Dynamics between Piscivorous Fish and Juvenile Salmon in Lakes

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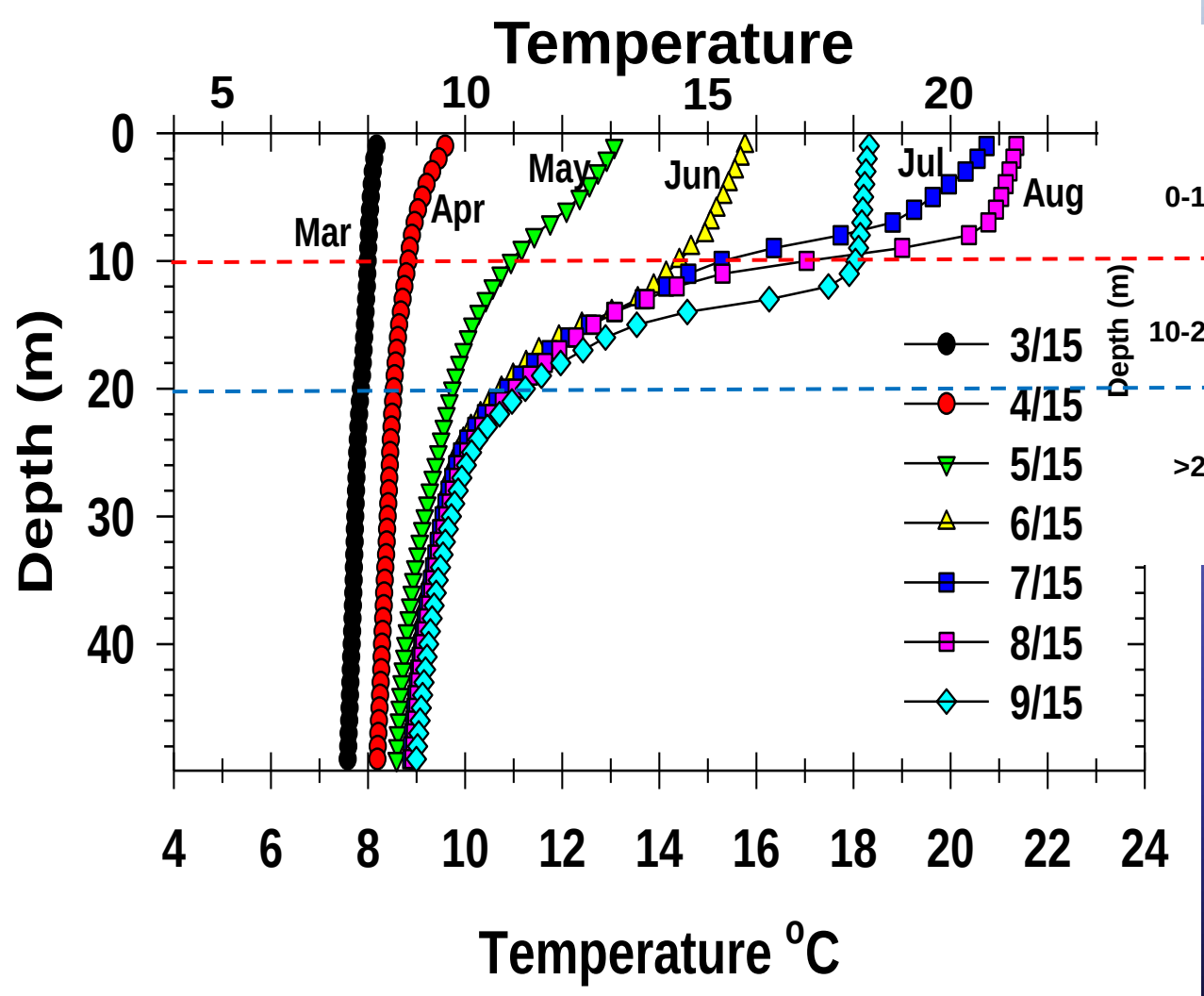
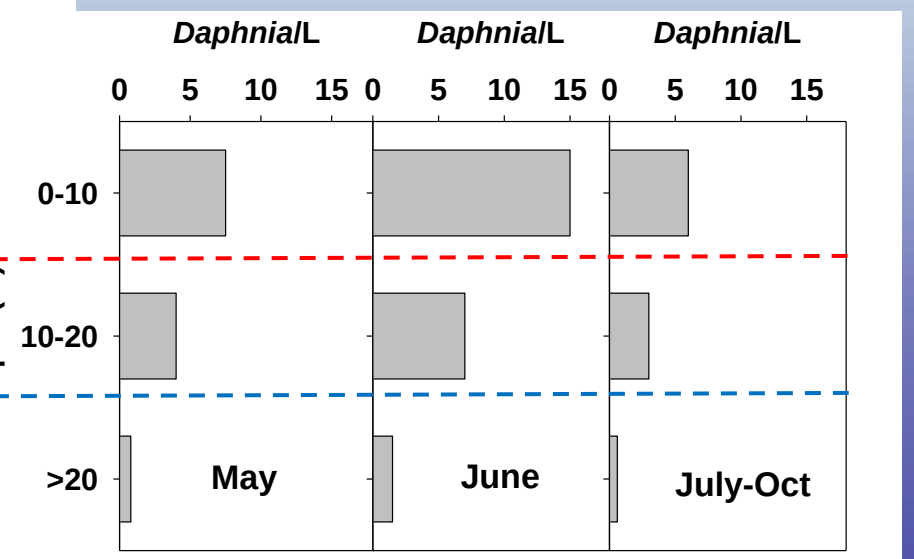
Feeding & Growth Linked to Juvenile Salmon Survival

- **Feeding & Growth**
  - Thermal Regime (timing & magnitude of thermal stratification)
  - Food Supply (seasonal productivity cycles, competitors)
  - Access to food across time & space
    - Diel Vertical Migration
    - Vertical distribution of zooplankton
    - Thermally Stressful surface waters?
- **Survival**
  - Size-related vulnerability to predation & marine survival
  - Predation risk:
    - Spatial-temporal overlap with predators, detection/encounter capability
    - Vulnerability: Size-selective mortality, anti-predation behavior

Vertical Gradients: Thermal Stratification & Food Availability





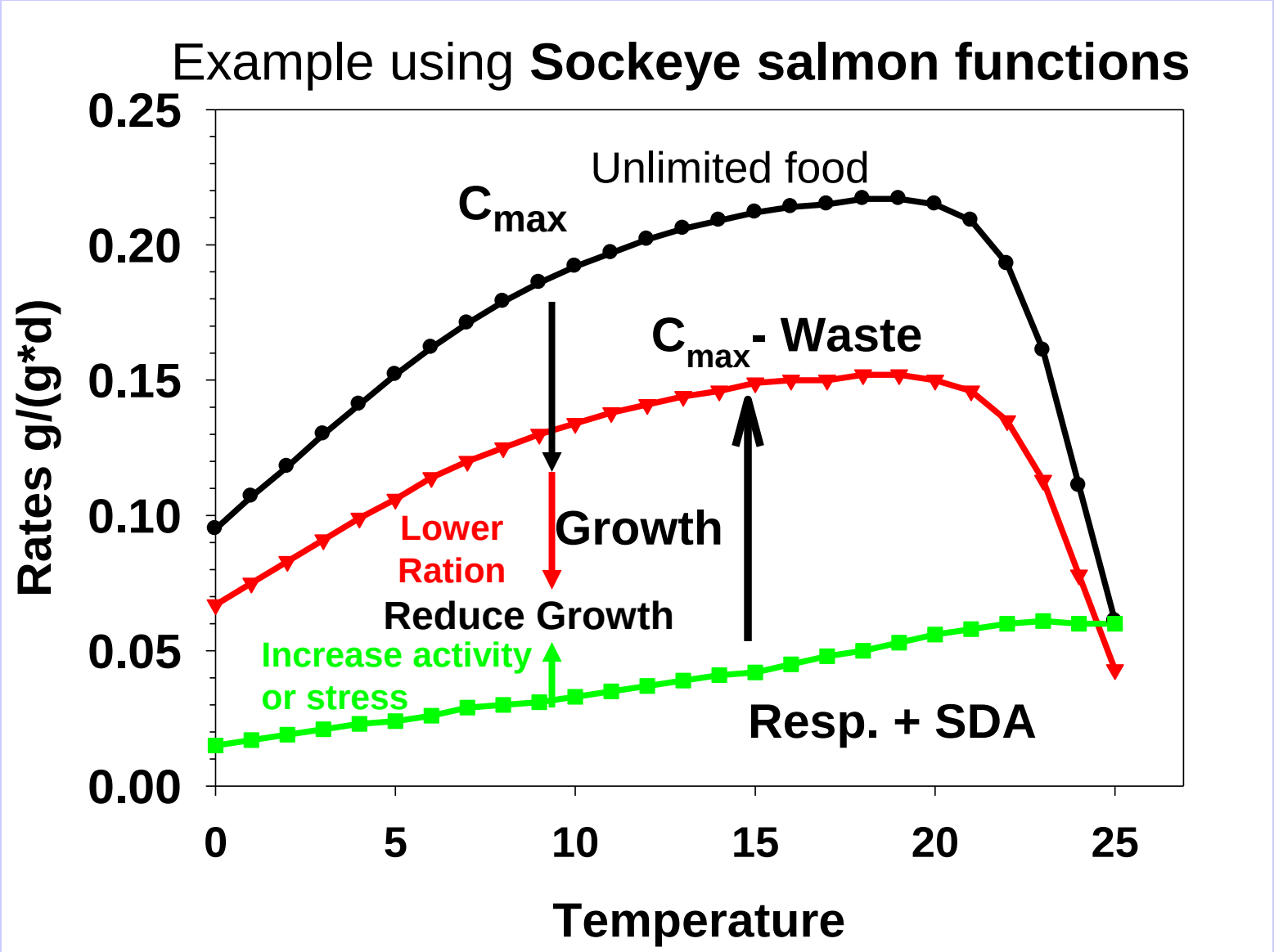
Daphnia densities:
Highest in epilimnion
~50% lower w/in thermocline
Very low (~10%) deep

Trade-off between Thermal Stress & Food Availability

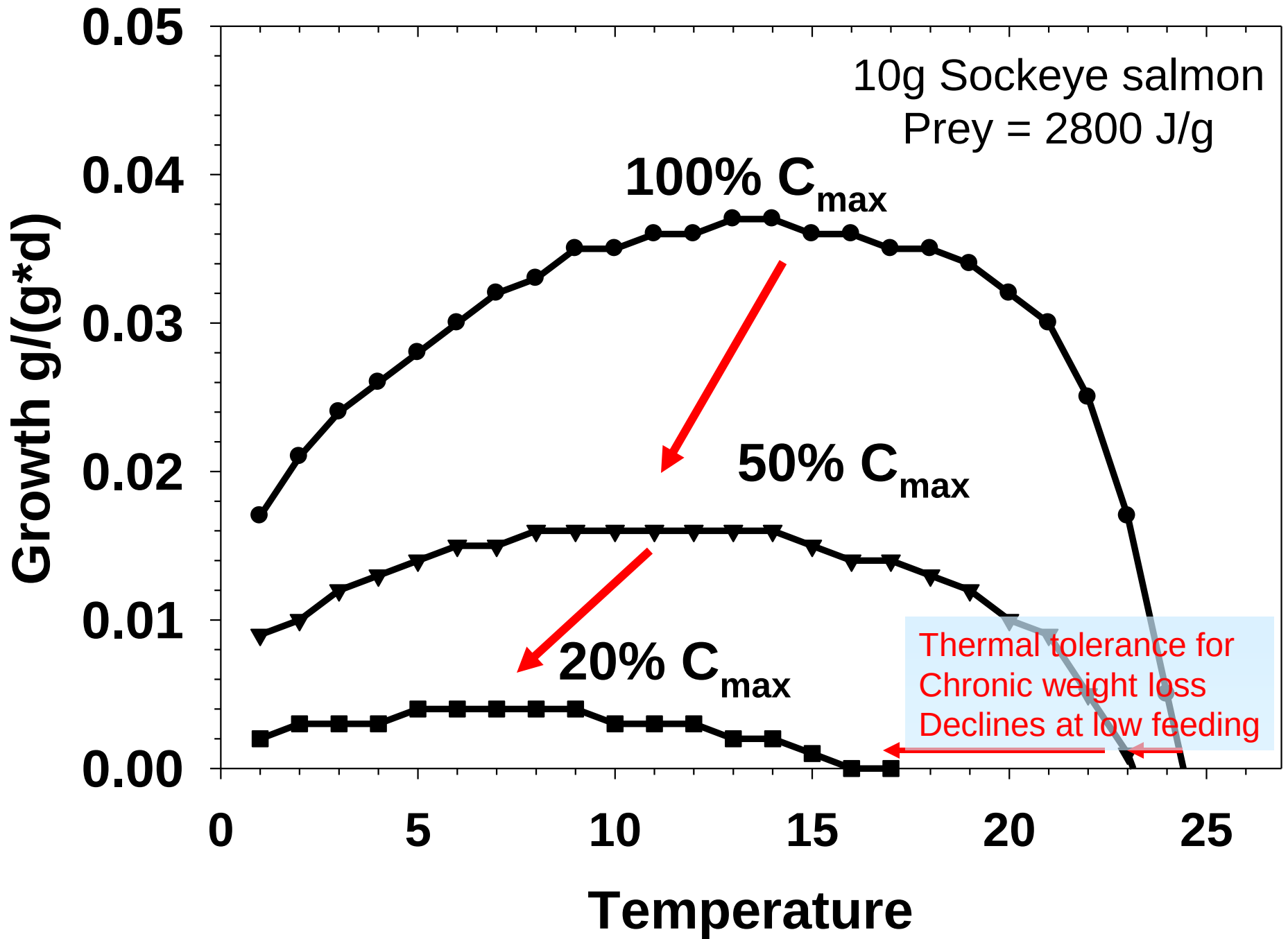
Bioenergetics: Temperature-Dependent Energy Budget

Stereotypic thermal Response curves by all Ectotherms:

Spp differences in:
-Temp Min-Opt-Max
-Rate & magnitude



As Ration Declines, Optimal Temperature for Growth Declines



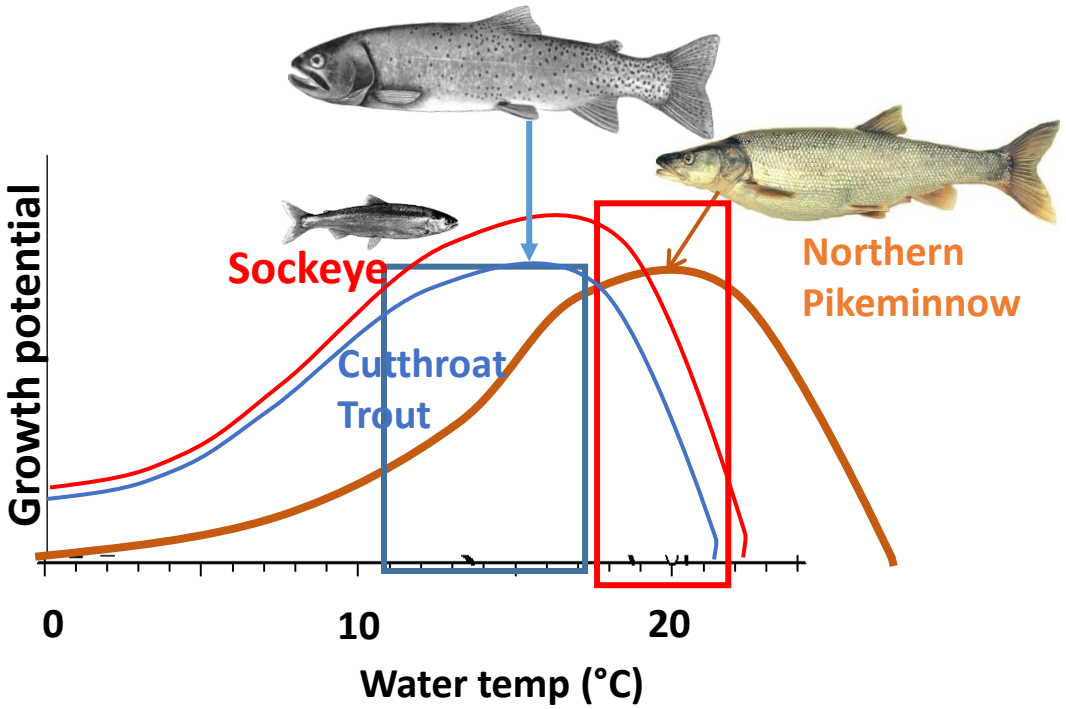
Thermal Effects on Bioenergetic Performance of Predators and Access to Prey

Differing thermal responses Influence:

-Predation potential

-Spatial-temporal overlap

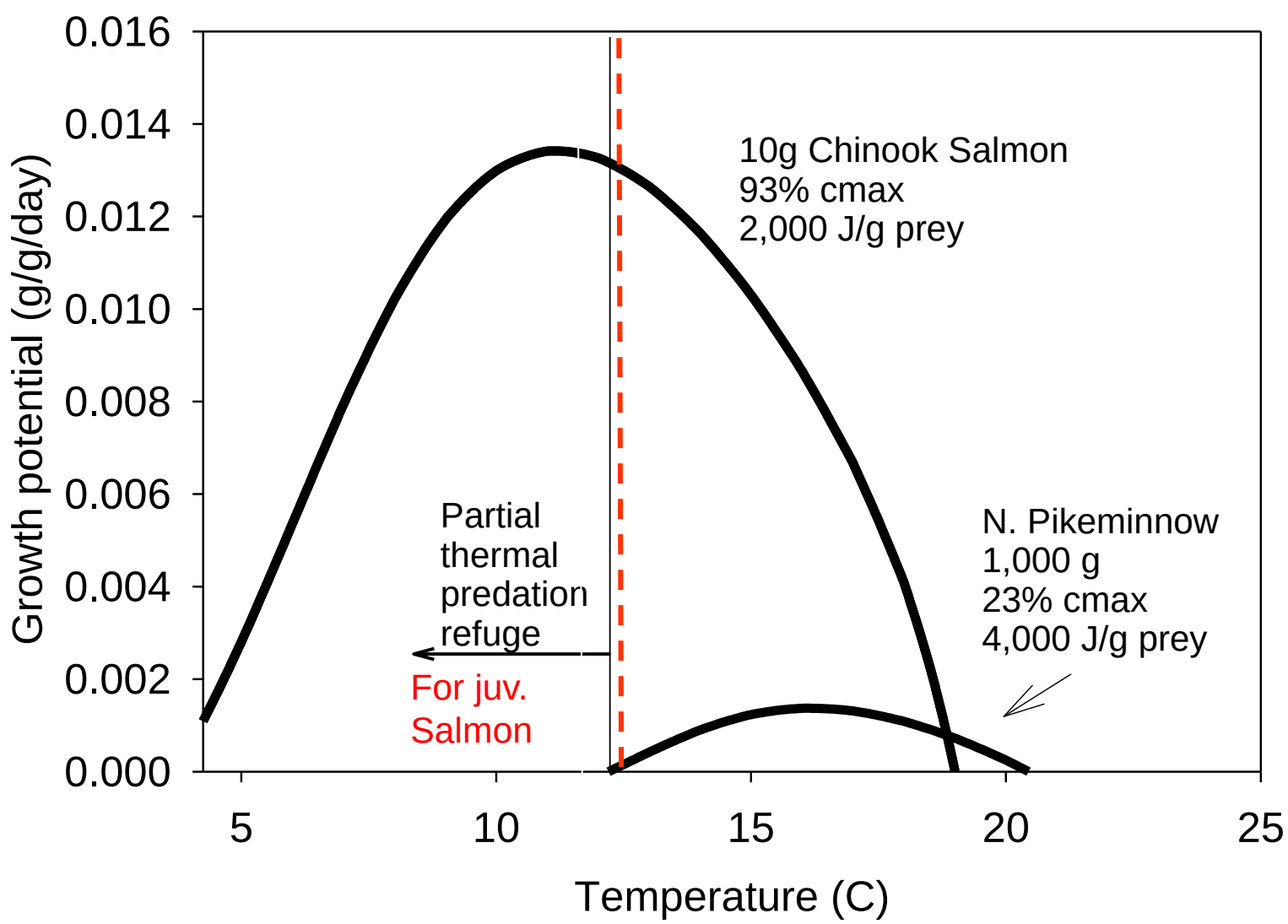
-Segregate or concentrate predators & prey



Differing Thermal Growth Responses can segregate predators from prey during thermal stratification

“Coolwater” predatory N. Pikeminnow grow better above the thermocline during Summer

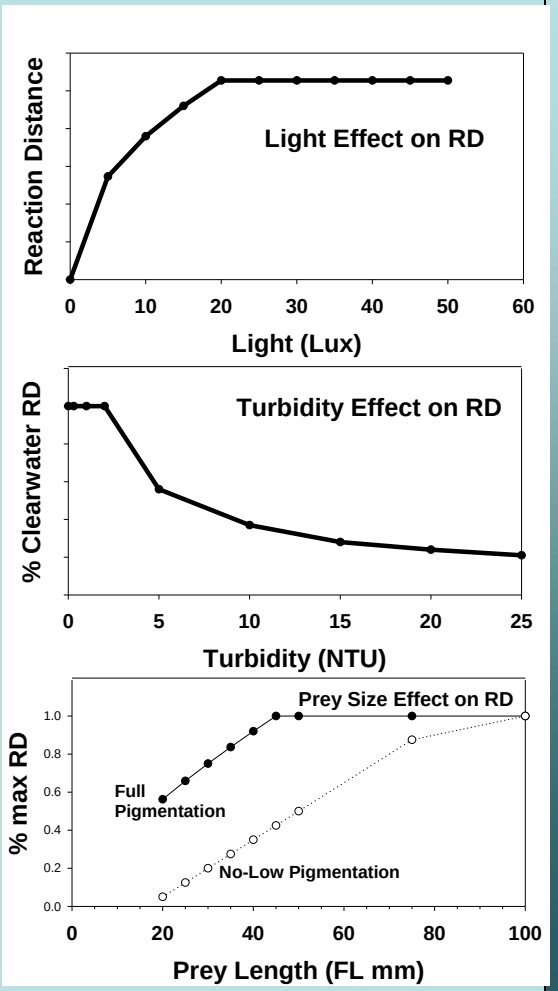
Mostly Segregated from Coldwater salmonids during Peak growing season

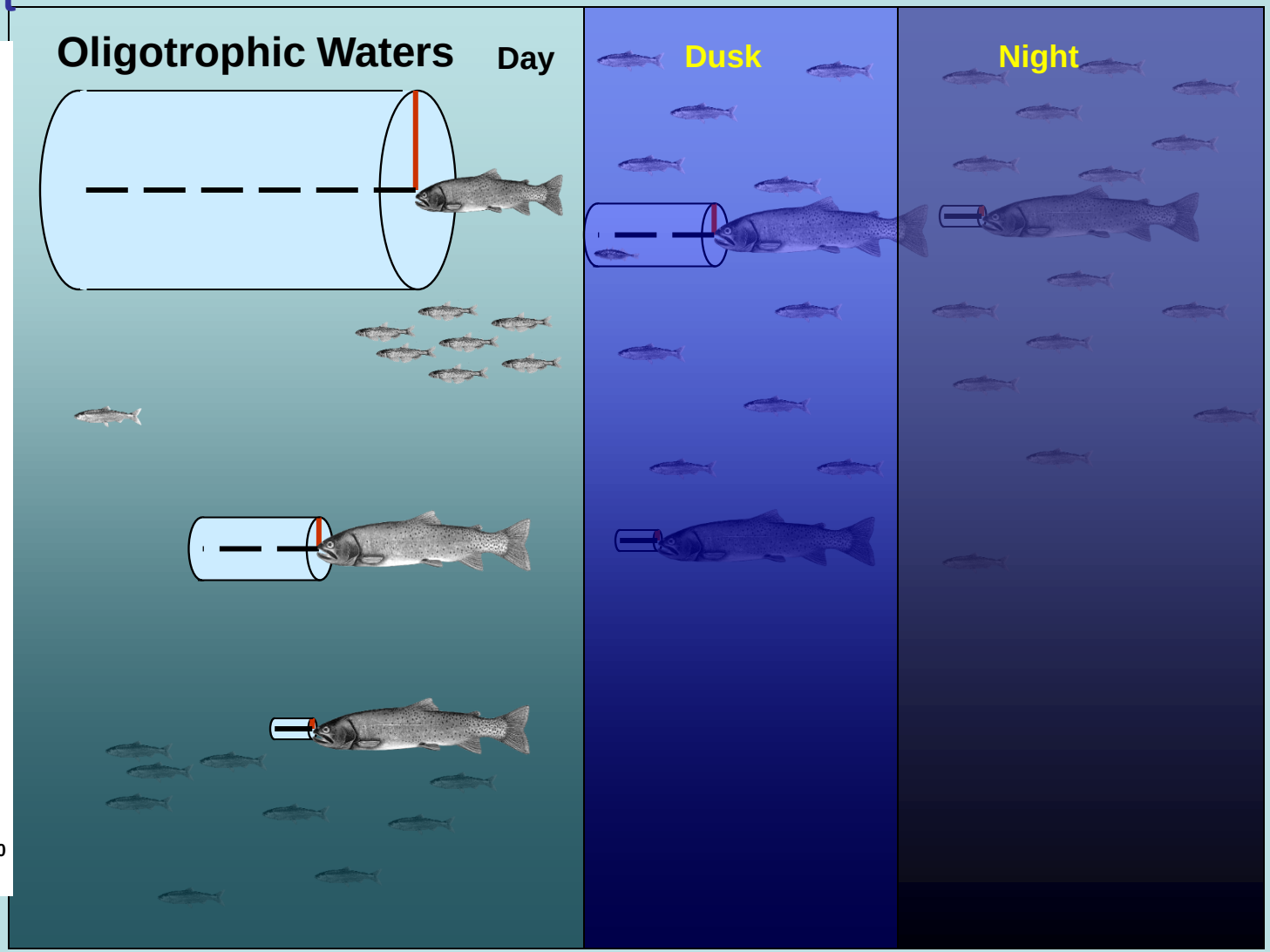


Sorel et al. 2016 TAFS

Visual Capabilities of Piscivores & the Pelagic Environment

Vertical Gradients: Predation Risk



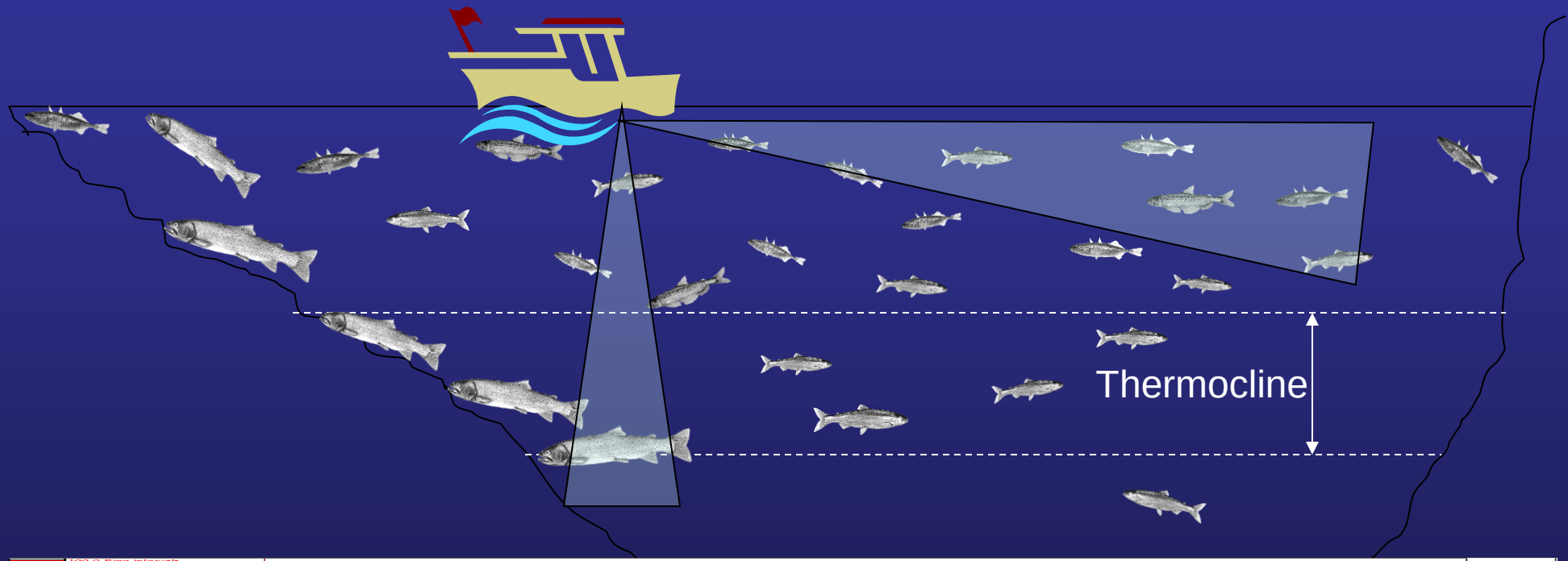


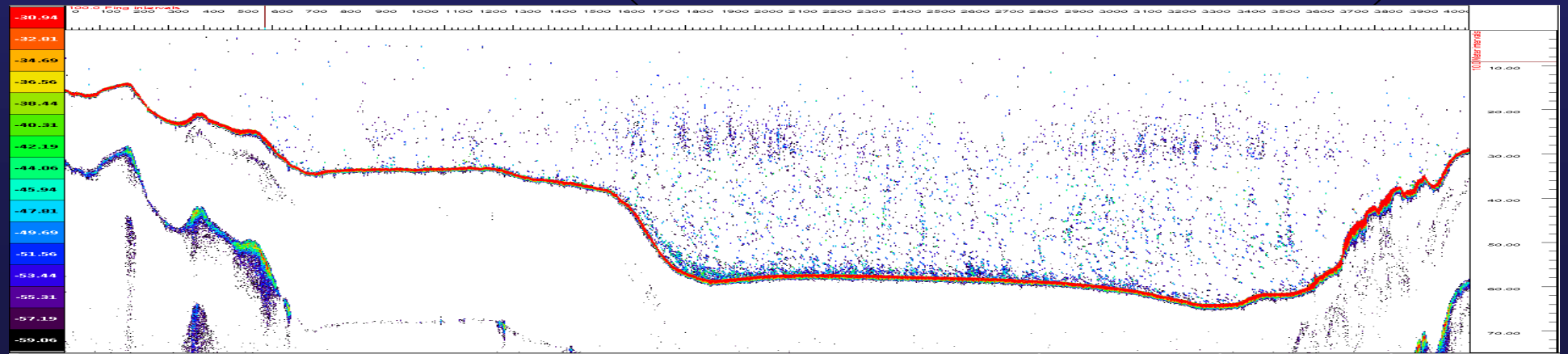
Distribution & Abundance

HYDROACOUSTICS Measure fish density & abundance:

-For different size classes of fish

-At each depth interval

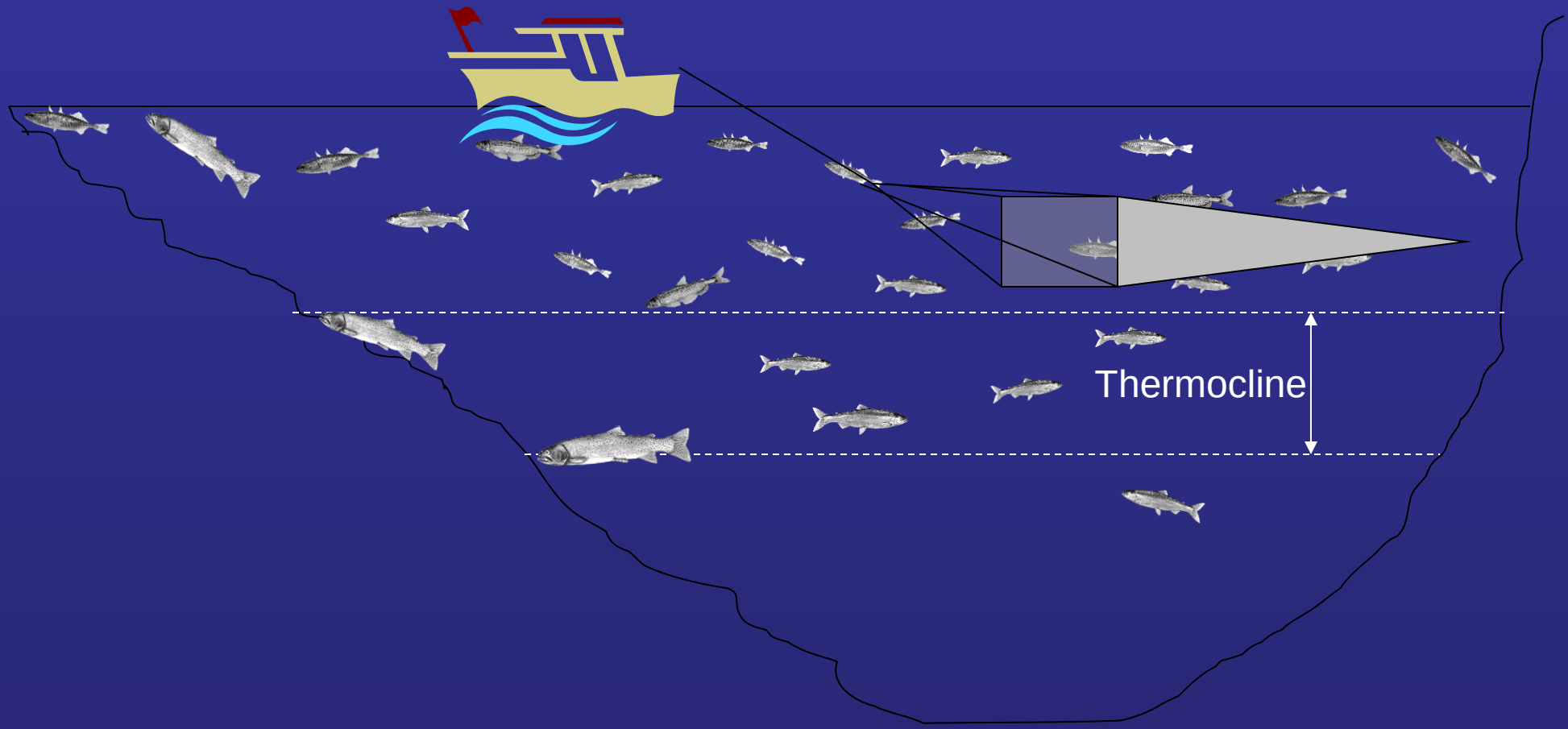




MIDWATER TRAWLING:

-samples species composition by depth

-provides biological data (size, growth, diet)



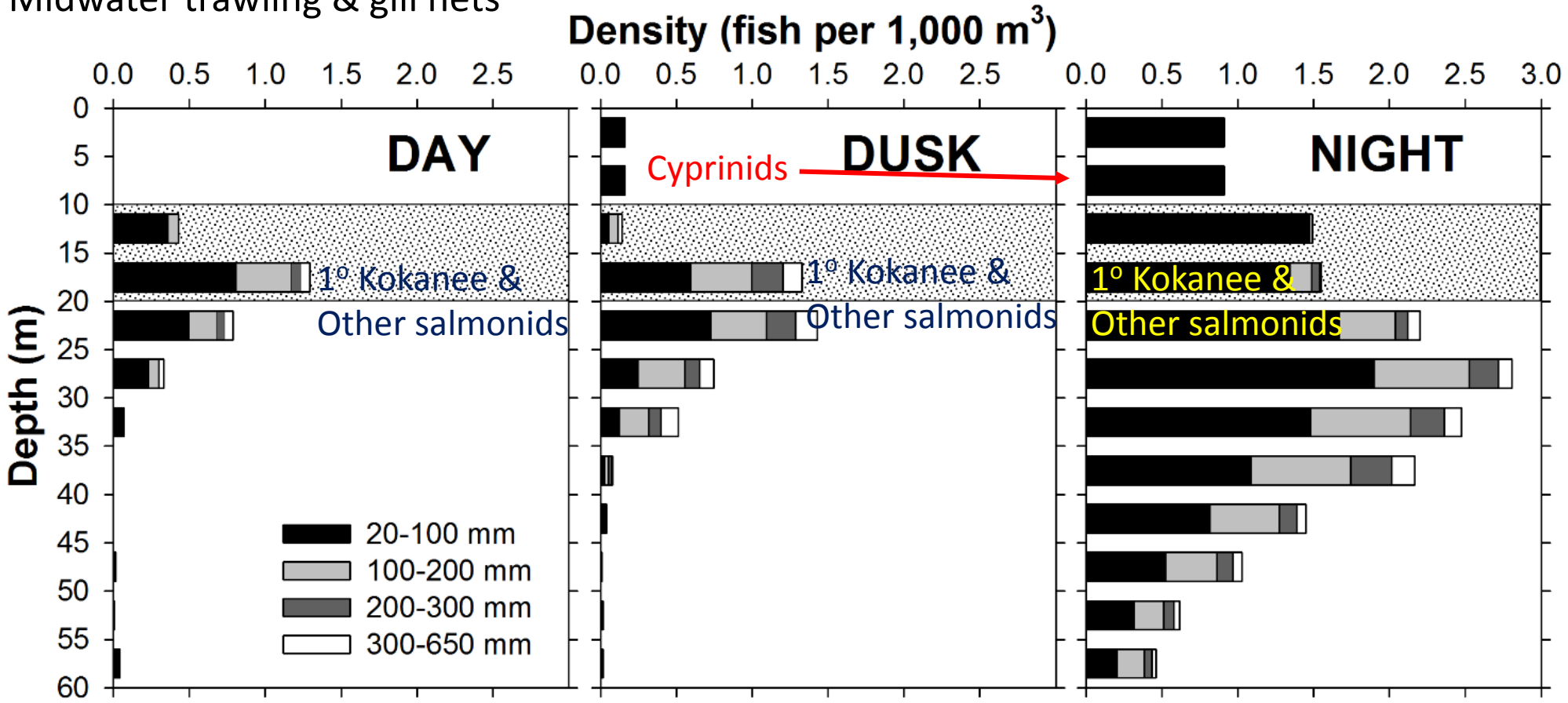
Diel Depth Distribution

Hydroacoustics

Midwater trawling & gill nets

Kachess Lake

August 2014

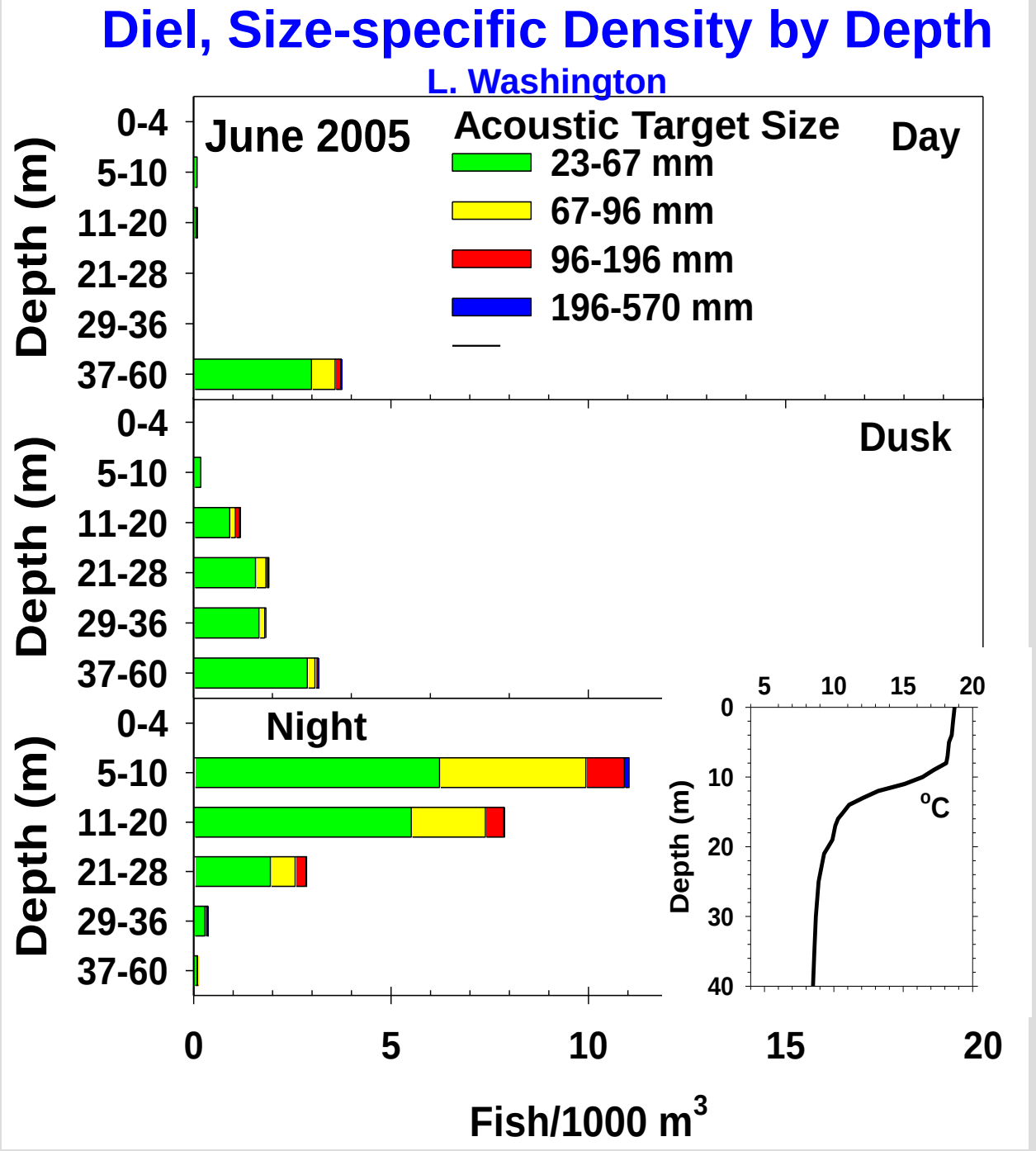


Hansen et al. 2015

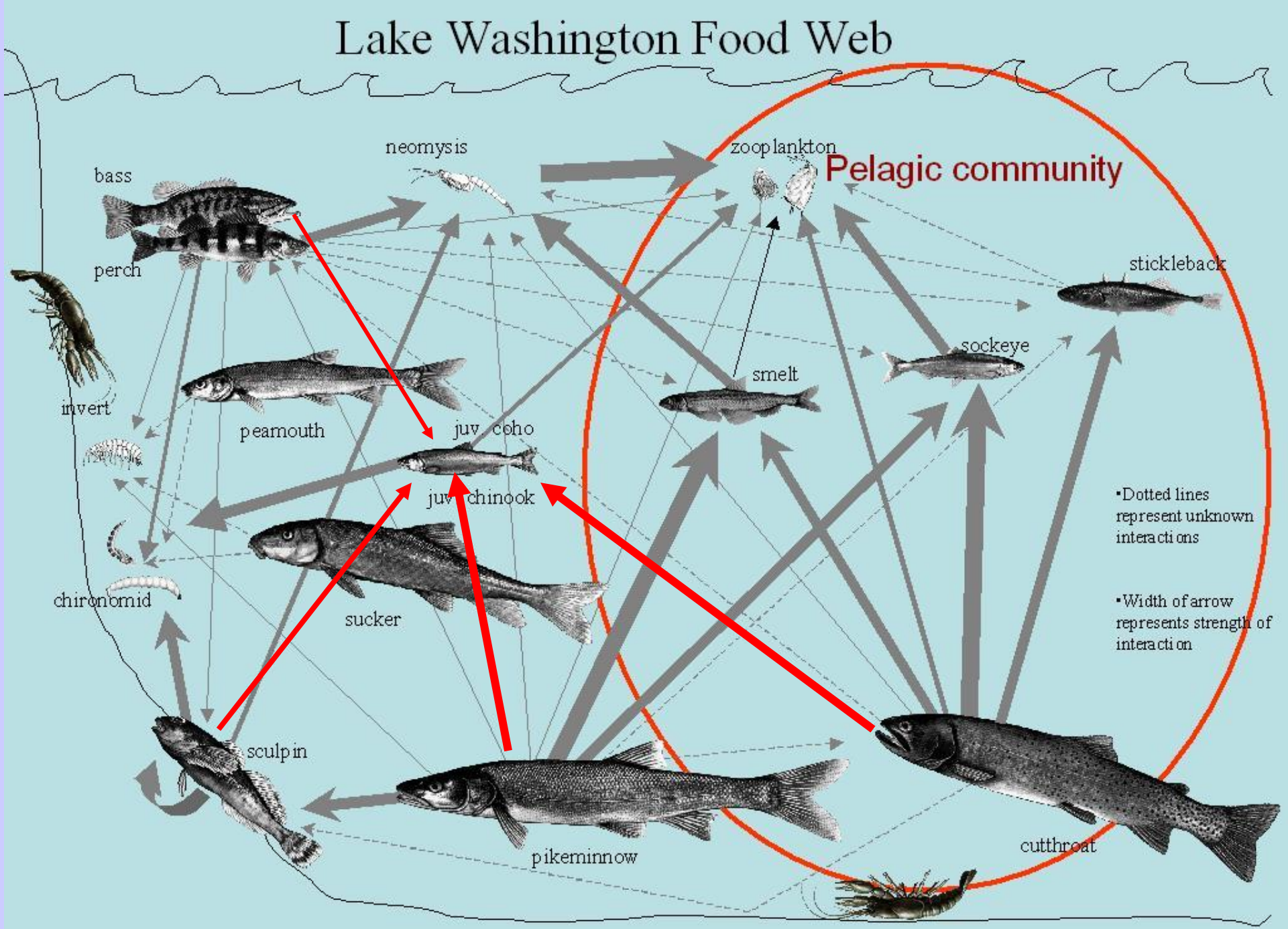
Daylight:
-Few fish are in the upper water column during daylight except large and very small fish
-Could be in schools, near bottom or near shore

Dusk
-Smolt-sized targets migrate To upper 20 m at dusk

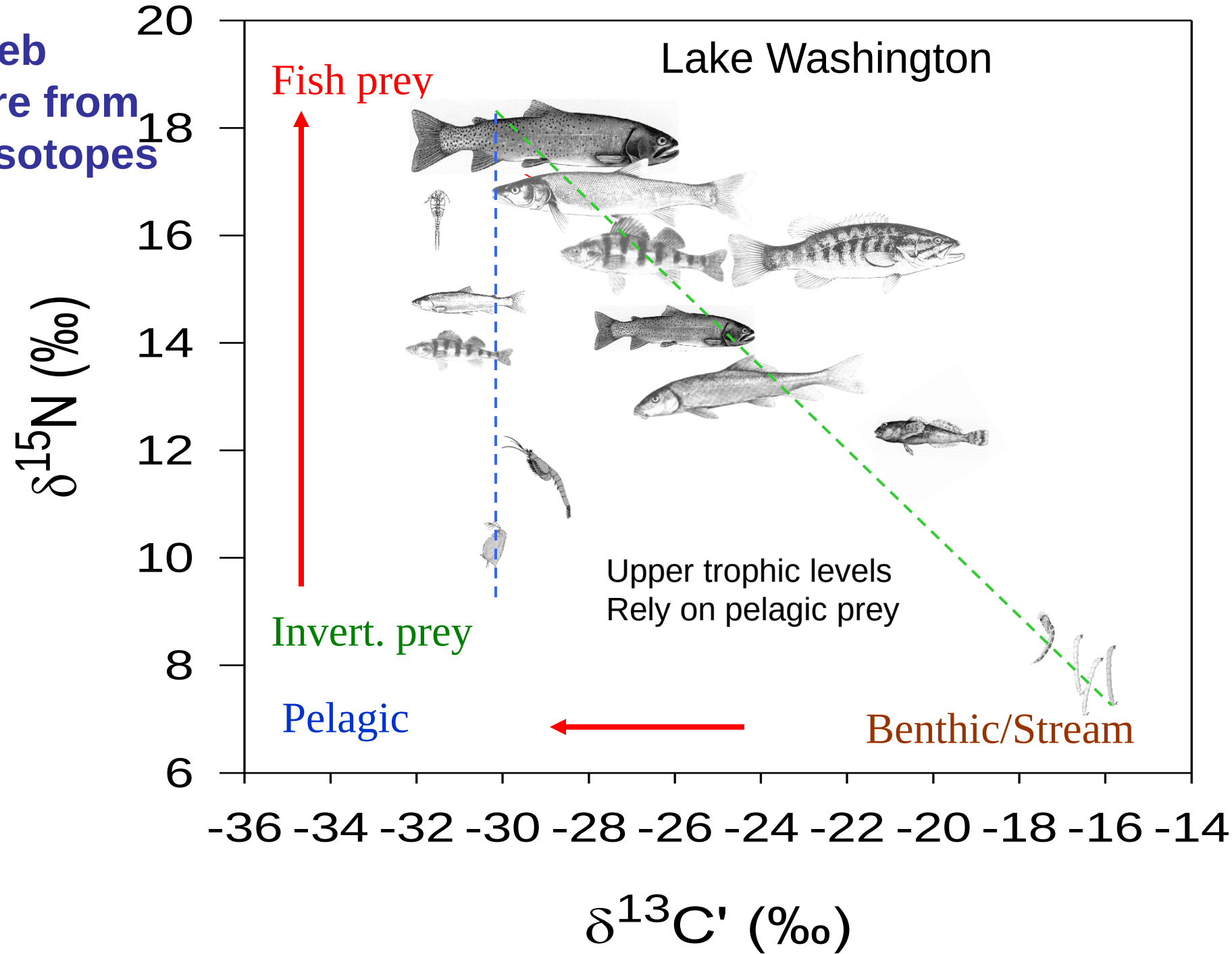
Night
-Smolt-sized targets fully dispersed in upper 20 m at night
-Net samples confirmed that chinook, sockeye, smelt, sticklebacks & cutthroat composed most of the targets



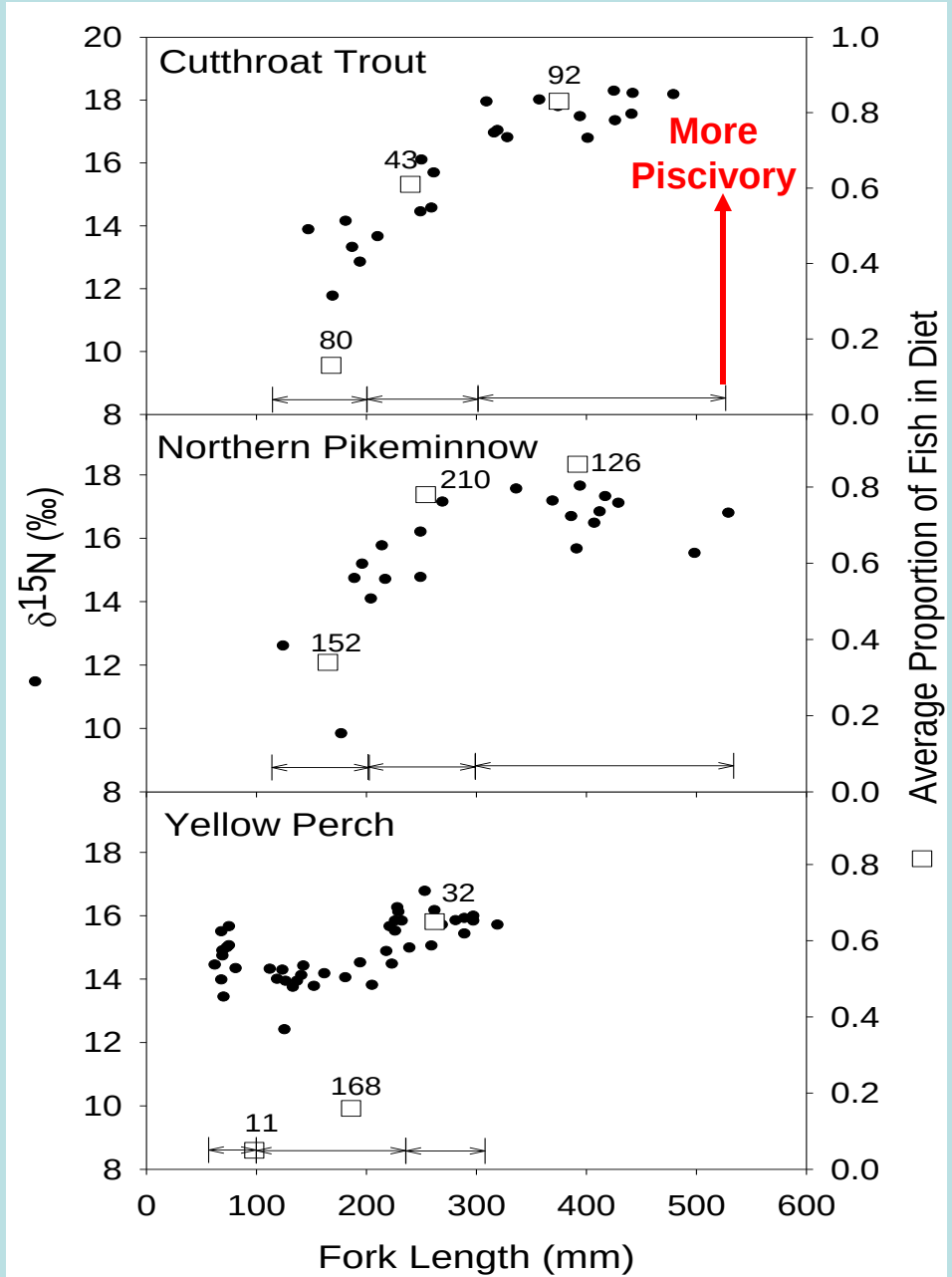
Quantifying Predation Mortality

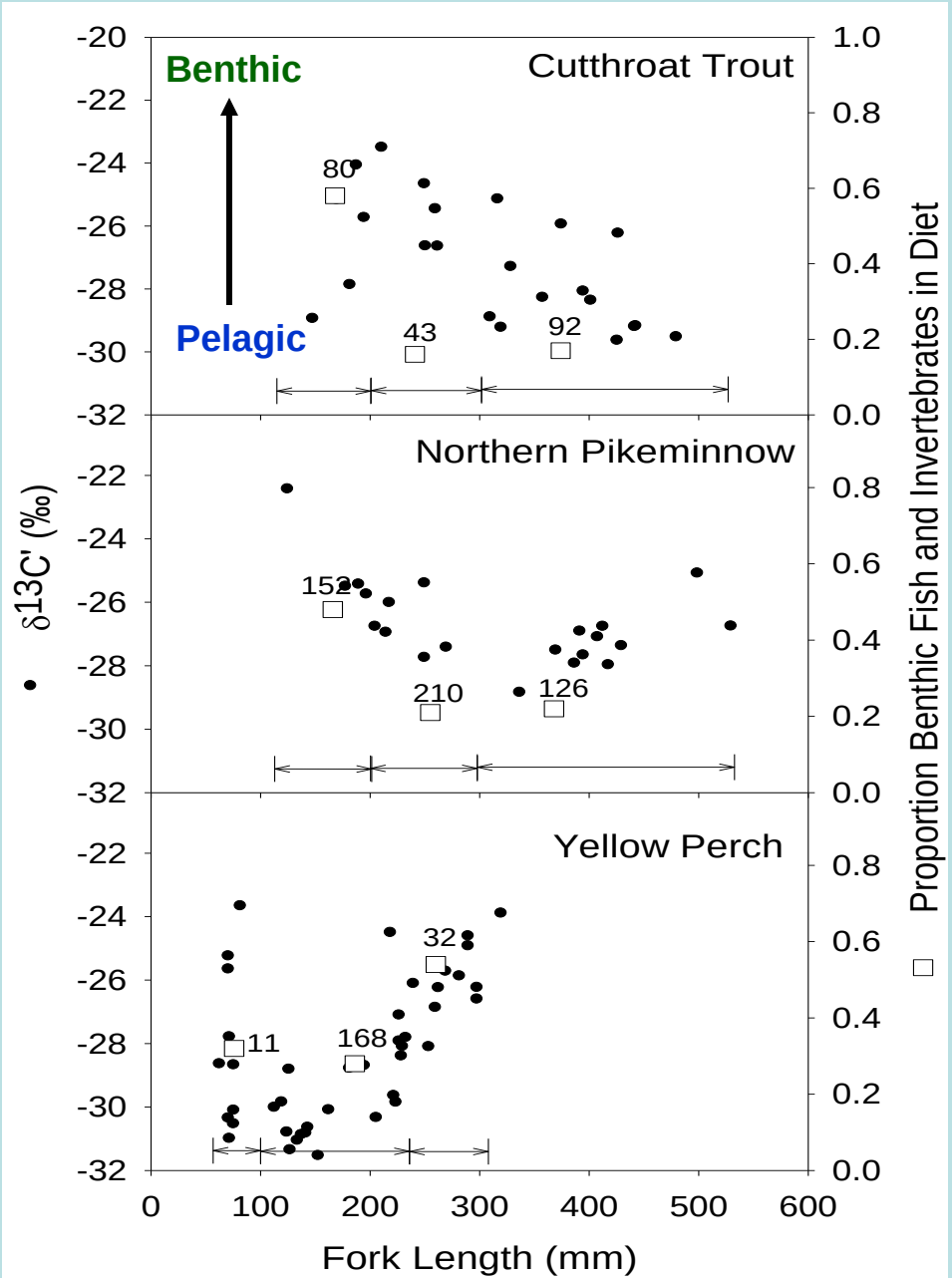

Lake Washington Food Web
neomysis
zooplankton
Pelagic community
bass
perch
stickleback
sockeye
smelt
invert
peamouth
juv coho
juv chinook
chironomid
sucker
•Dotted lines represent unknown interactions
•Width of arrow represents strength of interaction
sculpin
pikeminnow
cutthroat

Food Web Structure from Stable Isotopes



Diet & Stable Isotopes in L. Washington: Cutts & Pikeminnow shift from Benthic Inverts to Pelagic Fish w\ increasing size. Perch shift toward Benthic Fish





McIntyre et al. 2006

Modeling Process

Diet Composition

Consumer Growth

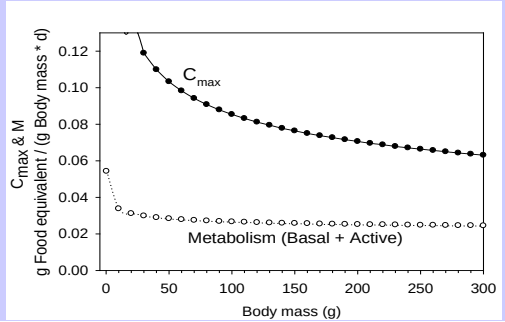
Predator Energy Density

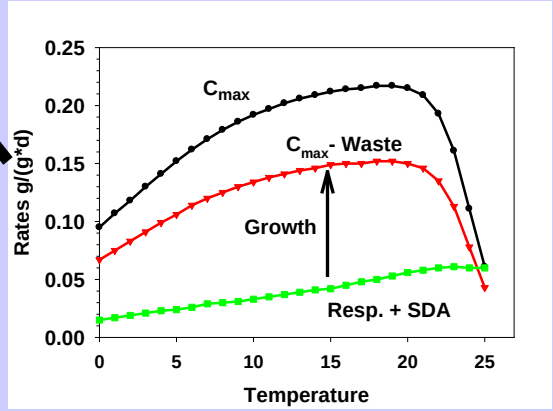
Thermal Experience

Prey Energy Density

Bioenergetics Model

$$C = M + W + G$$





How much food must be **Consumed** to satisfy observed **Growth**? or

How much **Growth** given **Consumption**?

Consumption Estimate

Daily time step

Quantifying Predation Mortality

Directed Field Sampling for:

Diet variability by season & size

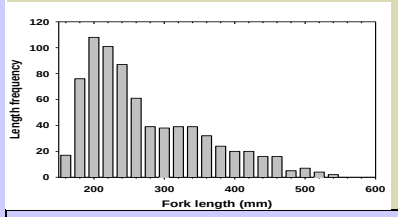
Predator Growth ($W_t - W_0$)

Predator Energy Density

Thermal Experience

Prey Energy Density

Bioenergetics Model



Predator Size Structure & Abundance

Consumption Estimate (g/d of each prey)

$\Sigma(C_t \times N_t)$

Population Consumption

Biomass of Exploitable prey

Consumption as % of Prey Biomass or Production

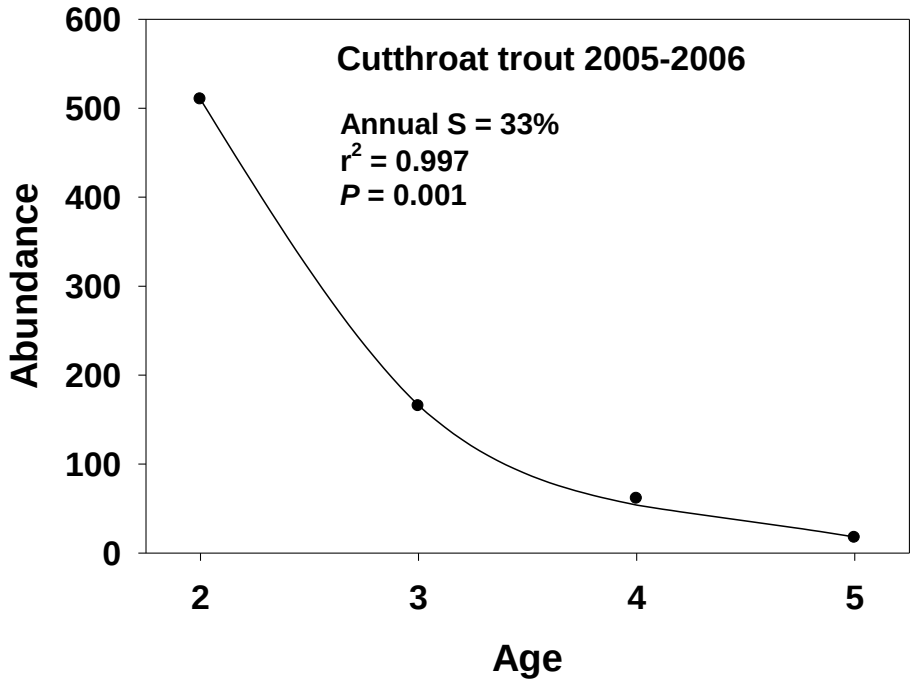
Size Structure, Survival & Growth

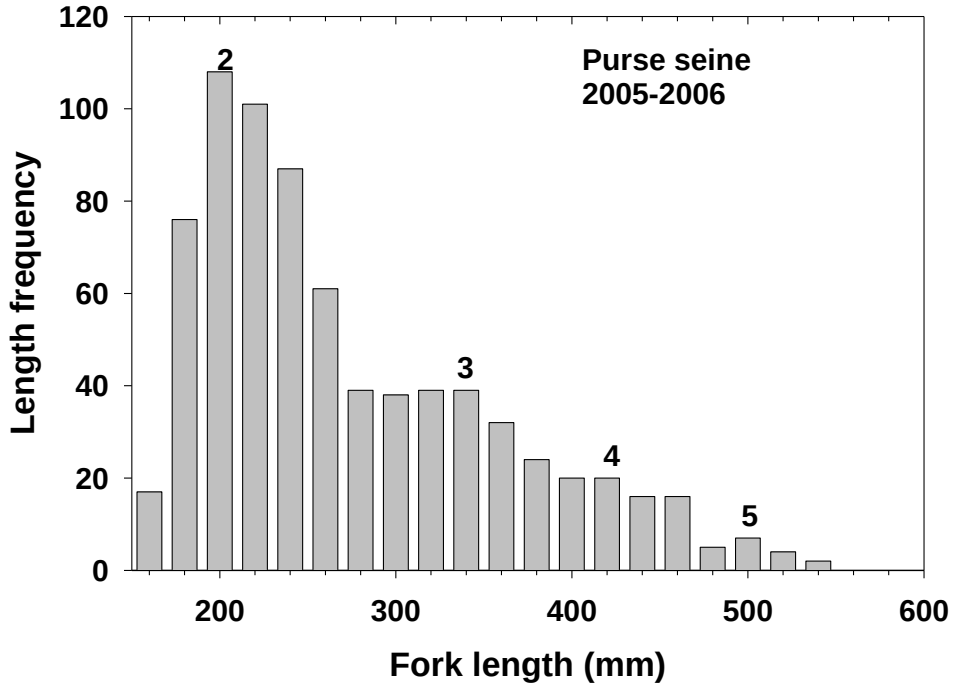
L. Washington 2005-06

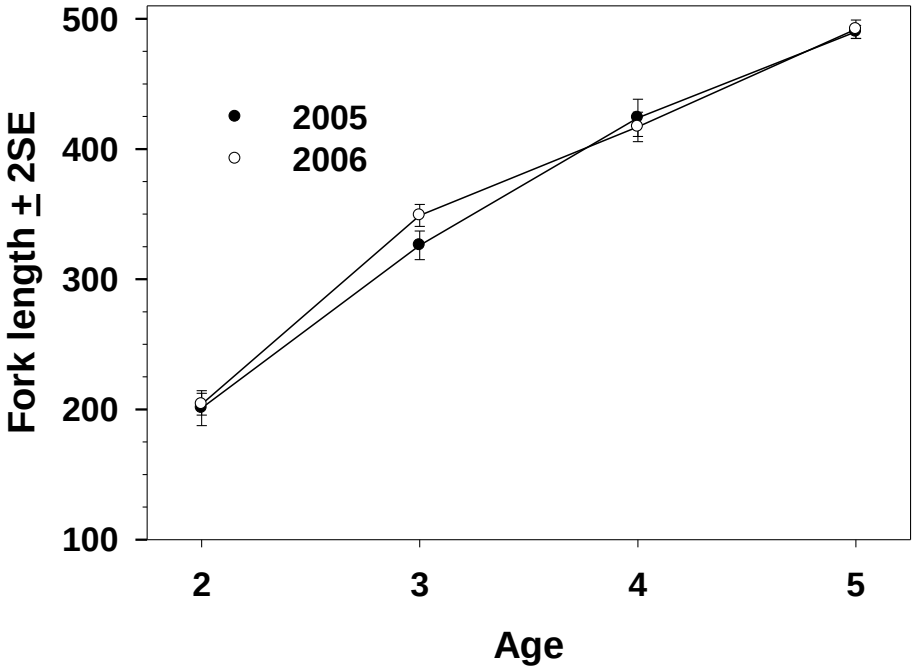
Cutthroat trout

Ages & Length Freq Modes

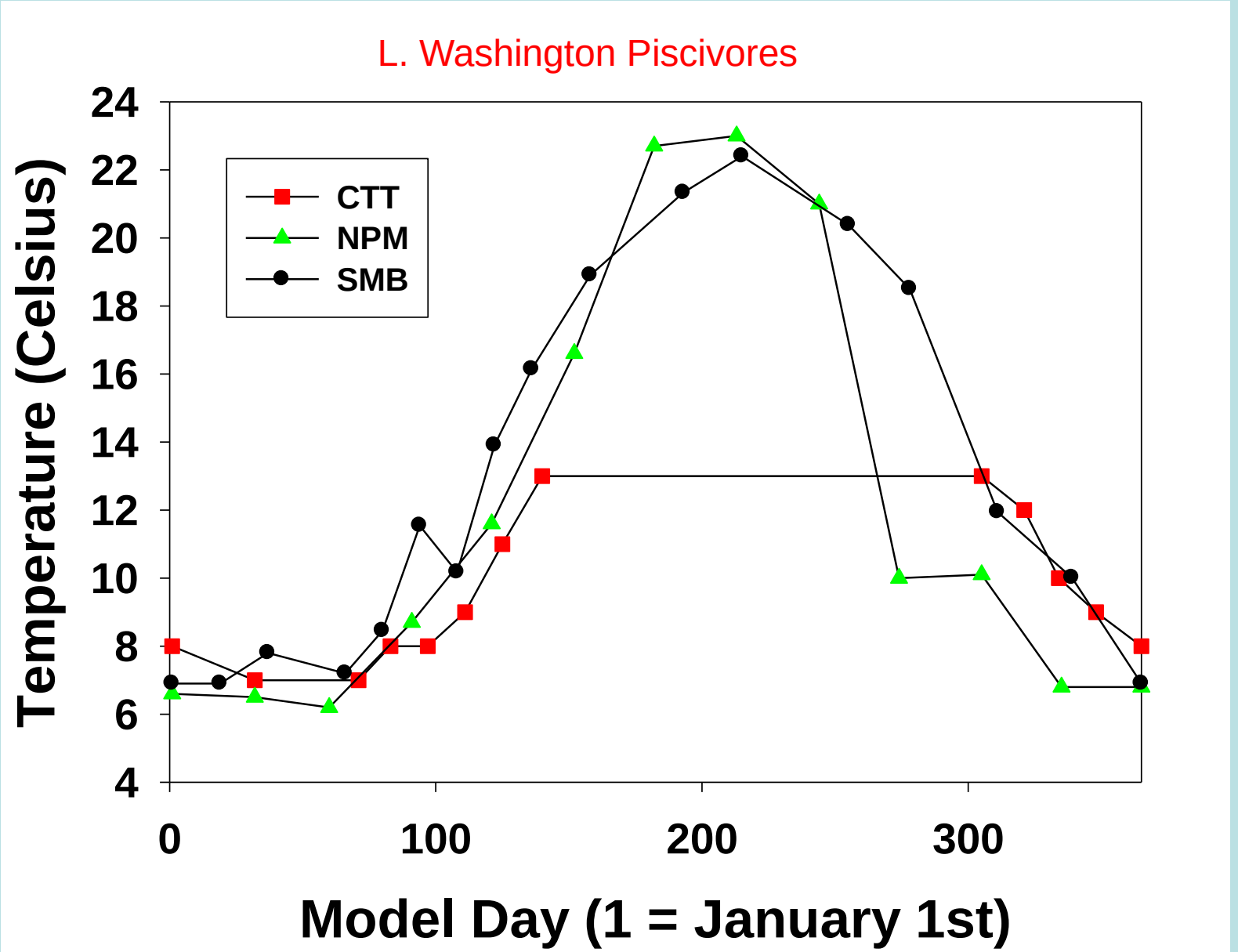
Confirmed by aging w\ scales



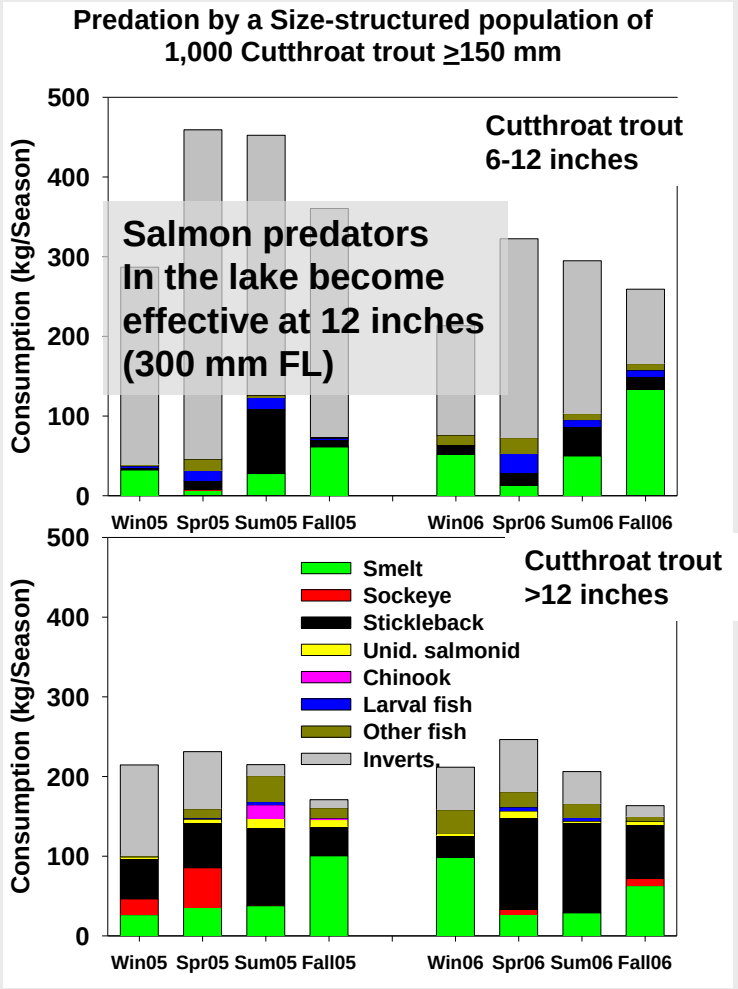


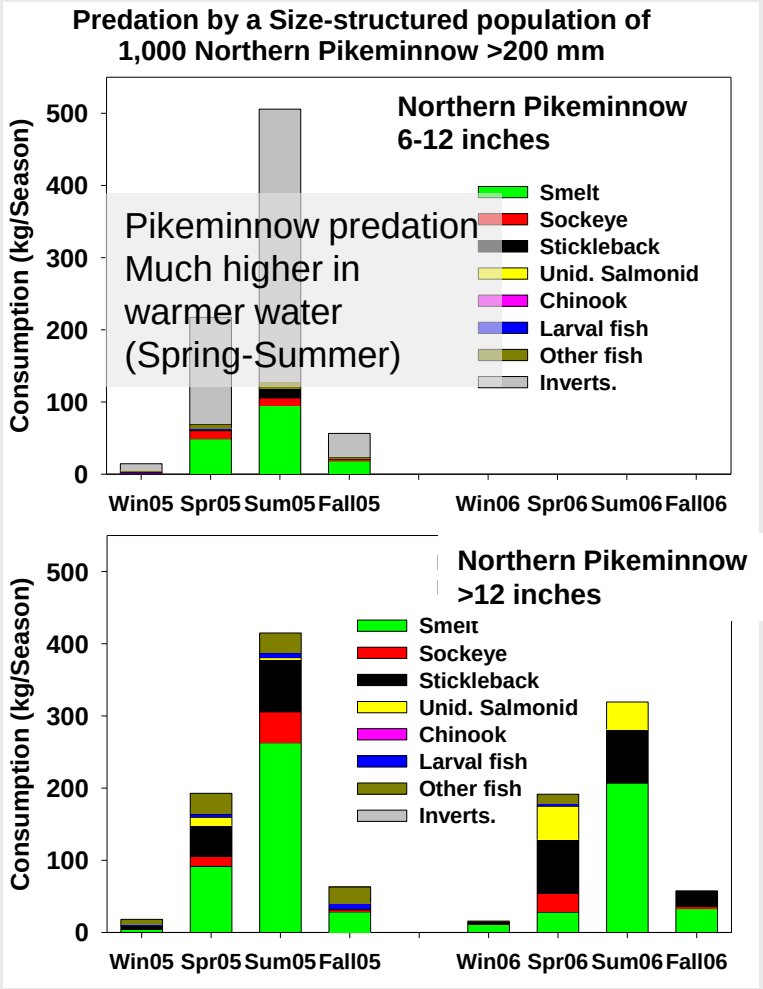


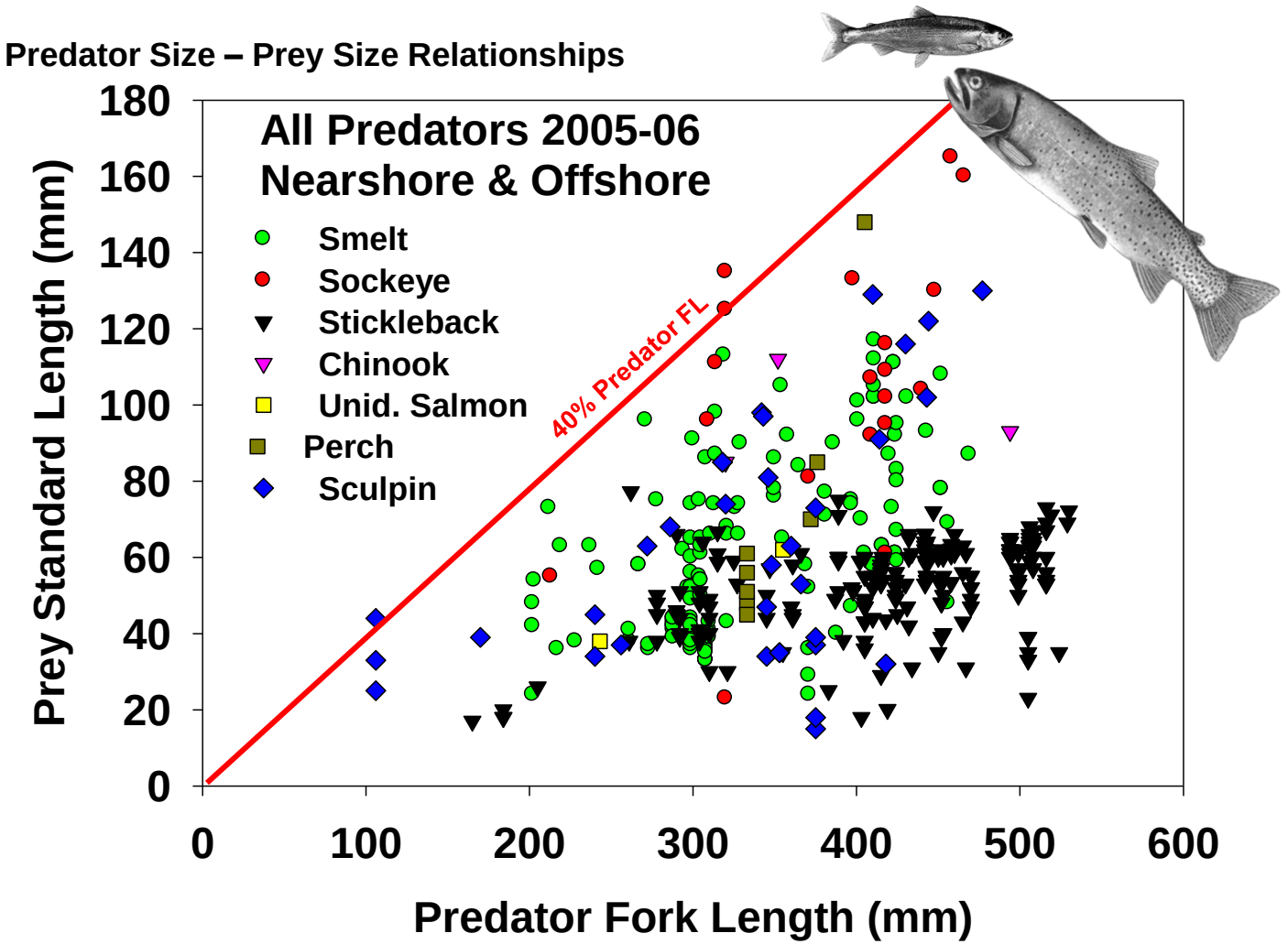
Modeled thermal experience for each species



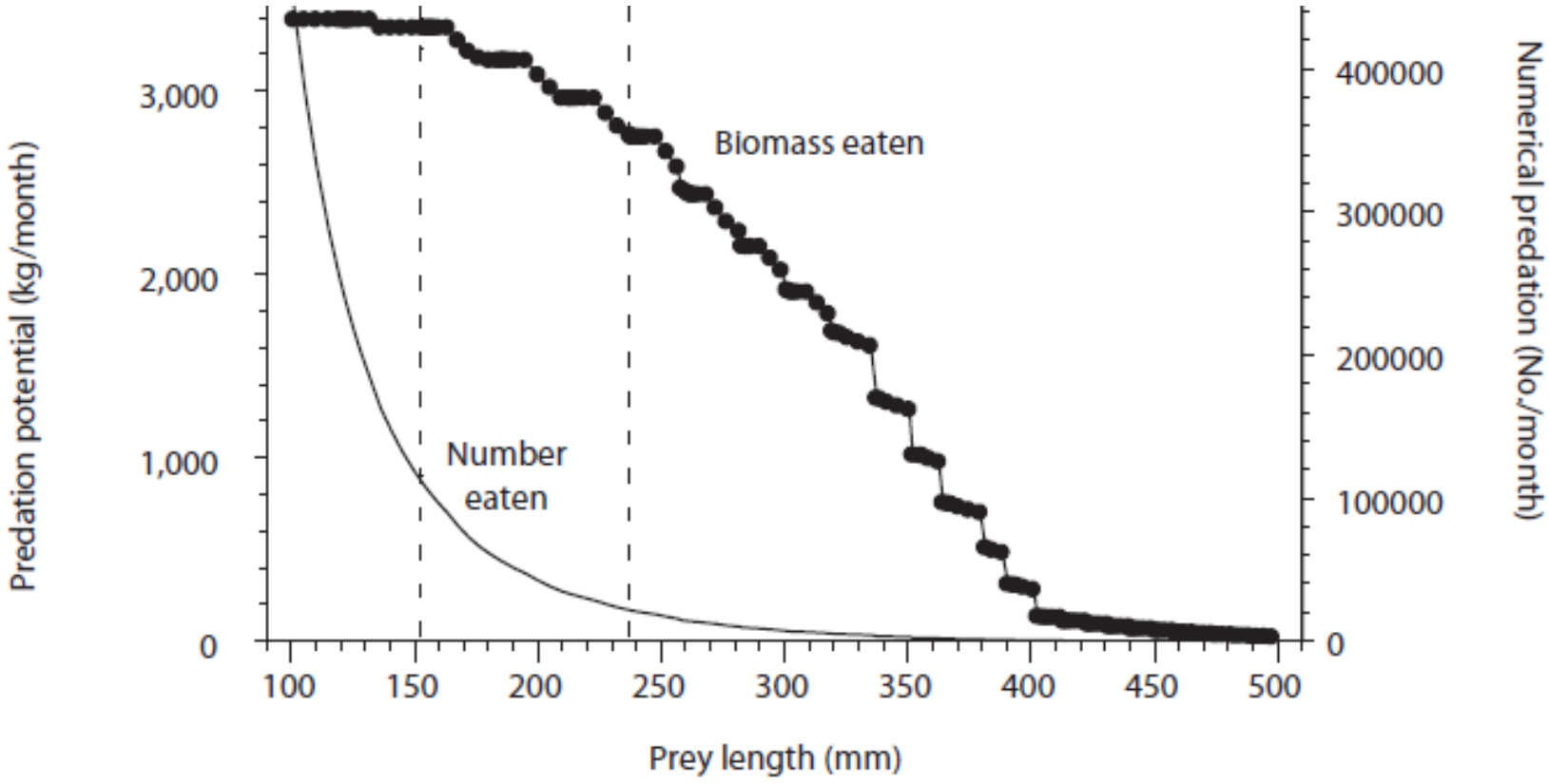
Predation Patterns: L. Washington 2005-2006






Predator Size – Prey Size Relationships
All Predators 2005-06
Nearshore & Offshore
Smelt
Sockeye
Stickleback
Chinook
Unid. Salmon
Perch
Sculpin
40% Predator FL
Prey Standard Length (mm)
Predator Fork Length (mm)
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600

Prey Growth and Changing Size-selective Mortality
(Kokanee-Lake trout example)

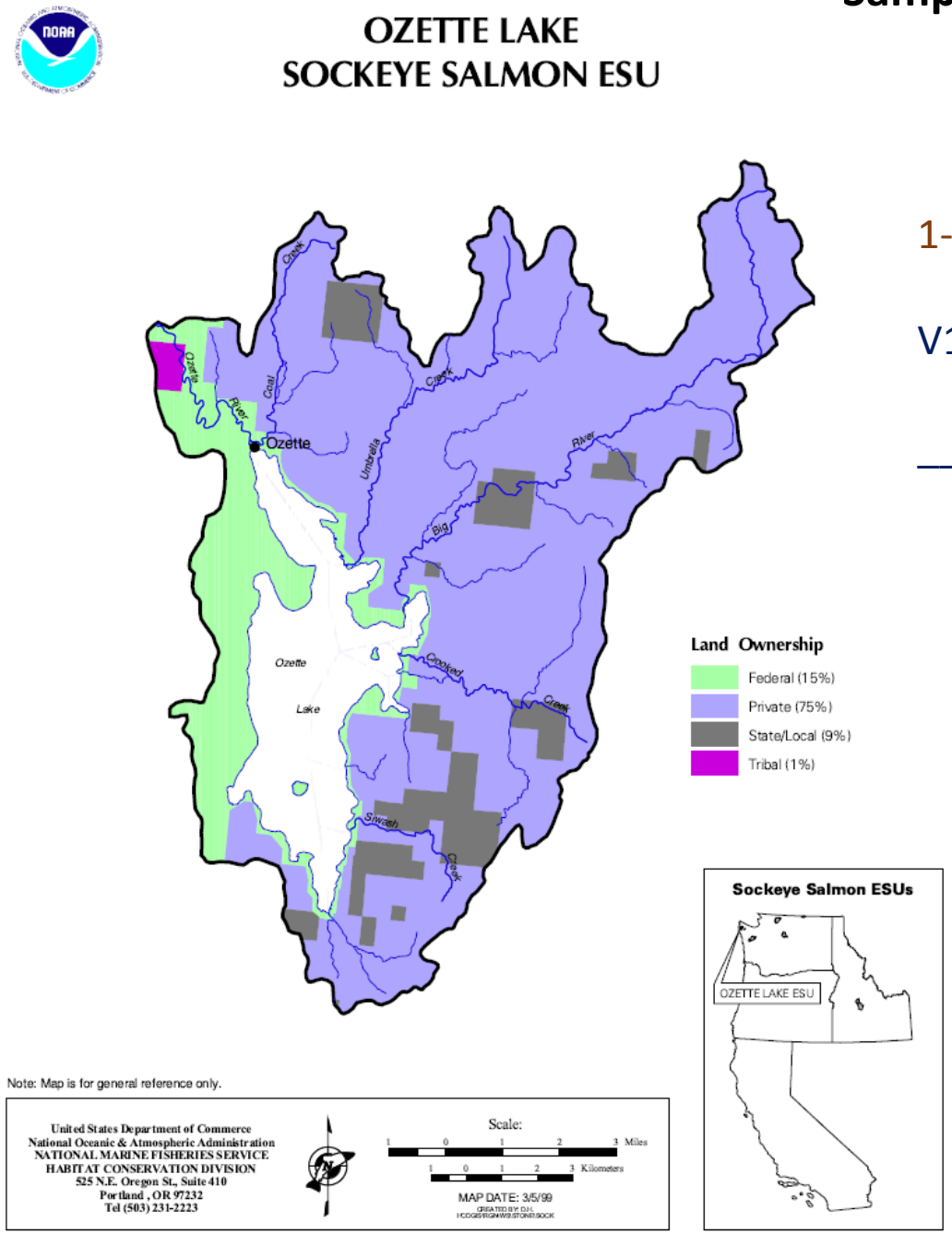


Beauchamp et al. 2007. Predator-Prey Interactions, *in* Guy & Brown, eds. Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society. Bethesda.

Example of Predation Impact Estimates: 2005 & 2006

2005 Prey species	Predation Mortality per 1,000 Cutthroat Trout
Sockeye	**0.6%**
Chinook	**1.1%**
Smelt	**0.6%**
Stickleback	**1.6%**
2006	
Sockeye	0.1%
Chinook	**0.0%**
Smelt	0.8%
Stickleback	1.9%

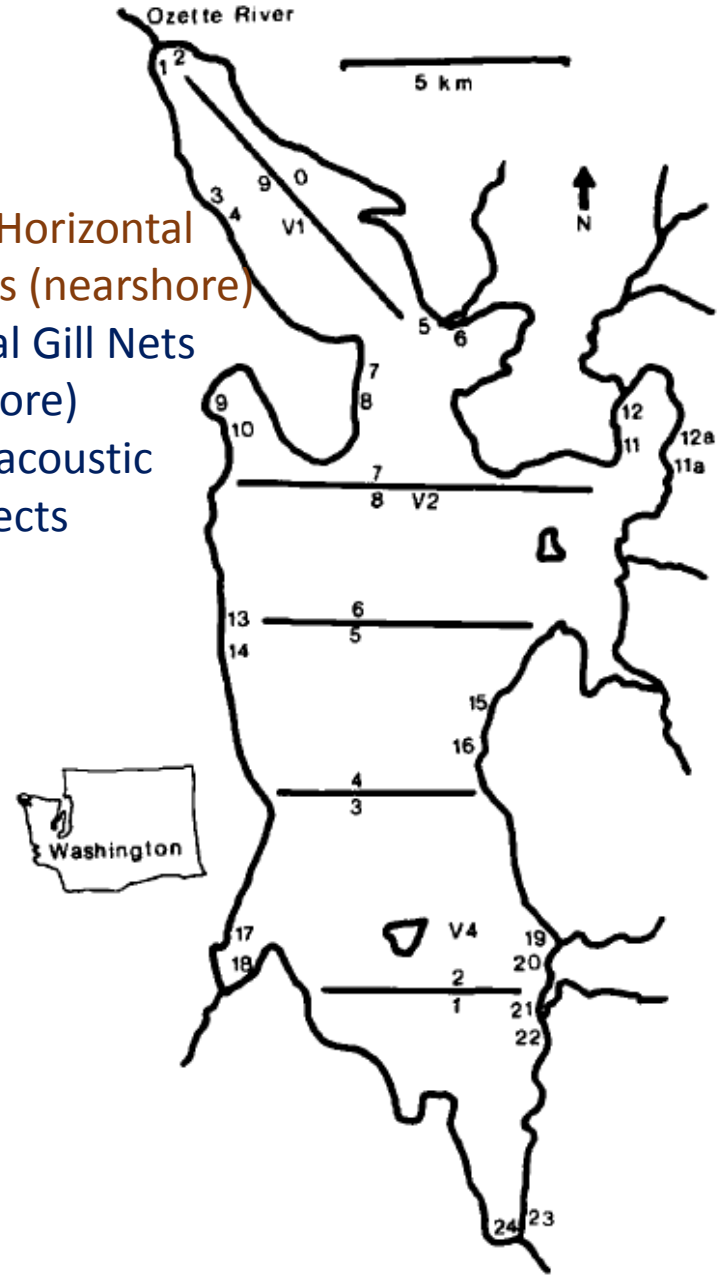
Sampling Stations in L. Ozette (Beauchamp et al. 1995)



1-24: Sinking Horizontal Gill Nets (nearshore)

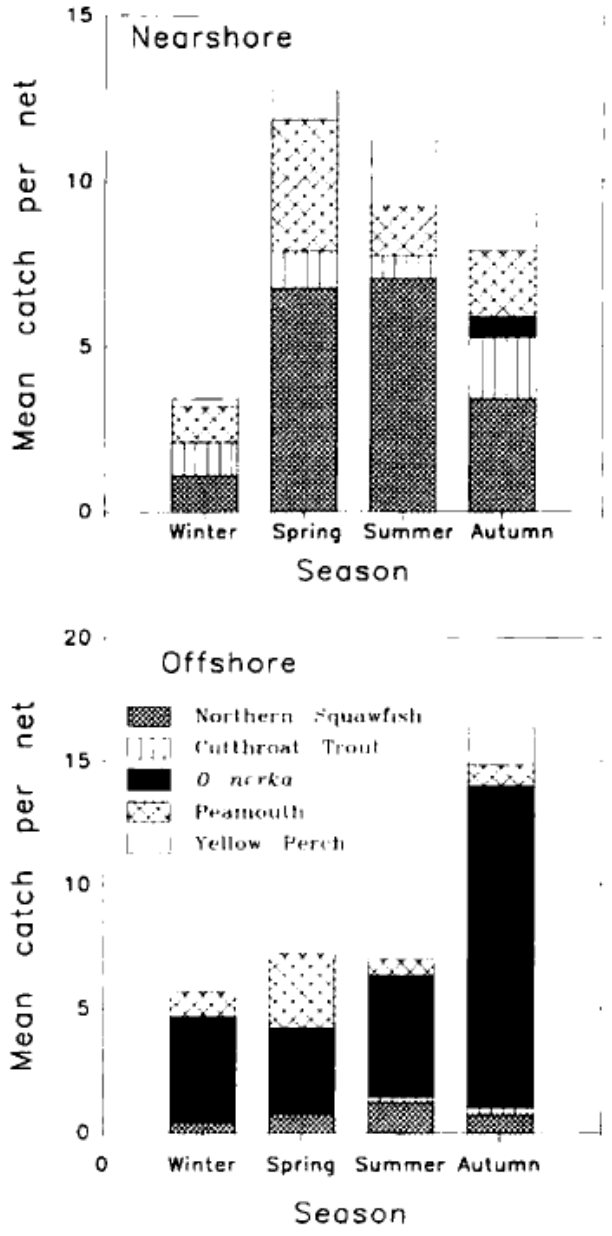
V1-V4: Vertical Gill Nets (offshore)

_____Hydroacoustic Transects



Lake Ozette

Seasonal Nearshore-Offshore
Catch Rate by Species in Gill Nets



Beauchamp et al. 1995. NAJFM

L. Ozette

Dimensions Of Predation

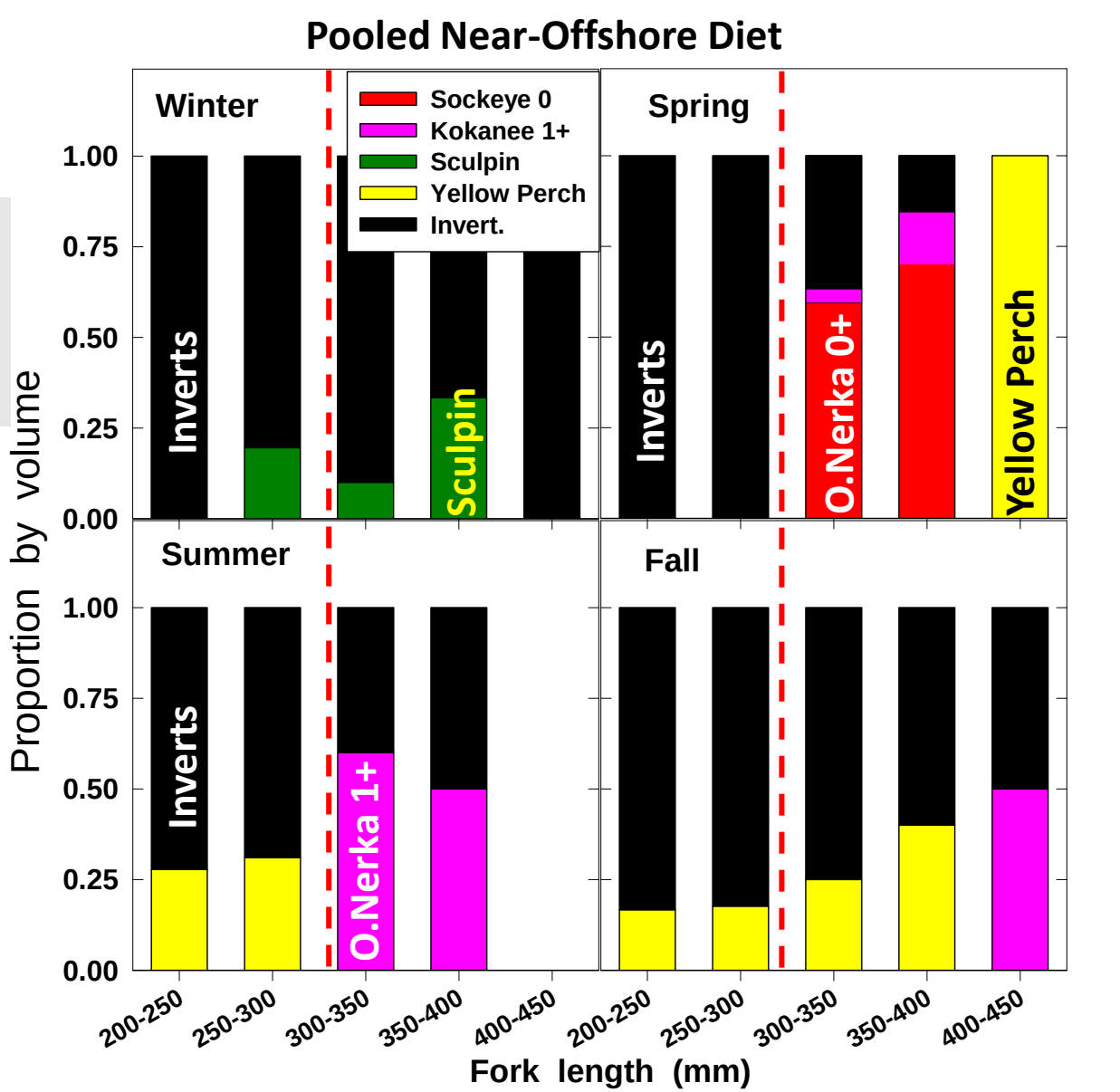
Effective pelagic Salmon Predators FL > 300 mm

Predation differs Among predators & Seasons:

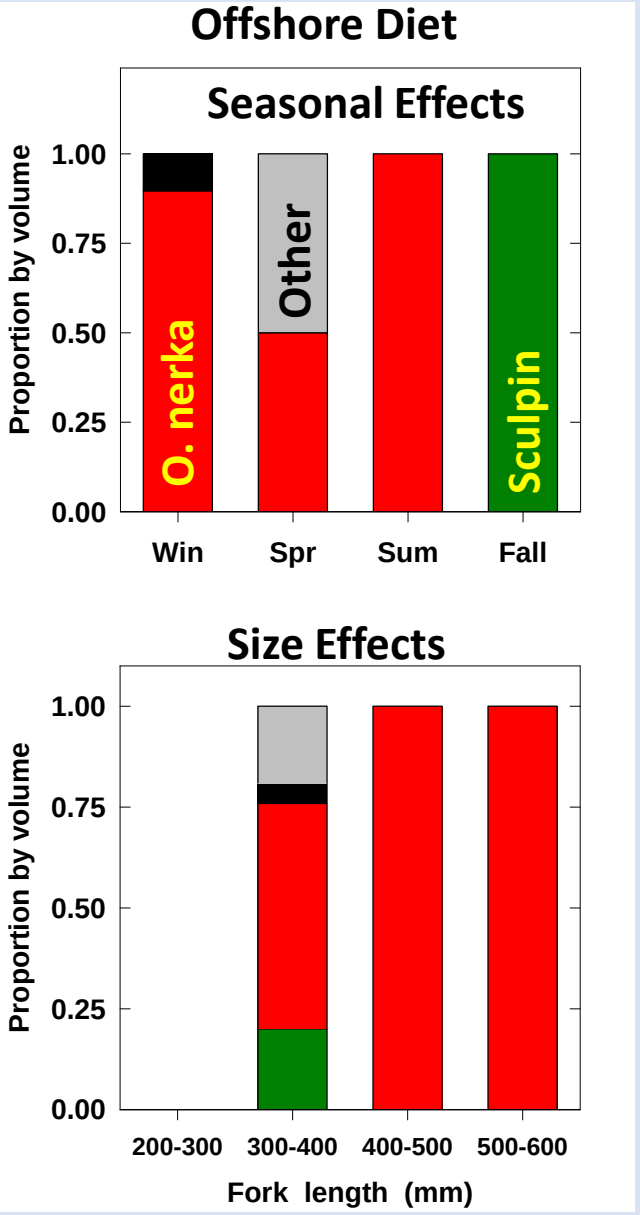
Cutts: Spr, Sum, Fall

NPM: Wtr, Spr, Sum

Cutthroat Trout Seasonal, Size-related Diets



N. Pikeminnow



Beauchamp et al. 1995

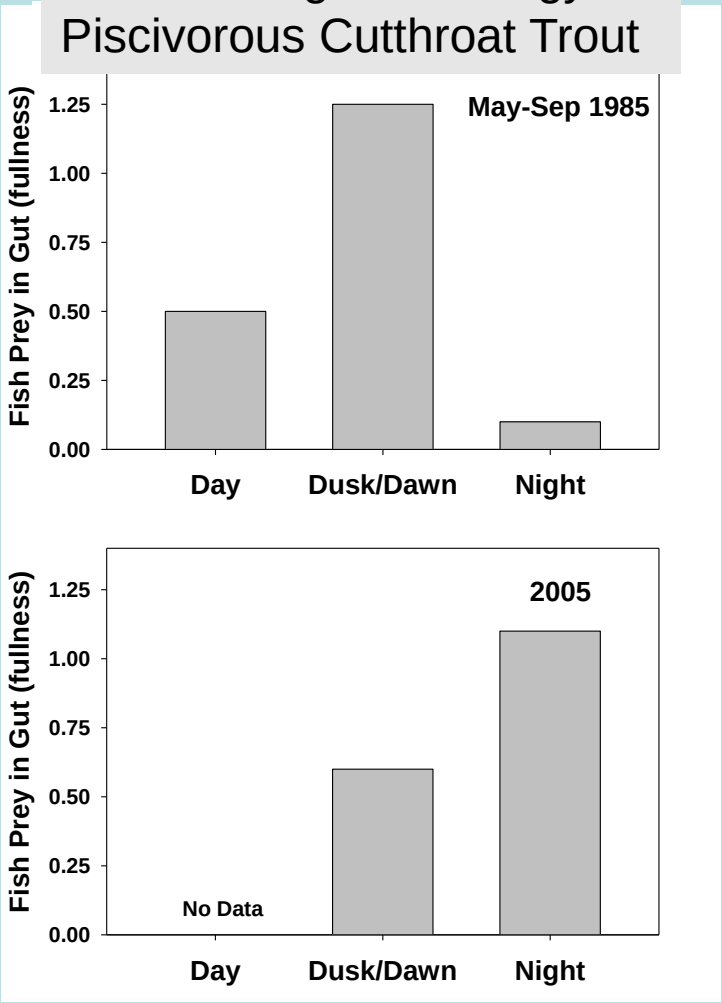
Summary

- **Size structure & Abundance of predators matter**
  - **Effective predator size & per capita consumption rates**
- **Predation Impact varies Seasonally by Spp & Size**
- **Vertically-Structured Predation:Foraging trade-offs**
  - **Thermal Stratification**
  - **Thermal responses Segregate or Concentrate Some Predators & Prey**
    - **Affect seasonal & depth-specific consumption capacity & G**
  - **Light Gradients affect predation risk across depths**
    - **Diel Vertical Migration or Schooling as anti-predation strategy**
    - **Affected by changing Transparency & Artificial Light Pollution**

Shift in Diel Feeding by Piscivorous Cutthroat Trout in Lake Washington over 30 years in response to increasing Nocturnal Light Pollution

-1980s strong dawn/dusk predation peak (~3 hr/day of high predation risk)

-2005-2015 peak predation thru the night (8-15 hr/day of high predation risk)



Beauchamp et al. 1992. NW Sci.

Hansen & Beauchamp. 2014. Freshwater Biol 59:2328-2341.

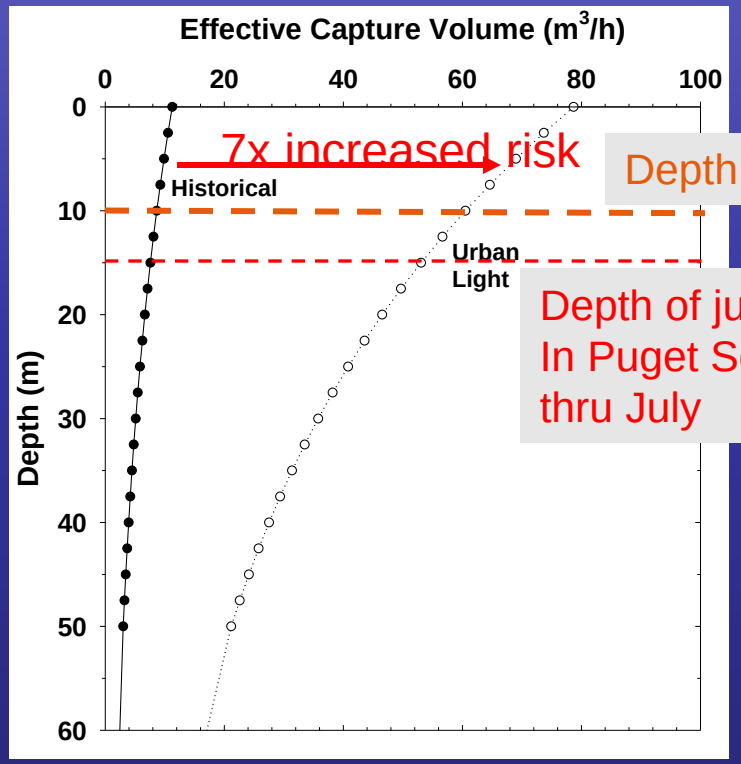
Effect of Urban Light Pollution on Predation Risk:
-Nocturnal Migratory Corridors & Feeding Habitat
-Dark Nocturnal Refuge in Early Marine Life

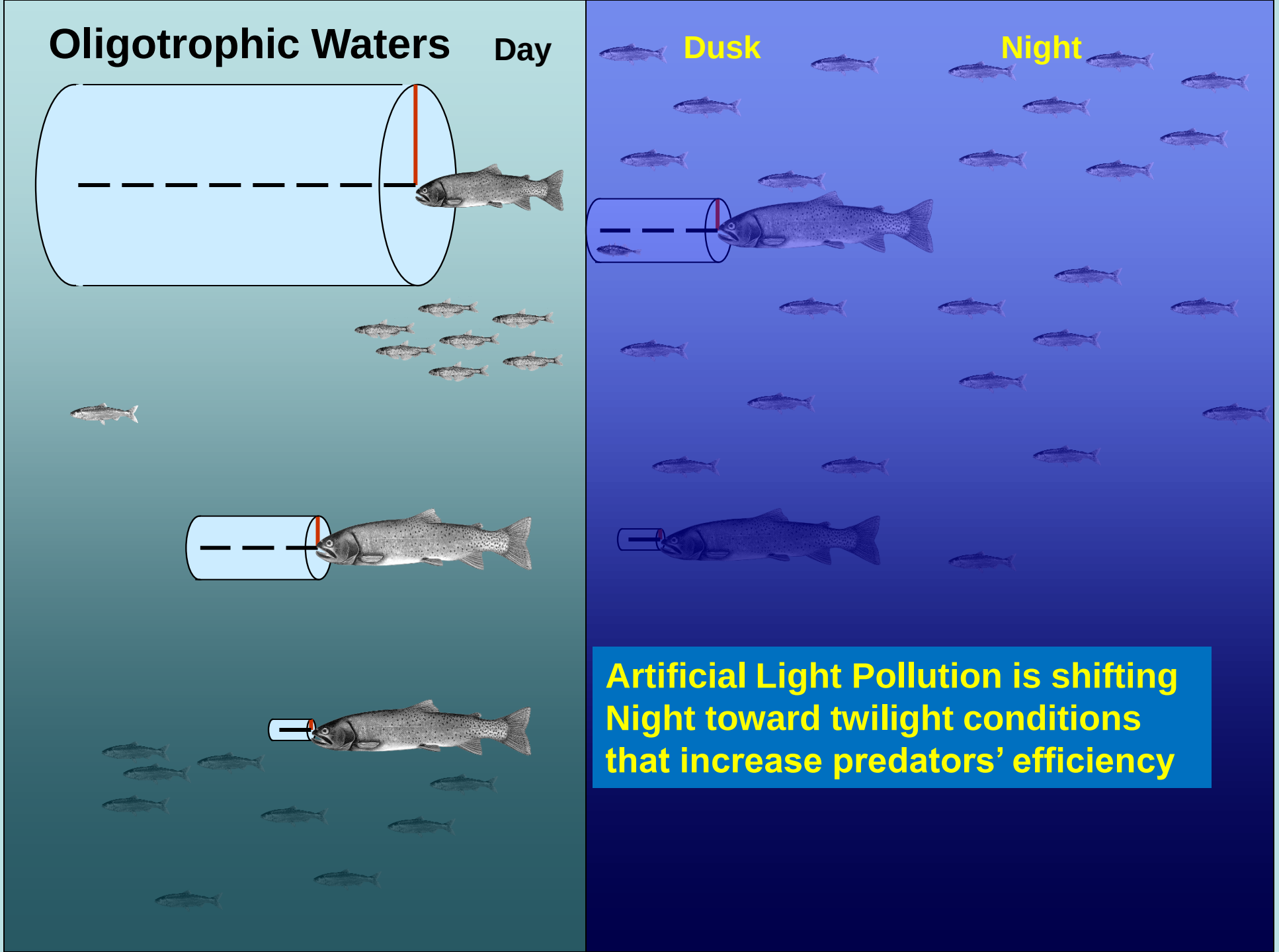
Seattle:

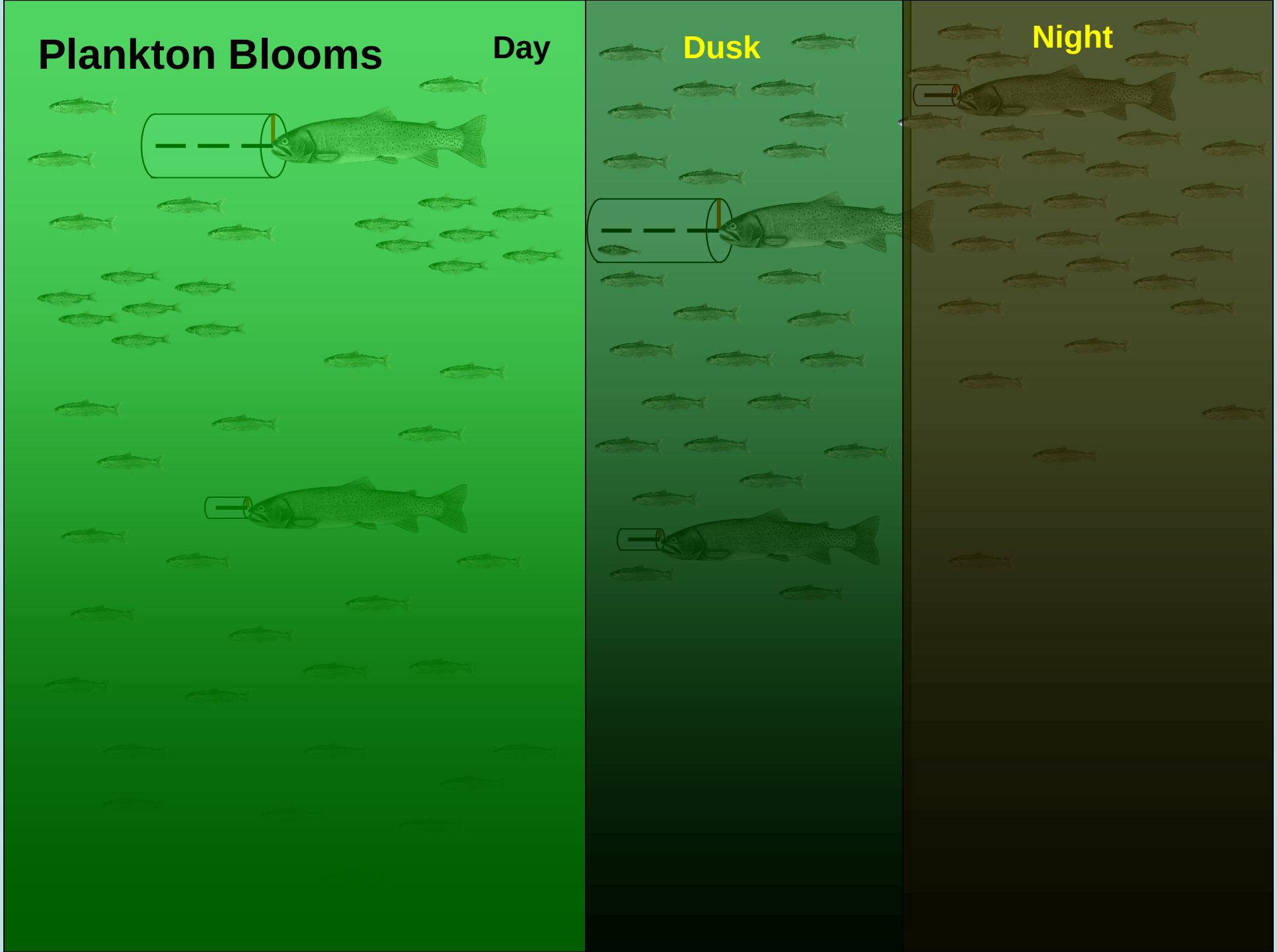
Urban Light Pollution & Skyglow
Increased Night Predation Risk 7x

Juv. salmon migrate downstream & through estuaries at night

Juv. Salmon stay in 0-15 m depths In pelagic marine waters-no DVM




Oligotrophic Waters
Day
Dusk
Night
Artificial Light Pollution is shifting Night toward twilight conditions that increase predators' efficiency


Plankton Blooms
Day
Dusk
Night

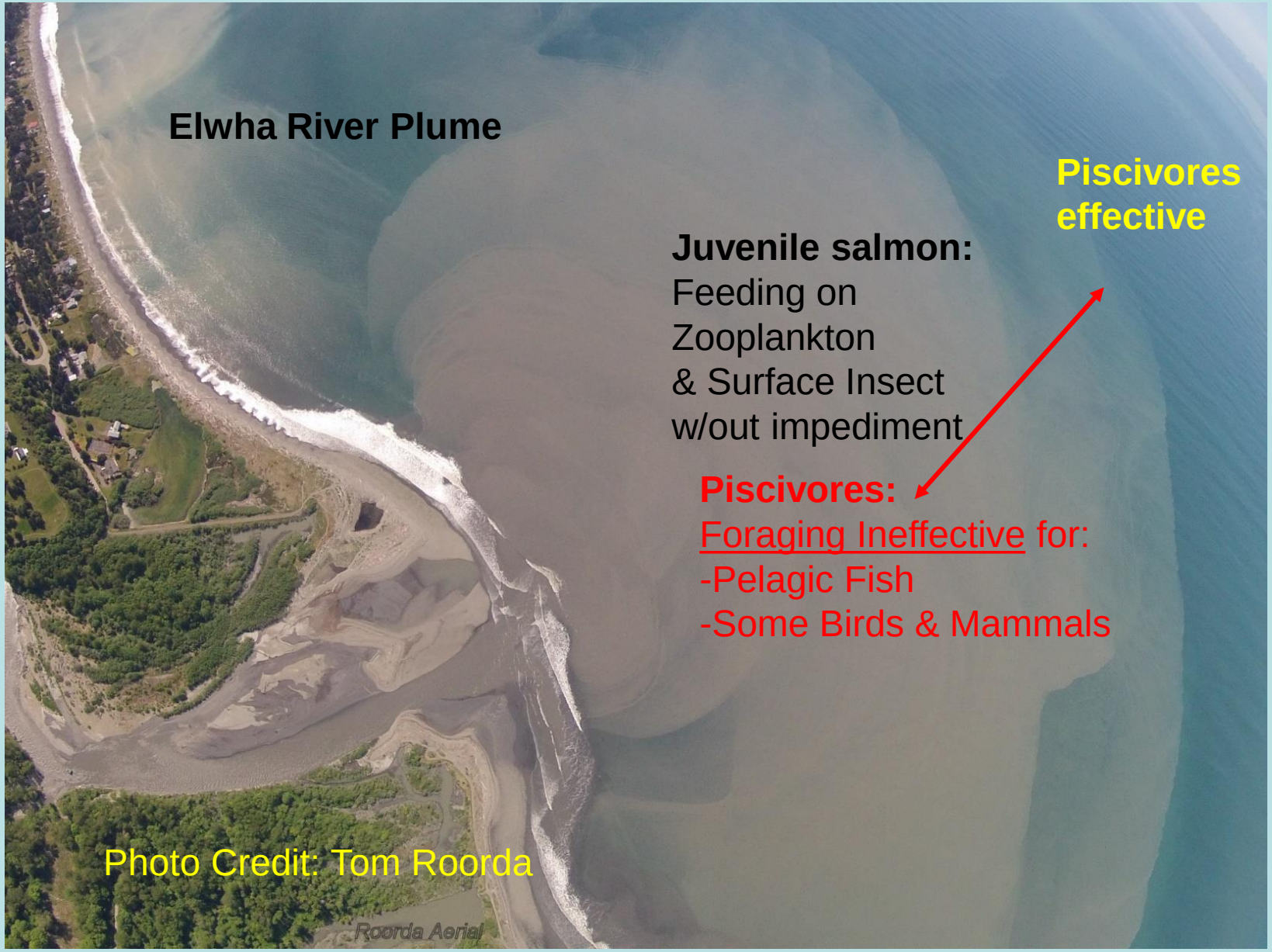
Supplementary Material Follows

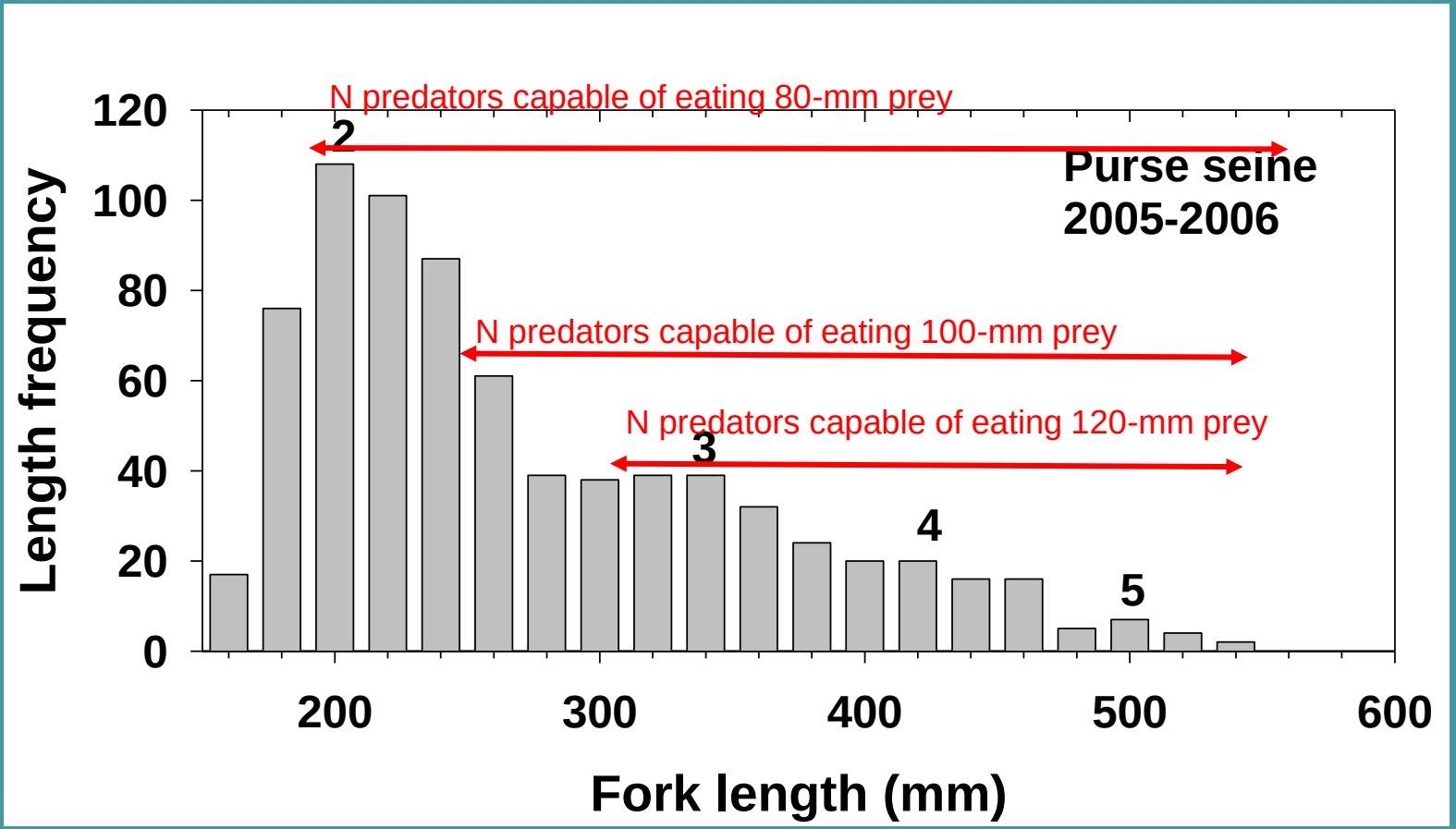
Summary: Top-Down Processes

- **Piscivorous Fish exhibit size-selective predation**
  - **Size-selectivity likely more variable for mammals & birds**
  - **Harbor seals implicated in marine mortality of Puget Sound 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)**

Remedies for Reducing Predation Mortality

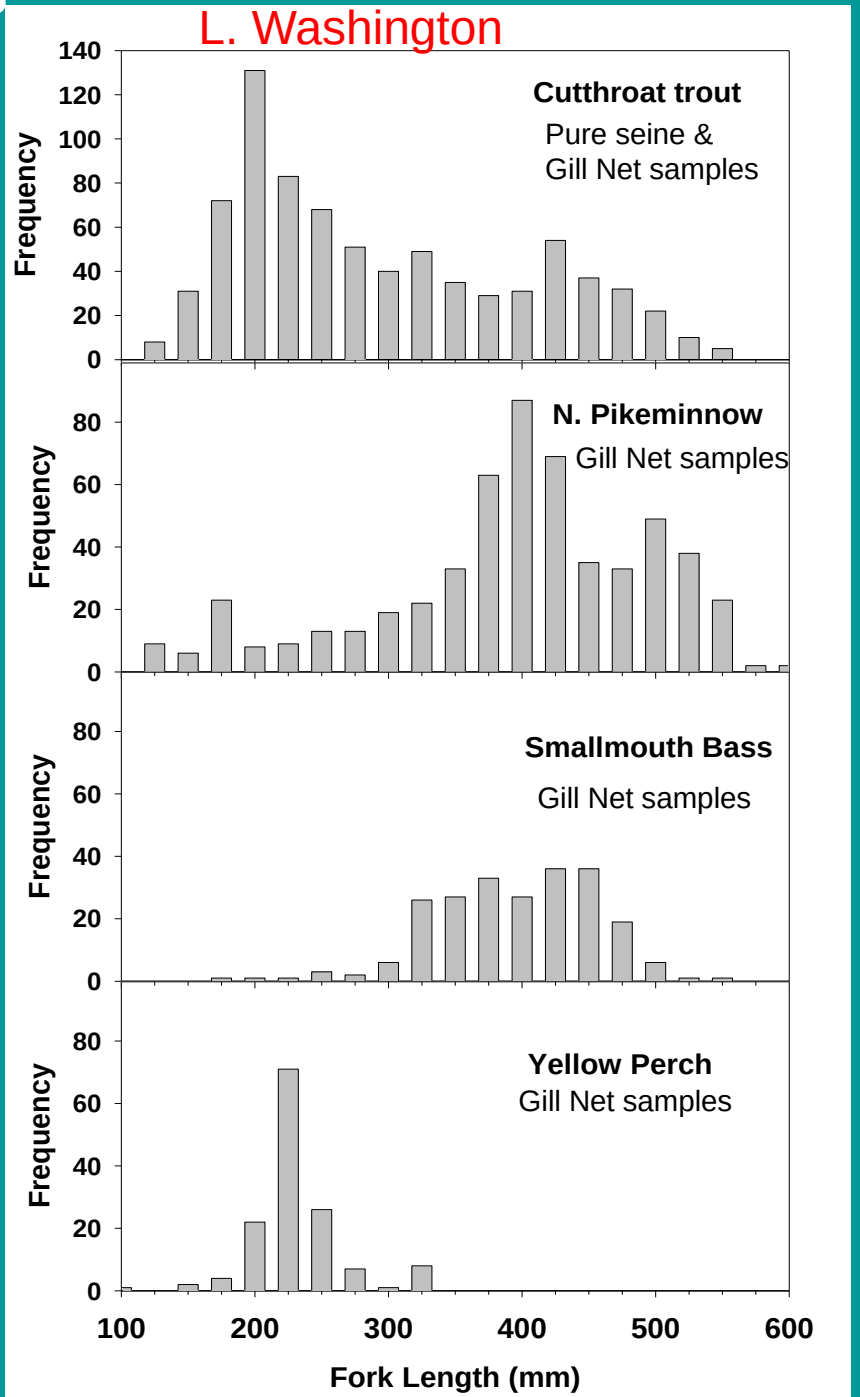
- **Reduce Predator Population & Size Structure**
  - Potential Directed harvest or Suppression netting (co-managers' decision) informed by:
  - This study: Identify Times & Locations for effective catch
  - This study: determine how much reduction in # & size, based on estimated abundance & predation rates
- **Reduce the efficacy of predators:**
  - Reduce access to prey through time or space
  - Reduce ability to find prey during periods of effective predation
  - Reduce artificial light pollution
  - Exploit phytoplankton blooms & sediment plumes


Elwha River Plume
Piscivores effective
Juvenile salmon:
Feeding on
Zooplankton
& Surface Insect
w/out impediment
Piscivores:
Foraging Ineffective for:
-Pelagic Fish
-Some Birds & Mammals
Photo Credit: Tom Roorda
Roorda Aerial


N predators capable of eating 80-mm prey
2
Purse seine
2005-2006
N predators capable of eating 100-mm prey
N predators capable of eating 120-mm prey
3
4
5
Length frequency
120
100
80
60
40
20
0
200
300
400
500
600
Fork length (mm)

Piscivore Size Frequencies Sampled 2005-2006

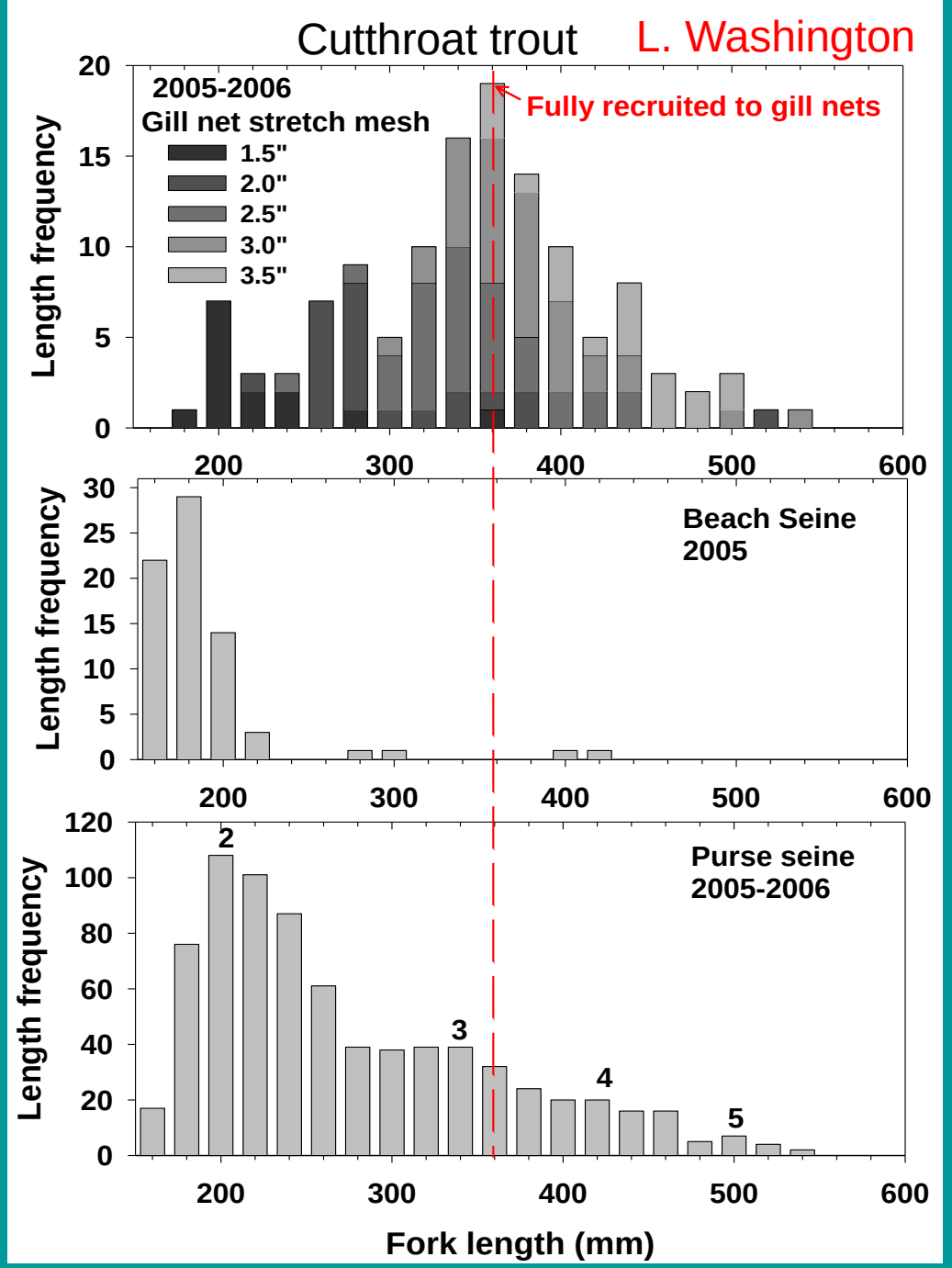
L. Washington



Gear Bias & Size Selectivity

Size-selective Bias Affects
Size structure of fish sampled with
Gill Nets & Beach Seines,

But no apparent size-bias when
Sampling with Purse seines



Thermal Environment

Vertical temperature profiles structure:

-Depth Distributions
-Onshore-Offshore Distributions
-Affect Zooplankton & Benthic Prod.
-Separate OR Concentrate
Predators & Prey
Organisms & preferred habitat

Warm surface waters during summer

-Preclude Salmonids seasonally
-Optimal growth range for:
Stickleback
Perch
Age-0 Smelt
-Epilimnion favorable to non-salmonids & higher zooplankton densities during summer

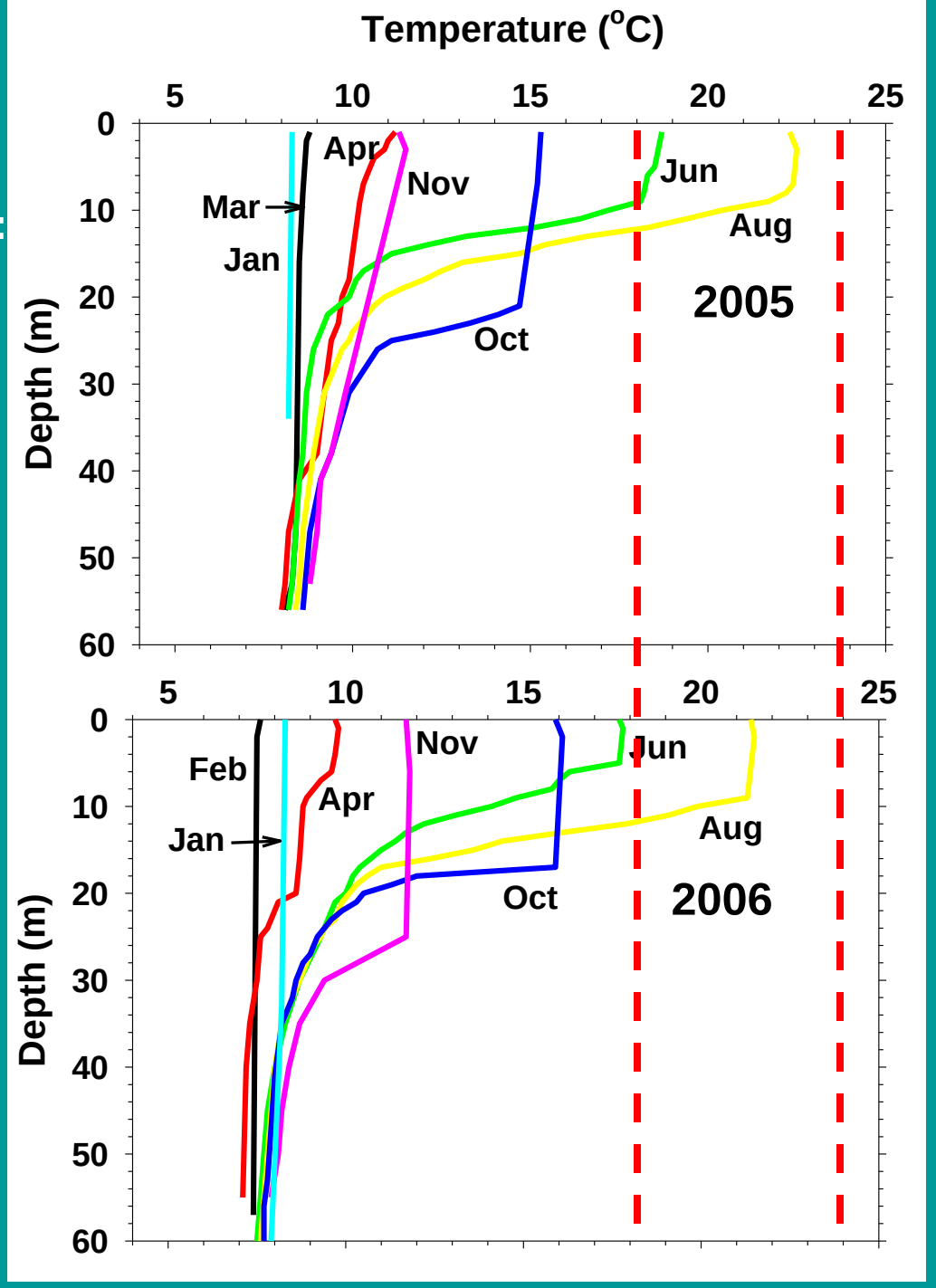
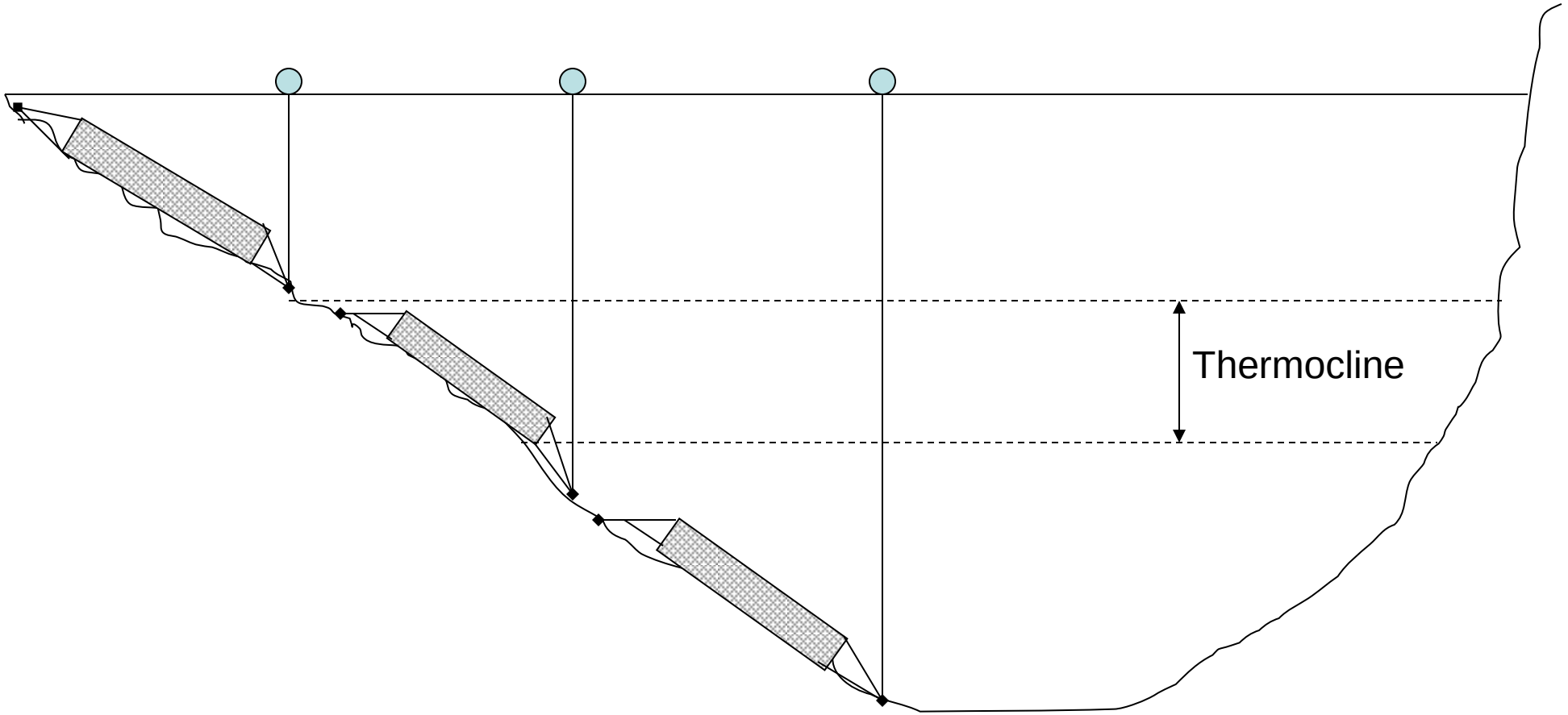


Figure 7.1. Sinking Gill Nets in Littoral and Slope Zones



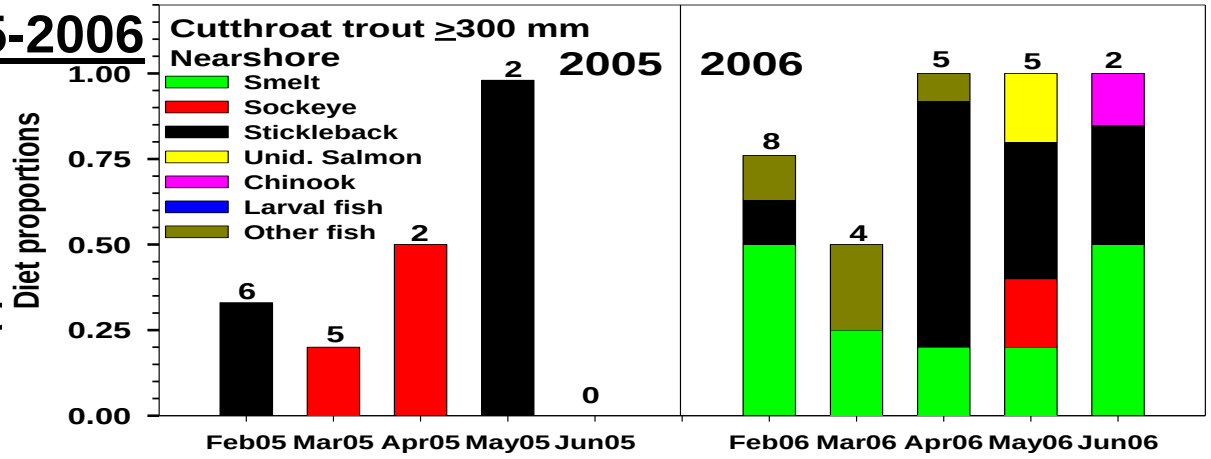
L. Washington

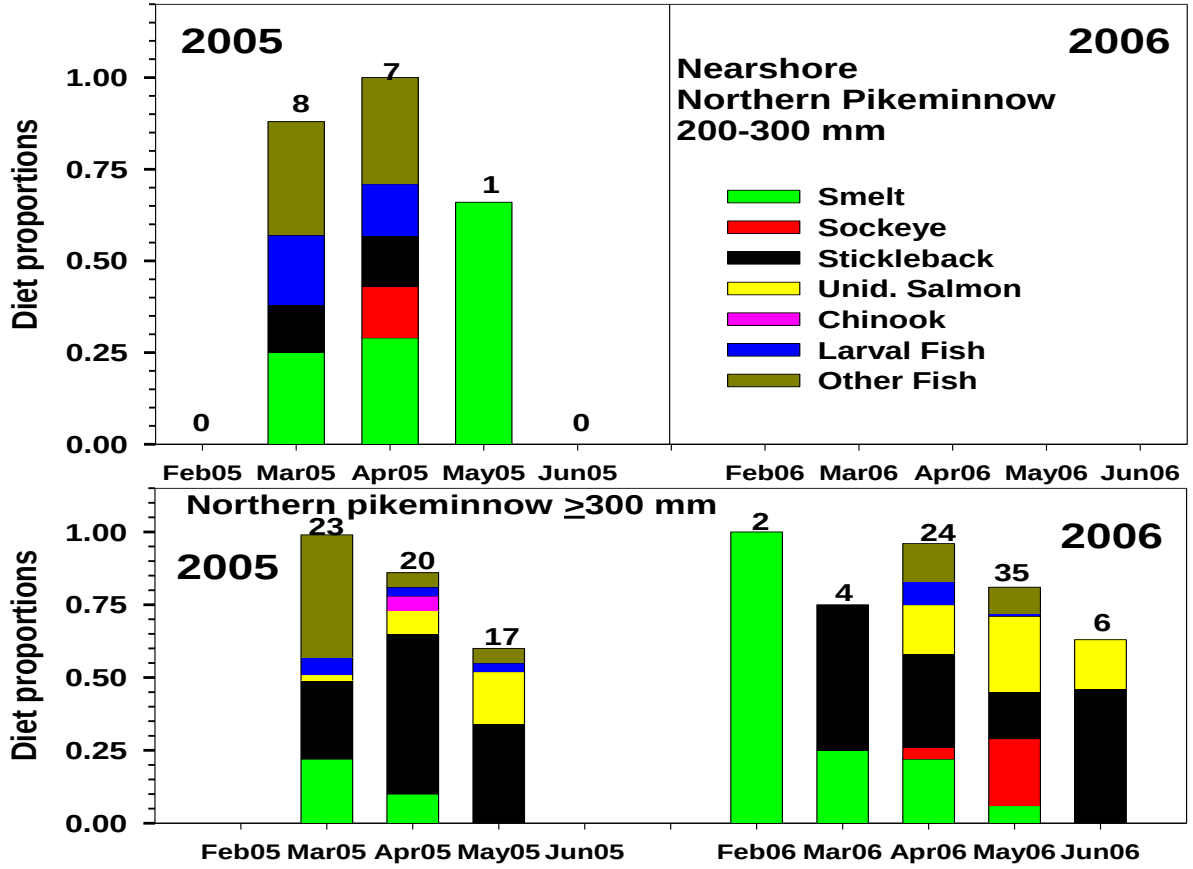
Nearshore Predation 2005-2006

Cutthroat: **Smelt** important buffer prey in 2006, **Sticklebac**
Eaten heavily **both years,**
Sockeye in 2005

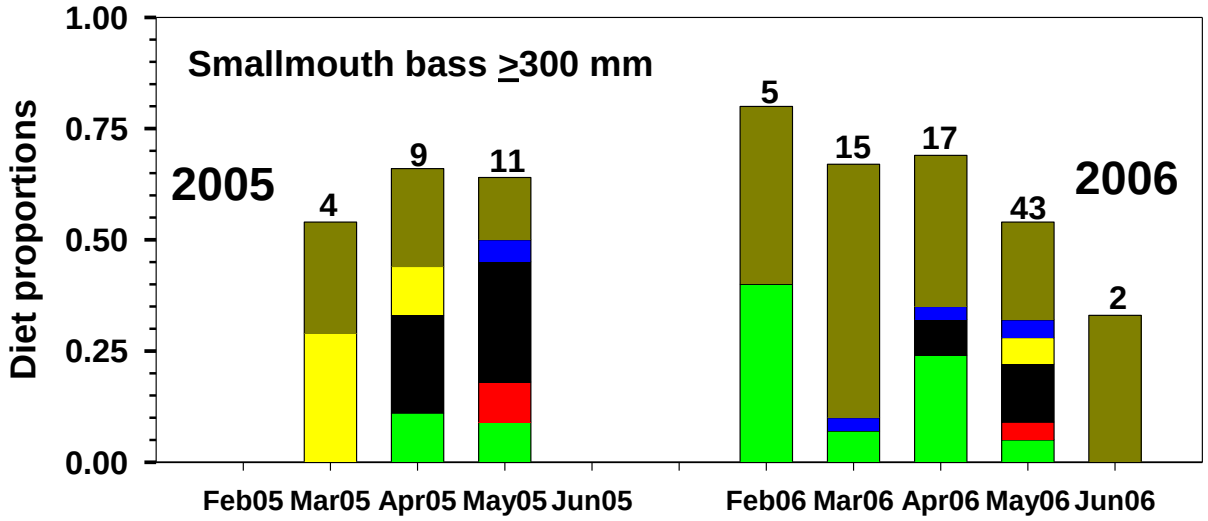
Small Pikeminnow: eat **Smelt**
Larval fish, Sticklebacks,
Sockeye, Sculpin

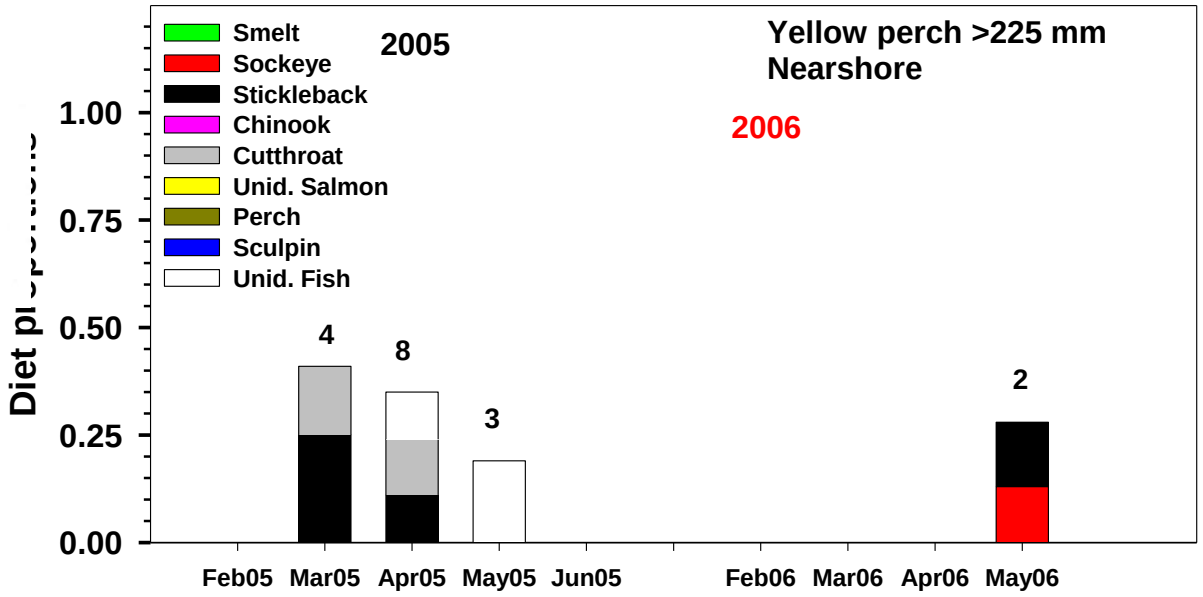
Large Pikeminnow: eat **Smelt**
Sticklebacks, Sockeye,
Chinook, Cutthroat, Sculpin





SM Bass also eat **Smelt, Stickleback**, **Sockeye, Unidentified salmon, & Other fishes (sculpin, Cutthroat trout)**





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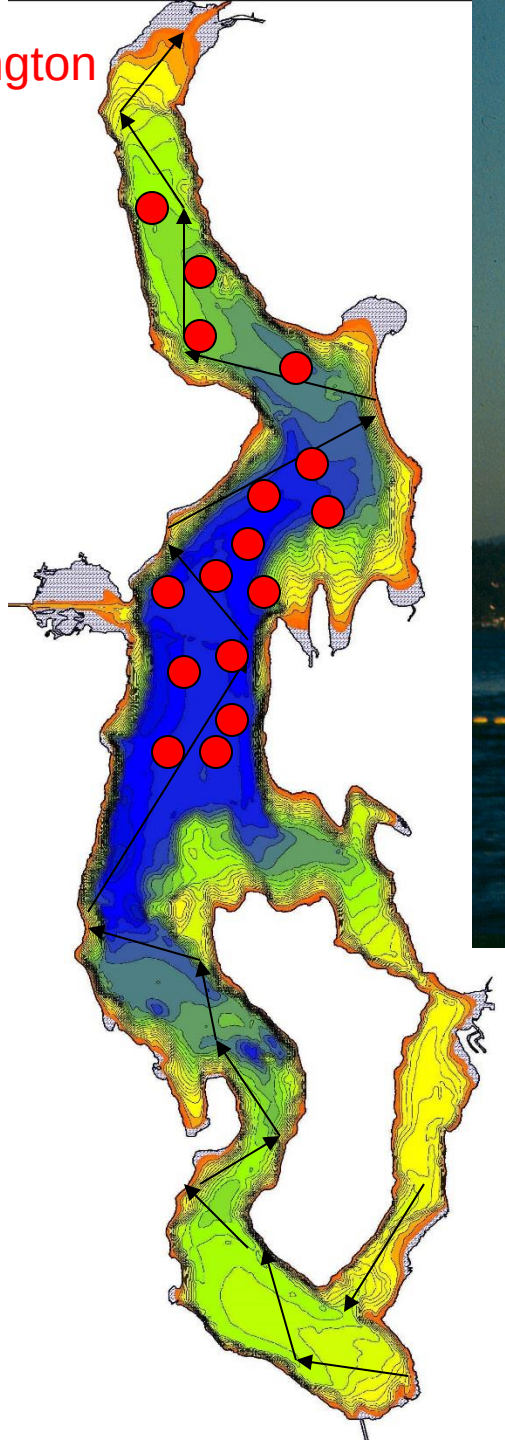


- **Purse seining Concentrated in Areas 1-3**

<u>Seasonality:</u>
May
June
Summer (July or Sept)
November

L. Washington

Offshore Predation

Small Cutthroat

Larval fish & juvenile Stickleback in June-Summer

Age-0 smelt become important in fall

Large Cutthroat

-Sticklebacks important All year

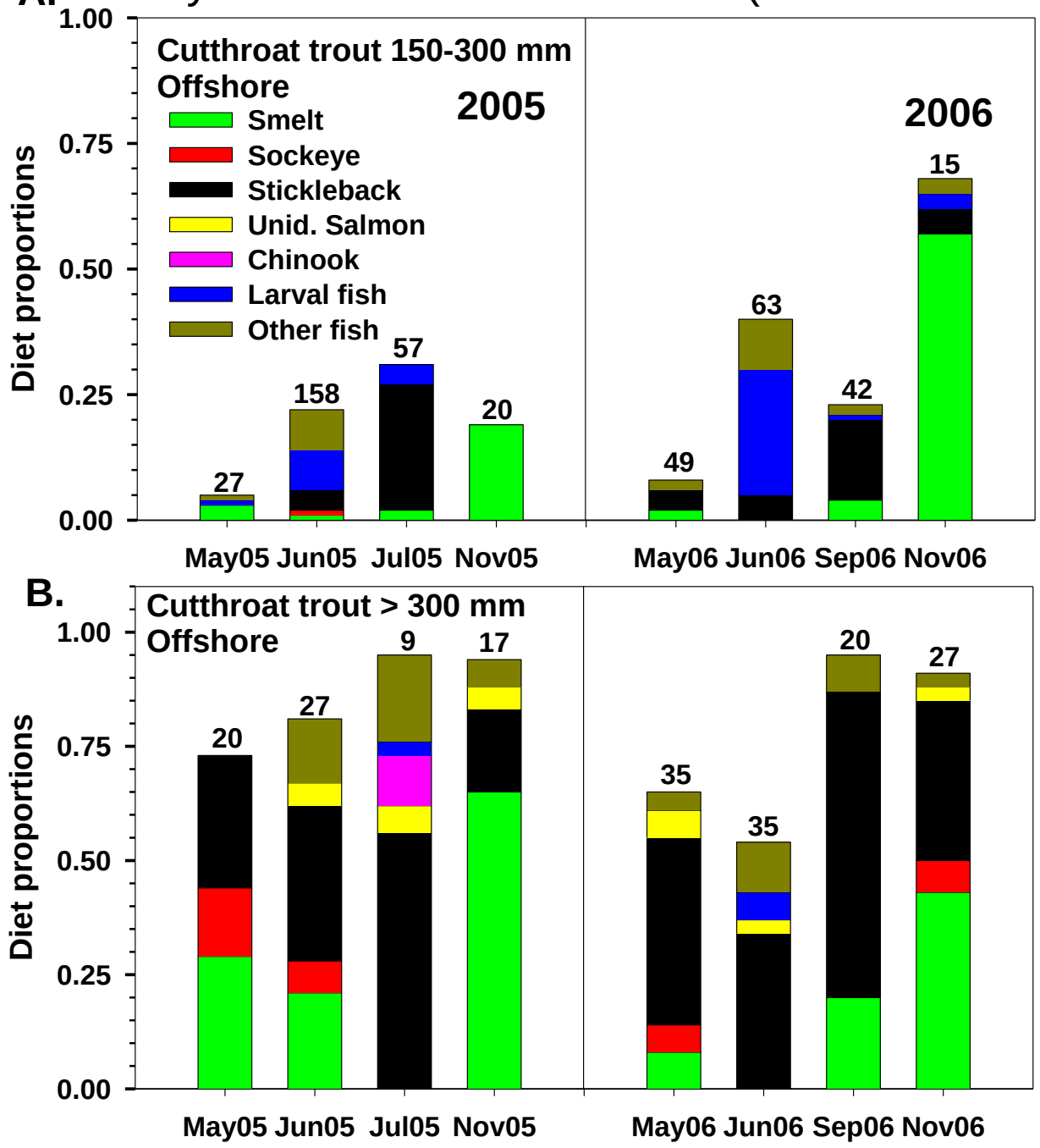
-Sockeye smolts in Spr

-Chinook in July

-Age-0 smelt become Vulnerable in fall

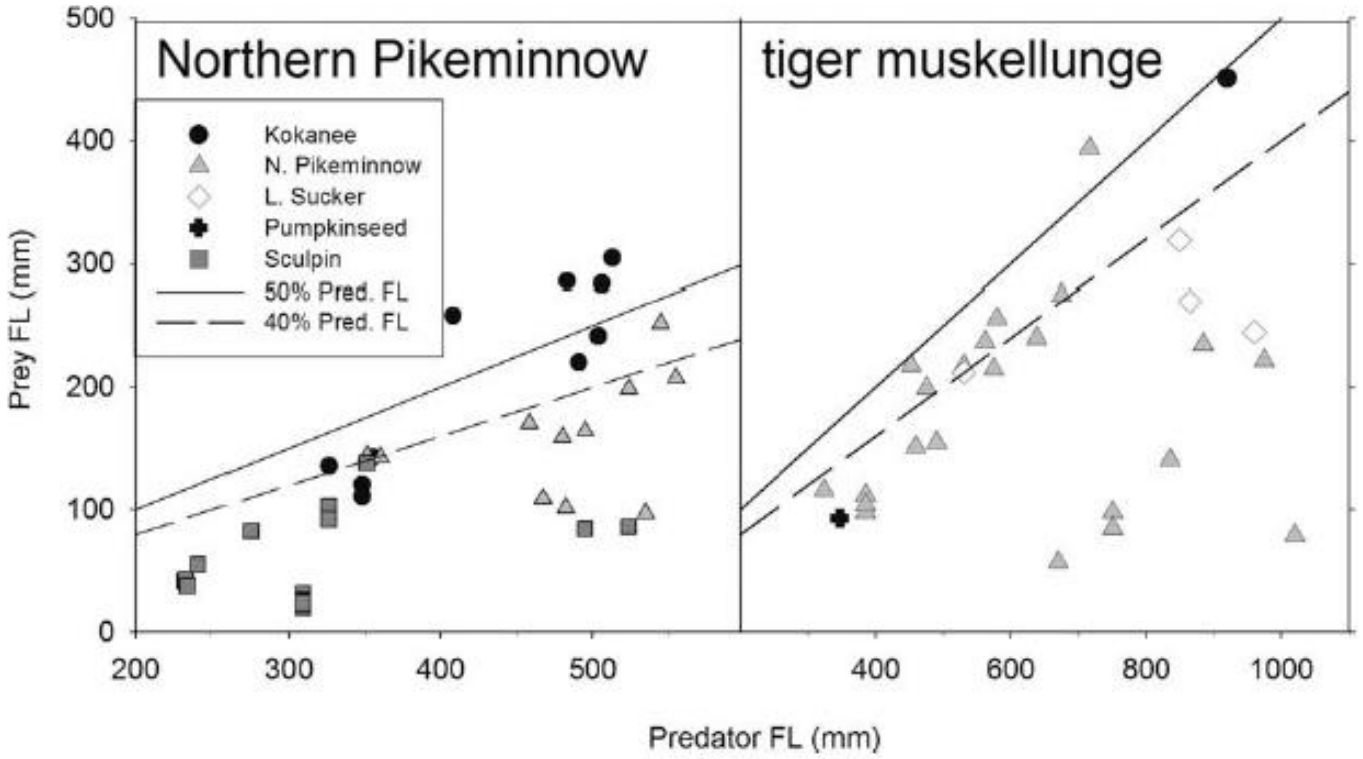
-Age-1 smelt eaten All year

Only fish-fraction of diet shown (inverts omitted)

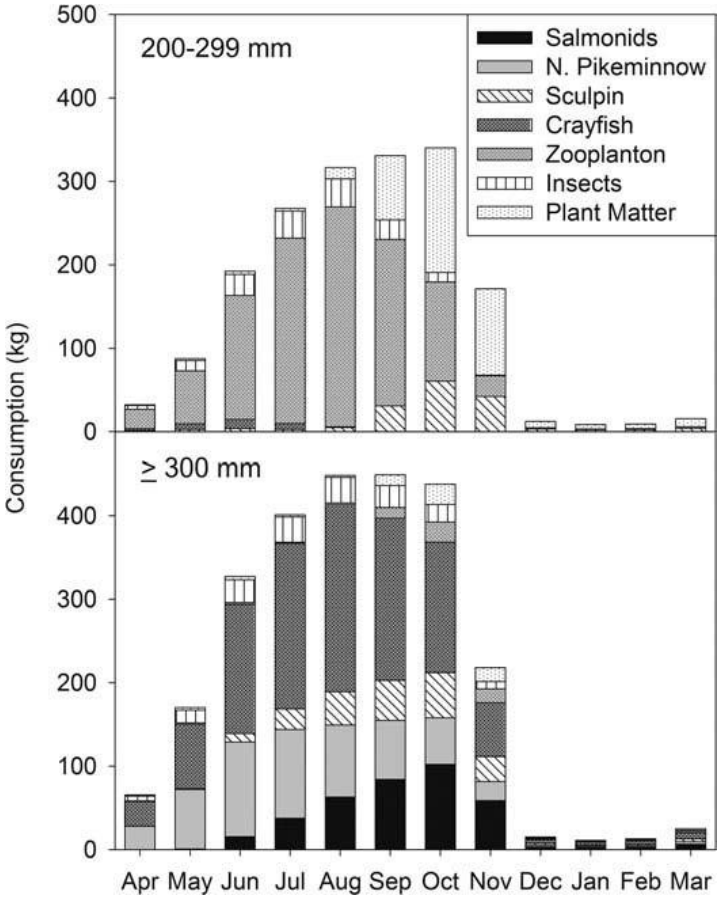


Lake Merwin

Predator Size : Prey Size Relationships



Monthly Predation by a size-structured unit population of 1,000 Northern Pikeminnow



Sorel et al. 2016. Predation by Northern Pikeminnow and tiger muskellunge on juvenile salmonids in a high–head reservoir: implications for anadromous fish reintroductions. Transactions of the American Fisheries Society. 145:521-536.