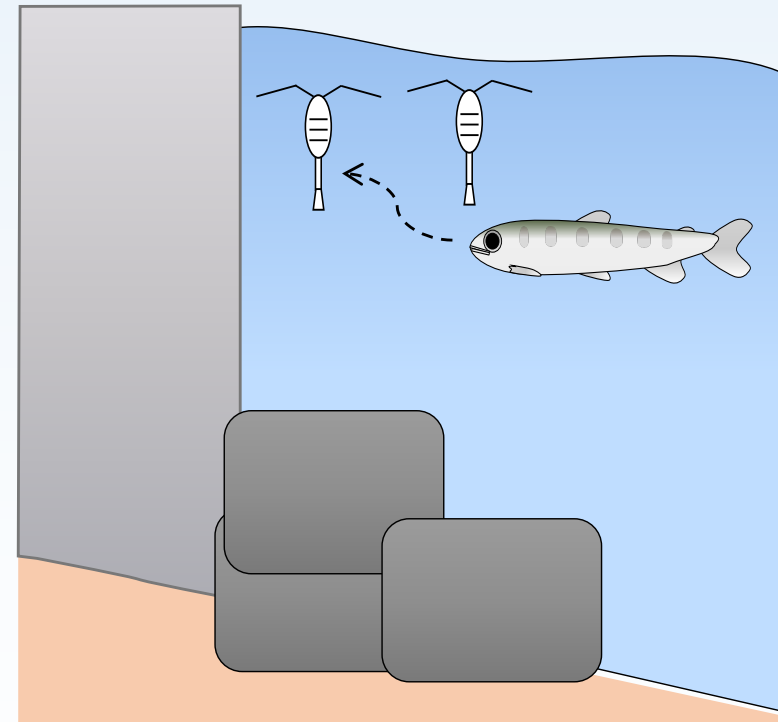
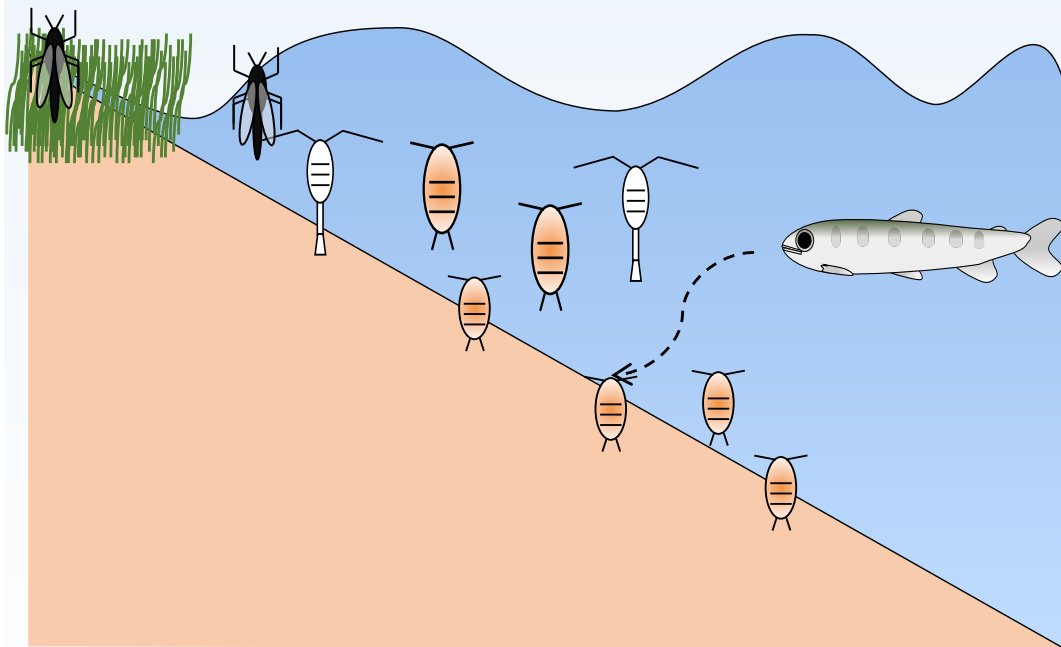


- Large predatory fish (lingcod) occupy deep rocky waters created by armoring<sup>1</sup>
- Small fish probably occupy inappropriately deep habitats along armored shorelines<sup>2</sup>

1. Munsch, Cordell, Toft 2015 *Ecological Engineering*

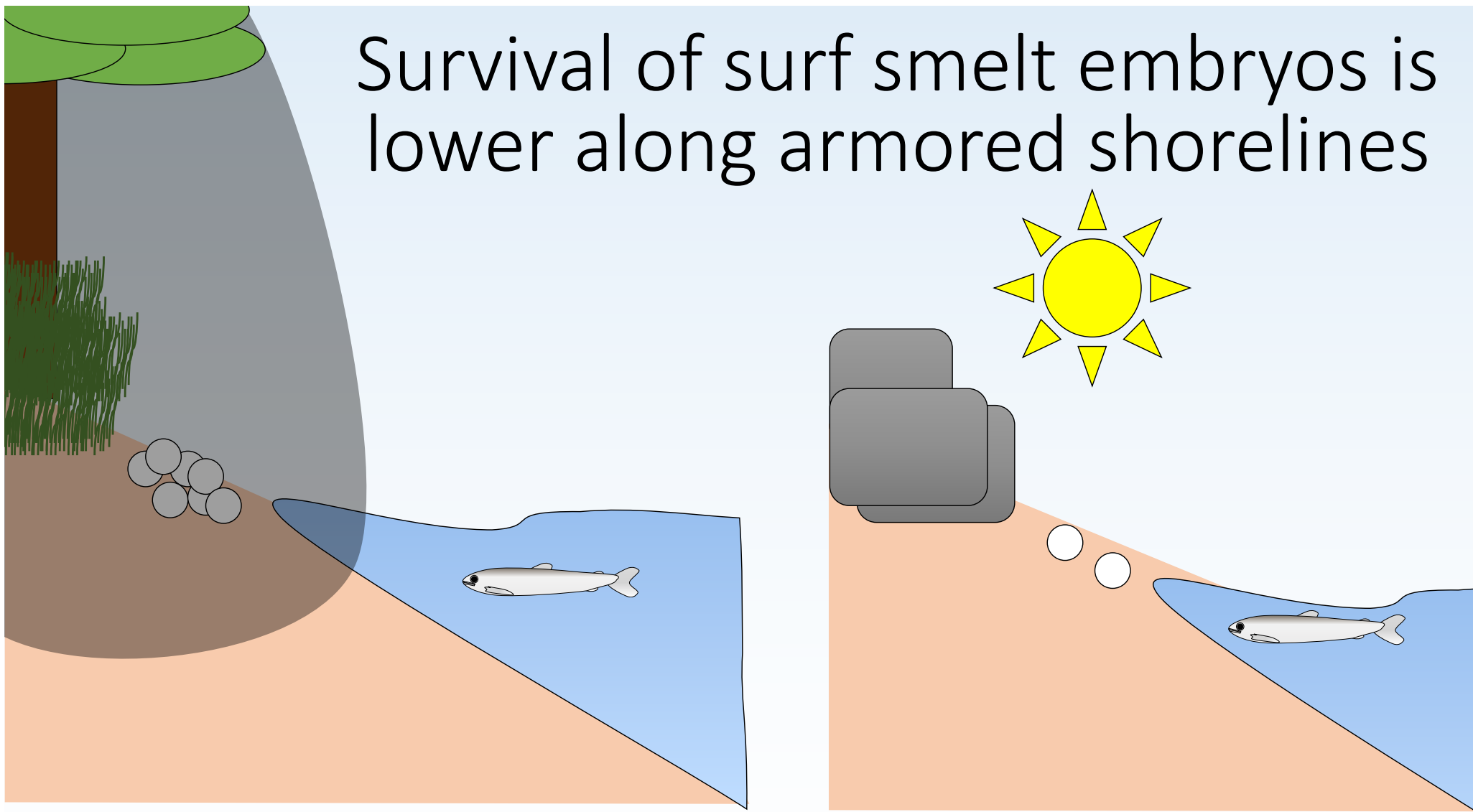
2. Munsch, Cordell, Toft 2016 *Marine Ecology Progress Series*

# Juvenile salmon eat less epibenthic and terrestrial prey along armored shorelines



1. Toft, Cordell, Simenstad, Stamatiou 2007 *North American Journal of Fisheries Management*
2. Morley, Toft, Hanson 2012 *Estuaries & Coasts*
3. Munsch, Cordell, Toft 2015 *Marine Ecology Progress Series*

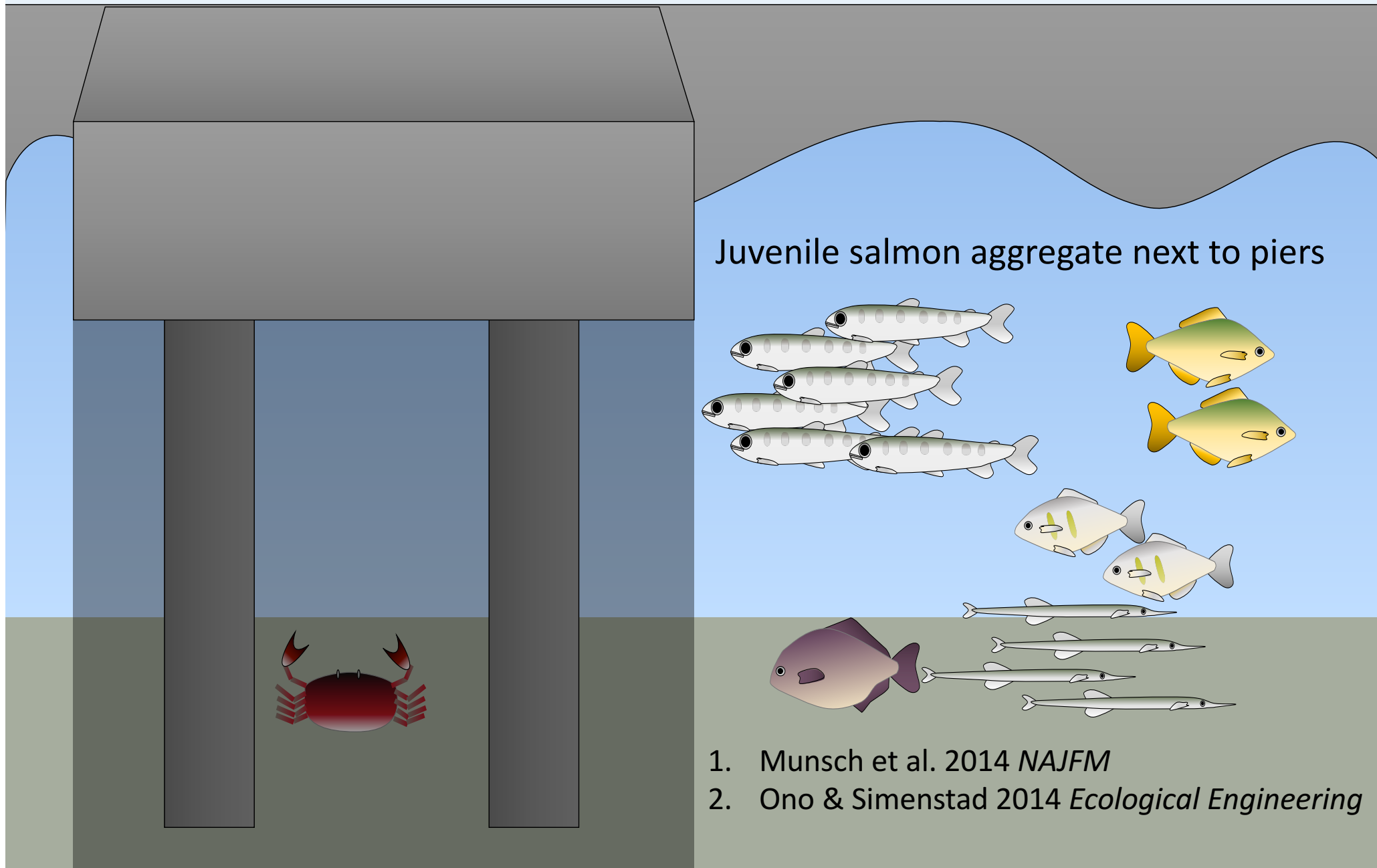
# Survival of surf smelt embryos is lower along armored shorelines



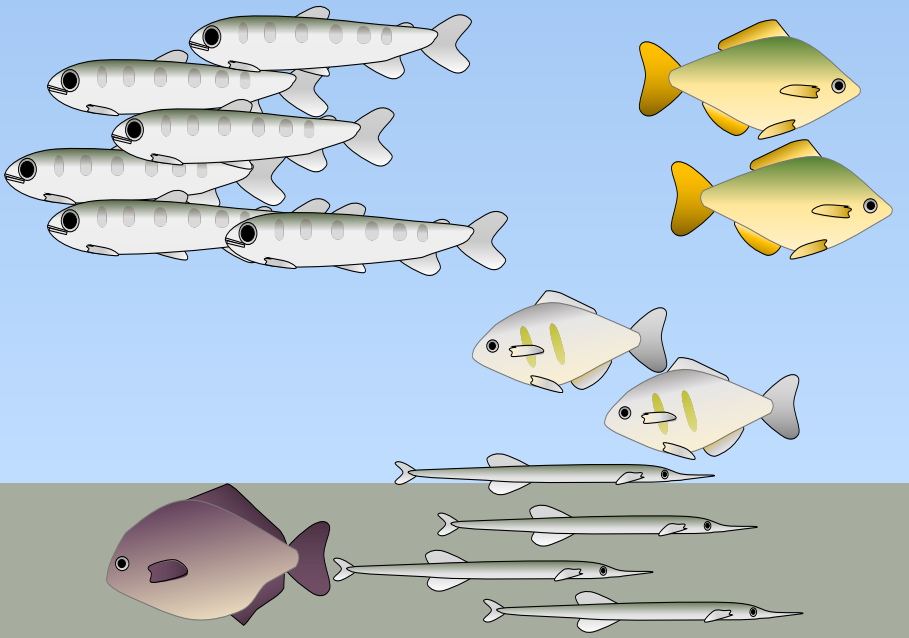
Light intensity, air temperature, substrate temperature, and air dryness higher along an armored shoreline compared to vegetated unarmored shoreline

1. Rice 2006 *Estuaries & Coasts*

# Most fish, especially juvenile salmon, avoid shaded areas created by large piers

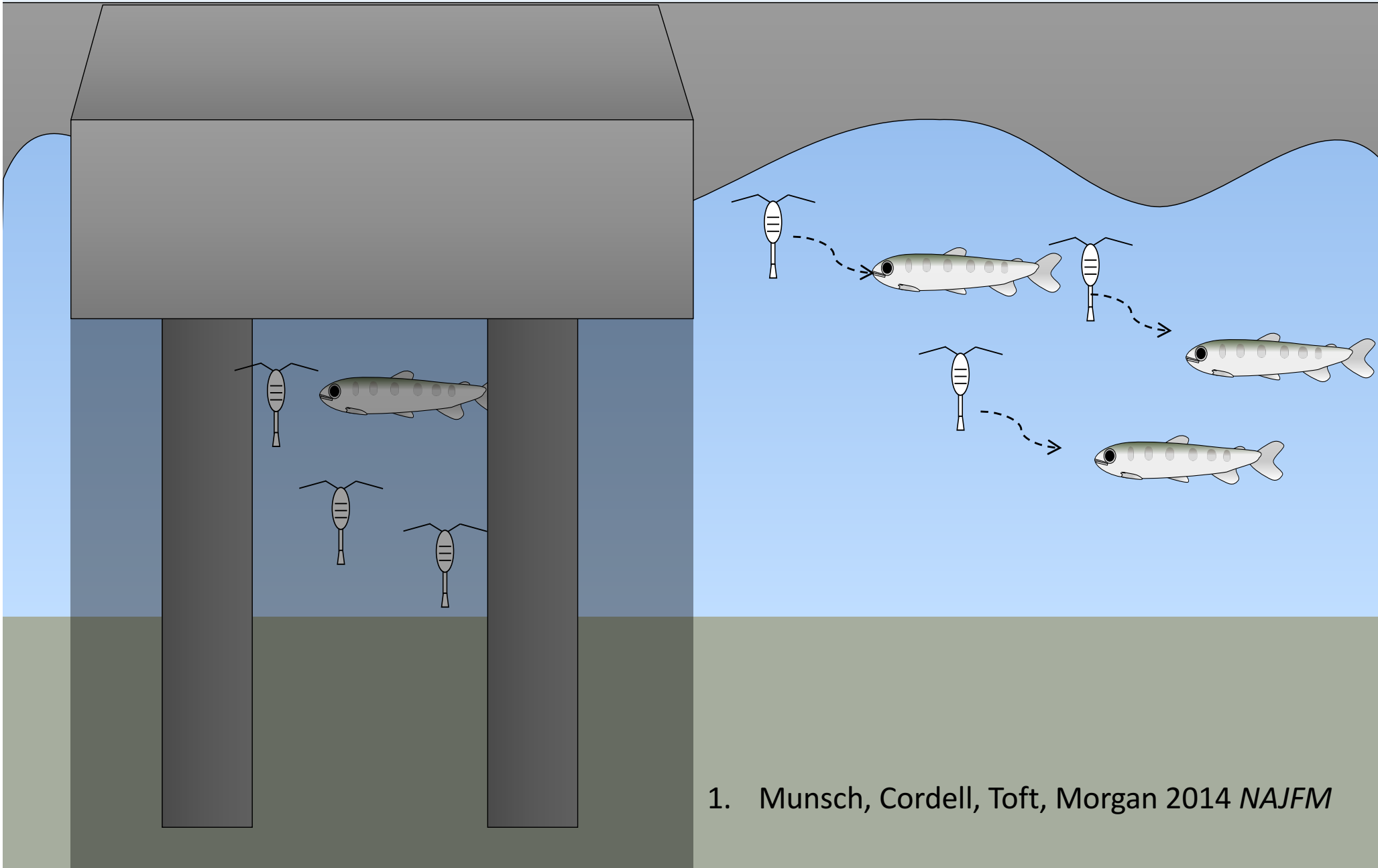


Juvenile salmon aggregate next to piers



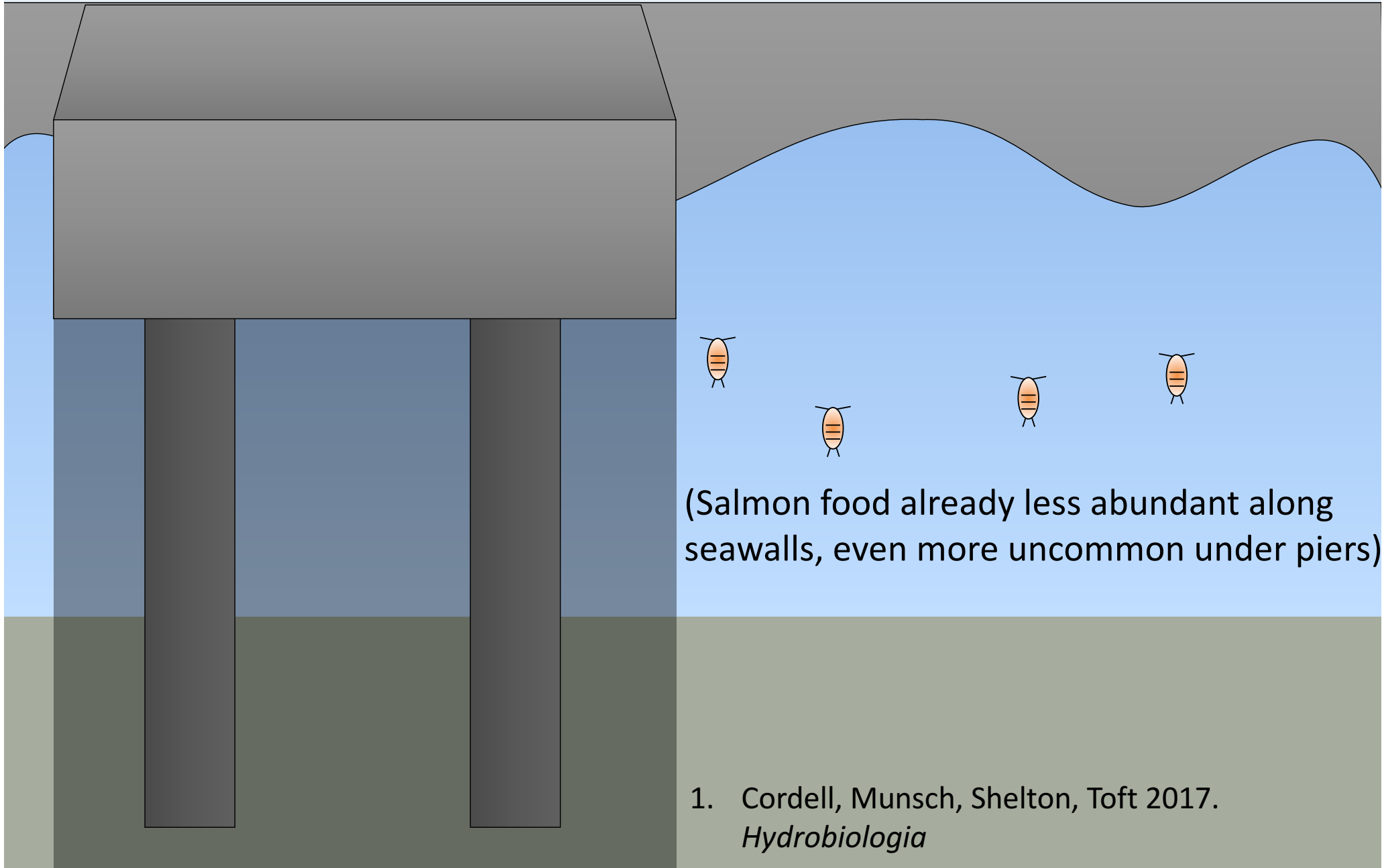
1. Munsch et al. 2014 *NAJFM*
2. Ono & Simenstad 2014 *Ecological Engineering*

# Salmon rarely feed under piers



1. Munsch, Cordell, Toft, Morgan 2014 *NAJFM*

# Salmon food is less abundant under piers



1. Cordell, Munsch, Shelton, Toft 2017.  
*Hydrobiologia*

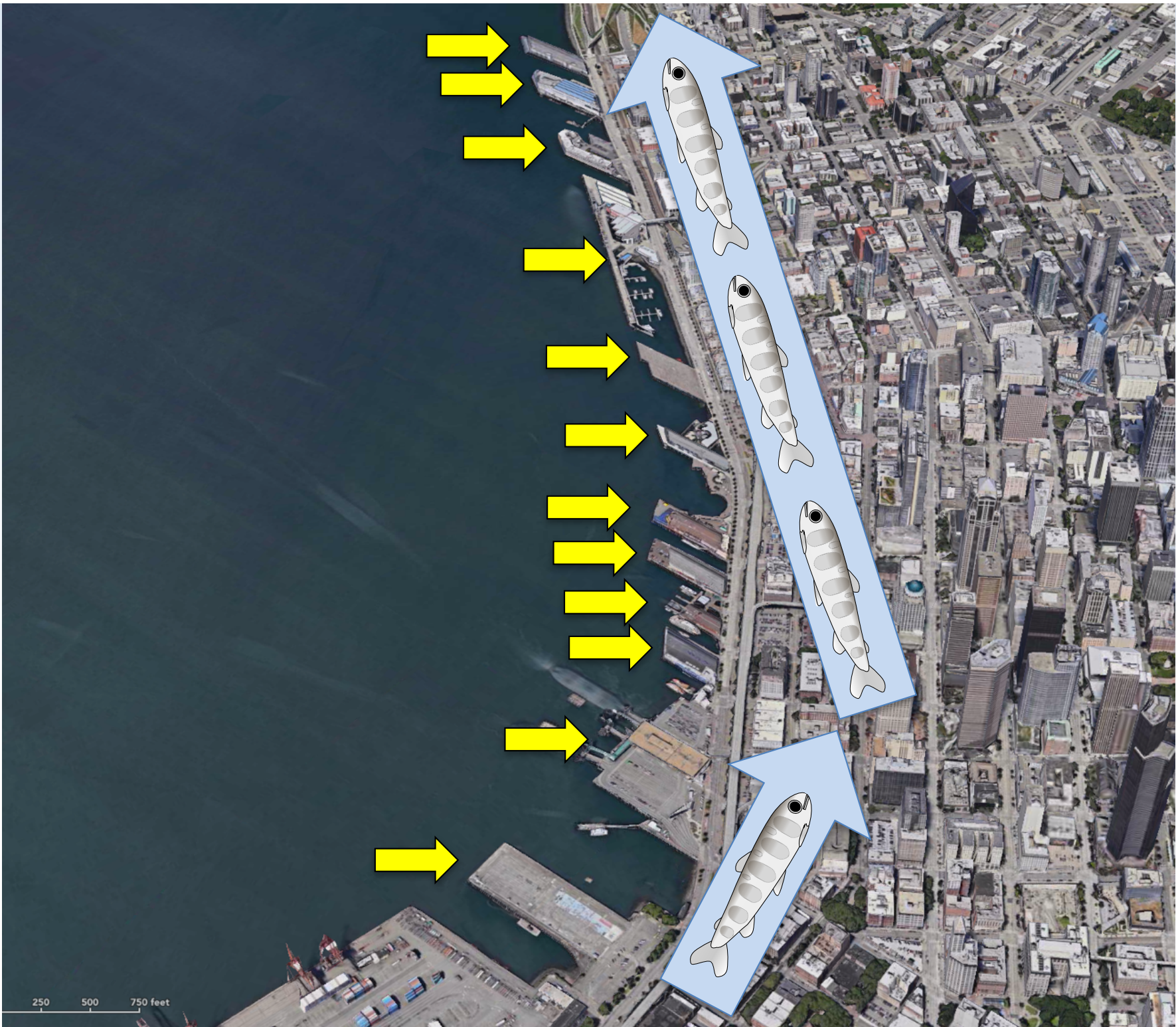


250 500 750 feet





250 500 750 feet



250 500 750 feet

# Summary

- Armoring can
  - Alter species composition
  - Prevent ontogenetic habitat shifts
    - Small fish can't access protective shallows
  - Expose small fish to predators
  - Prevent consumption of preferred prey
  - Lower egg survival
- Overwater structures can
  - Reduce fish abundance
    - May reduce localized habitat connectivity
  - Interfere with movements of migratory fish
    - May delay seaward migrations of juvenile salmon
  - Prevent fish from feeding
  - Reduce prey abundance



# Can we repair lost habitat functions?

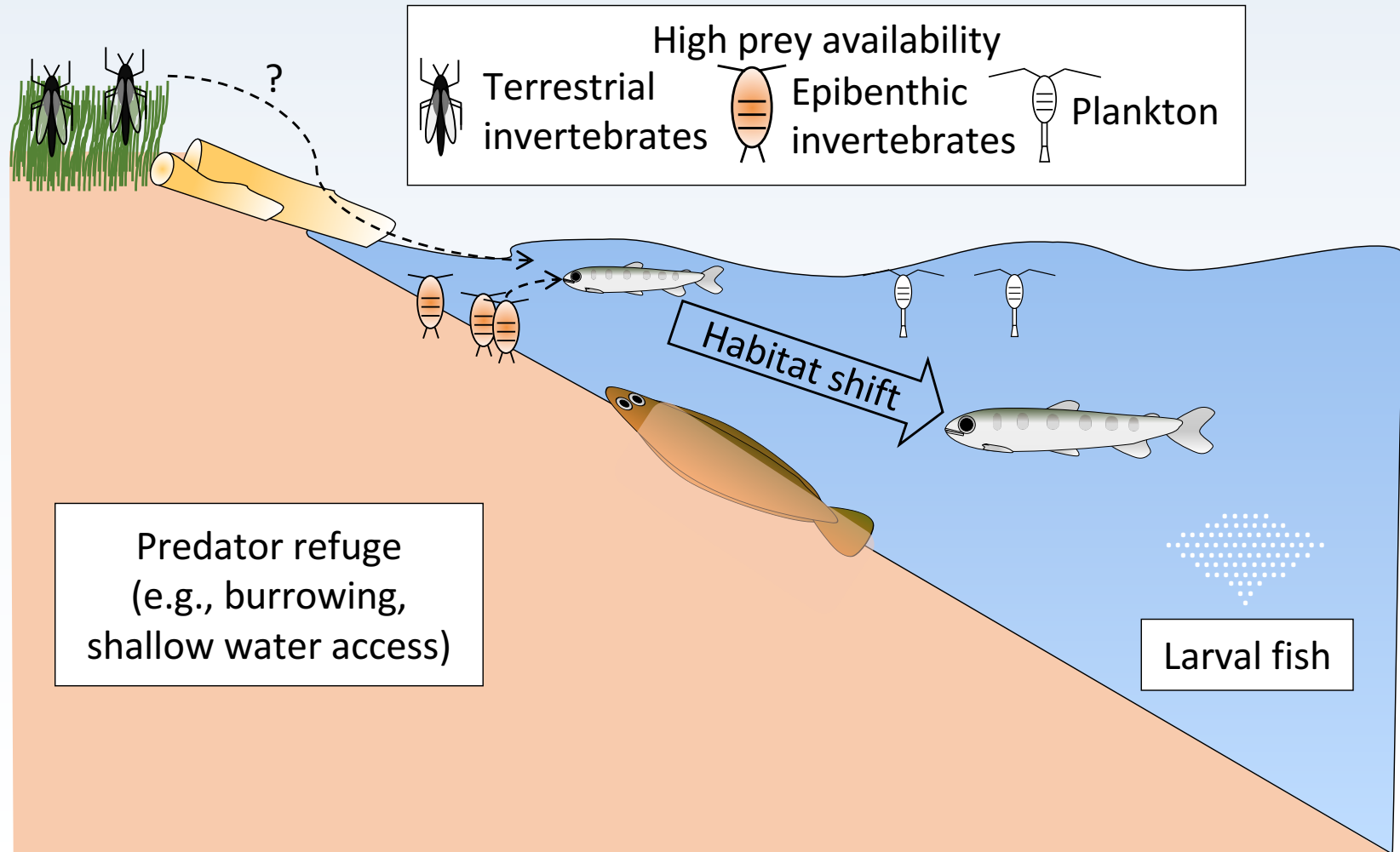


# Built beaches provide better habitat than armored shorelines

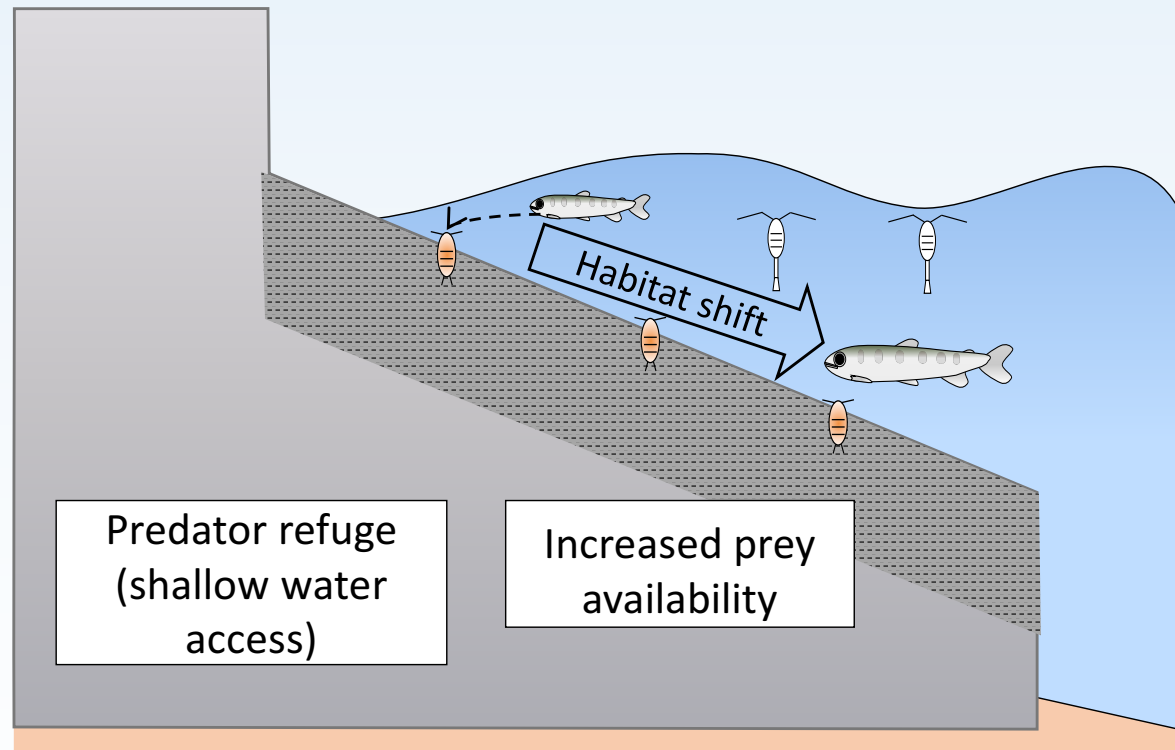


Replacing an urban armored shoreline with a beach described in  
Toft et al. 2013 *Ecological Engineering*

# Built beaches provide better habitat than armored shorelines

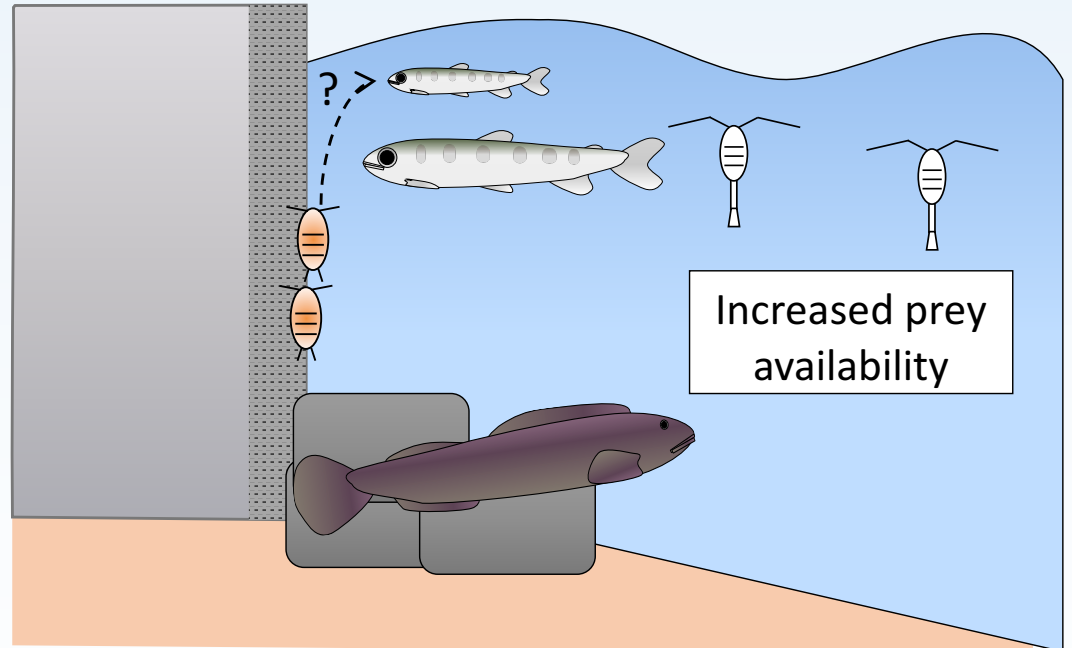


# Built intertidal zones (“habitat benches”) enhance habitats along modified waterfronts



Adding a habitat bench in front of shoreline infrastructure described in  
Toft et al. 2013 *Ecological Engineering*

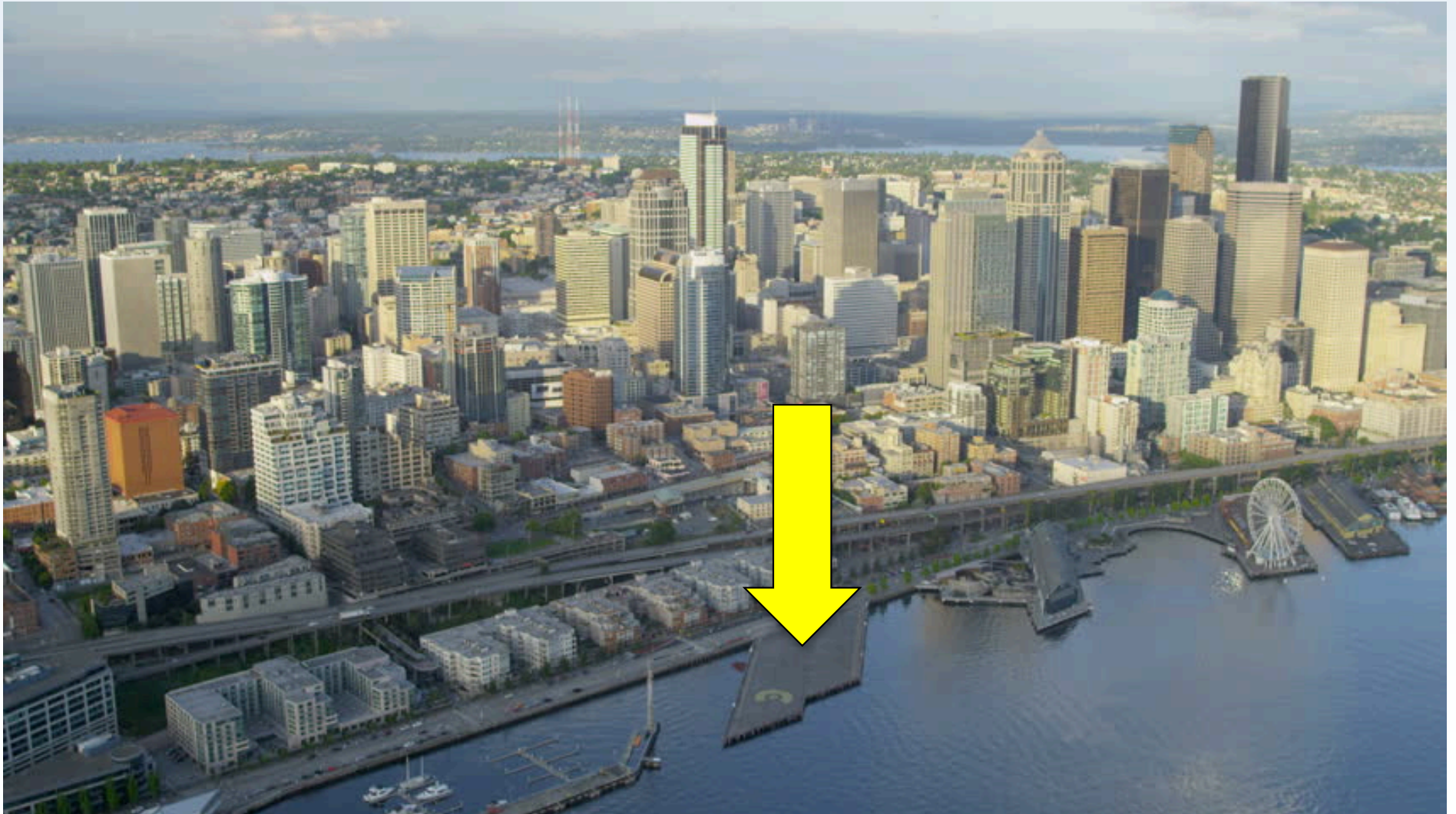
# Texturing may increase prey availability along seawalls



- Goff 2010 UW SAFS Thesis
- Cordell, Toft, Munsch, Goff 2017  
In: Living Shorelines: The Science and Management of Nature-based Coastal Protection



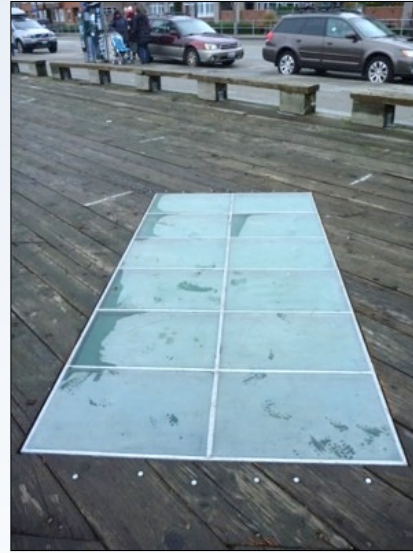
Pilot study: Can light penetrating surfaces increase fish presence under piers?



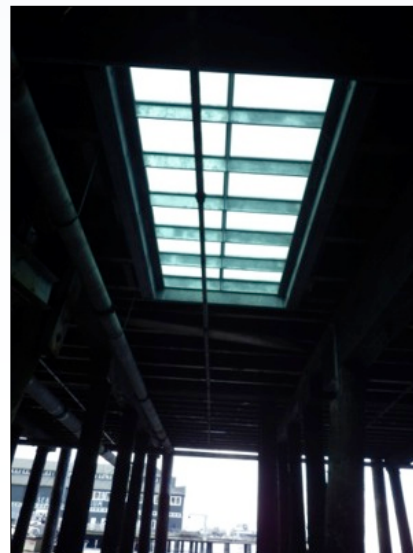
# Pilot study: Can light penetrating surfaces increase fish presence under piers?



Metal Grating



Glass Panels



Solar Tube



We observed a more even distribution of fish after LPS installation



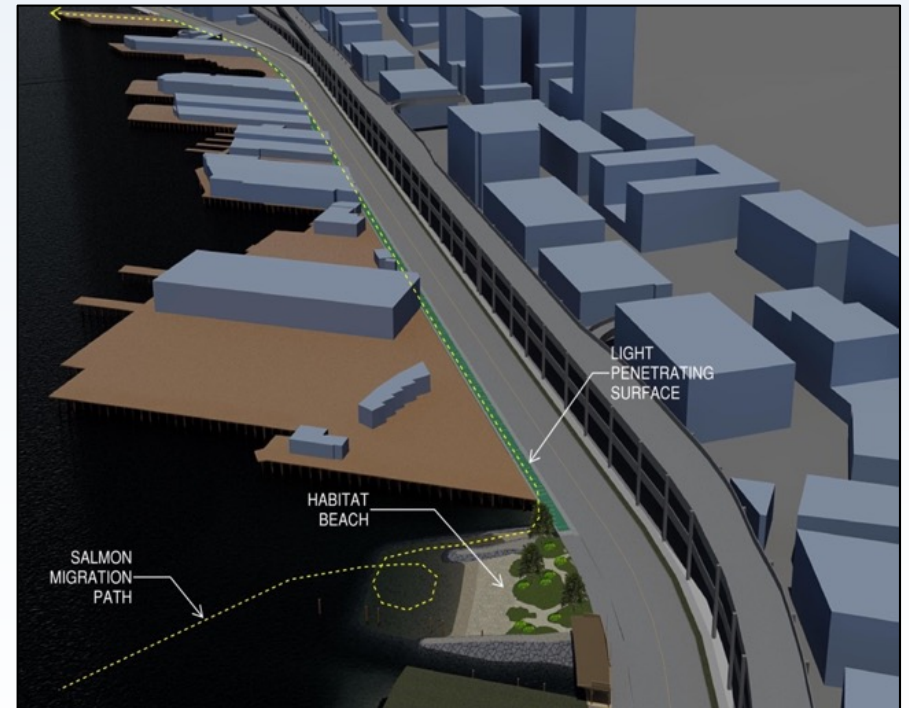
The diagram shows a brown pier structure with a white sign that reads "Feeding opportunities?". Below the sign, two vertical brown posts support the pier. Three fish are clustered between these posts. To the right, three fish are swimming in the water. A large black arrow points from a callout box on the right towards the space between the pier posts. The background is a light blue water area with a grey ground area at the bottom.

Feeding opportunities?

Under-pier access, migration corridor?

Cordell, Toft, Munsch, Goff 2017  
In: Living Shorelines: The Science and Management of Nature-based Coastal Protection

Light penetrating surfaces may provide migration corridors, improve fish feeding abilities, & produce more prey along seawall



Corridor of light penetrating surfaces installed along Elliott Bay



# WATCH THE NEW SEAWALL TAKE SHAPE

Replacing the Elliott Bay Seawall provides an opportunity to restore the nearshore ecosystem. As Seattle grows, so did the waterfront, and the shoreline was filled in to create a deep water port. The new seawall provides a shallow, well-lit and textured habitat for juvenile salmon, marine invertebrates and other local critters.

- 1 LIGHT PENETRATING SURFACE**  
PROVIDES MORE LIGHT
- 2 ZEE PANEL**  
ALLOWS SPACE FOR HABITAT
- 3 FACE PANEL**  
INCORPORATES TEXTURE
- 4 HABITAT SHELF**  
GROWTH OF VEGETATION
- 5 MARINE MATTRESS**  
CREATES SHALLOWER WATER

WWW.WATERFRONTSEATTLE.ORG/SEAWALL/TOUR

YOU'VE GOT QUESTIONS? WE'VE GOT ANSWERS  
seawall@waterfrontseattle.org | 206.618.8584 | Waterfront Seattle

## SAM OLYMPIC SCULPTURE PARK POCKET BEACH

**PROJECT OVERVIEW**  
The Seattle Art Museum has partnered with SAM to create a new habitat for juvenile salmon and other marine life. The project includes installing a new seawall structure, creating a pocket beach, and installing a marine mattress. The project is part of the SAM Seawall Rehabilitation Program, which aims to restore the nearshore ecosystem and create a healthier habitat for marine life.

**SCIENTIFIC RESEARCH**  
SAM has implemented a scientific research program to monitor the health of the nearshore ecosystem. The program includes installing a network of sensors to monitor water quality, sediment levels, and the growth of vegetation. The program also includes installing a network of cameras to monitor the behavior of marine life. The program is part of the SAM Seawall Rehabilitation Program, which aims to restore the nearshore ecosystem and create a healthier habitat for marine life.

**PROTECTING SHORELINES**  
SAM is committed to supporting marine conservation efforts at the Olympic Sculpture Park. Efforts include organizing volunteer beach cleanups, removing invasive species, and installing signage to educate the public. The project is part of the SAM Seawall Rehabilitation Program, which aims to restore the nearshore ecosystem and create a healthier habitat for marine life.

**YOU CAN HELP ENSURE THE SAFETY OF MARINE LIFE BY**

- Leaving any marine invertebrates where you find them, observing them gently
- Carefully replacing any rocks that you turn over
- Depositing litter into waste and recycling receptacles
- Maintaining distance from marine mammals and reporting issues to security personnel

SAM Seawall Rehabilitation Program

# HABITAT RESEARCH

In the spring, if you look over the railing, you will see thousands upon thousands of small chum salmon up against the shoreline.

**Where is high tide?**  
A common question for visitors is "Where is high tide?" The answer is that it varies along the waterfront. In fact, the water level can be several feet higher at one end of the waterfront than at the other. This is because the waterfront is not a straight line, and the water level is affected by the shape of the coastline. The water level is also affected by the wind and the moon. The water level is highest when the moon is full and the wind is blowing towards the shore.

**Who's afraid of the dark?**  
When it comes to habitat research, one of the biggest challenges is that it is often done at night. This is because many of the organisms that we are studying are nocturnal. This means that we have to use artificial light to see them. However, artificial light can be disruptive to the organisms. This is why we use special lighting that is designed to be as invisible as possible to the organisms. We also use special cameras that are designed to take photos in low light conditions.

**State of the science**  
The state of the science of habitat research is constantly evolving. This is because we are learning more about the nearshore ecosystem and the organisms that live there. This is why it is important to continue to fund habitat research. This is why we are proud to be part of the SAM Seawall Rehabilitation Program, which is helping to restore the nearshore ecosystem and create a healthier habitat for marine life.

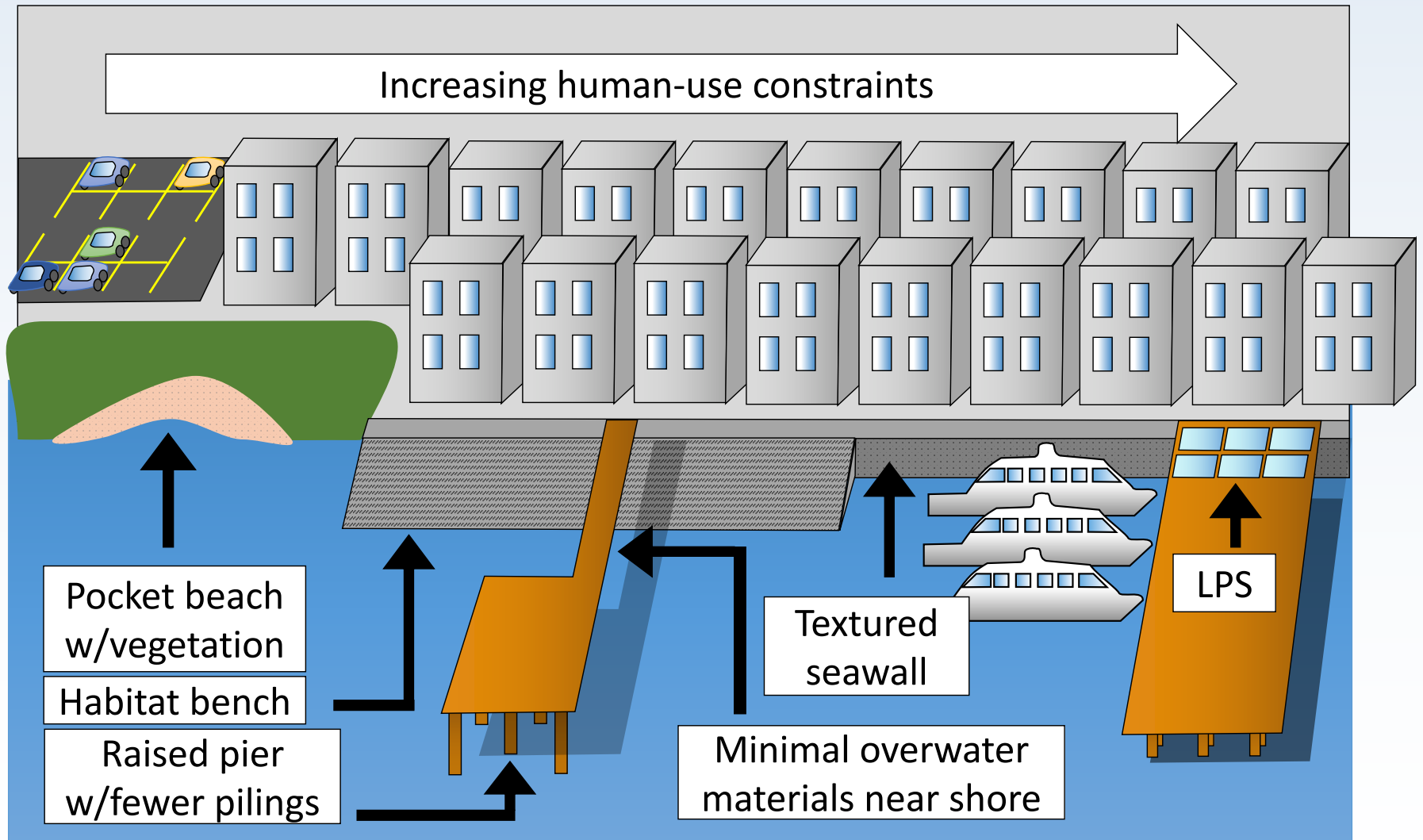
**Enhancing the habitat beyond the shoreline**  
The habitat research program is not just about the shoreline. It is also about the water. This is because the water is an important part of the nearshore ecosystem. This is why we are installing a network of sensors to monitor water quality. This is why we are installing a network of cameras to monitor the behavior of marine life. This is why we are installing a network of buoys to monitor the water level. This is why we are installing a network of cameras to monitor the behavior of marine life. This is why we are installing a network of buoys to monitor the water level.

Neil Conrad  
Research Manager, Seattle Department of Waterfront

City of Seattle

HABITAT RESEARCH

# Improving habitat within human-use constraints



# Big picture

- Many nearshore waters provide critical fish habitat
- Shorelines are modified worldwide
- Effects of shoreline modifications on fish occur outside of Puget Sound
- Shoreline infrastructure will be increasingly common as sea levels rise
- Improving fish habitat aligns with many societal goals
  - Flood protection
  - Carbon sequestration
  - Recreation & interacting with “nature,” particularly in urban settings
  - Education
    - Organized events (e.g., field trips)
    - Kiosks
- Efforts to improve fish habitat along urban shorelines are unprecedented
  - Monitoring efforts in Elliott Bay can guide management of developed waterfronts worldwide



# Acknowledgements

- Funding:
  - NSF GRFP
  - Seattle Department of Transportation
- Advice: Charles “Si” Simenstad
- Overarching reference:
  - Munsch, Cordell, Toft. 2017. Effects of shoreline armouring and overwater structures on coastal and estuarine fish: Opportunities for habitat improvement. *Journal of Applied Ecology*

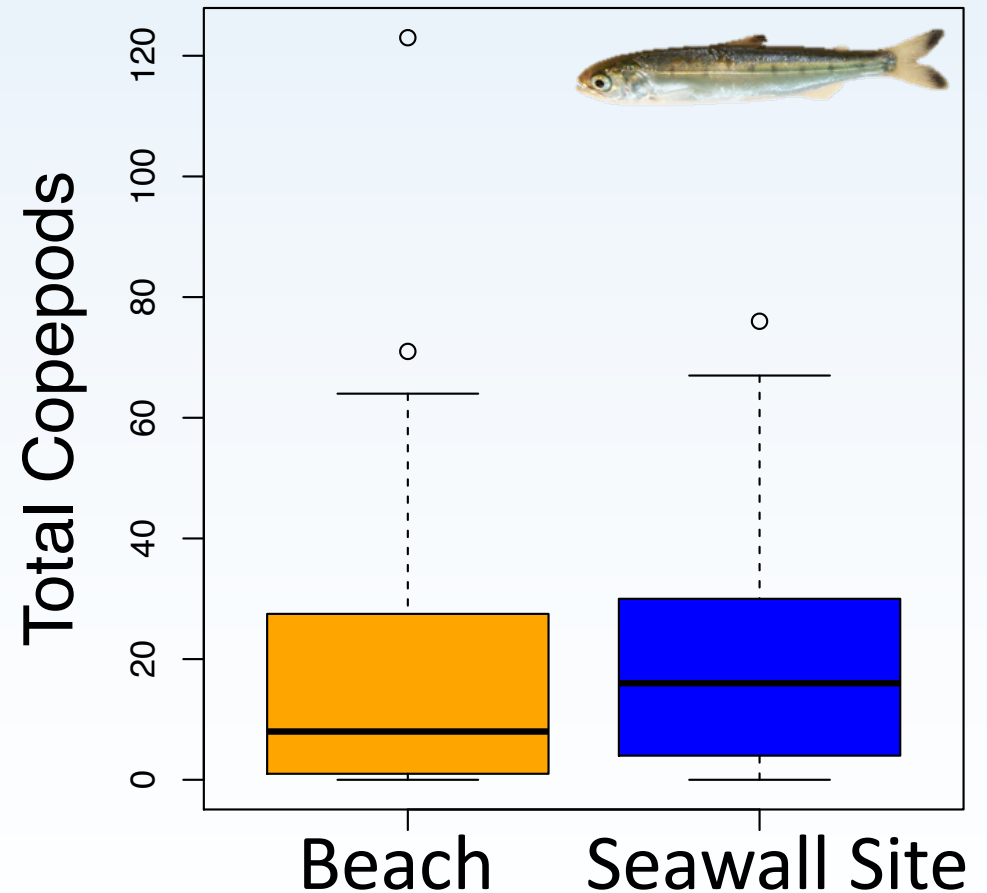
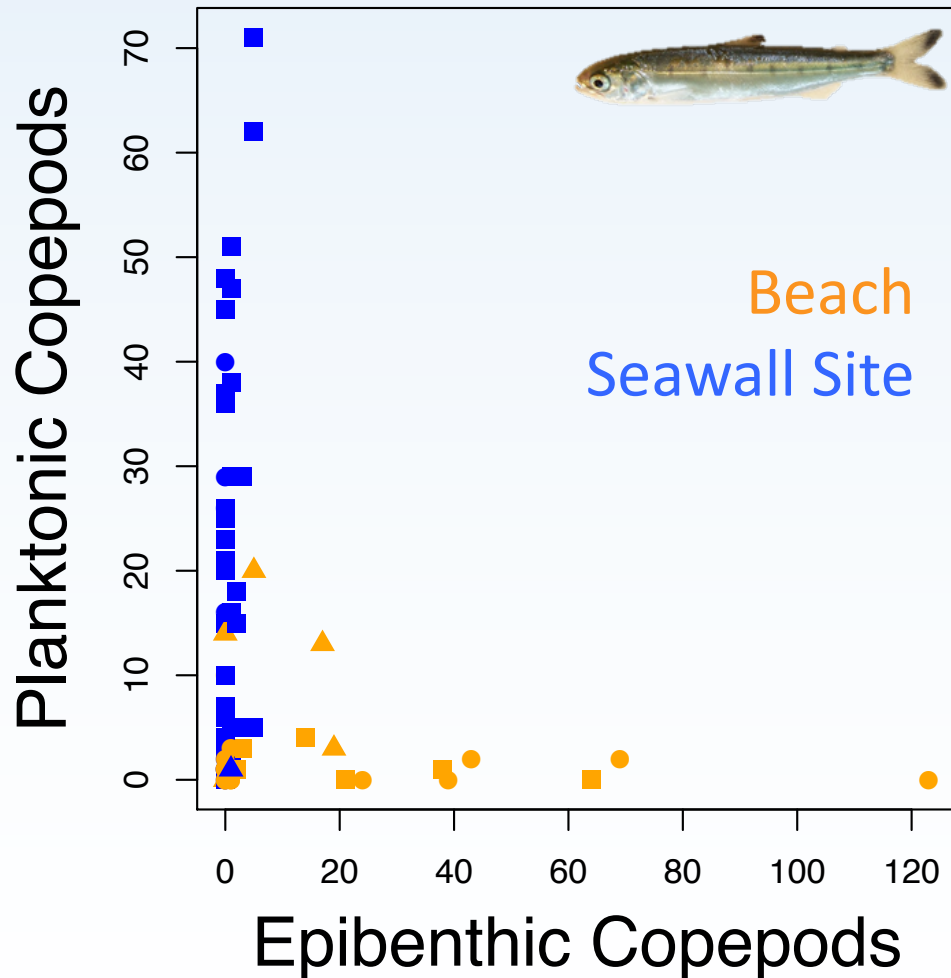


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- Munsch SH, Cordell JR, Toft JD. 2015. Effects of seawall armoring on juvenile Pacific salmon diets in an urban estuarine embayment. *Marine Ecology Progress Series* 535: 213-229.
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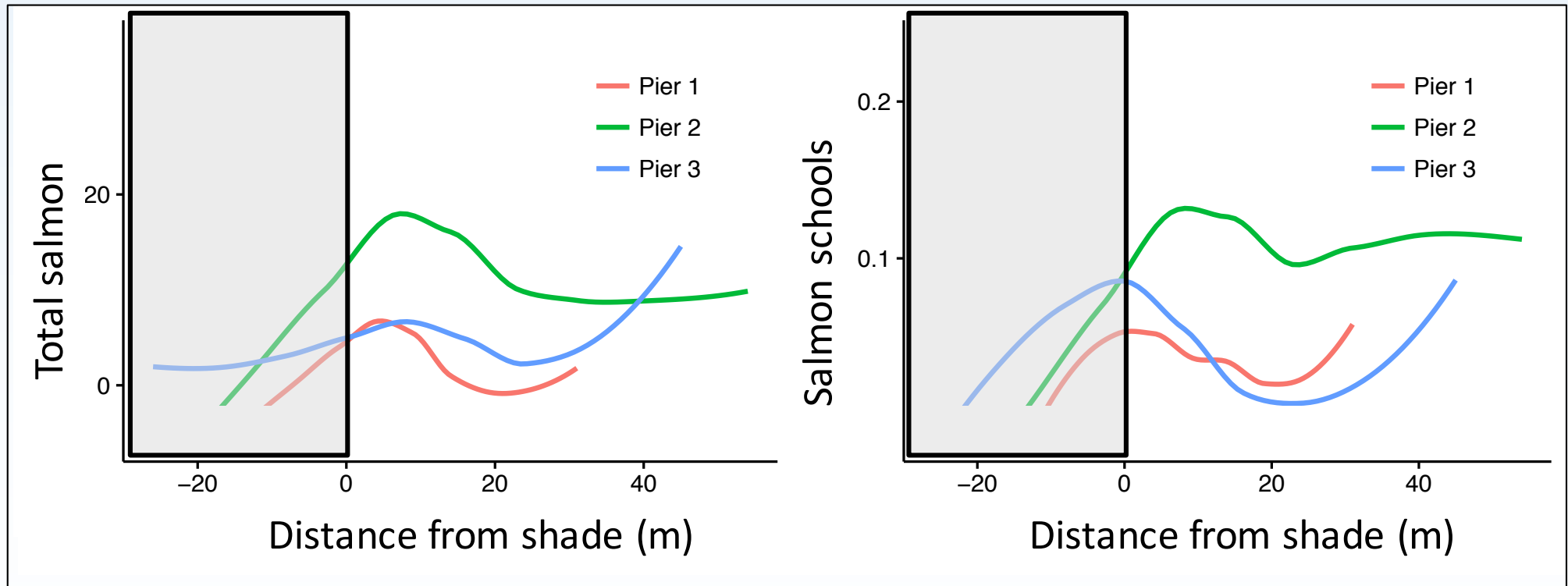


# Small chum salmon switch to alternative prey along armored shorelines



Are they feeding on prey that takes more effort to find, lower in energy content, or more evasive?

# Salmon aggregate next to piers



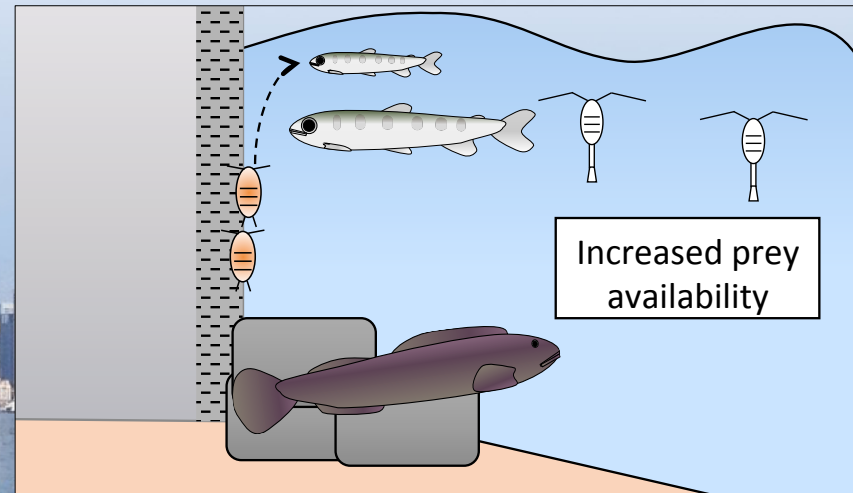
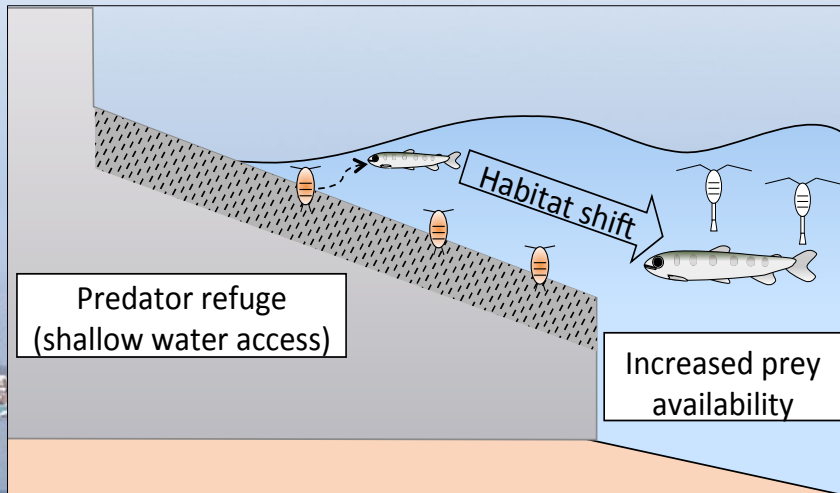
1. Munsch, Cordell, Toft, Morgan 2014 *NAJFM*

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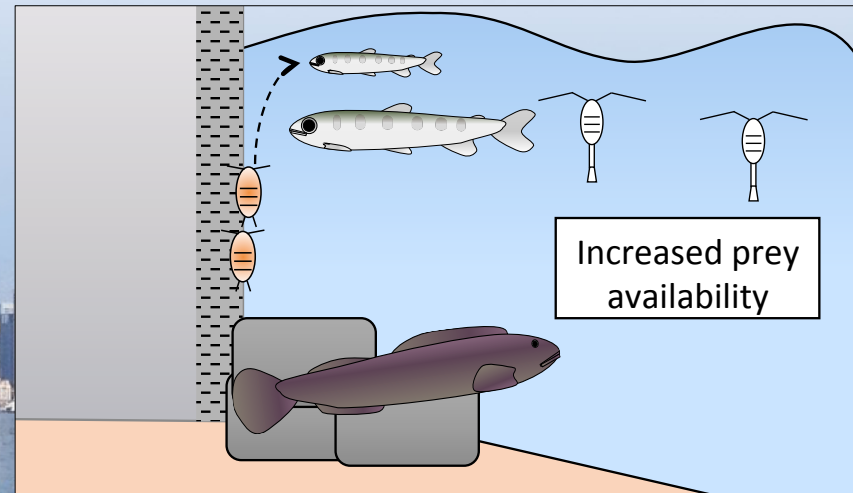
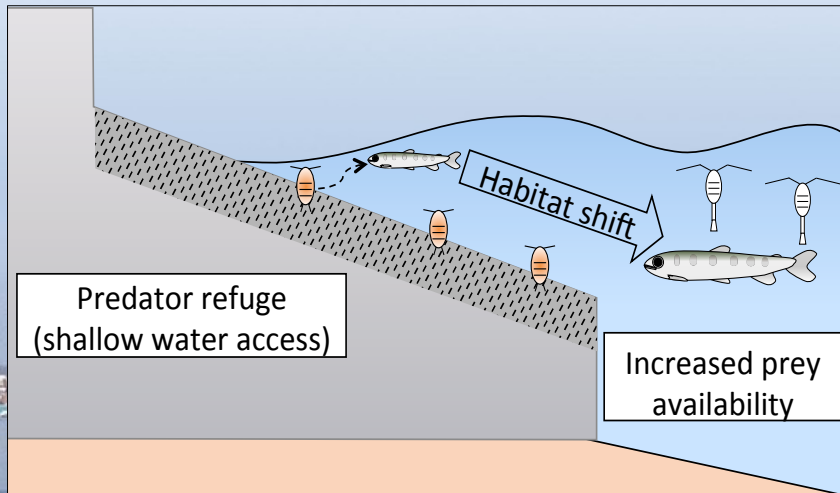
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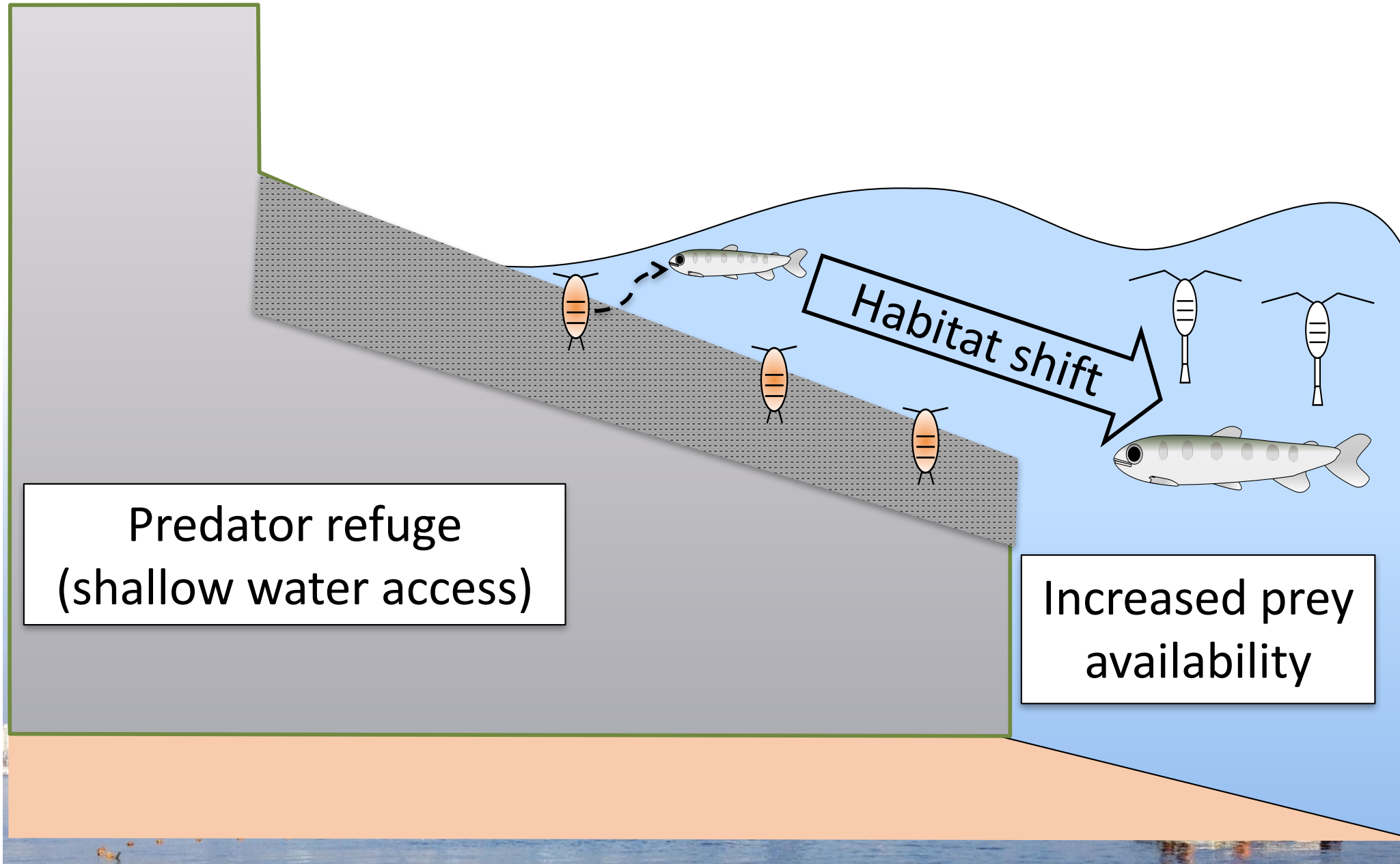
# Built intertidal zones and seawall texturing enhance habitats along modified waterfronts



# Built intertidal zones and seawall texturing enhance habitats along modified waterfronts

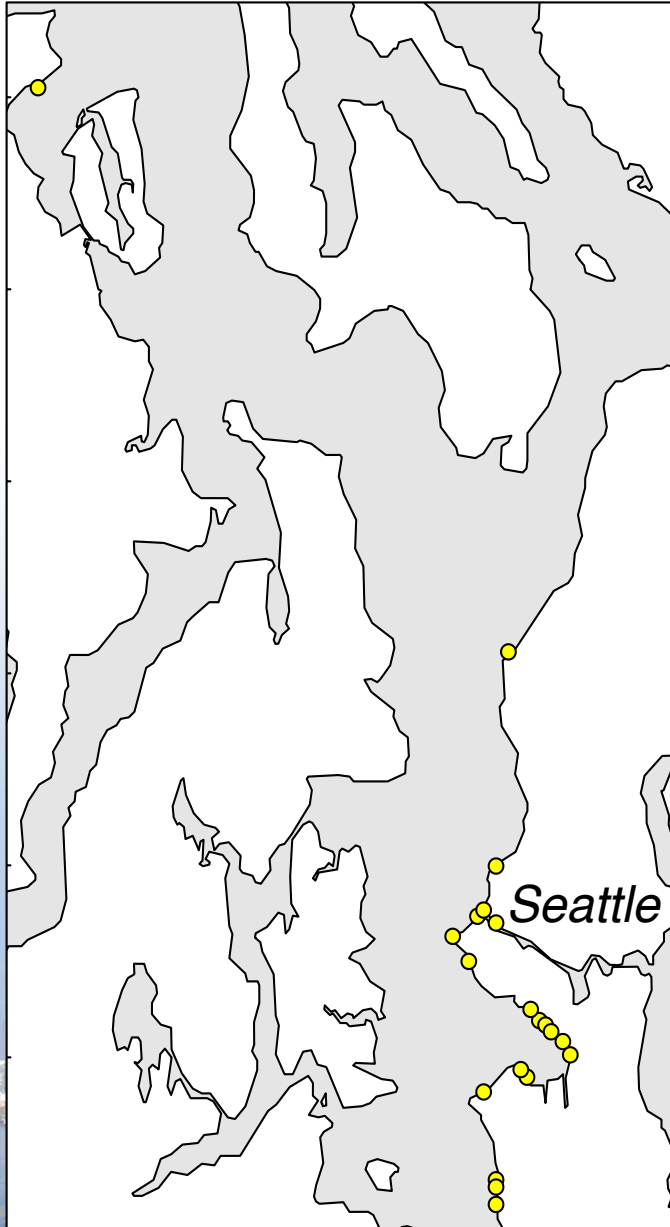
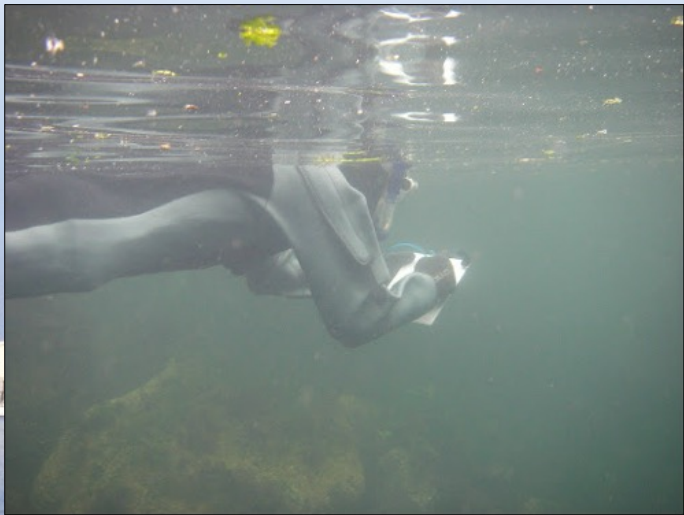


# Built intertidal zones (“habitat benches”) enhance habitats along modified waterfronts



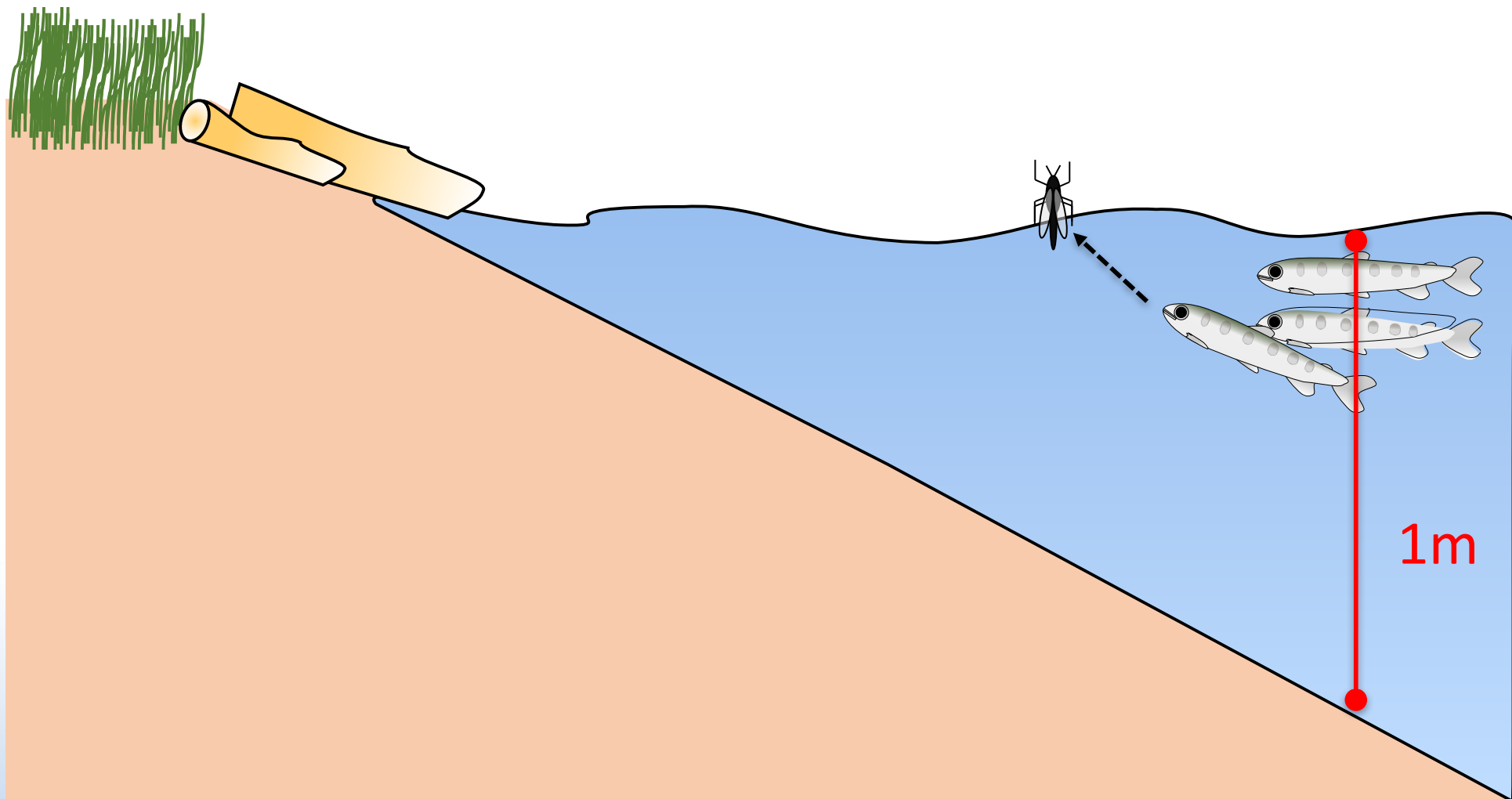


# Primary method: snorkel surveys



- 817 surveys
- 2003 – 2013
- Spring & summer
- Recorded:
  - Water depth
  - Species
  - Fish length
  - Group size
  - Behavior
  - Water column position of fish (thirds)
  - Fish depth estimated from water depth & water column position

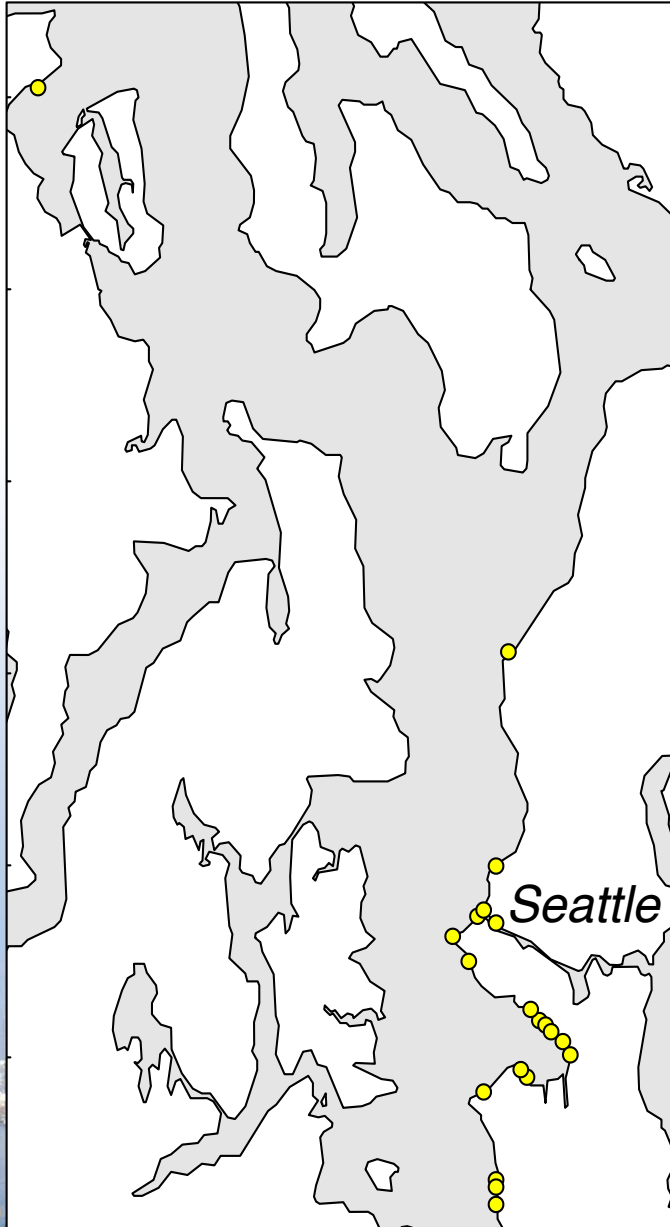
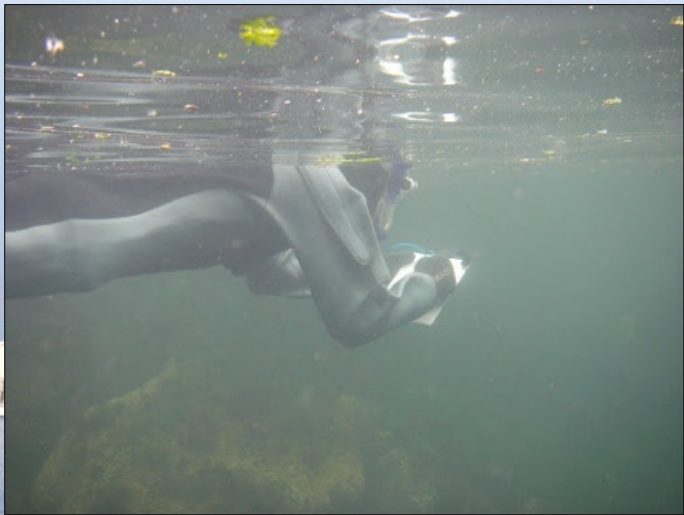




Water Depth	Species	Length	Behavior	Water column position	Group size	Fish depth
1 m	Chum salmon	5 cm	Feeding	Top	3	1/6 m

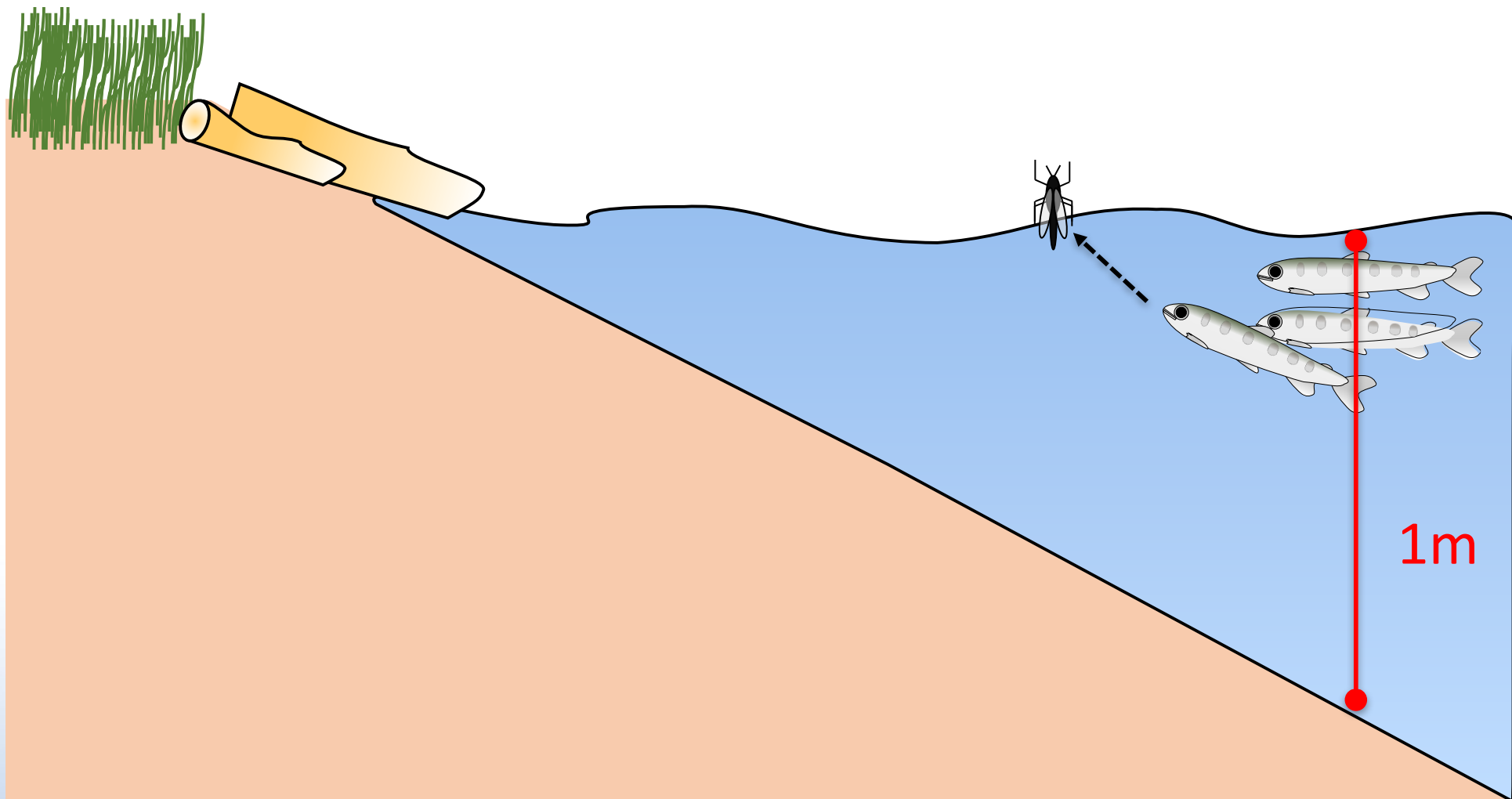


# Primary method: snorkel surveys



- 817 surveys
- 2003 – 2013
- Spring & summer
- Recorded:
  - Water depth
  - Species
  - Fish length
  - Group size
  - Behavior
  - Water column position of fish (thirds)
  - Fish depth estimated from water depth & water column position





Water Depth	Species	Length	Behavior	Water column position	Group size	Fish depth
1 m	Chum salmon	5 cm	Feeding	Top	3	1/6 m









**waterfront SEAWALL**

# WATCH THE NEW SEAWALL TAKE SHAPE

Replacing the Elliott Bay Seawall provides an opportunity to restore the nearshore ecosystem.

As Seattle grew, so did the waterfront, and the shoreline was filled in to create a deep water port. The new seawall provides a shallow, well-lit and textured habitat for juvenile salmon, marine invertebrates and other local critters.

- 1 LIGHT PENETRATING SURFACE**  
PROVIDES MORE LIGHT
- 2 ZEE PANEL**  
ALLOWS SPACE FOR HABITAT
- 3 FACE PANEL**  
INCORPORATES TEXTURE
- 4 HABITAT SHELF**  
GROWTH OF VEGETATION
- 5 MARINE MATTRESS**  
CREATES SHALLOWER WATER

[WWW.WATERFRONTSEATTLE.ORG/SEAWALL/TOUR](http://WWW.WATERFRONTSEATTLE.ORG/SEAWALL/TOUR)

**YOU'VE GOT QUESTIONS? WE'VE GOT ANSWERS**  
seawall@waterfrontseattle.org | 206.618.8584 | Waterfront Seattle

**HEY KIDS!**

Can you find 2 on this panel?

→

