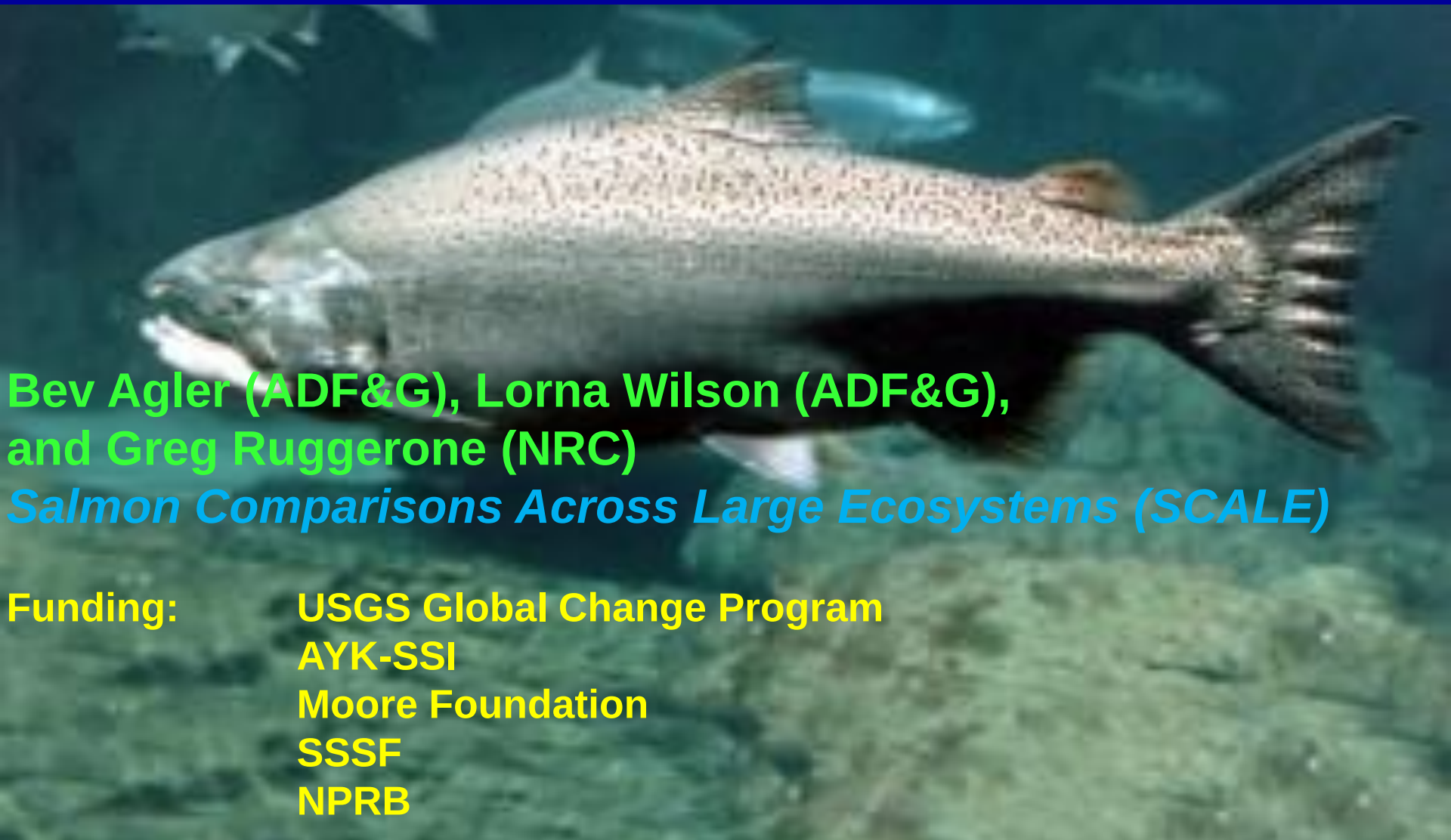
Using salmon scales to test hypotheses about salmon growth, climate, and carrying capacity

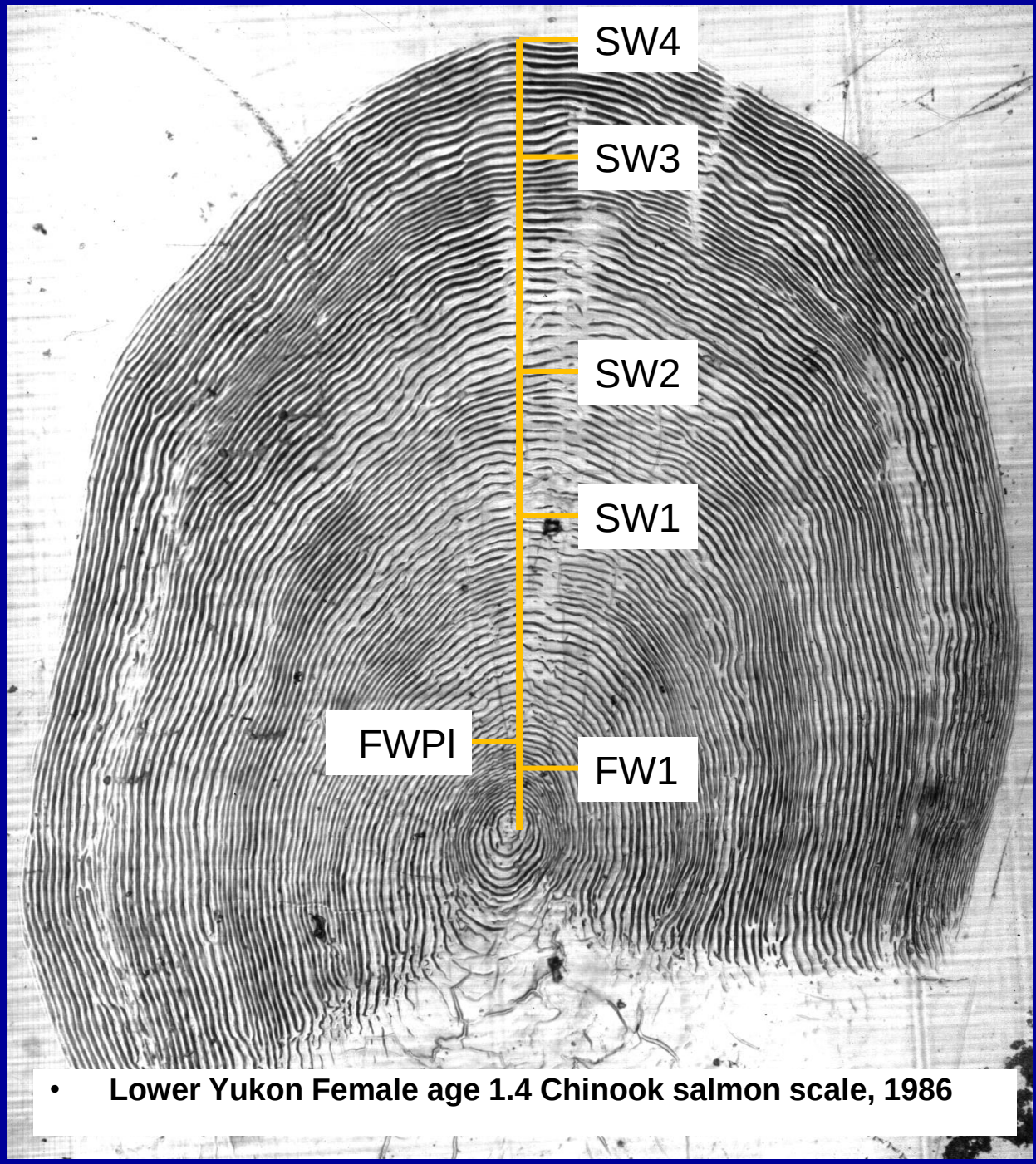


Bev Agler (ADF&G), Lorna Wilson (ADF&G), and Greg Ruggerone (NRC)

Salmon Comparisons Across Large Ecosystems (SCALE)

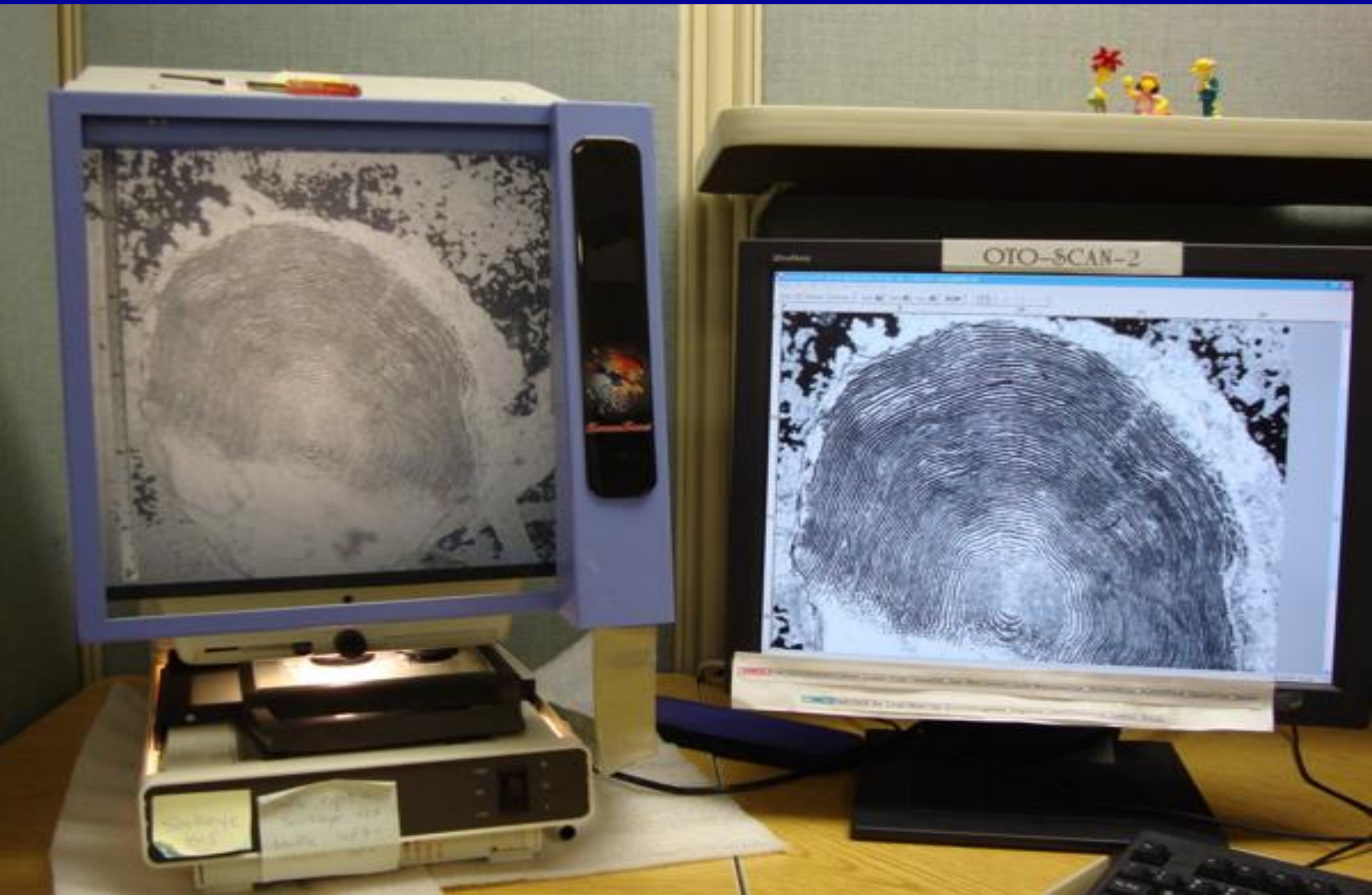
Funding: USGS Global Change Program
AYK-SSI
Moore Foundation
SSSF
NPRB

Salmon Scales: “the natural data logger”



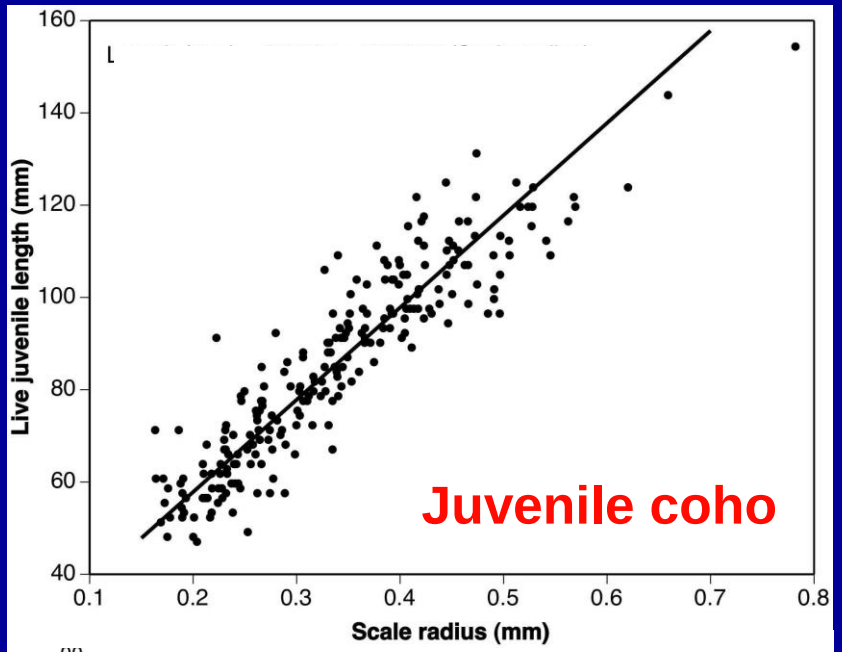
- **Lower Yukon Female age 1.4 Chinook salmon scale, 1986**

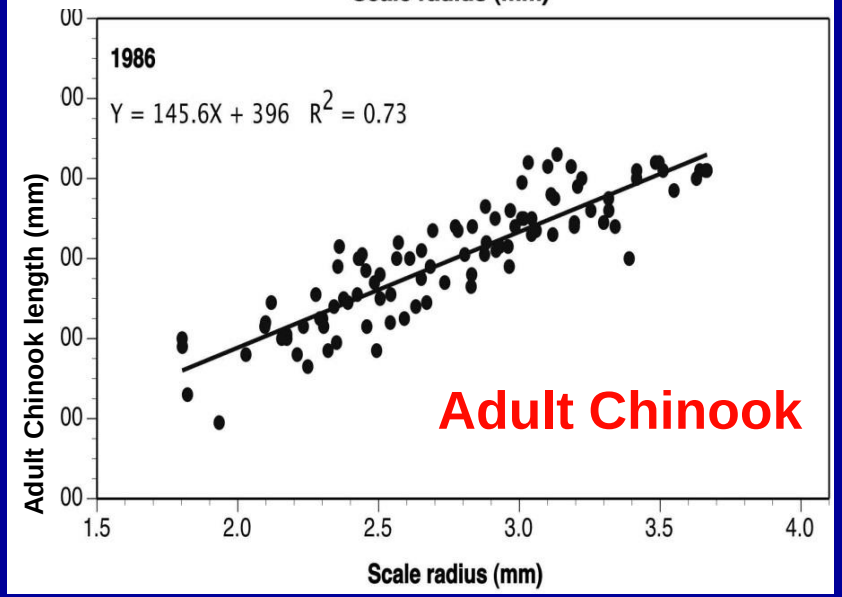
Scale Digitizing Equipment



Circuli & Annuli Measurements

- Scale growth as proxy for overall growth
- Mean growth per year
- 50 scales per year per age

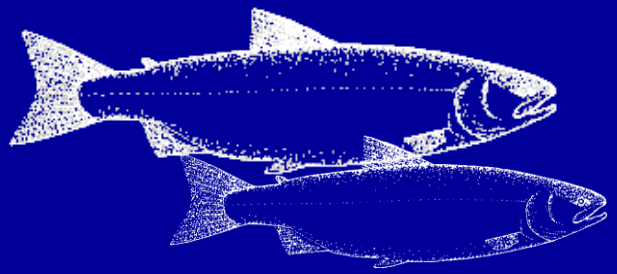




Scale Measurements

- 43 salmon stocks measured
- Measurements stored in ORACLE database
- Dominant ages by species and stock
- ~9.6 million measurements
- Terrabytes of data – storage is an issue!

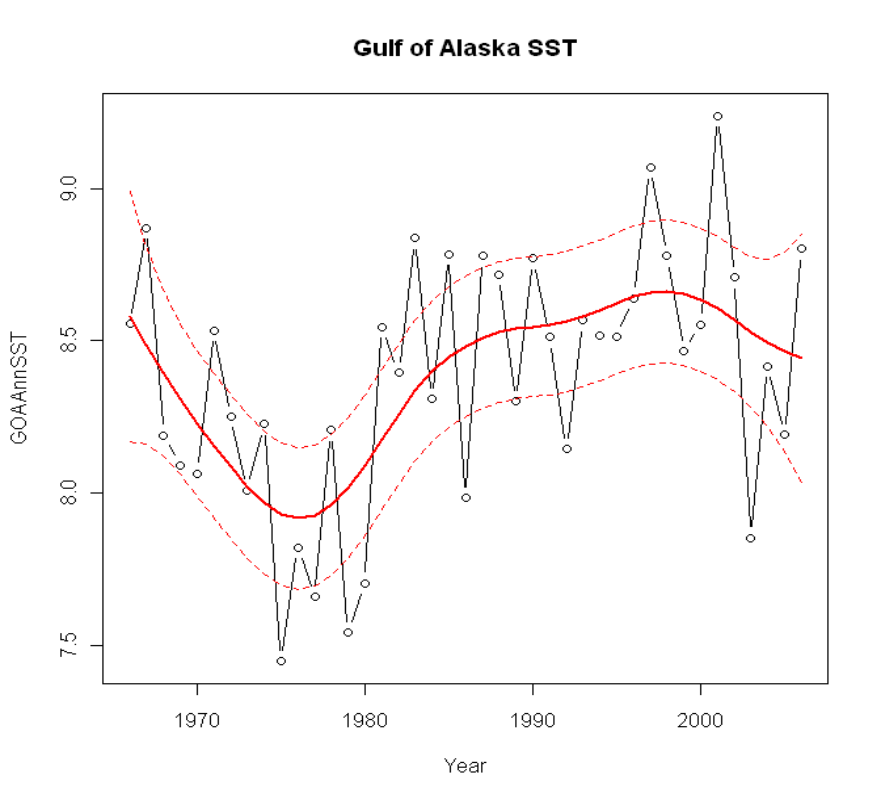
Why?



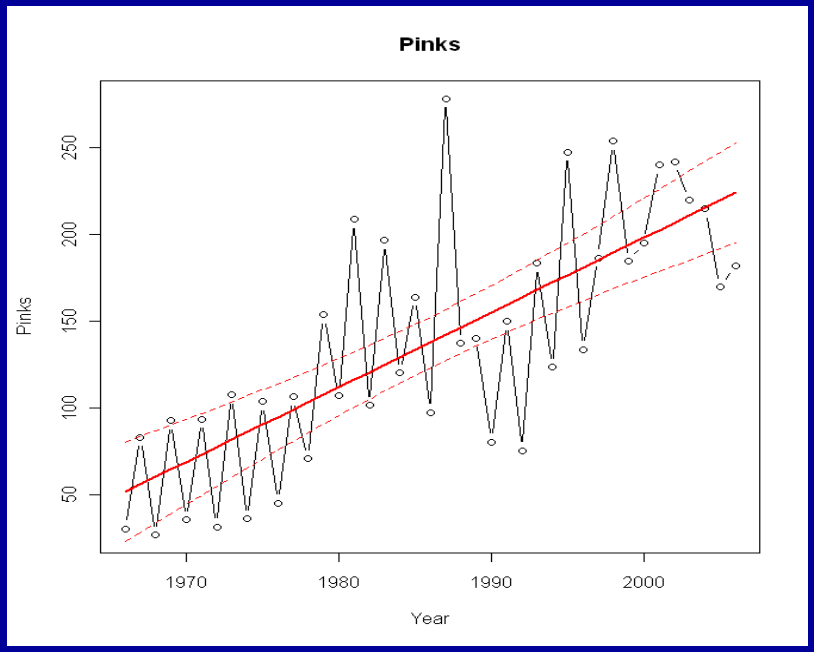
- Life and growth histories
- Climate change
- Competition – species interactions
- Relate to abundance data – Survival
- Juvenile histories and watershed characteristics
- Relate juvenile growth to spawning escapements
- Relate with smolt data – Selectivity

Explanatory Variables

SST from specific areas

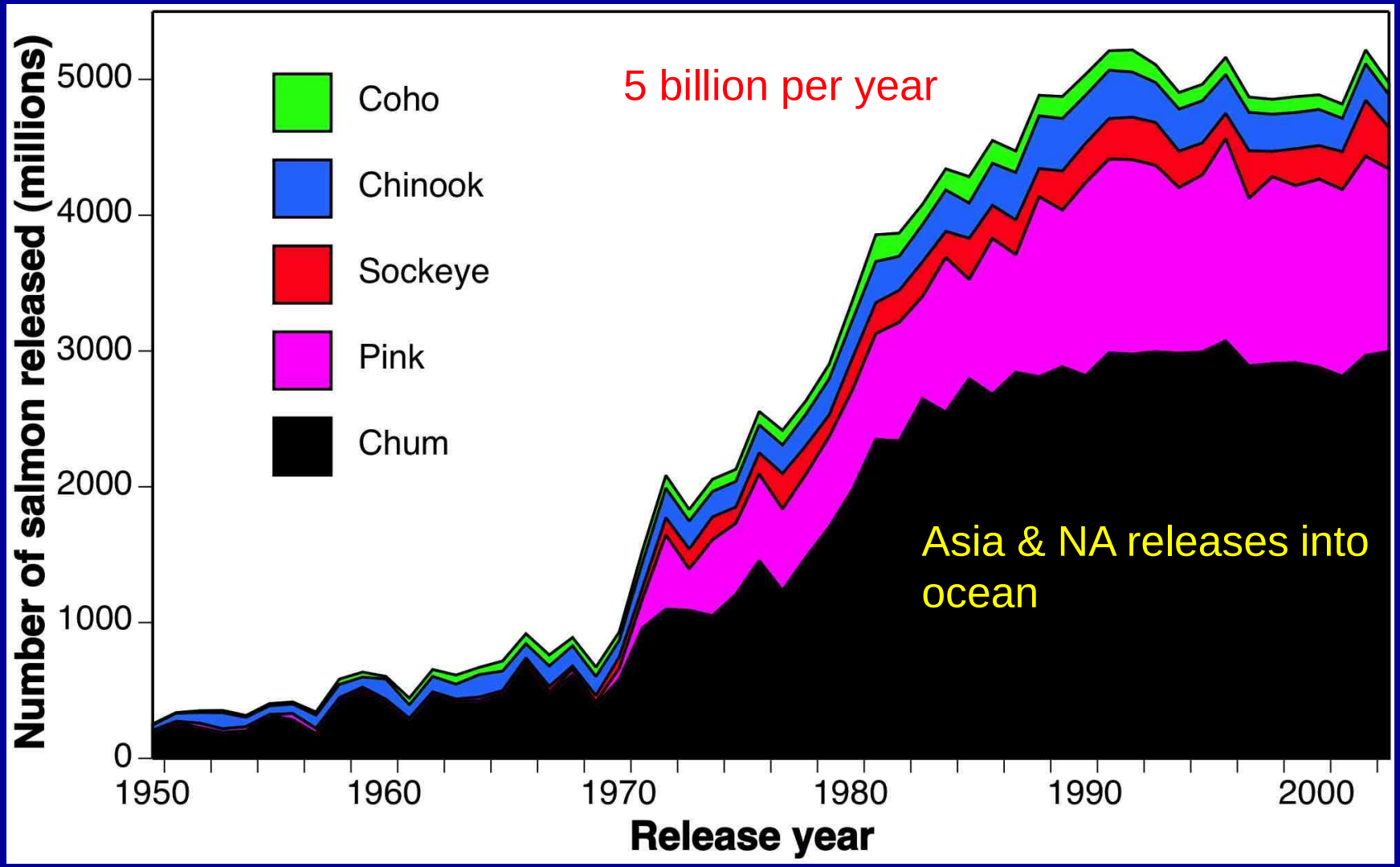


Pink salmon abundance - total catch and escapement - Russia

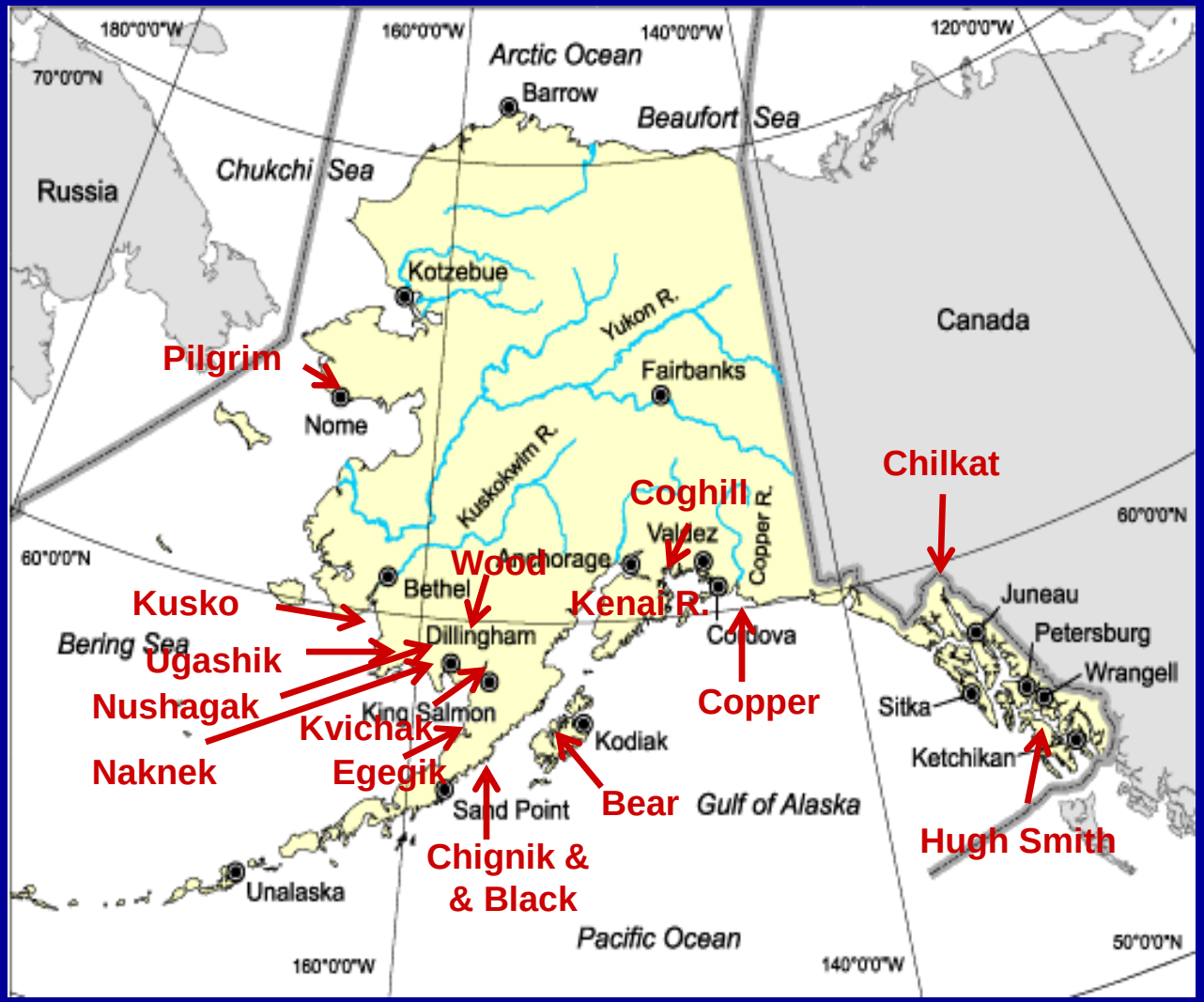


Data: Ruggerone et al. 2010 and NPAFC website

No. of Hatchery Releases Potential for Competition?



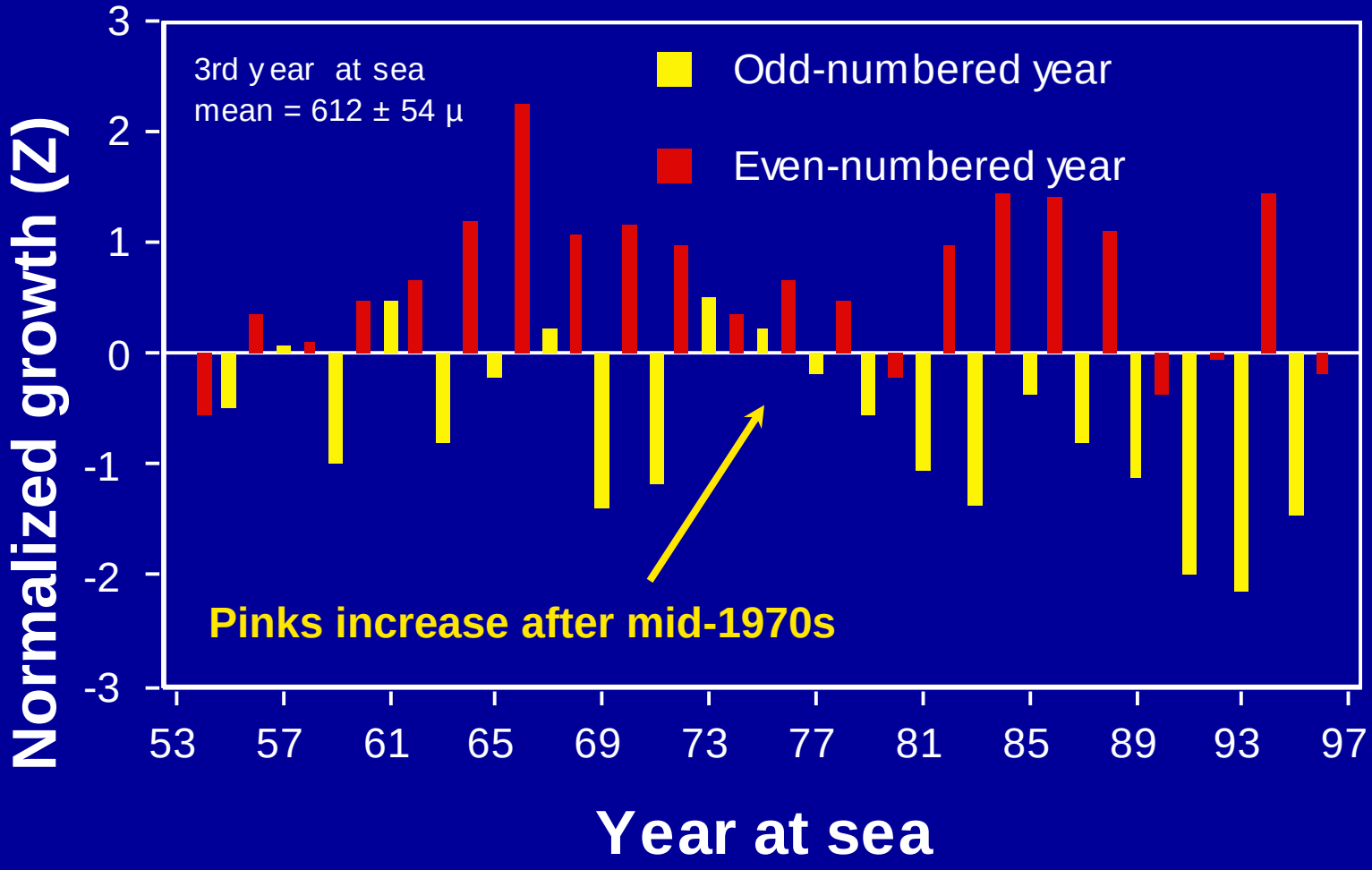
Sockeye Salmon Samples



Samples from 16 AK stocks

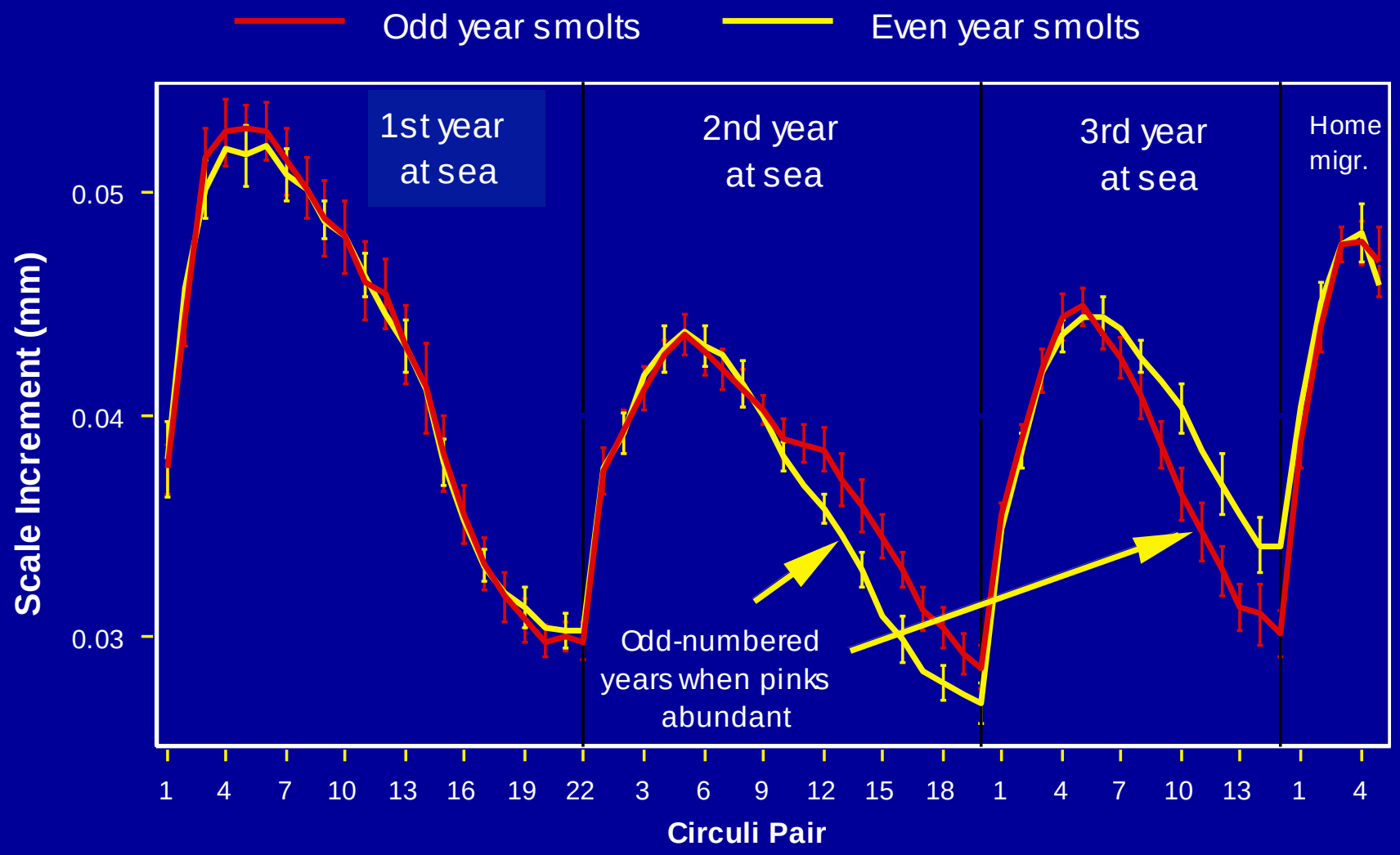
Also Bering Sea Juveniles and Immatures

BB sockeye scale growth reduced during odd years at sea (SW2 & 3)



Ruggerone et al. 2003

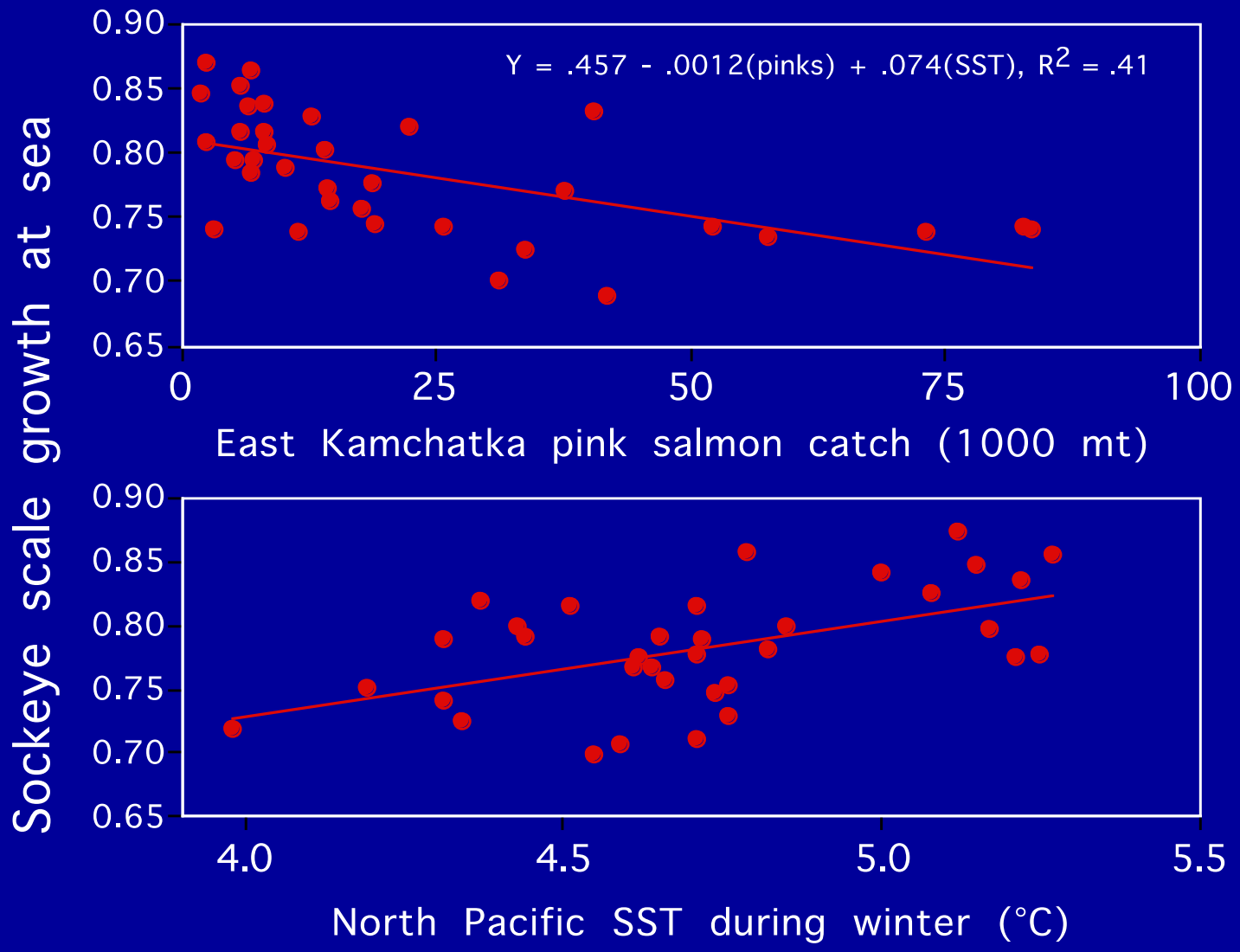
Seasonal scale growth during odd & even years at sea, 1955-2000



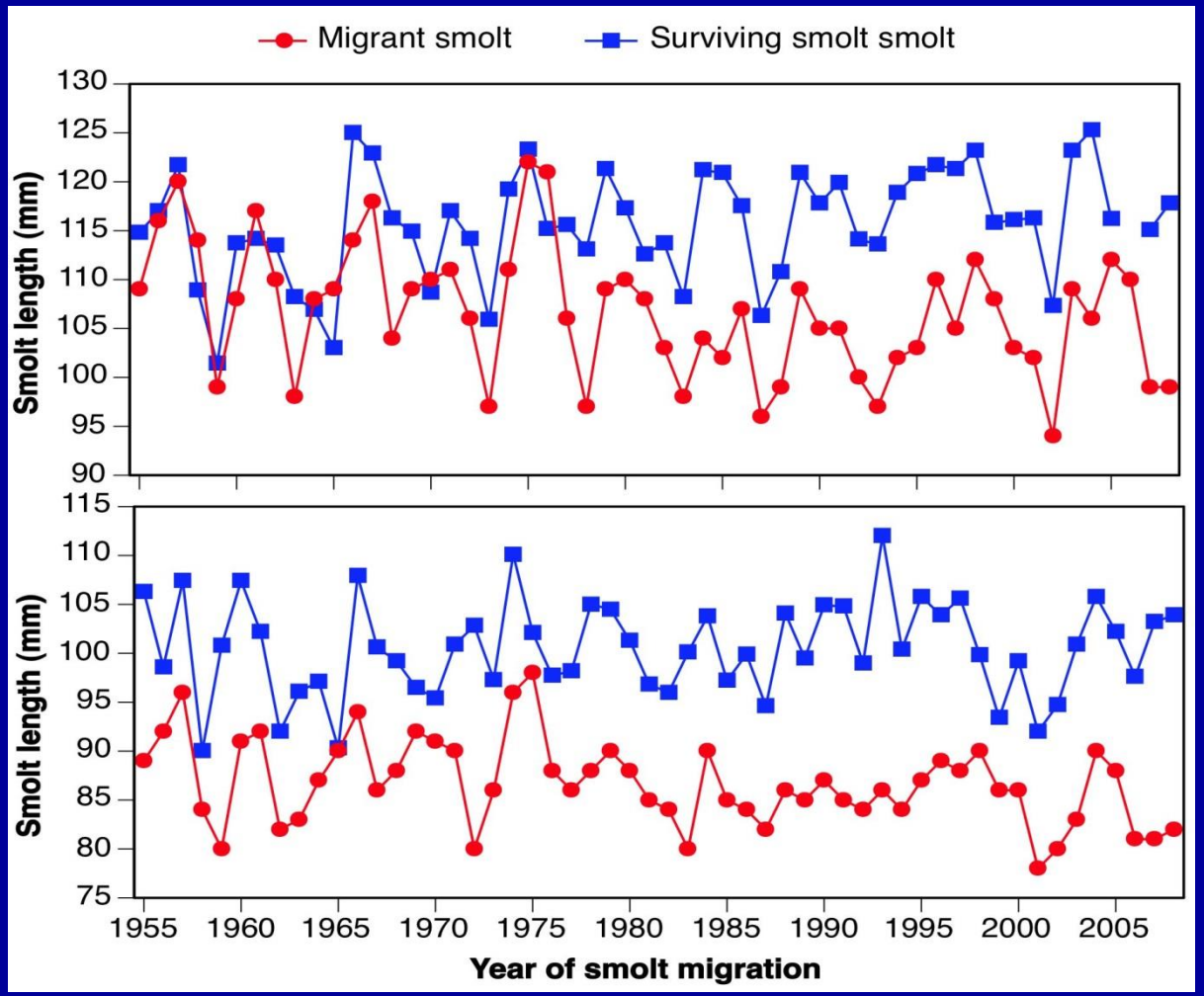
Ruggerone et al. 2005

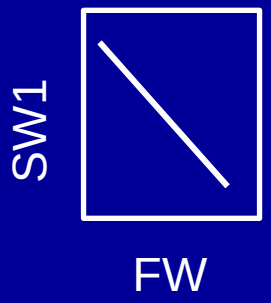
Competition and temperature effects on salmon scale growth

SW2



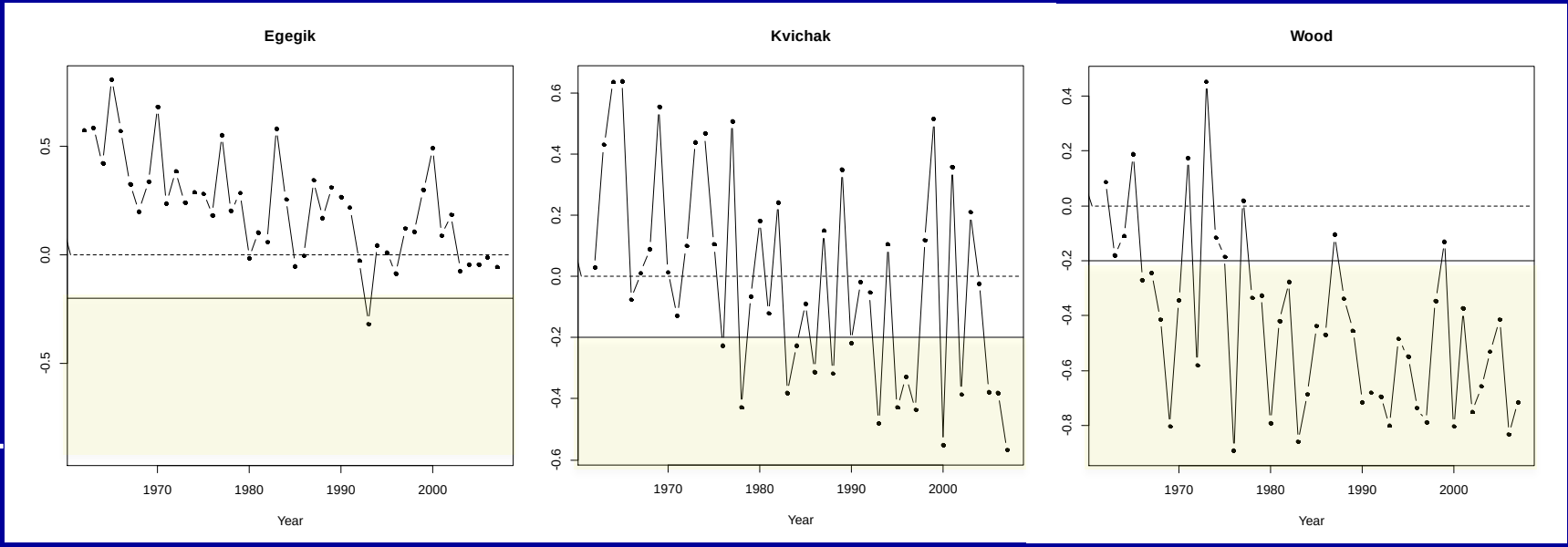
Length of migrating and surviving Kvichak smolts, 1955-2008





Compensatory growth

Slope coefficients



Weak	Intermediate	Strongest
Trending to increased compensatory growth	Increased when smolt were larger & after 1977.	Significant regime effect
No regime effect	No regime effect	
0.55AR(1), 0.28AR(2)	-0.11smolt size, 0.56AR(5)	-0.48Regime

Courtesy Ellen Yasumiishi, NOAA

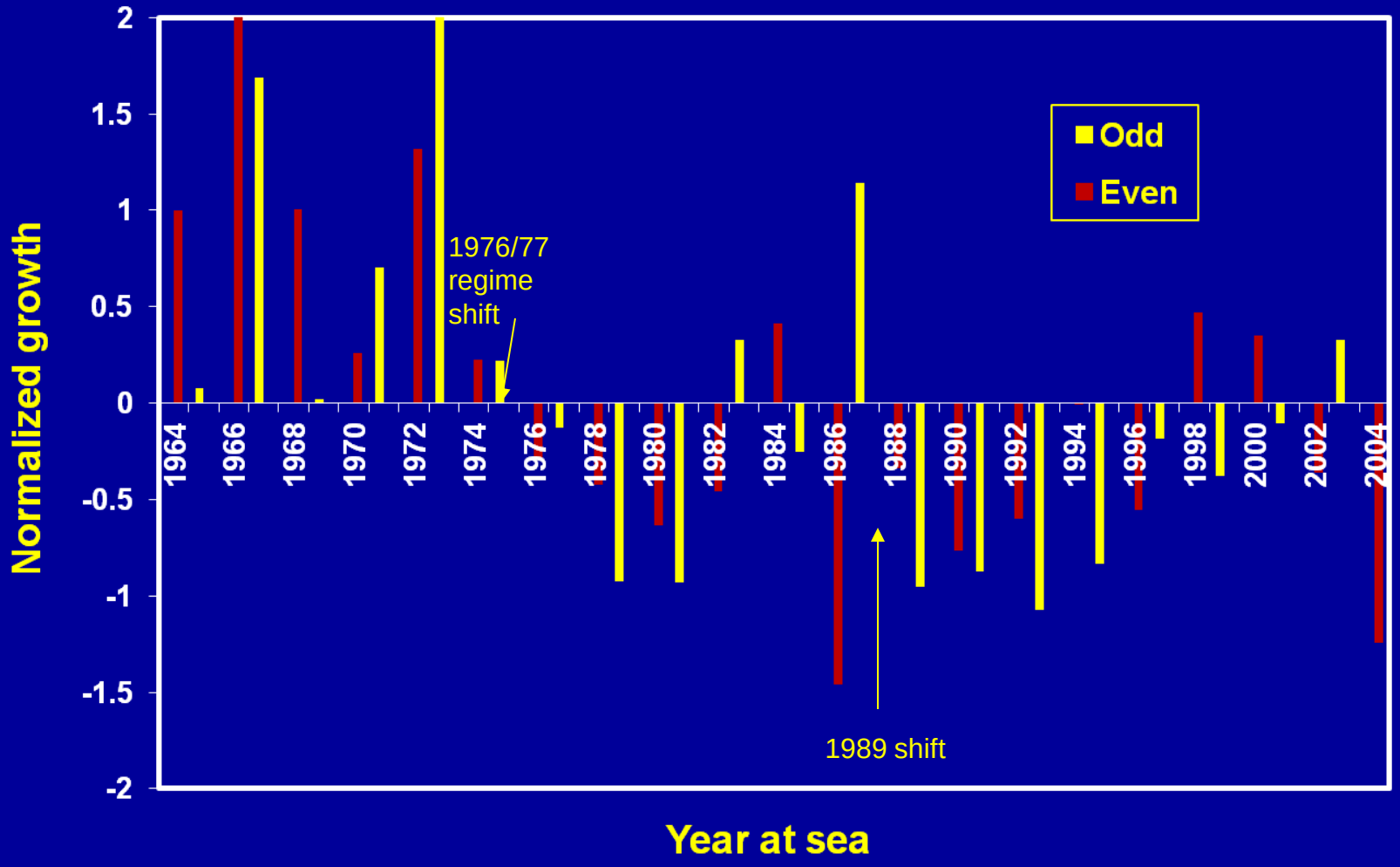
Chum salmon samples

- Norton Sound – Unalakleet R 1975-2006 & Kwiniuk R 1969-2006
- Yukon R – 1965-2006
- Kuskokwim R – 1967-2007
- Bristol Bay – 1966-2006
- Russia – Anadyr R 1962-2007
- Japan – Chitose R 1976-2008

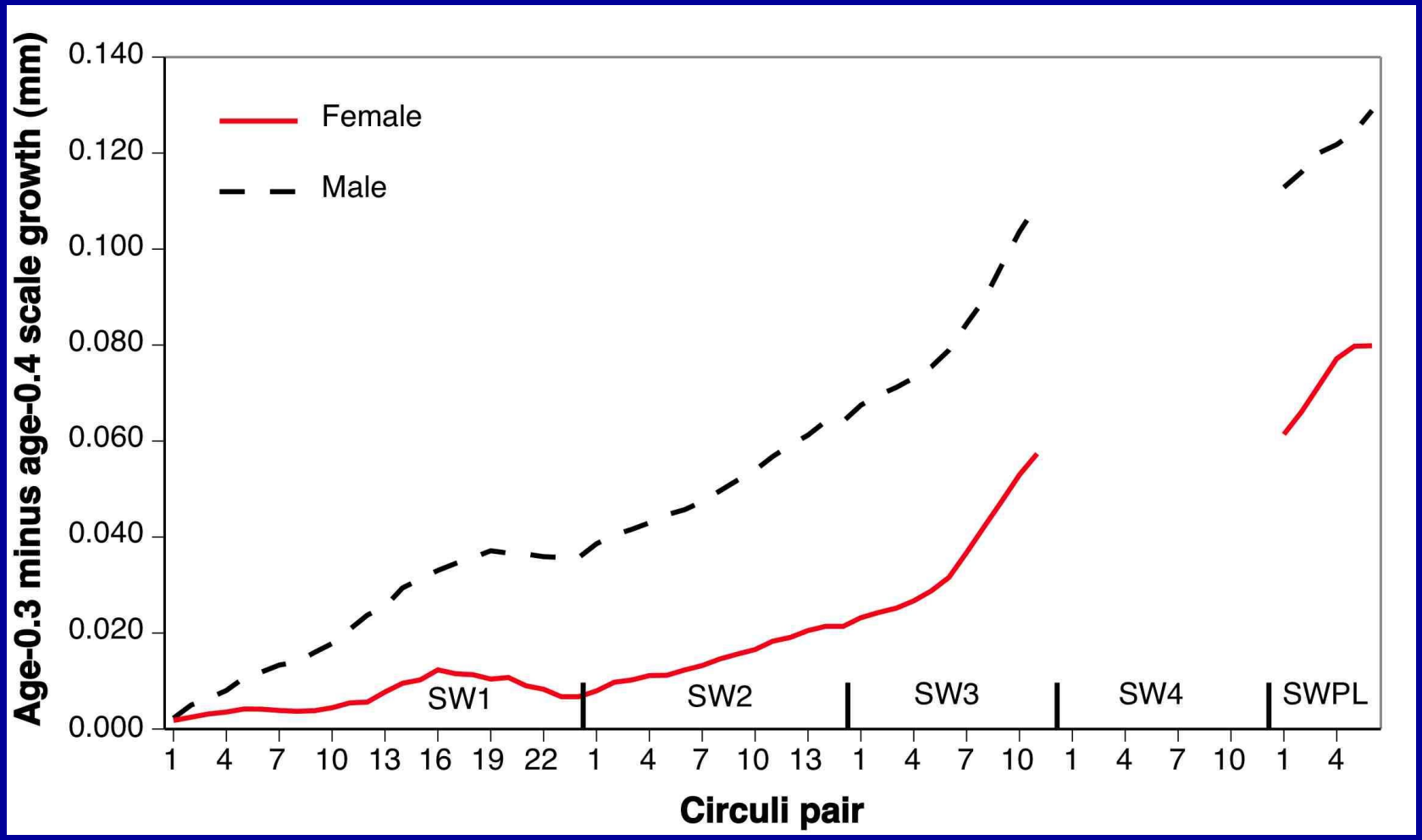
Also have unanalyzed:

- Yukon River Fall
- Upper Cook Inlet
- Taku R.
- Kotzebue

BB SW3 growth during even vs. odd years at sea



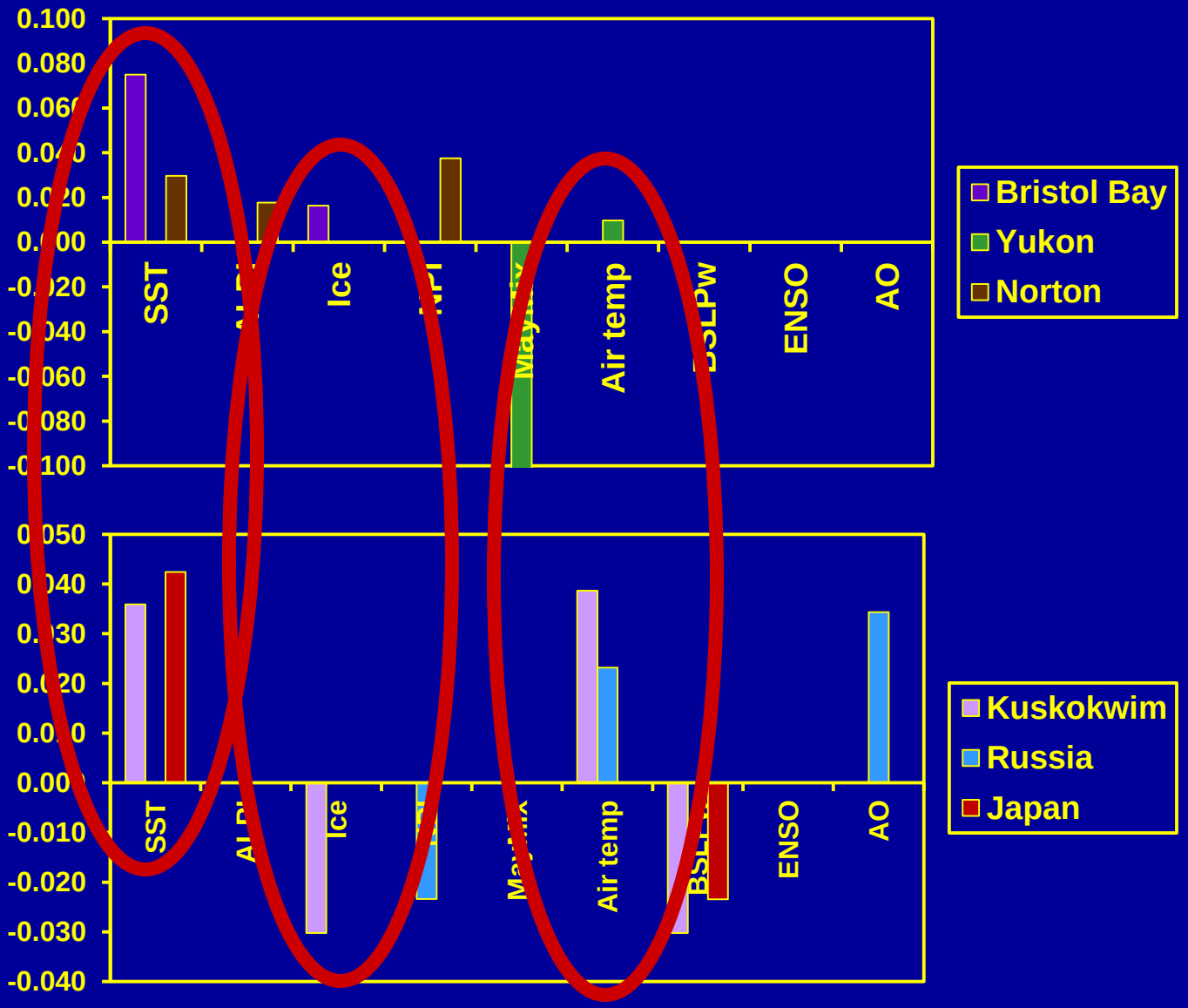
Greater growth of age 0.3 chum begins immediately



Are there climatic factors that affect growth of chum salmon?

Best models

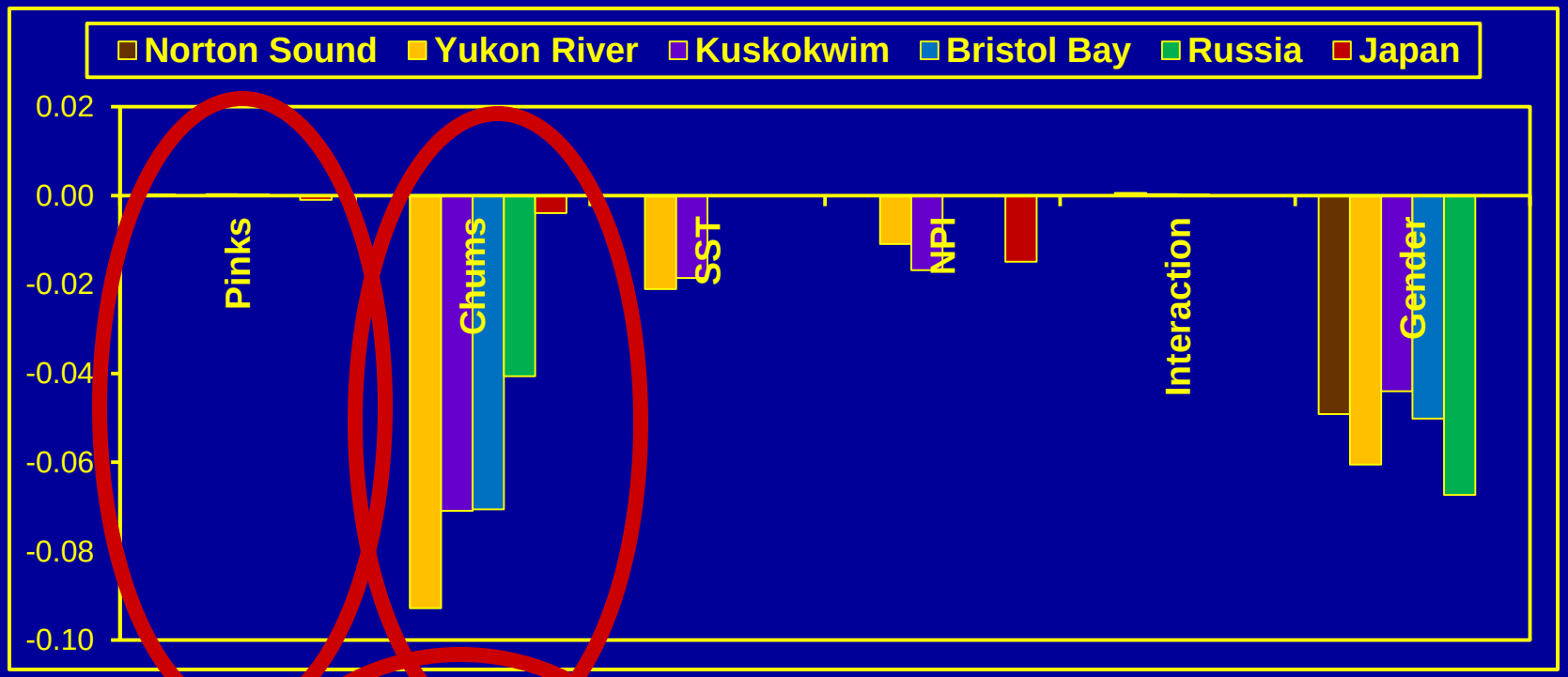
SW1
Age 0.3



What affects growth?

Best models

SW3 – Age 0.3



Norton Sound: SW3 = Pinks + Gender

Yukon River: SW3 = Pinks + Asian chums + NP SST + NPI + Interaction + Gender

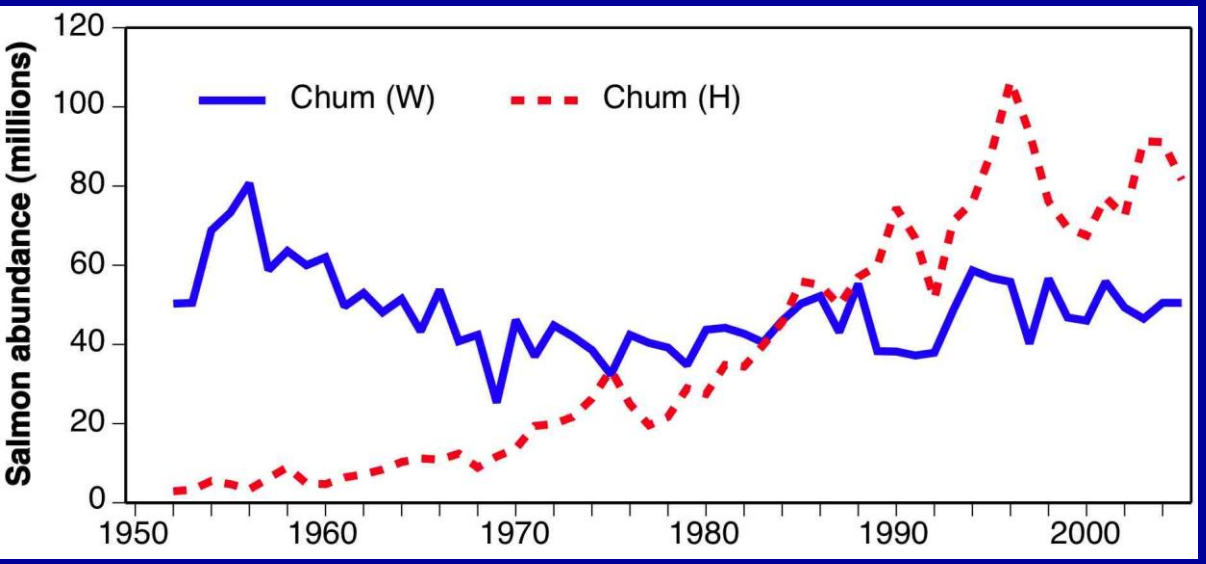
Kuskokwim R: SW3 = Pinks + Asian chums + NP SST + Interaction + Gender

Bristol Bay: SW3 = Pinks + Asian chums + Interaction + Gender

Russia: SW3 = Asian chums + Gender

Japan: SW3 = Pinks + Asian chums + NPI + Interaction

Do AK chum compete with Asian chum salmon?

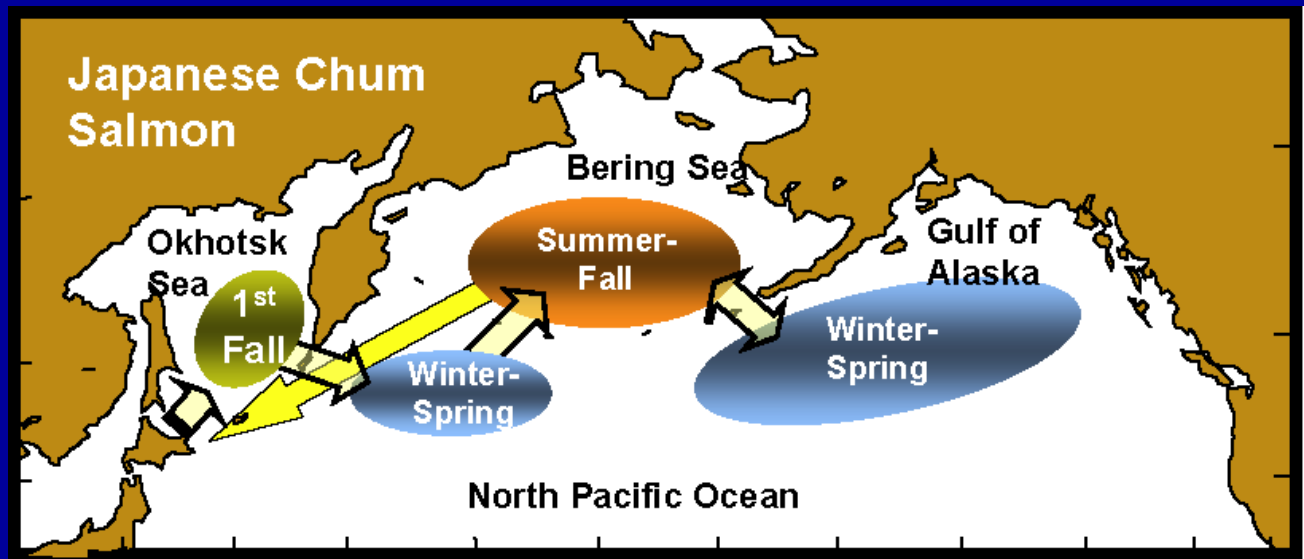


Wild chum did not increase after 1977; hatchery chum (mostly Japan)

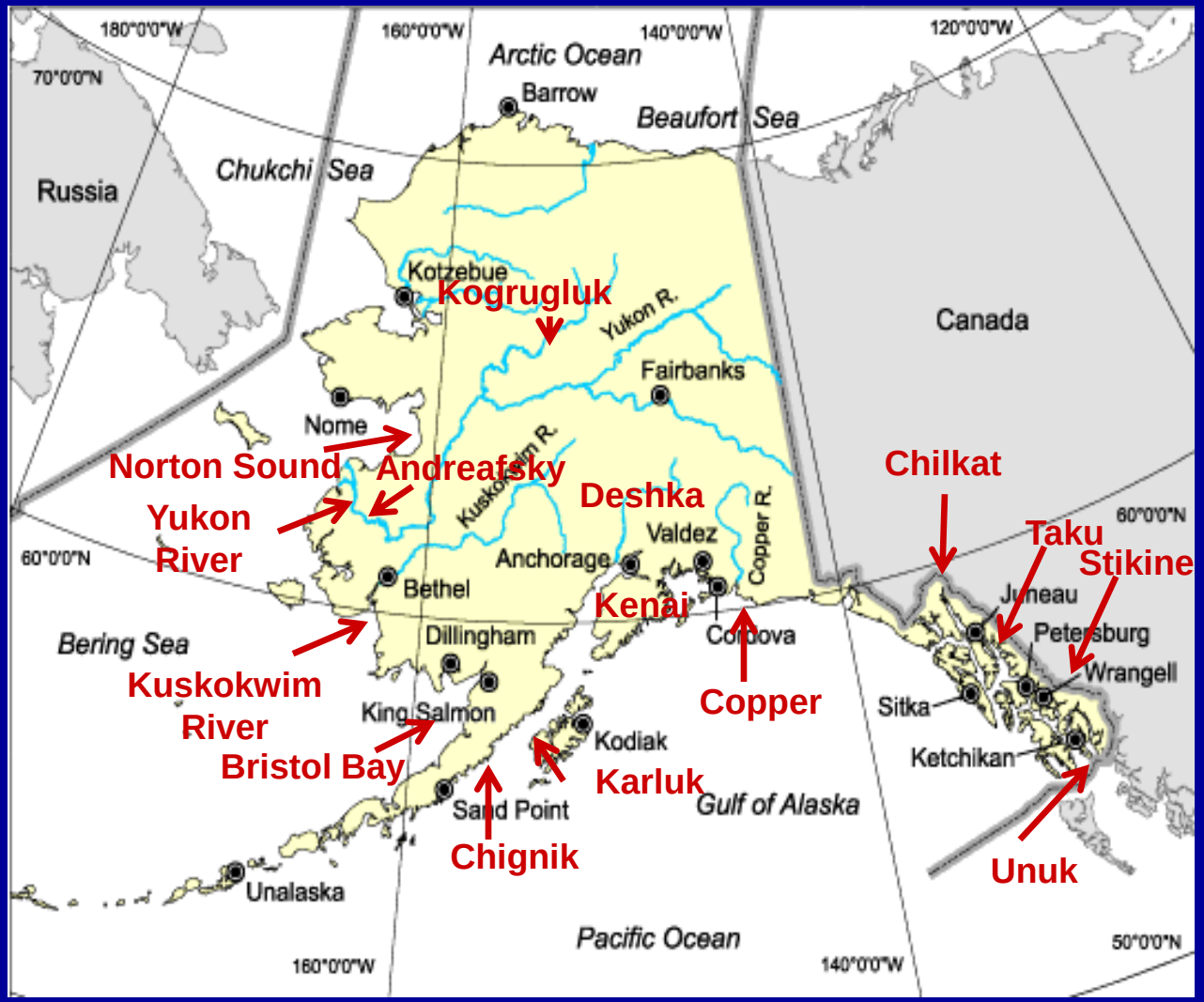
Ruggerone et al. 2010

AYK chum overlap Japanese hatchery chum salmon

K. Myers, UW
Urawa et al. 2008



Chinook salmon samples

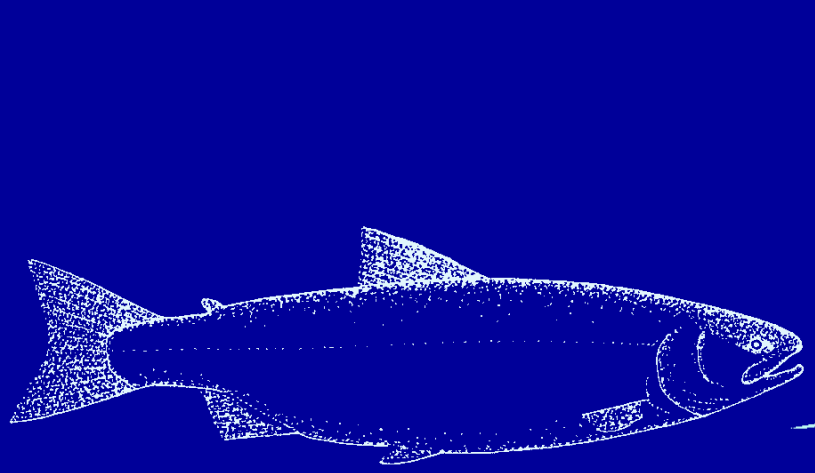


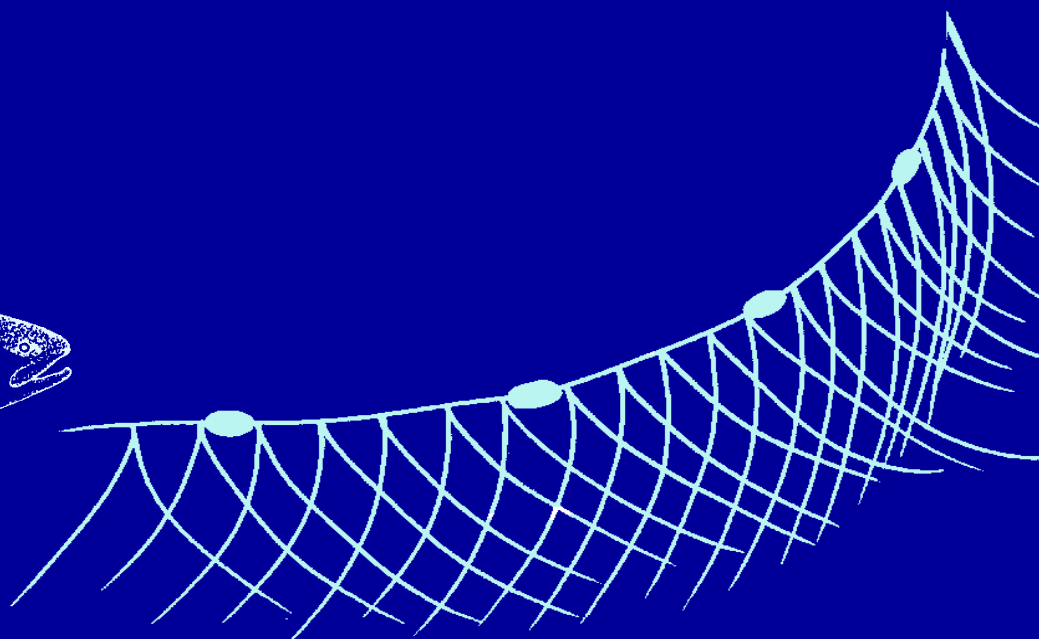
Current scale Samples from 4 W AK regions

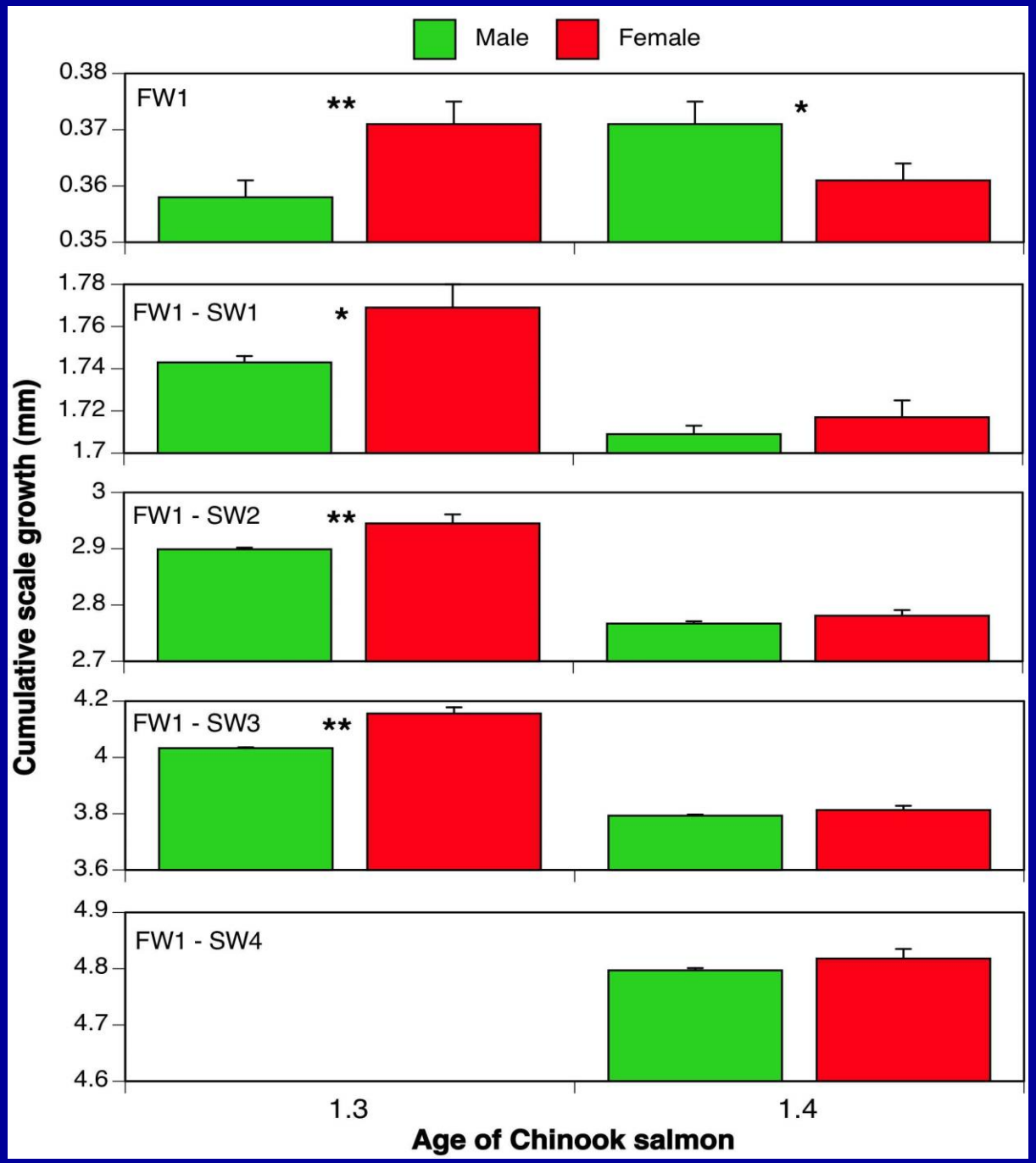
Beginning 12 system statewide project, plus 2

Chinook salmon hypotheses

- Growth is related to climate
- Growth of individual depends on previous growth
- Indirect effect of pink salmon on growth
- Sexual dimorphism begins at early age
- Growth especially important to female Chinook







Female > Male growth

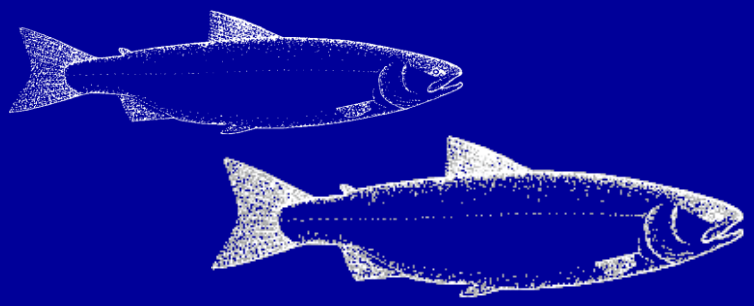
Female mean cumulative scale growth greater than males for age 1.3 Nushagak Chinook salmon

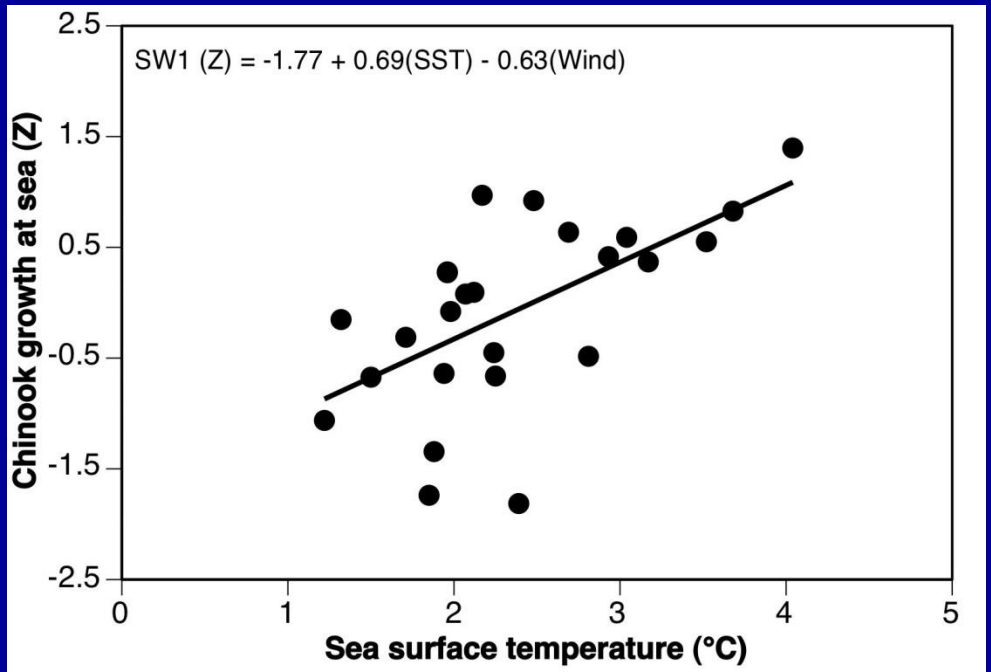
BB Chinook results

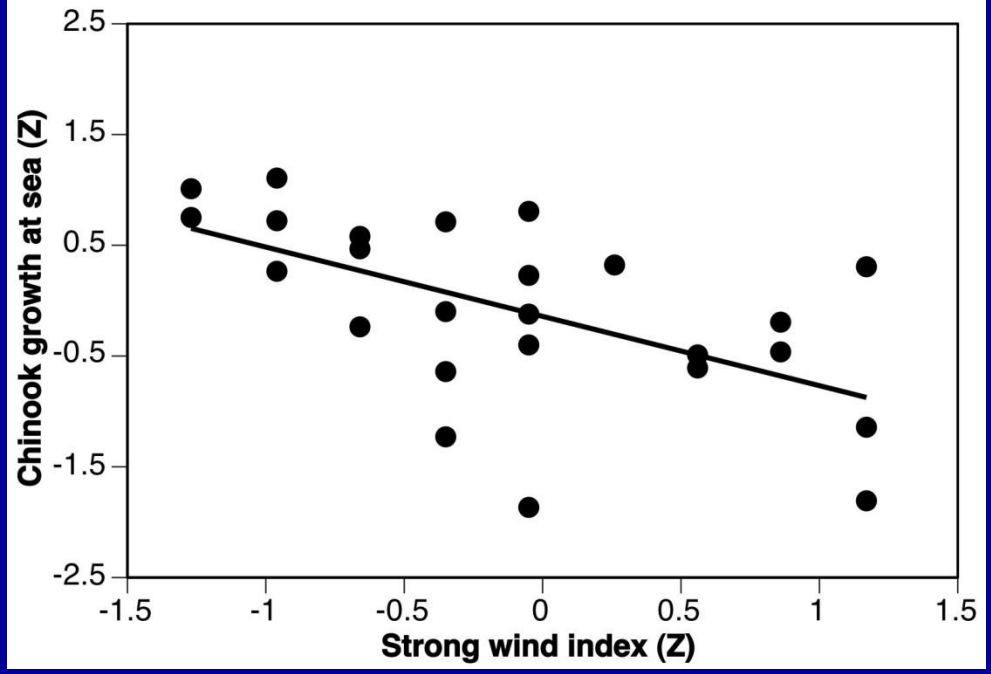
SW1

May SST in SE Bering Sea and strong wind index (negative).

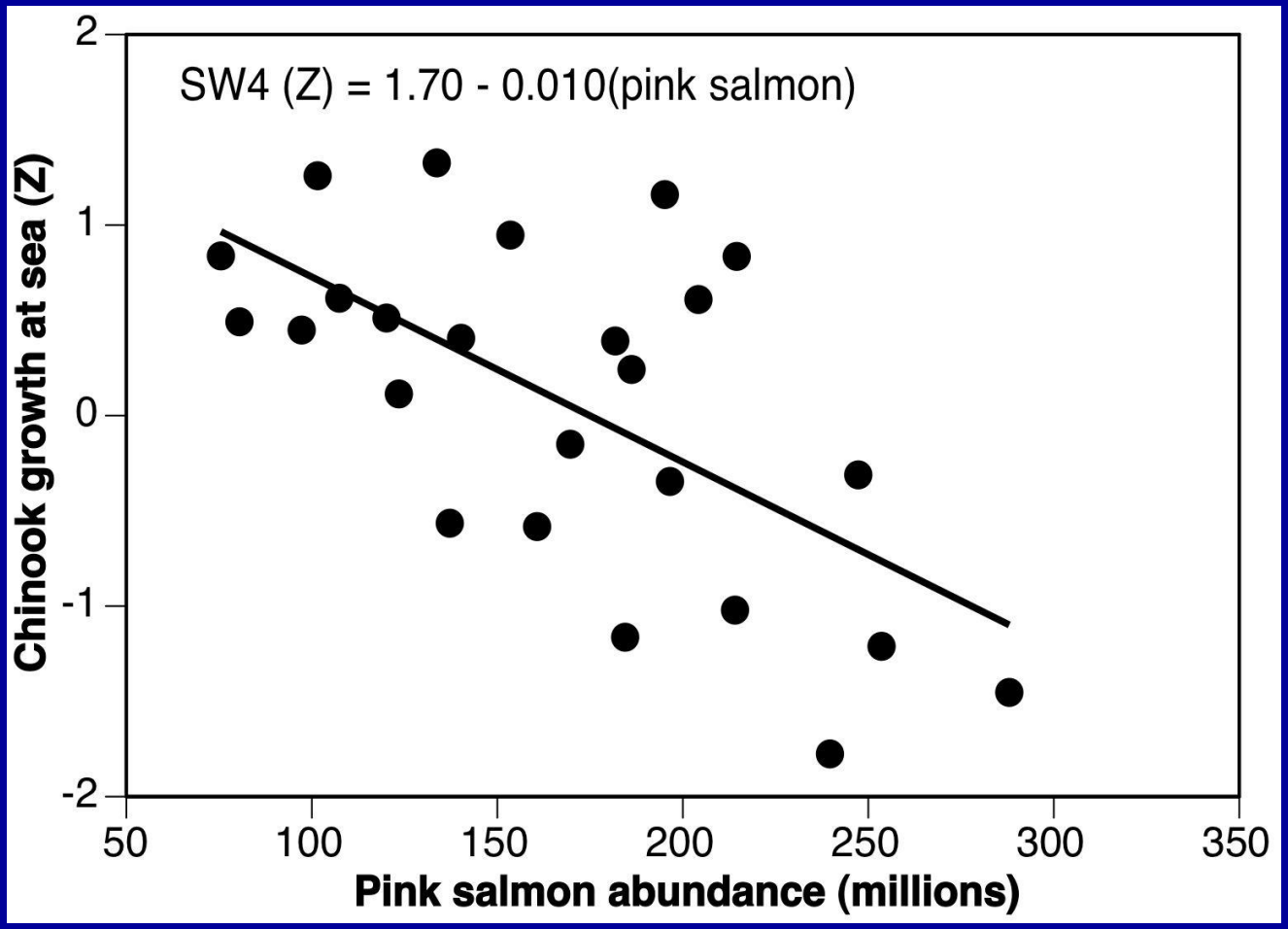
$R^2 = 0.50$







BB Chinook & pink salmon

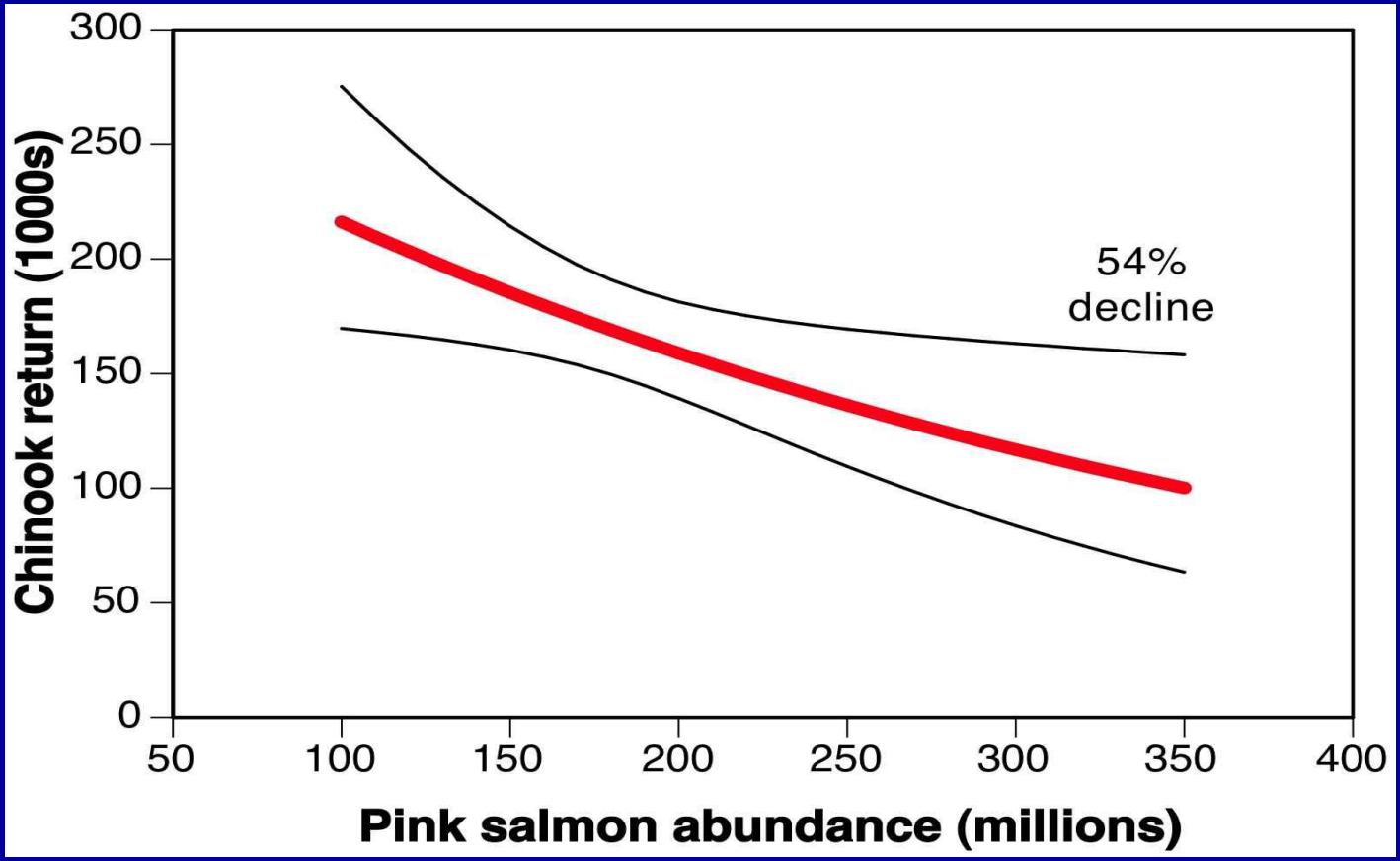


SW4

Growth was negatively correlated with pink salmon abundance.

$R^2 = 0.36$

BB Chinook & pink salmon



Parent spawner abundance and SST were held constant as pink salmon varied.

Conclusions

- Chum salmon, intraspecific competition likely.
- Female Chinook larger at age, older, and less abundant than males.
- Sockeye & Chinook – interspecific or indirect competition with pink salmon?
- Examine selectivity, growth, abundance.

- Salmon scales provide annual and seasonal growth data that can be used to test difficult hypotheses.
- Long-term scale collections are key.

Acknowledgements

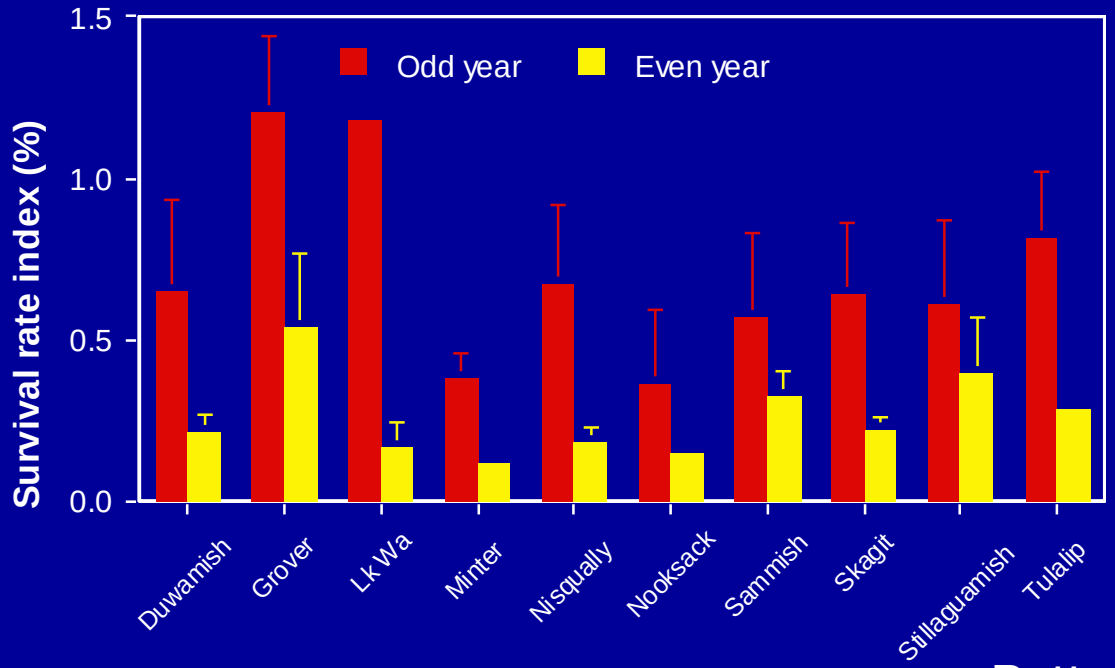
Co – Principal Investigators:

Dr. Pete Hagen, NOAA
Dr. Jennifer Nielsen, USGS, retired
Dr. Ed Farley, NOAA
Jim Murphy, NOAA
Dr. Katie Howard, ADF&G
Dr. Ellen Yasumiishi, NOAA
Dr. Kate Myers, UW, emeritus
Dr. Bill Smoker, UAF, emeritus
Dr. Franz Mueter, UAF
Dr. Gordon Kruse, UAF
Dr. Milo Adkison, UAF
Dr. Megan McPhee, UAF

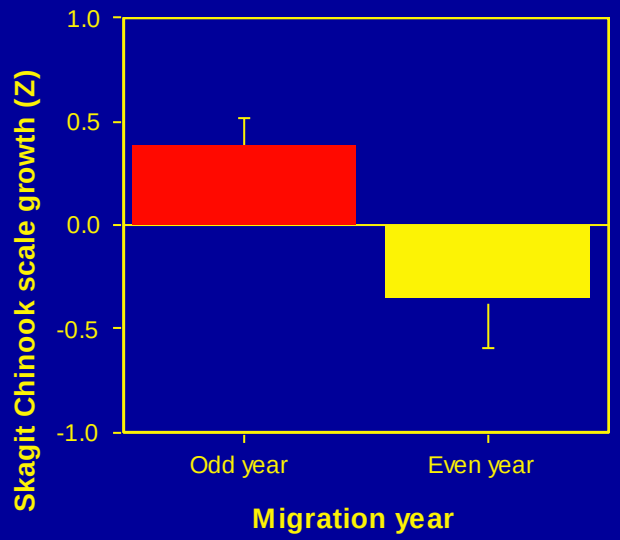
Many readers and digitizers
Regional ADF&G staff provided scales and information
MTA Lab IT staff: Tim Frawley, Bil Rosky, Bill Johnson

Chinook survival 62% lower in even years w/ pinks, 1984-97

Survival



Growth



Cascading food web link?

Effect occurs in 1st yr

No effect WA Coast - no pinks

Pattern shift after 1982/83 El Nino

Warm climate favors pinks

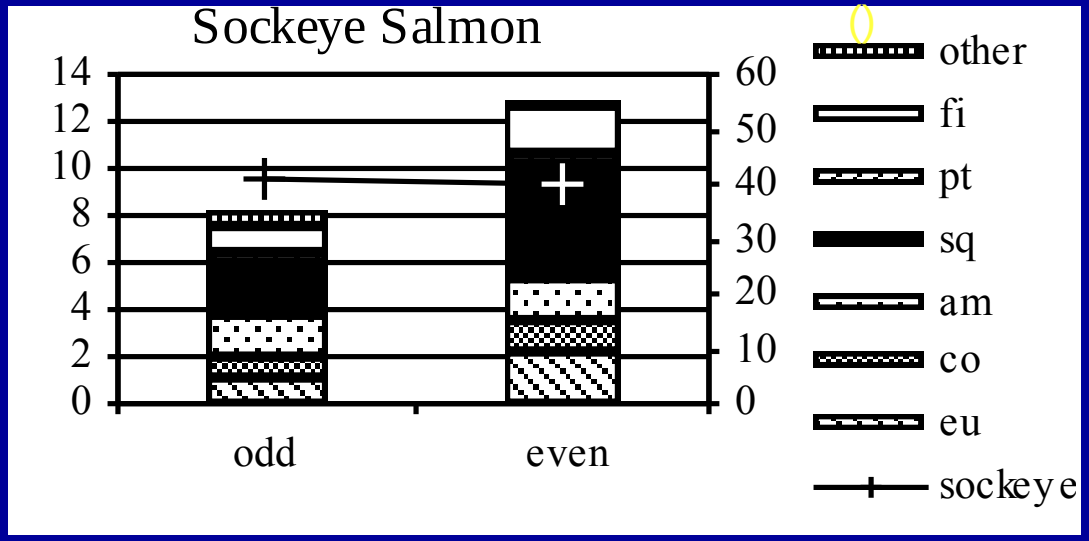
Pinks enter ocean early

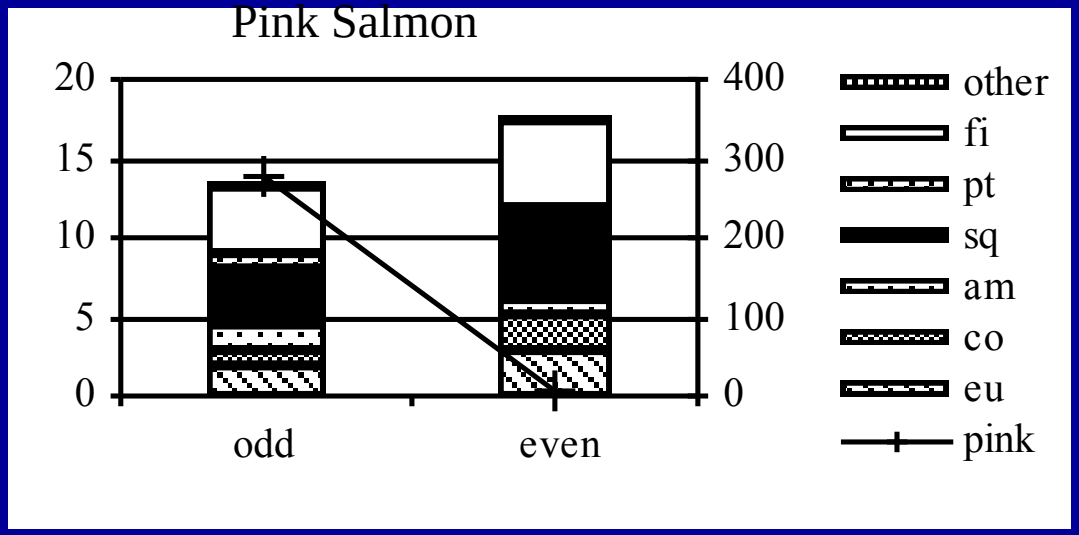
Severe predator decline

Ruggerone & Goetz 2004

Unpublished scale analysis

Sockeye & Pink Salmon Diet Overlap in Bering Sea, 1991-2000

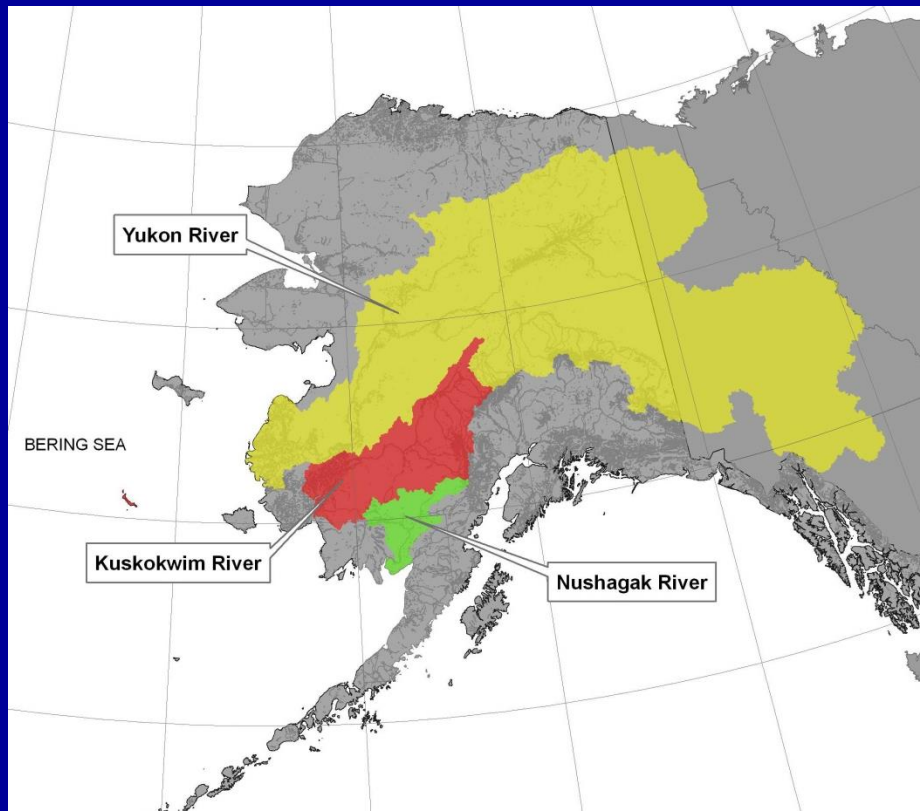




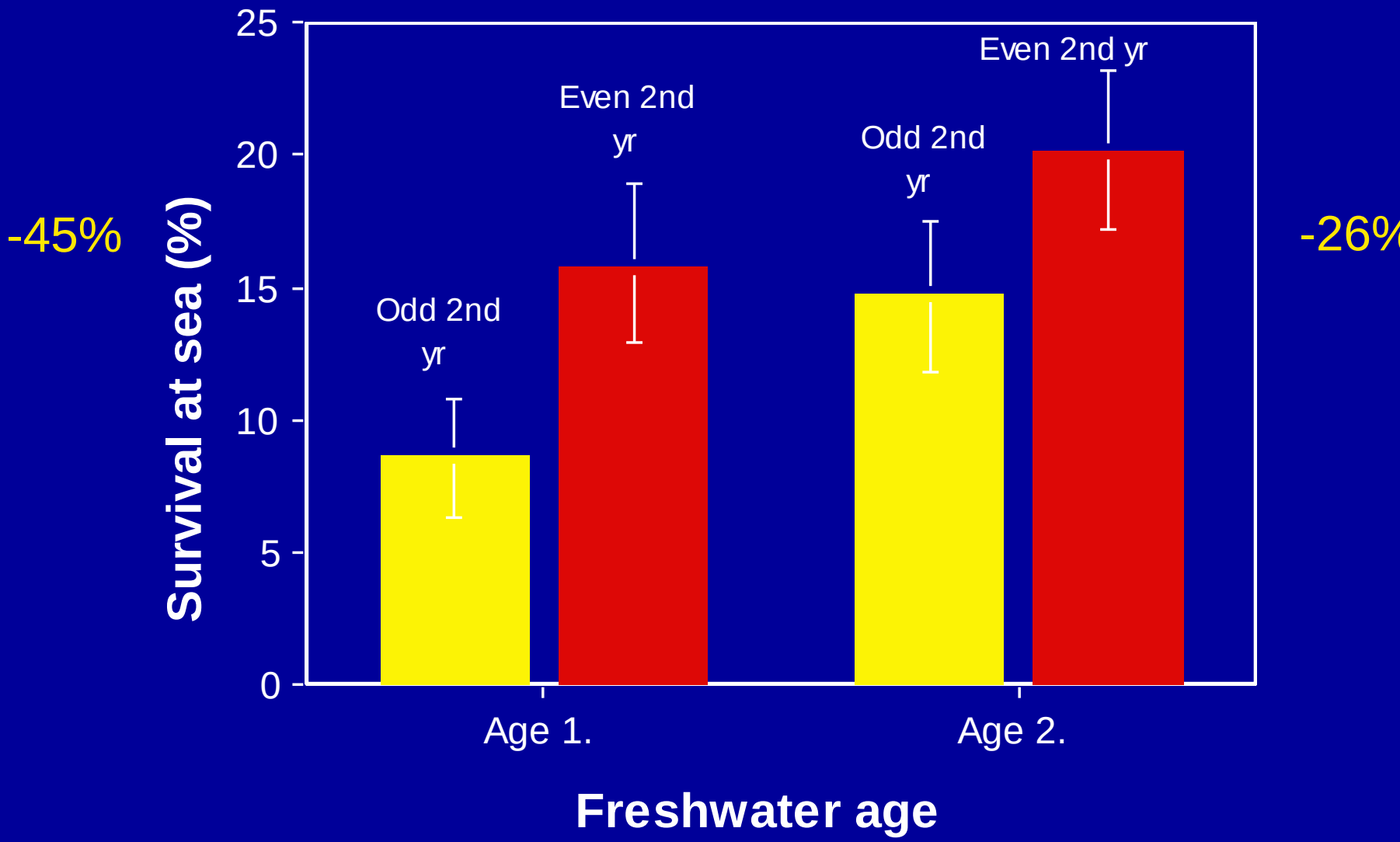
- Stomach content of sockeye & pink salmon declined 36% & 24% in odd-years.
- Key prey (squid & fish) declined 27% in sockeye, 7% in pinks.
- Pink CPUE was 58x greater than sockeye.

Davis et al. 2005

Growth Characteristics of Yukon & Kuskokwim Chinook Salmon

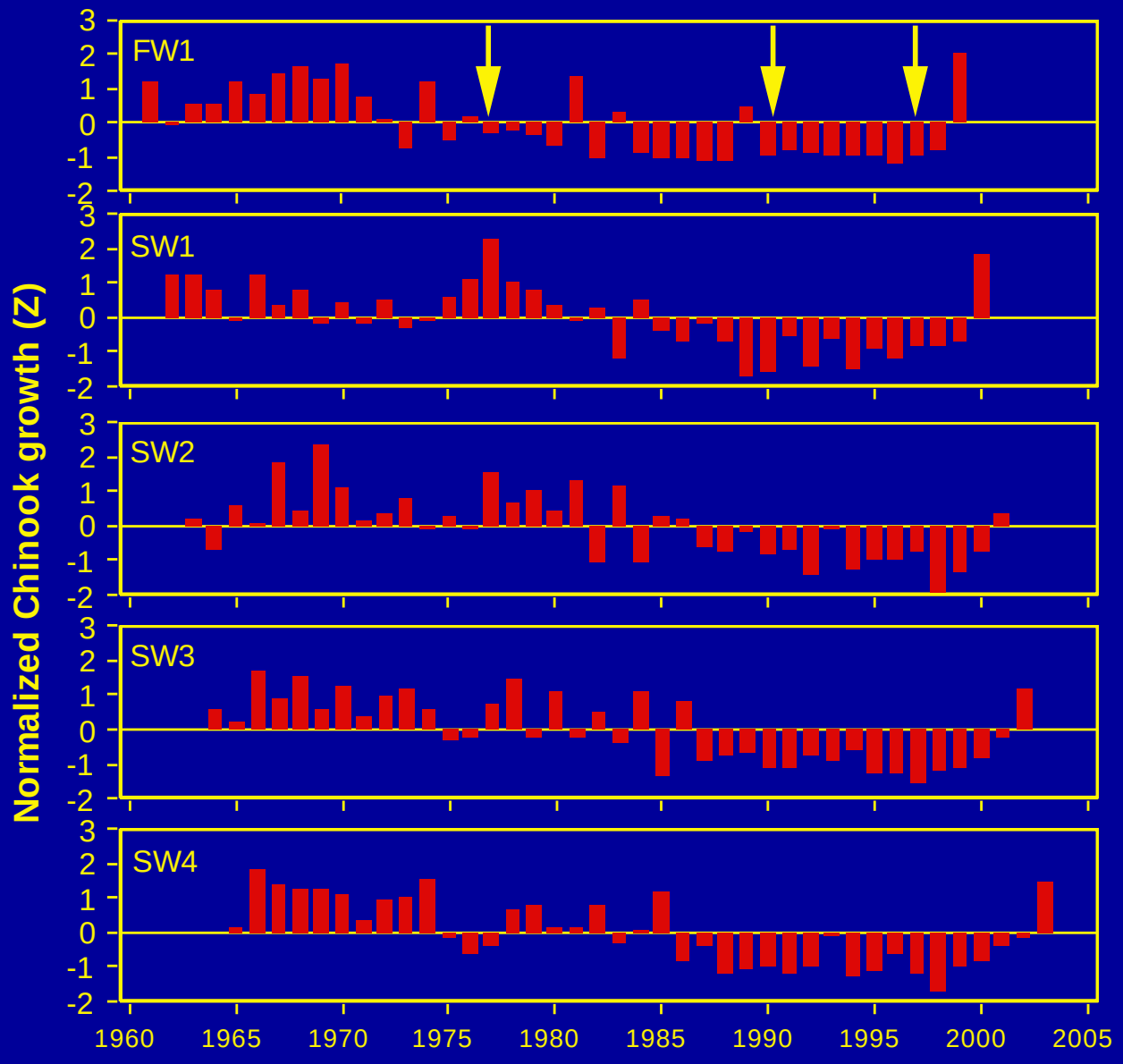


Smolt to Adult Survival, 1977-1997



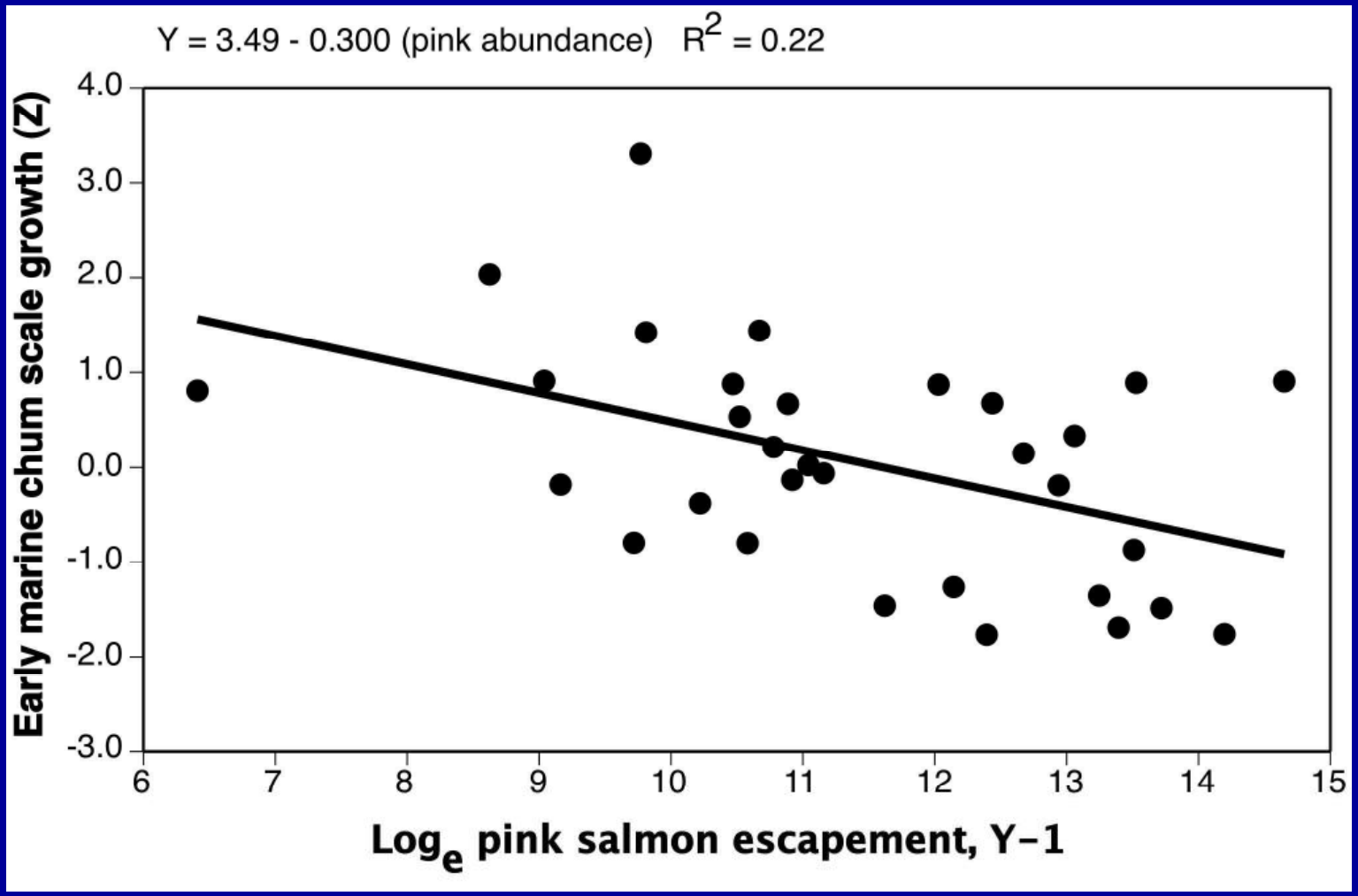
Ruggerone et al. 2003

Annual Yukon Scale Growth

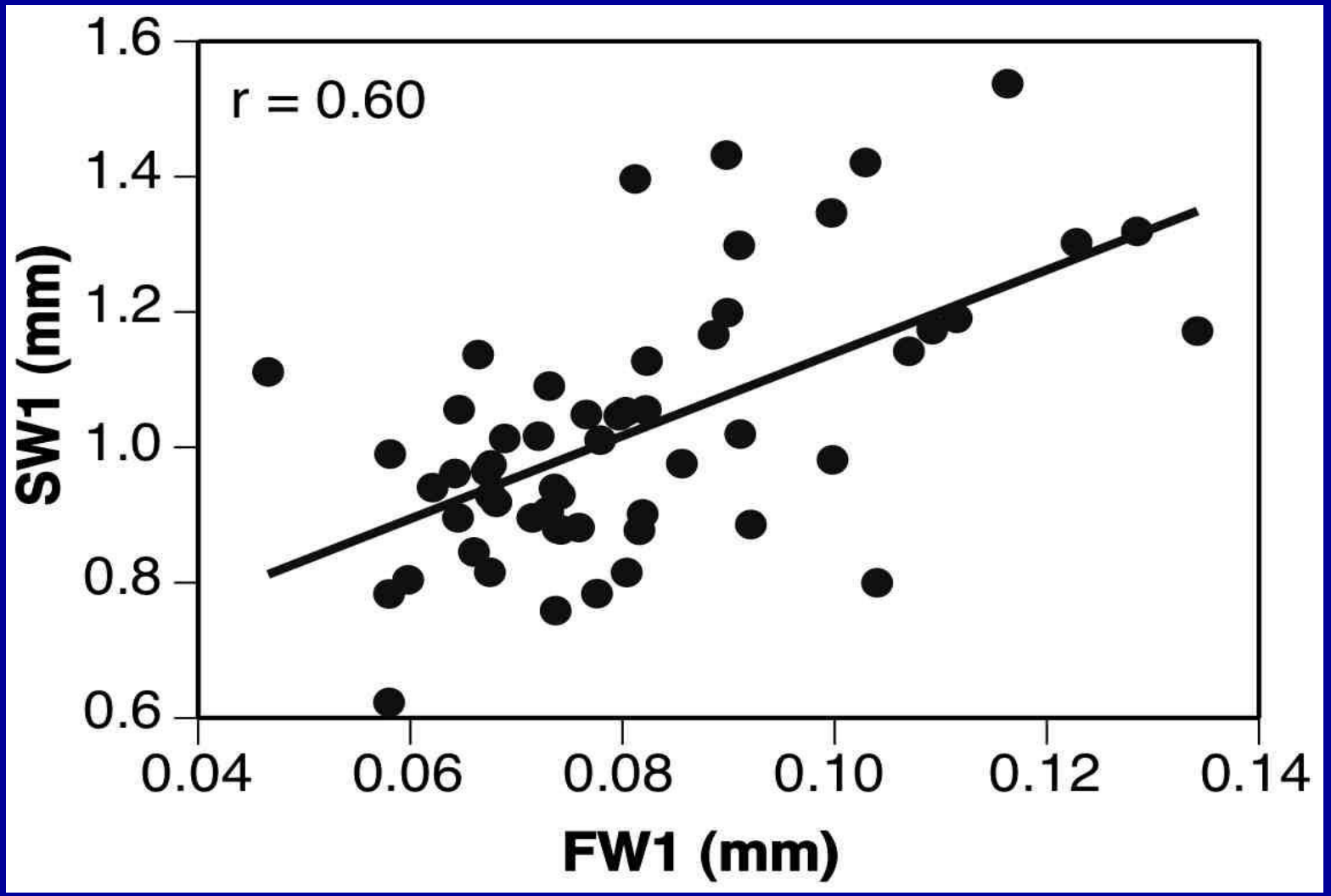


- **Scale growth does not clearly reflect climate shifts.**
- **No obvious growth-abundance relationship**
- **Growth dependency?**

Do pink fry affect chum fry growth in Norton Sound?



Chinook Ocean Growth Dependent on FW Growth



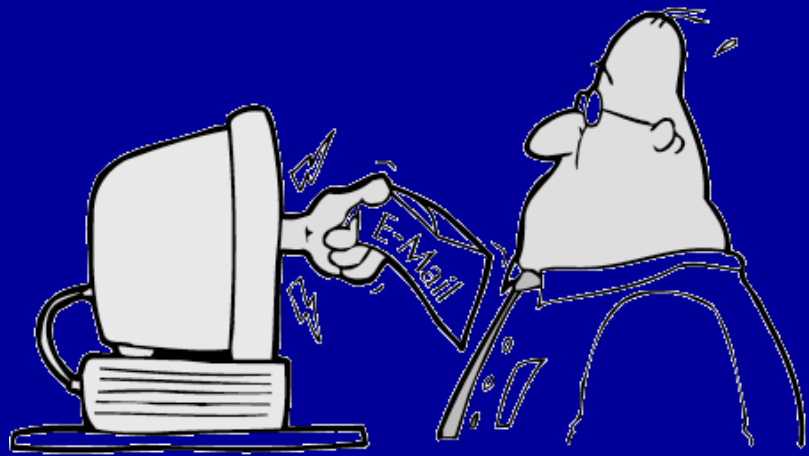
Year: 1991

Ruggerone et al. 2009

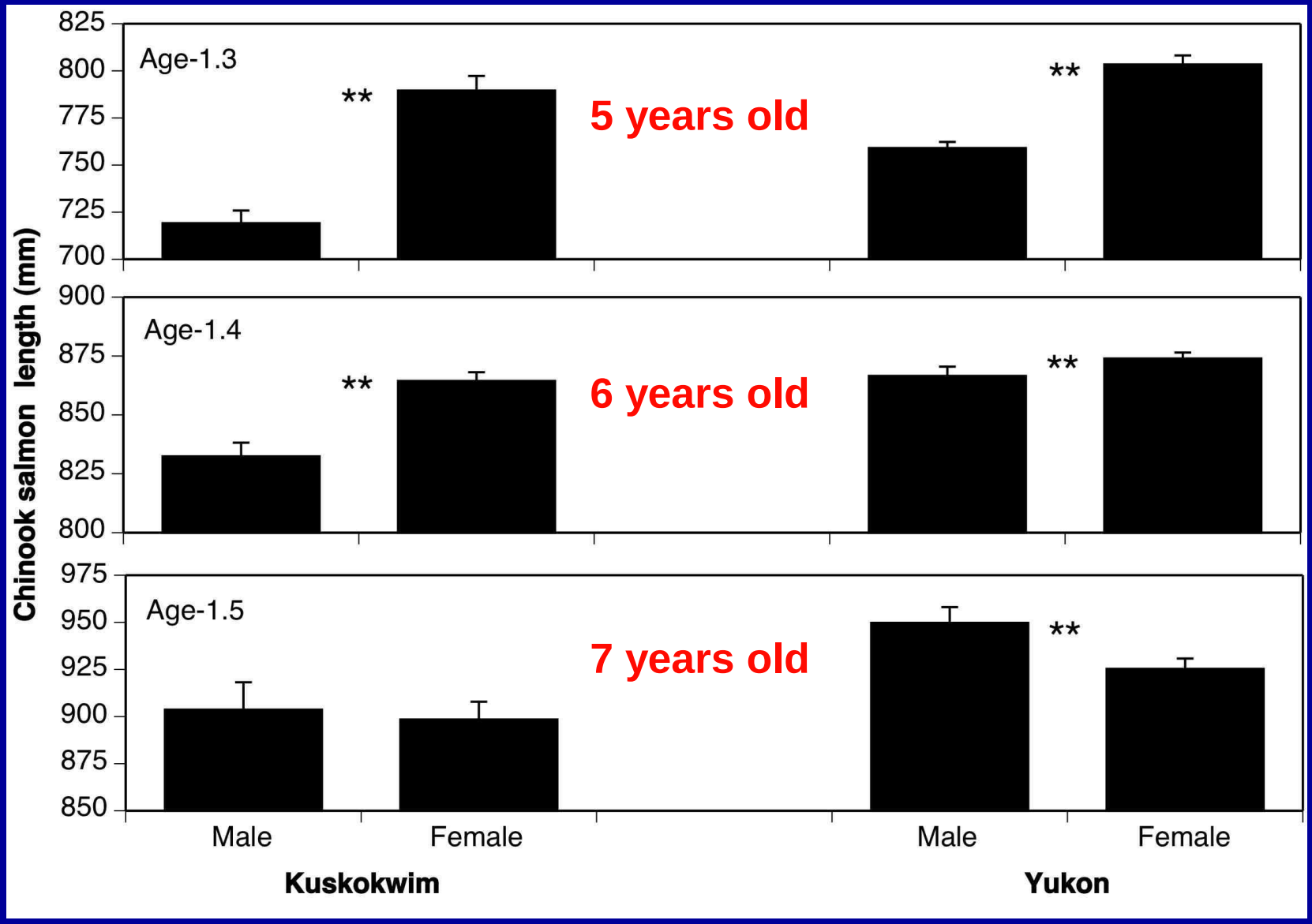
Are Male Chinook Bigger than Female Chinook at Age?

- Sockeye male > female at age.
- Chum male > female at age.
- Coho male < = female (Holtby & Healey 1986).

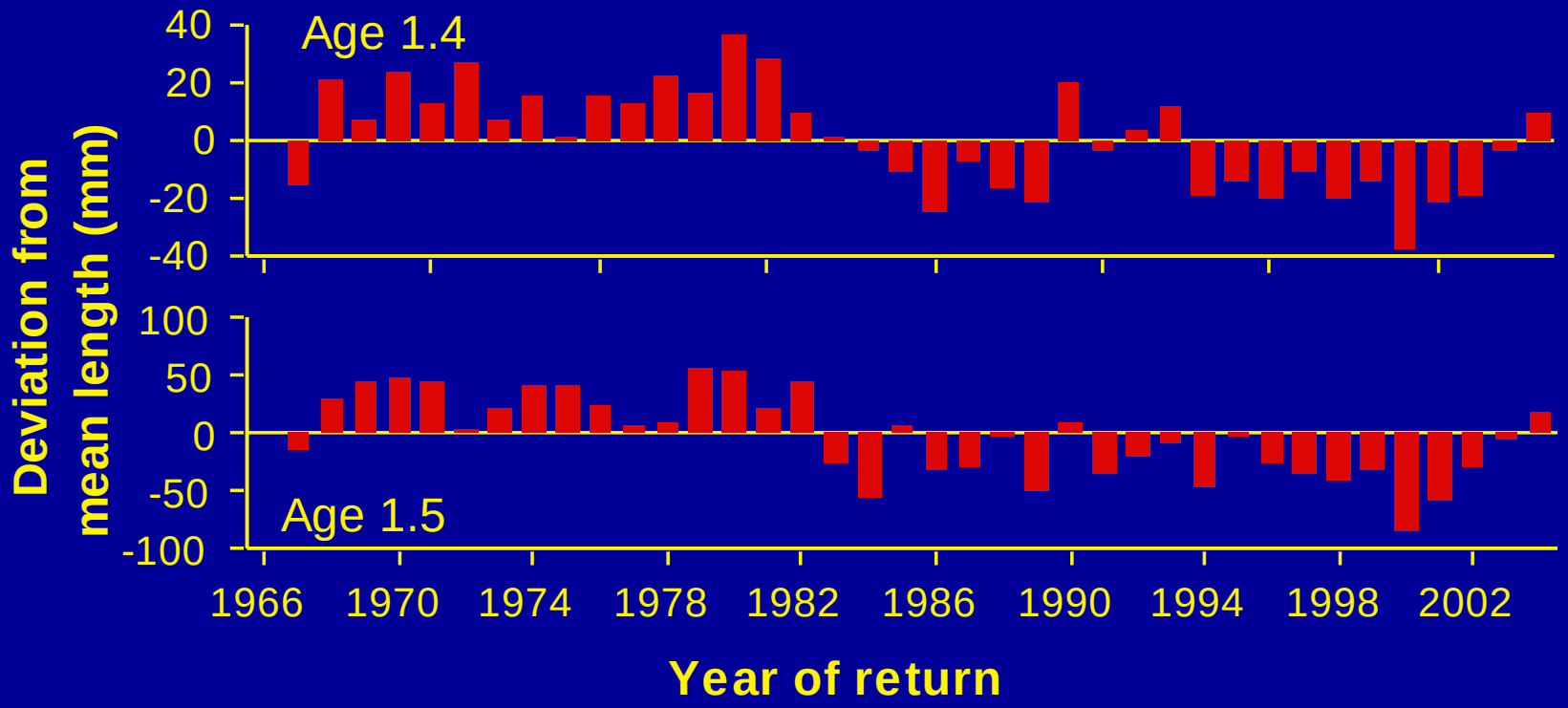
- Chinook Length at Age?



Female Length > Male Length

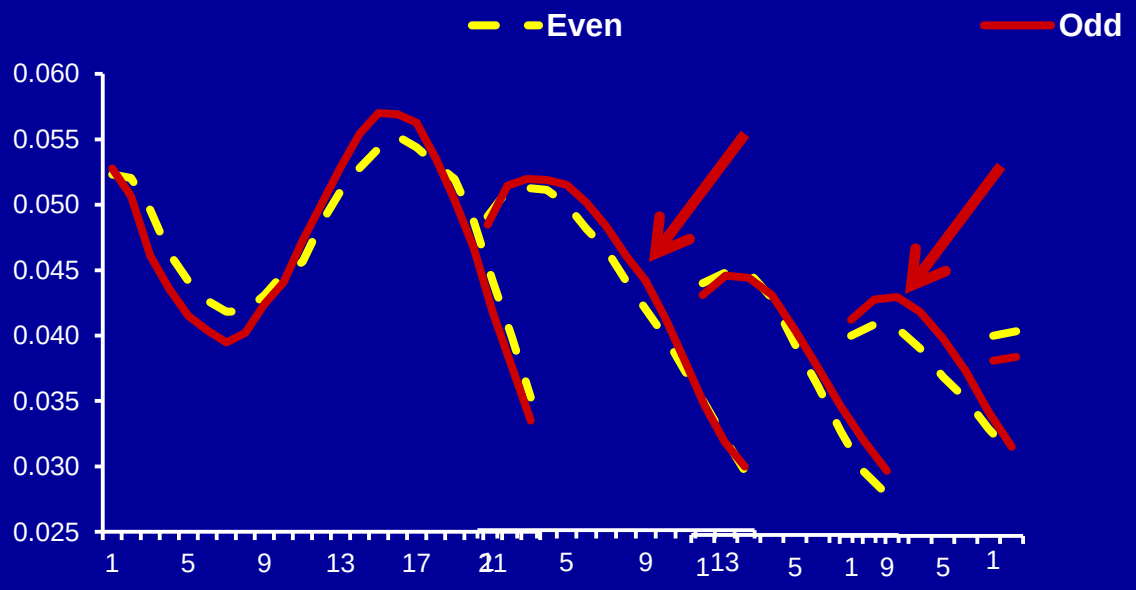


Yukon Chinook Length at Age



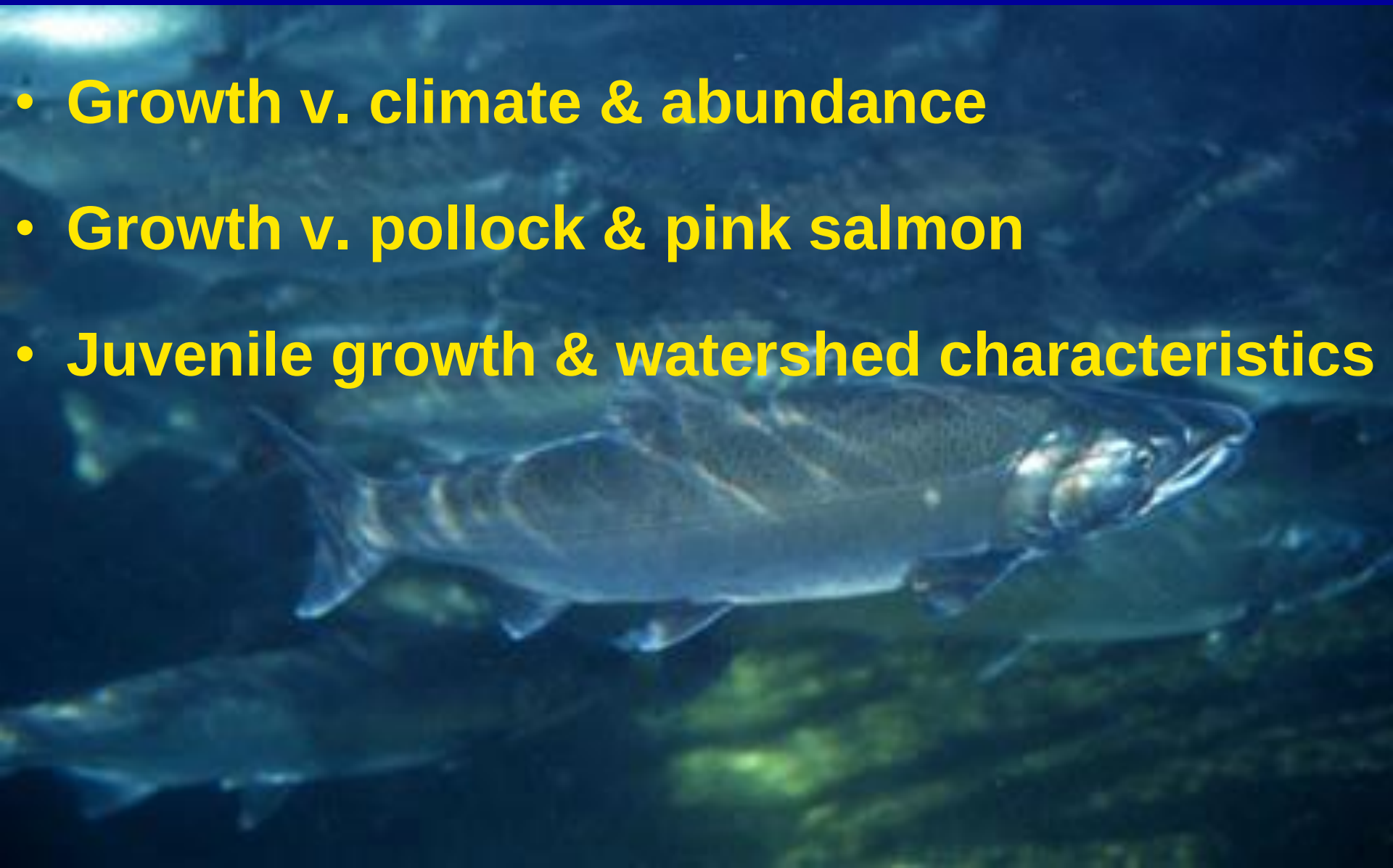
ADFG ASL data, lower river, large mesh only

Seasonal Growth
Norton Sound Age 0.4



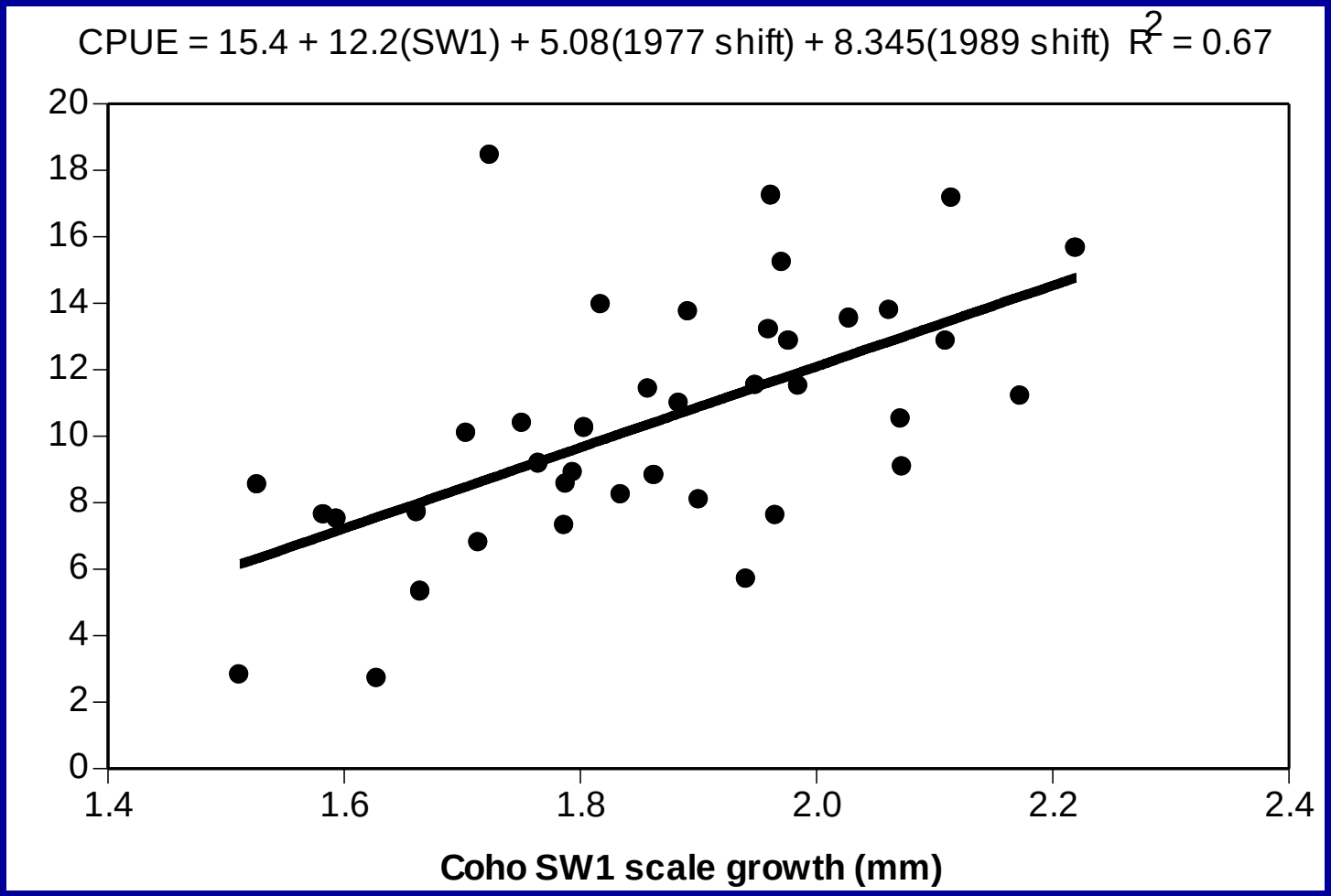
Some possible compensatory growth – red arrows

Kuskokwim Coho Salmon



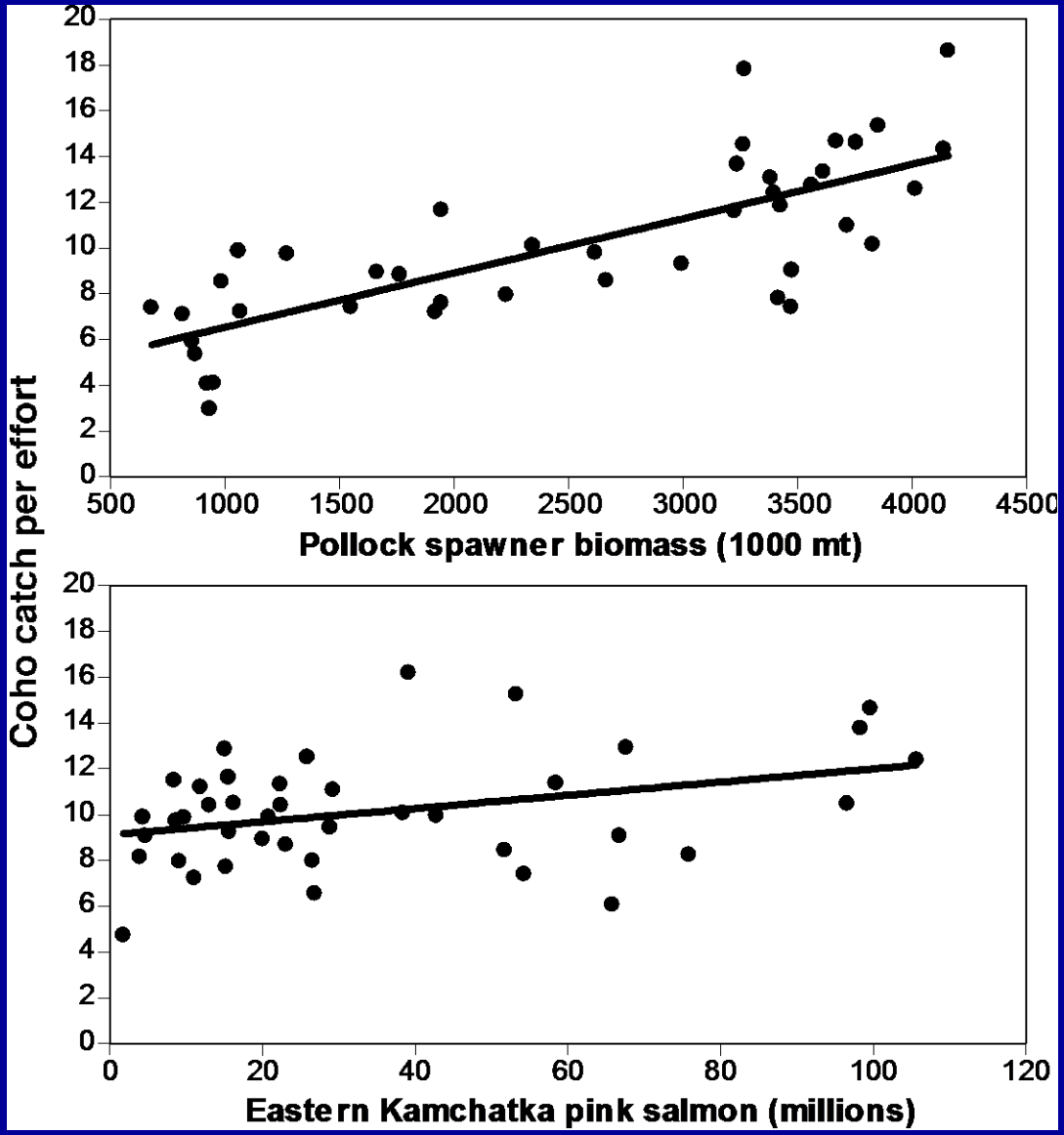
- **Growth v. climate & abundance**
- **Growth v. pollock & pink salmon**
- **Juvenile growth & watershed characteristics**

Coho Abundance Related to Early Marine Scale Growth



Multi-variate model accounts for regime shift effects on coho: 1977, 1989, 1997

Coho CPUE v. Pollock & Pink Salmon



Pollock larvae are important to coho growth & survival

Indirect competition w/ pinks

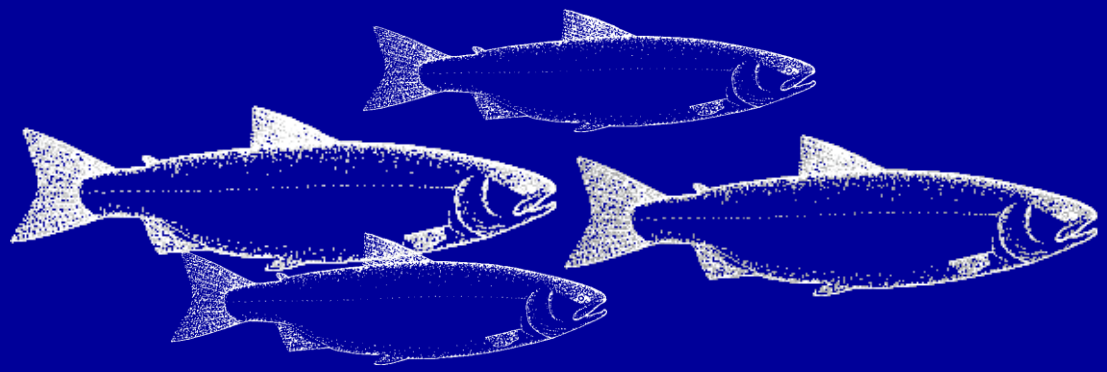
Something else associated with climate shifts influenced coho abundance

CPUE = 0.643 + .0024 (pollock) + .029 (pink salmon) + 3.6 (1977 shift) + 6.7 (1989 shift) $R^2 = 0.80$

Coho Summary

- Abundance related to climate & early ocean growth
  - pollock larvae & pink salmon.

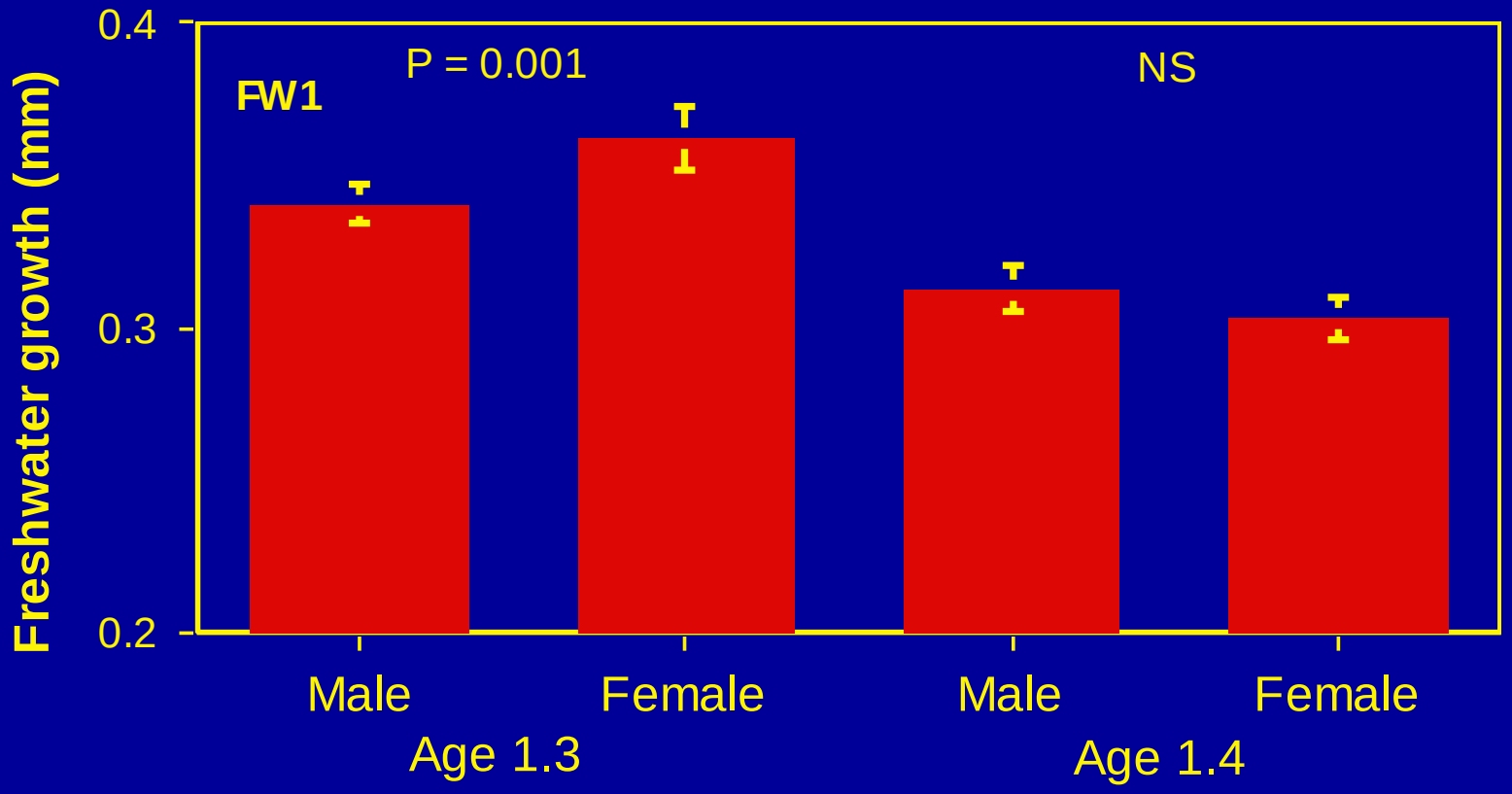
- Juvenile growth varies by watershed.
  - Floodplain habitat & temperature key to growth.



When Does Differential Growth Begin?

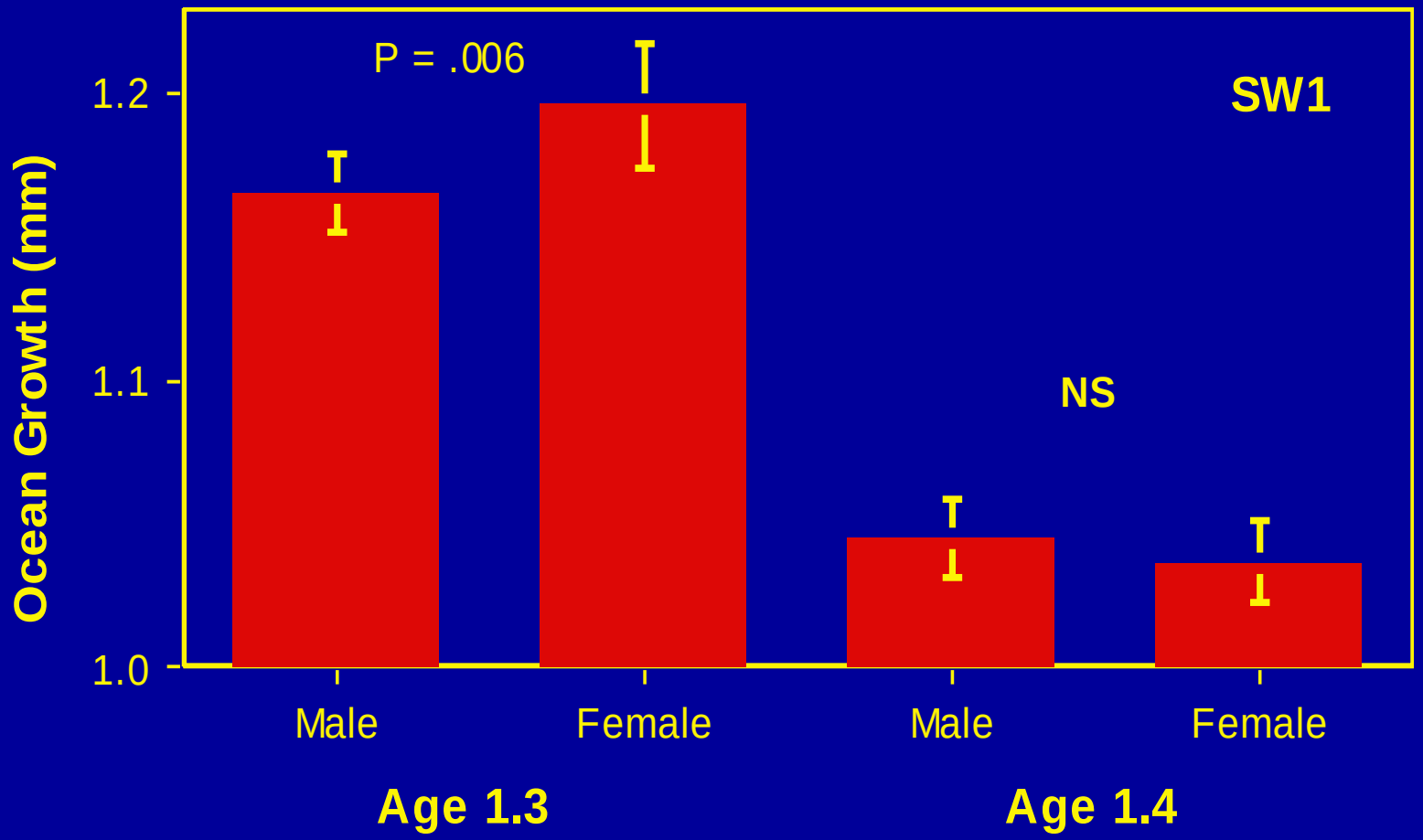
Age 1.3 > Age 1.4 freshwater growth

Age 1.3 Female > Male; Age 1.4 Female = Male



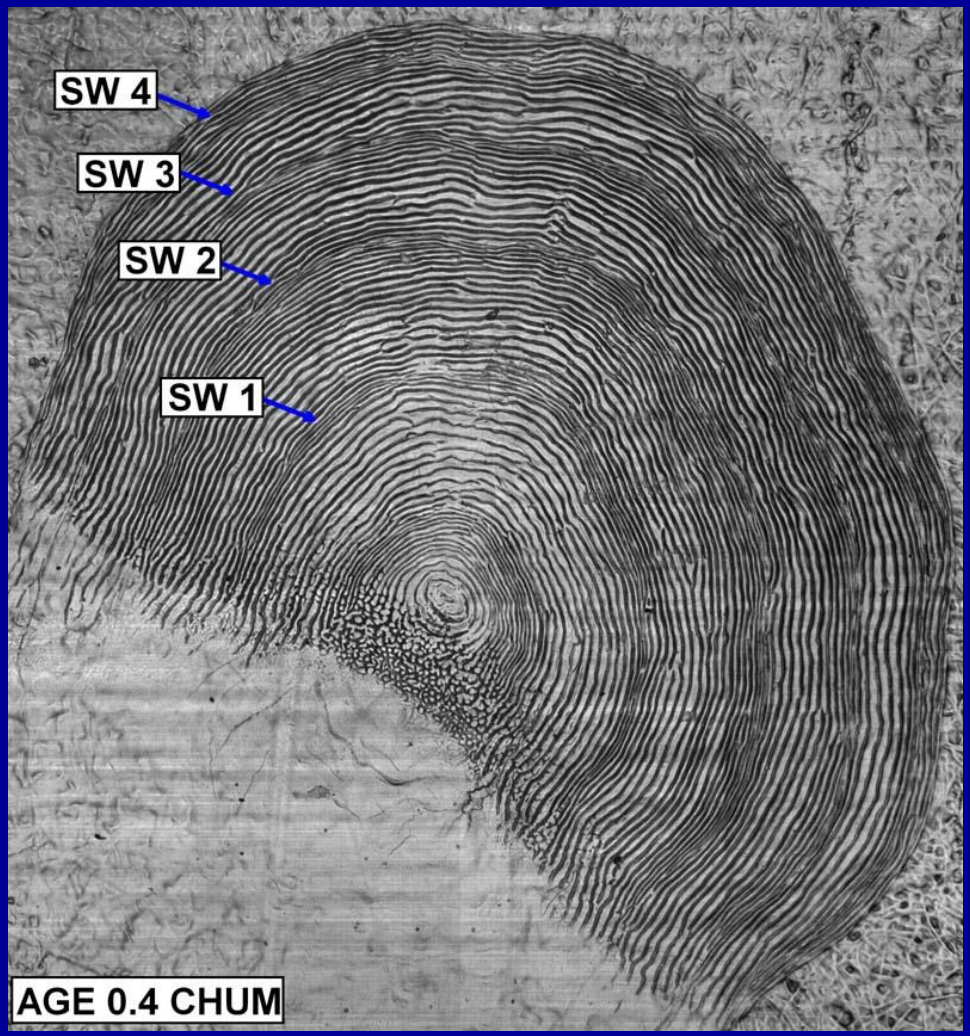
When Does Differential Growth Begin?

Age 1.3 > Age 1.4 SW1 Growth
Age 1.3 Female > Male



Patterns consistent for Yukon & Kuskokwim Chinook

Annuli & Circuli Measurements



Chum Salmon scale

- Used mean growth per year.

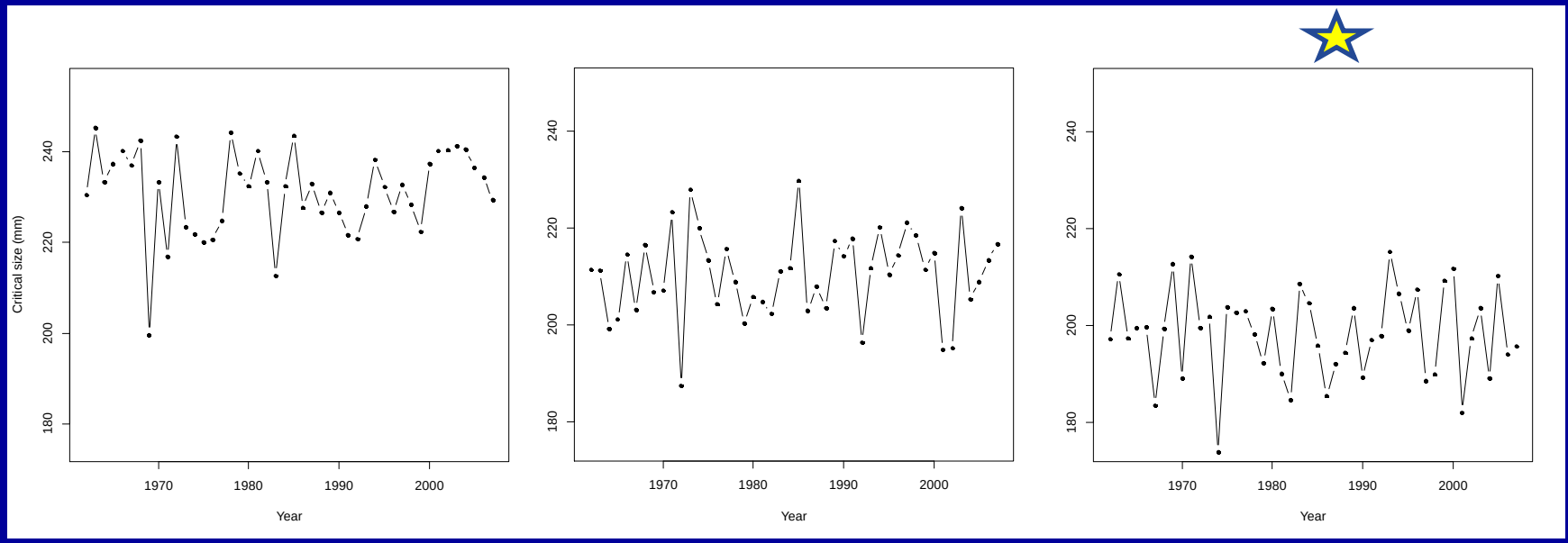
- Age 03 or 4-year old fish &
- Age 04 or 5-year old fish

- First compared all growth zones then chose to model 2 growth zones:
  - SW1: Critical period – Critical size hypothesis
  - SW3: Time when fish "choose" to stay in marine waters or return

Size-selective mortality

Egegik | Kvichak | Wood

Critical size (mm)

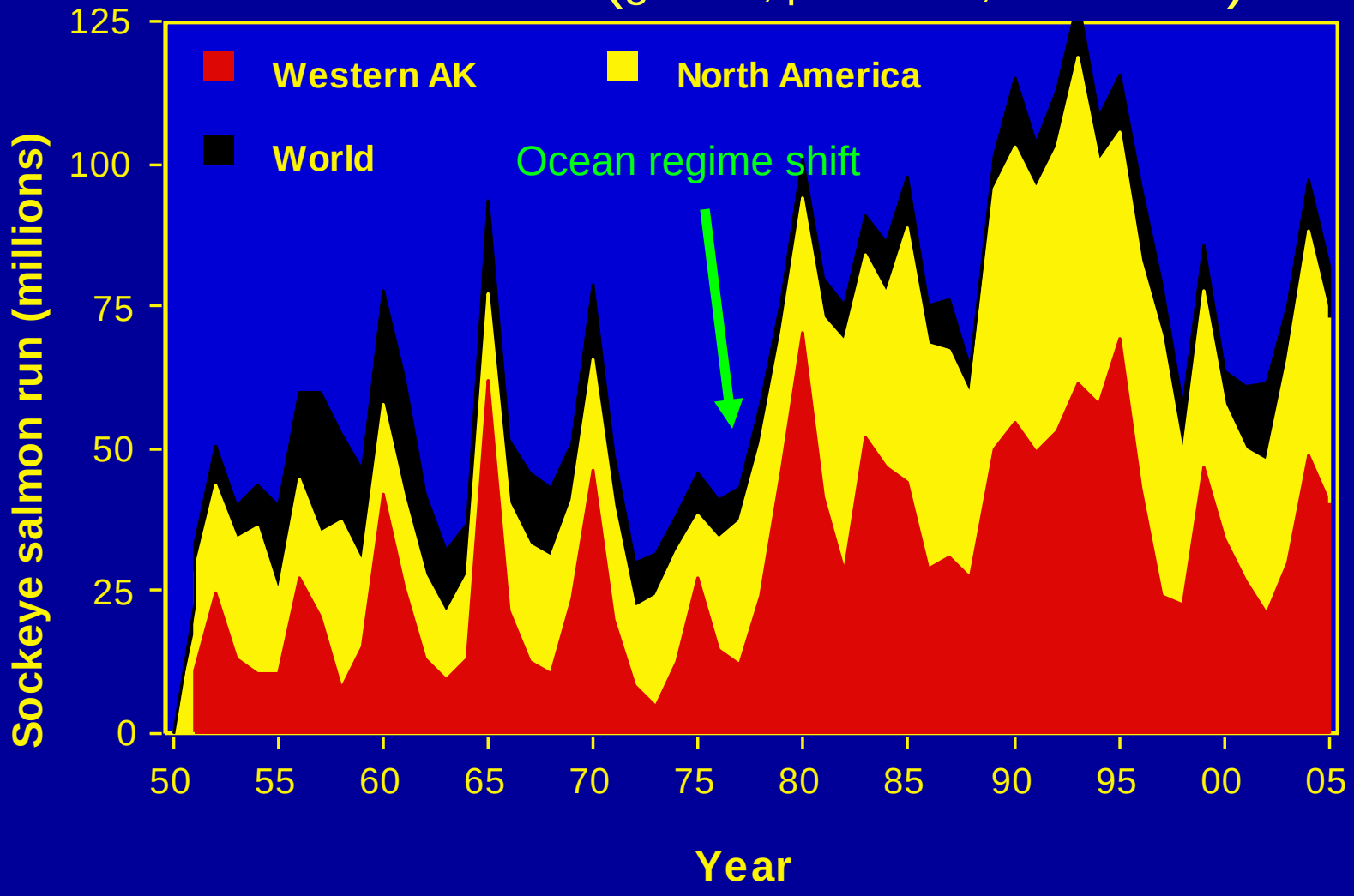


	Egegik	Kvichak	Wood
	Positive SST effect effect	Positive regime effect	No regime or SST
		AR(1), AR(2)	Evidence for SSM
Critical size	231 (200-245)	211 (187-230)	198 (173-215)

Courtesy Ellen Yasumiishi, NOAA

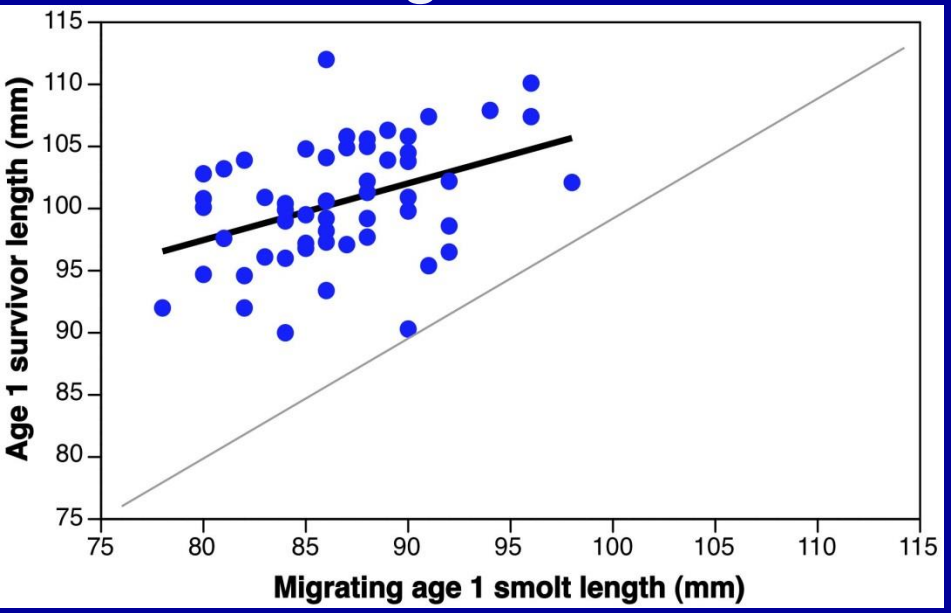
Alaska sockeye salmon abundance doubled after 1977

Mechanism? (growth, predators, distribution)

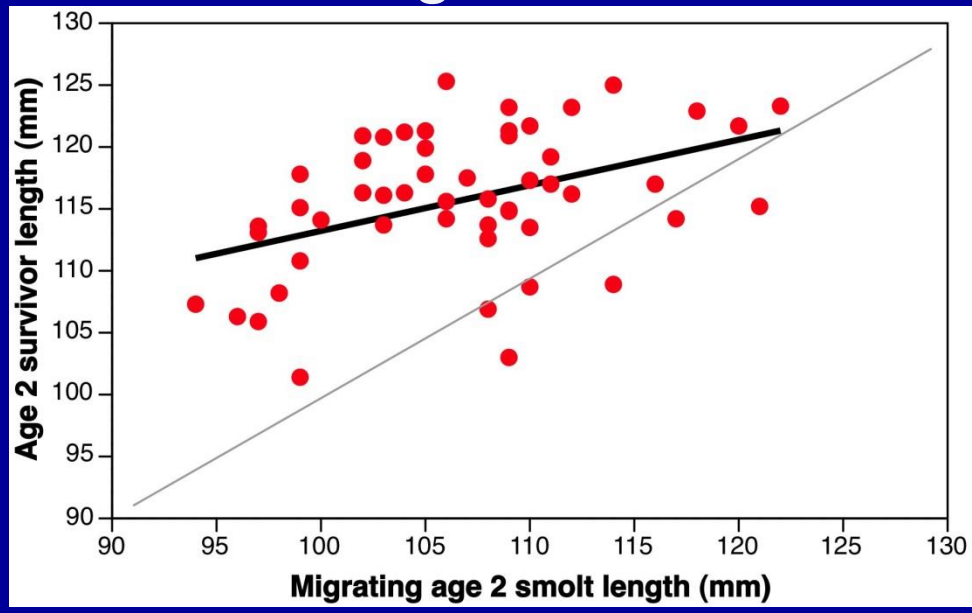


Length of surviving smolt increases with greater length of migrating smolt

Age-1 smolt

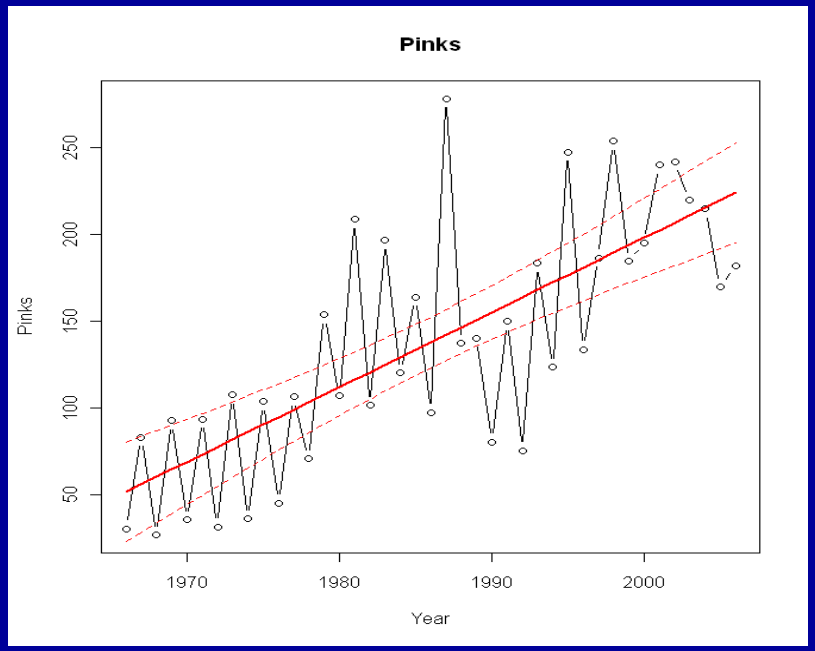


Age-2 smolt



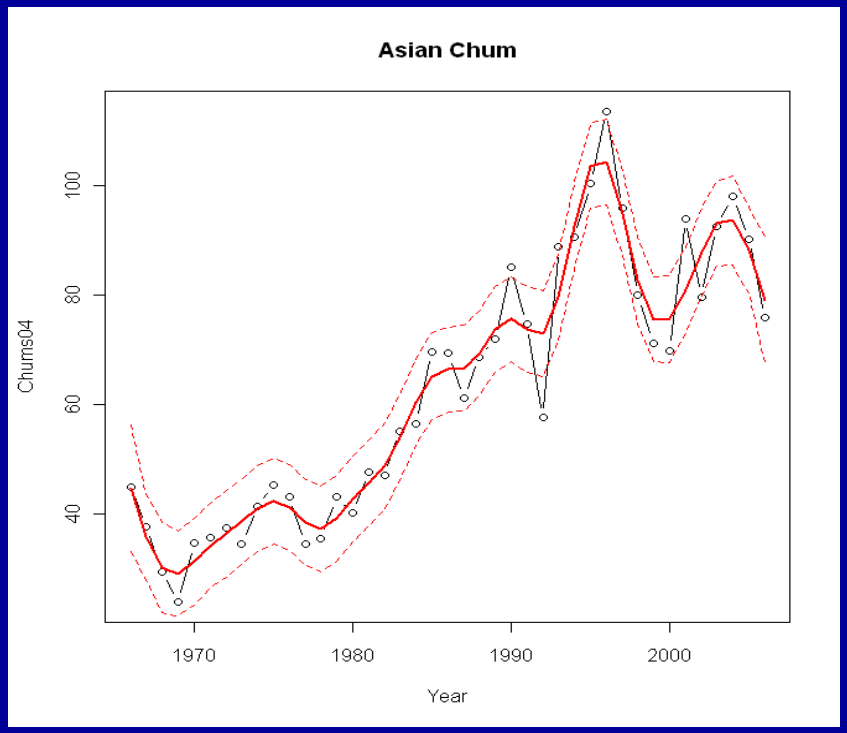
- Note that slope is <1, suggesting more benefit at smaller size.

Abundance Data



Pink Salmon Abundance

- Total catch and escapement from Russia



Asian Chum Salmon Abundance

- Catch and escapement data in millions of fish from Japan and Russia
- 4-year running average

Data: Ruggerone et al. 2010 and NPAFC website

Climate Shifts & Harvest Trends of AYK Salmon