Ontogenetic Shifts in Trophic Roles & Consumption by Chinook Salmon & Pacific Herring in Puget Sound

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USGS science for a changing world

SALISH SEA MARINE SURVIVAL PROJECT
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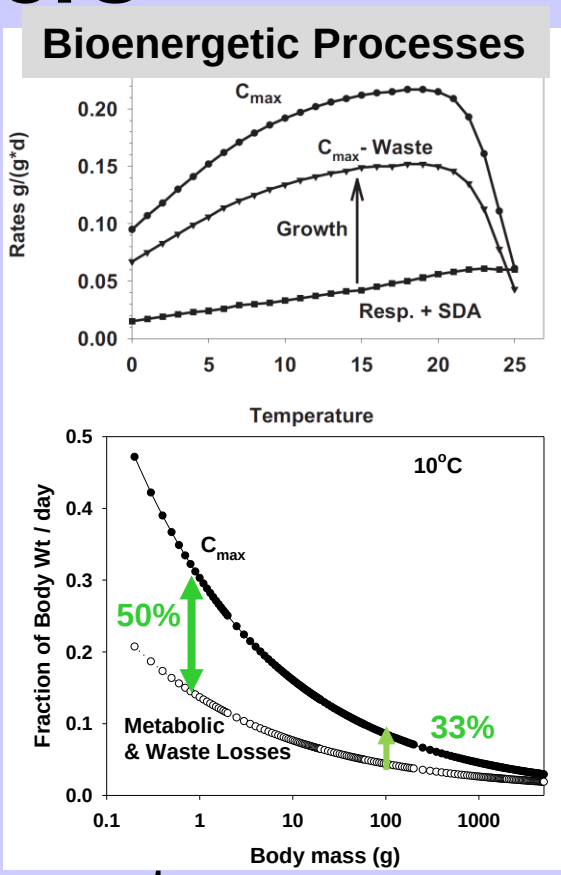
Photo credit: Anne Shaffer, Coastal Watershed Institute

Characteristics of Fish as Consumers

- **Ectotherms--** Temperature affects all rates:
  - Consumption, Metabolism & Growth rates
  - Spatial-temporal distribution (Temp optima & tolerance)
  - Overlap among prey, predators & competitors
- **Indeterminant Growth:**
  - >10x size@age range reflect env. & feeding history
  - Allometric influences on growth & feeding ontogeny
- **Gape-limited Feeding:** Size-selective predation impacts
- **Mobile & Feed visually in pelagic habitats**
  - Light & Turbidity effects, Prey Size-Contrast affect encounters



Bioenergetics Model Applications

Diagnose Growth Limits, Quantify Predation, Competition

Inputs from Sampling-Literature:

Diet proportions by Wt thru time

Growth: $W_0 \rightarrow W_t$

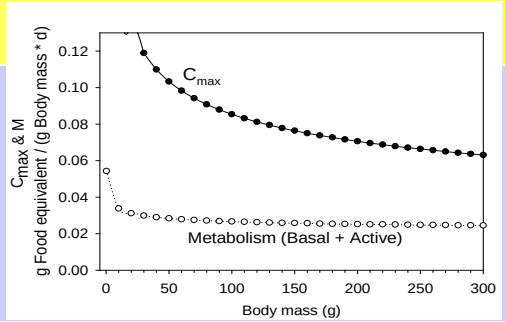
Predator Energy Density (J/g)

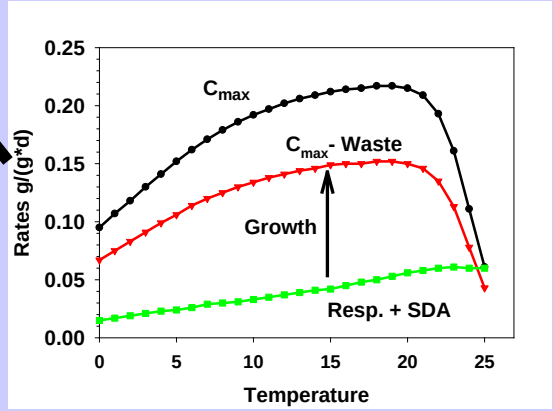
Thermal Experience thru time

Prey Energy Density (J/g)

Bioenergetics Model

$$C = M + W + G$$





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

or

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

1-Daily Consumption g/d by prey group

2-Feeding Rate %Cmax

Daily time step

Simulation day 0 → day t

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- **ESA-listed Puget Sound Chinook declined precipitously in 1980s without recovery**
  - **Decline paralleled reduced marine survival**
  - **Size-selective mortality strongly affect adult returns**
    - **What factors affect size, growth & survival?**
  - **30% of subyearling Chinook adopt a Resident life history strategy**
- **Pacific Herring are a keystone planktivore & forage fish**
  - **Largest & latest spawning population at Cherry Pt. declined 90%, whereas other spawning populations highly variable**
  - **Little known about their trophic role in Puget Sound:**
    - **Prey? Competitor? Mechanistic links to other spp in food web?**

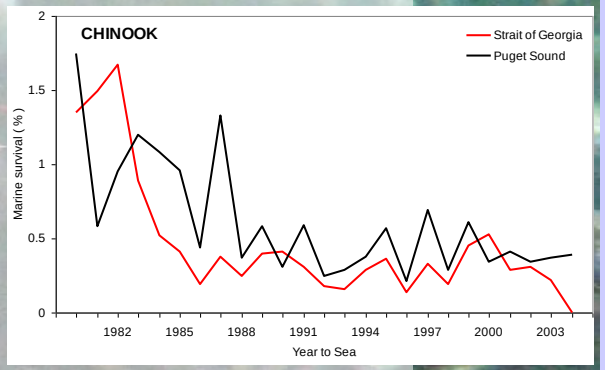


Photo credit: Anne Shaffer, Coastal Watershed Institute

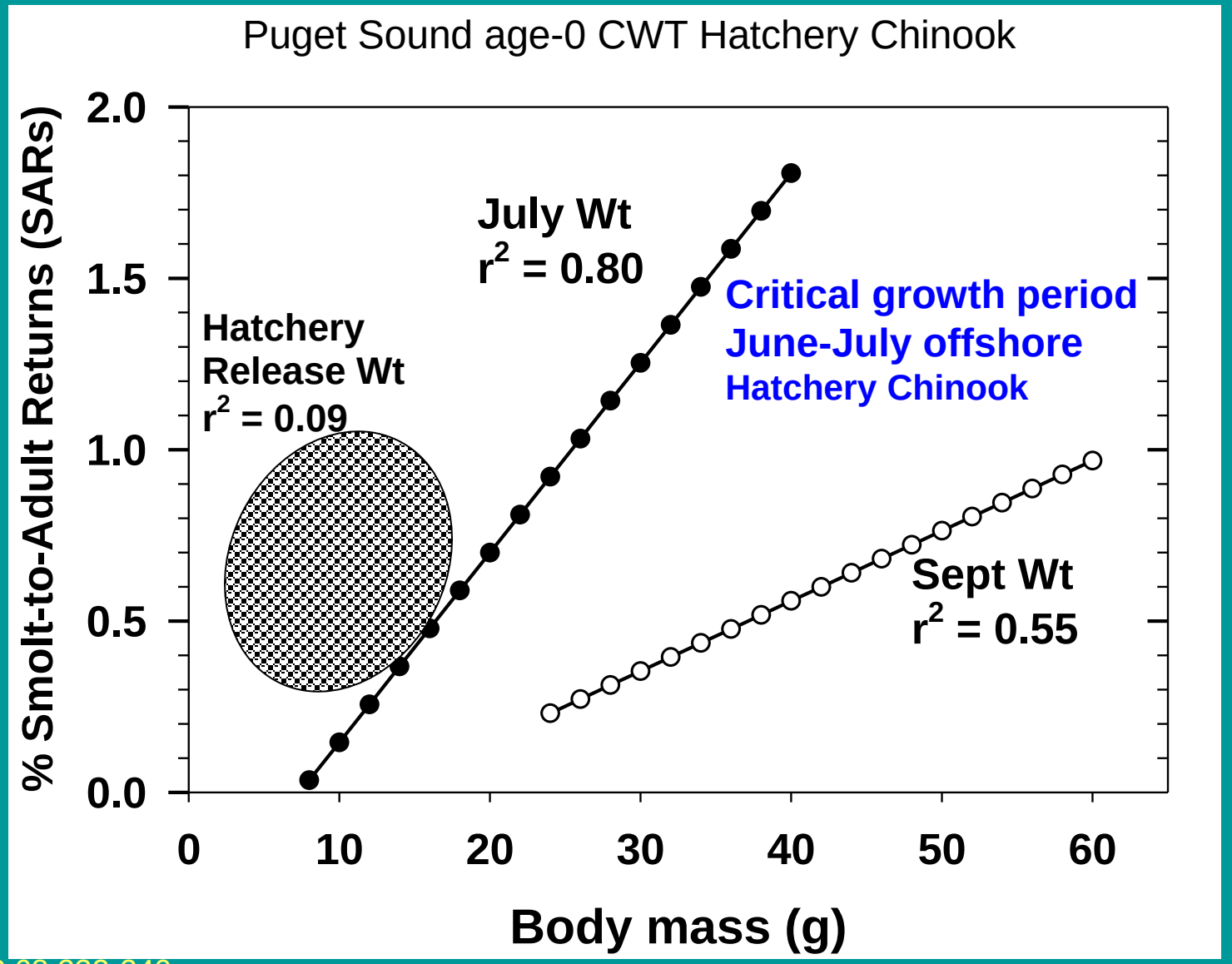
Chinook:
Marine Survival Linked to Size achieved during Critical Growth Period

Size at release & Marine entry NOT Correlated to Survival

Marine survival Strongly linked to Wt <u>after 1 month</u> <u>Epi-pelagic feeding</u> In Puget Sound through July

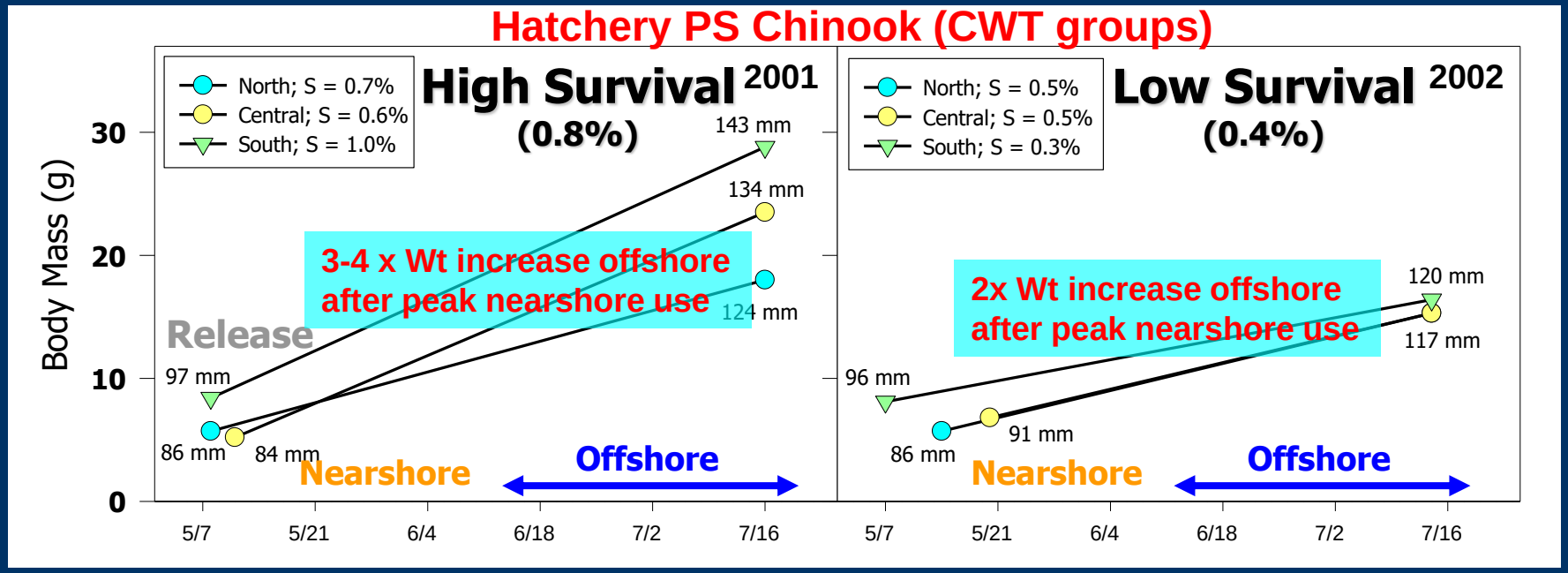
2-4 fold Wt gain during 1º <u>pelagic</u> feeding

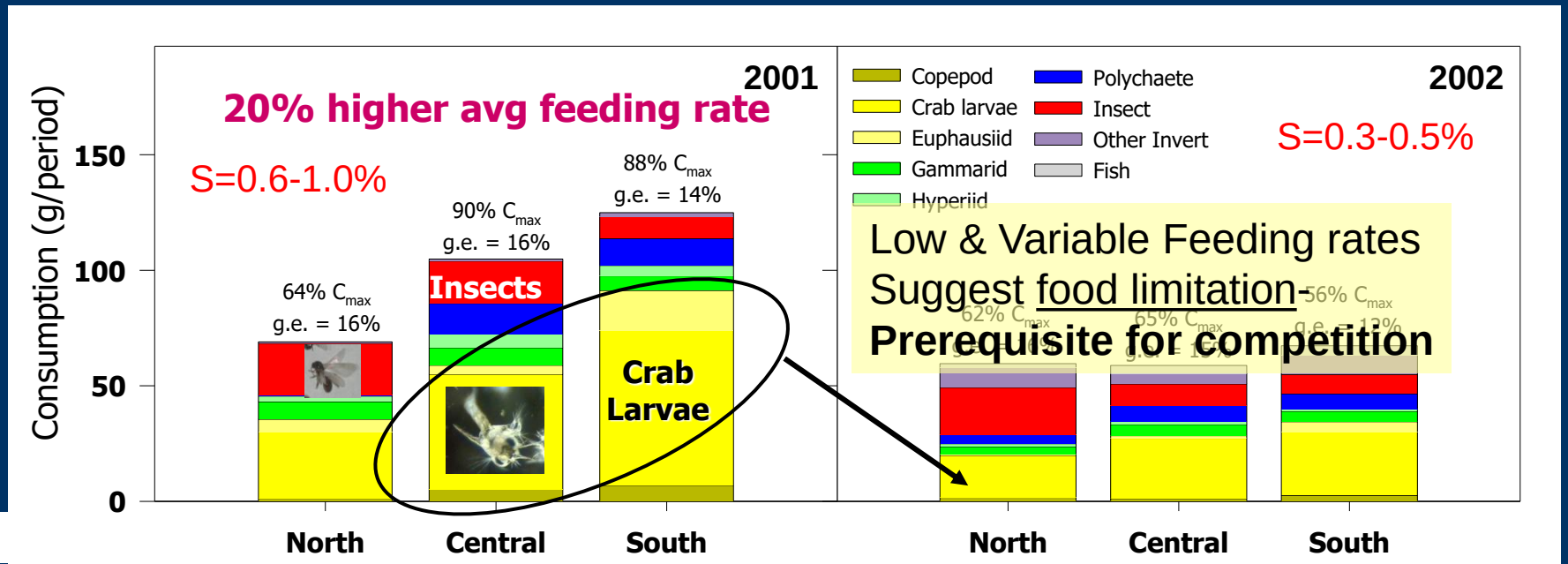
Weaker pattern In Sept.



Duffy & Beauchamp 2011 CJFAS 68:232-240

Higher Feeding Rate = Higher Growth & Survival





Duffy 2009 Dissertation

Juvenile Chinook:
Food Supply & Temperature Impacts on Growth more extreme in Shoreline than Openwater habitats in Puget Sound

Shoreline Feeding ~week(s)

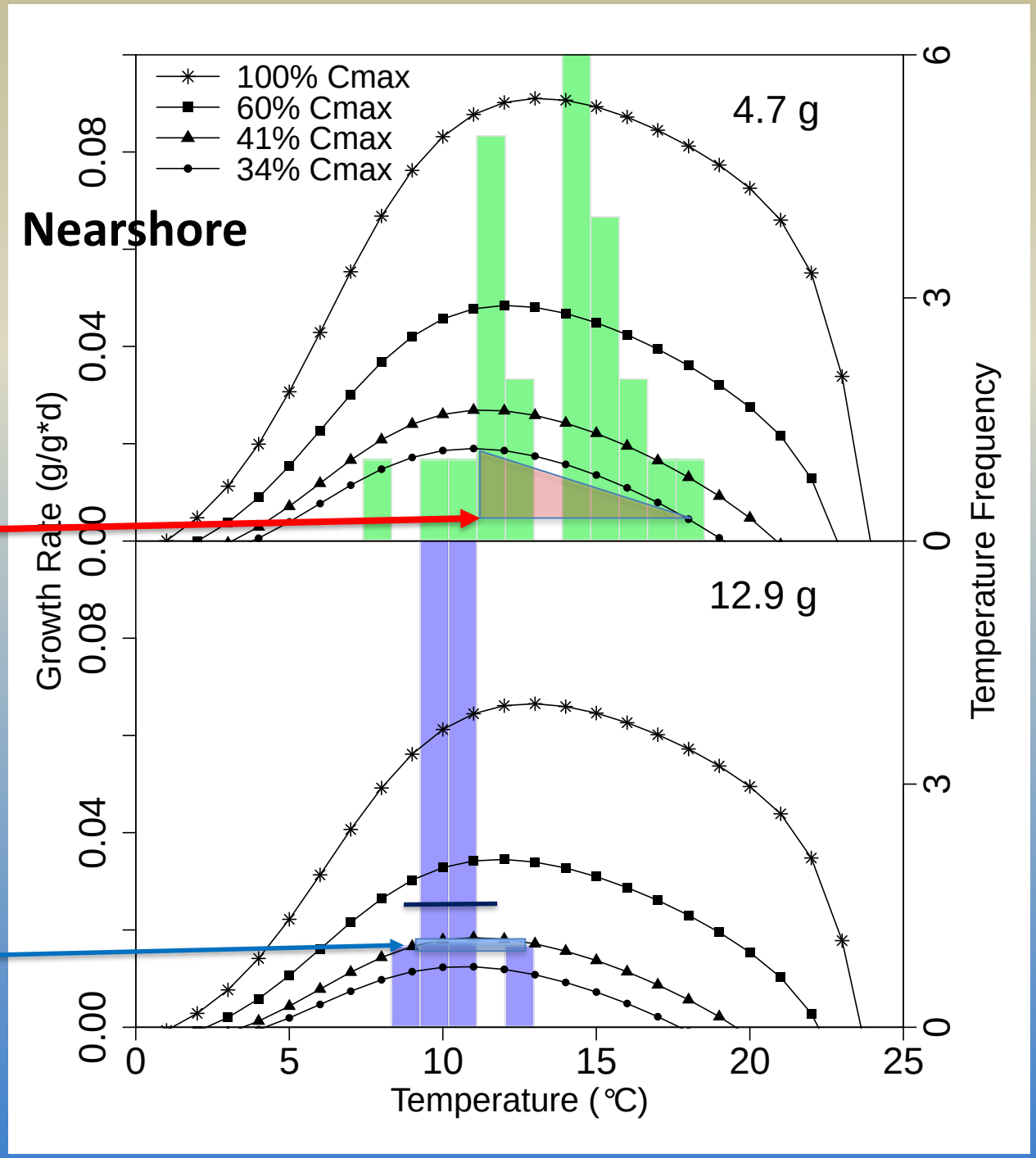
-Low feeding rate ~35% Cmax

-Warmer temperatures can Reduce growth rates by 60%

Epi-Pelagic Feeding ~ months in Puget Sound)

-Higher feeding rate ~50% Cmax

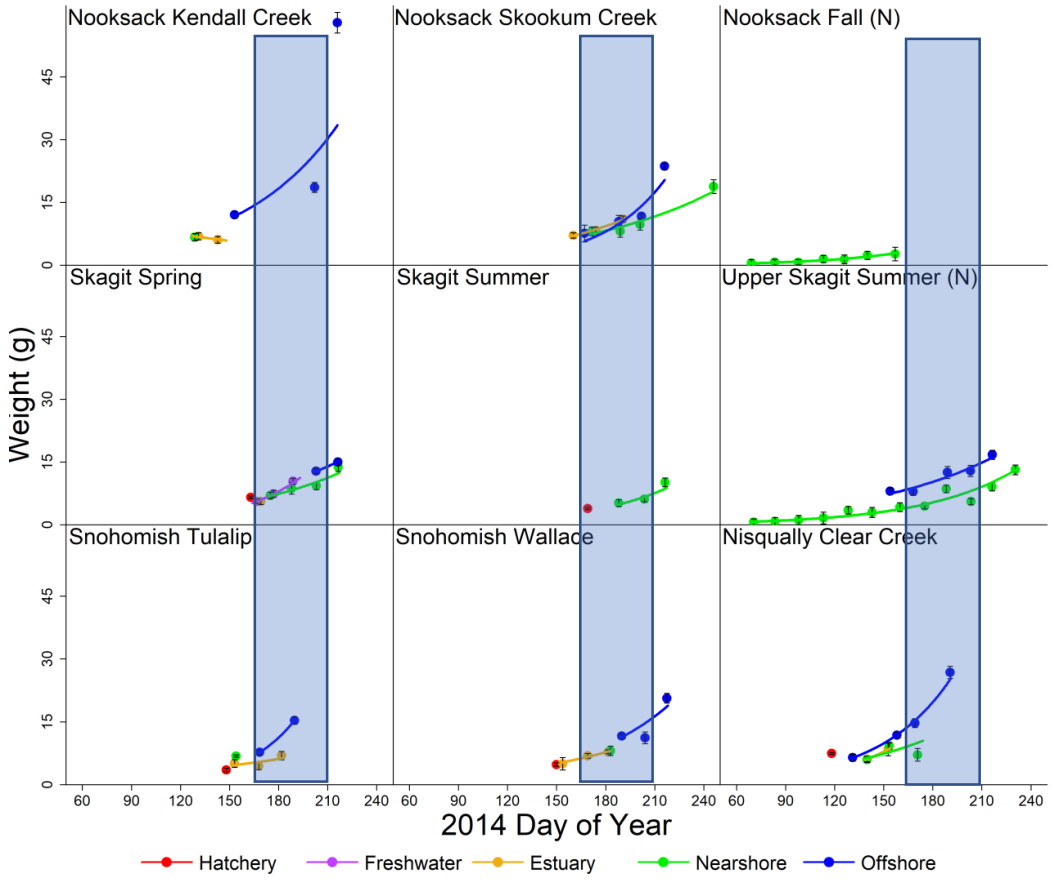
-Openwater temperatures are near Optimum for growth. Minimal effect of Temperature on growth: <10%

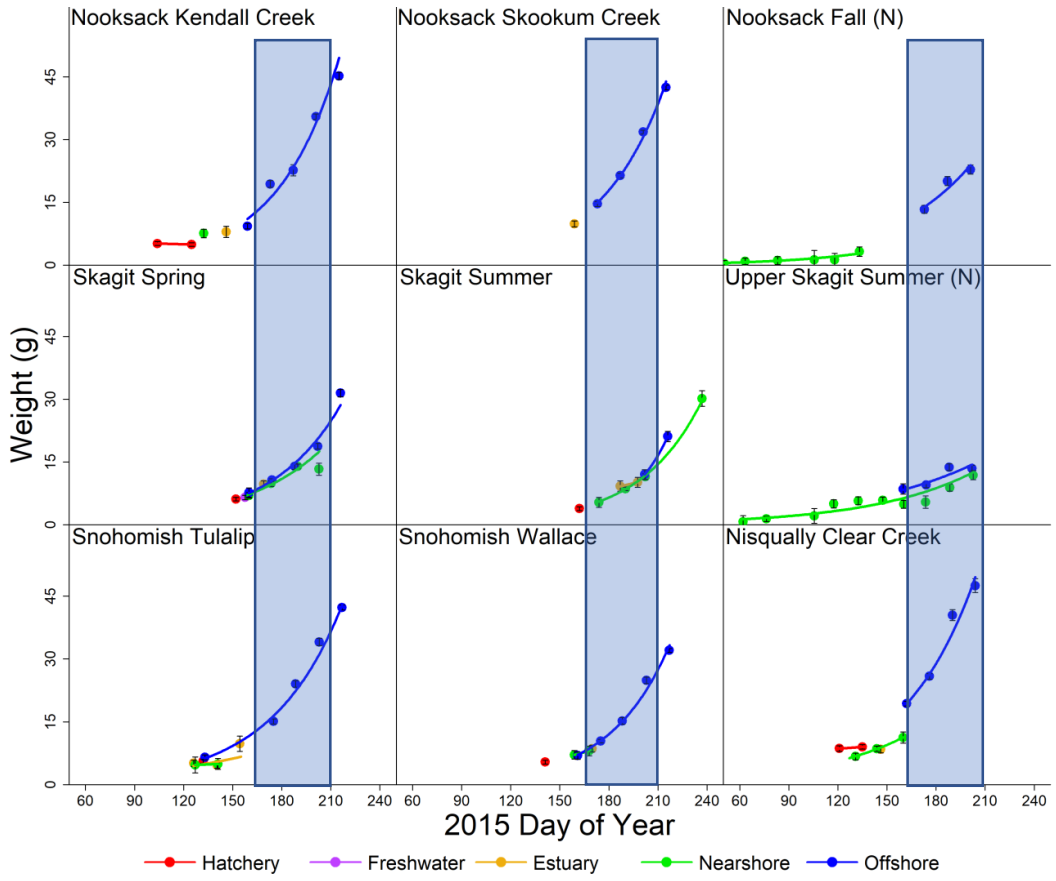


Madi Gamble 2016 MS Thesis

Juvenile Chinook Salmon
Critical Growth Period Associated with Epi-Pelagic Feeding During June-July

-Different growth performance among years & regions tracked for known-origin Hatchery & Wild stocks





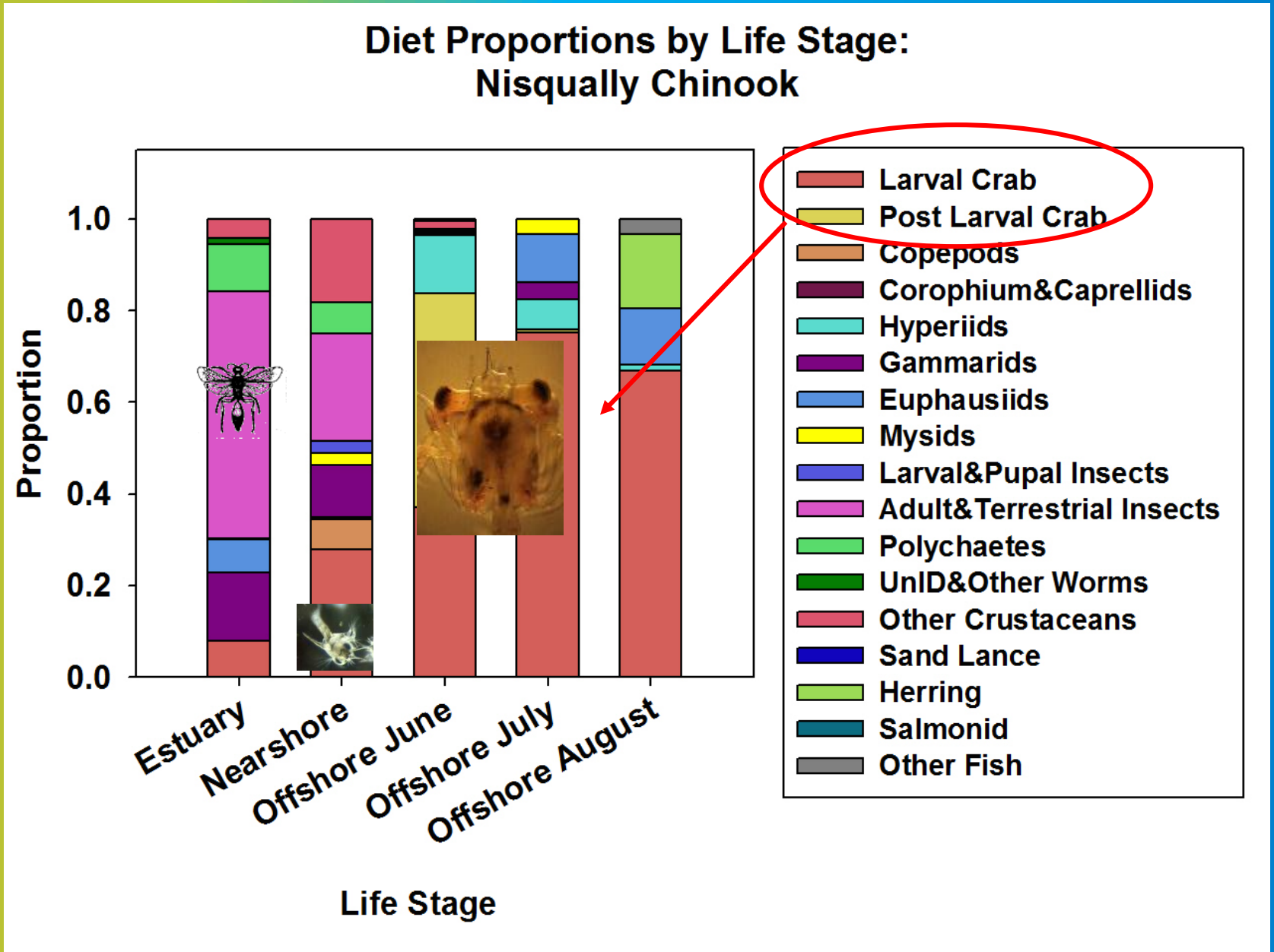
= Mid-June through July "Critical Growth Period"

Gamble et al. 2018 TAFS

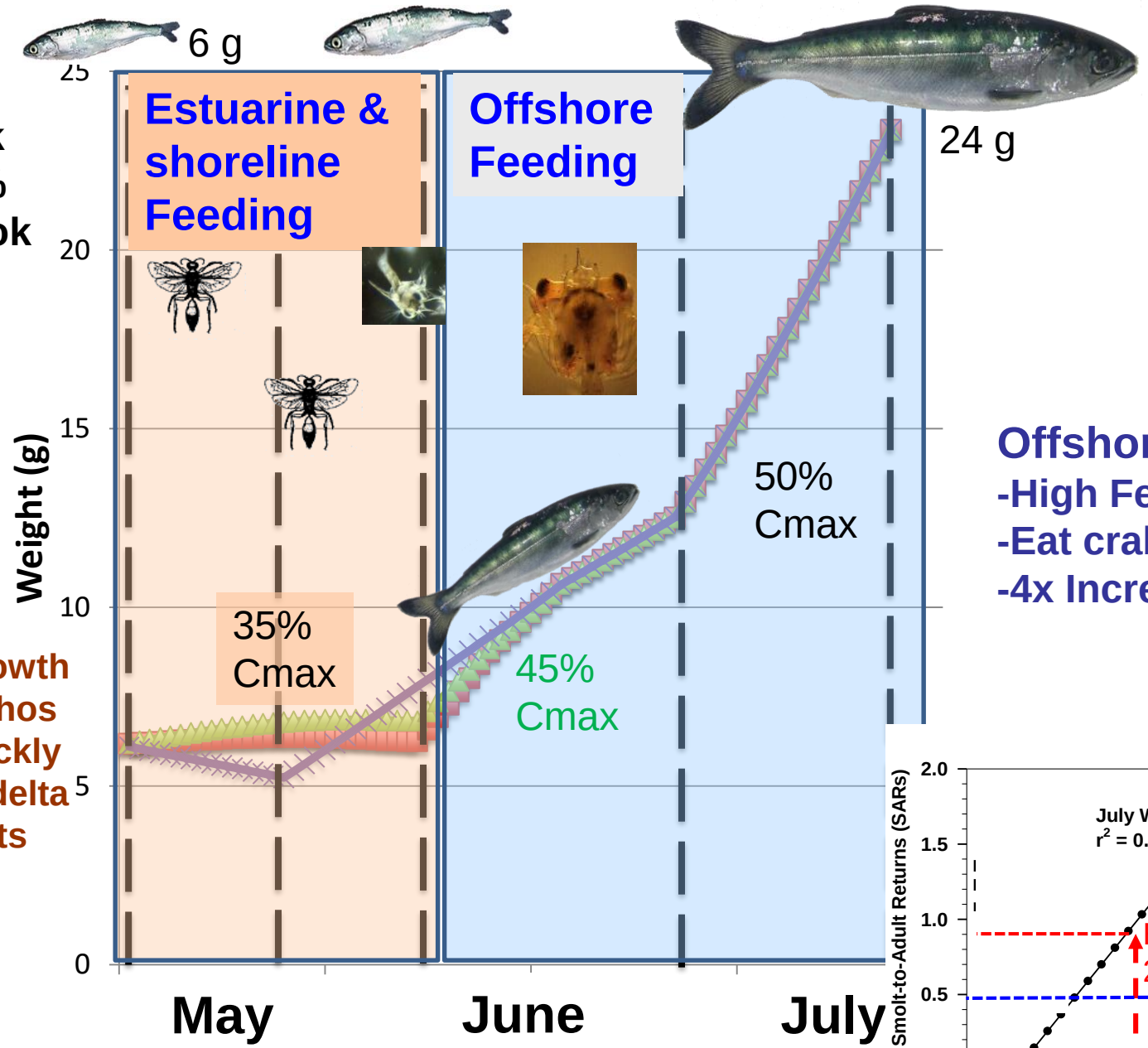
Diet Shift from Insects to Larval Crabs

Insects important in estuarine delta feeding

Larval crab more Important Offshore Feeding

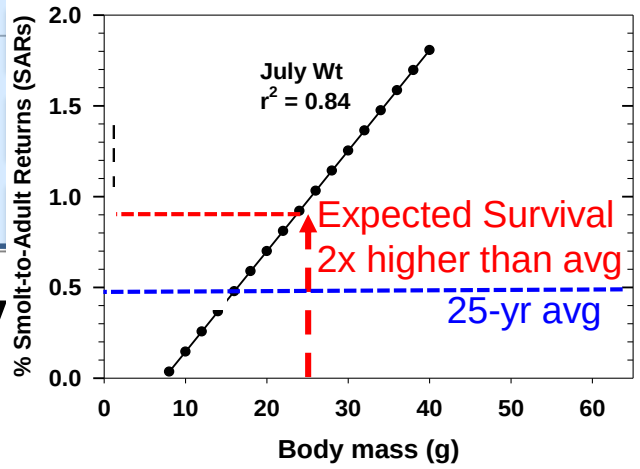


Hatchery Chinook Represent 80-90% of juvenile Chinook in Puget Sound



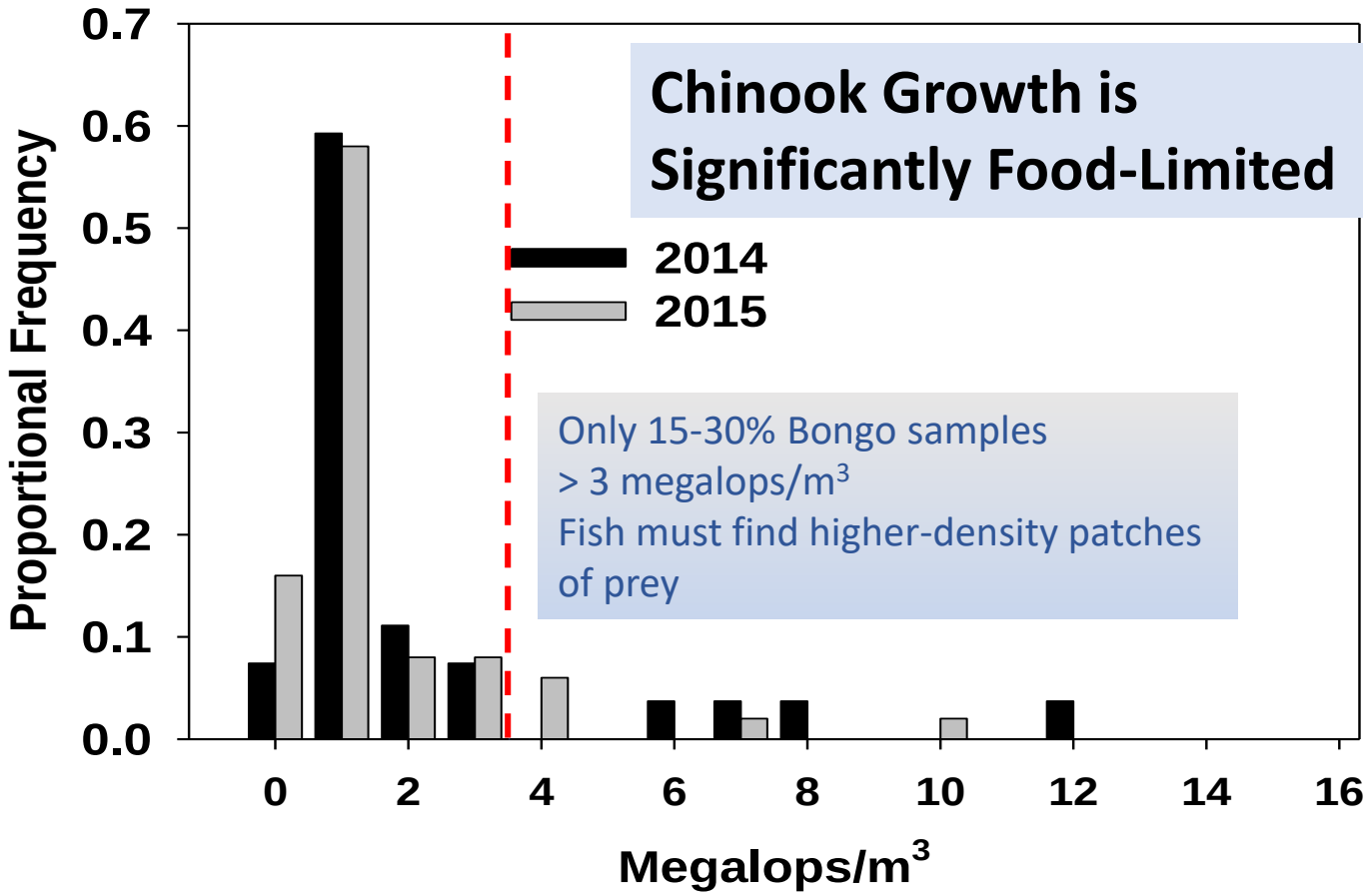
Nearshore:
-Low Feeding & Growth
-Eat Insects & Benthos
-Pass relatively quickly through Estuarine delta & Nearshore habitats

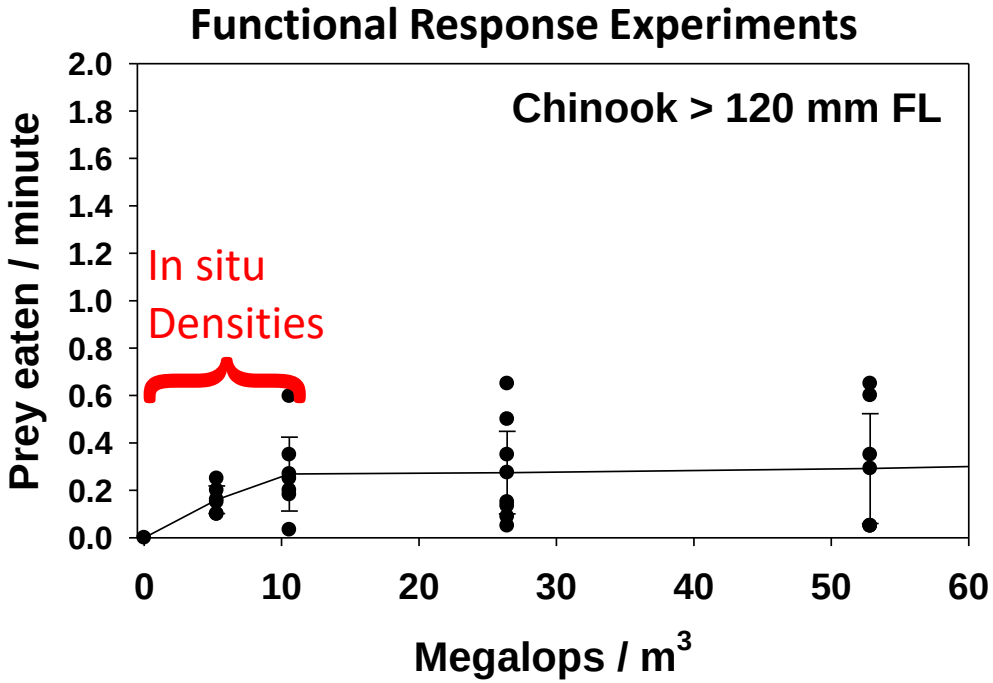
Offshore (epi-pelagic):
-High Feeding & Growth
-Eat crab larvae
-4x Increase in Mass

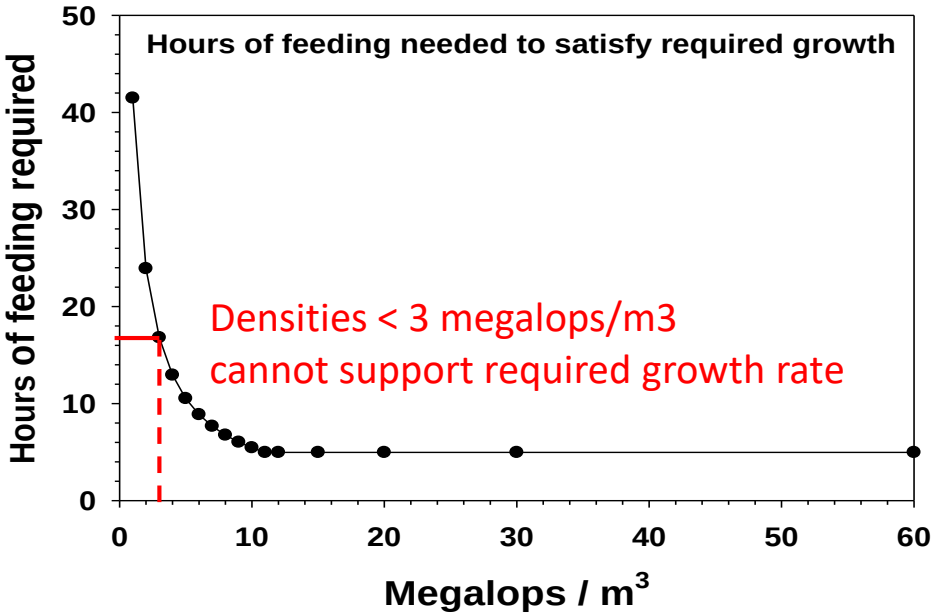


Juvenile Chinook Foraging on Larval Crab

-Chinook transition offshore in early-mid June
-Larval crab fuels critical growth period (June-July offshore)
-1º feed on Red Rock Crab Megalops & some Z5 zoea
-Prey field assessed via oblique Bongo tows 0-30m
60-cm diameter, 335-µm mesh, daylight samples







Herring as a Competitor with Salmon

Overlap in Time & Space?

Diet Overlap?

Relative consumption demand for key prey?

Demonstrated Food limits to growth & survival for subyearling Chinook salmon

Potential Pelagic Competitors During Critical Period:

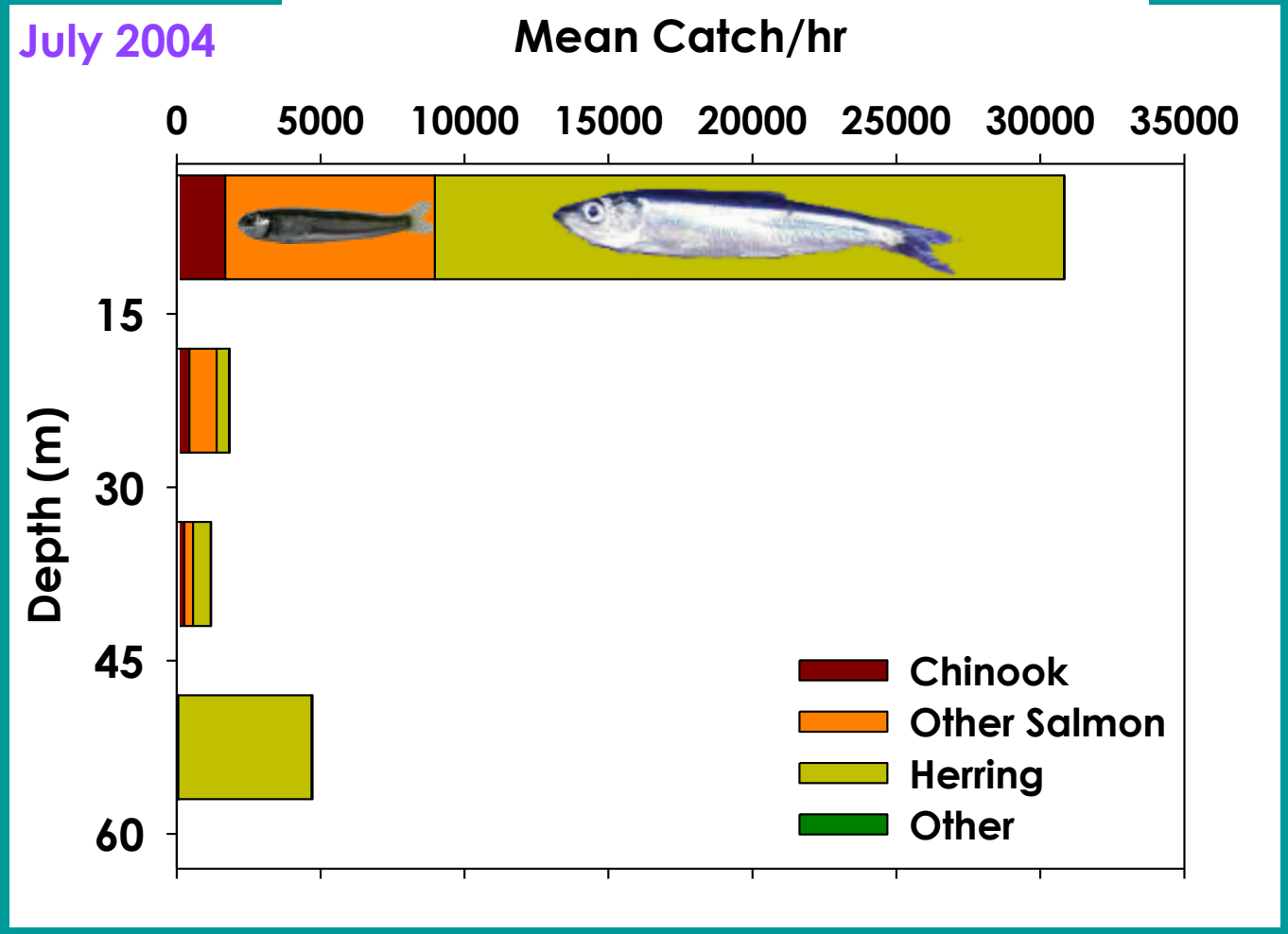
Biomass & Spatial Temporal Overlap

Pacific Herring dominate the biomass of epi-pelagic planktivores

Shallow: 0-15 m

Herring: smaller aggregations at greater depth (scattering layer)

Daylight Planktivore Community



DFO Canada
Midwater trawl

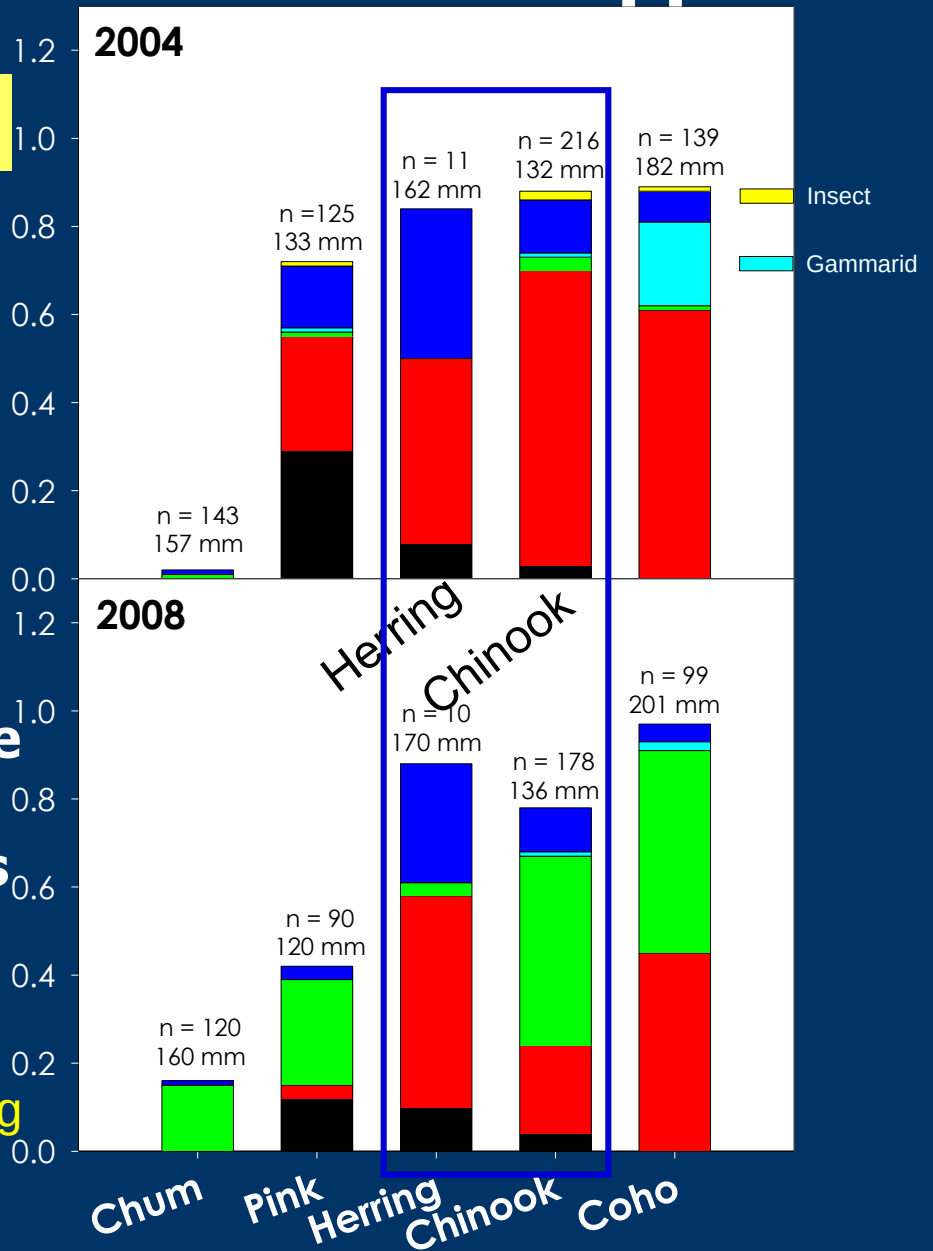
Strong Diet Overlap during Critical Growth Period Among juvenile Salmon spp. and Herring

JULY

Key Prey Overlap:
- **Crab Larvae**
- **Hyperiids**
- **Euphausiids**

Key Prey & degree of Diet overlap Vary among years

Chum Salmon show Least overlap with Other salmon & herring



Hyperiid

Crab Larvae

Copepod

Euphausiid

Estimating Population-Level Impacts

Consumer Growth

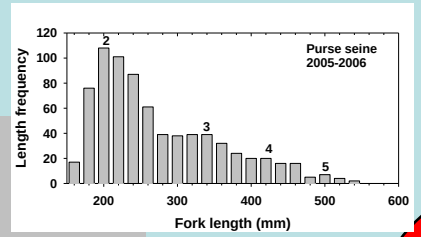
Temporal Diet Composition

Predator Energy Density

Thermal Experience

Prey Energy Density

Bioenergetics Model



Consumer Size Structure & Abundance

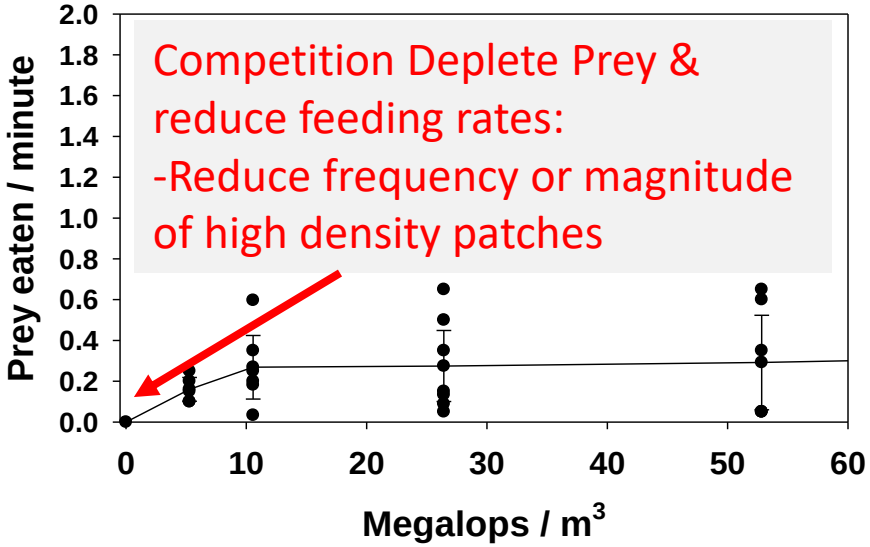
Consumption Estimate

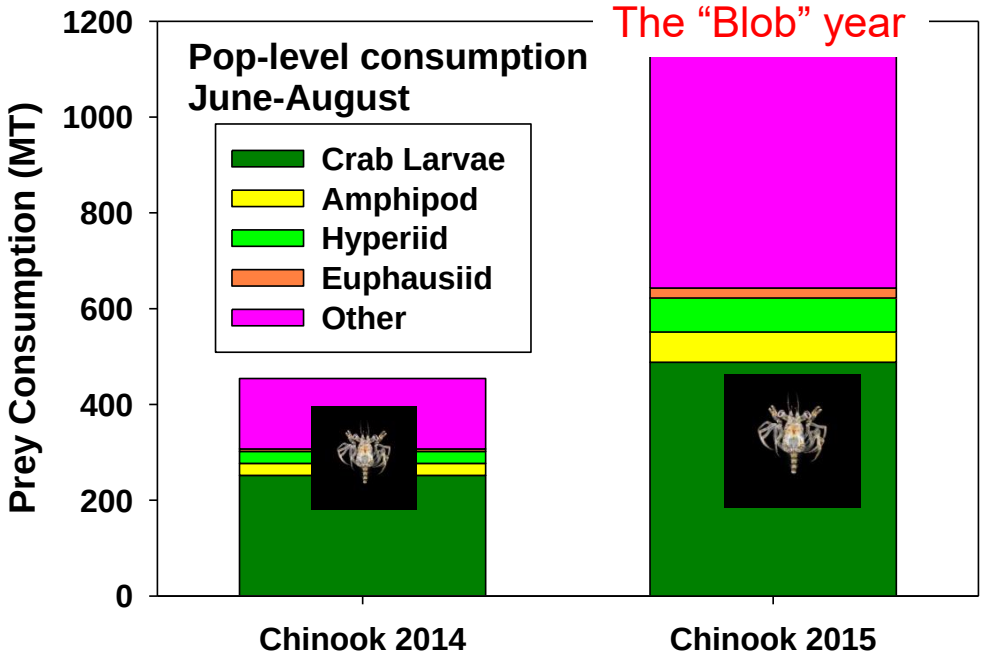
Population Consumption

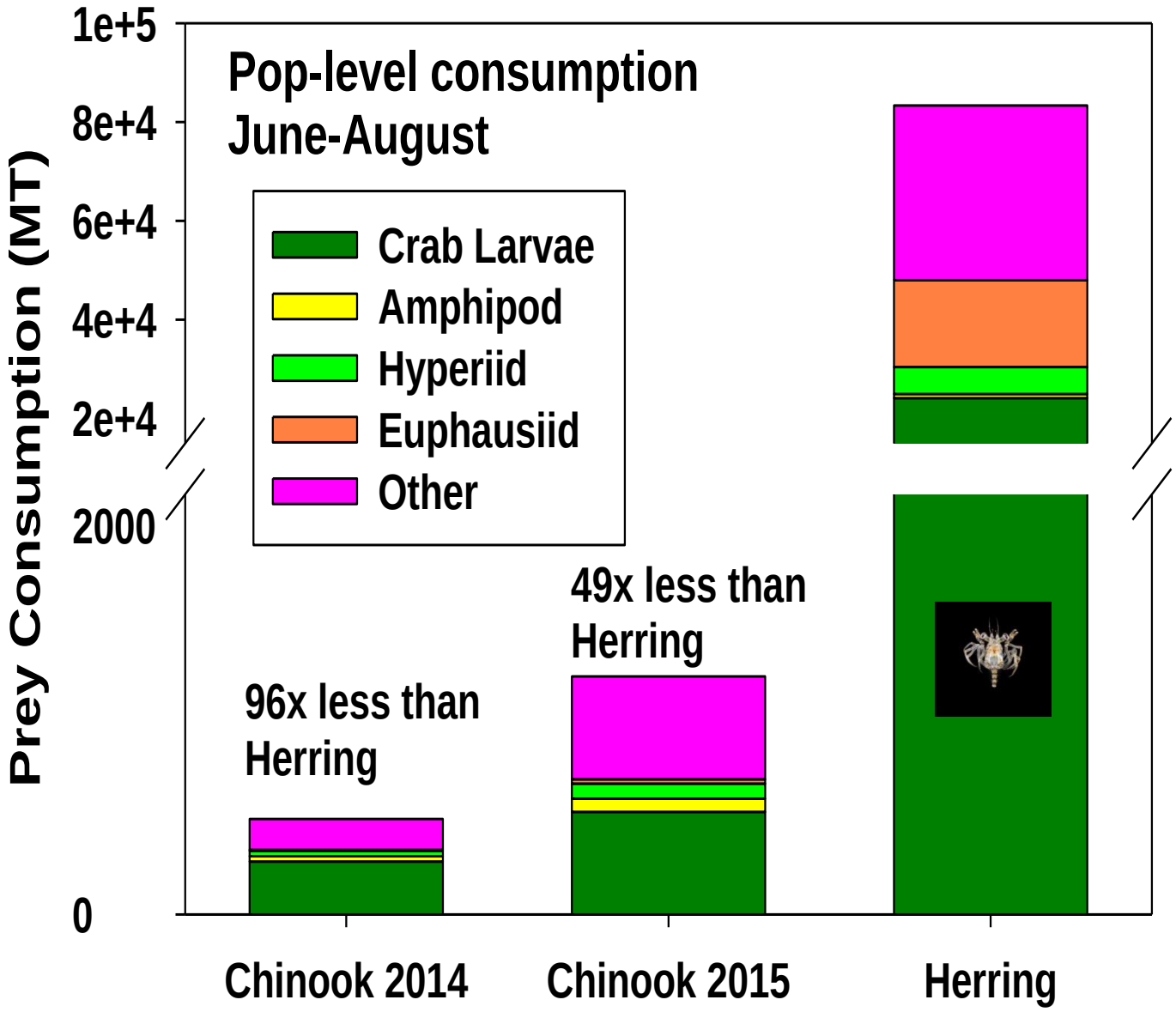
Biomass of Exploitable prey

Consumption as % of Prey Biomass or Production

Consumption by age-0 Chinook & all Herring during Critical Growth Period







Salmon Transition to Piscivory & Role as Predators

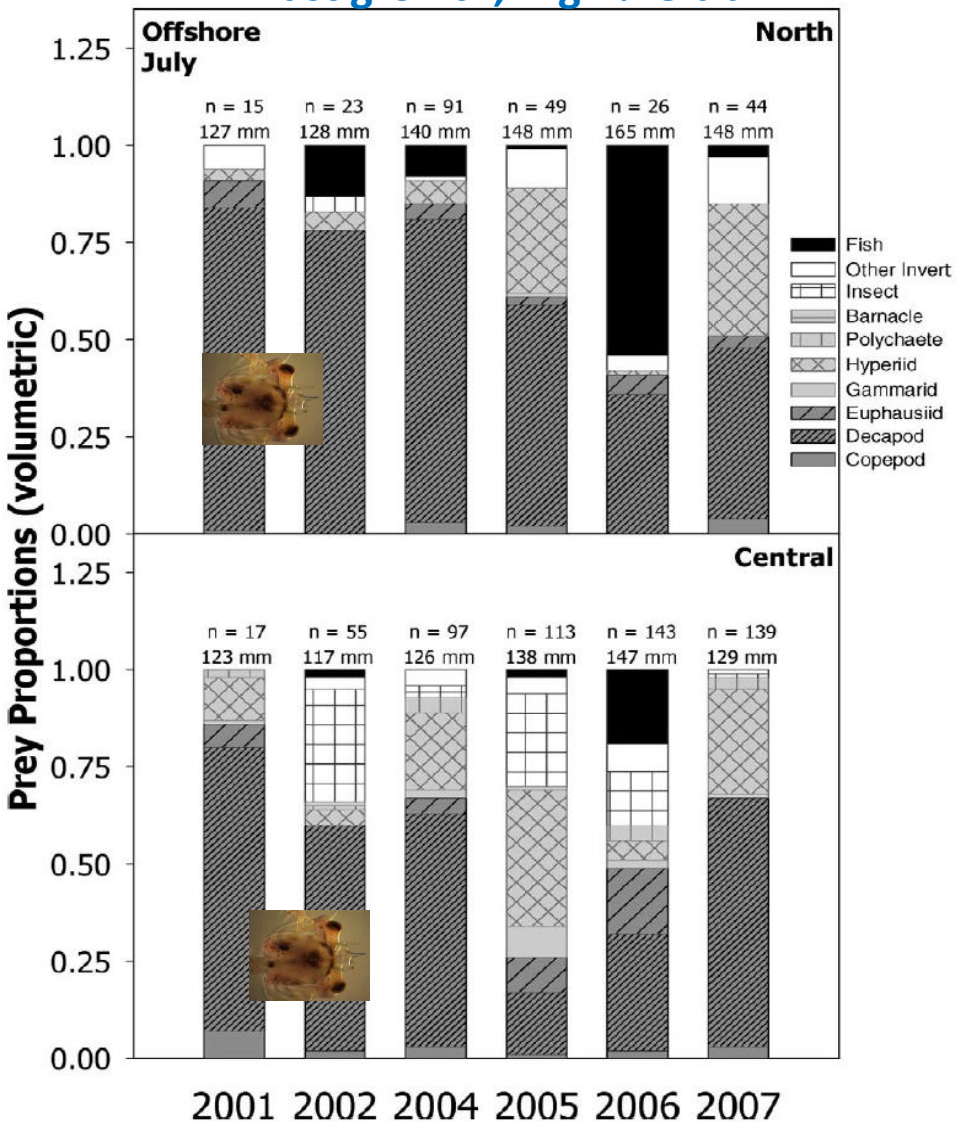
Gape limitation and influence of temporal growth and predator:prey size

Quantify Seasonal, size-based consumption demand

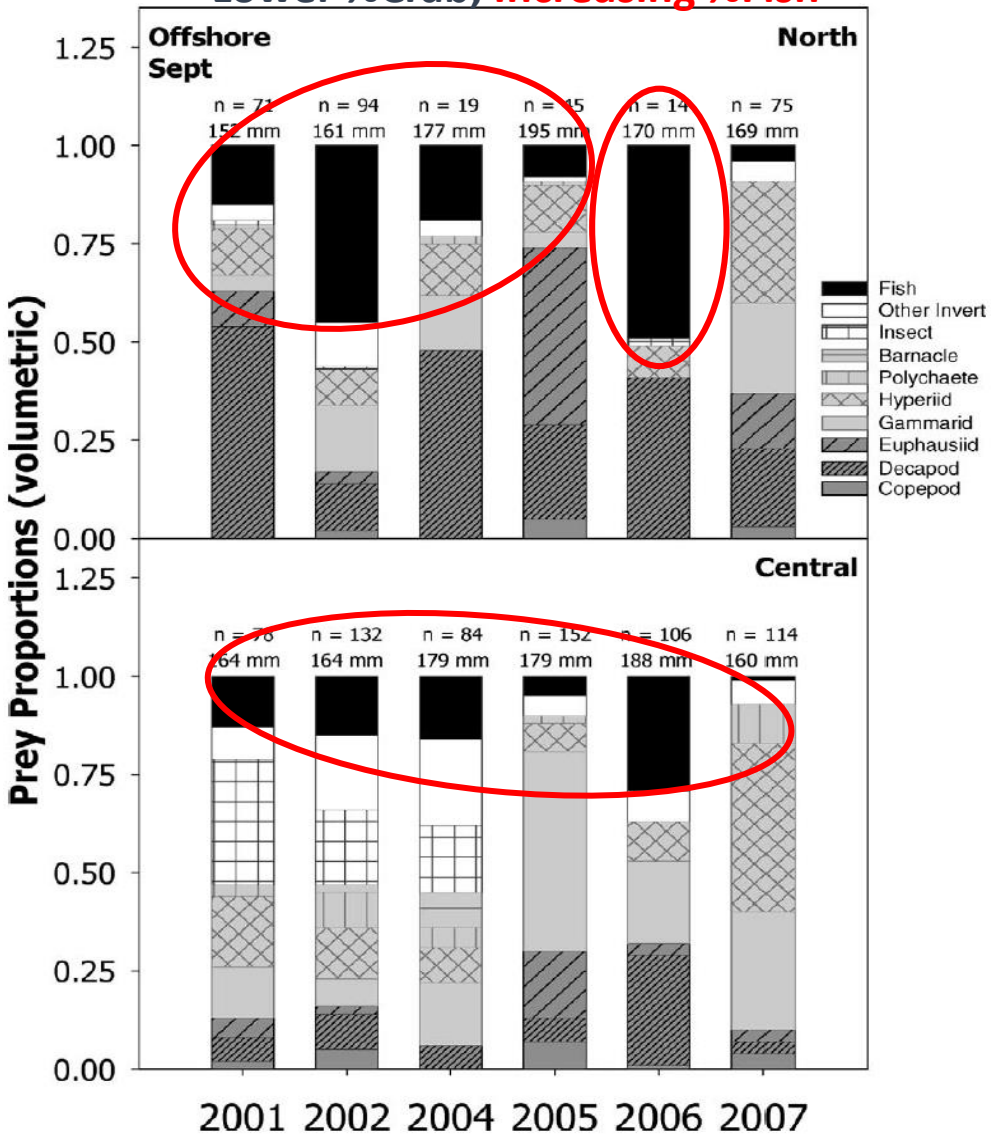
Relative predation impact on Prey Population

Seasonal Feeding Ontogeny of age-0 Chinook

July Offshore (Critical Growth Period):
Fast growth, High %Crab



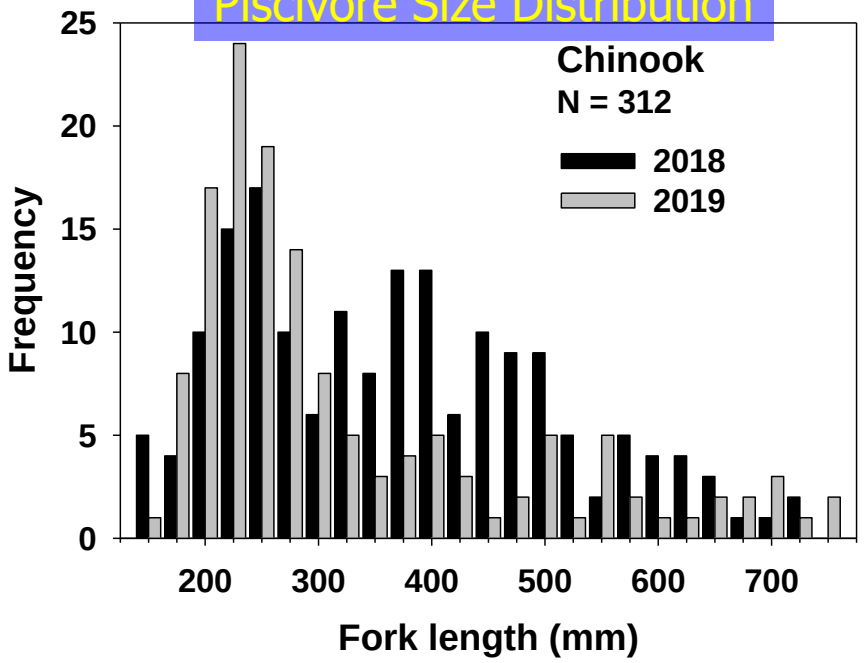
Sept Offshore (Ocean Emigration):
Lower %Crab, Increasing %Fish

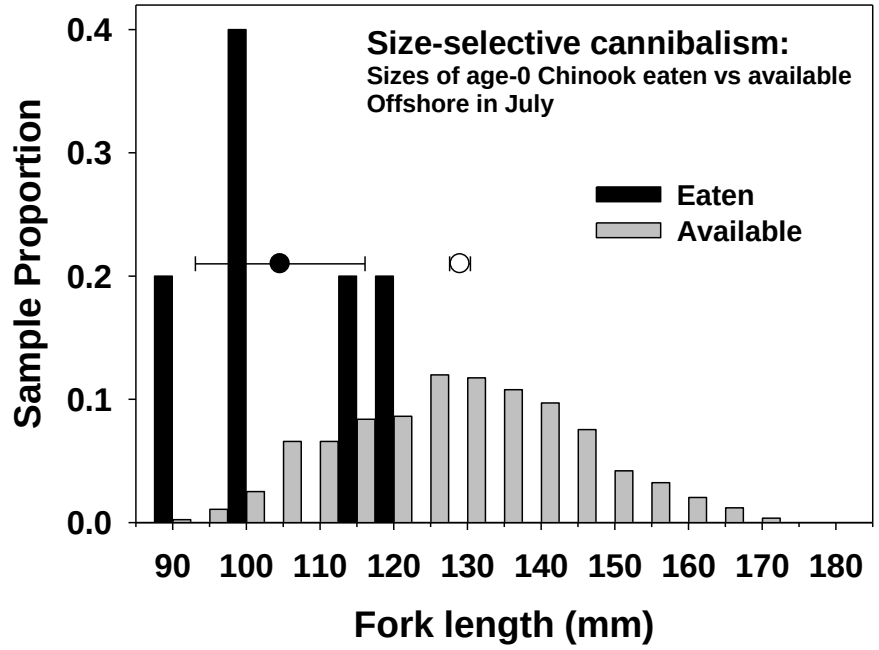


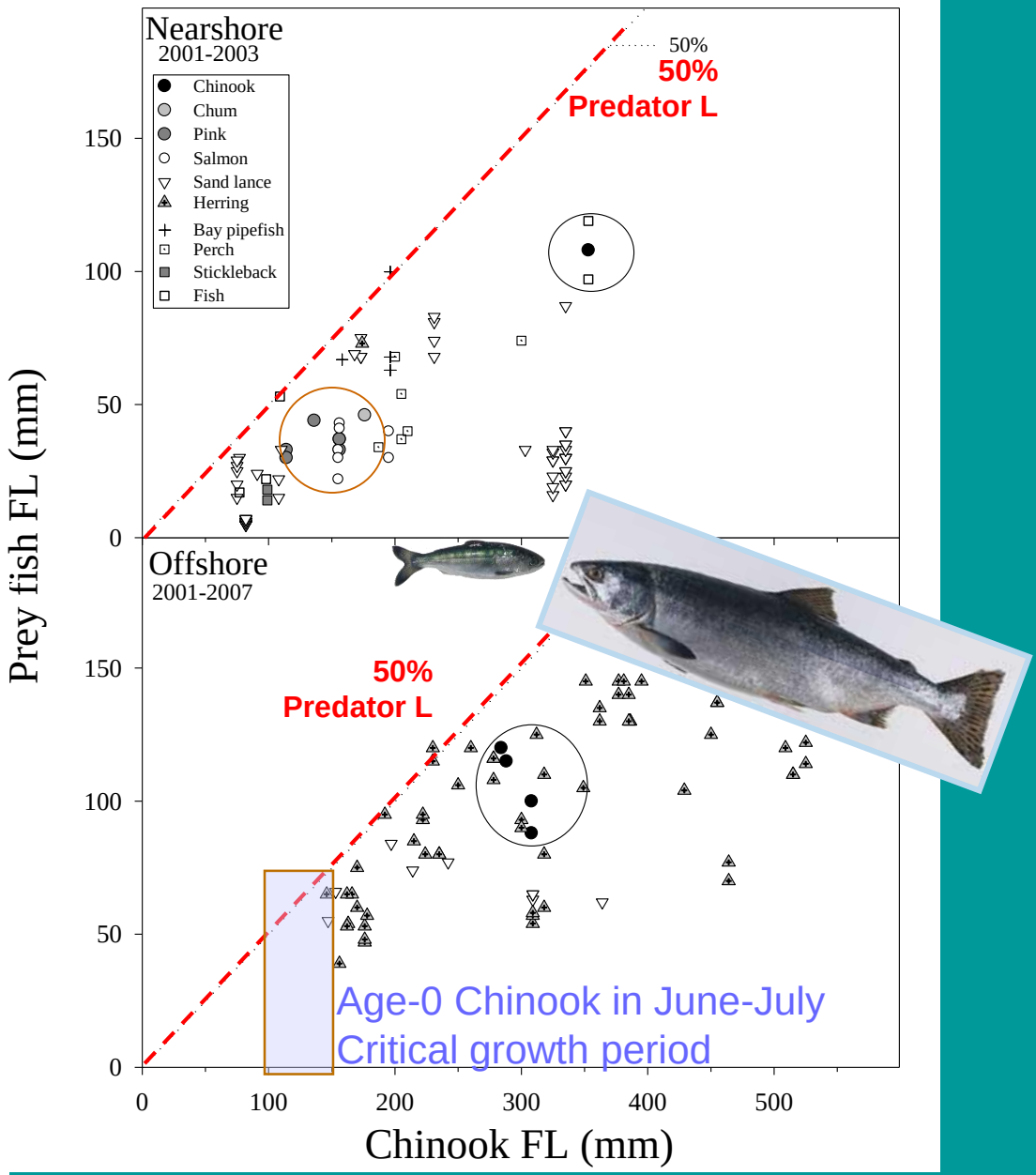
Duffy et al. 2010 Trans. Amer. Fish. Soc. 139:803-823.

Gape Limitation & Predation by Older Resident Chinook

Piscivore Size Distribution

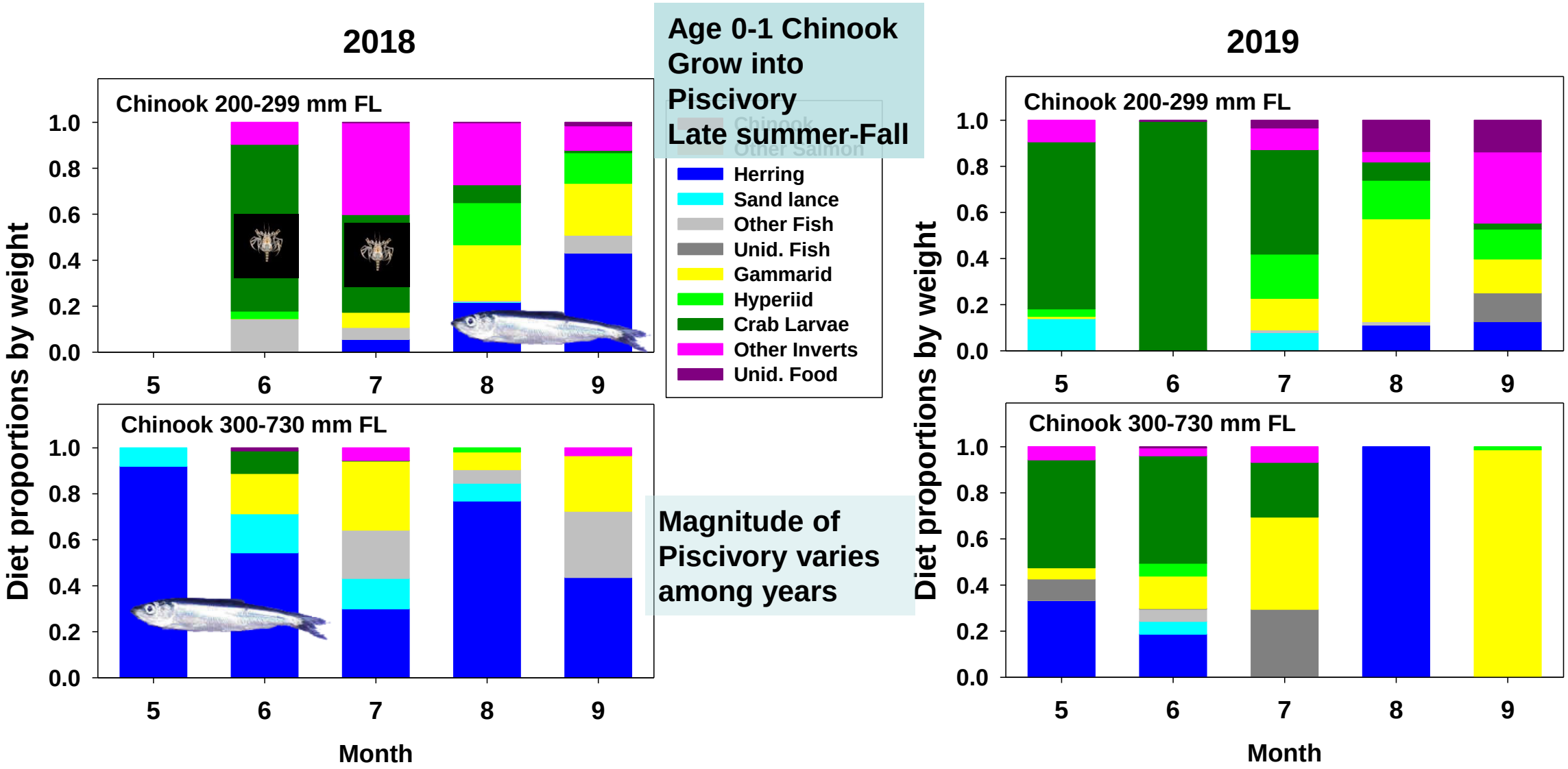




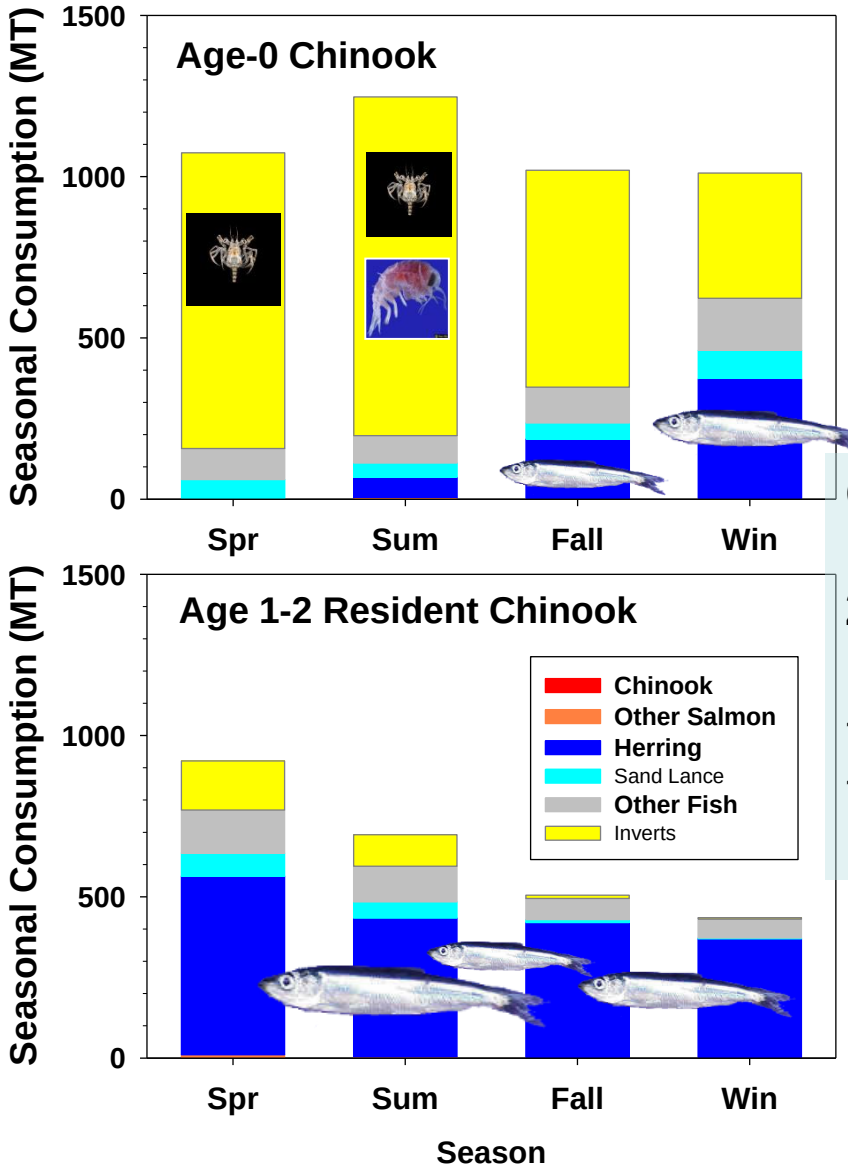


Beauchamp & Duffy 2011. Pacific Salmon Commission Rept.

Ontogenetic Shift to Piscivory & Interannual Variability in Seasonal Diet by Chinook Salmon

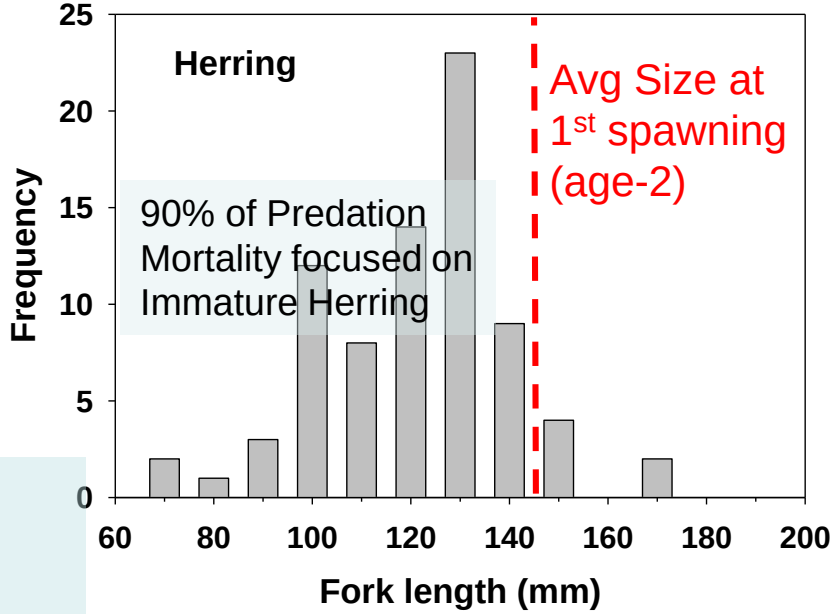


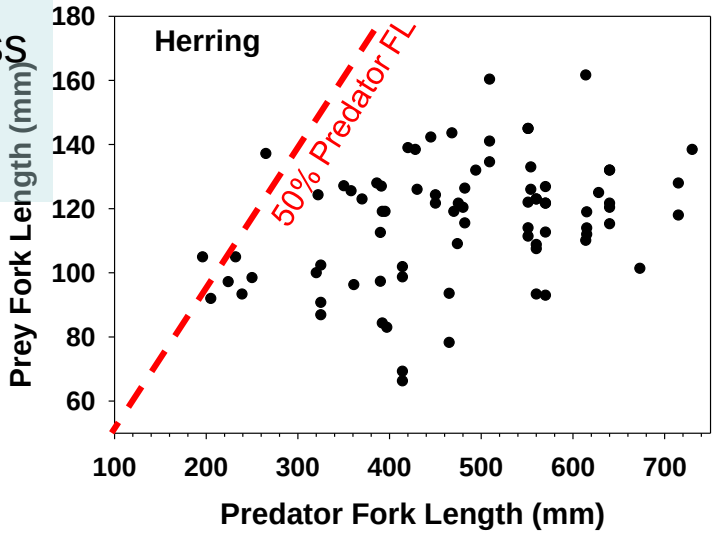
Chinook Population: Seasonal, Size-based Predation Demand in Puget Sound



Chinook Predation Demand on Herring = **2,400 MT/yr:**

~50% Immature Biomass
~ 5% Adult Biomass





Summary-1

- Most Fish are Gape-limited, Ectothermic Consumers
  - Implications for thermally & size-related influence on distribution & food web interactions
  - Phenology & growth differences can alter predator-prey interactions
- Juvenile Chinook: Size-selective mortality strongly linked to epi-pelagic feeding conditions during Critical Growth Period (June-July)
  - Growth limited by availability of larval crab
  - Key prey supply possibly depleted by **competition** from Herring
  - Herring too large for subyearling Chinook to eat during critical growth period in Puget Sound. Size mismatch due to early spawning phenology by Herring
- Herring are initially important competitors with juv. Chinook
  - Consume 50-100x more biomass of key prey during critical growth period

Summary-2

- Chinook as Piscivores
  - Grow into herring predators after critical growth period
  - Significant predation (consume 50% mean annual biomass) on immature Herring (60-140 mm)
  - Minor predation on Adult herring
  - Not responsible for truncated size structure of Herring (1^{o} age-2 spawners)
- Implications for increasing production of hatchery Chinook to feed Southern Resident Killer Whales (SRKW)