Applying Food Web Models to Fisheries Management

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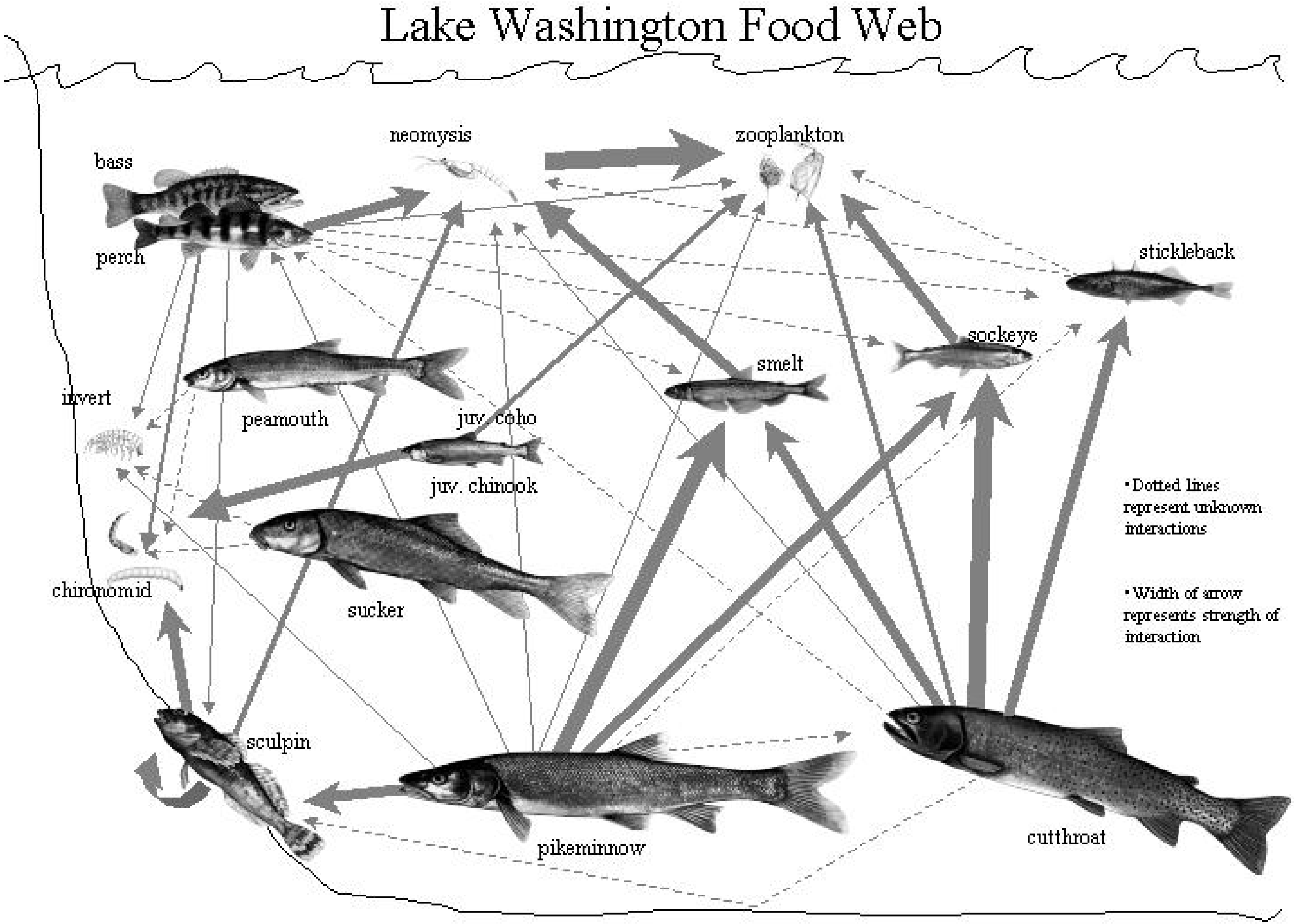
Biotic Interactions are Essential Elements of Aquatic Habitats

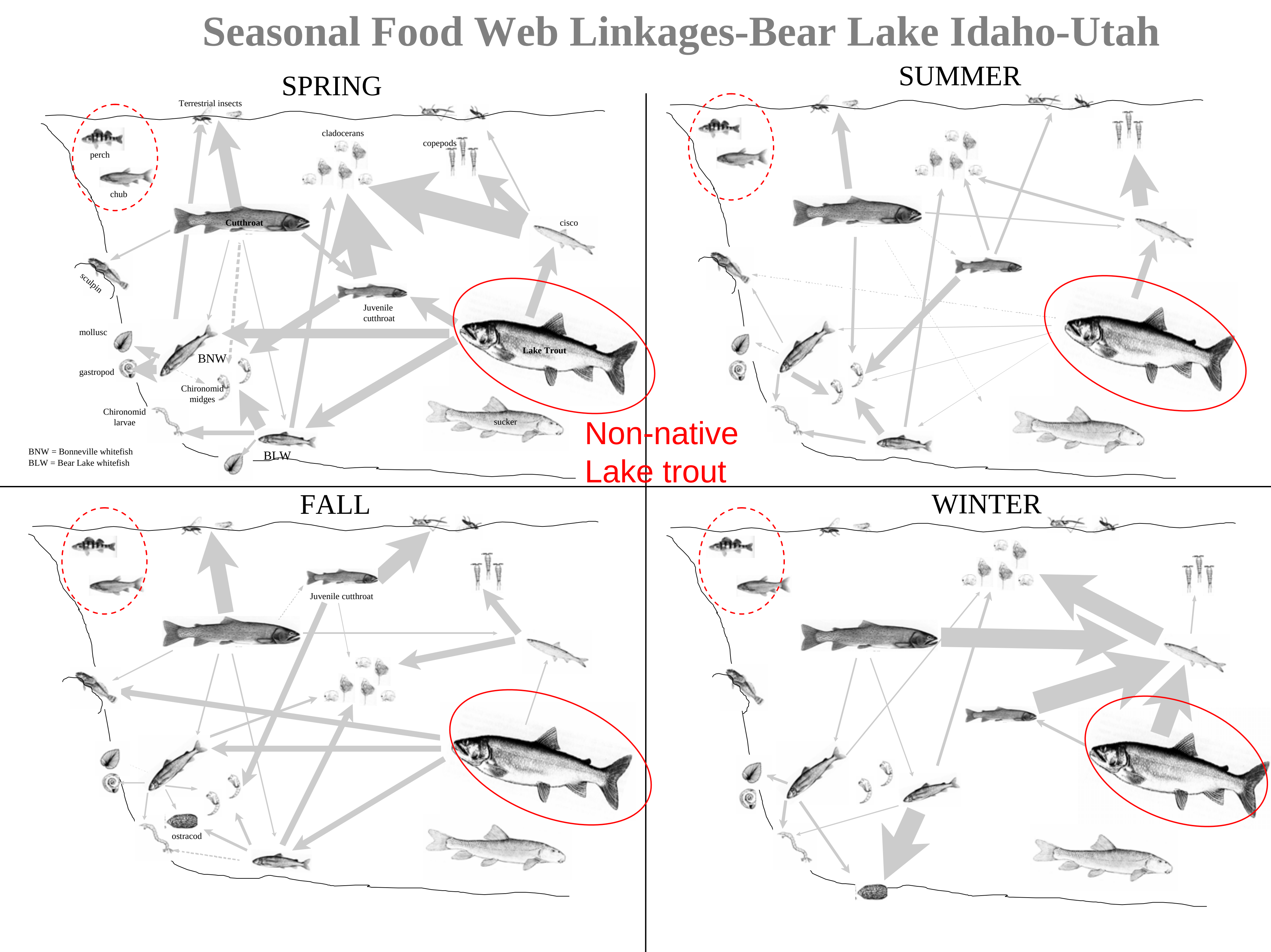
- Physical habitat and water quality define the "potential" for supporting & sustaining species
- That potential will be realized or undermined by biotic processes:
  - Seasonal Food Supply & Access
  - Competition
  - Predation
- Habitat Conservation and Restoration Strategies need to consider food web processes explicitly

Quantifying Trophic Linkages. Interaction Strength may vary among seasons or between life stages



Characteristics of Large Western Lakes

- Food web processes very dynamic in Time & Space
  - Prey availability varies spatially and temporally over diel & seasonal cycles
  - Highly mobile consumers move vertically & laterally to feed & satisfy other ecological needs
  - Predator-Prey Size relationships & life stage-specific processes are important
- Non-native Species usurp key ecological roles as: top predators, competitors, prey:
  - Lake trout, Mysids, Kokanee, Brook & Brown trout
  - Bass, Walleye, Shad, Sunfishes, Crayfish



Seasonal Food Web Linkages-Bear Lake Idaho-Utah
SPRING
Terrestrial insects
perch
chub
cladocerans
copepods
Cutthroat
cisco
sculpin
Juvenile cutthroat
mollusc
BNW
Lake Trout
gastropod
Chironomid midges
Chironomid larvae
sucker
BLW
BNW = Bonneville whitefish
BLW = Bear Lake whitefish
SUMMER
Non-native Lake trout
FALL
Juvenile cutthroat
ostracod
WINTER

Key Questions

- What processes regulate production and distribution of key species in an aquatic community?
  - Mortality? Predation, Starvation, Disease
  - Growth? Food supply & access, competition
  - Environmental stressors? Temp, O_2, Contaminants
- How do human & natural disturbances disrupt trophic structure & energy pathways?
  - Species invasions/introductions
  - Climate change
  - Land-water use & management

Conceptual Approach

- Identify & Quantify key interactions within a Temporal-Spatial and Ontogenetic framework
- Mechanistically link individual behavior & physiology to structure & function of the ecosystem
- Employ a combination of modeling & directed sampling + the rare experiment

Tools

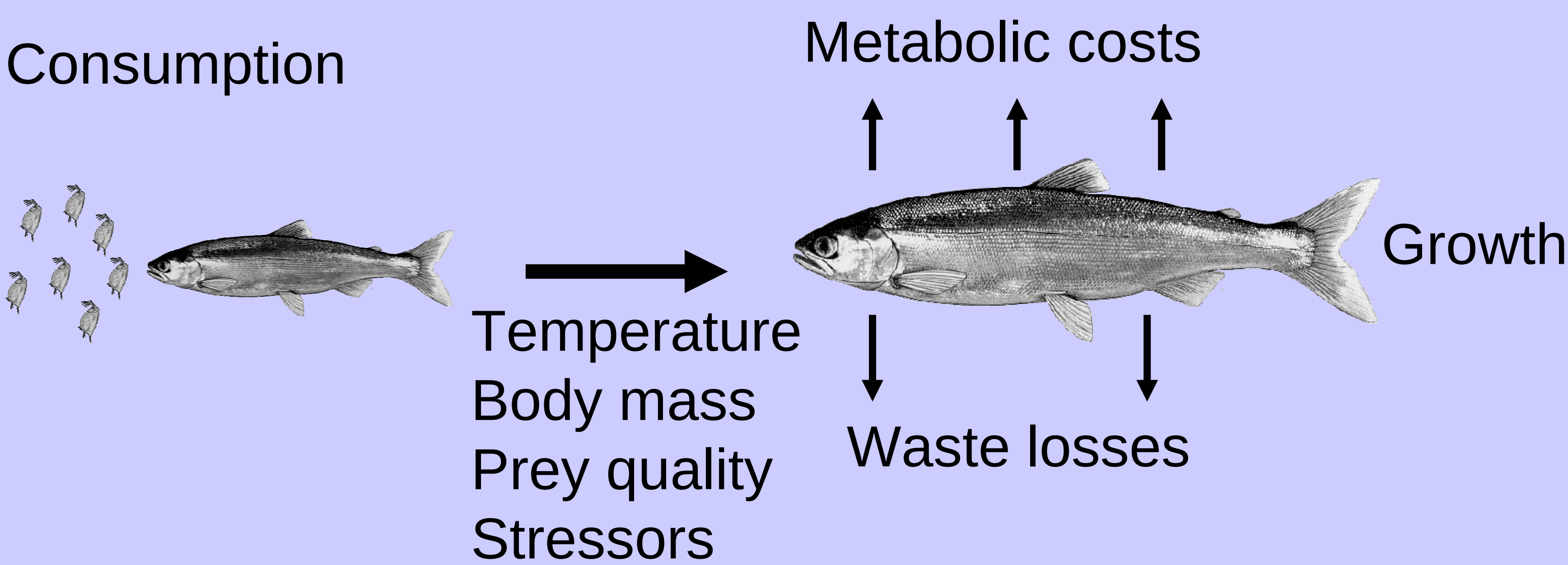
- Modeling (tightly linked to empirical data)
  - Bioenergetics: Link physiological response of consumers to their [changing] environment
  - Foraging (visual foraging, functional response)
  - Population dynamics
- Field sampling & Analysis to feed the models
  - Temporal-Spatial Distribution
  - Abundance (relative or absolute)
  - Size structure, age & growth
  - Diet, Stable Isotopes, Calorimetry

Bioenergetics Models are useful
Ecological Diagnostic Tools

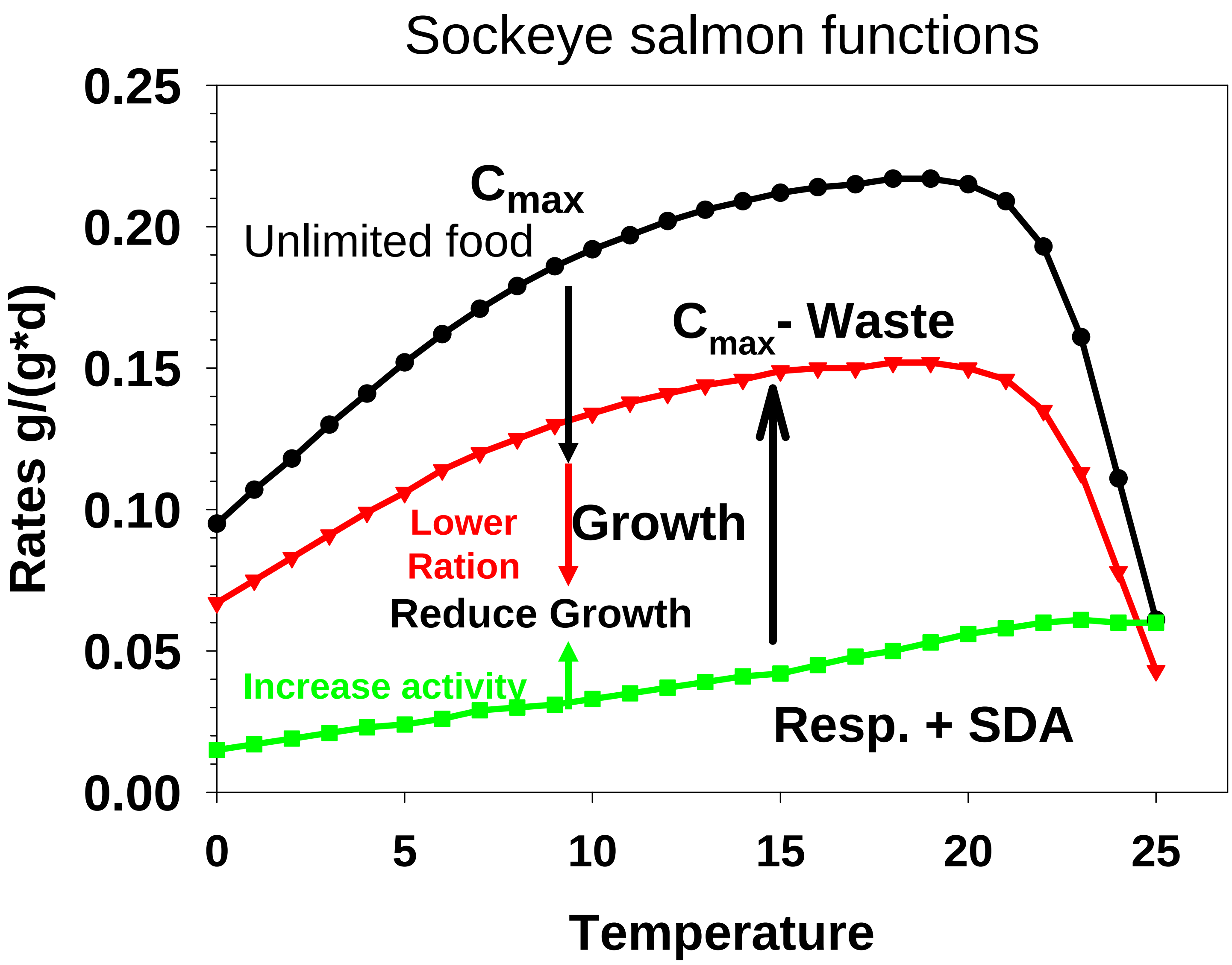
- Quantify trophic linkages & account for variation in diet composition, temperature, & prey quality
- Identify potential ecological bottlenecks through time or space: **Predation, Food Supply, Competition, Thermal regime**
- Model utilizes routine sampling data:
  - diet, growth, distribution, temperature
- Conceptual framework for integrating data, identifying priorities, & managing uncertainty

Bioenergetics Model:
An Energy Balance Equation

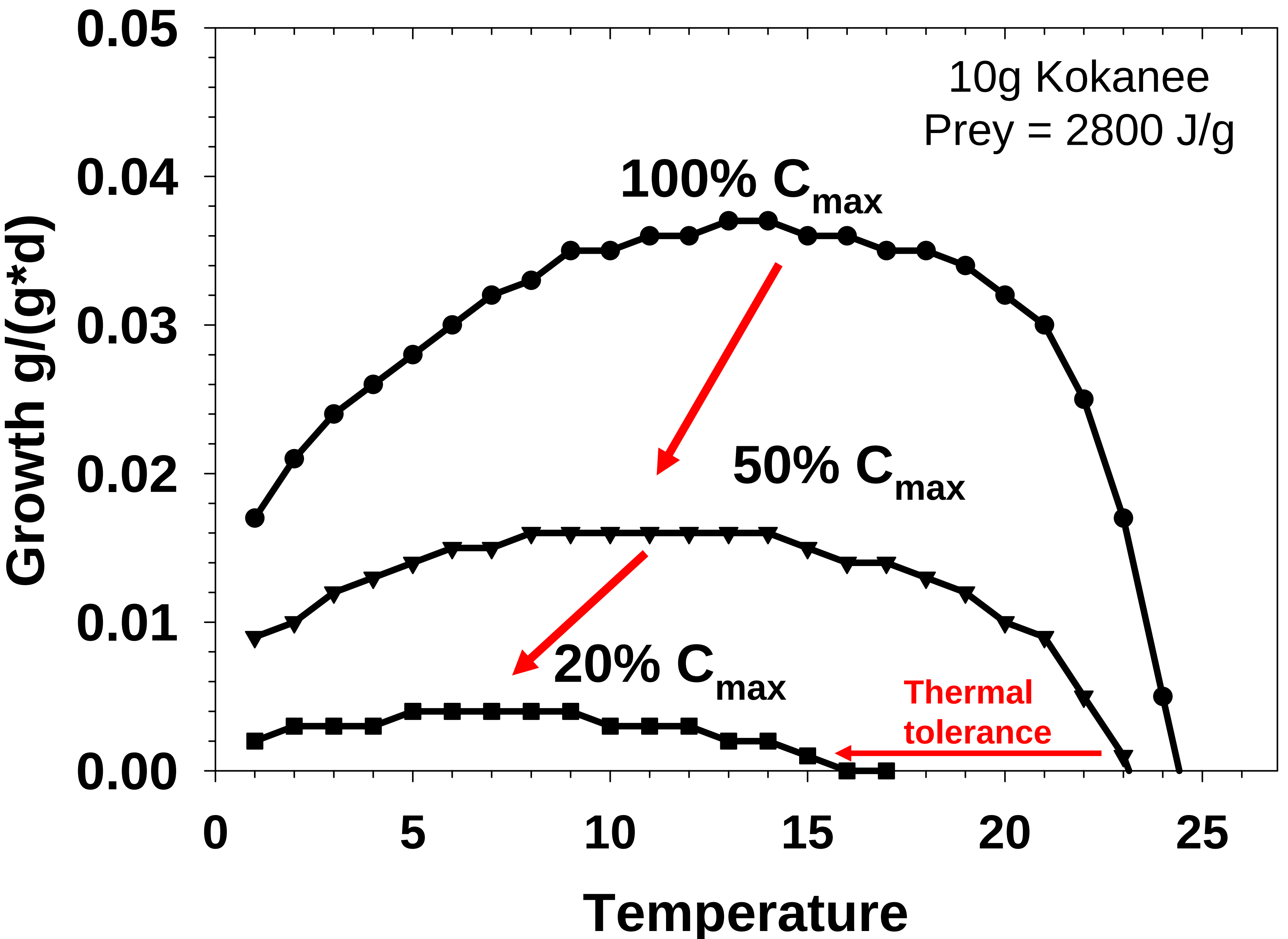
- **INPUT = OUTPUT**
  - Consumption must balance costs plus Growth
- **Consumption = Waste + Metabolism + Growth**



Temperature-Dependent Energy Budget



As Ration Declines, Optimal Temperature for Growth Declines



Modeling Process

Diet Composition

Consumer Growth

Predator Energy Density

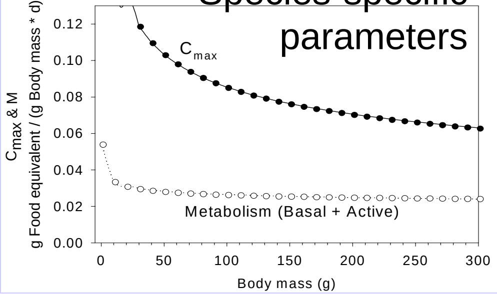
Prey Energy Density

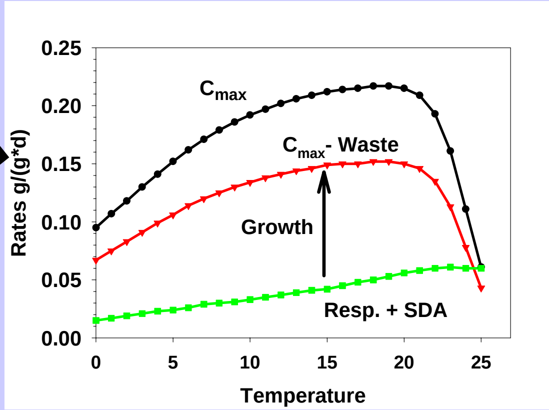
Thermal Experience

Bioenergetics Model

$$C = M + W + G$$

Species-specific parameters





Consumption Estimate

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

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

Daily time step

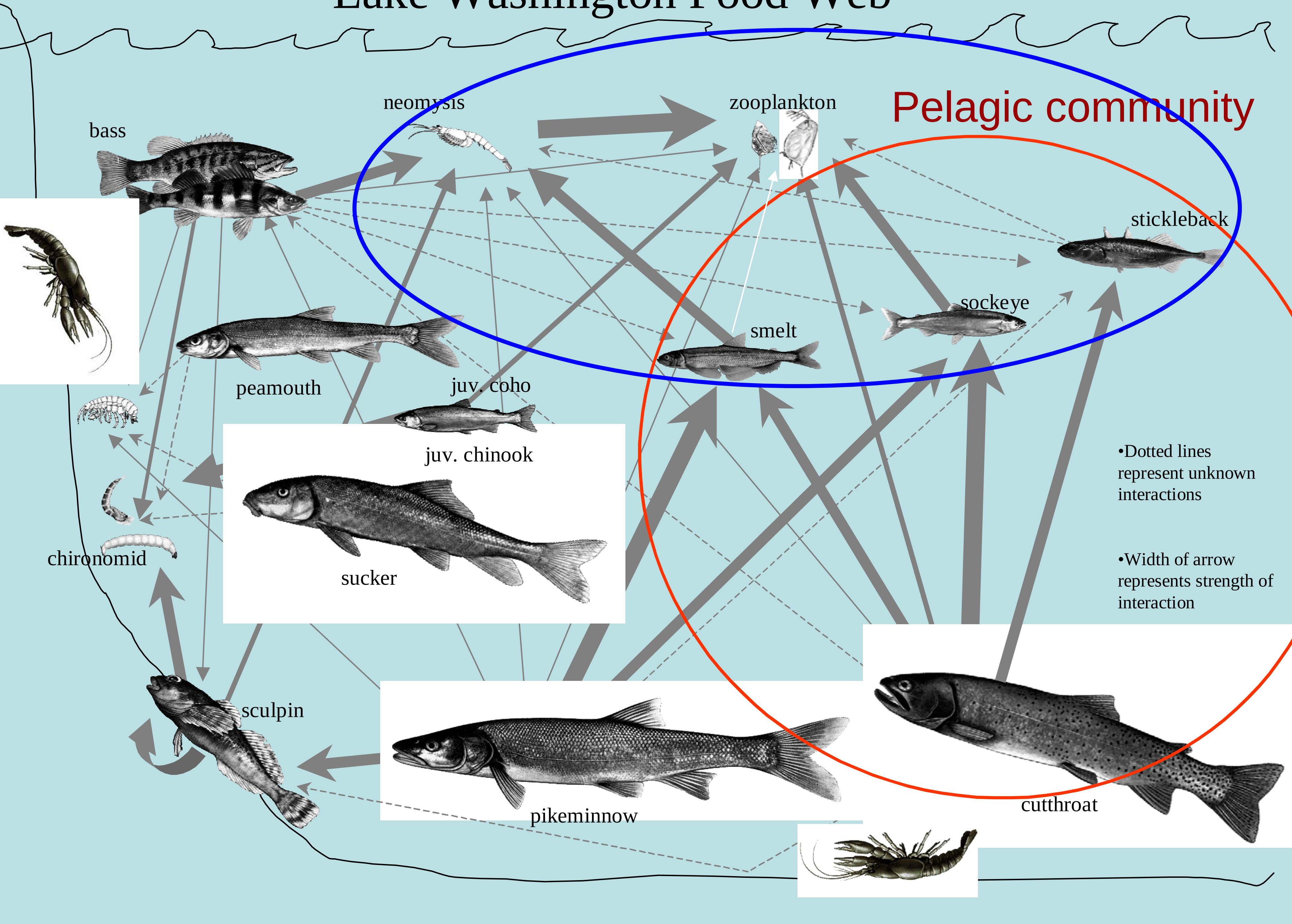
Some Model Applications

- Seasonal Carrying Capacity
- Competition
- Predation Mortality
- Spatial-temporal Growth Potential
- Comparing Net Energetic Benefit among Different Habitats (restoration priority?)
- Effects of Species Introductions
- Effects of Climate Change
- Contaminant Bioaccumulation
- Nutrient Recycling

Lake Washington Applications

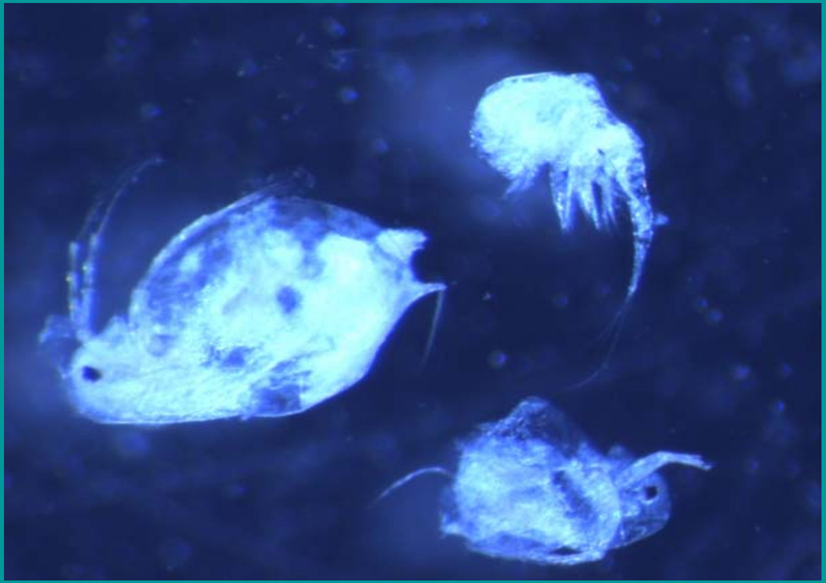
- **Sockeye hatchery & winter carrying capacity**
- **Is Predation a serious source of mortality for juvenile salmon in the lake?**
  - Sockeye salmon rear in lake for a year
  - ESA-listed Chinook salmon rear/migrate for 1-5 months in lake
- **If so, which predators are most important?**
  - Species, size, age
  - When is predation most severe?
  - Where does predation occur?
  - What factors alter predation?

Lake Washington Food Web



Early Feeding Demand and Food Supply of Sockeye Salmon Fry

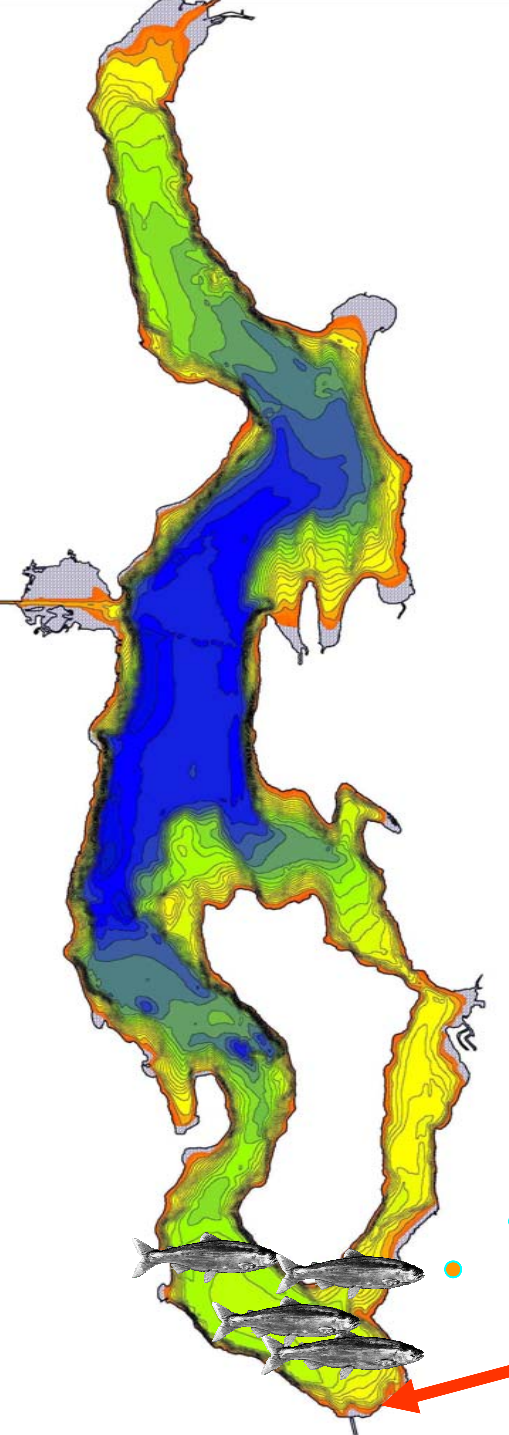
Dave Beauchamp, Chris Sergeant, Mike Mazur
•USGS-WA. Coop. Fish & Wildlife Res. Unit,
UW-School of Aquatic & Fisheries Sciences



Kurt Fresh & Dave Seiler
•WDFW

Jenn & Mark Scheuerell, Daniel Schindler, Tom Quinn
•UW- School Aquatic & Fish. Sci.

Funded by Seattle Public Utilities & King County



Sockeye fry migrate from Cedar River to lake during Feb-Apr when food supply is low

If fry remained aggregated at south end of the lake, localized food limitation could occur

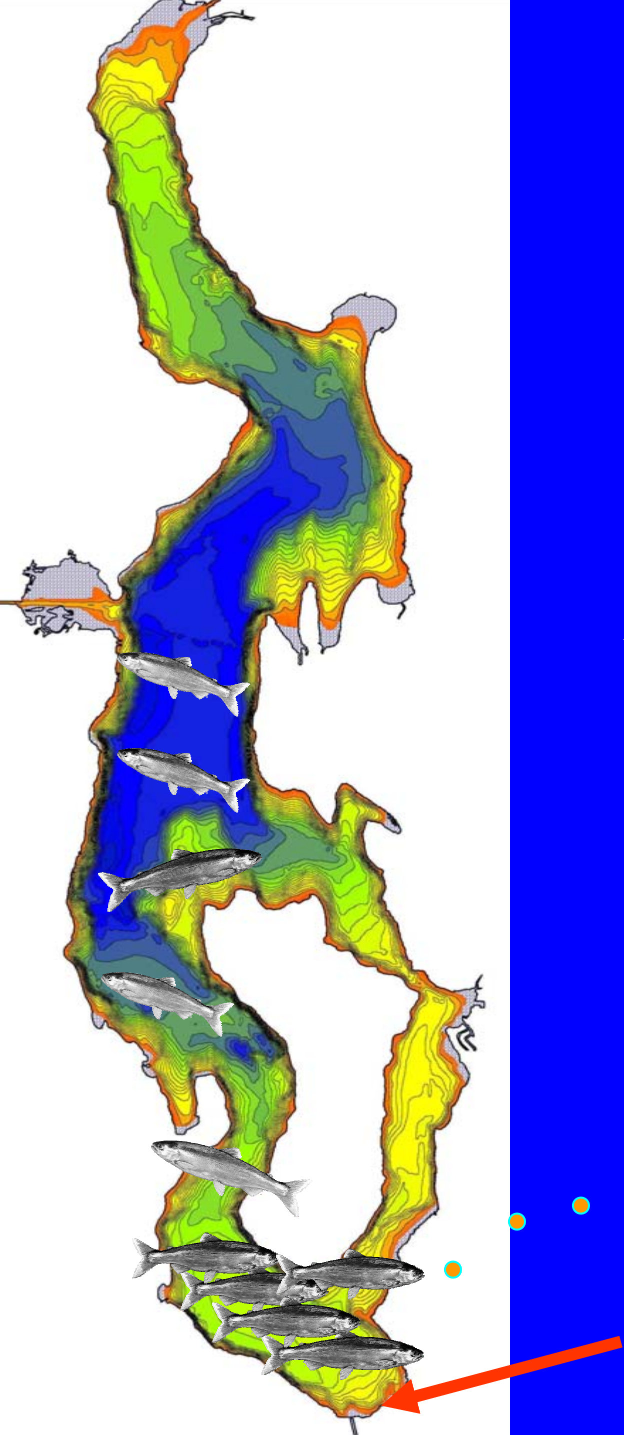
Will increased hatchery fry output exceed winter carrying capacity?

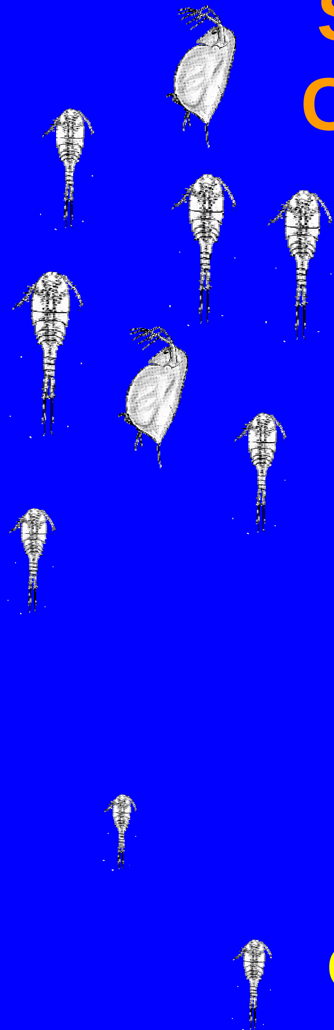
Study coincided with highest fry production in history

Where’s the food?

Cedar River

Credit-Mike Mazur





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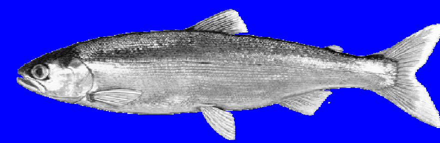


Food may be limiting on a localized scale

Will increased hatchery fry output overshoot winter carrying capacity?

OR-Will fry disperse northward to gain access to a larger pool of zooplankton?

Where's the food?

Cedar River

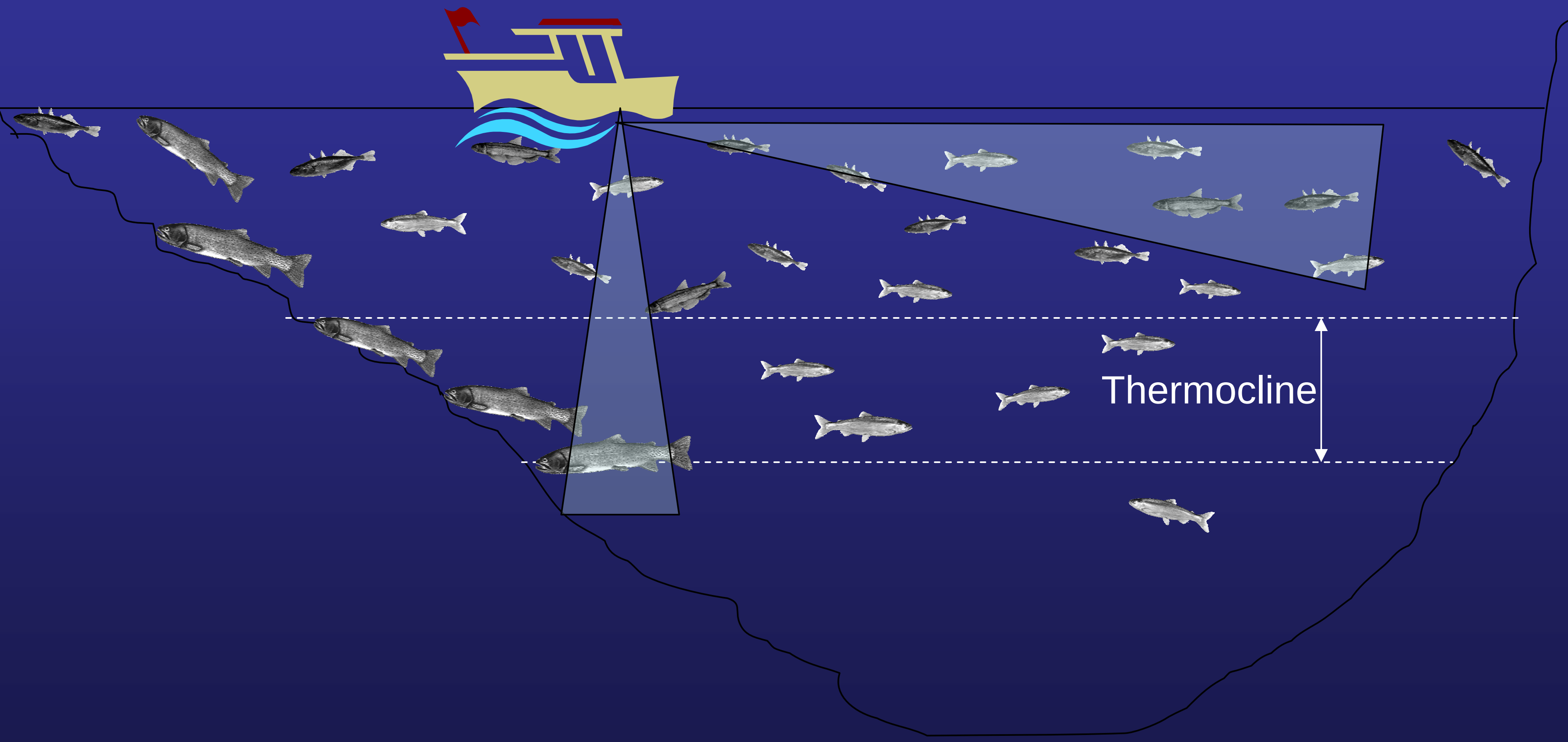
Credit-Mike Mazur

HYDROACOUSTICS

Measures fish density/abundance:

-For different size classes of fish

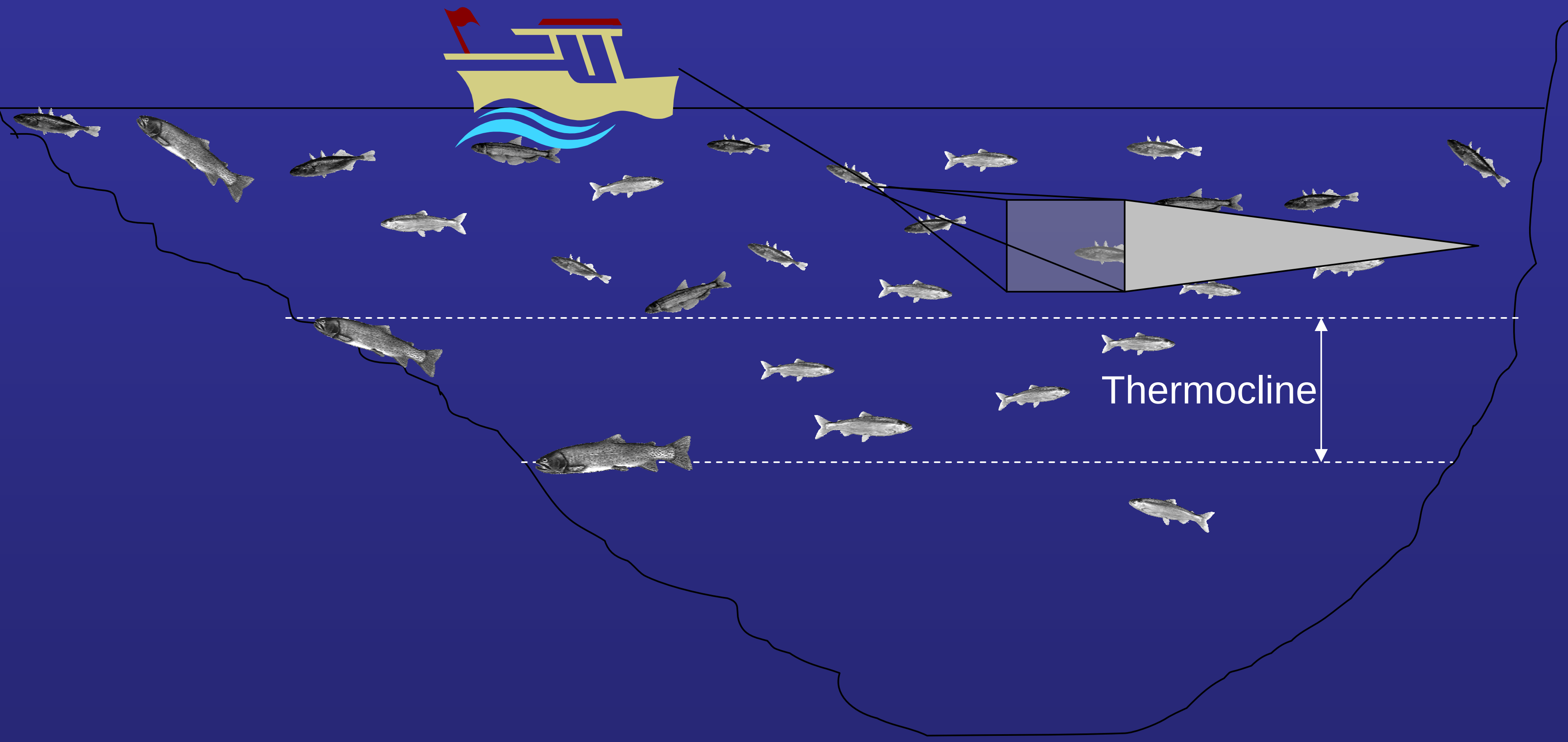
-At each depth interval



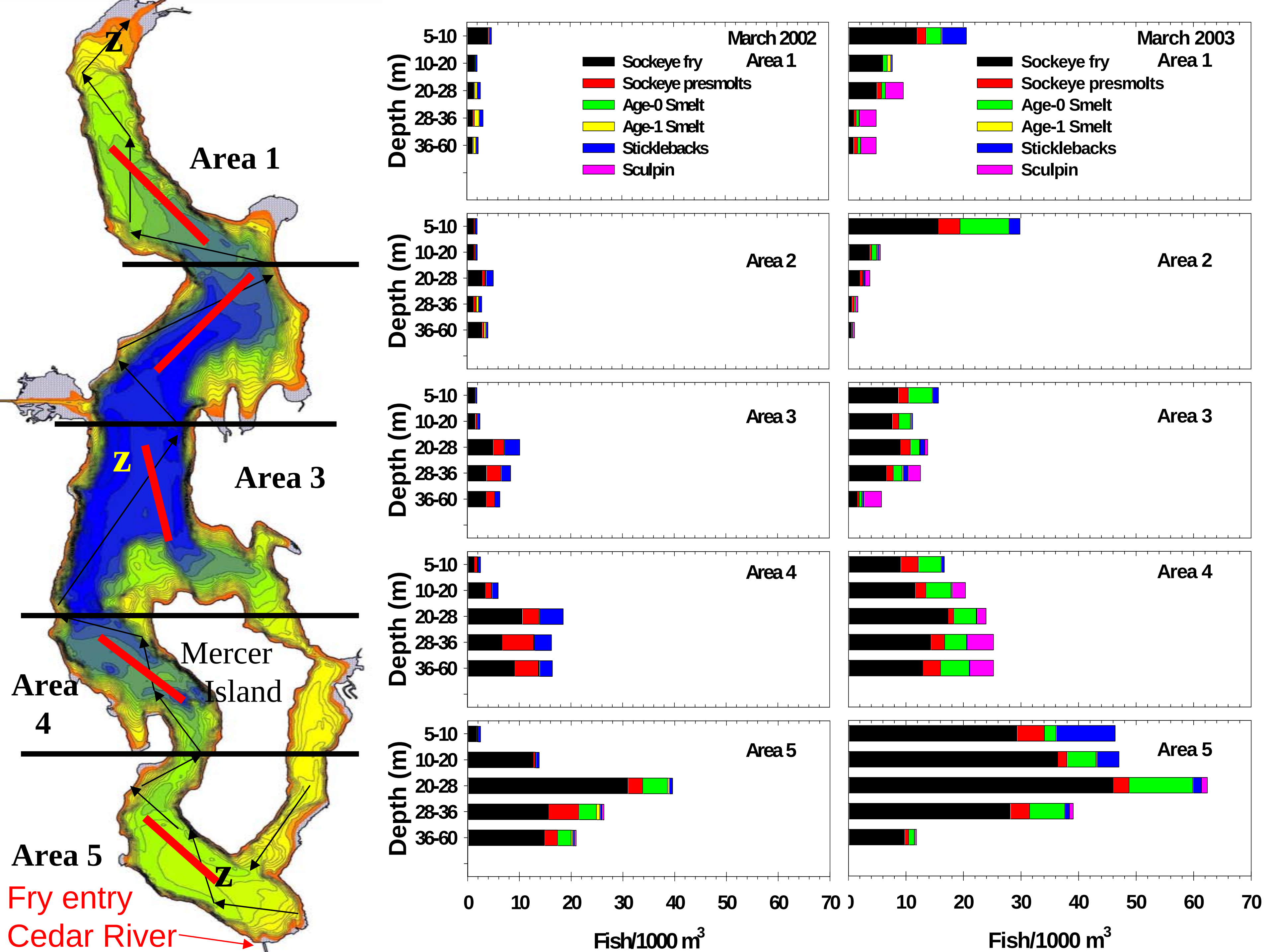
MIDWATER TRAWLING:

-samples species composition by depth

-provides biological data (size, growth, diet)



Fish caught in Midwater Trawl Help identify what species are detected by SONAR



Z
Area 1
Z
Area 3
Mercer
Island
Area
4
Area 5
Z
Fry entry
Cedar River
March 2002
Area 1
Sockeye fry
Sockeye presmolts
Age-0 Smelt
Age-1 Smelt
Sticklebacks
Sculpin
Depth (m)
5-10
10-20
20-28
28-36
36-60
Area 2
Area 3
Area 4
Area 5
0
10
20
30
40
50
60
70
Fish/1000 m3
March 2003
Area 1
Area 2
Area 3
Area 4
Area 5
Fish/1000 m3

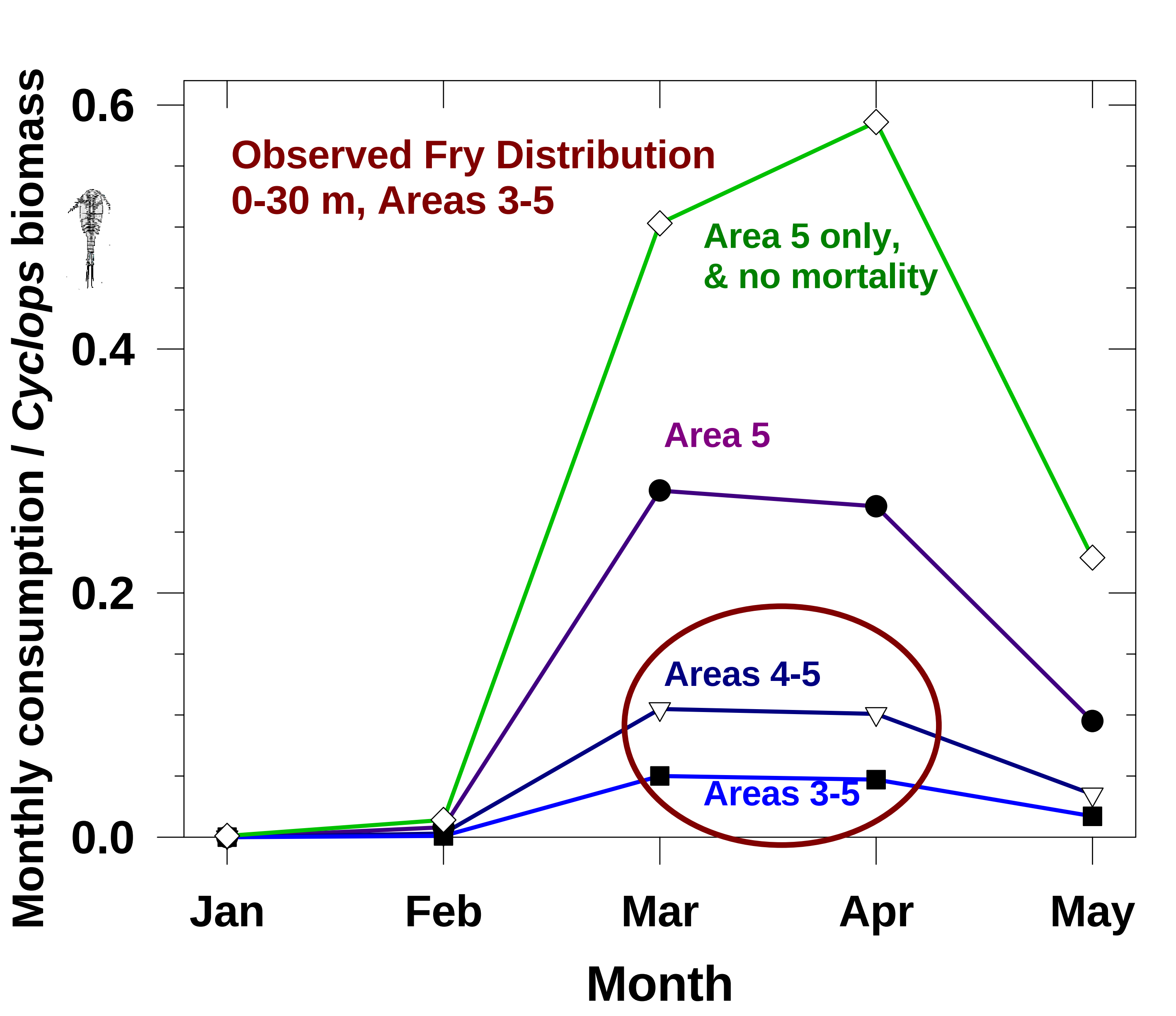

Zooplankton Sampling
Depth-stratified sampling:
Day: Zooplankton 153 µm
Night: Mysids 500-1000 µm

Model Scenarios: Monthly Food Supply and Demand by Sockeye Fry

Peak feeding
Demand by fry
In March-April

Peak Demand
was **7-12%** of
Localized
Prey biomass

Demand would
Increase to **30%**
if Fry confined to
Area 5 only,
60% if no fry
Mortality in lake



Summary

- **Winter food supply sufficient to support the projected increase in fry numbers entering the southern end of the lake projected for the expanded hatchery program.**
- **Management implication: Sockeye hatchery enhancement would not exceed winter carrying capacity of Lake. A major uncertainty removed.**
- **Future Monitoring Concerns:**
- **Interannual variability in zooplankton**
- **Dynamics of other planktivores could still create trophic bottlenecks**
- **Climate change, other factors affecting zooplankton production**

Quantifying Predation Mortality

Lake Washington Applications

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  - Where does predation occur?
  - What factors alter predation?

Modeling Process

Consumer Growth

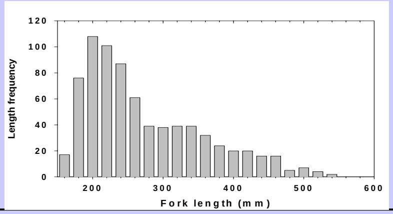
Temporal Diet Composition

Predator Energy Density

Prey Energy Density

Thermal Experience

Bioenergetics Model



Consumer Size Structure & Abundance

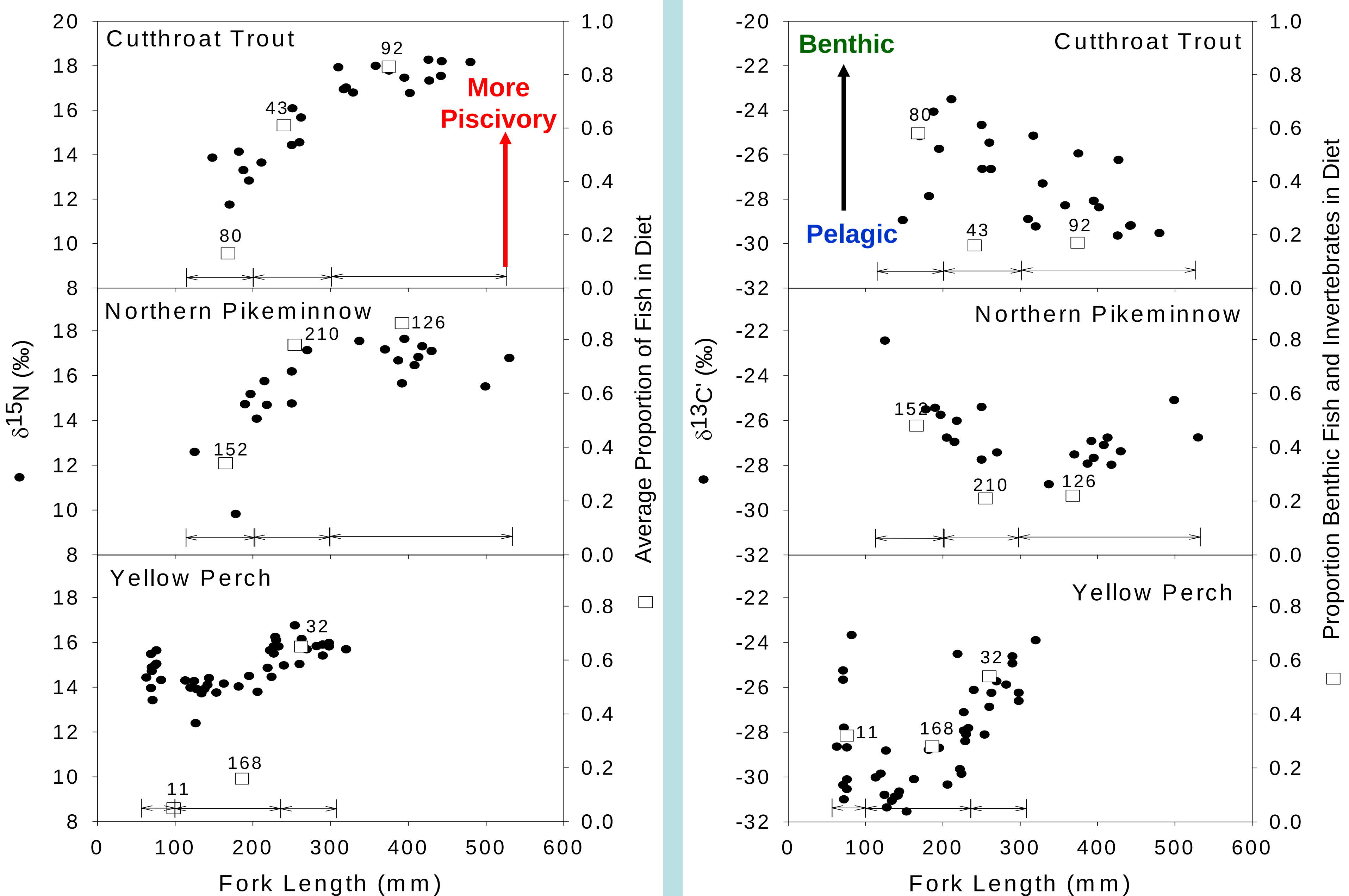
Consumption Estimate

Population Consumption

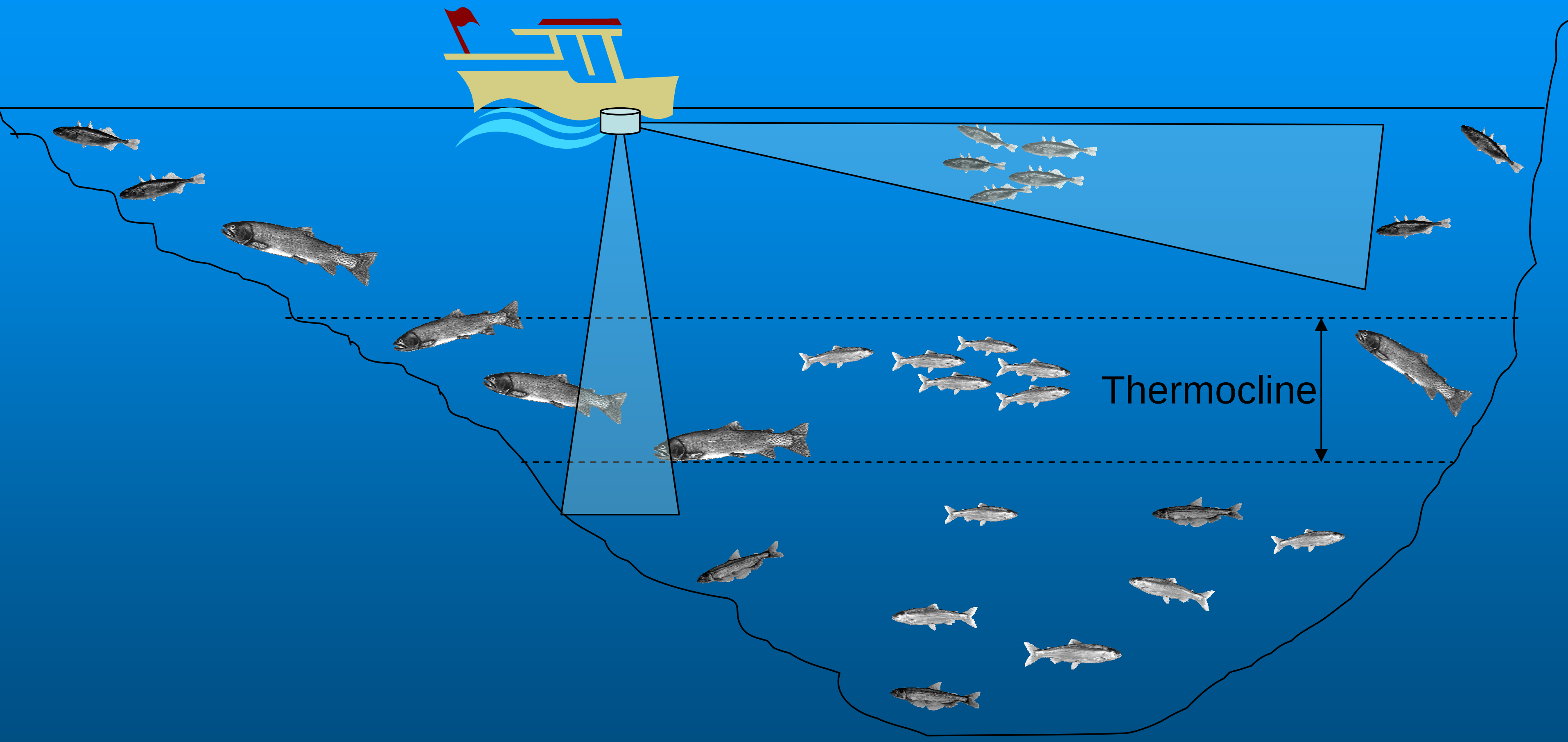
Biomass of Exploitable prey

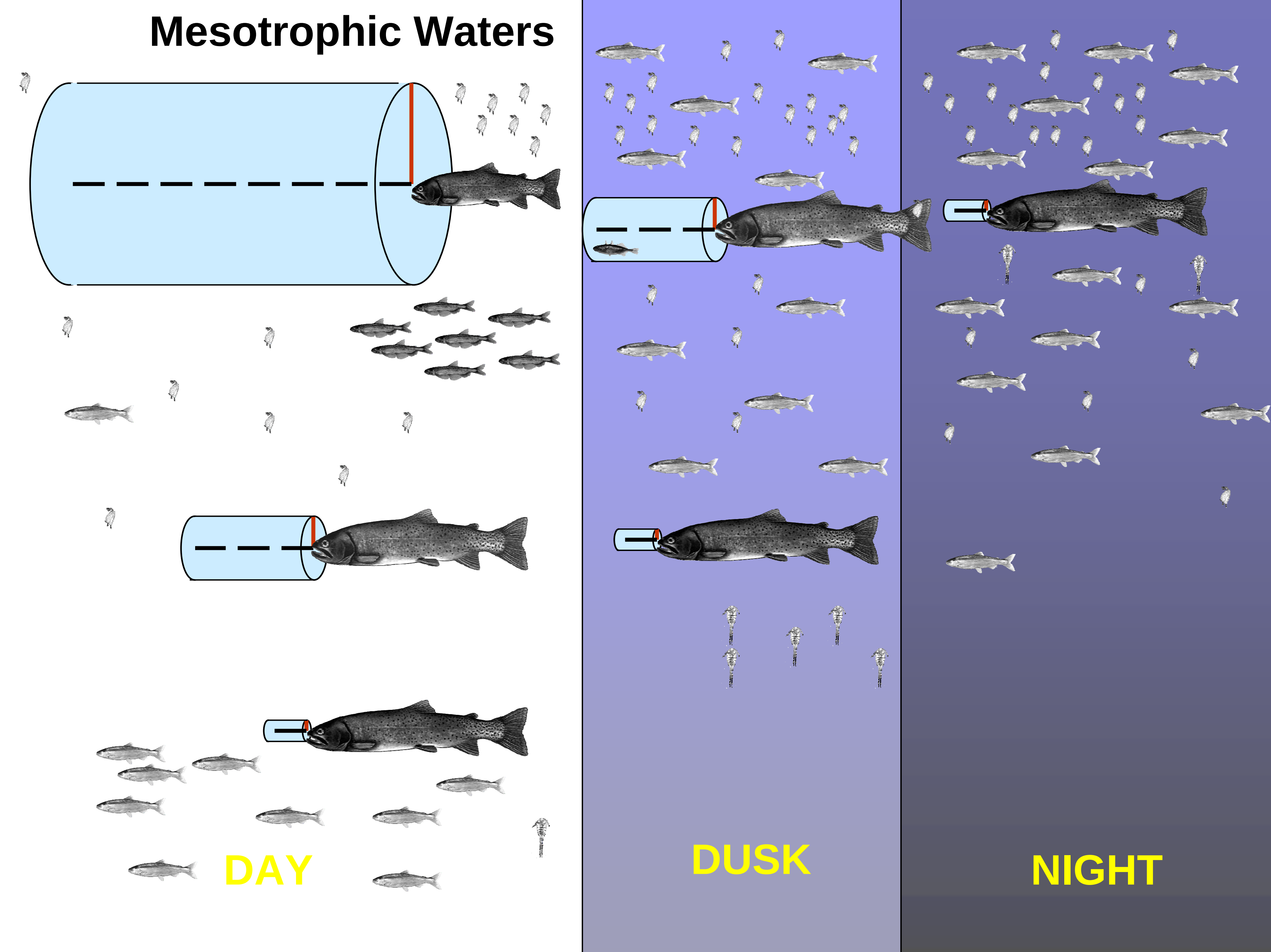
Consumption as % of Prey Biomass or Production

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



HYDROACOUSTICS
DAYLIGHT DISTRIBUTION
Prey fish schooled, deep, or nearshore



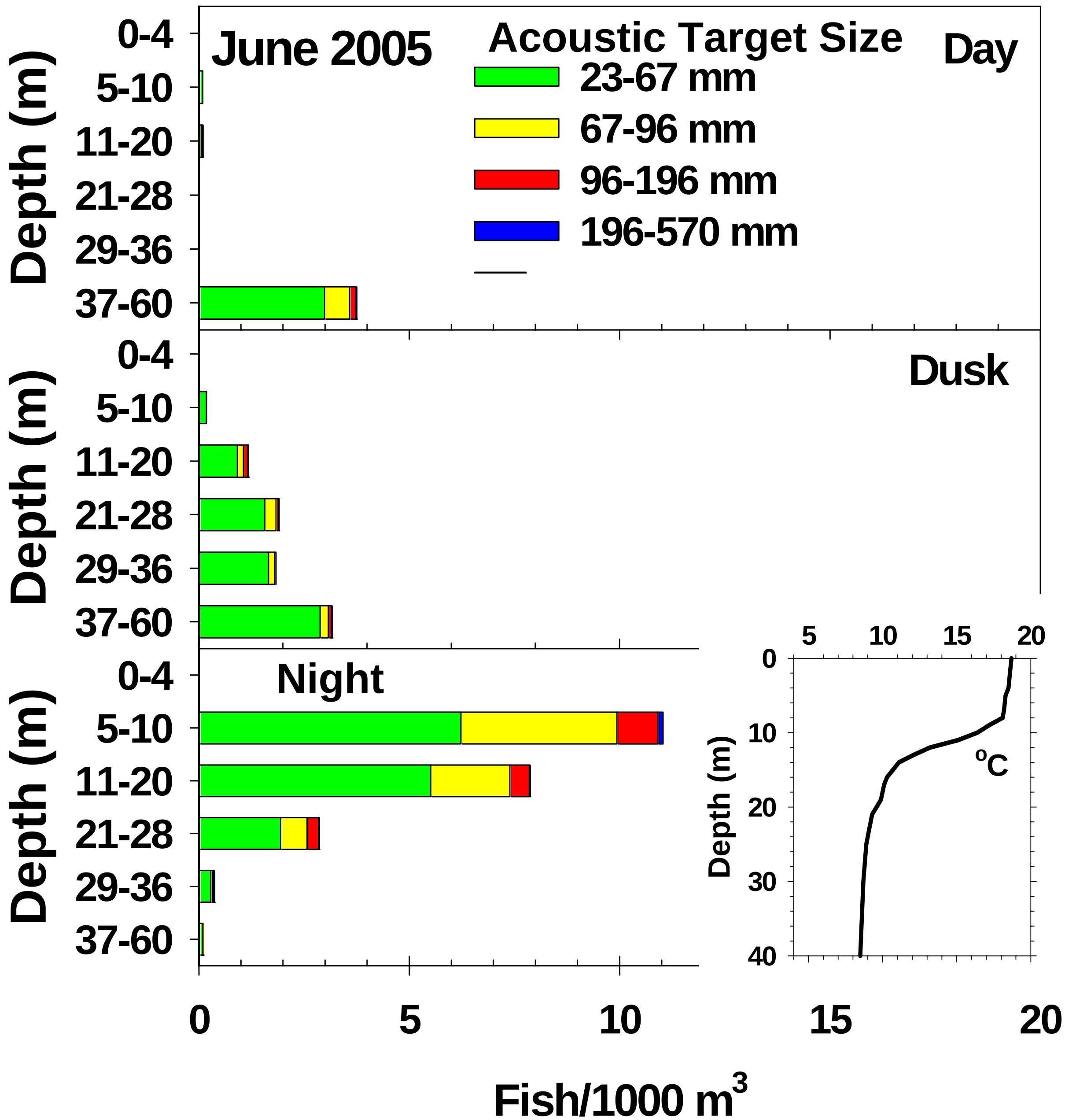

Mesotrophic Waters
DAY
DUSK
NIGHT

Diel Size-specific Depth Distribution

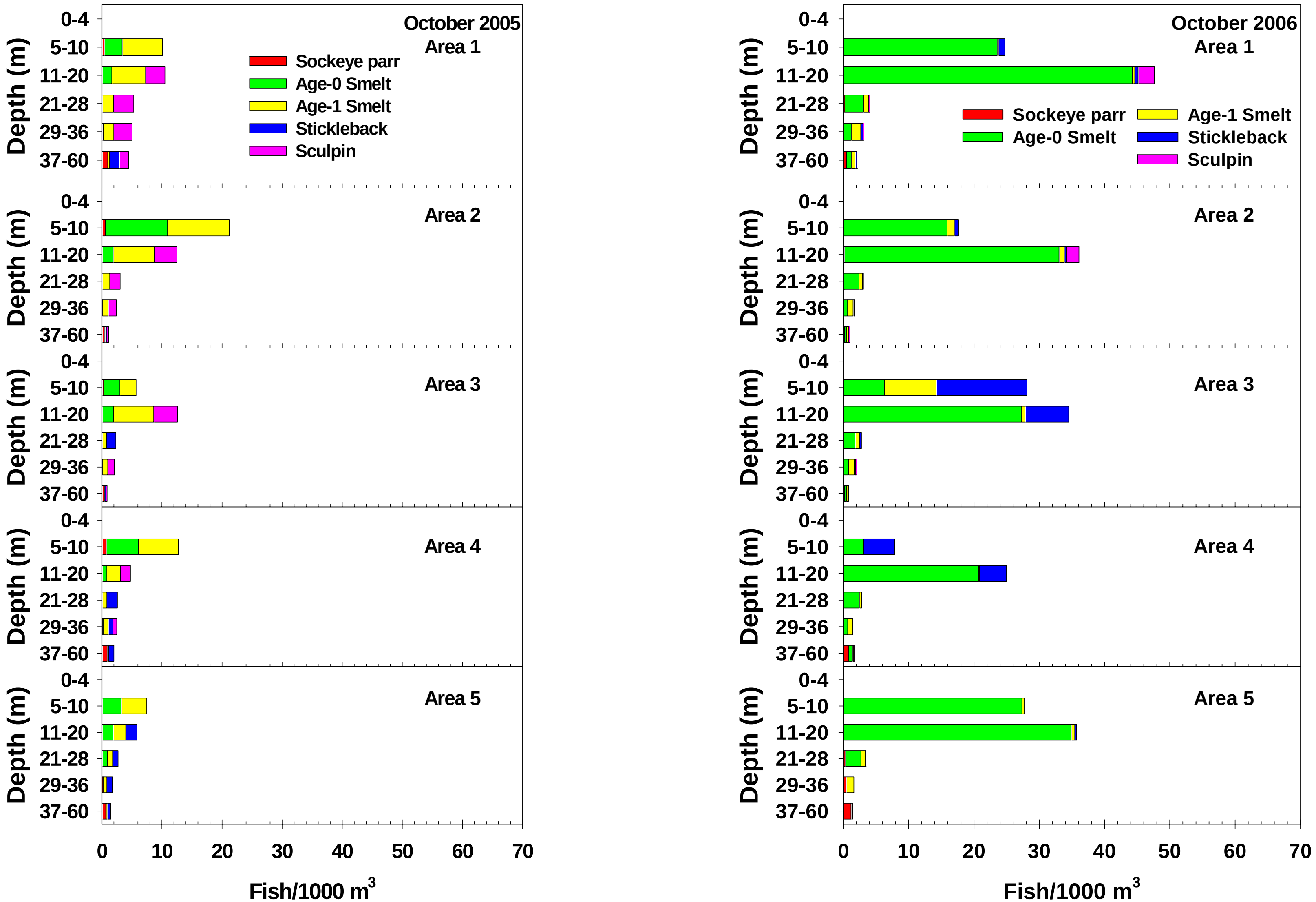
Daylight:
-Few fish are in the upper water column during daylight except large and very small fish
-Could be in schools, near bottom or near shore

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



Quantitative Fall Acoustic-Midwater Trawl Survey

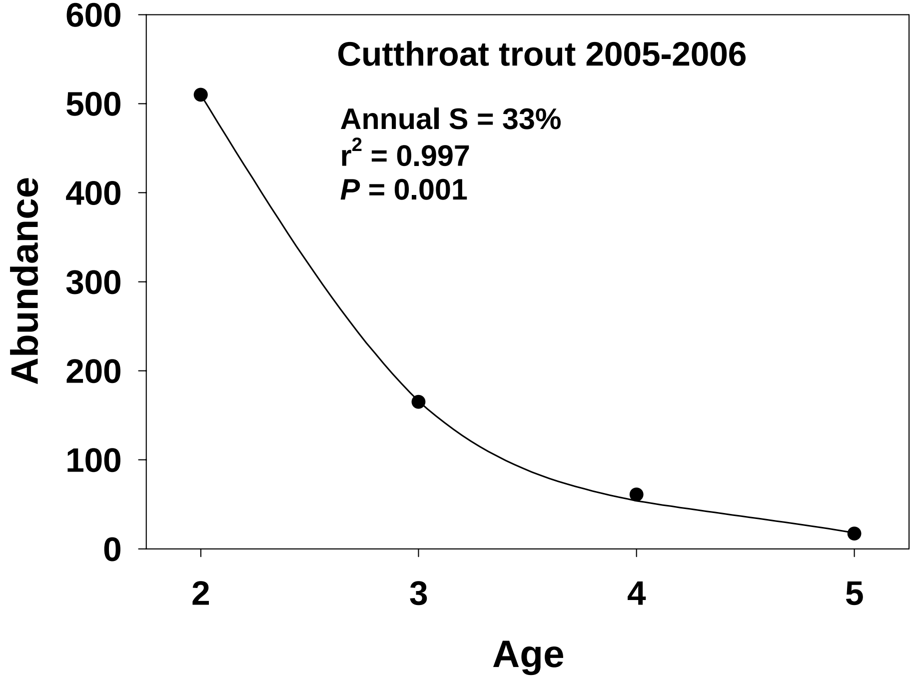


Prey Availability influenced by cyclic odd-even year class Fluctuations in longfin smelt abundance

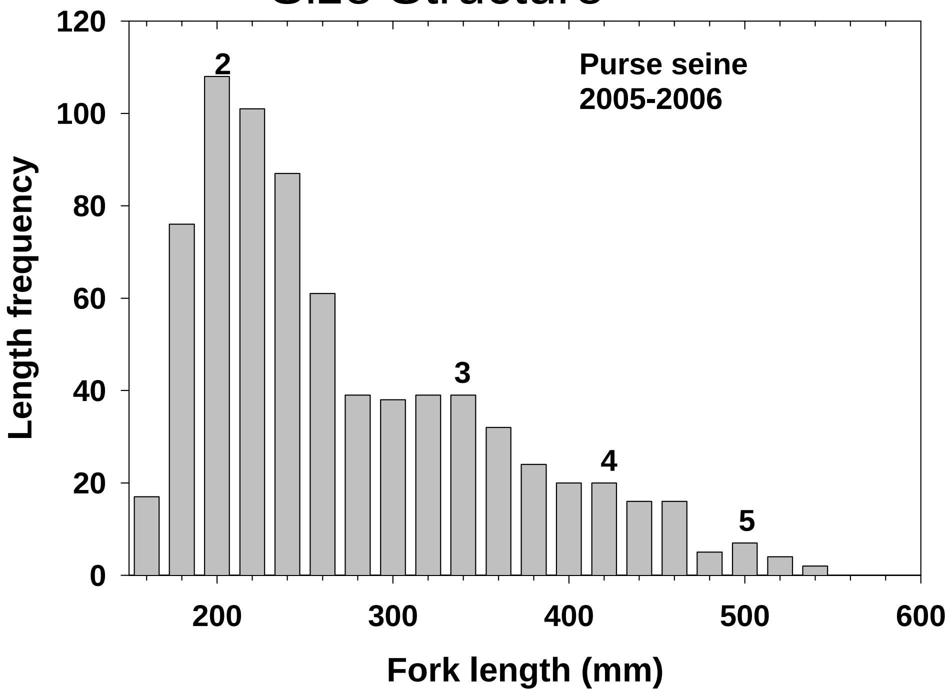
Predator Population
Size Structure, Survival & Growth

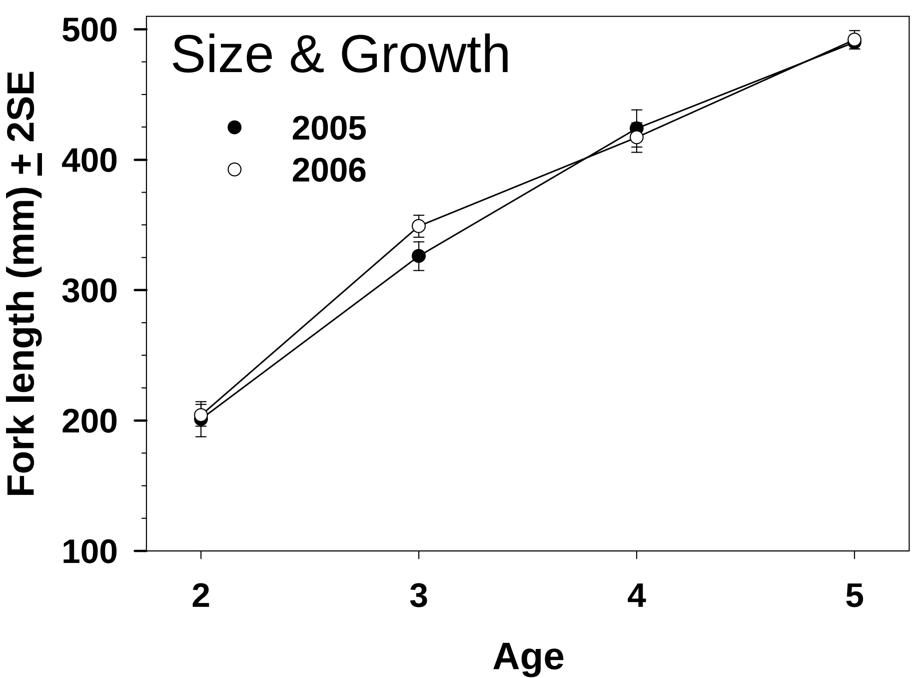
L. Washington 2005-06
Cutthroat trout
Ages & Length Freq Modes Confirmed by aging w\ scales

Survival



Size Structure





Cutthroat trout

Seasonal Size-structured Predation by a standardized Population of 1,000 predators FL > 150 mm (age-2 & older)

Smaller Cutts feed mostly on Inverts, YOY Smelt, Sticklebacks & Larval fish

Larger Cutts feed heavily on Fish throughout the year:

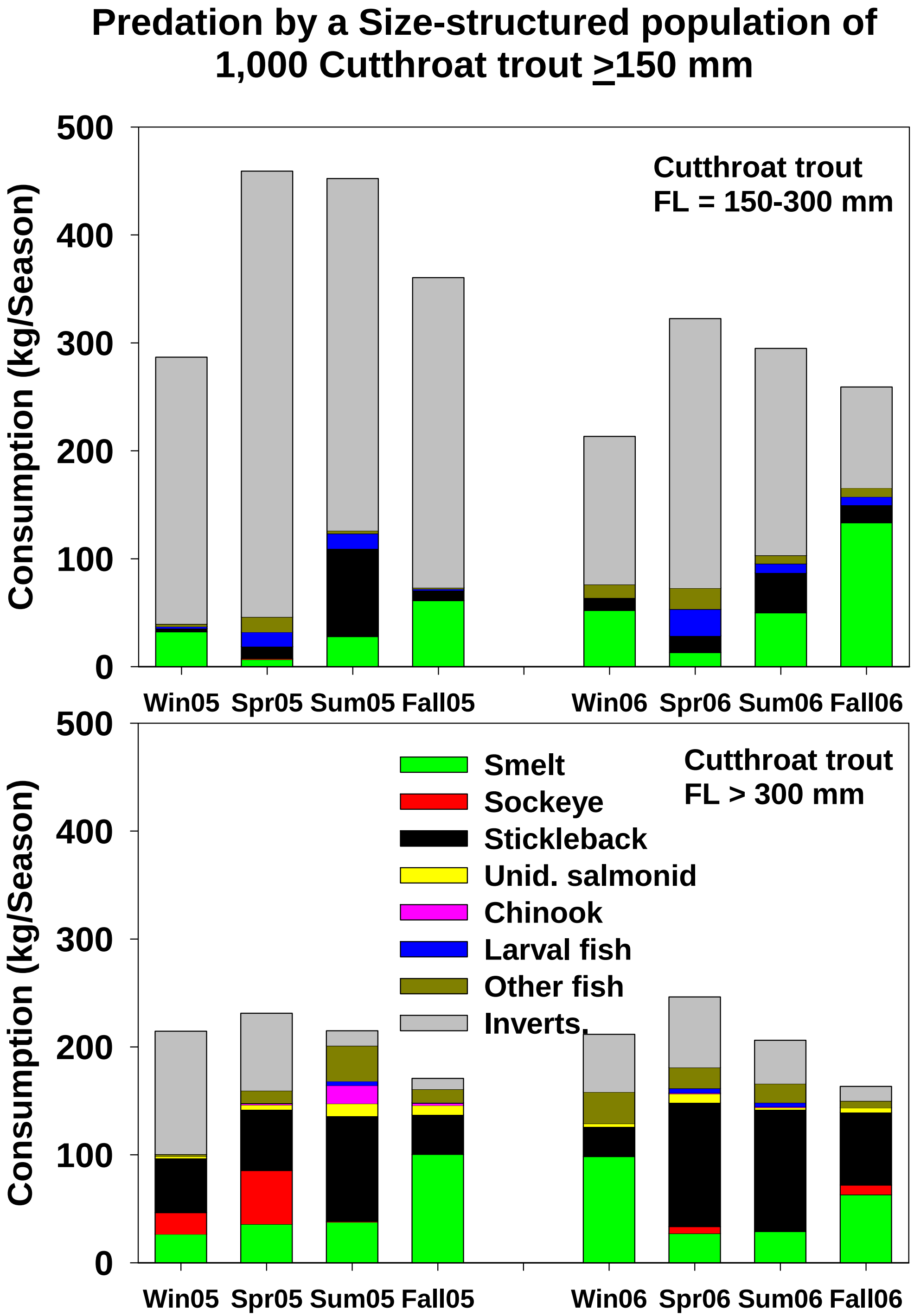
Sticklebacks

Smelt

Sockeye

Other (Sculpin & Perch)

Chinook salmon



Northern Pikeminnow

Seasonal Size-structured Predation by a standardized Population of 1,000 predators FL > 200 mm (age-2 & older)

Smaller Pikeminnow feed mostly on Invertebrates, YOY Smelt & other fish

Larger Pikeminnow feed heavily on fish:

Smelt

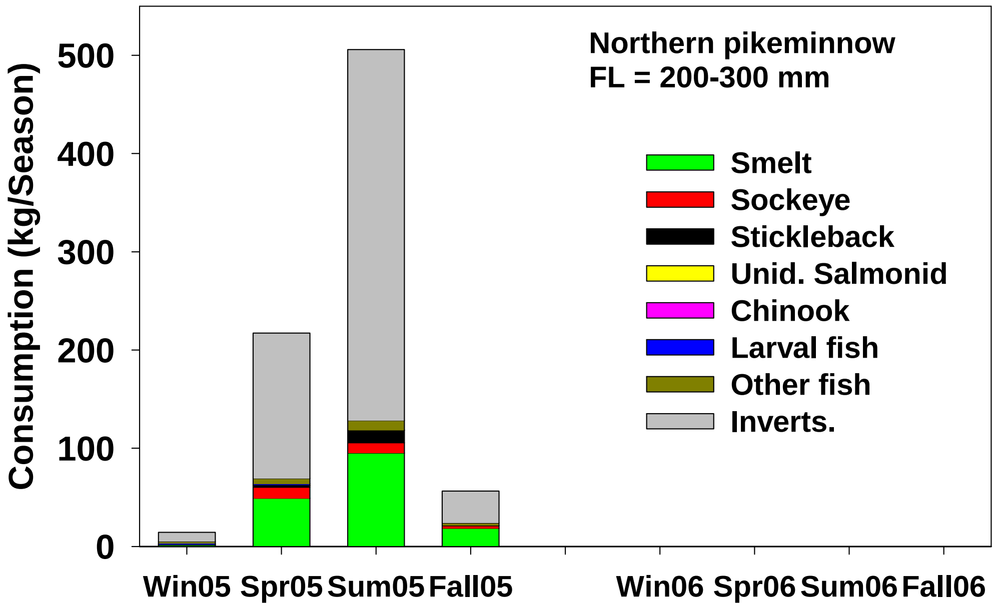
Sticklebacks

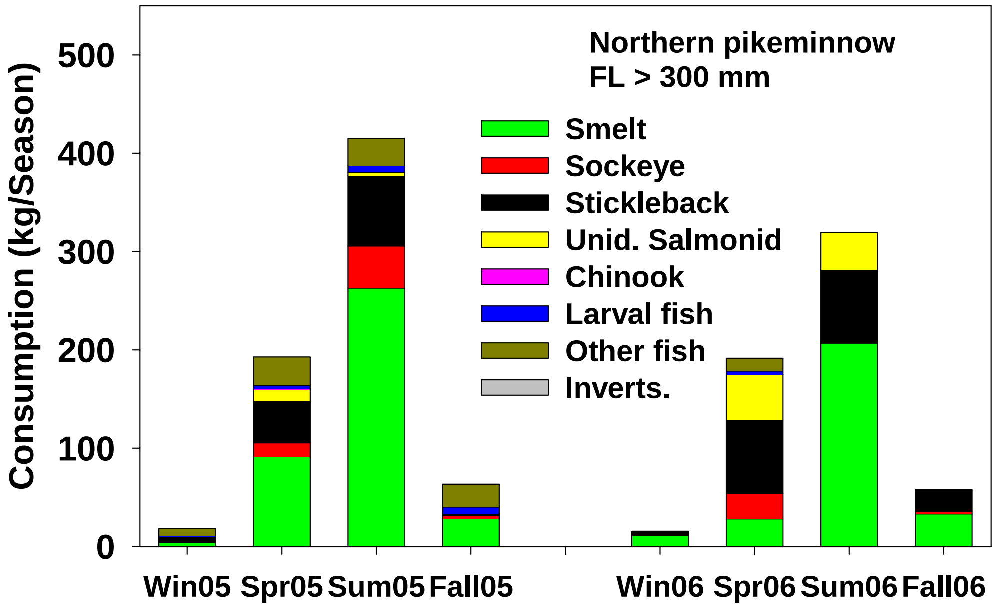
Sockeye

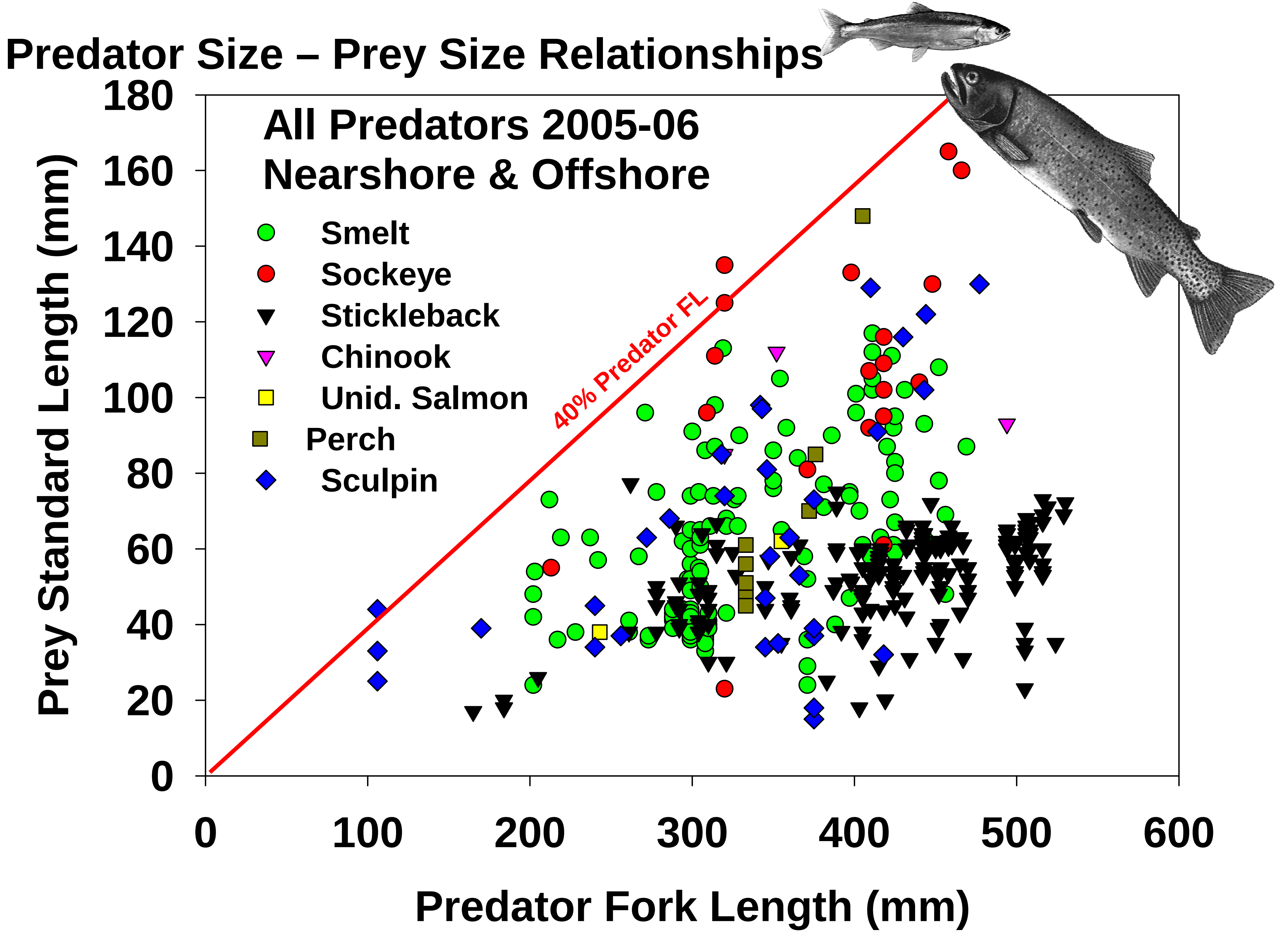
Unid. salmonids

Other (Sculpin & Perch)

Predation by a Size-structured population of 1,000 Northern Pikeminnow >200 mm







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

Mortality rates per 1000 Predators

- **2005 Cutthroat trout**
- 0.6% Smelt
- **0.6% Sockeye**
- 1.6% Stickleback
- **1.1% Chinook**
- **2006 Cutthroat trout**
- 0.8% Smelt
- **0.1% Sockeye**
- 1.9% Stickleback
- **0% Chinook**

- **2005 N.Pikeminnow**
- 0.9% Smelt
- **1.4% Sockeye**
- 0.4% Stickleback
- **0.1% Chinook**
- **2006 N.Pikeminnow**
- 0.2% Smelt
- **0.2% Sockeye**
- 0.5% Stickleback
- **0% Chinook**

Predation Summary- Lake Washington

- Predators are capable of regulating populations of juvenile salmon and other forage fish
  - 50k - 100k Cutts plus 50k-100k Pikeminnow would impose severe mortality on most prey populations
- Cutthroat trout & N. Pikeminnow most piscivorous after reaching 300mm FL
- Both predator species exerted similar predation pressure overall, but at different times and in different habitats
  - Cutts: Nearshore during winter, Pelagic Spr-Fall
    - **Sticklebacks, Smelt, Sockeye, Chinook**
  - Pikeminnow: Nearshore during Spring-Summer
    - **Smelt, Sockeye, Sticklebacks**

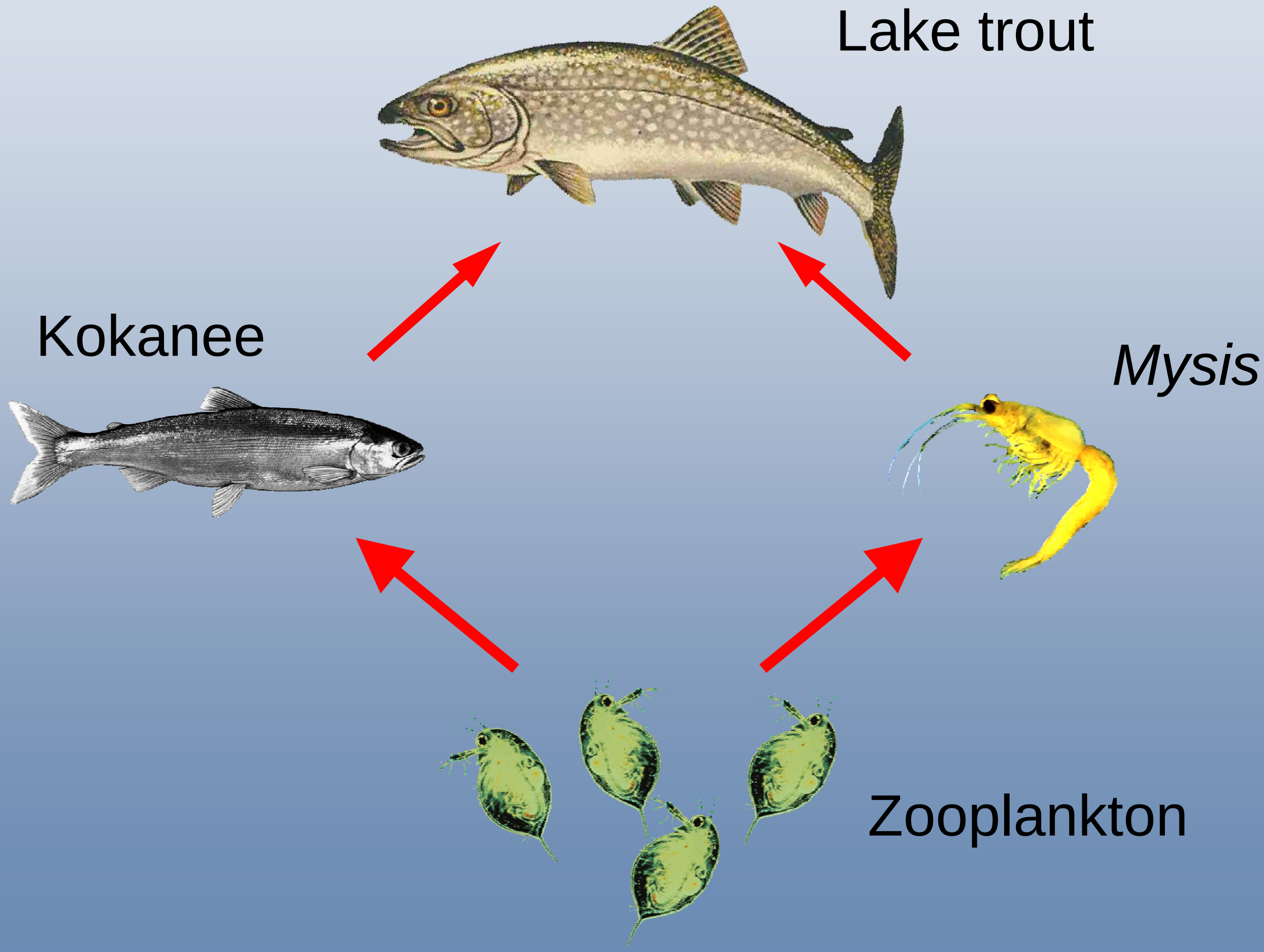
If Predation Mortality is Important, What can Managers Do?

- Assign loss to correct life stage & source:
  - Spp & size of predator, time, and location
  - Is this a population bottleneck?
  - Can habitat efforts overcome this bottleneck or are “upstream” gains undermined by predation here?
- What factors contribute to predation-Can management actions mediate these effects?
  - Predator/competitor control: regain ecological balance
  - Temperature, water quality modification
  - Shoreline/riparian/upland modification
  - Urban Light pollution
  - Fishing regulations, Non-native species mgt.
- Focus effort directly where, when, how needed

Past-Current Applications

- Washington: Puget Sound, L. Washington, Sammamish, Ozette, Chelan, Roosevelt, Skagit River
- Alaska (SE): Margaret & Redoubt L., Prince William Sound-Gulf of Alaska
- Oregon: L. Billy Chinook
- California/NV: L. Tahoe
- Idaho: Sawtooth Valley Lakes, Bear L.
- Utah: Strawberry Res, Bear L.
- Montana: Flathead L.
- Wyoming: Yellowstone L.

Flathead Lake-Non-native Introductions:
Lake trout & *Mysis* effects on kokanee



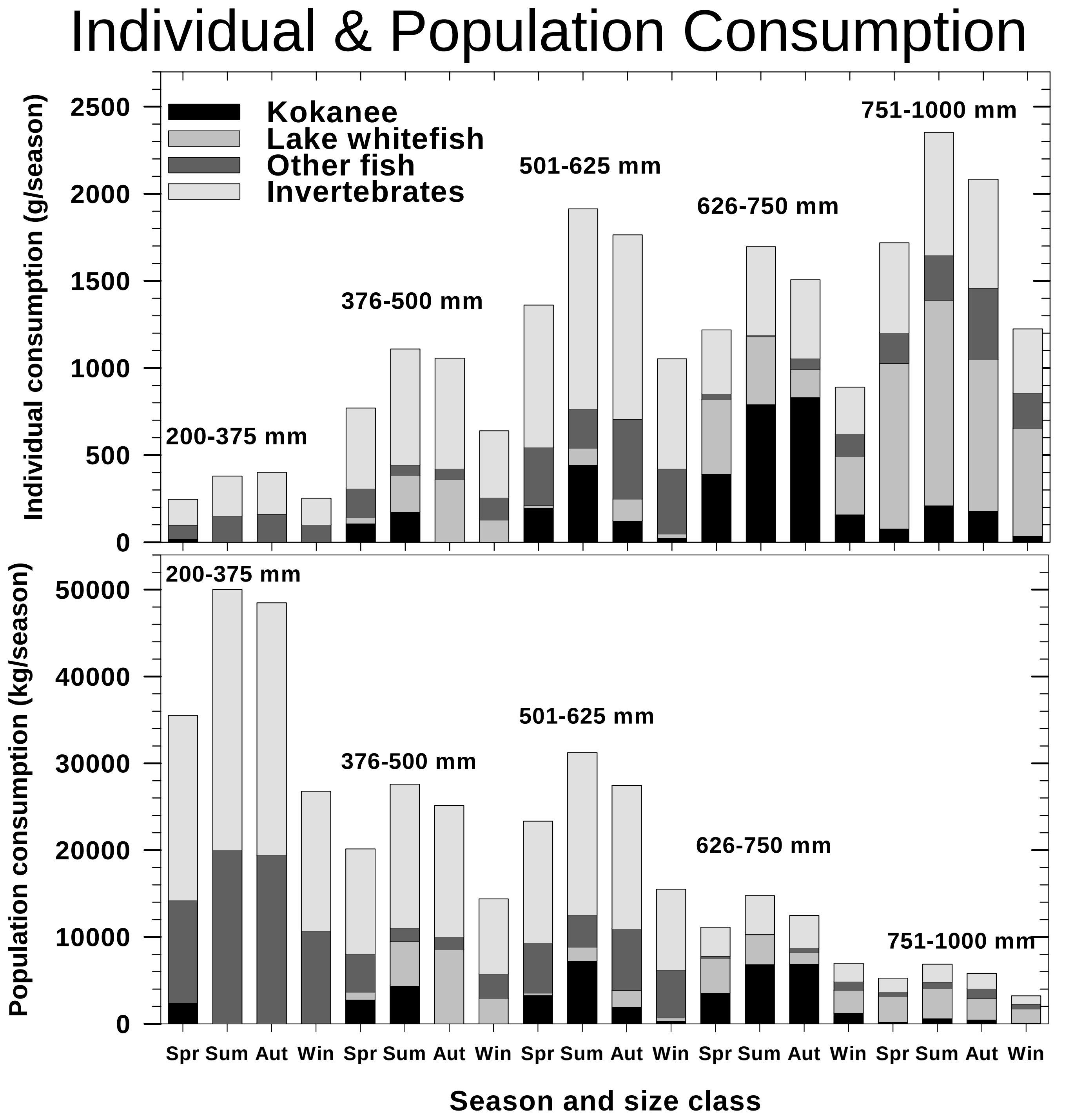
Flathead Lake Case Study

- Kokanee crashed in mid-1980s: declined from 500k - 1 million adults to <10k, coincident with invasion of *Mysis relicta*
- Non-native Lake trout populations increased 10-fold during 1980s
- Native Bull trout and Westslope cutthroat declined ~10-fold over same period
- In early 1990s, a 5-yr effort to restore kokanee by stocking 800,000 yearlings (>120 mm) in May-June was producing few adults

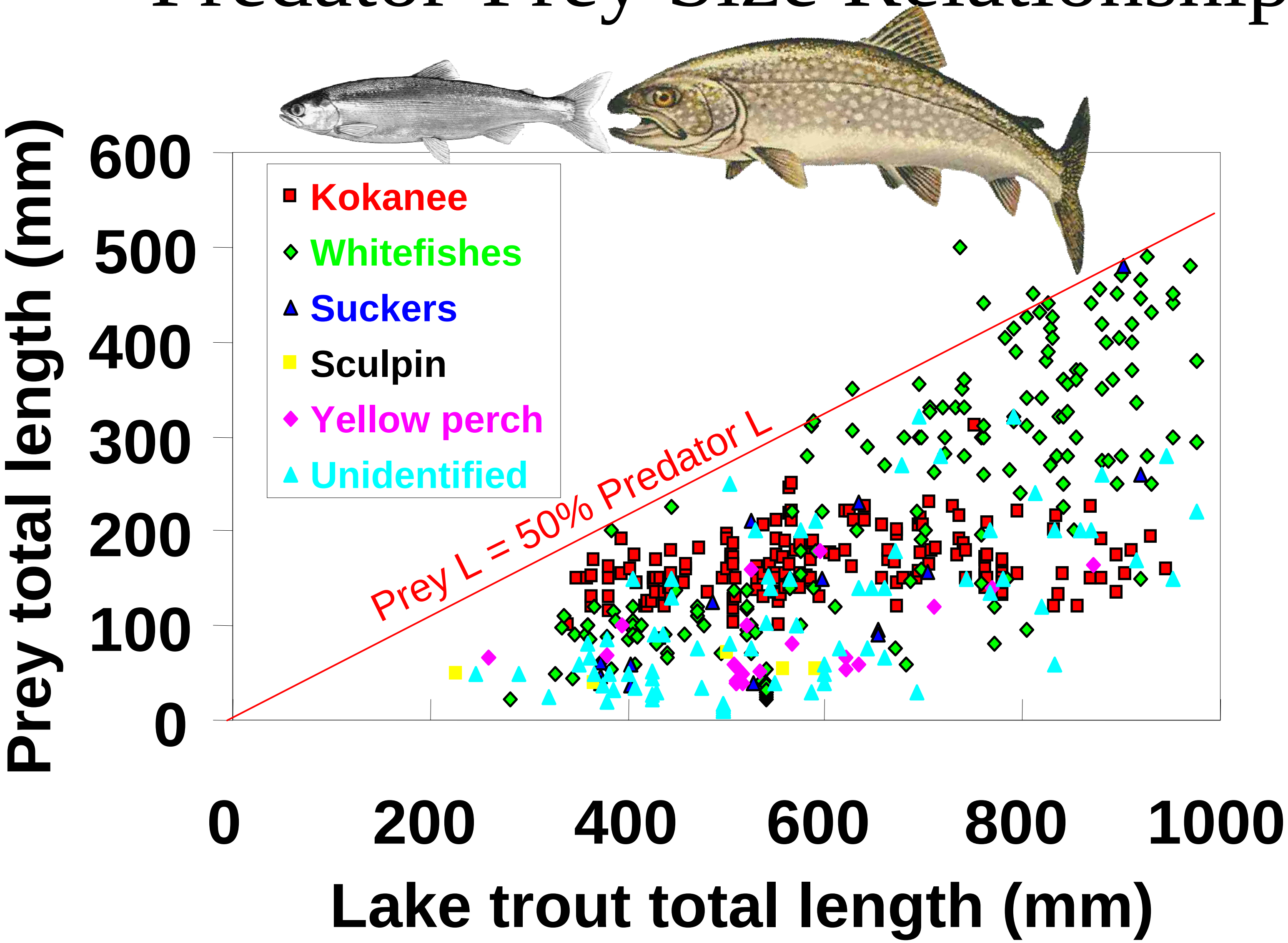
Predation by Lake Trout in Flathead Lake 1993-1996 Kokanee Restoration

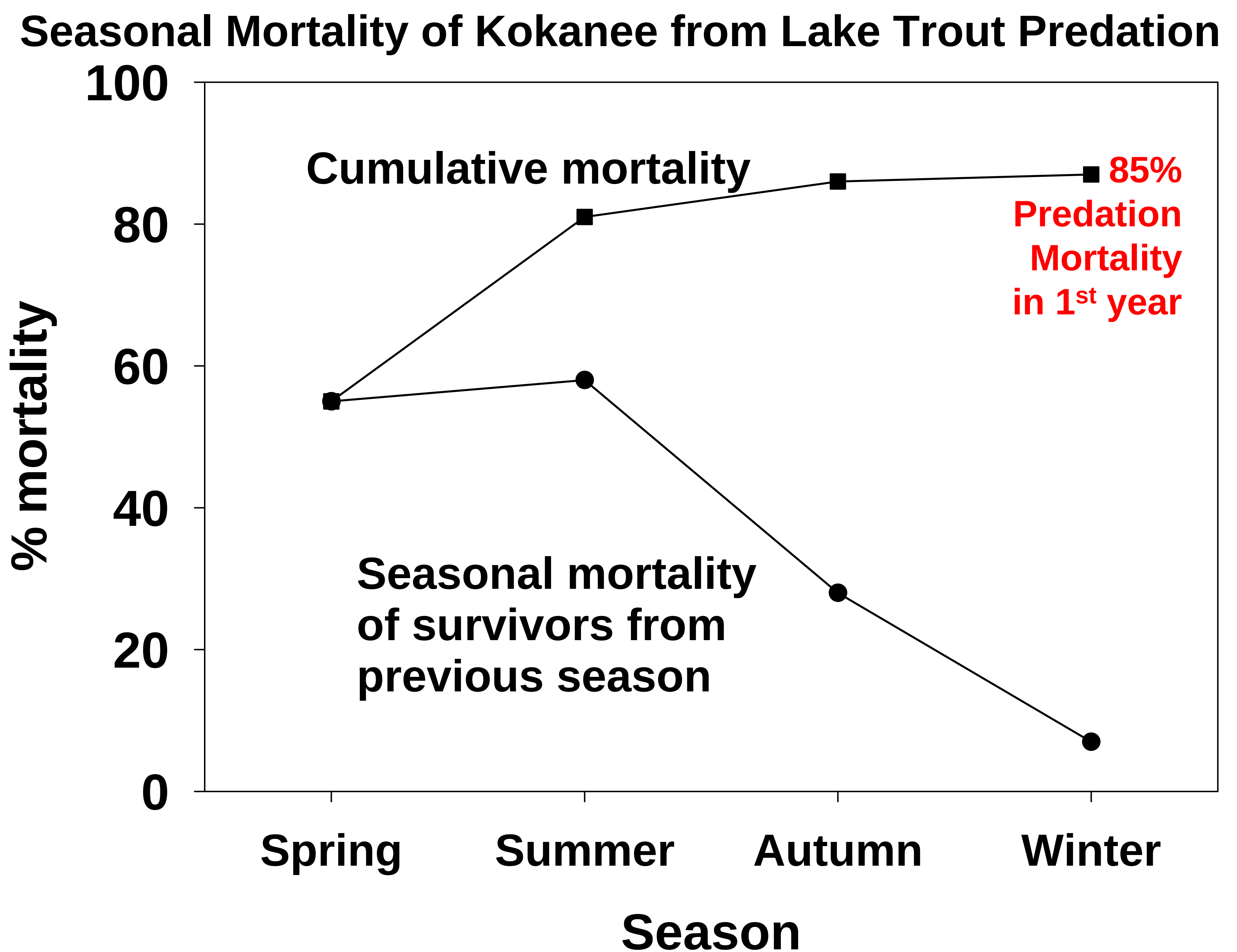
Smaller L. trout Eat less, but More numerous

Mid-size L. trout 500-750 mm FL Imposed highest Mortality on kokanee



Predator-Prey Size Relationship

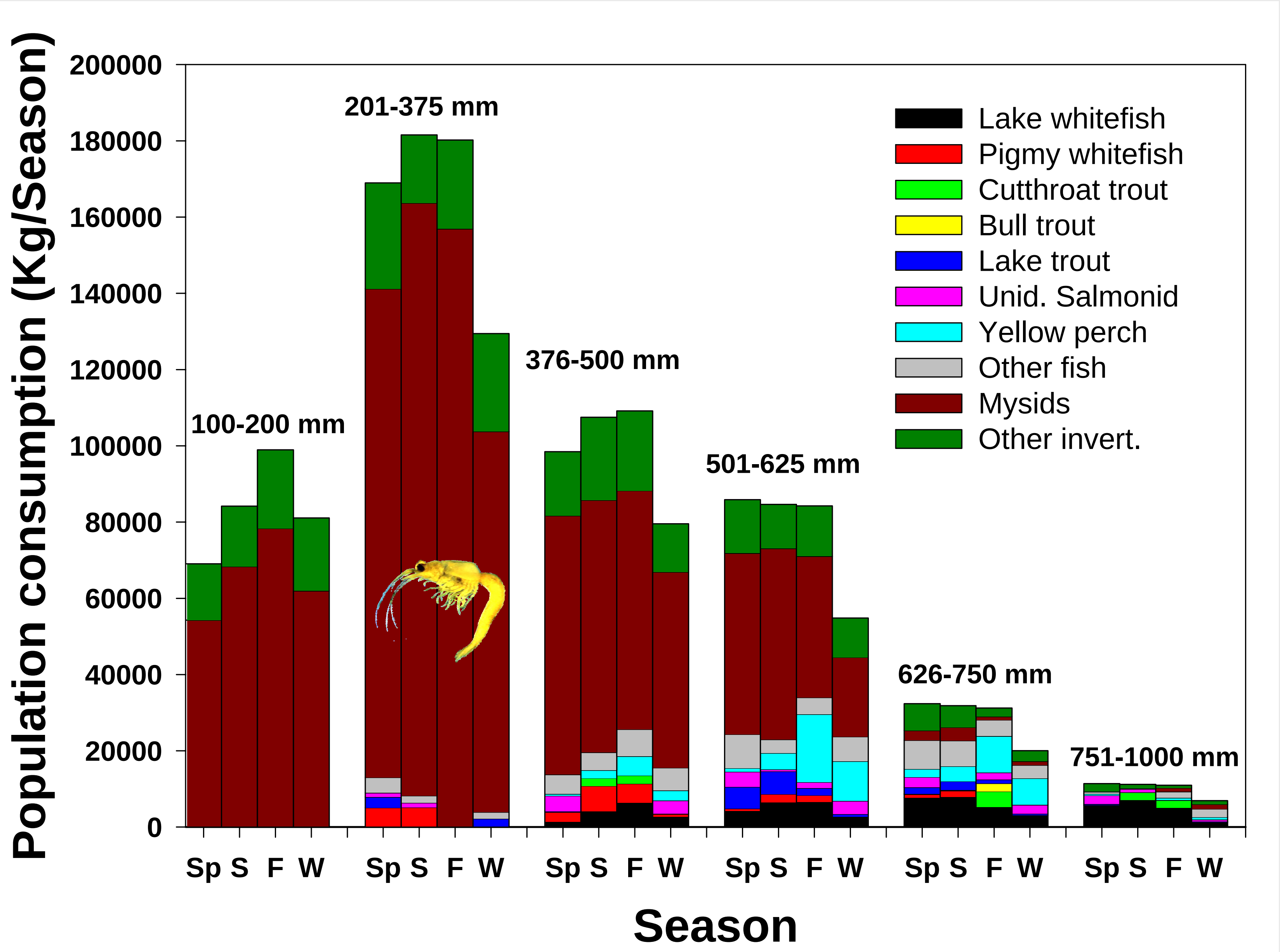



Seasonal Mortality of Kokanee from Lake Trout Predation
100
80
60
40
20
0
% mortality
Cumulative mortality
85% Predation Mortality in 1st year
Seasonal mortality of survivors from previous season
Spring
Summer
Autumn
Winter
Season

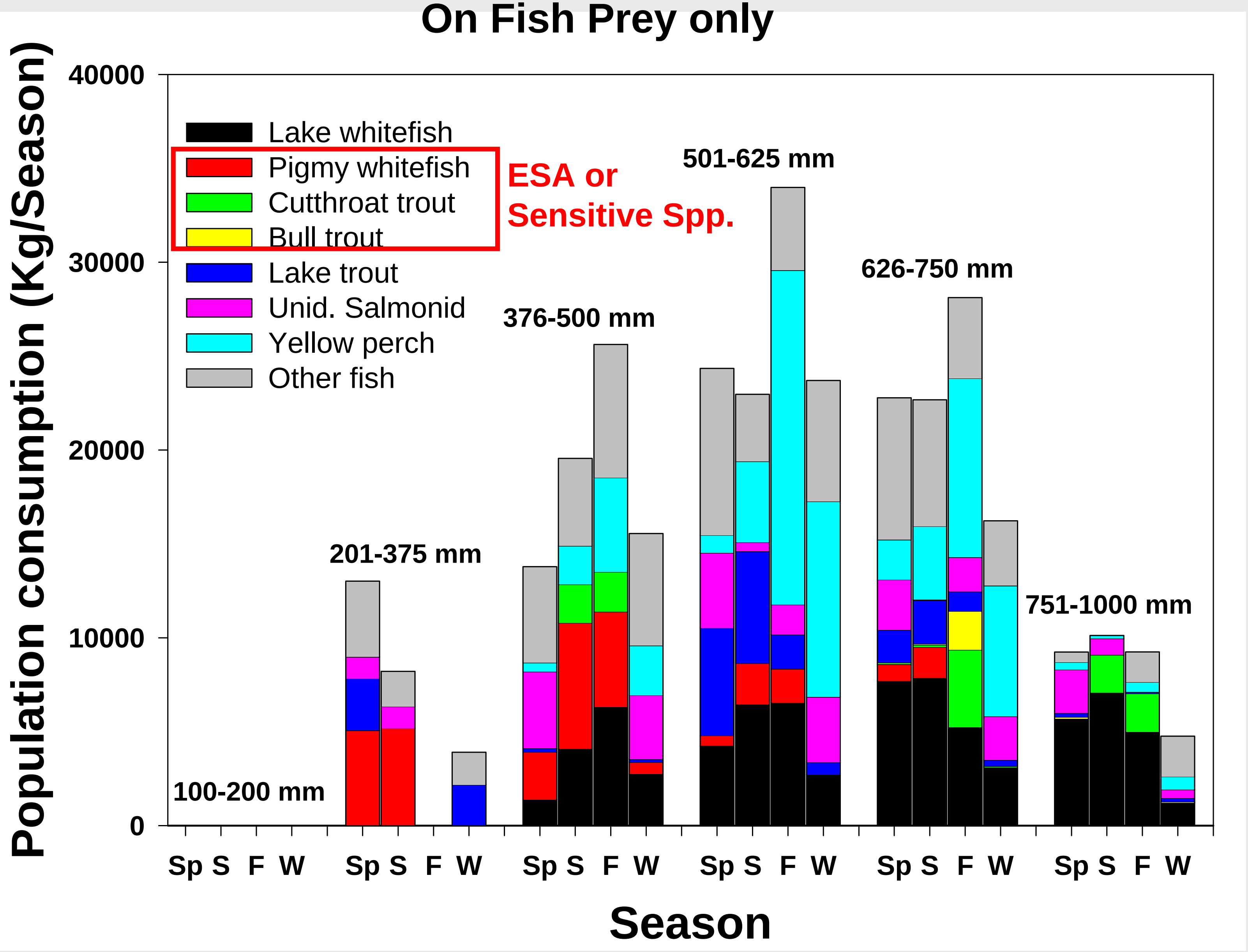
Conclusions

- Lake trout predation removed ~85% of the 800,000 yearling kokanee within the first year, and mostly within the first 4 months after stocking
- Hatchery capacity was too limited to produce large enough numbers or sizes of kokanee to overcome the predation demand
- Sensitivity analyses indicated that lake trout populations needed to be reduced by >90% to enable sufficient survival of kokanee under current hatchery capacity
- Kokanee restoration program was terminated as a result

Post-Kokanee Era in Flathead Lake
Size-Structured Seasonal Consumption by Lake Trout



Size-structured Seasonal Predation Rates by Lake Trout On Fish Prey only



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- Montana: Flathead L.
- Wyoming: Yellowstone L.

Precipitation, freshwater run-off & wind drive coastal currents, salinity, stratification and circulation patterns

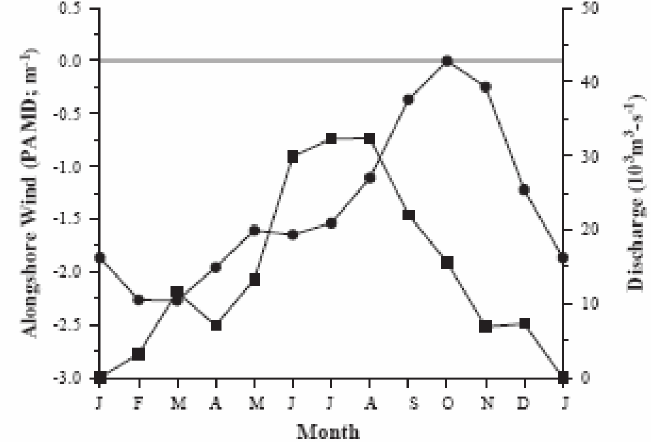
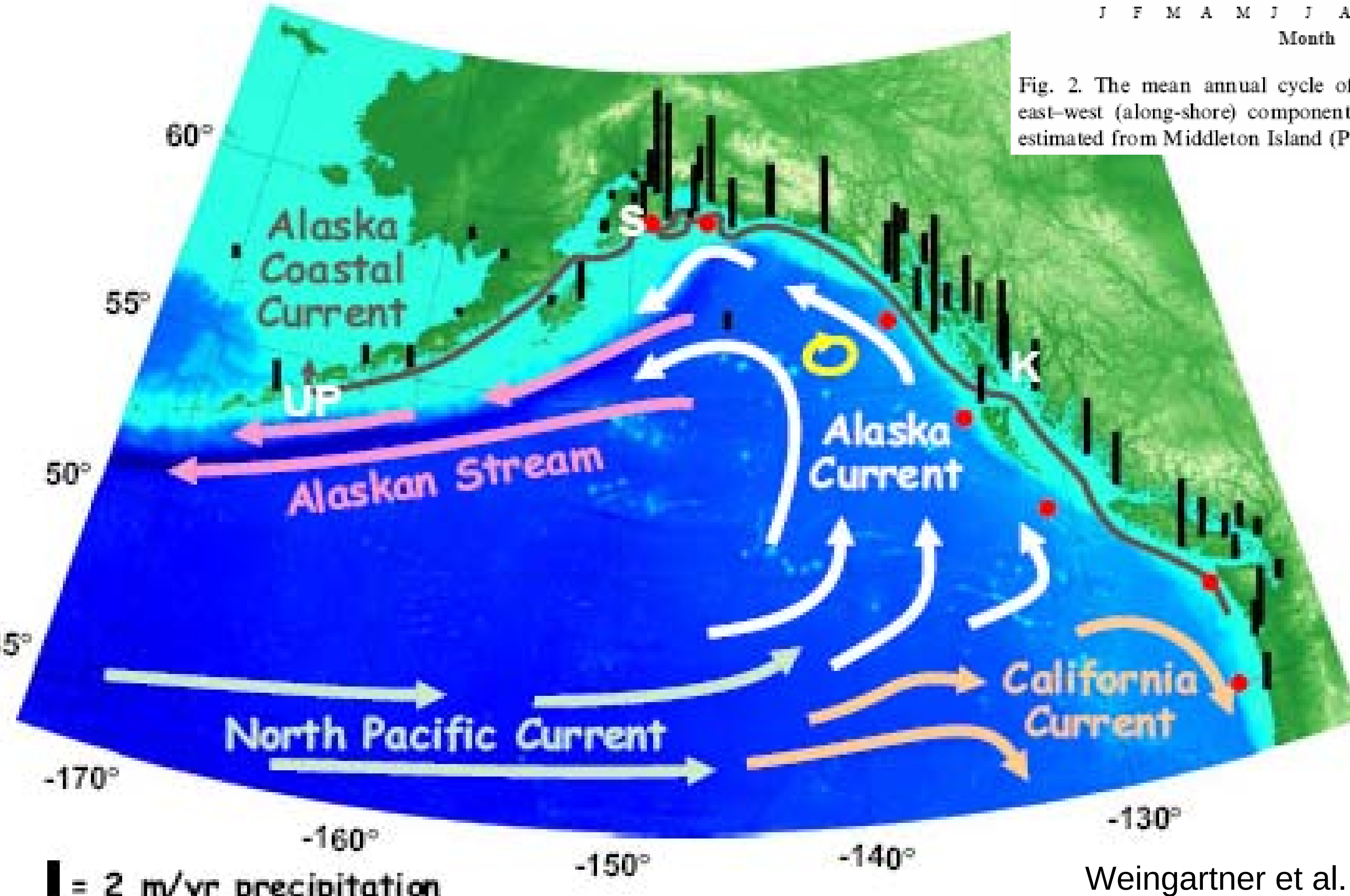


Fig. 2. The mean annual cycle of runoff (circles) and the east–west (along-shore) component of wind speed (squares) estimated from Middleton Island (PAMD) measurements.

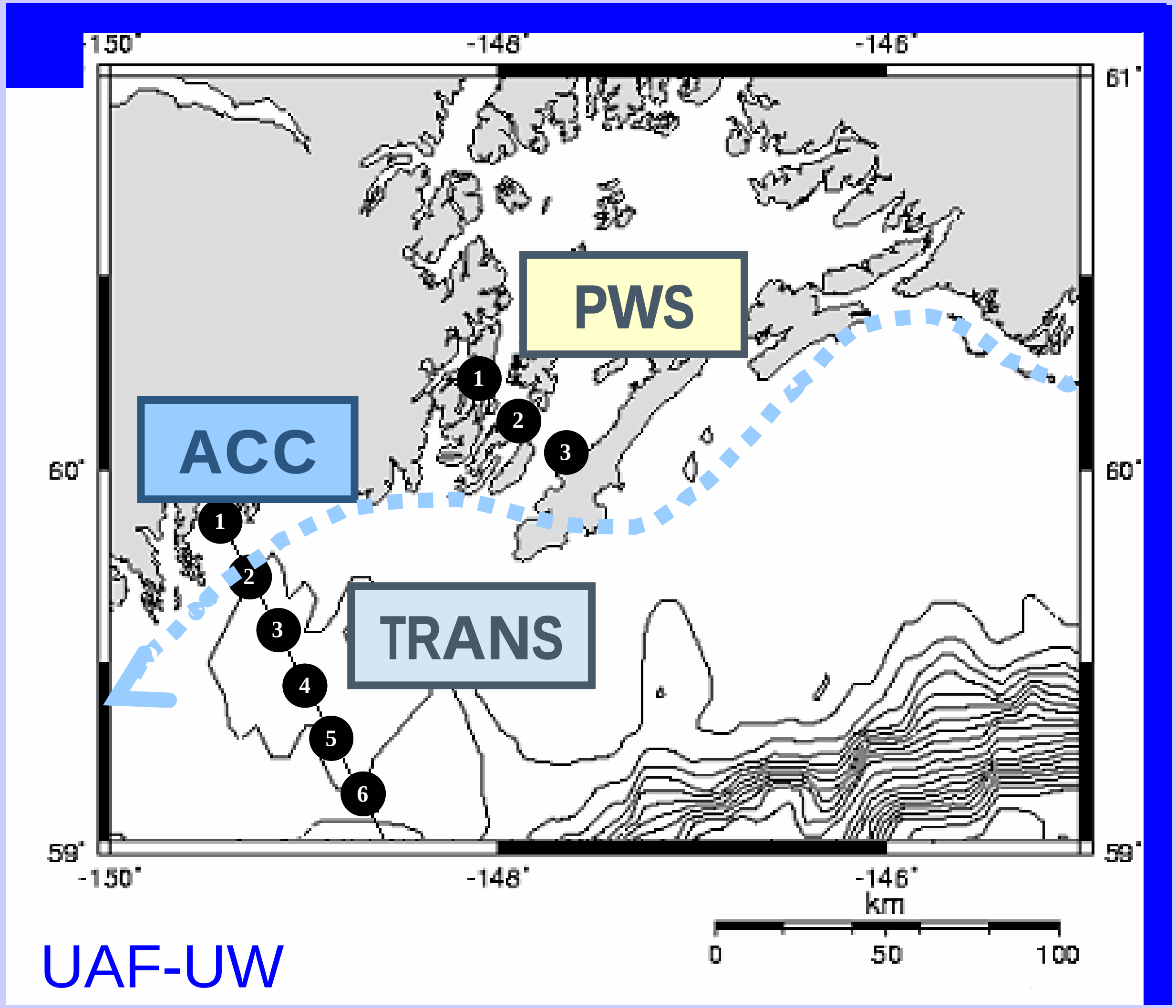


Weingartner et al. 2005

2001-2004 Gulf of Alaska

Monthly sampling July-Sept/Oct:

Zooplankton, CTD, Fish Diet, Size, Age



NOAA-OCC cruises

Divergent Growth & Survival

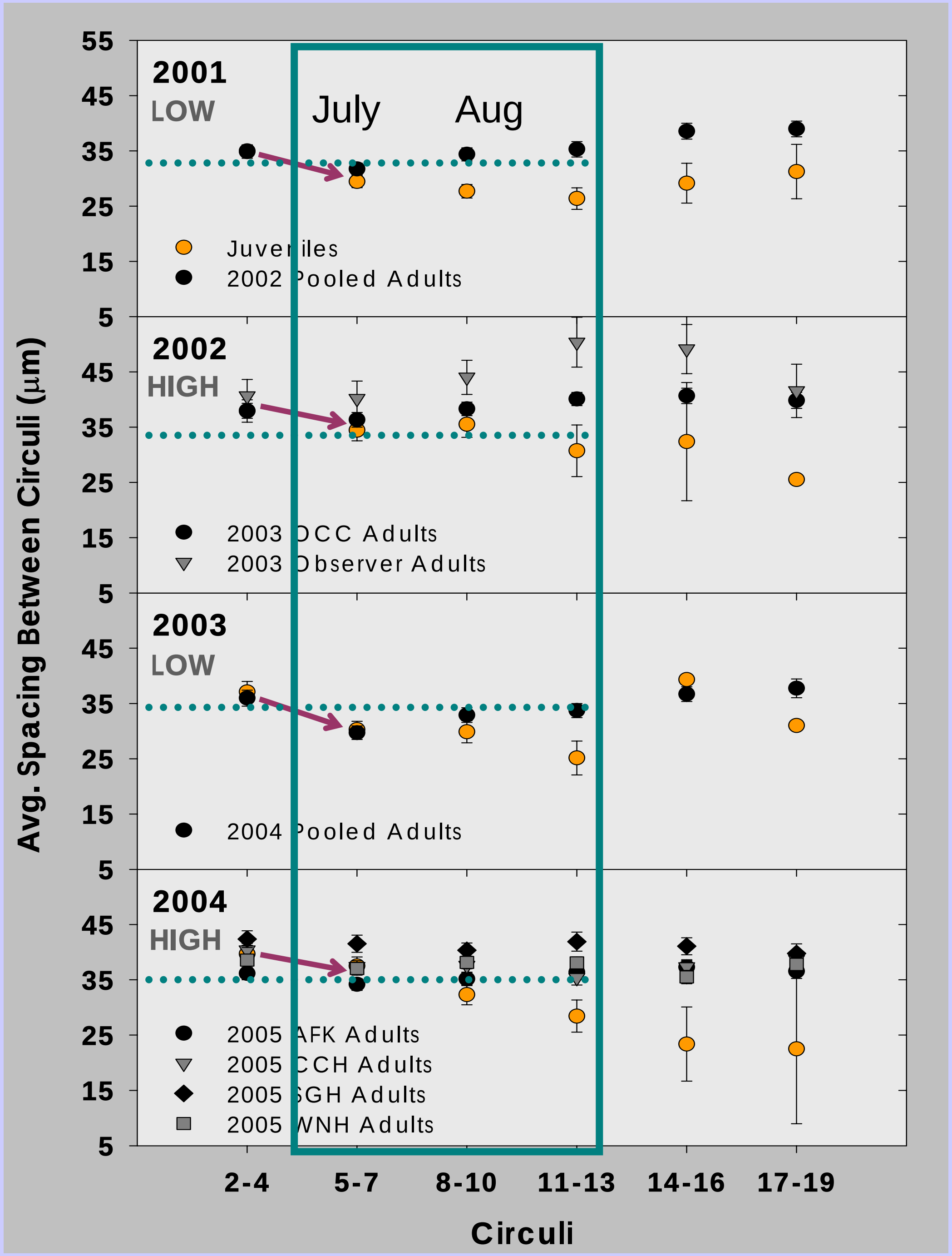
Growth declined from late June to early July

Survivors grew faster than average juveniles.

Growth of survivors diverged from avg. juveniles during July-Aug

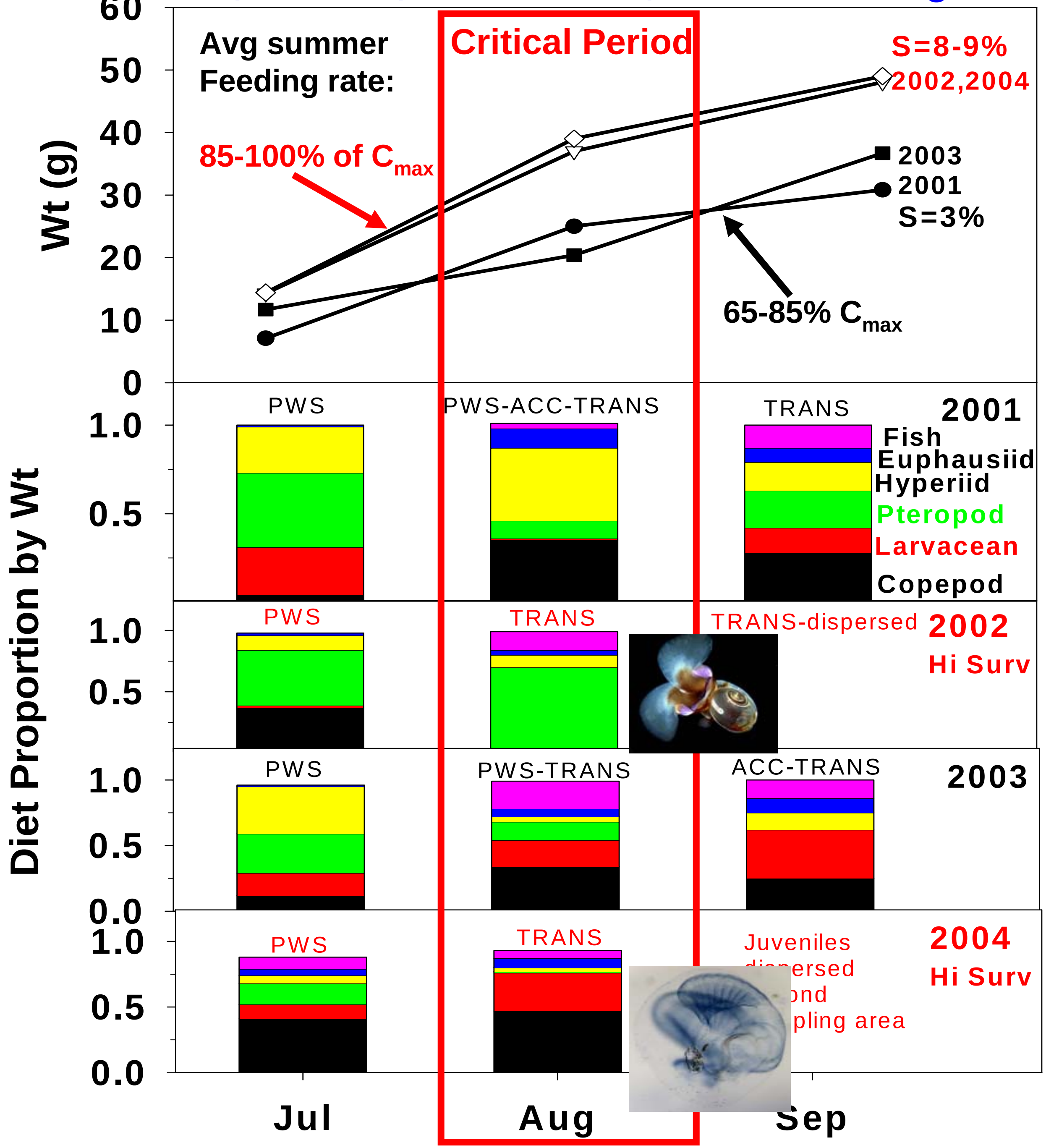
Growth was faster through August during high-survival years

August = “Critical period?”
(e.g., Beamish & Mahnken 2001)



Source: Alison Cross

Survival, Growth, Distribution, Diet & Feeding Rate



GROWTH:
Larger juveniles =
Higher survival

DISTRIBUTION:
Higher survival =
Earlier, wider dispersal
during Aug-Sep

DIET:
Diet highly variable
among months &
Years.
Non-Crustaceans
Important.

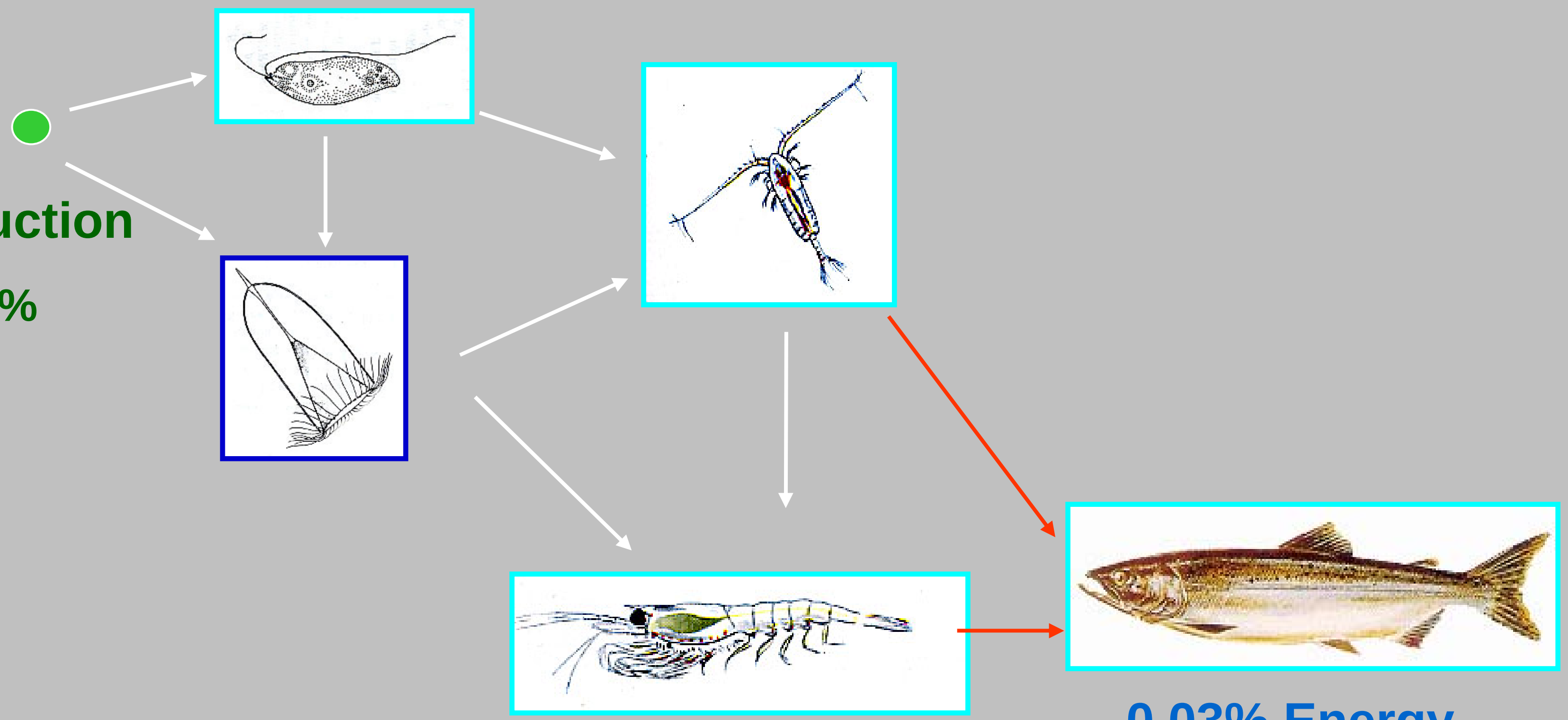
FEEDING RATE:
Higher during
High Survival Years…

Suggests higher prey
availability

Food webs based on small phytoplankton & crustacean zooplankton are long (Summer production system)

1^{o} production

100%

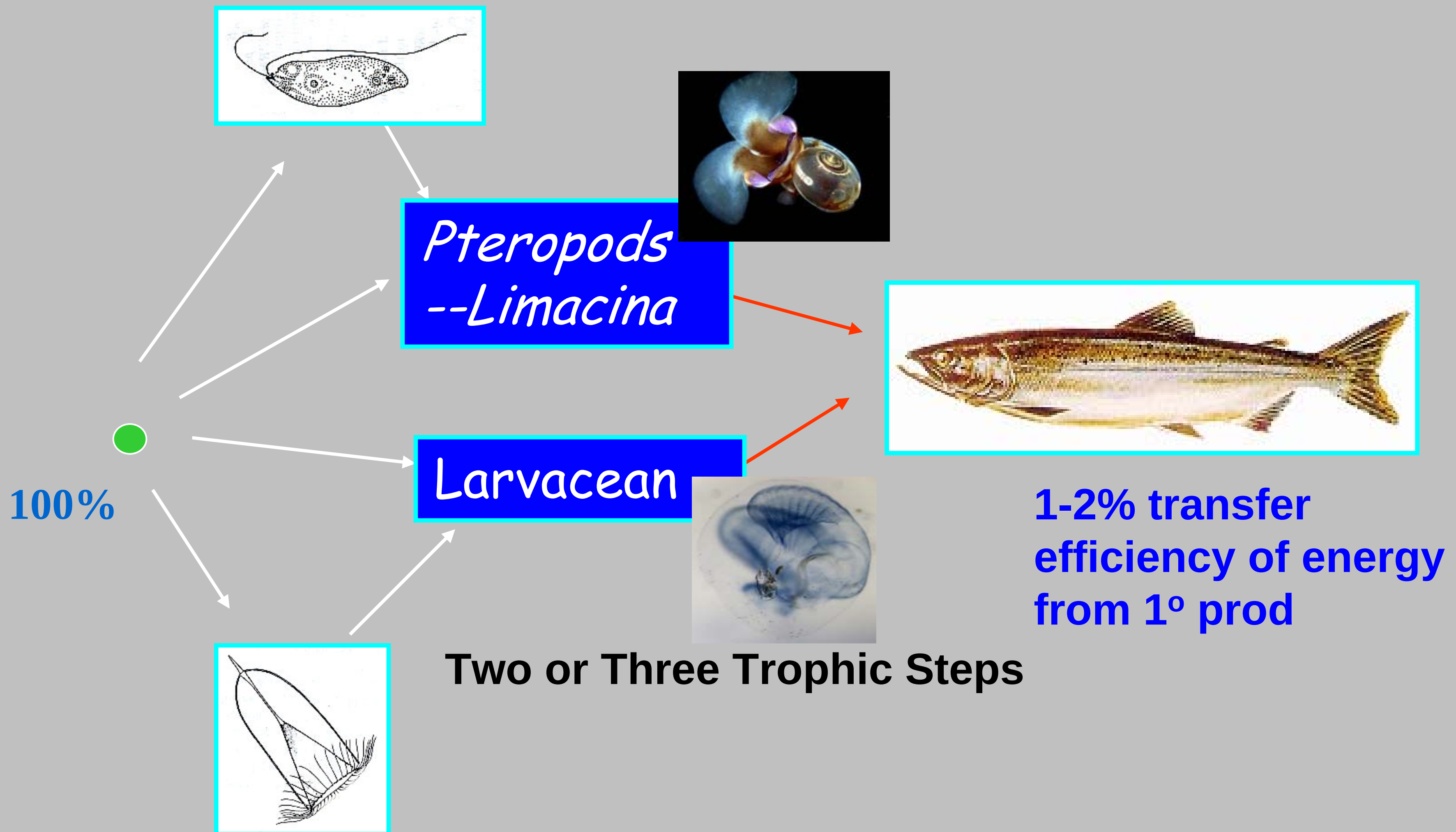


3 - 5 Trophic Steps

0.03% Energy transfer efficiency

Strom et al.

Food webs with small primary producers and cast net feeders are shortened



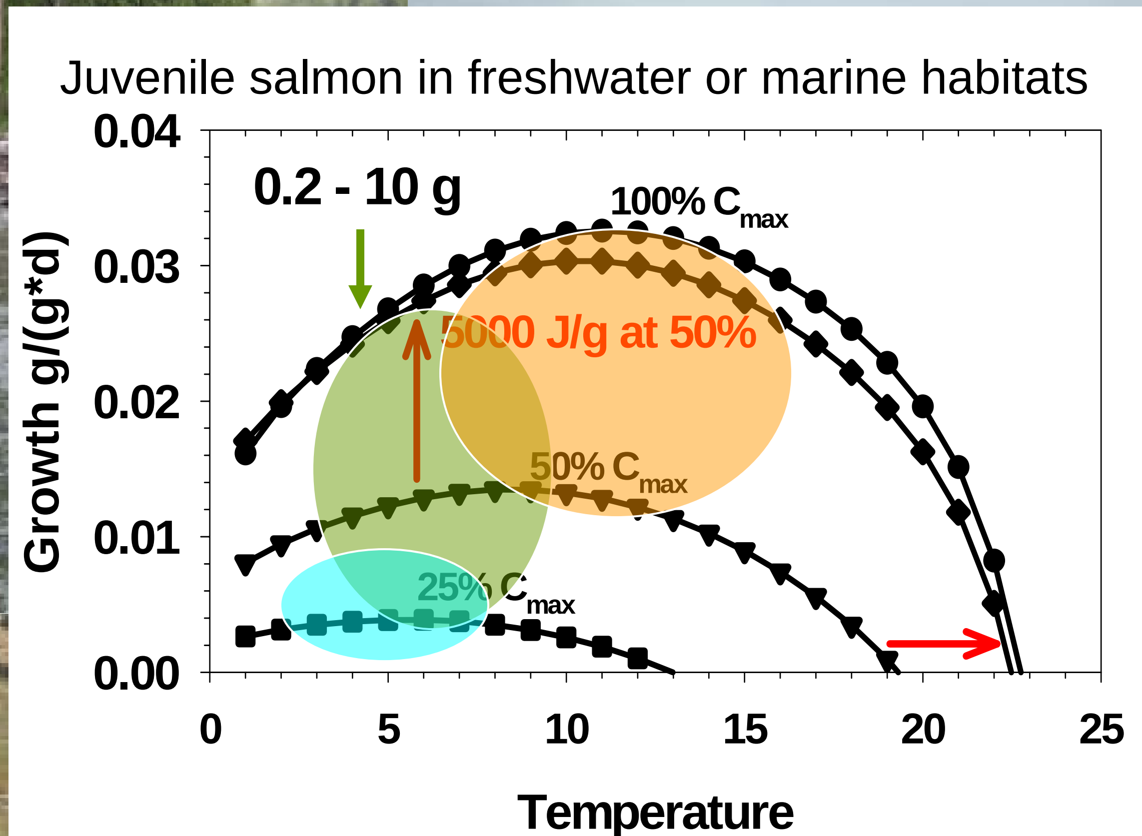
Strom et al.

Seasonal Growth Limitations:

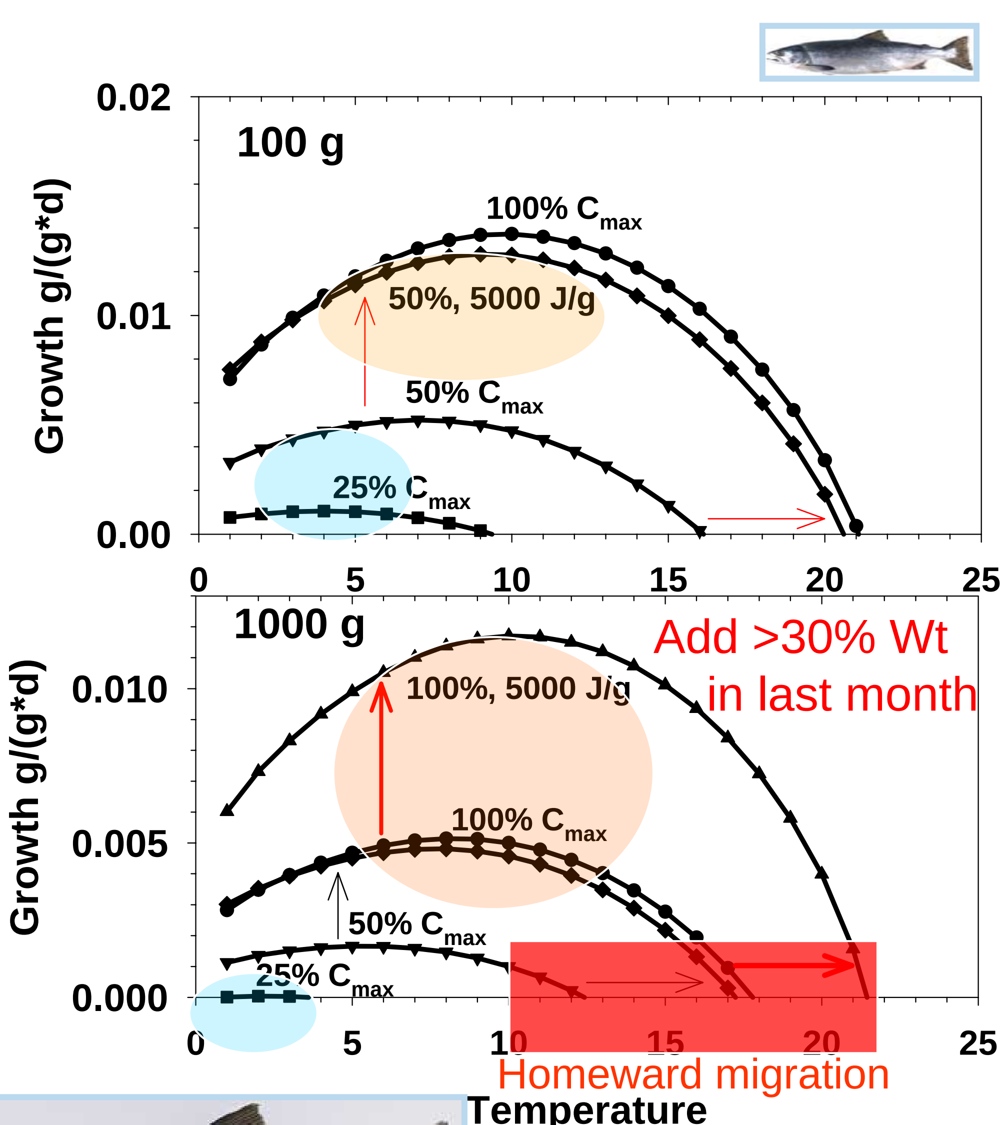
Spr-Cold, Food

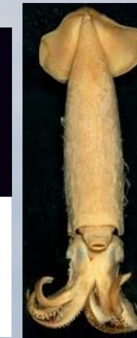
Sum-Food

Wtr-Food



Immature & Adult Salmon at Sea





3500-
7000 J/g

- High feeding rate in Summer 60-100% C_{max}
- Fast growth requires high-quality prey
- Thermal tolerance sensitive to ration & prey quality
- Low ration = Low thermal limits for adults

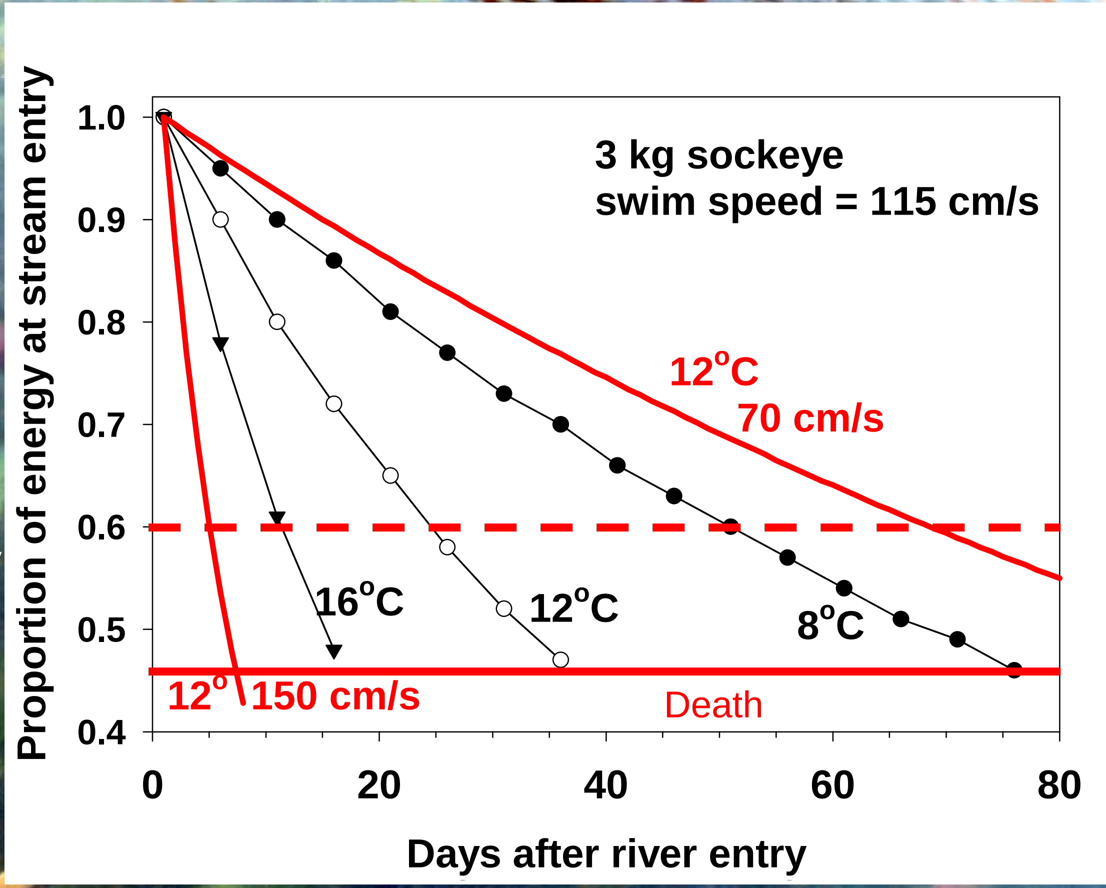
2800 J/g

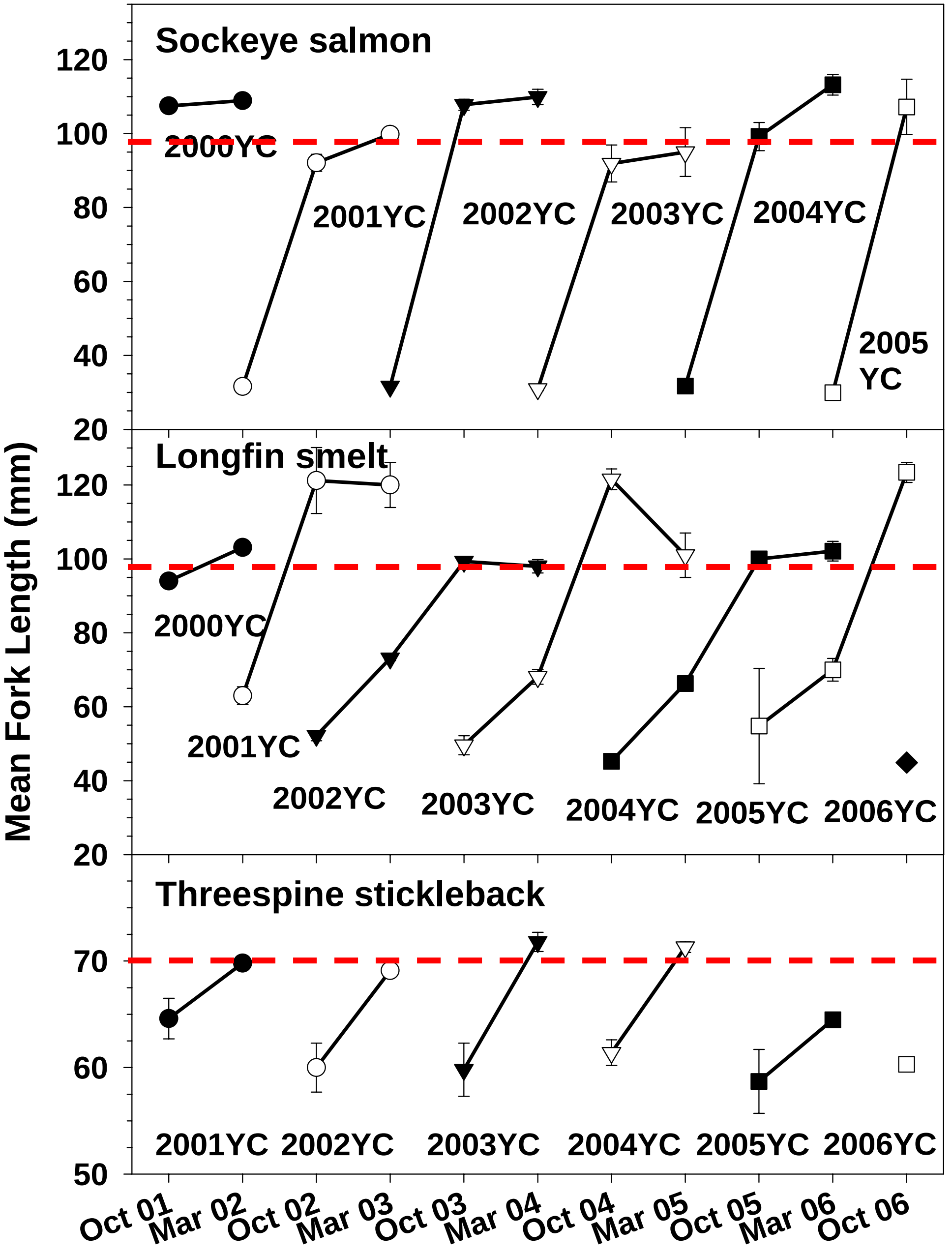
Spawning Migration: Energy Depletion & Survival

River Entry- No Feeding
Metabolic losses continue:
Temperature & Activity

Remaining Energy Needed
On Spawning Grounds
60% at Arrival
-15% Gonad + Activity

Death:
Energy depleted down to
45% Energy at River Entry





Sockeye salmon
Longfin smelt
Threespine stickleback
Mean Fork Length (mm)
120
100
80
60
40
20
70
60
50
2000YC
2001YC
2002YC
2003YC
2004YC
2005
YC
2005YC
2006YC
Oct 01
Mar 02
Oct 02
Mar 03
Oct 03
Mar 04
Oct 04
Mar 05
Oct 05
Mar 06
Oct 06