Top-down and bottom-up linkages among climate, growth, competition, and production of sockeye salmon populations in Bristol Bay, Alaska, 1955-2003

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Global Change and Bering Sea Sockeye Growth Study Objectives

1. **Inventory and retrieve archival scales for Bristol Bay sockeye.**

2. **Develop new scale reading methodology and database management.**

3. **Select stocks and age groups for analyses.**

4. **Assemble long-term environmental and biological databases.**

5. **Time series analysis of data on growth and climate.**

6. **Analyze freshwater and marine growth trends in relation to fish production and climate.**
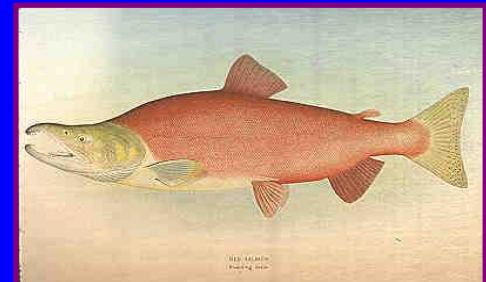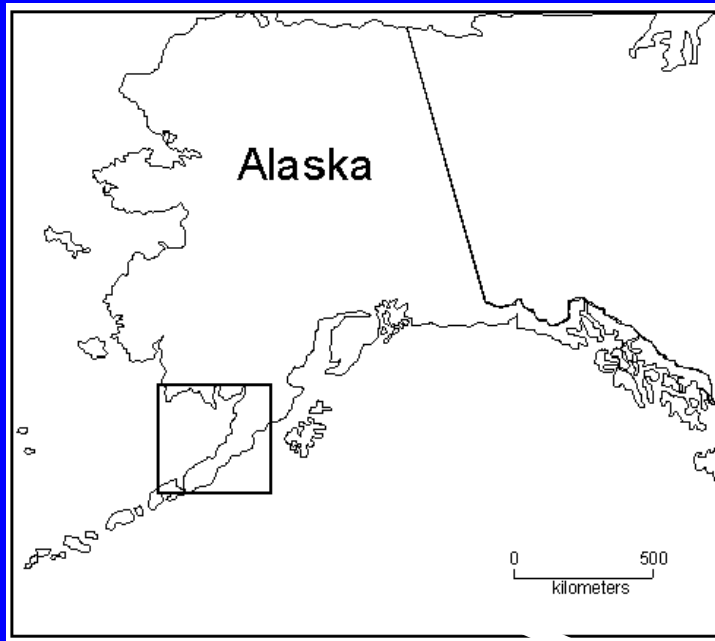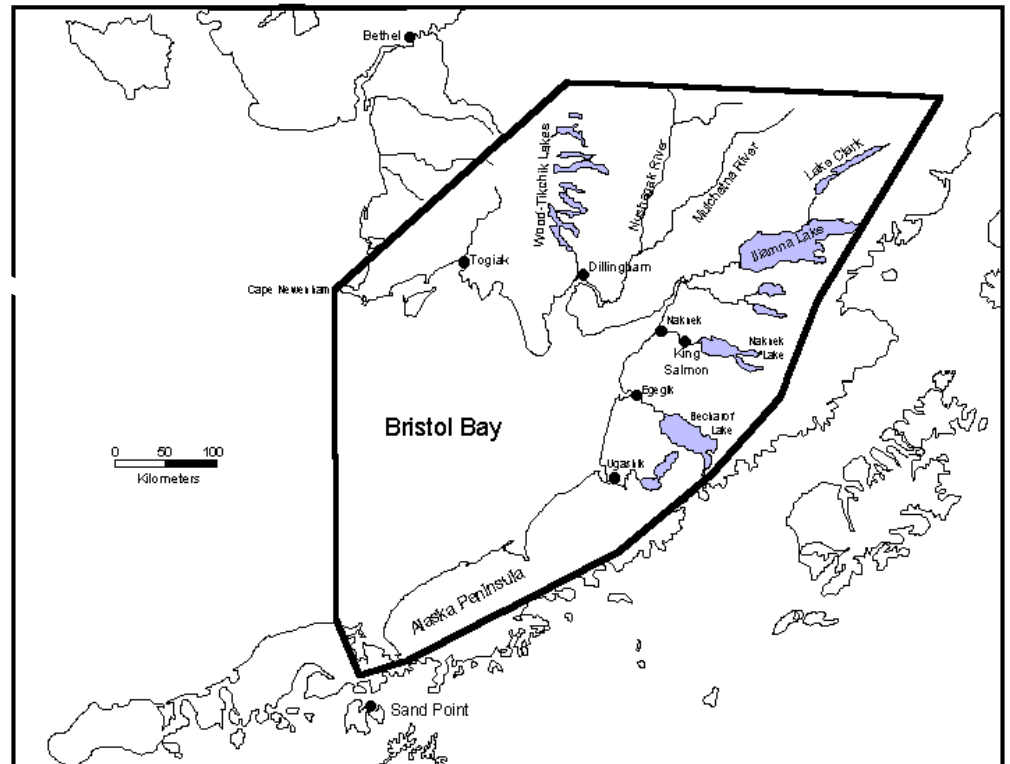
**Study Locations
USGS Alaska
Global Change Project**

Inventory and Retrieval of Archival Scales

1955-1960 FRI's collection of historical scales

1960-2000 ADFG's collection in Anchorage

Brood tables by stock and check for missing scales

Systems: Kvichak, Egegik, Ugashik, Naknek,
　　　　　　　 Nushagak and Wood rivers

Sex and age-class tables for database development

Kvichak total count 1960-2000 = 80,349

SALMON SCALES AS DATA LOGGERS:
AN IMAGE ANALYSIS APPROACH FOR DATA EXTRACTION

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VALUE OF IMAGE ANALYSIS

- Tens of thousands of salmon scales are routinely collected in Alaska each year for age analysis.
- These scale collections are extensive, containing millions of scales and covering over forty years of data.
- Current projects with USGS, NMFS, UAF and ADFG are examining scale growth in relationship to density and climate change.

SPECIFICATIONS OF OUR SYSTEM

- High resolution image capture.
- Standard microfiche viewing.
- Efficient data input to relational database.
- Semi-automated measurement extraction.
- Able to document reader criteria.
- Provide saved images for analysis by other researchers.

Rationale

Scales are collected in every corner of the state for ageing, but other valuable information remains untapped. This provides the opportunity to investigate patterns across regions.

Scale growth reflects fish growth.*

*Ruggerone and Rogers, 1998 EVOS
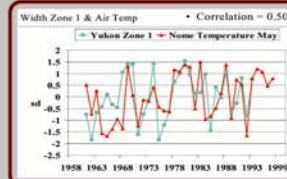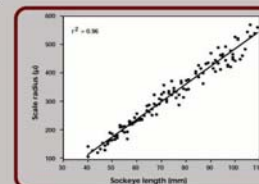
Circuli patterns may also record temperature and food availablity.*

* Smoker and Sands, in prep.

How are Scales Processed?

1. SCALE SELECTION
- VB interface connects to scale selection database.
- High resolution microfiche scanner captures scale images at 14 Megapixels.

2. IMAGE ANALYSIS
- Import scale images into customized Optimas imaging software.
- Optimas flags individual circuli.
- Circuli flags are based on edge detection algorithm applied to the image's luminesence profile.
- Reader marks annuli and edits flag placement on touchscreen.

Luminescence profile along a scale transect

Weighted values of transect profile
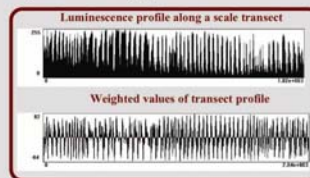
3. DATA EXTRACTION
- Results in a transect overlay that includes flags on circuli and annuli.
- Overlay stored as separate image for documentation
- Counts circuli and measures distances.
- Exports data to Access database.

Digital Scale Image Acquisition and Data Extraction
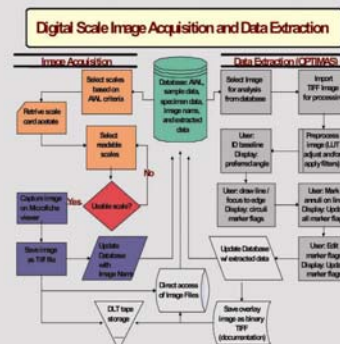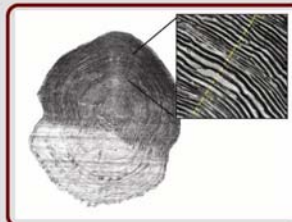
PERFORMANCE
- Automated flag placement accuracy ~60-95%.
- Between reader differences negligible.
- Digitizing Rate = 120-150/day*
- Analysis Rate = 80-120/day*
    * under current projects

Freshwater age of sockeye salmon influenced growth during the first year at sea.

❖ Peak SW1 scale growth of two-winter freshwater sockeye (age-2.) with earlier seaward migrations and larger size was greater than that of salmon spending only one winter (e.g. Pearcy et al. 1999).

❖ Age-one smolts exhibited a broader range of growth during 1st summer at sea, reflecting later migration and time spent in Bristol Bay after temperature and zooplankton increased in coastal waters.

❖ Individual salmon having relatively greater early marine growth tended to experience reduced scale growth during the latter portion of their second year as opposed to hypothesis presented in Aydin (2000).

❖ We assume that salmon with poor early marine and low SW2 growth did not survive and were not represented in the scale collection.

Bering Sea Sockeye and PDO

Example of Sockeye Annuli Measurements

SWPL
SW2
SW1
FWPL
FW2
FW1
Focus
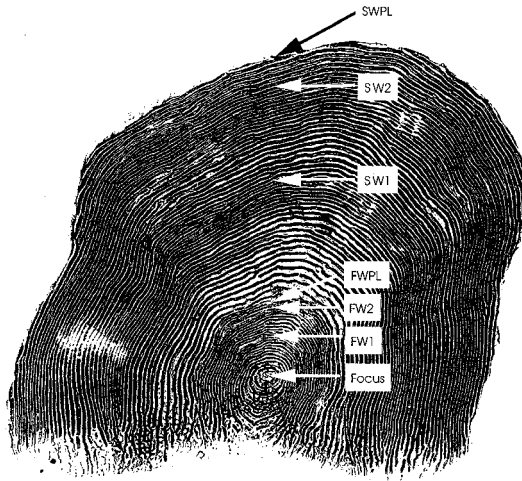
- Physical ocean regime shift around 1977.

- Zooplankton and squid biomass increases especially in coastal regions.

- North Pacific salmon abundance doubles.

- Maximum zooplankton biomass shifts two months earlier.

Francis & Hare 1994; Anderson and Piatt 1999

Bering Sea sockeye growth during 1st and 2nd years tended to stay the same.

No observation of earlier growth in sockeye post-PDO in relation to temporal shift in zooplankton.

Greater spring growth most apparent in 3rd year at sea for sockeye.

Seasonal scale growth patterns for Bering Sea sockeye over 45 years show significant differences between SW2 and SW3 scale growth during odd- and even-years.

Eastern Kamchatka pink salmon and Sakhalin hatchery production has increased steadily over the last 4 decades with the highest production during odd-numbered years (162 million adults – Rogers 2001).
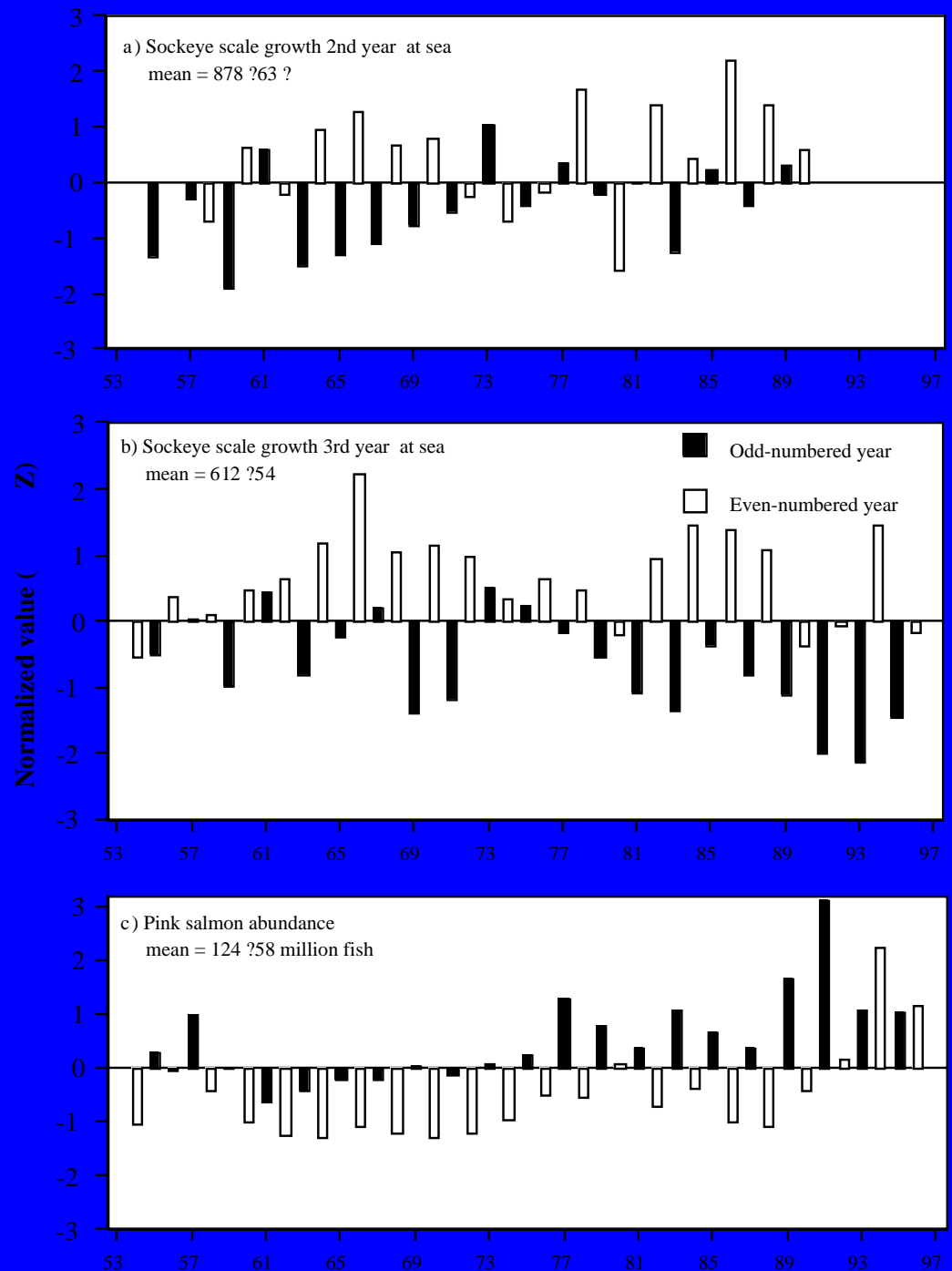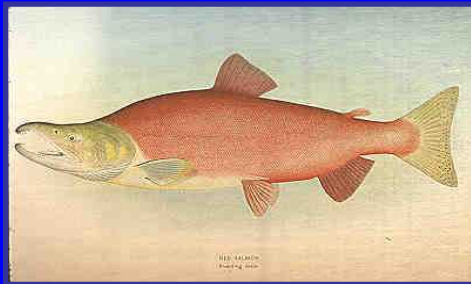

At the same time, survival of Bristol Bay sockeye salmon smolts to adults have declined 26% (age-2 smolts) to 45% (age-1 smolts).
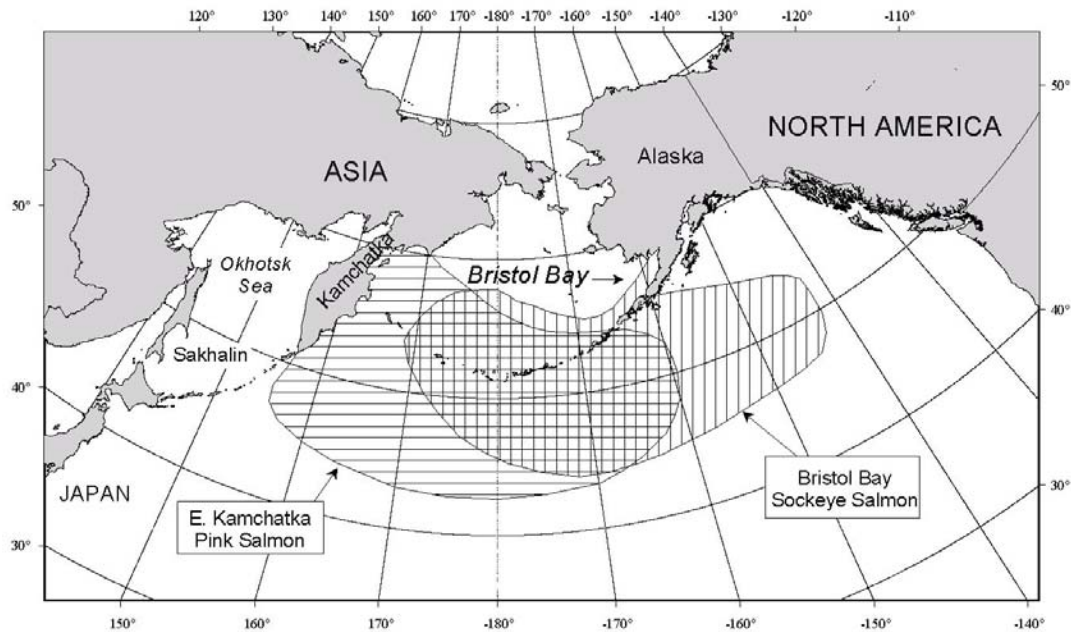
Known range of immature Bristol Bay sockeye and maturing eastern Kamchatka Peninsula pink salmon based on international tag recoveries.

Bristol Bay sockeye growth during second and third growing season at sea and corresponding abundance of Asian pink salmon.

a) Sockeye scale growth 2nd year at sea
mean = 878 ?63 ?

b) Sockeye scale growth 3rd year at sea
mean = 612 ?54

Odd-numbered year

Even-numbered year

c) Pink salmon abundance
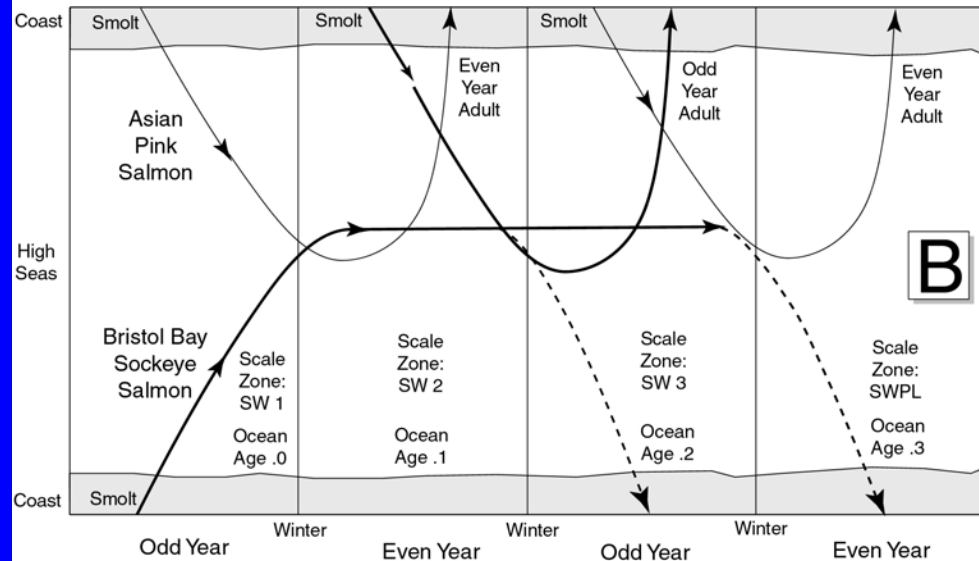mean = 124 ?58 million fish

Normalized value (Z)

Temporal overlap between Asian pink and Bristol Bay sockeye salmon.
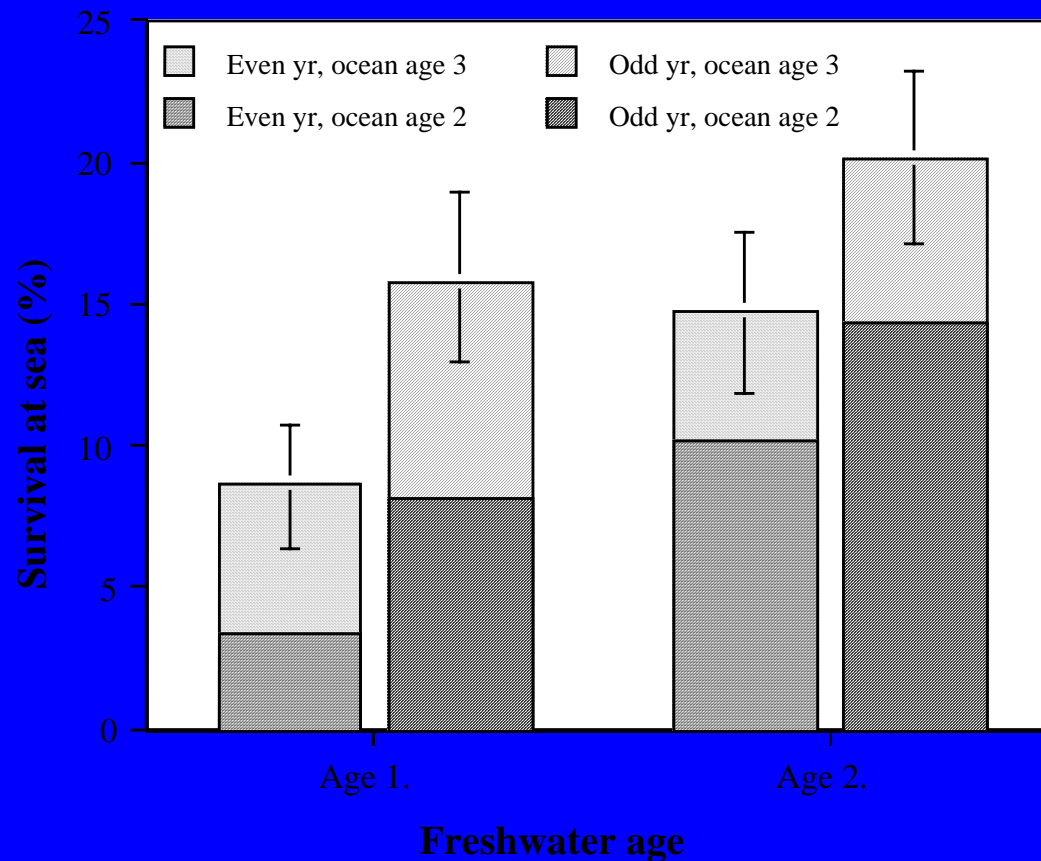
A. Even-year sockeye meet pinks during 1st year at sea and 2nd growing season.
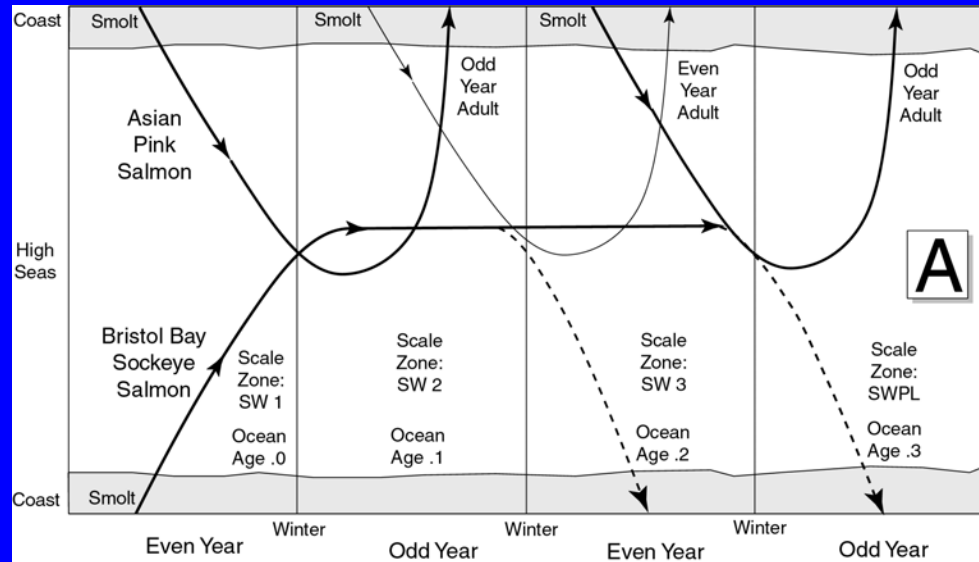
B. Odd-year sockeye smolts encounter abundant pink salmon in 2nd winter at sea and 3rd growing season.

Odd-year pink salmon may reduce prey abundance prior to emigration from the high seas to coastal areas during June and July.

Average smolt to adult survival of freshwater age-1 and age-2 sockeye show negative correlations between Bering Sea sockeye abundance and production of Asian pink salmon in odd-numbered years.

➢ In odd-years, pink salmon tend to arrive on summer feeding grounds in the Bering Sea 2-3 weeks prior to Alaska's sockeye salmon and are responsible for altering observed declines of macro-zooplankton in the central North Pacific Ocean (Shiomoto et al. 1997).

➢ The effects of prey reduction affects sockeye growth from early summer through fall when prey availability is greatly reduced by natural mortality and ontogenetic vertical migrations of some prey (Mackac and Tsuda 1999).

Average number of adult sockeye returning from juveniles entering the ocean, 1977-1997
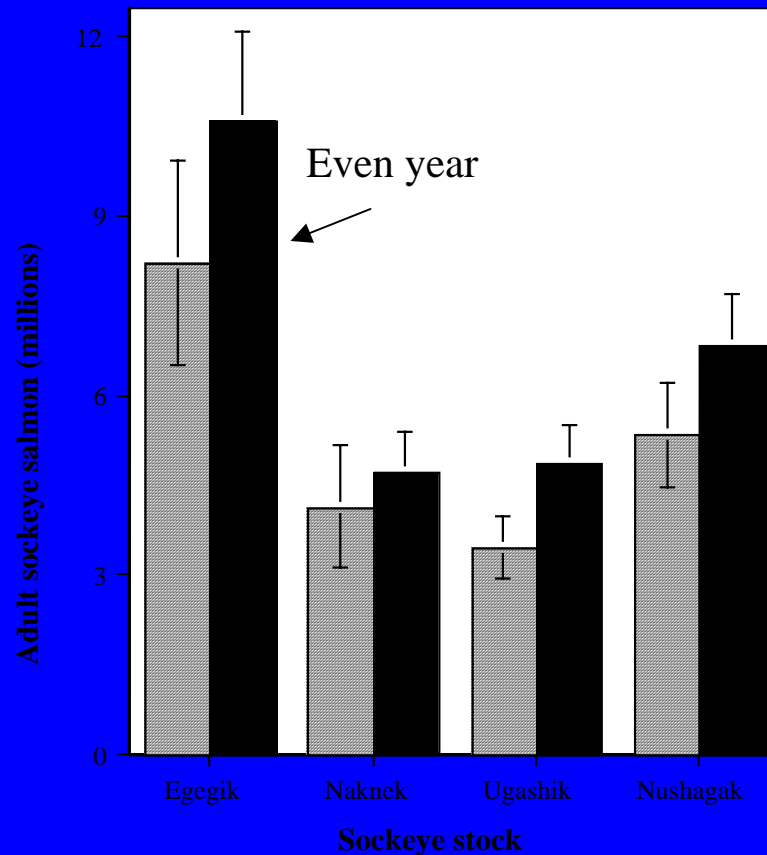
Odd-year salmon abundance decreased 26% (7 million fish/biennium)
Resulting in a $29 million biennial loss to the Alaska fishery.

CONCLUSIONS

1. Spatial and temporal overlap between Asian pink salmon and Bristol Bay sockeye suggest ocean competition and North Pacific carrying capacity.

2. Greatest overlap occurs late spring and early summer during odd-year cycles when pink salmon are most abundant.

3. Timing and duration of growth effects influenced by prey species with 2-yr life cycle, such as micro-nekton squid.

4. Bottom-up impacts of global change must consider top-down effects and anthropomorphic activity as well as natural climatic cycles, including activities that develop outside of traditional national jurisdiction boundaries.

Evidence for top-down and bottom-up processes in the North Pacific Ocean impacting salmon highlights the need for ecosystem-scale international management of fish production and harvest.

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2 – University of Washington, Seattle, WA