Natural Stable Isotope Abundance as an Indicator of Status and Change within North Pacific Marine Ecosystems

Thomas C. Kline, Jr. Ph. D.
Prince William Sound Science Center
Cordova, Alaska, USA

View of Cordova harbor from PWSSC

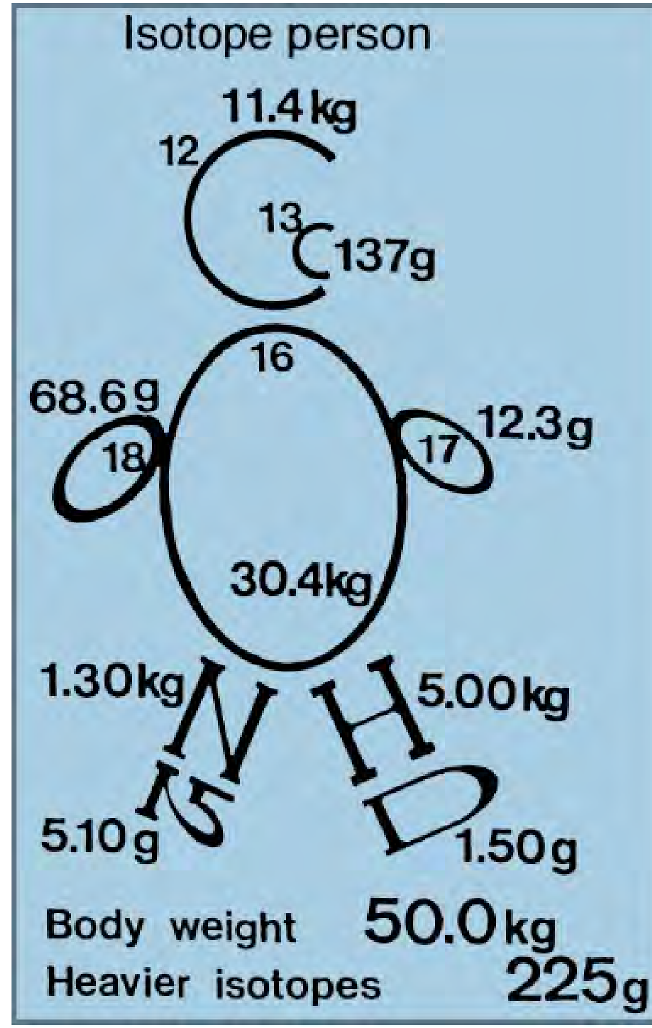
Indicators of Status and Change within North Pacific Marine Ecosystems: A FUTURE Workshop
PICES, Honolulu, Hawaii, April 2011

Outline

- Natural stable isotope abundance
- Rationale
- Isoscapes
- Anthropogenic carbon
- Isotope records in marine organisms
- Records of isotope change in sediments on different time scales
- Integrate into routine sampling
- Avoid over-aggregation of data

Natural stable isotope abundance

- Many elements exist as different forms that vary by the number of neutrons – isotopes
- The NON-radioactive forms are called stable isotopes
- About 0.4% of N and 1.1% of C in the biosphere consists of, respectively, ^{15}N and ^{13}C; precise amount varies in nature
- Food vs. water pathways – conservation of matter
- NSIA expressed in delta units reflecting that there was more (higher value) or less (lower value) of the minor (heavy) isotope in the sample



Wada et al. 1991

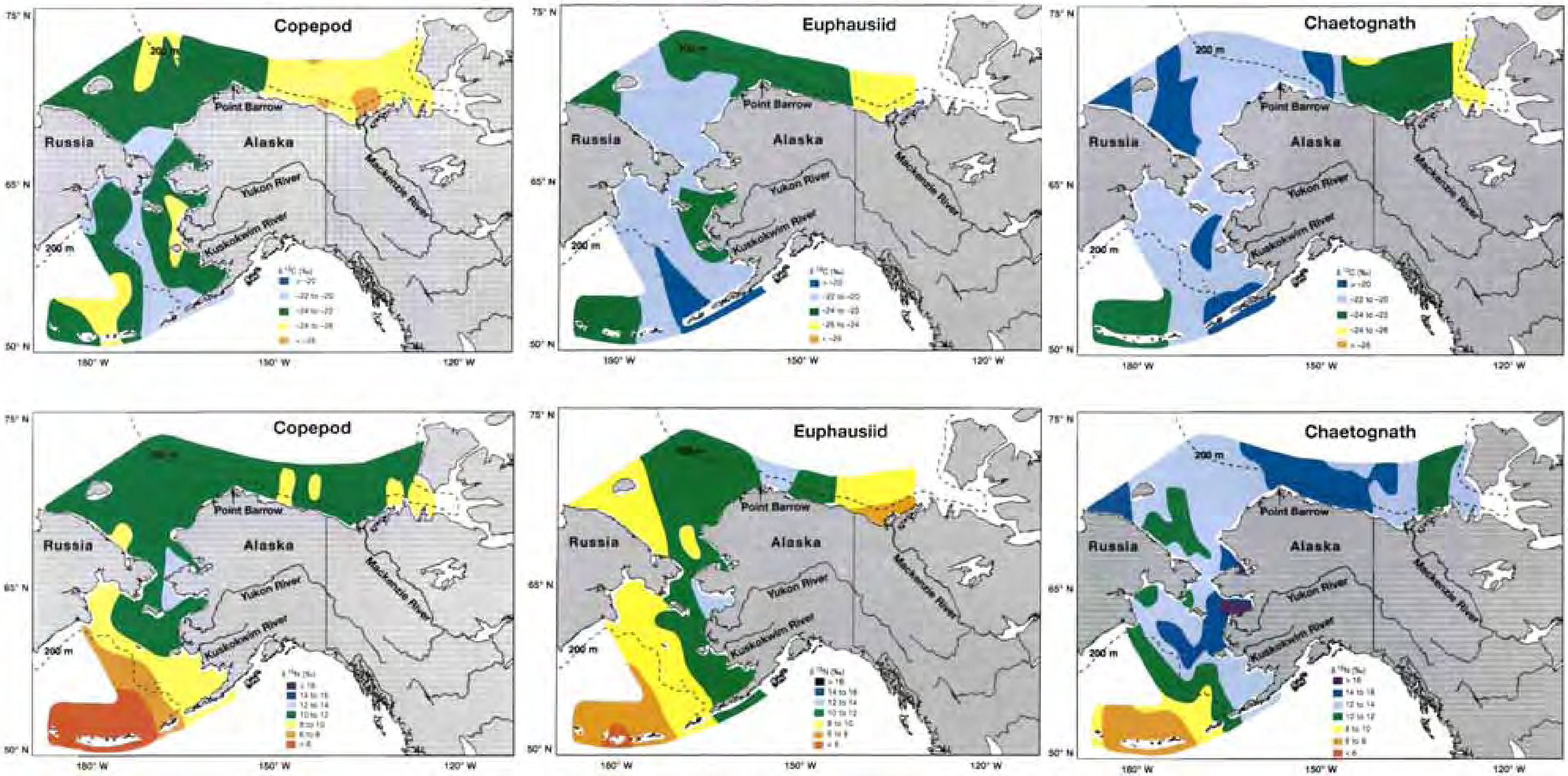
Rationale

- Natural stable isotope abundance (NSIA) compliments more conventional biological ecosystem metrics (e.g., body size, growth rate, survival rate, and population) as well as physical environmental parameters
- In the north Pacific, NSIA has signaled change on geological, multi-decadal, and inter-annual time scales.
- NSIA variations are easily measured in higher trophic level consumers from a variety of tissues.
- NSIA variation is driven by primary producers and conserved in food chains so observations reflect processes driving upper trophic levels from the bottom up.
- Examples will be given that show relationships between NSIA and factors driving marine ecosystem change.

Isoscapes

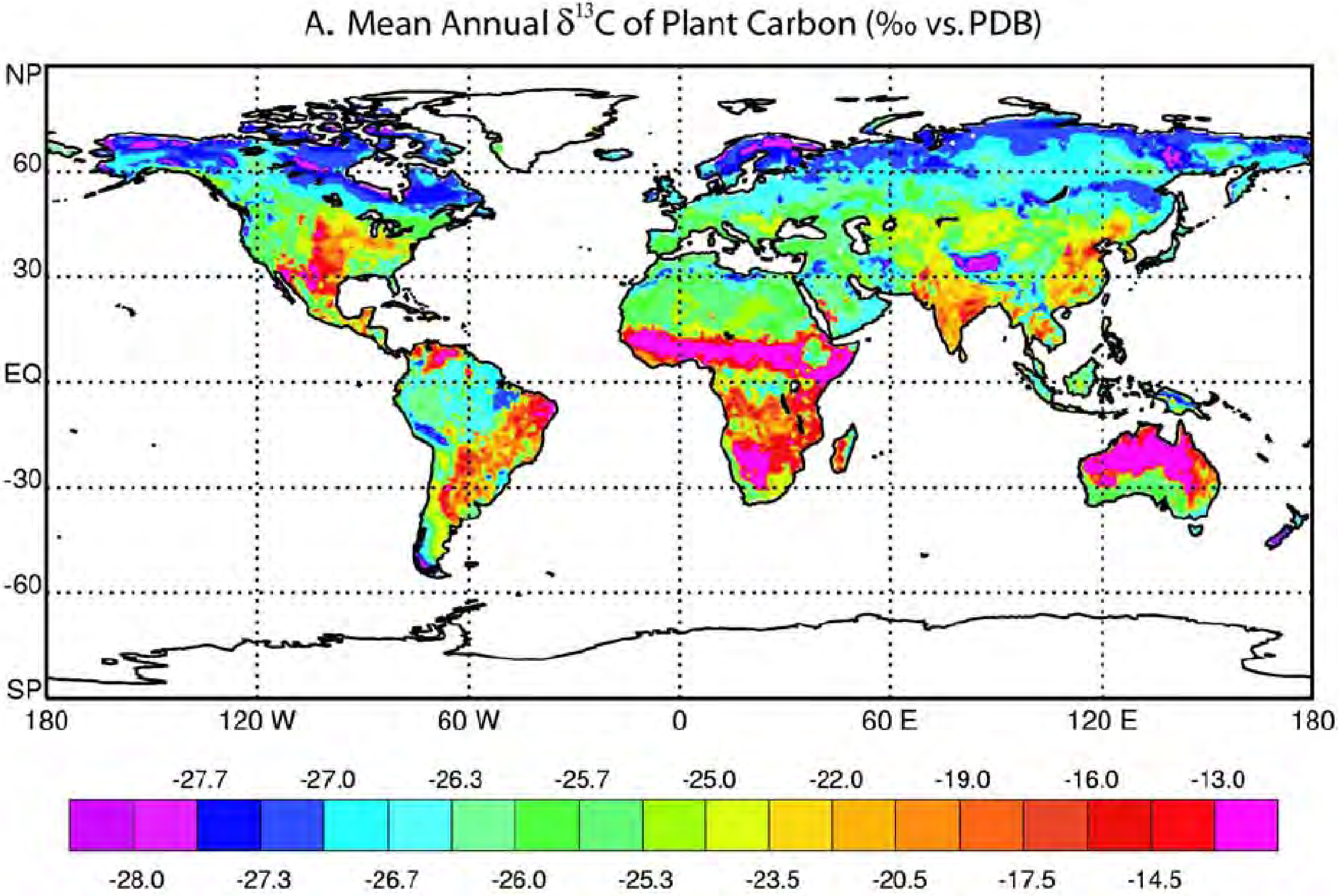
- Maps showing spatial isotopic variation known as isoscapes.
- Provide context for interpreting NSIA
- Isoscapes may follow zonal gradients.
- For example:
  1. Very low $\delta^{13}C$ values: organic carbon generated in iron-limited oceanic waters (some terrestrial sources).
  2. High $\delta^{13}C$ values: more productive coastal waters.

Isoscapes from Schell et al. 1998



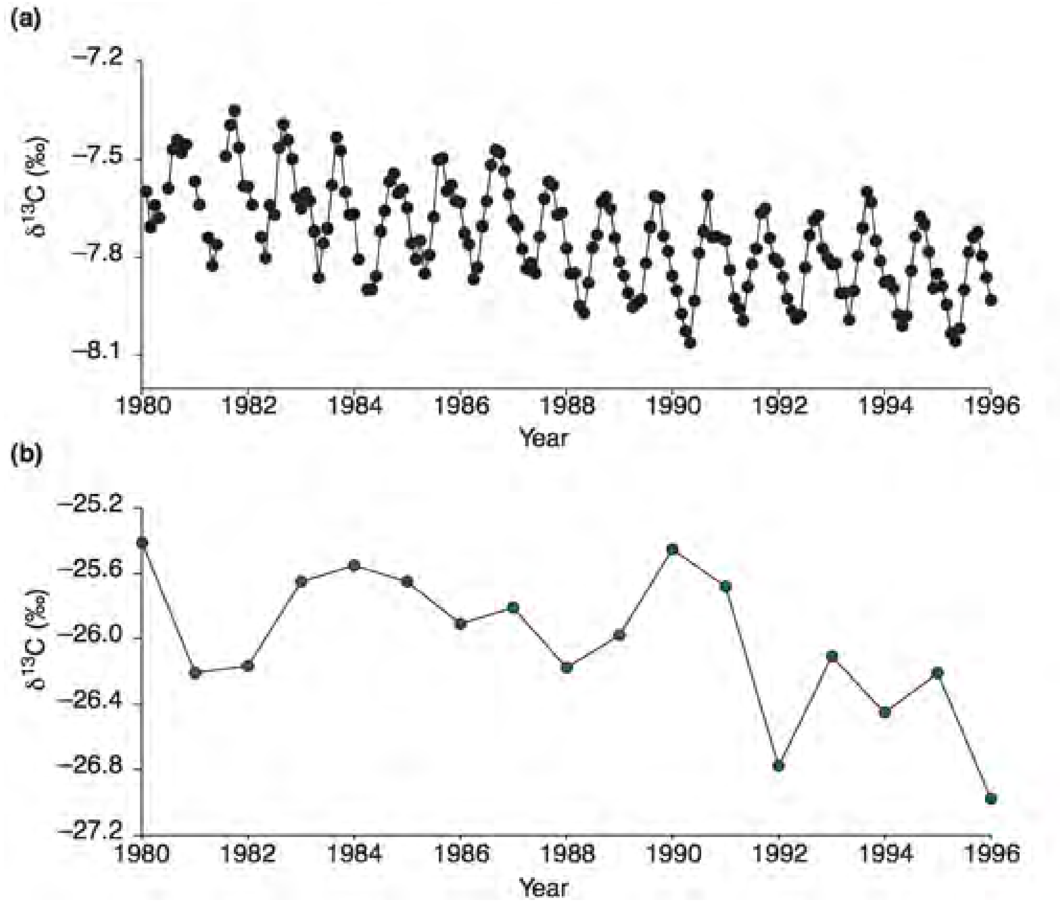
- Data averaged over ten years and multiple projects: C top panels, N bottom panels
- Gradients propagate up food chains (conservation of mass); trophic level effect
- High C on productive outer Bering shelf
- Low C and N in Fe limited waters of Aleutians
- Low C from terrestrial input Mackenzie River & Y-K Rivers delta

Terrestrial isoscapes are better known



Suits *et al*.2005.GBC

Anthropogenic carbon: Seuss effect



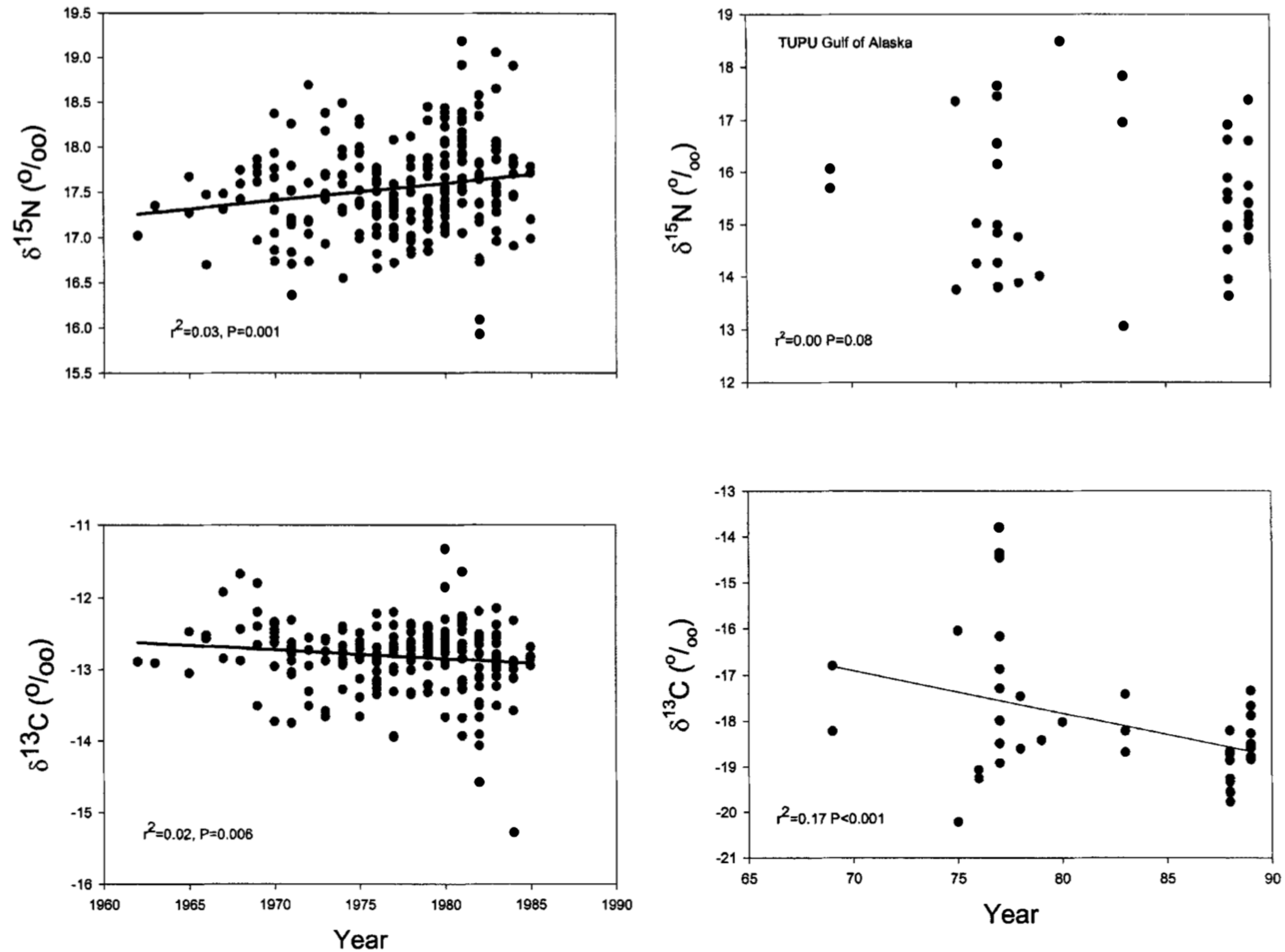
Figures from West et a. 2006. Top panel: $\delta^{13}C$ of atmospheric CO_2 at Manua Loa, HI
Bottom panel: Oak tree ring cellulose

- One can detect anthropogenic C in biosphere through systematic decrease in $\delta^{13}C$
- $\delta^{13}C$ values expected to decrease with time as anthropogenic C enters ocean

Isotope records in marine organisms

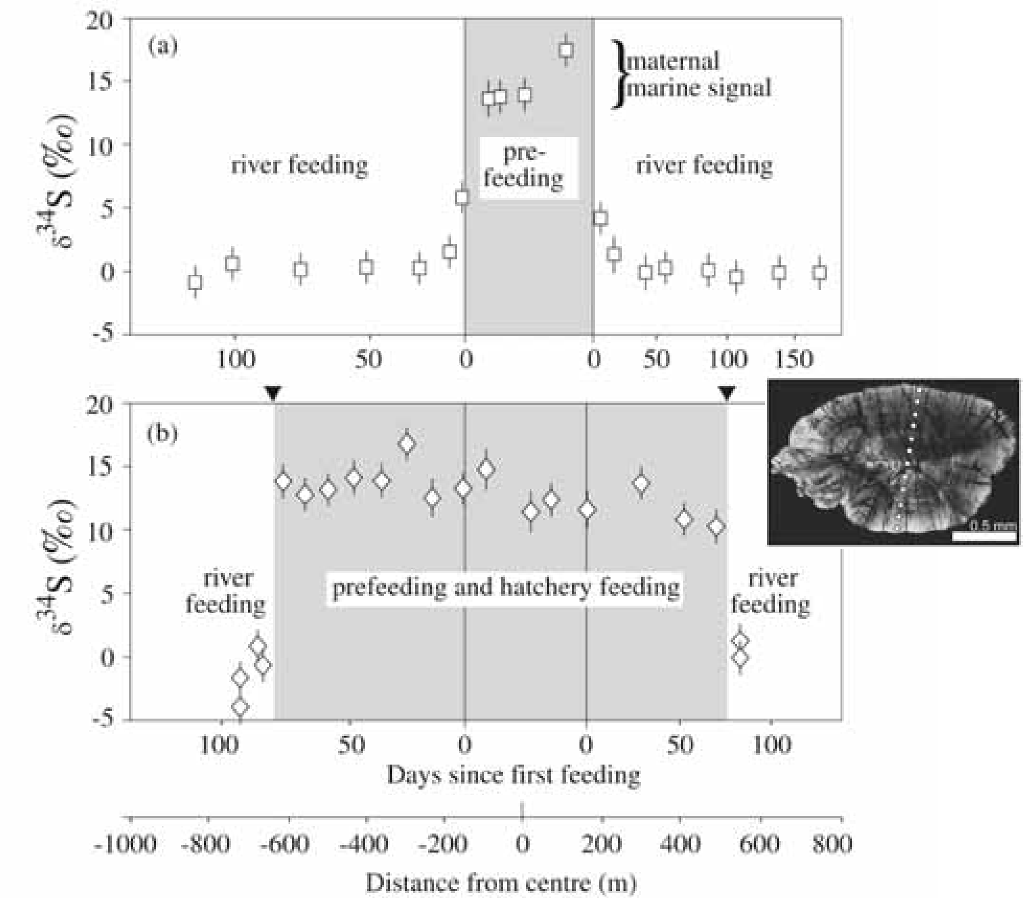
- NSIA can provide a history that is recorded in organismal hard structures such as otoliths, bones, feathers, scales, claws, vibrissae, and baleen.
- When organisms migrate across gradients within isoscapes the isotopic variation is recorded in these hard parts.
- An historical collection can be used as an indicator of change in migration pattern or a change in the isoscape.

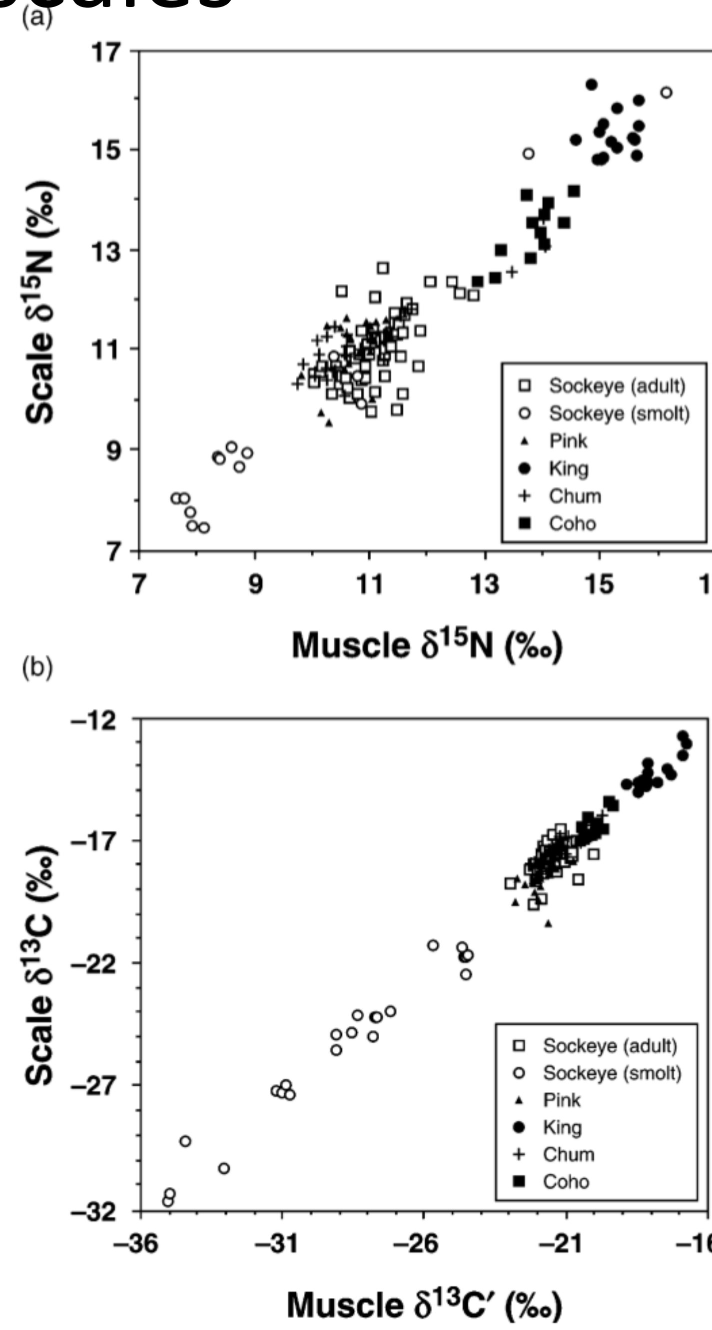
Teeth and feathers



Reconstructed NSIA from Steller's sea lion teeth annuli (left) and tufted puffin feathers (right) collected from the Gulf of Alaska (Hobson et al. 2004)

Otoliths and scales

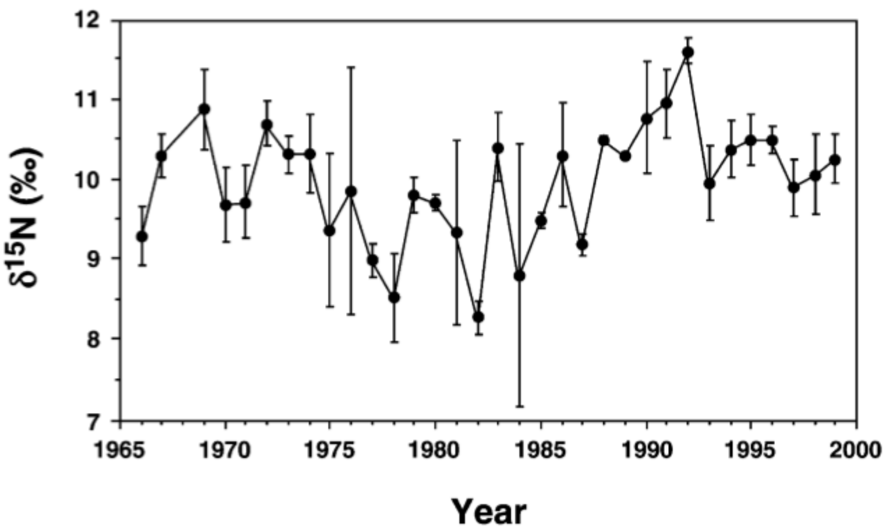


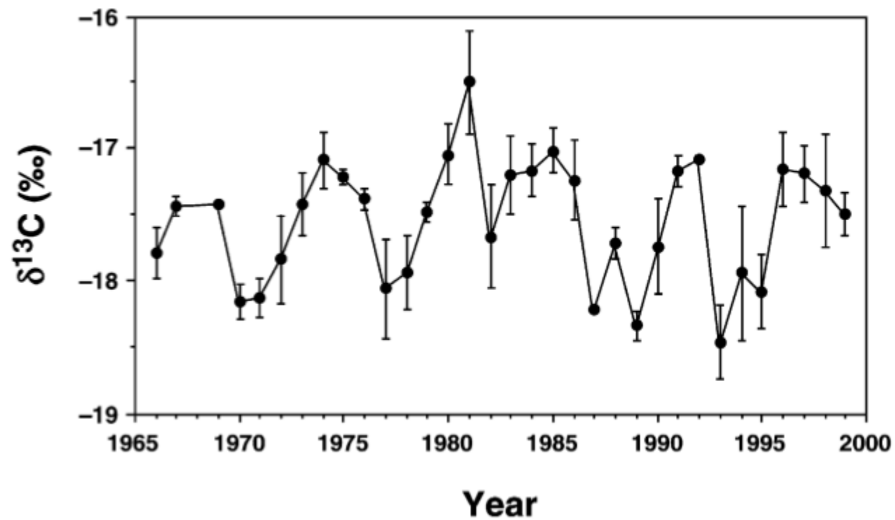


(Above) Feeding history recorded by $\delta^{34}S$ of Chinook salmon otoliths; wild (top) vs. hatchery (bottom). From Weber et al. 2002.

(Right) scales and soft tissues NSIA well-correlated in salmon (C offset of ~+4 may need to be corrected). From Satterfield and Finney 2002.

Reconstructed history based on scales

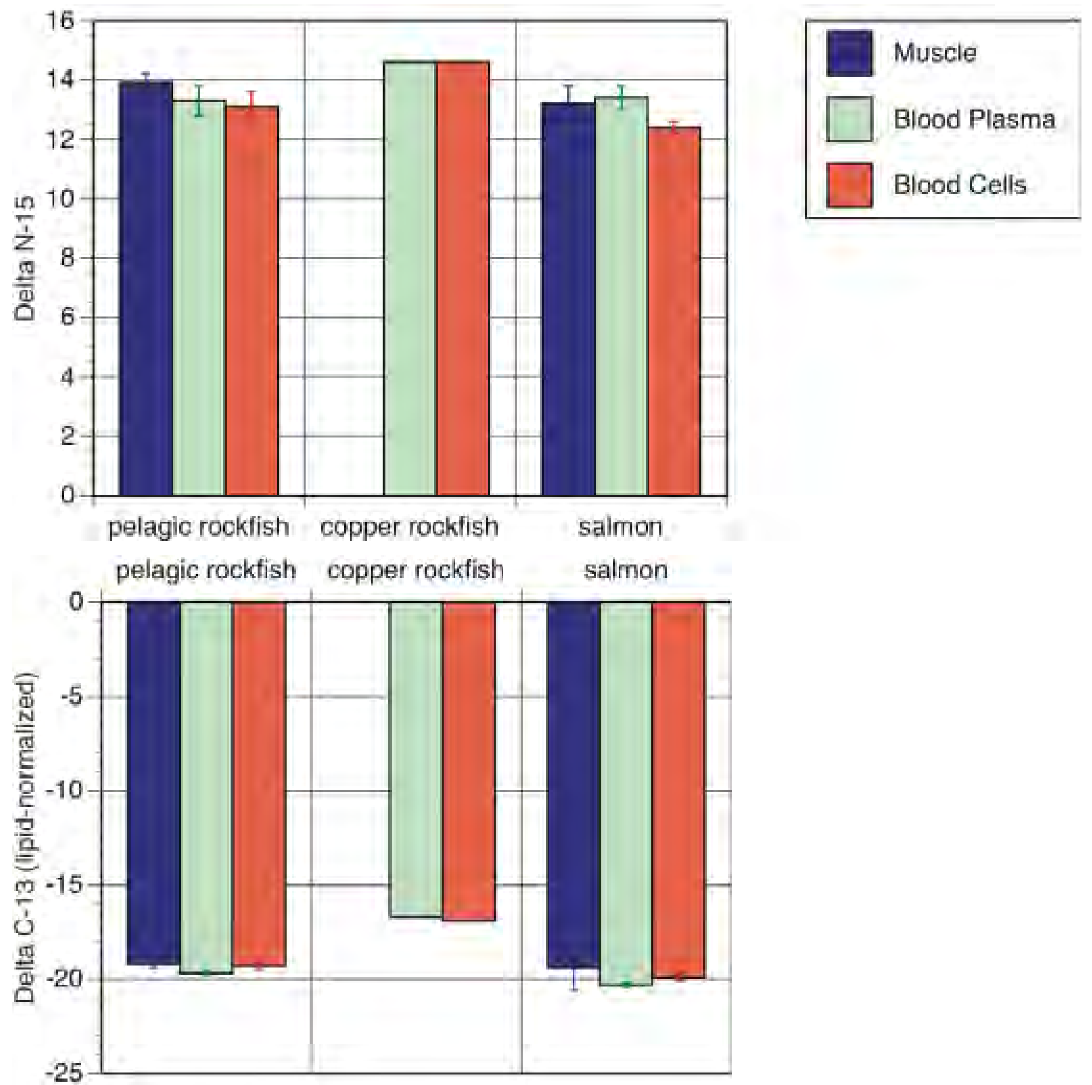




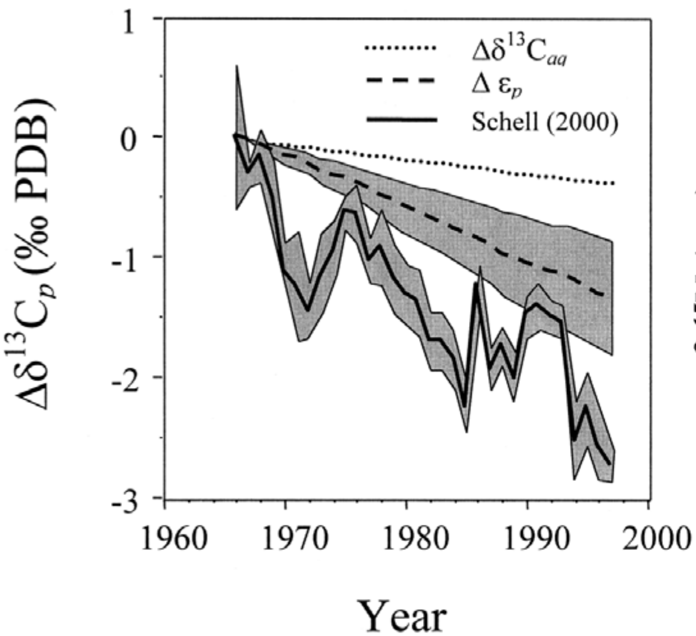
Scales collected from 2-6 adult sockeye salmon returning to Red Lake, Kodiak Island each year from 1966 to 1999.
Satterfield and Finney 2002

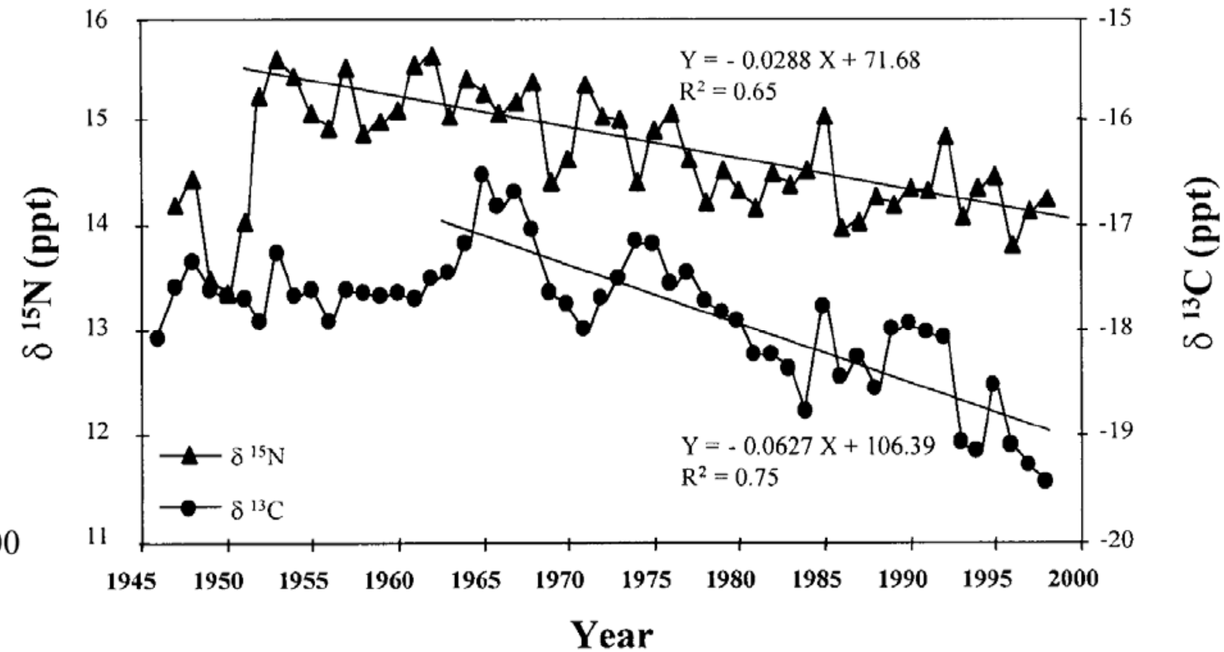
Alternative tissues

- Muscle vs. blood
- Blood can be sampled non-lethally
- Plasma has shorter turn-over time
- Data from Kline (2005)



Bering Sea historical change in NSIA reconstructed from bowhead whale baleen

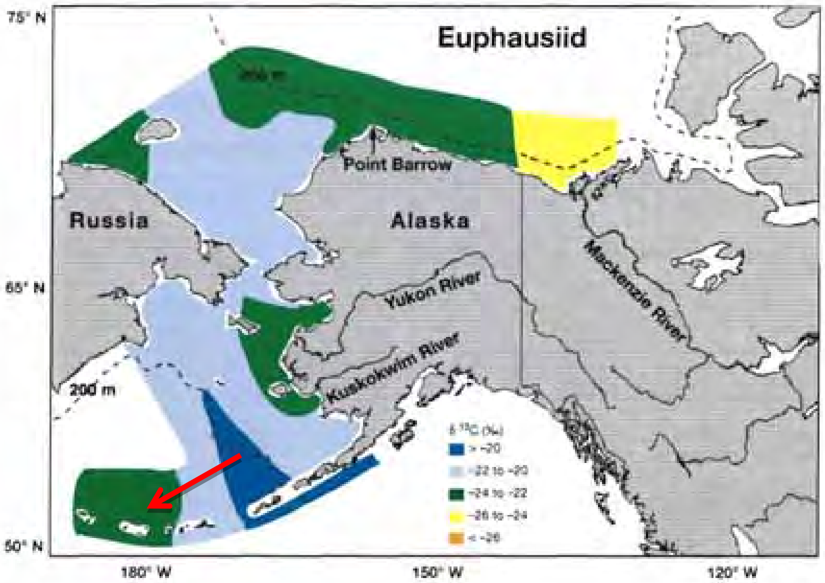


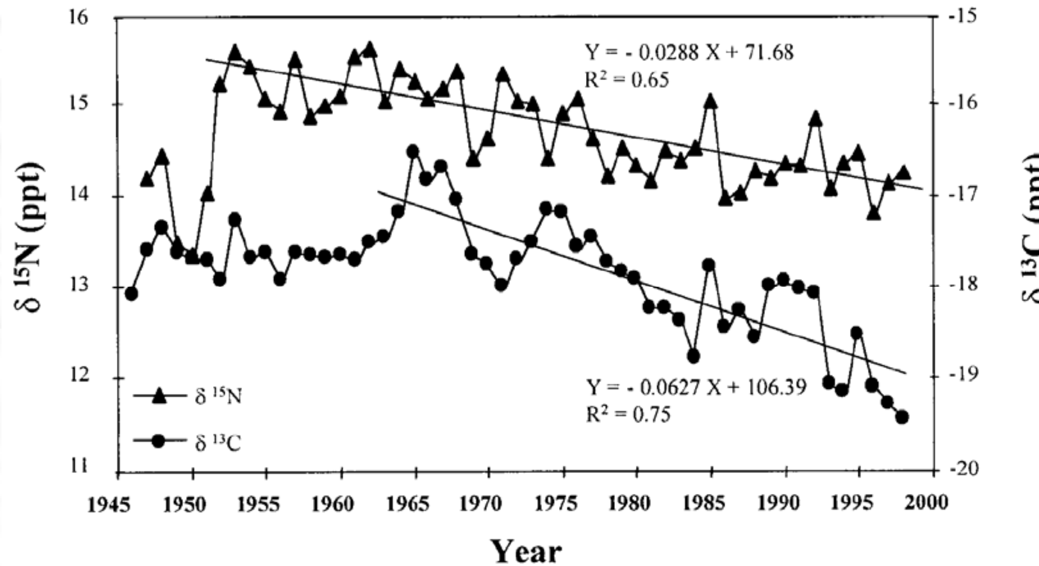


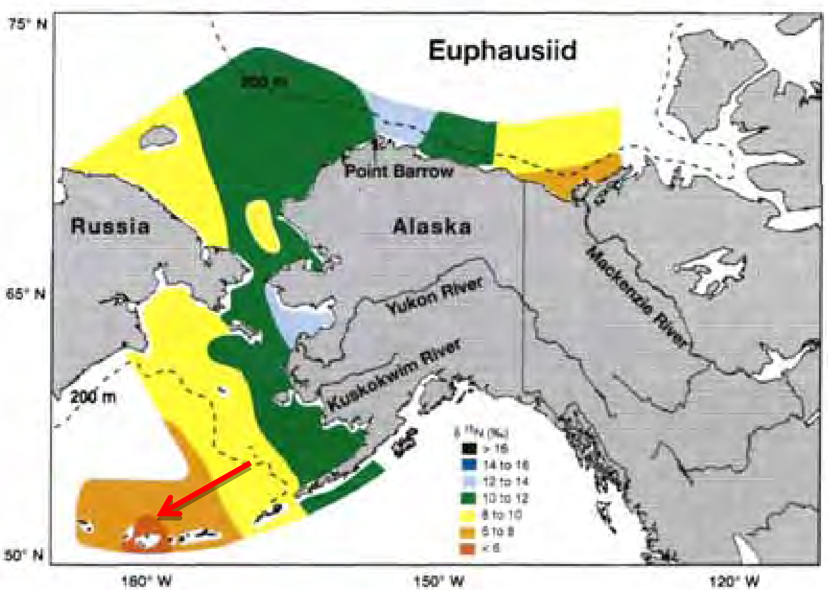
- Neither Seuss effect (dotted line) nor change in isotopic discrimination by phytoplankton (dashed line) can explain observed change in bowhead whale baleen (solid line) (left; Cullen et al. 2001).

- These explanations also fail to explain concordant $\delta^{15}N$ shift (right; Schell 2001)

Observations + Isoscapes = Behavior Change



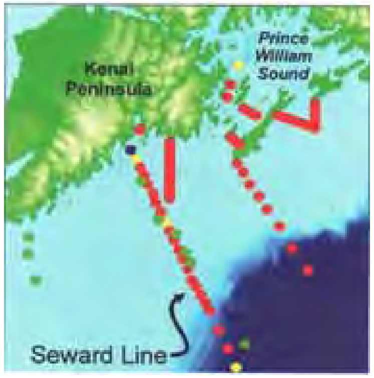




- A simpler explanation for the data is that the whales changed migration to where there are lower C and N values in zooplankton; in a general southwest direction
- Primary assumption: isoscape is fixed in time

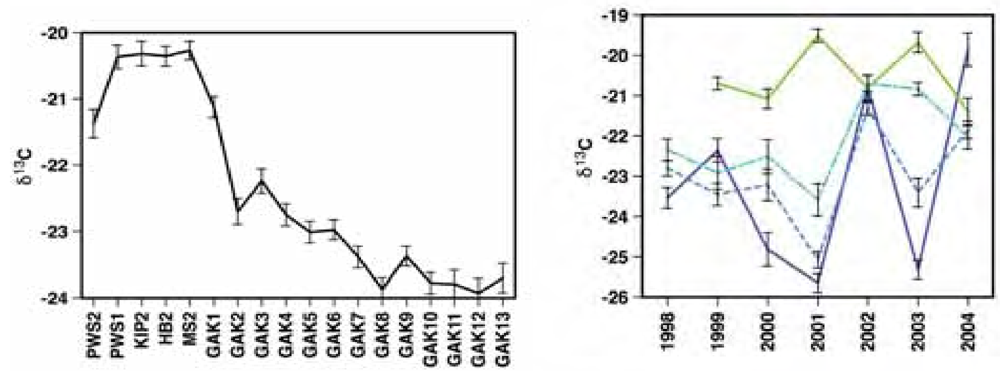
Schell et al. 1998 and Schell 2001

Variability within isoscapes

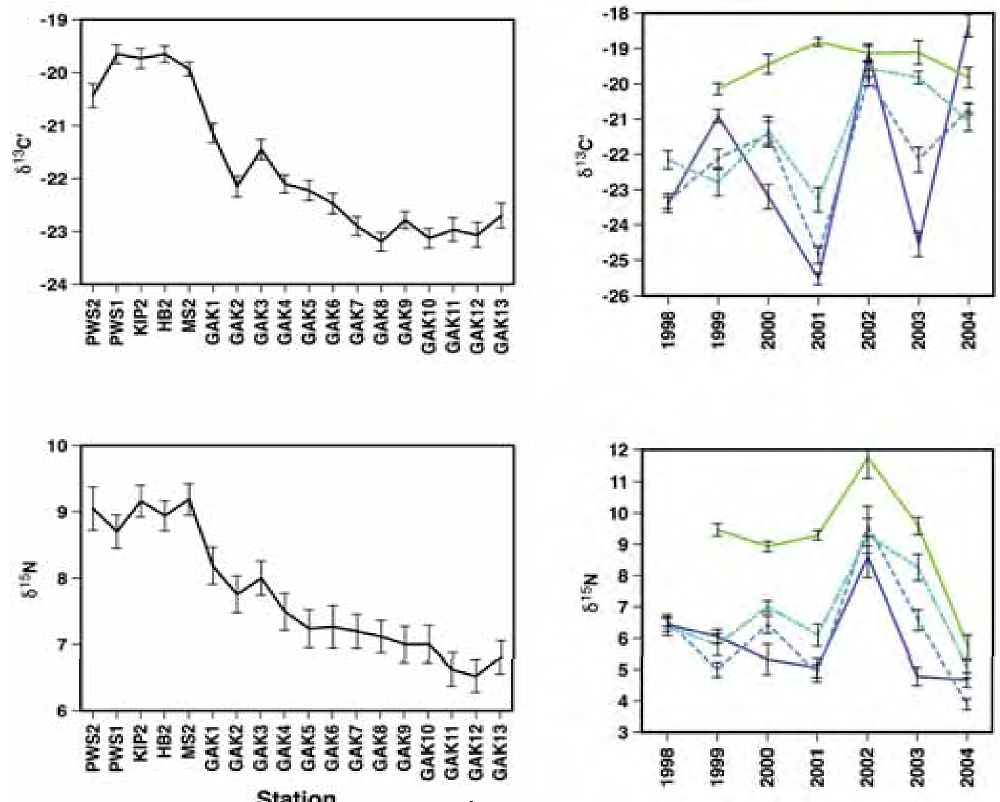


Section across shelf and slope on Seward Line and stations in Prince William Sound. Weingartner et al. 2002

- Sample mean (24 cruises from 1998 to 2004) suggests stable isotope gradients with low values on slope (GAK 10-13) and high values in Prince William Sound (PWS, KIP2, HB2, MS2)
- However, there were large inter-annual variations at the slope (GAK10-13) each May
- High PWS-like C values in 1999, 2002, and 2004
- Very low C values in 2001 and 2003

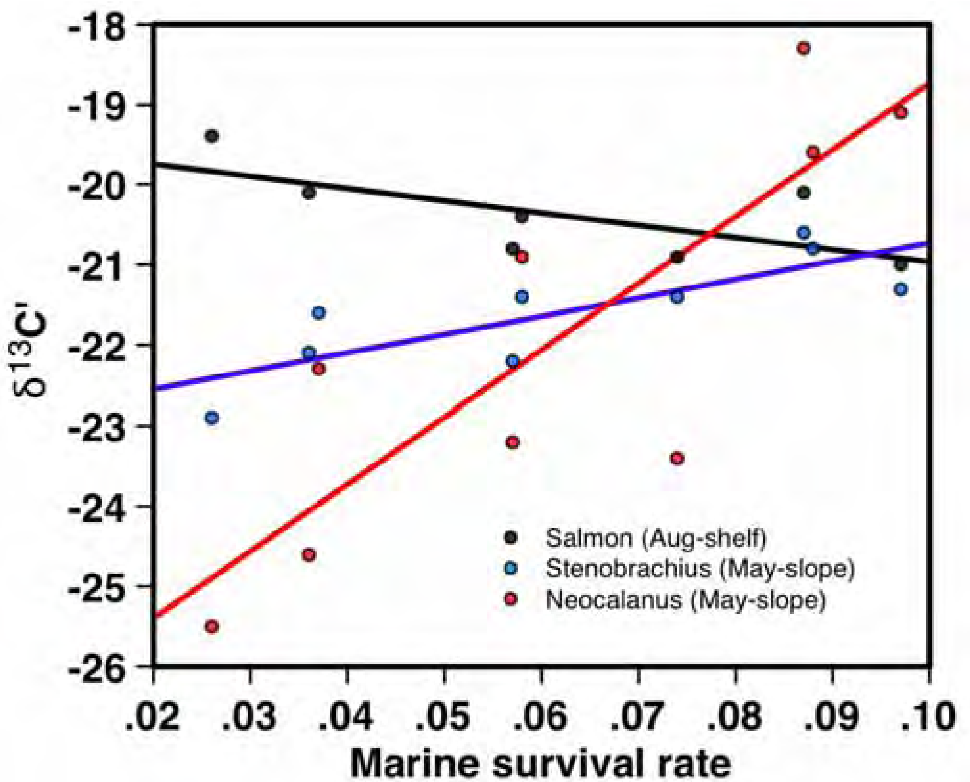


NSIA on *Neocalanus*



Kline 2009

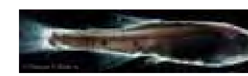
NSIA correlates of salmon marine survival



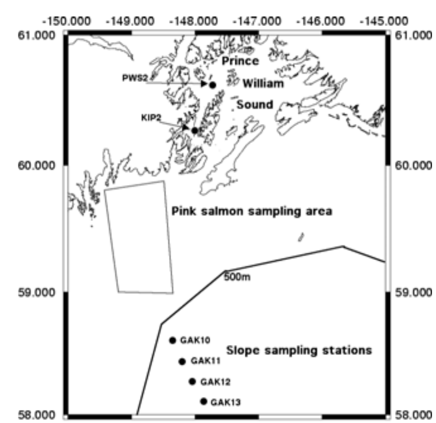
$\delta^{13}C$ of early marine pink salmon
$R^2 = 0.48$ $P = 0.084$ $N = 7$

$\delta^{13}C$ of *Neocalanus cristatus* copepod
$R^2 = 0.72$ $P = 0.004$ $N = 9$

$\delta^{13}C$ of *Stenobrachius leucopsarus*, a Myctophid fish
$R^2 = 0.67$ $P = 0.007$ $N = 9$



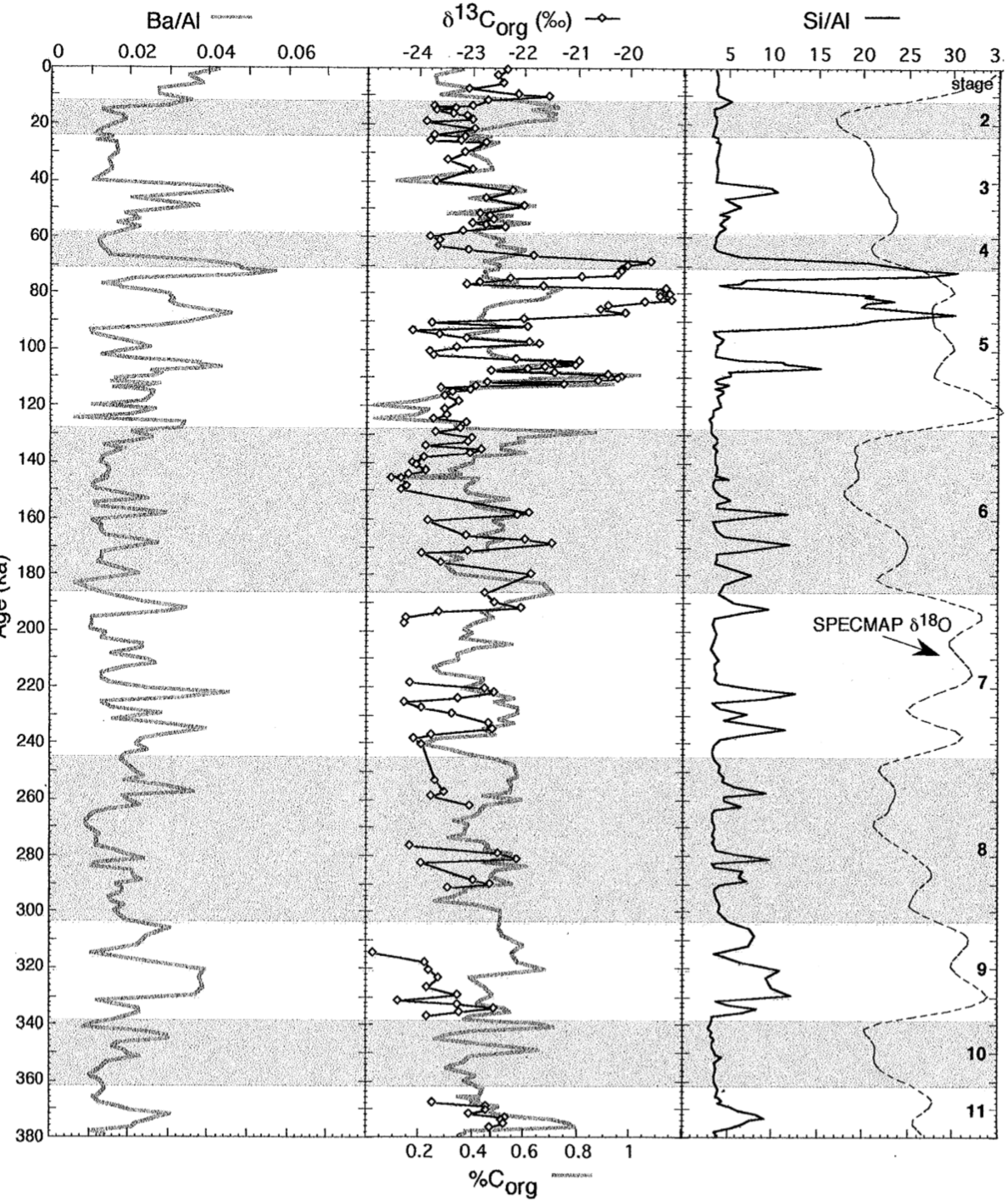
Multiple regression:
$R^2 = 0.91$ Adjusted $R^2 = 0.83$ $P = 0.042$

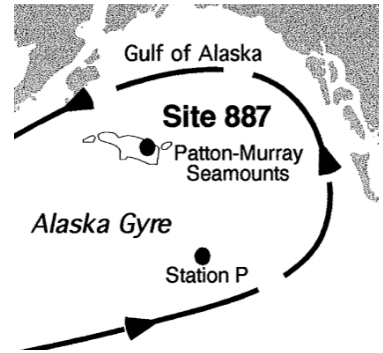


- ✓ Collectively, isotopic correlates explained > 80% of MSR variation, an improvement over any one component

Data from Kline et al. 2008, Kline 2009, 2010

NSIA variability on long time scales recorded in ocean sediments



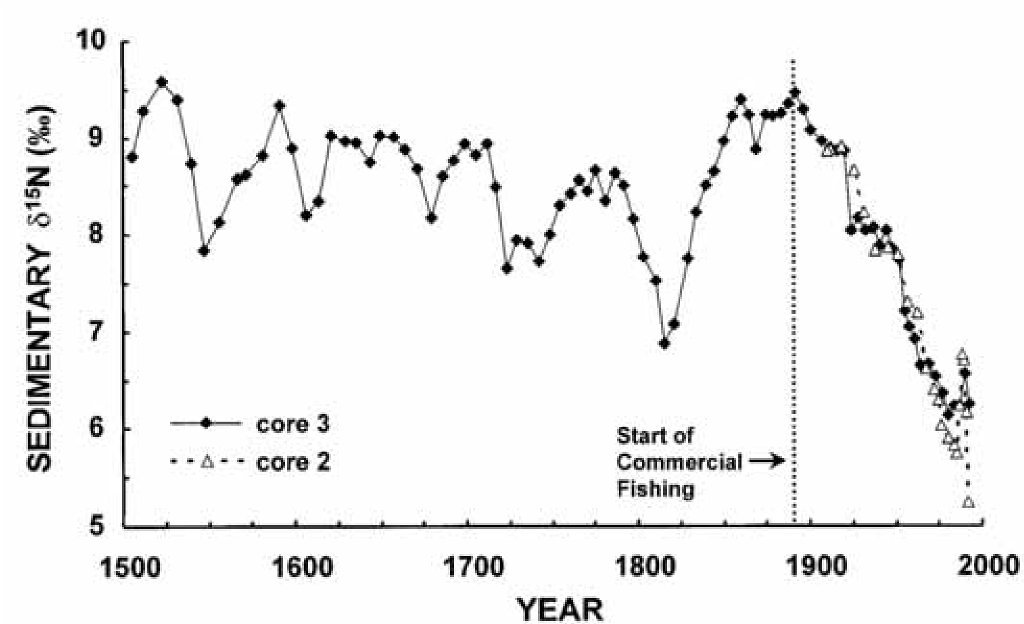


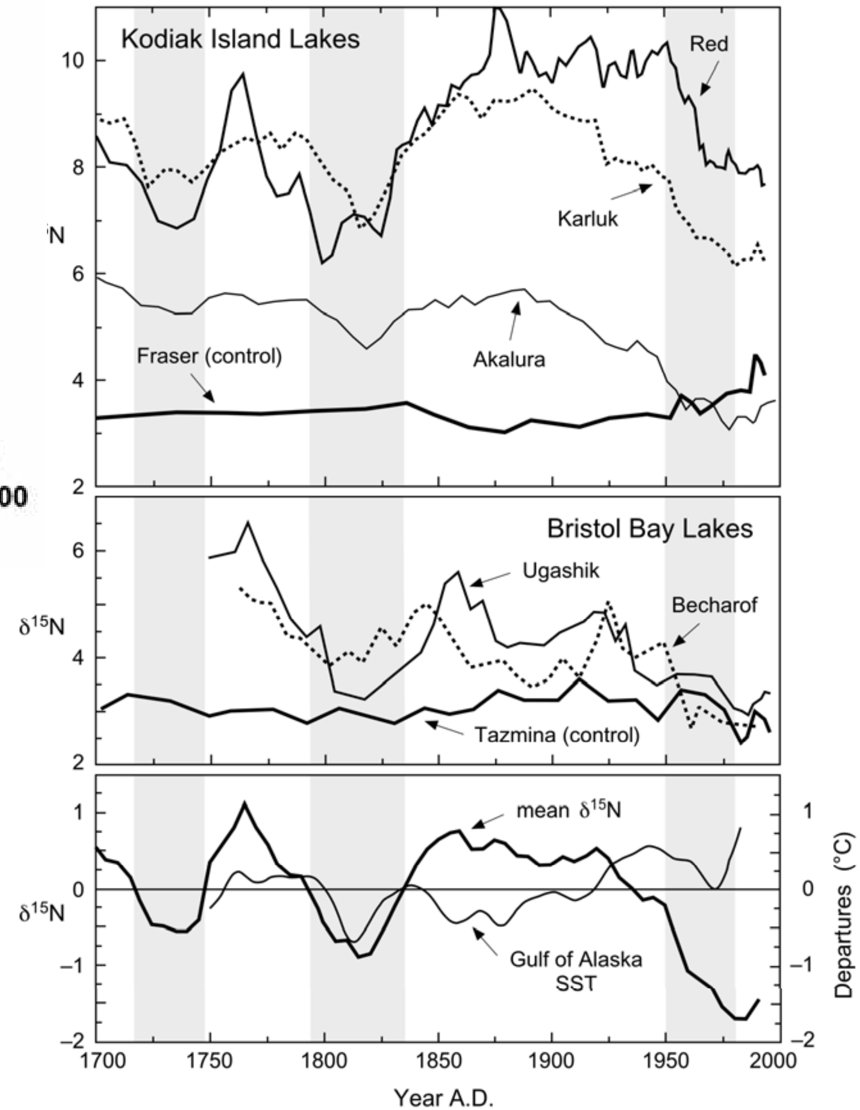
Multi-ka core from site 887 included $\delta^{13}C$ of organic carbon (McDonald et al. 1999)

✧ Organic carbon $\delta^{13}C$ range of -25 to -19 is similar to that measured farther north in copepods

✧ A period with high $\delta^{13}C$ values from 70 to 90 ka ago coincided with high diatom concentrations – speculated there was more freshwater entering ocean so coastal-like at the seamounts

Sockeye salmon run size variability on long time scales recorded in lake sediments



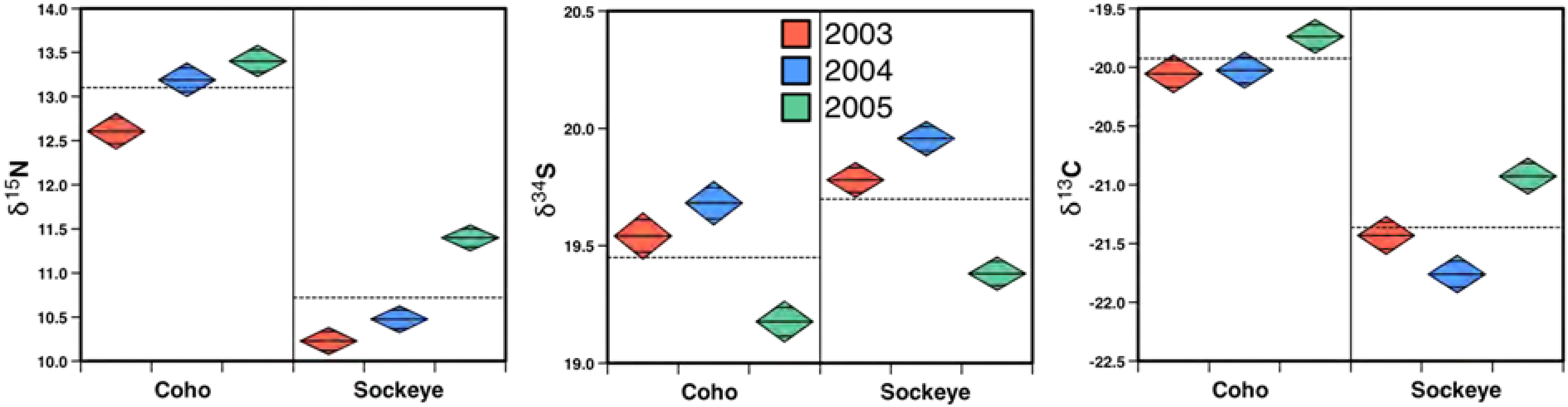


Above: Karluk Lake core data Schmidt et al. 2000

Right: Alaskan Lake core data Finney et al.

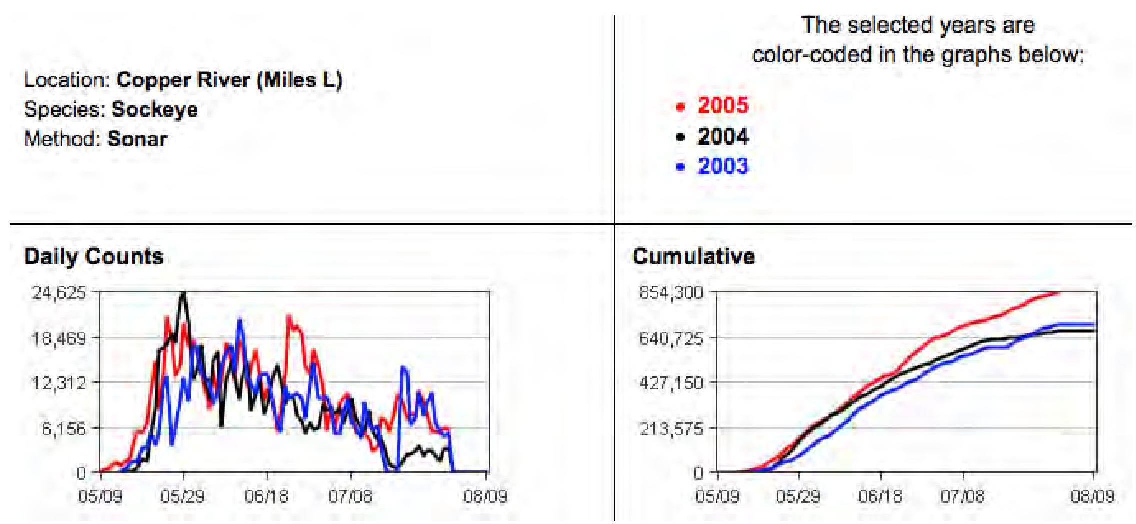
- $\delta^{15}N$ reflects input of N from salmon which is proportional to run size
- Evidence of run size variation in the absence of commercial fishing
- Cycles in run size may be climatically driven – mini ice age of 1800's

NSIA of adult salmon



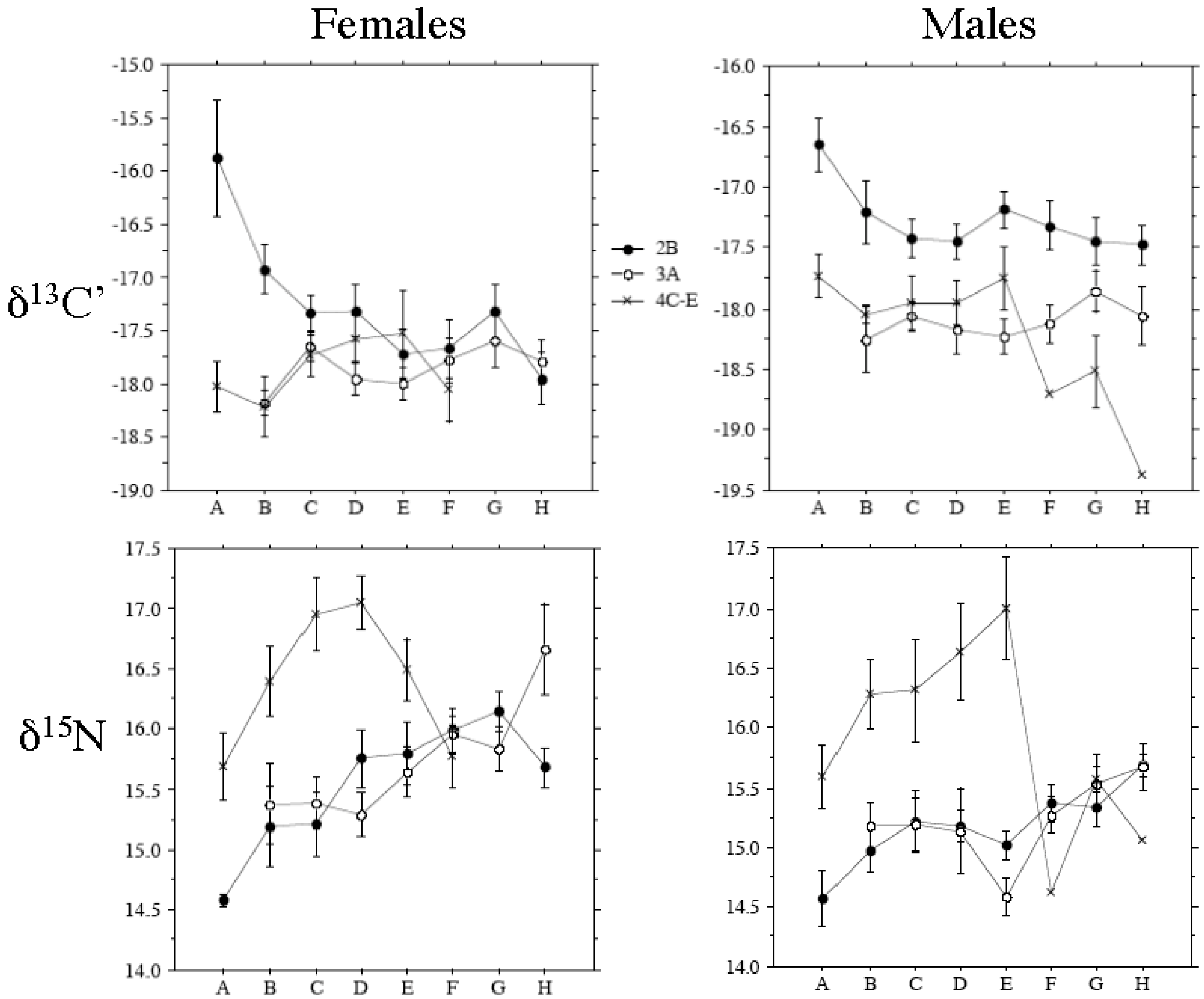
Kline et al. 2006 and unpublished

- $\delta^{15}N$ +10 to 11 (sockeye) +12.5 to 13.5 (coho)
- $\delta^{34}S$ +19 to 20
- $\delta^{13}C$ ~ -21.5 (sockeye) ~ -20.0 (coho)
- Coho salmon feed almost a trophic level higher than sockeye salmon
- Inter-annual differences small but significant
- Similar to Satterfield and Finney scale results
- Indicative of coastal feeding to a greater extent just prior to return in 2005
- Samples can be collected routinely – spawning ground survey or fishery



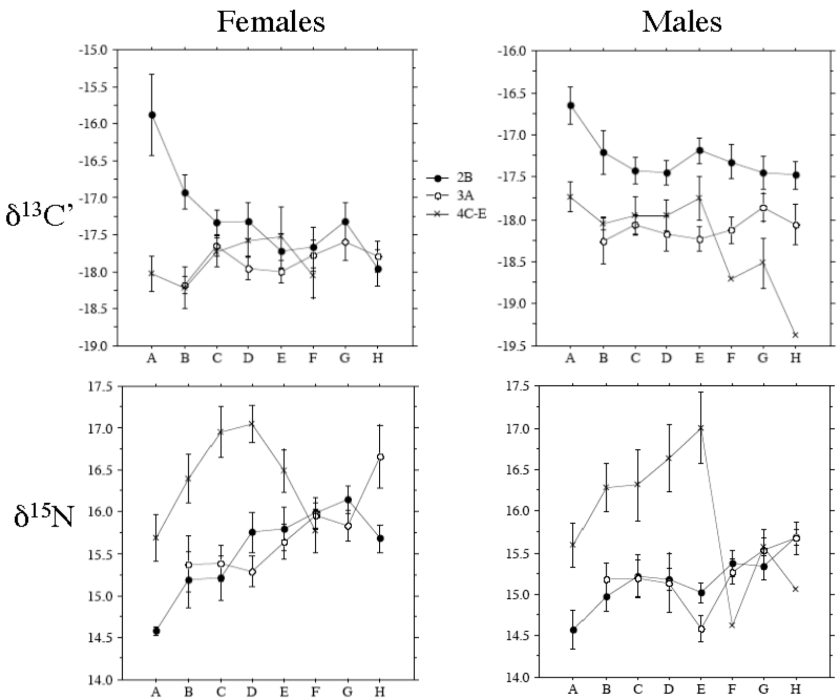
Data: ADFG web page

Ontogenetic, gender, and large-scale spatial NSIA variation in Pacific halibut

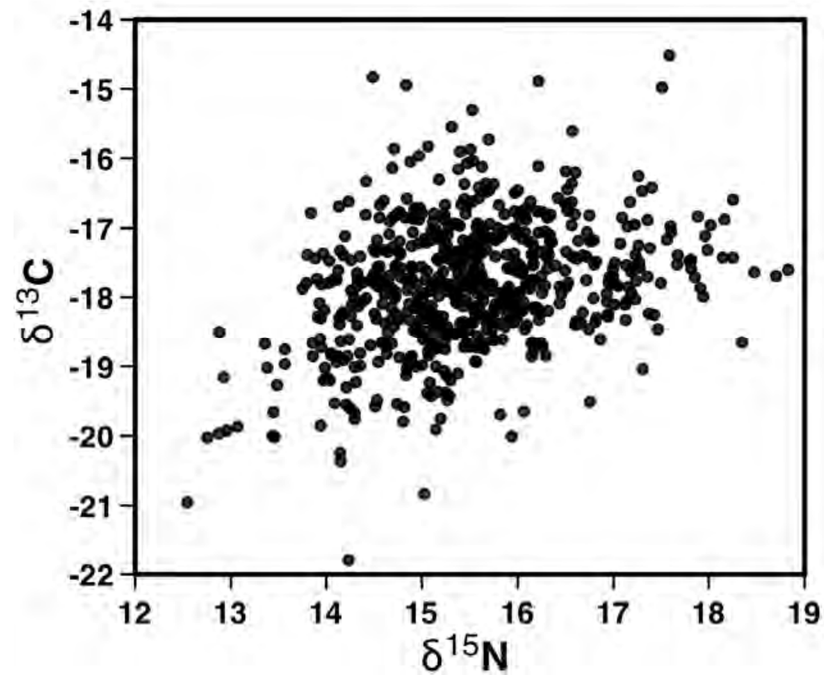


Kline and Hare in progress; A = age 2 to 4, B = age 5 to 7,... G = age 22 to 24, H = age 23 to 40

A few words of caution!



vs.



- Halibut data from previous slide shown in aggregate as X-Y plot
- Need to stratify sampling in order to resolve story (may be very important for understanding change)
- Need to sample adequately

Summary

- Isoscapes (spatial as well as temporal variation)
- Isotope records in various marine organisms in various tissues – technique enables integration across trophic levels
- Records of isotope change in sediments as well as organisms on various time scales
- Isotope change may be relatable to climate change, recruitment, growth rate, etc.

Thank you!