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Quesnel Lake Sockeye Salmon:

Large escapements, trophic surprises, and the consequences of density-dependence

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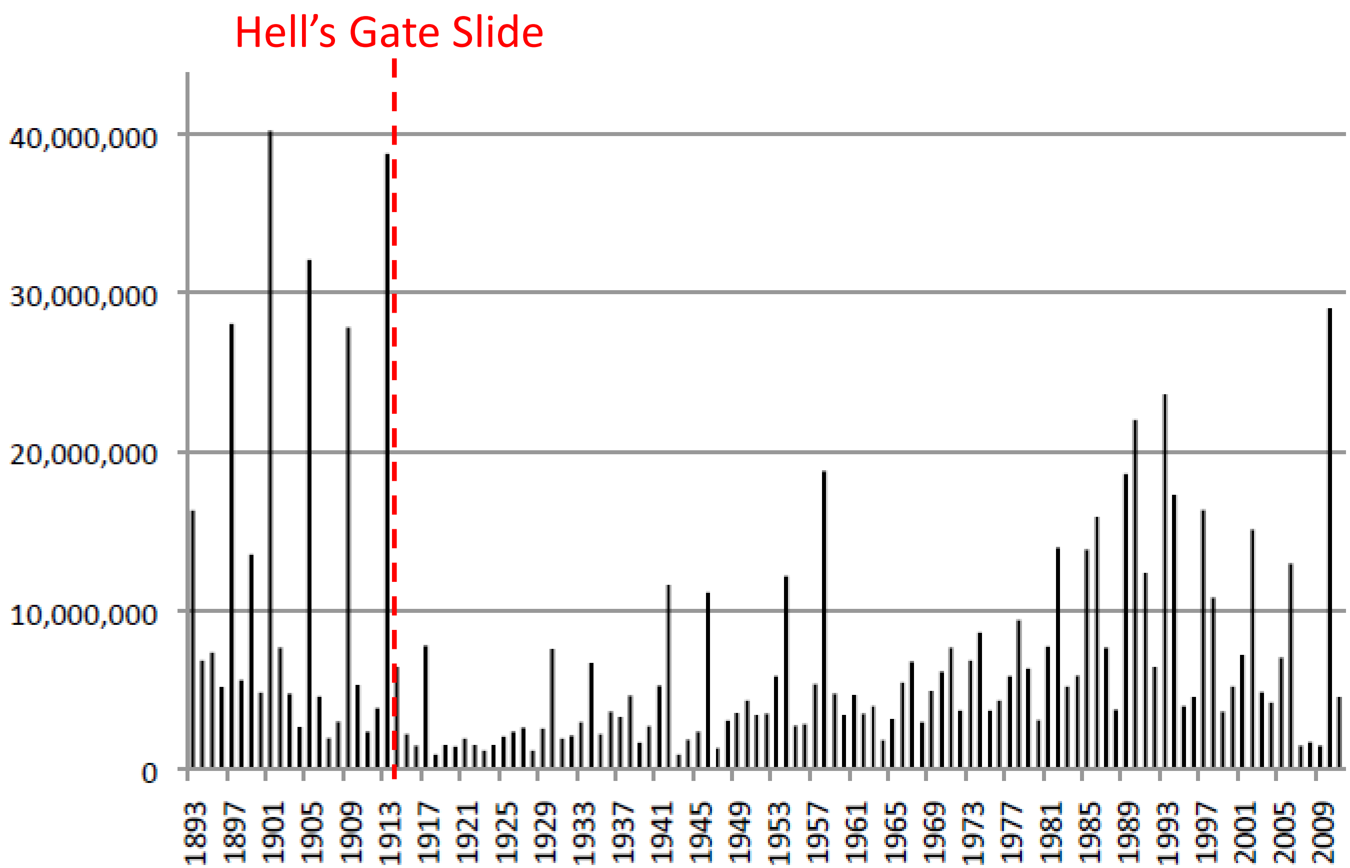
Science Branch, Fisheries and Oceans Canada

Quesnel Lake, BC Cariboo Region

Canada

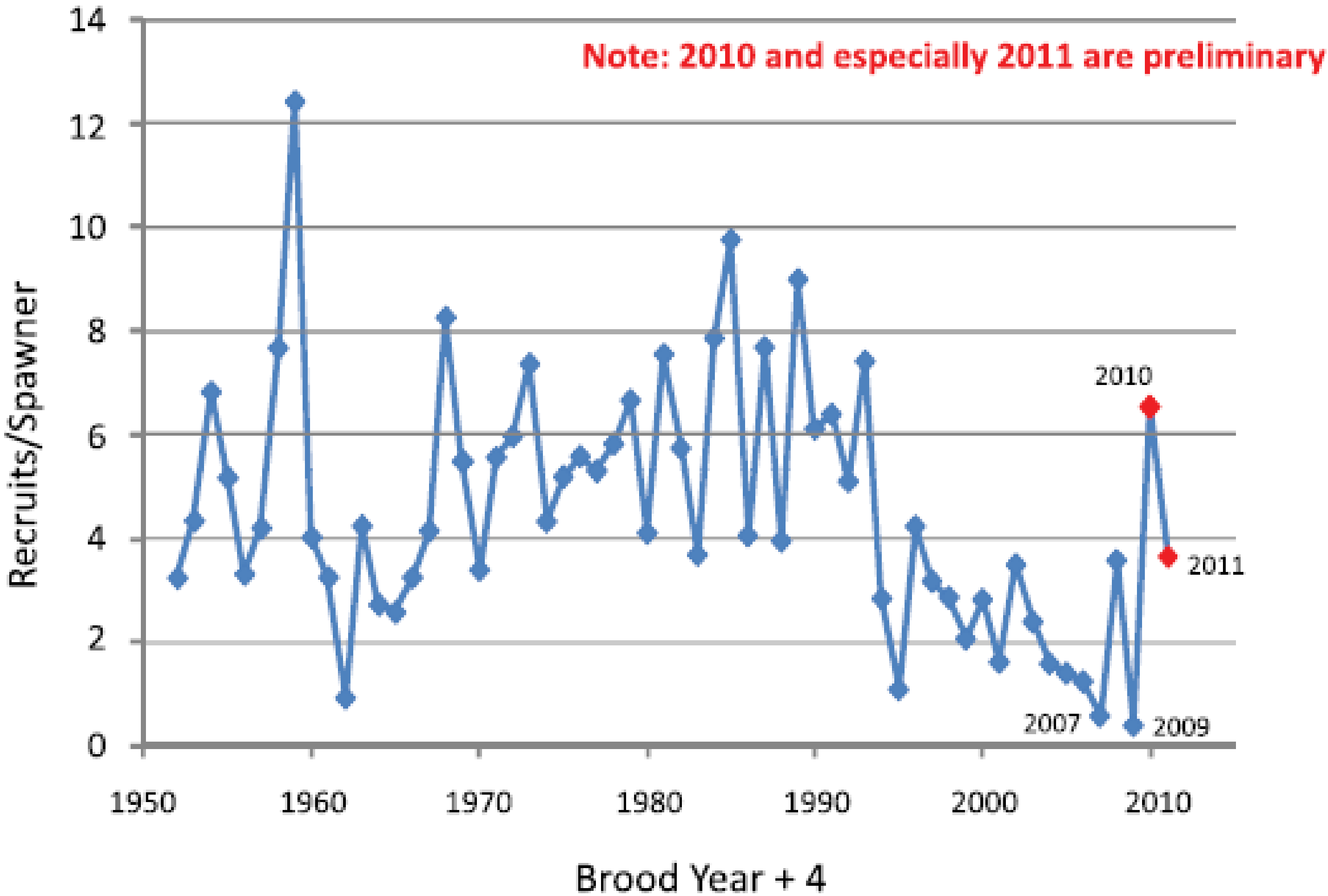
Fraser River Sockeye Salmon Returns



Total Fraser River Returns 1893-2011

Cohen Inquiry Report I, 2012

Declining Fraser River Sockeye Production



Cohen Inquiry Report I, 2012

Pacific Fisheries Resource Conservation Council

Does Over-Escapement Cause Salmon Stock Collapse?

Technical Paper

Prepared by
C. Walters, P. LeBlond, and B. Riddell

April 2004

The Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River

February 2011

TECHNICAL REPORT 10

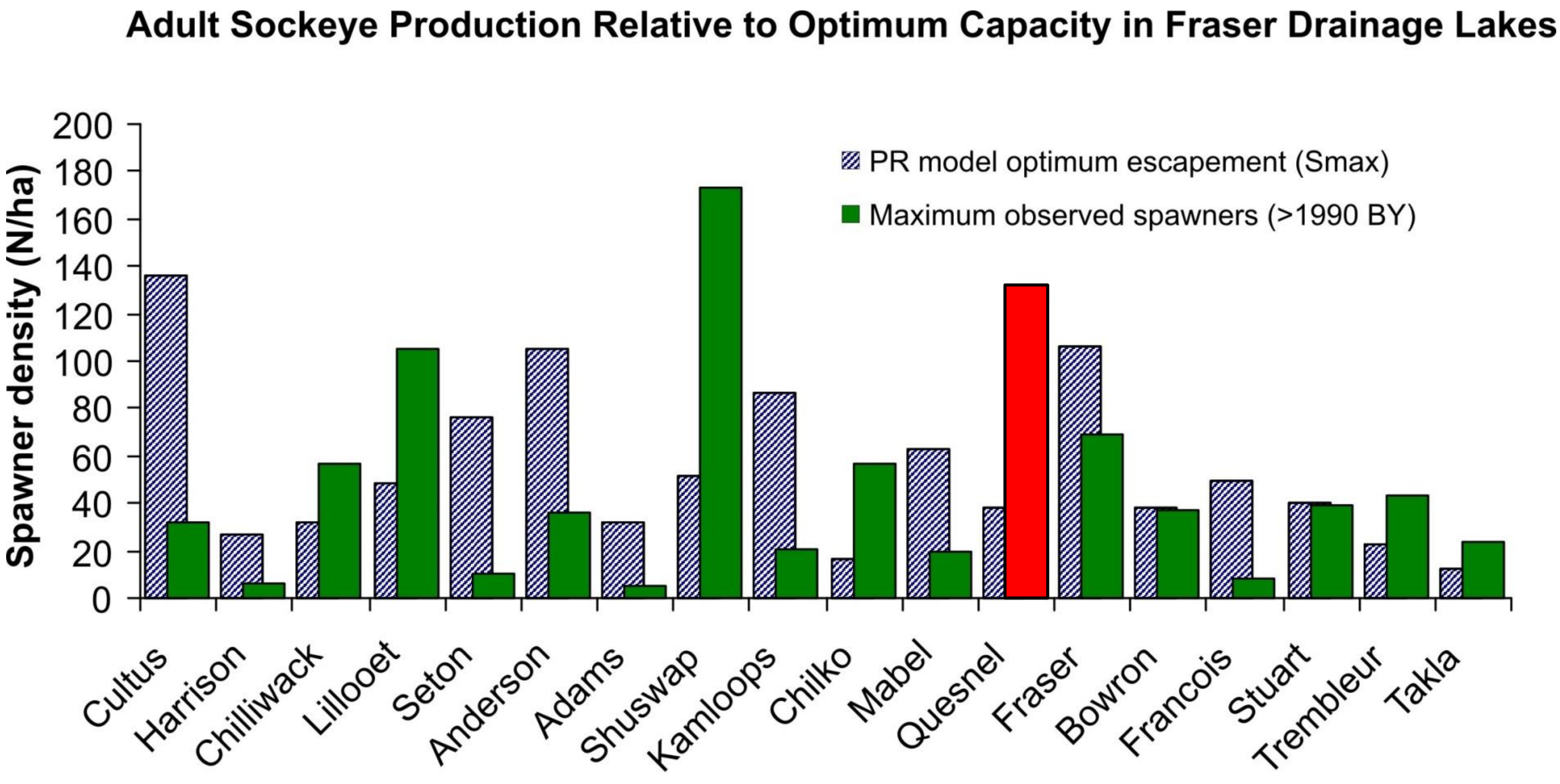
Fraser River Sockeye Production Dynamics

Randall M. Peterman and Brigitte Dorner

Freshwater Environmental Limitation of Stock Productivity

- Density-Dependent Factors
  - Spawning Limitation
  - Rearing Limitation
- Density-Independent Factors
  - Disease
  - Inter-Specific Competition
  - Predation
  - Environmental Variability
  - Environmental Stressors

Adams River 2010, Photo: R. Bailey, DFO

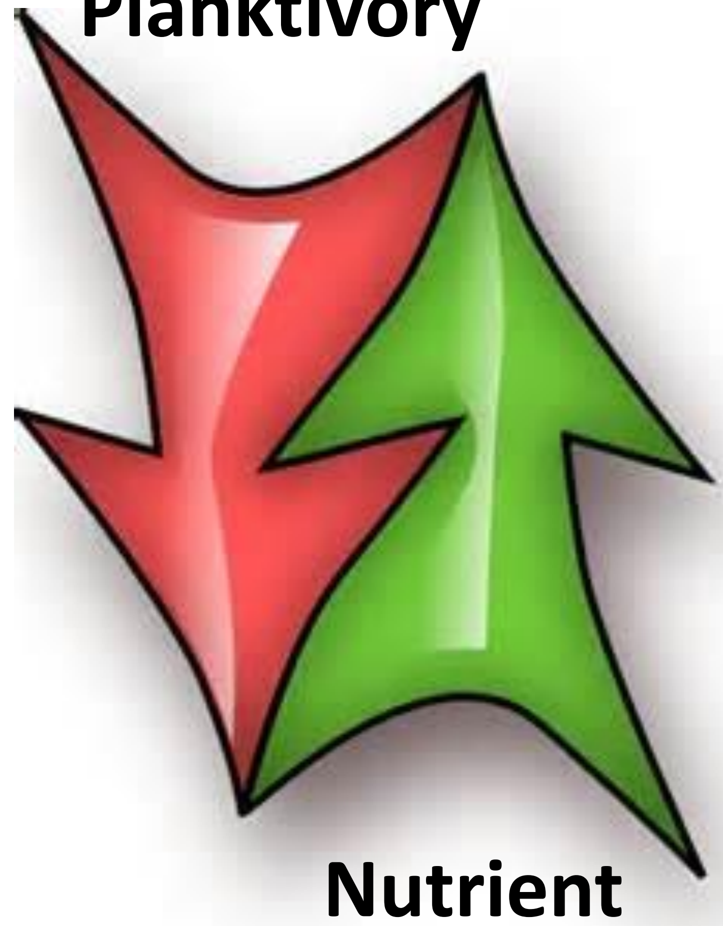


- Major stocks have exhibited spawning escapements in excess of modelled optimal escapements

Selbie et al. 2010, PSC Workshop Proceedings

Rearing Limitation

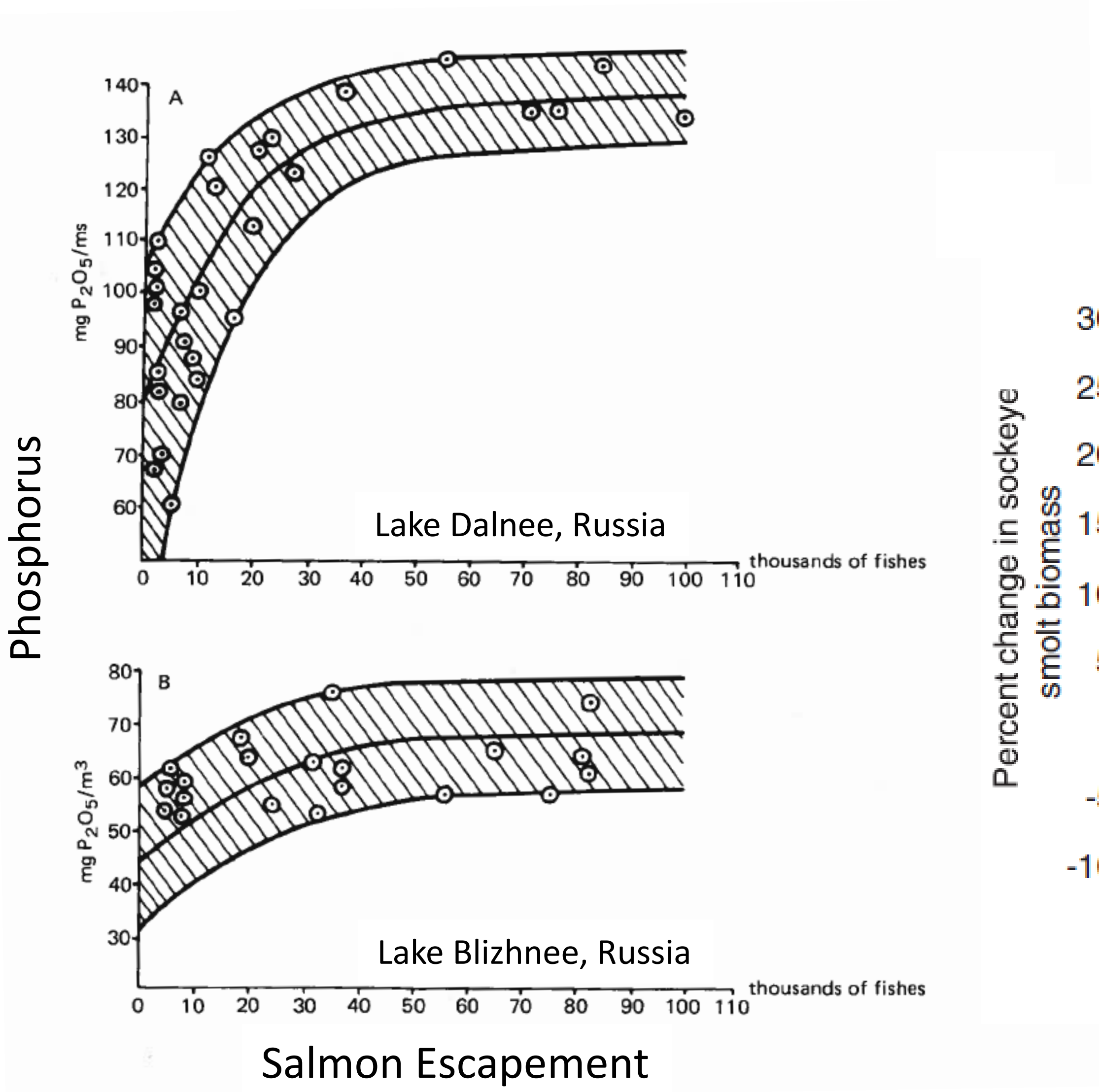
Sockeye Planktivory

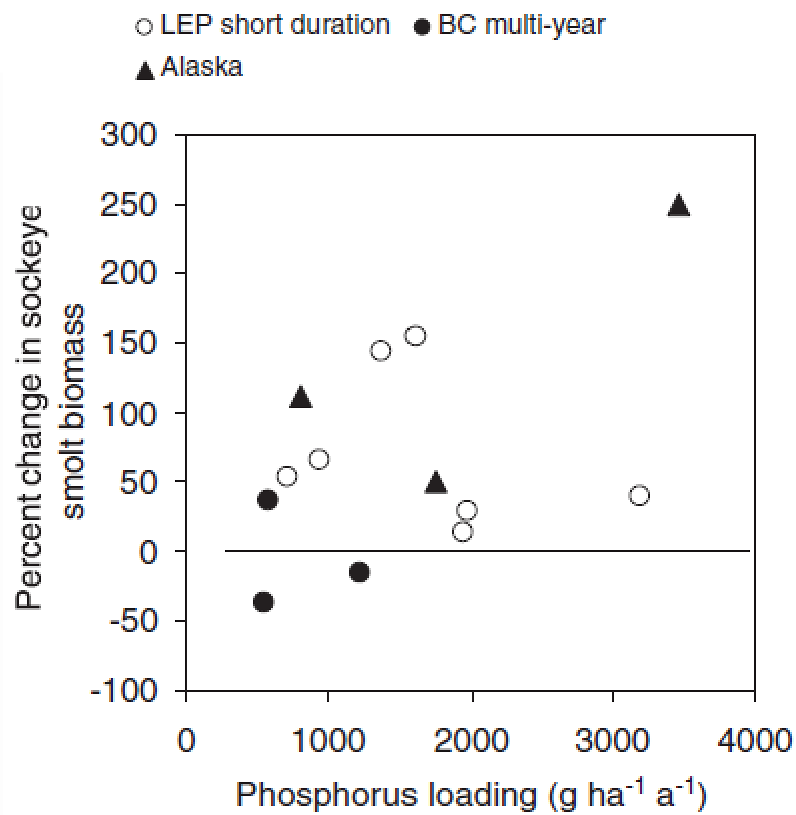


Nutrient Stimulation

Marine-Derived Nutrients

Bottom-Up: Marine-Derived Nutrients in Lakes





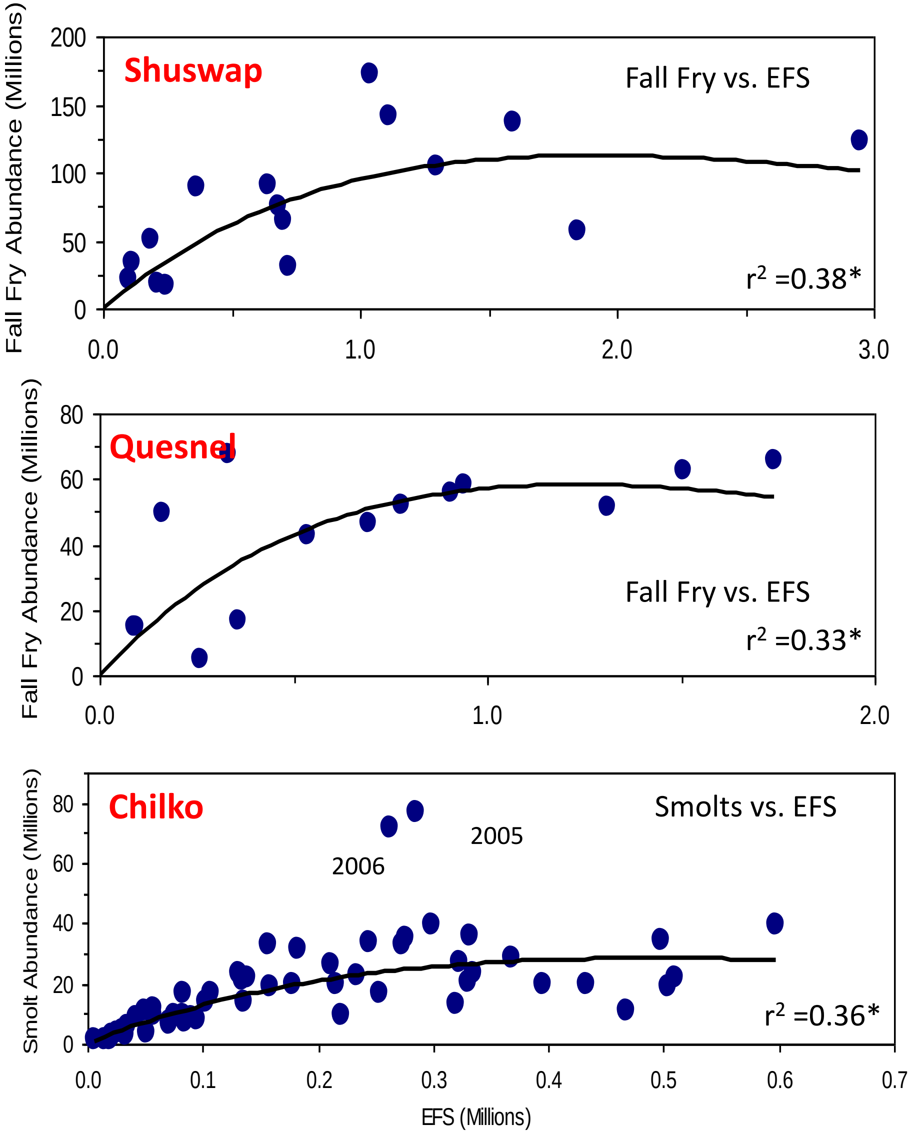
Krokhin 1975. Ecol. Studies.

Hyatt et al. 2004. Environ. Rev. 12: 133-162

Juvenile Productivity Index Density Dependence

Shuswap, Quesnel, Chilko lakes

- Evidence of density-dependent survival across escapement densities in Shuswap, Quesnel and Chilko lakes

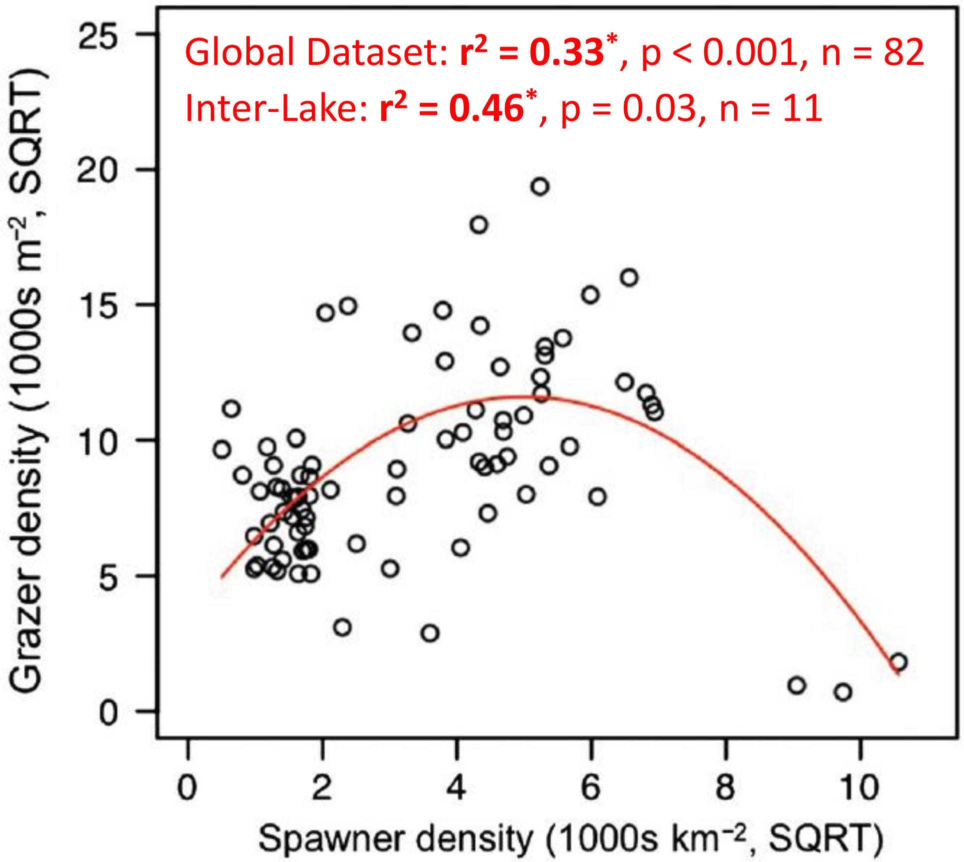


* Data include dominant and subdominant cycle years but not non-dominant years

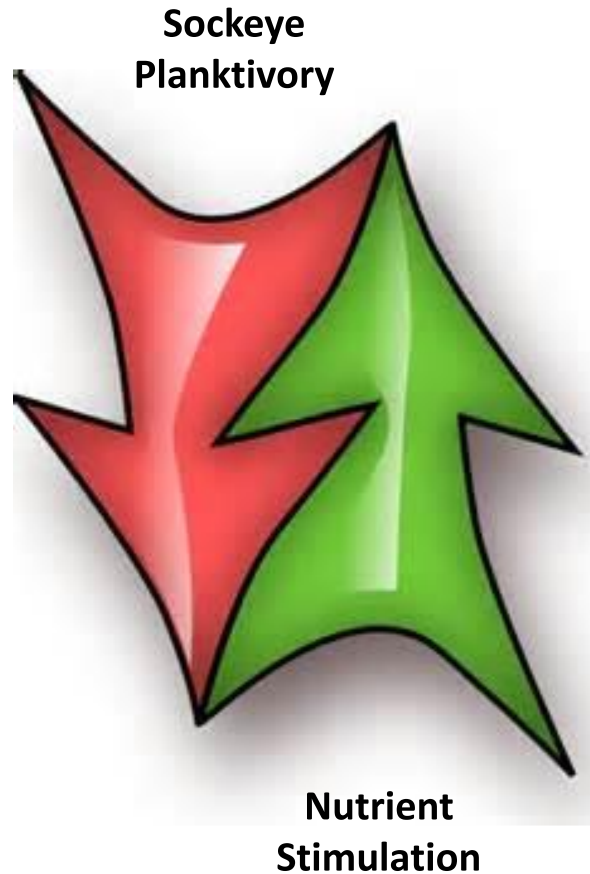
Selbie et al. 2010, PSC Workshop Proceedings

Reality: It's Top-Down & Bottom-Up

Zooplankton

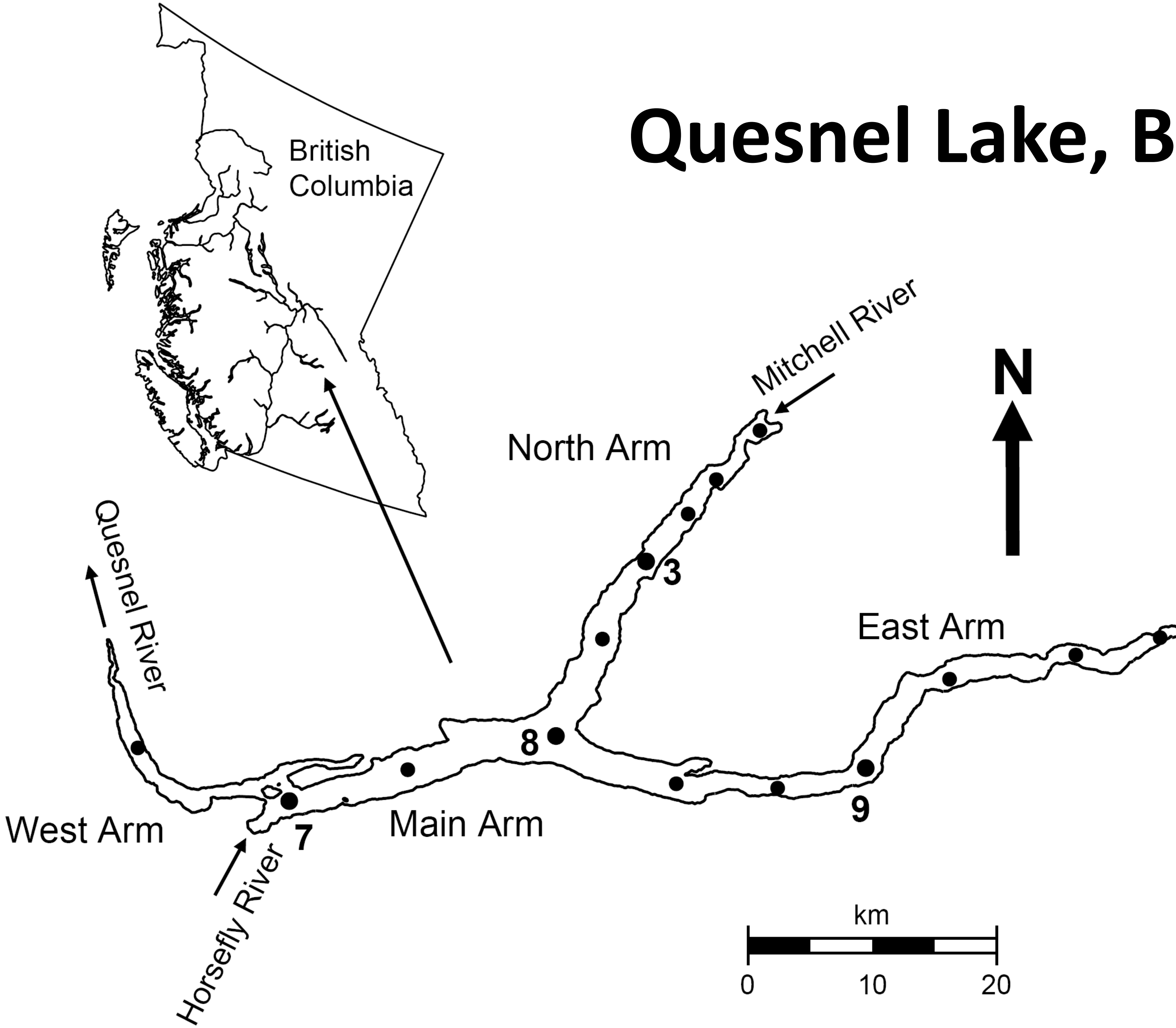


Salmon

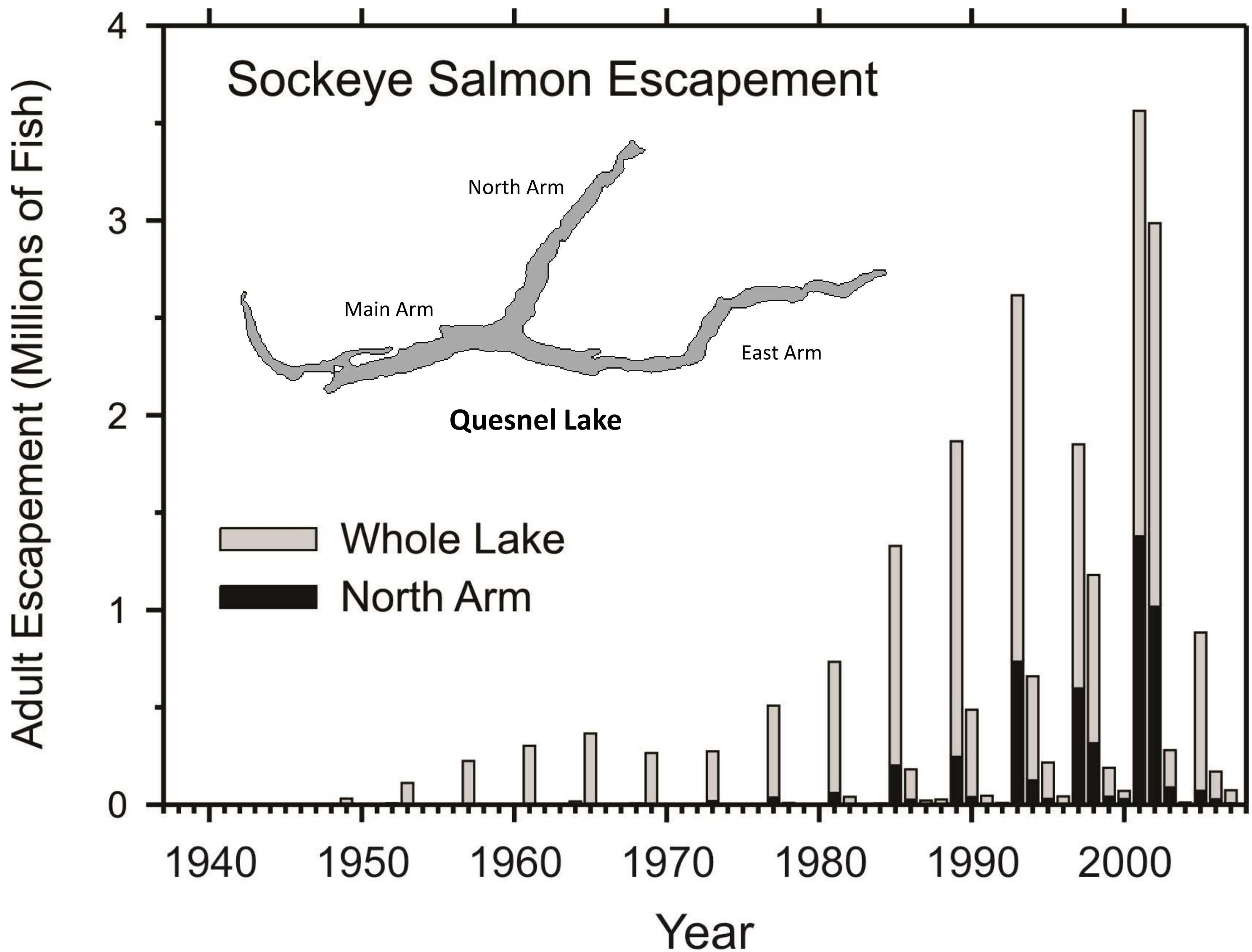


Chen et al. 2011. Oikos 120: 1317-1326.

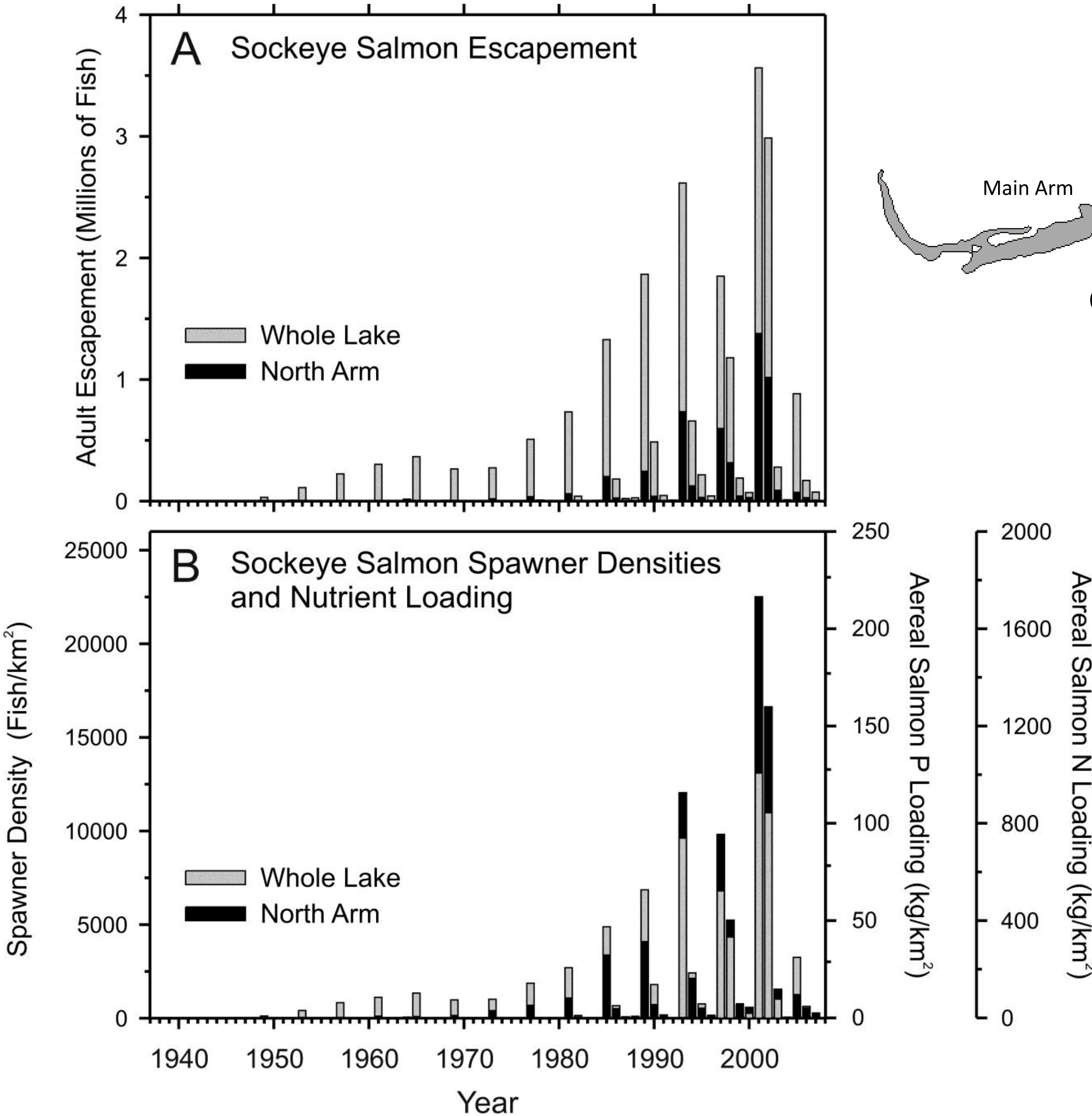
Quesnel Lake, BC

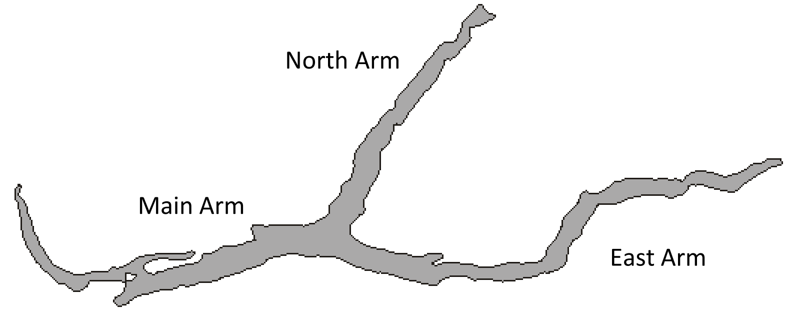


Selbie and Shortreed, *in prep.*



Selbie and Shortreed, *in preparation*



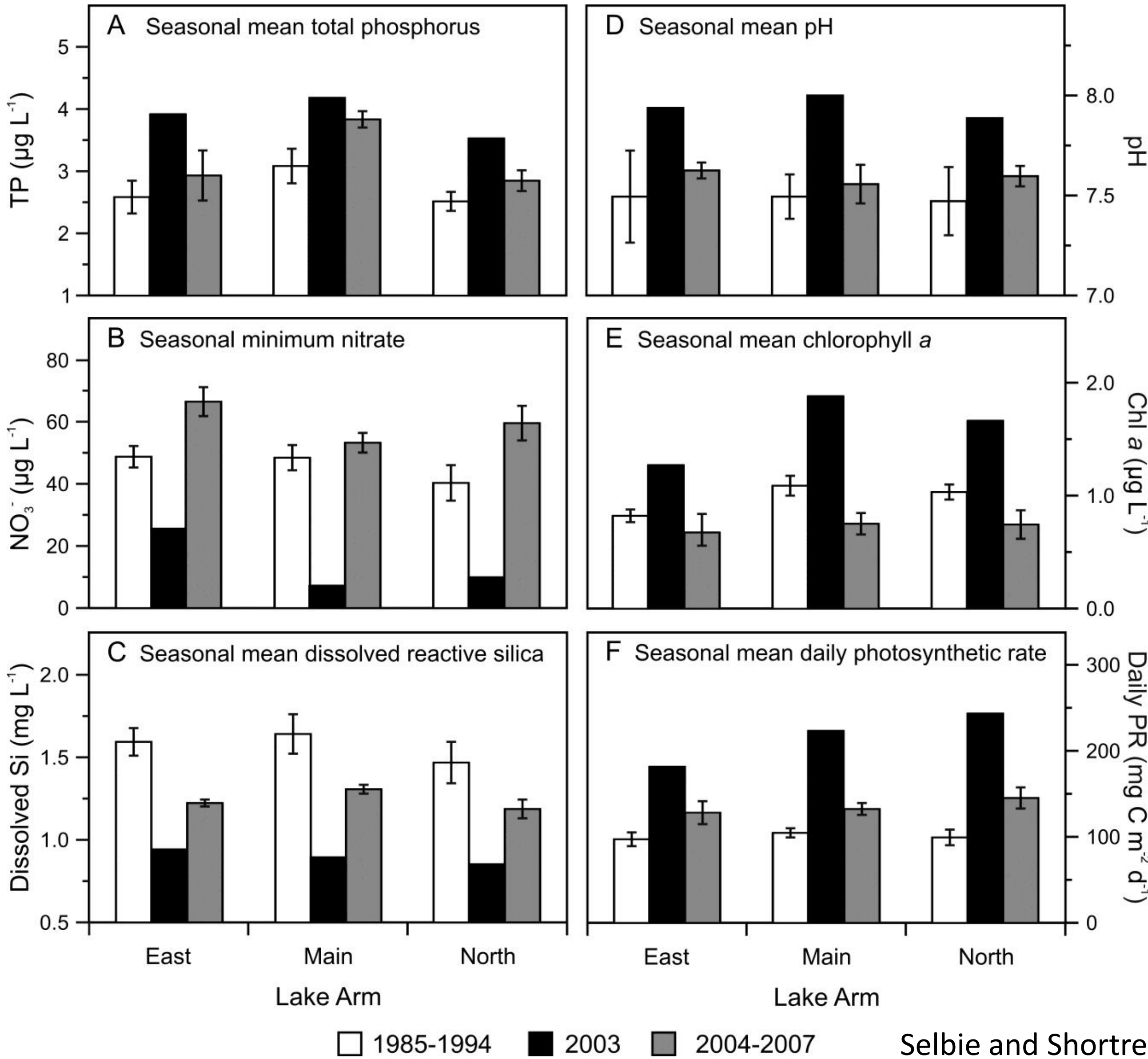


Quesnel Lake

Selbie and Shortreed, *in preparation*

Lake Responses to Variable Escapements

Water chemistry and primary productivity responses

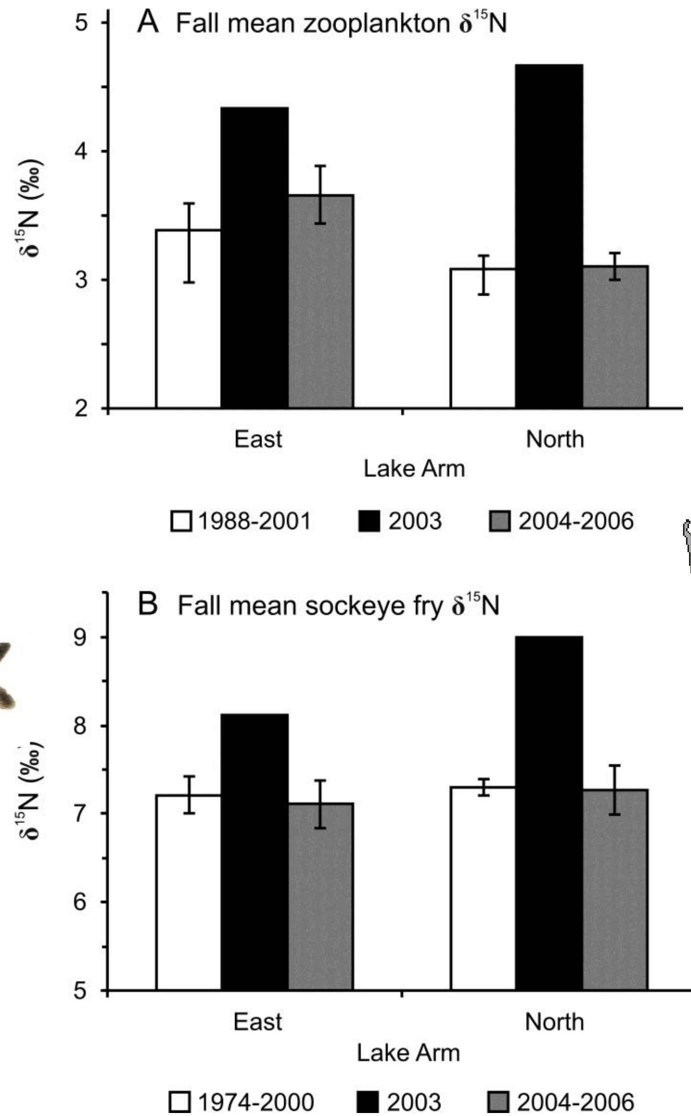


Selbie and Shortreed, *in preparation*

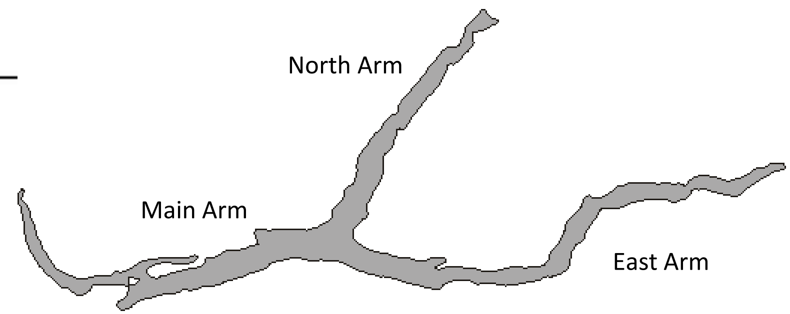
Marine-Derived Nutrients

Stable Nitrogen Isotope ($\delta^{15}N$) Tracer

Zooplankton



Juvenile Sockeye

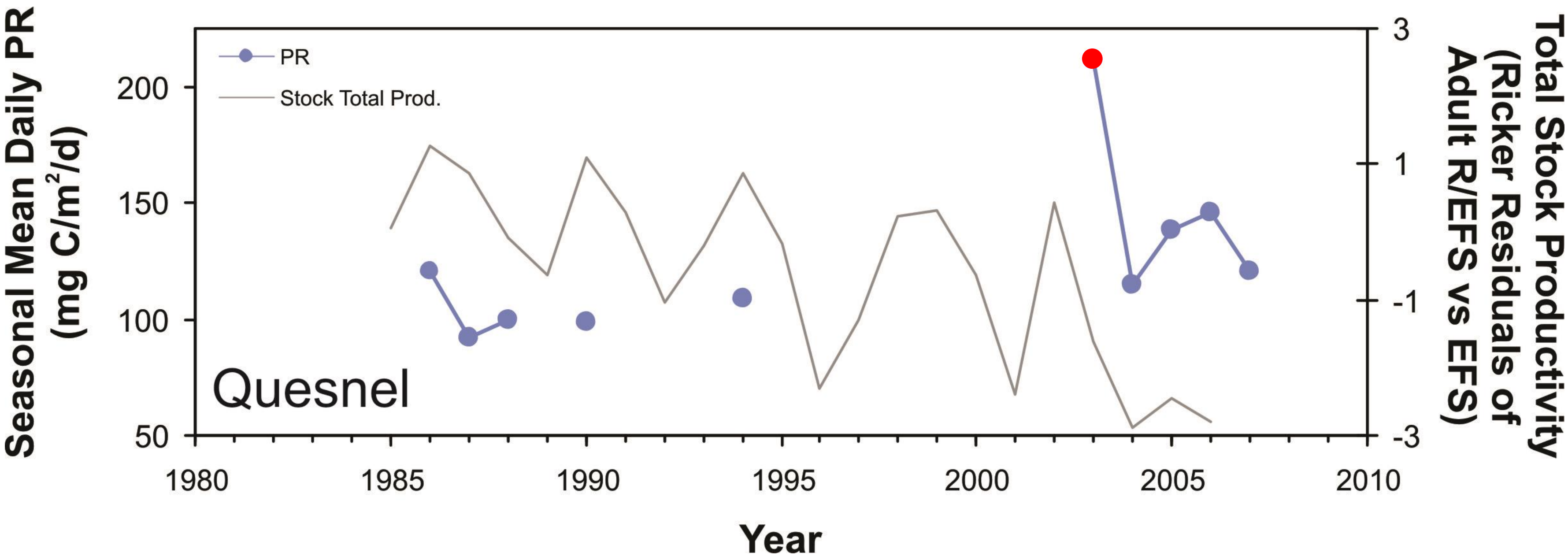


Quesnel Lake

Selbie and Shortreed, *in preparation*

Nursery Lake Primary Productivity

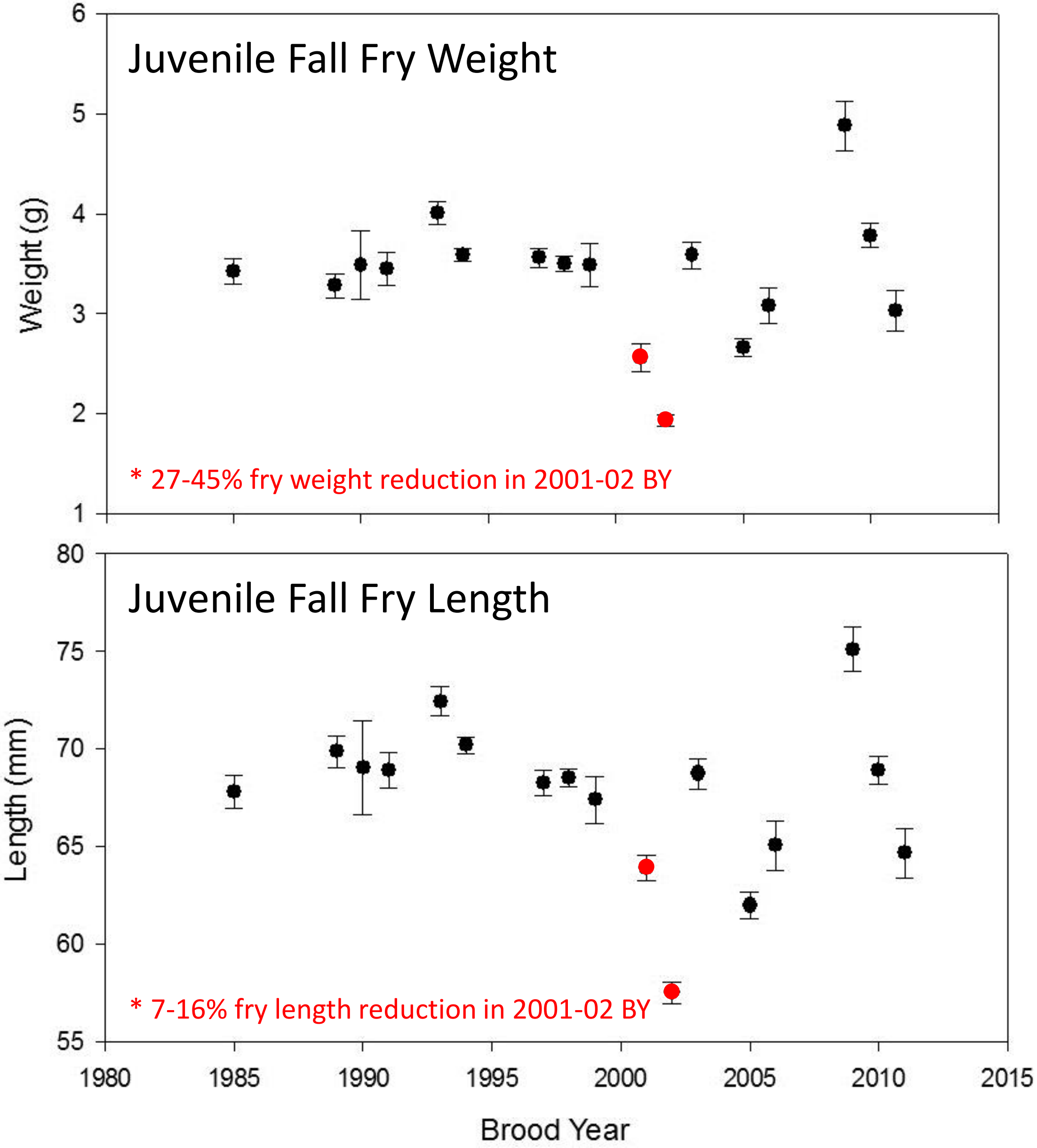
Seasonal Mean Photosynthetic Rates



• Lake productivity appears to have increased in Quesnel Lake since 1980's & 1990's

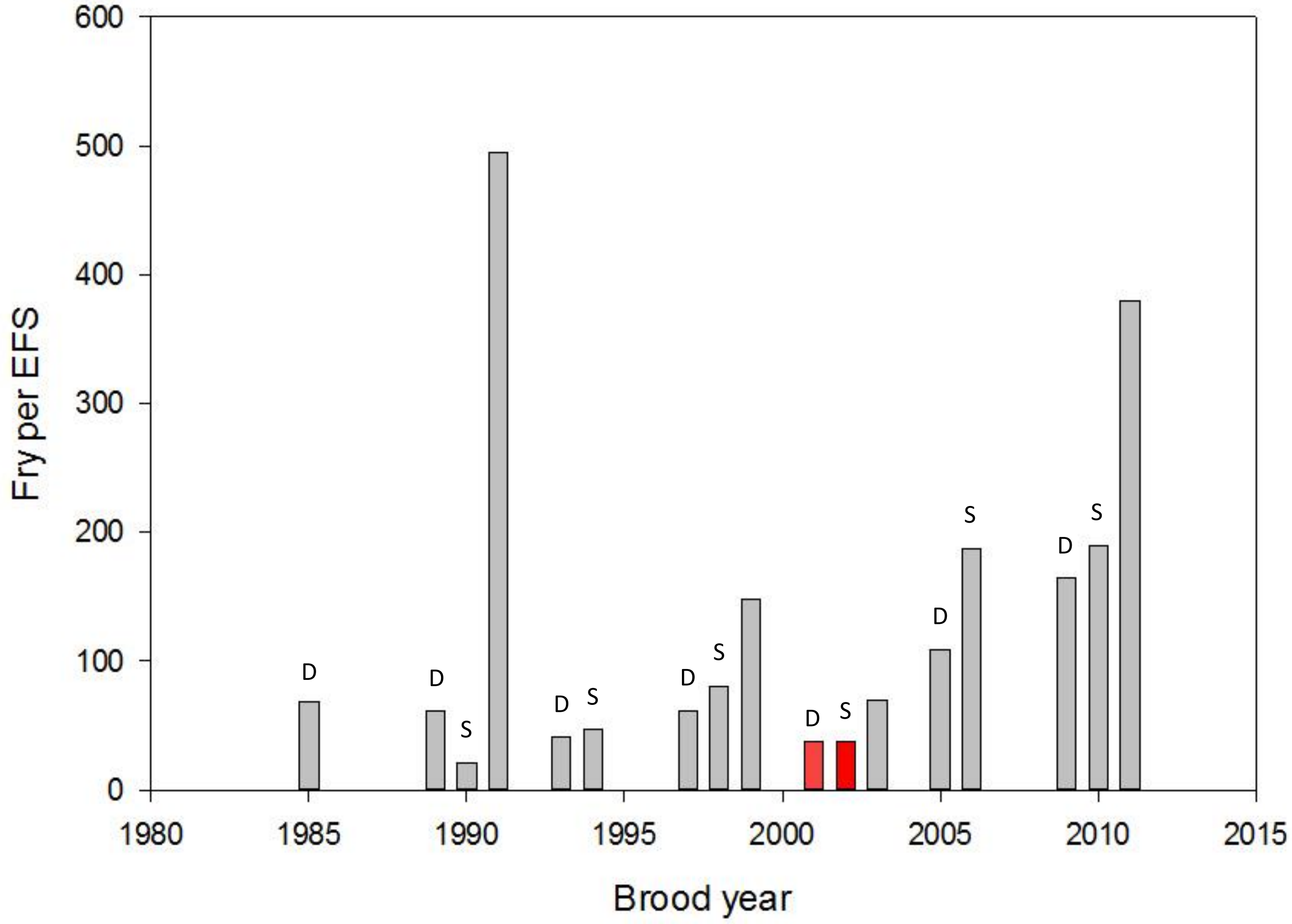
Selbie et al. 2010, PSC Workshop Proceedings

Juvenile Sockeye Salmon In-Lake Growth



Freshwater Survival Index

Fall Fry/Effective Female Spawner

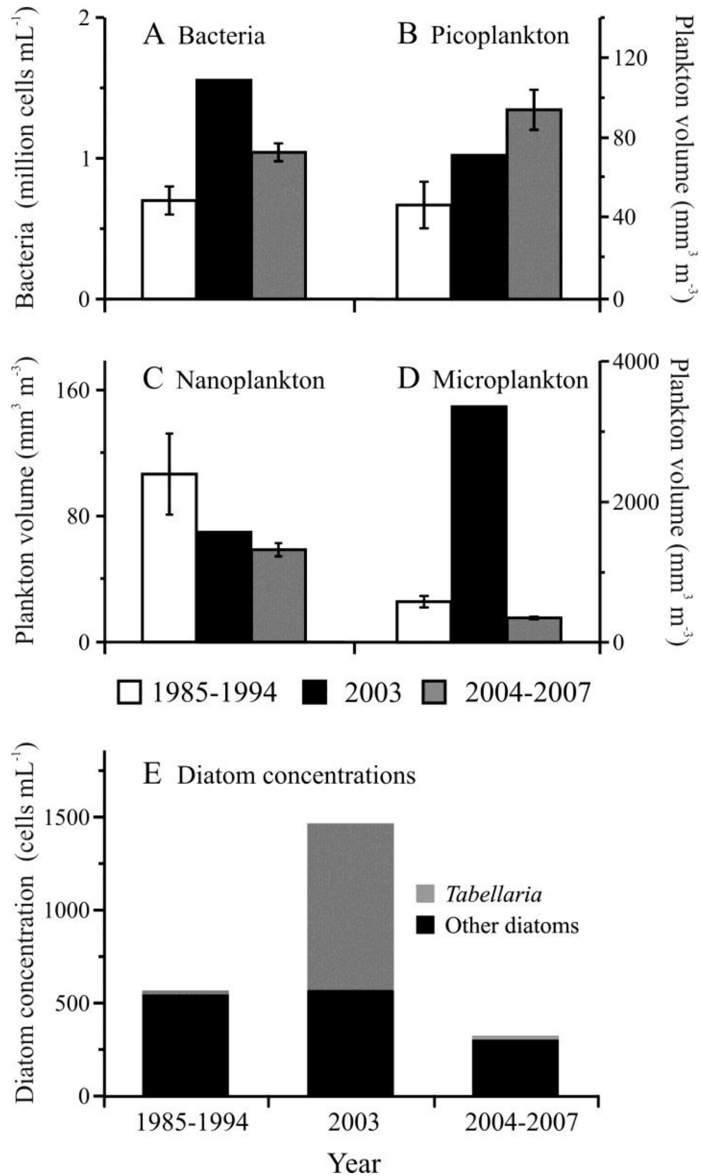


D – Dominant Cycle Line

S – Non-Dominant Cycle Line

Autotrophic Phytoplankton & Bacteriaplankton

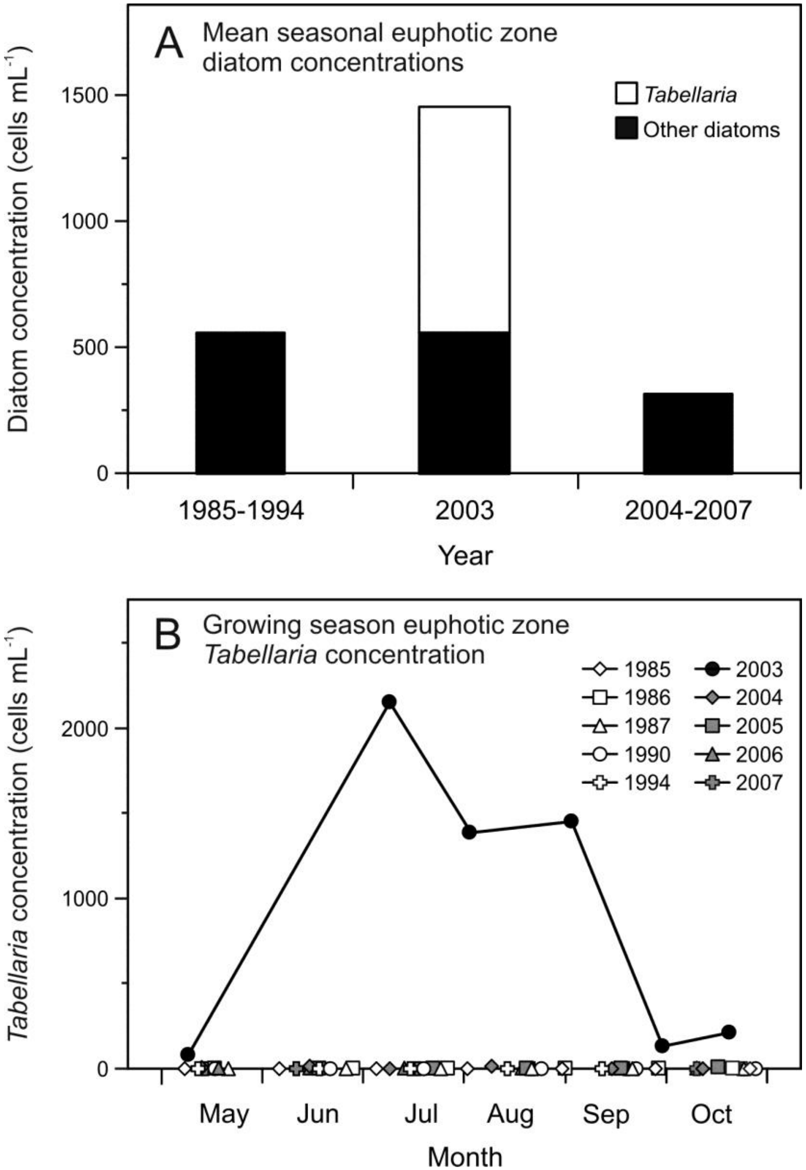
Composition & Production by Functional Size Class

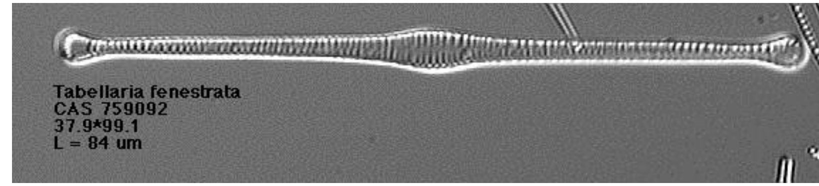


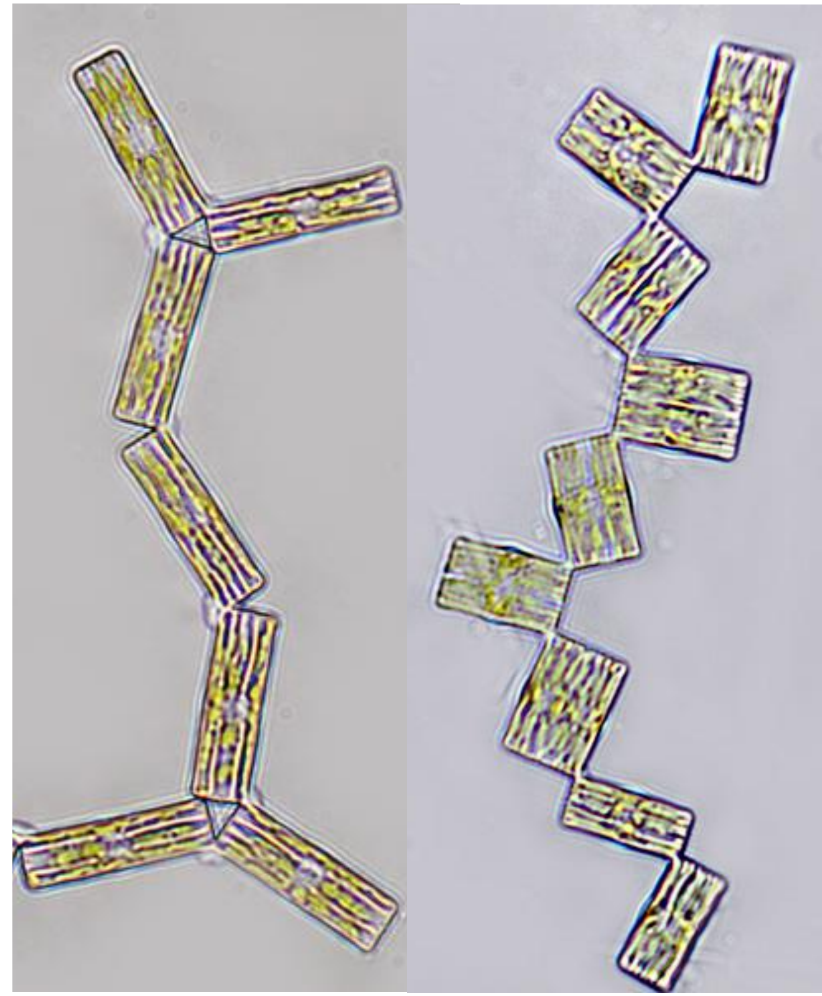
Selbie and Shortreed, *in preparation*

Diatoms: *Tabellaria* spp.

A trophic dead end?

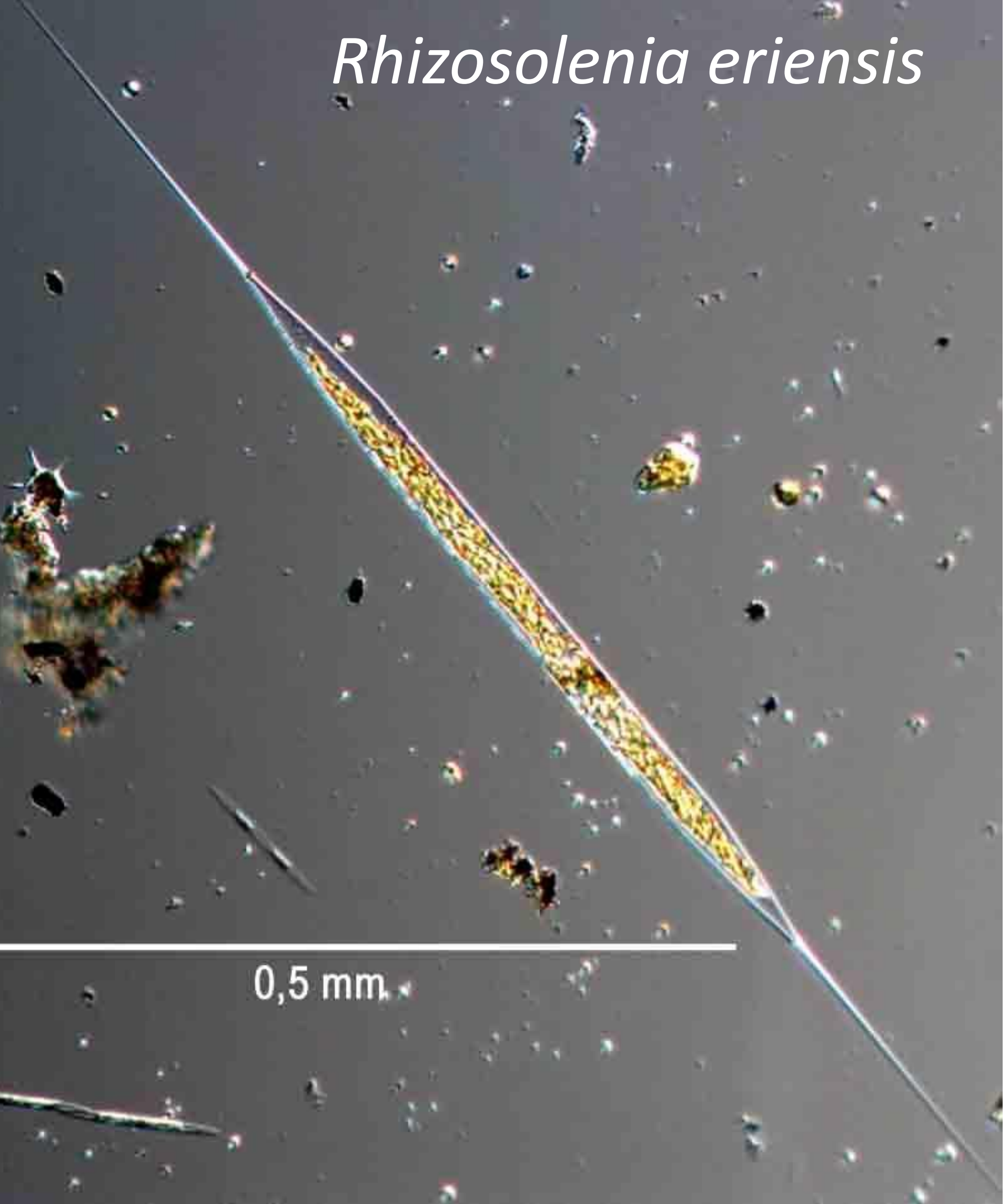




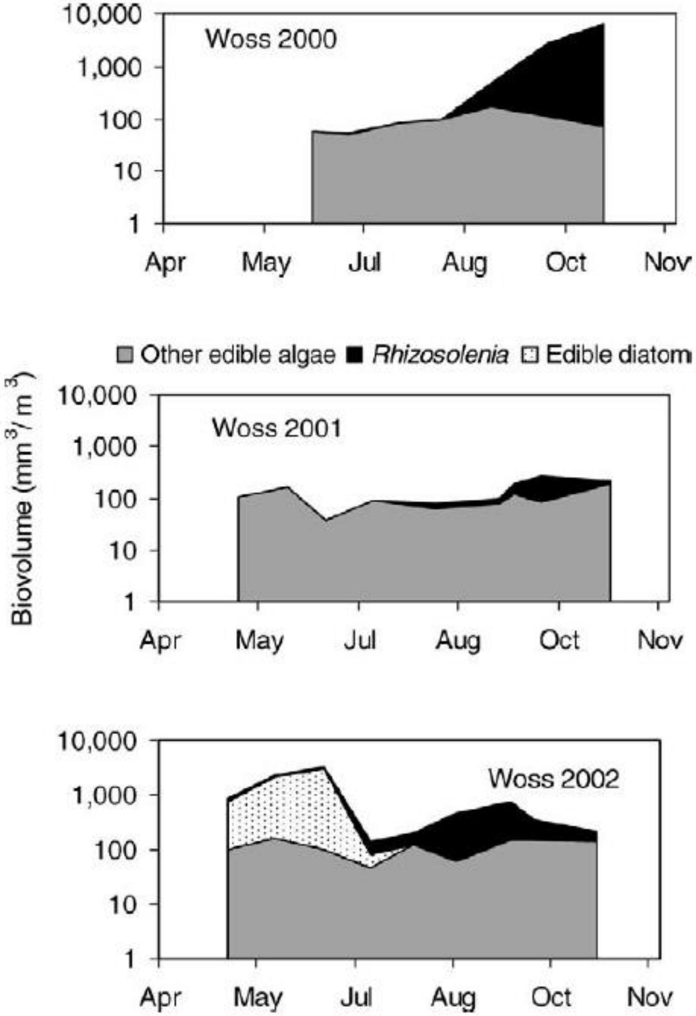


T. fenestrata

Selbie and Shortreed, *in preparation*



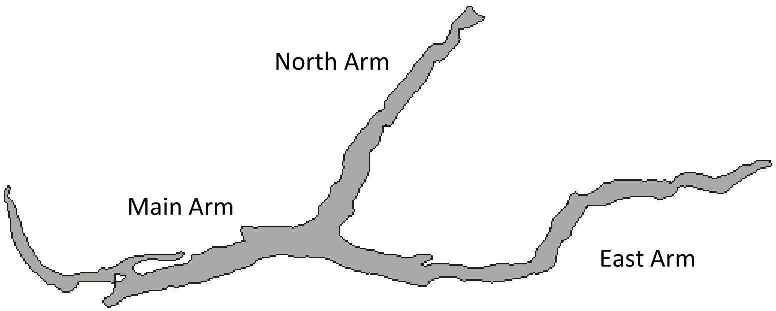
Lake P-fertilization



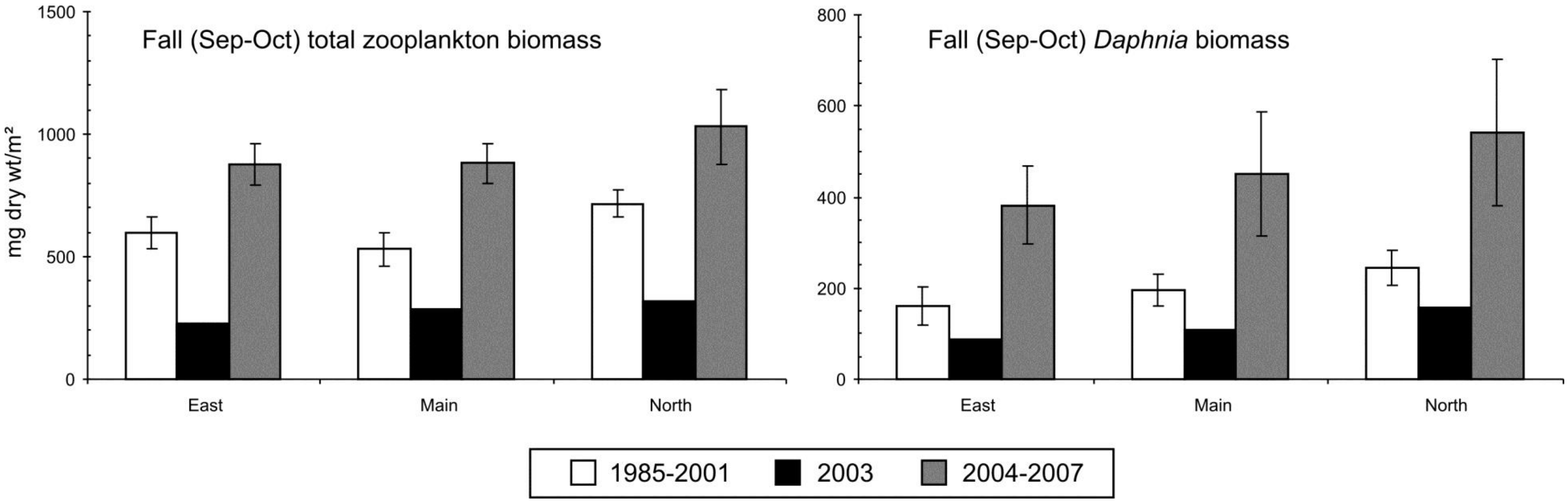
McQueen et al. 2007.
N. Am. J. Fish. Mgmt. 27: 369-386.

Zooplankton Biomass

Fall Total Zooplankton and *Daphnia*



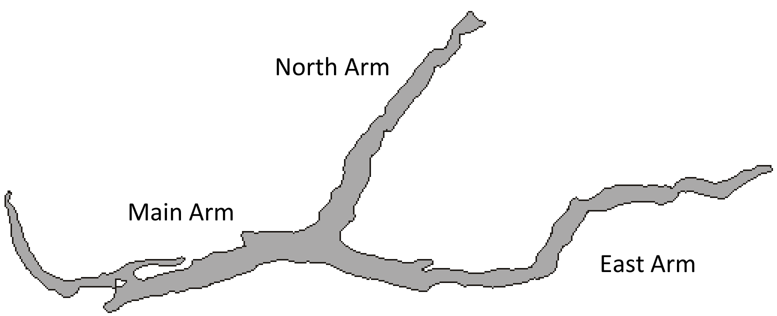
Quesnel Lake



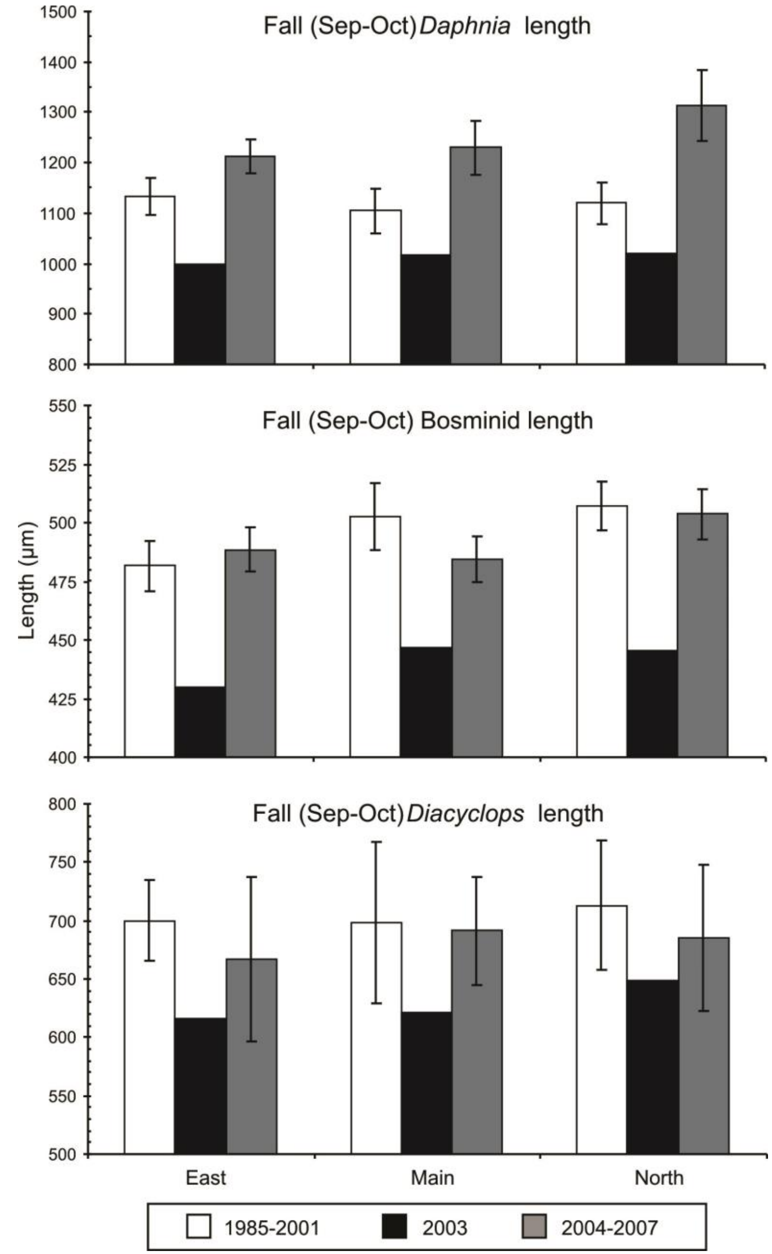
Selbie & Shortreed, *in preparation*

Zooplankton Size Variation

Dominant taxa



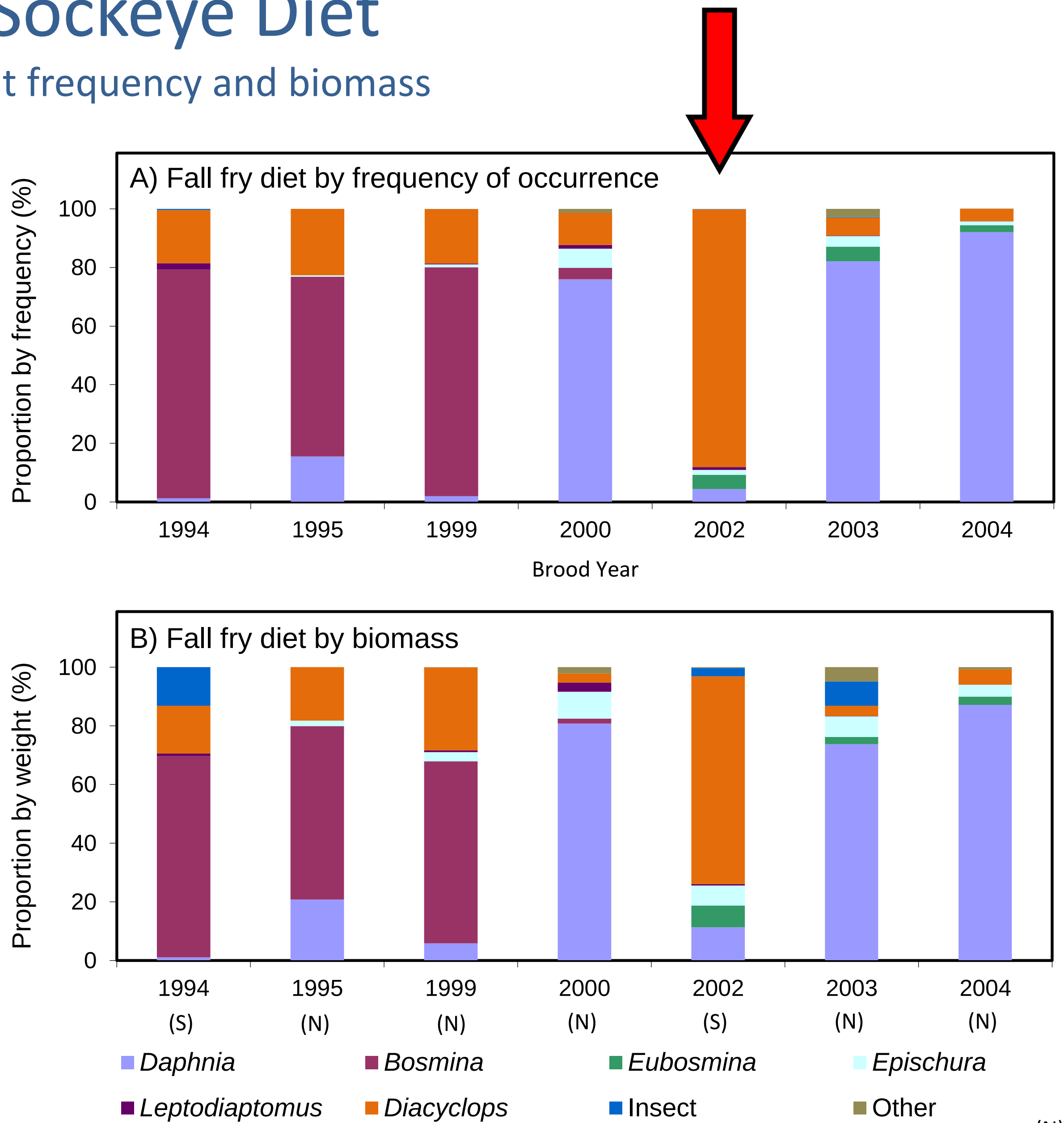
Quesnel Lake



Selbie and Shortreed, *in preparation*

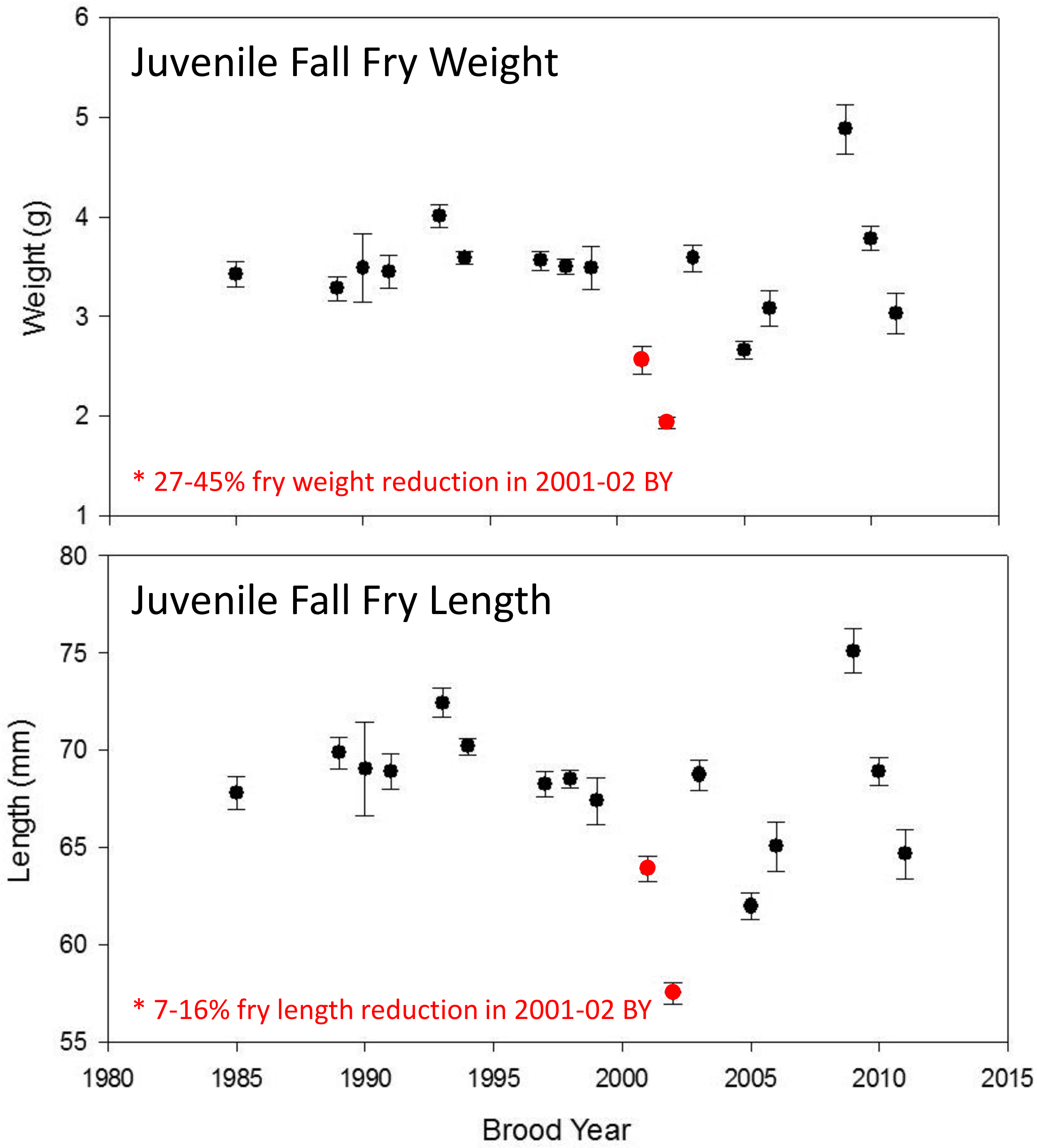
Juvenile Sockeye Diet

Stomach content frequency and biomass



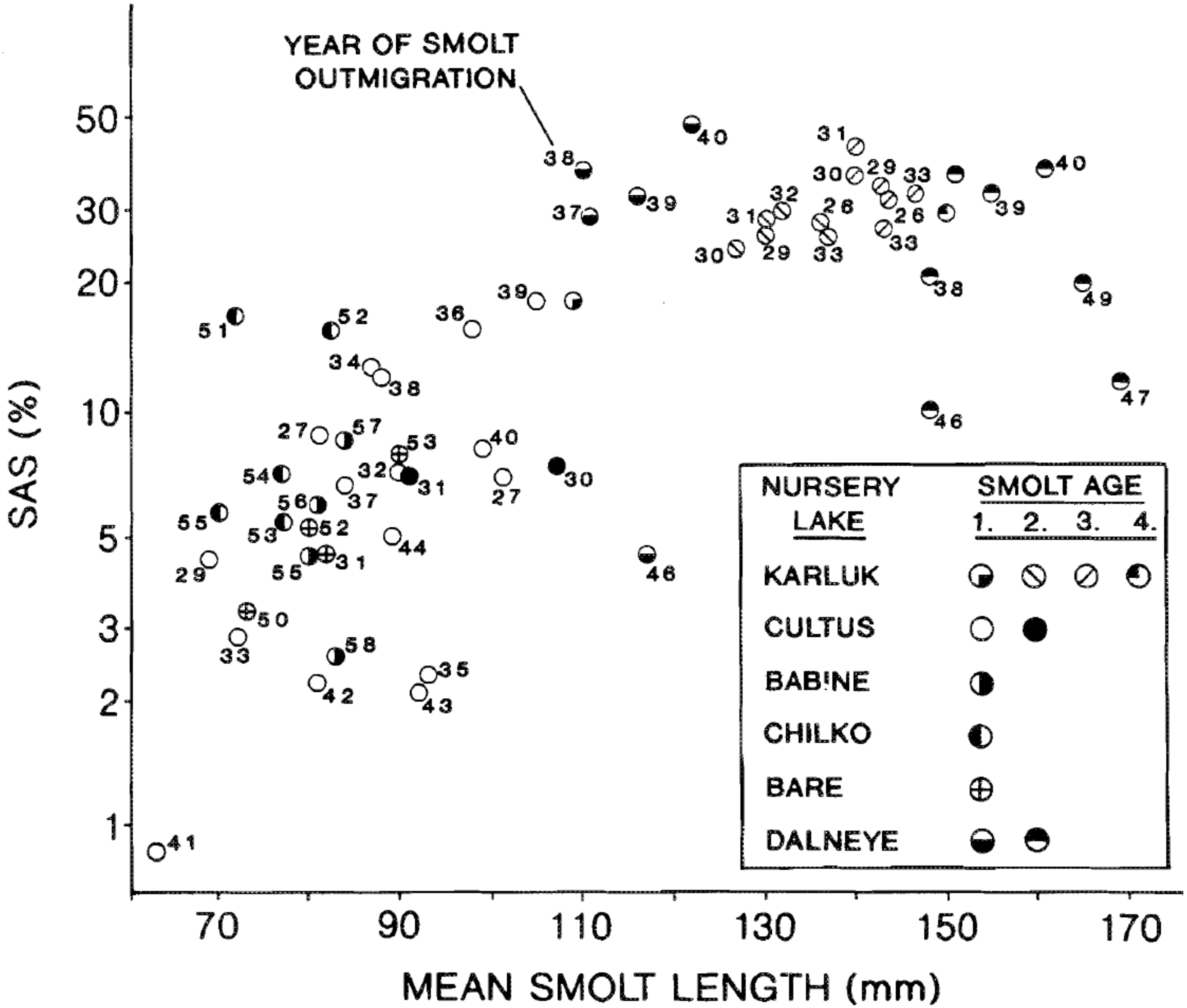
(N) – Non-Dominant Cycle Line
(S) – Sub-Dominant Cycle Line

Juvenile In-Lake Growth



Size Matters: Smolt to Adult Survival

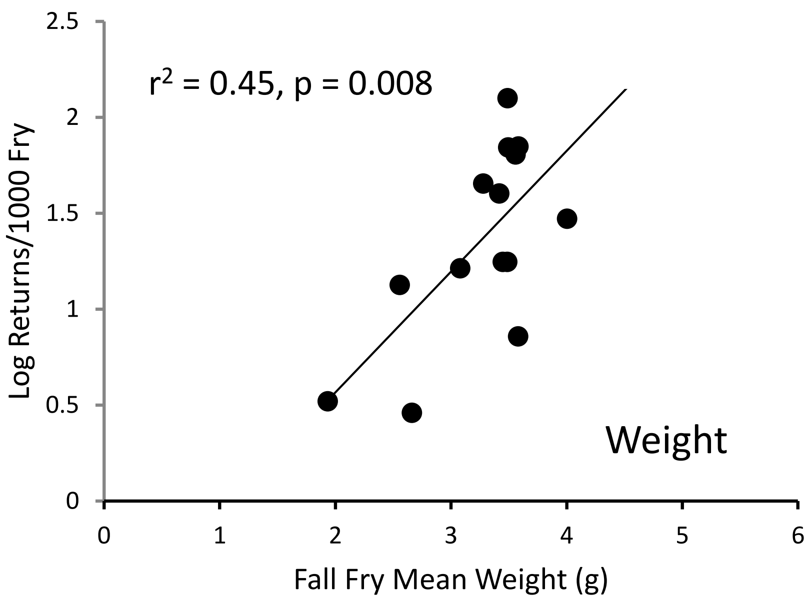
Dependency upon freshwater growth

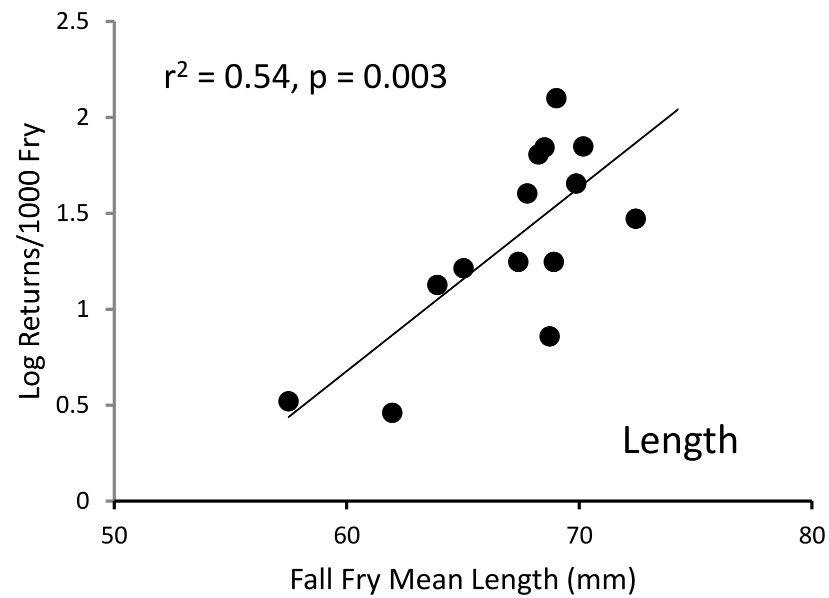


Koenings et al. 1993. Can. J. Fish. Aquat. Sci. 50: 600-611

Inter-Stage Freshwater Growth Effects

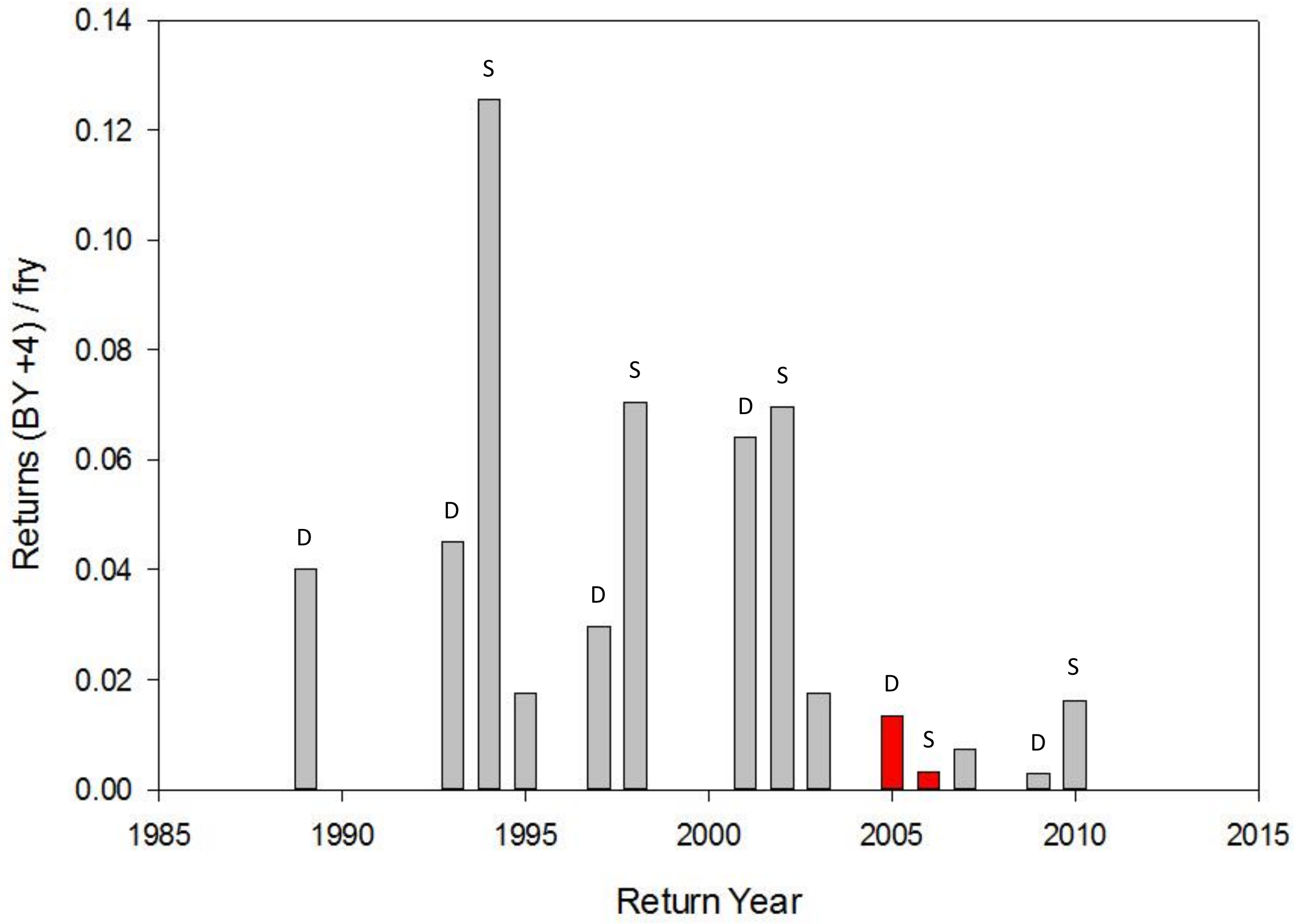
Post-Fall Sockeye Survival vs. Length & Weight





Overwinter & Marine Survival to Adult

Adult Returns/Fall Sockeye Fry

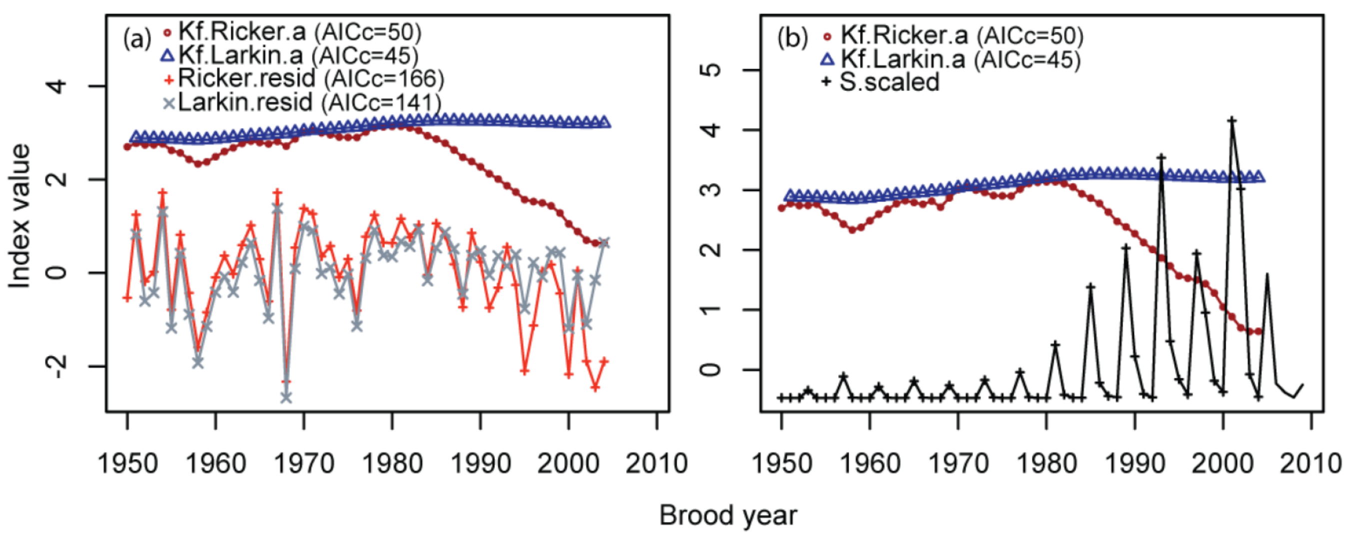


Delayed Density Dependence (DDD)

- Delayed Density-Dependence (DDD) (Brood Year Interactions)
    - Large escapements in a brood year negatively impact the brood and at least the following three broods (Peterman & Dorner 2011)
    - Explicit in Larkin S/R Model
    - A proposed explanation for cyclic dominance in Fraser sockeye
- Hypothetical Mechanisms for DDD
    - Dominant Cycle Line (1)
        - Simple density-dependent mechanisms (dominant brood year)
    - Successive Cycle Lines (2-4)
        - Disease on densely populated spawning grounds
        - Increased reproduction and survival of long-lived sockeye predators
        - Severe inter-annual depletion of nursery lake food webs

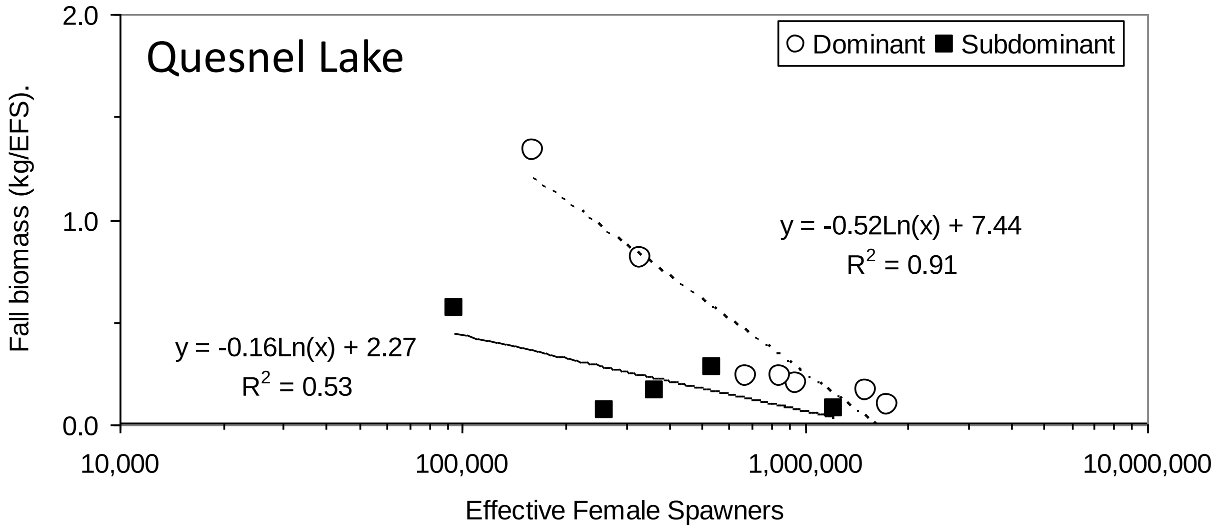
DDD: Fraser Stock-Recruit Evidence

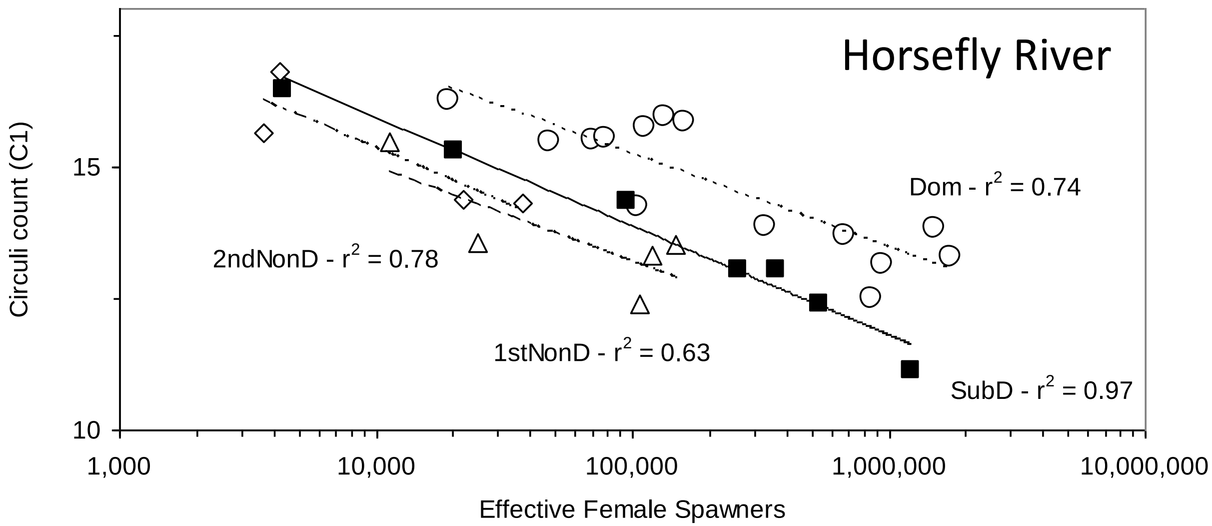
- Larkin vs. Ricker (Peterman & Dorner 2011)
  - Ricker Model – Stationary stock recruit
  - Larkin Model – Ricker model with cycle line interaction
  - Larkin better fit in 9 of 19 stocks
  - Quesnel, Scotch, Stellako – Larkin model best fit
  - Conclusion - DDD occurs in some stocks, but not all; Quesnel most pronounced evidence



Modified from Peterman and Dorner 2011, Cohen Commission Report #10

Evidence of Cycle Line Interactions





Woodey, Lapointe & Hume. *in prep*

Are there lessons to be learned from Alaska?

Lessons from Alaska

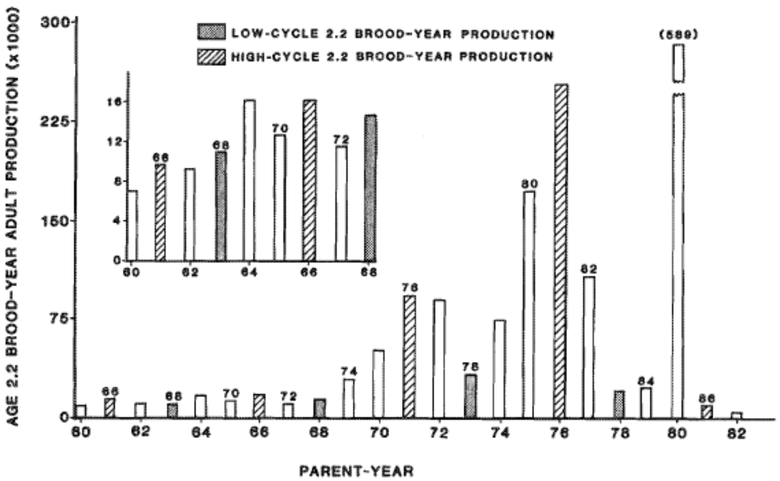
- Large Escapements & Productivity (Clark et al. 2007)
  - Long-term productivity declines & increased stock variability when escapement goals exceeded
  - Believed to be linked to surpassing nursery ecosystem productive capacity
- Delayed Density Dependence (Clark et al. 2007)
  - Detected DDD in 5 stocks with over-escapement
  - R/S fell below replacement for 2-5 yr following consecutive over-escapements (> 2x S_{max})

Lessons from Alaska

- Barren Lakes Experiments (Koening & Kyle)
  - Experimental sockeye introductions & fertilization
- Persistent Top-Down Effects
  - Restructuring of zooplankton community by sockeye can result in a resilient & resistant food web reinforced by modest planktivory
  - Severe/prolonged sockeye foraging can cause brood interaction & depression
  - Fertilization can re-establish bottom-up control, but time lags evident and potentially very long

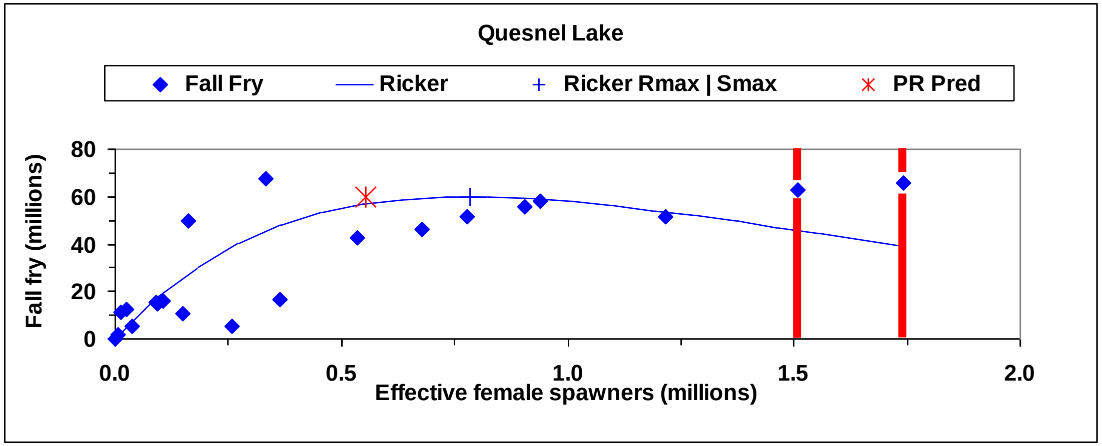
Lessons from Alaska

- Frazer Lake, AK
    - Sockeye introduced due to fish latter
    - Over-escapement resulted in collapse of dominant brood line and reinforcement of cyclic dominance



- Large escapements not independent (as per S/R assumptions)
    - Freshwater food webs are likely the linkage

Record Escapements

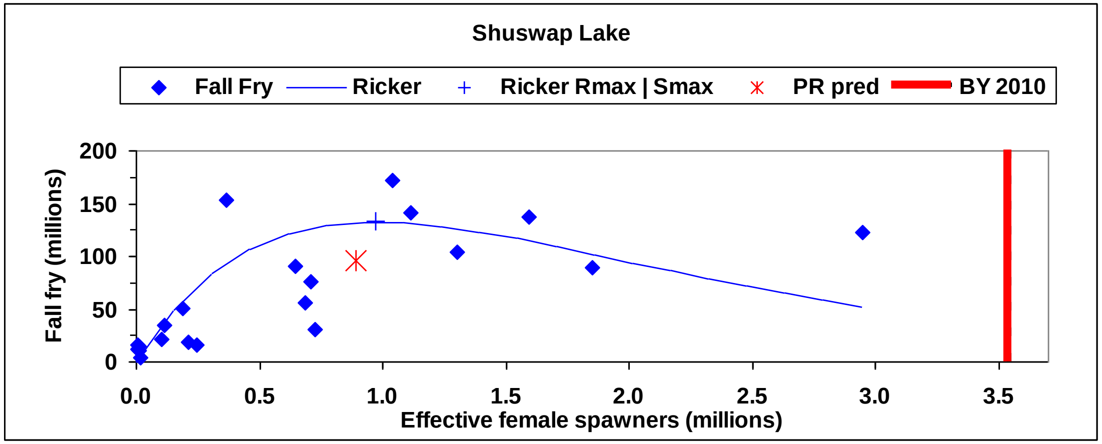


Quesnel (2001-02)

S/R_{adult}: 187-223% S_{max}

$S/R_{juvenile}$: 155-222% S_{max}

PR model: 280-334% S_{max}

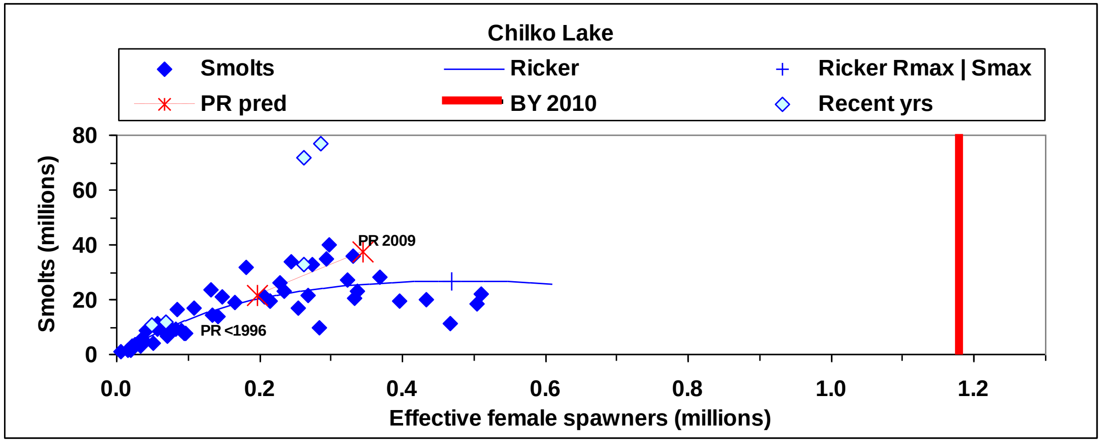


Shuswap (2010)

S/R_{adult}: 215% S_{max}

$S/R_{juvenile}$: 366% S_{max}

PR model: 481% S_{max}



Chilko (2010-11)

S/R_{adult}: 204-547% S_{max}

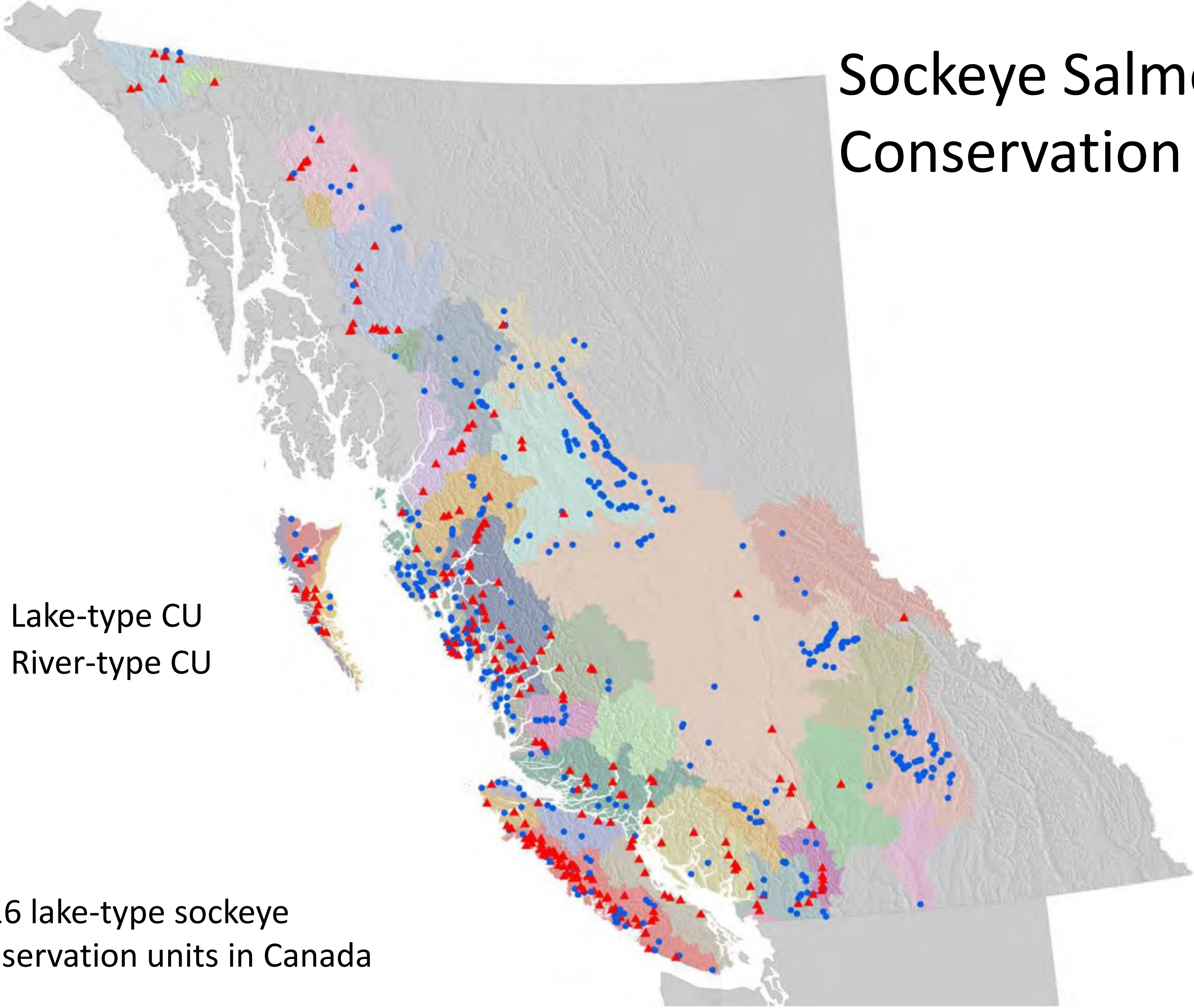
$S/R_{juvenile}$: 198-252% S_{max}

PR model: 151-357% S_{max}

Quesnel Summary

- Apparent Changes in Carrying Capacity
  - Forced by MDN variation at high escapements
  - Apparent long-term increase in photosynthetic rates and PR model carrying capacity estimates
- Trophic Interactions, Freshwater Growth & Survival
  - Trophic energy transfers can be largely interrupted by dead ends
  - Top-down forcings erode bottom-up influences at high densities
  - Ultimate impacts on juvenile condition and possibly late-lake/marine survival, which may be persistent
- Delayed Density Dependence (DDD) Potential
  - Peterman et al. (2010) & Peterman and Dorner (2011) found only Quesnel showed striking evidence to date
  - Supporting evidence from juvenile data (Woodey et al. *in prep*)
  - Are there concerns for other stocks?

Sockeye Salmon Conservation Units



~216 lake-type sockeye conservation units in Canada

Holtby and Ciruna 2007, CSAS Res. Doc. 2007/070