# A Long-term Perspective on Salmon Ecosystems in SWAN

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**Idaho State University**

# OVERVIEW

- Method for salmon reconstruction
- Overview of study
- Results
- Synthesis
- Future directions

# Pacific Salmon:

- **Cultural Icon**
- **Great Economic Importance**
- **Ecology: Keystone Species**

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

# Coastal terrestrial and freshwater ecosystems “revolve” around salmon

## >> Through delivery of Marine-derived nutrients

- Lake/stream productivity (~ 50% of annual N and P)
- Riparian vegetation and coastal rain forests
- Bears, eagles, etc.
- Humans

# Paleolimnology - Methods

- Coring
- Dating
- Proxy analysis

  $\delta^{15}N$ ~ nutrients from salmon

  Lake food web

  - Primary producers:

    assemblage/productivity rate

  - Zooplankton:

    community/productivity

  Paleo-environment / climate

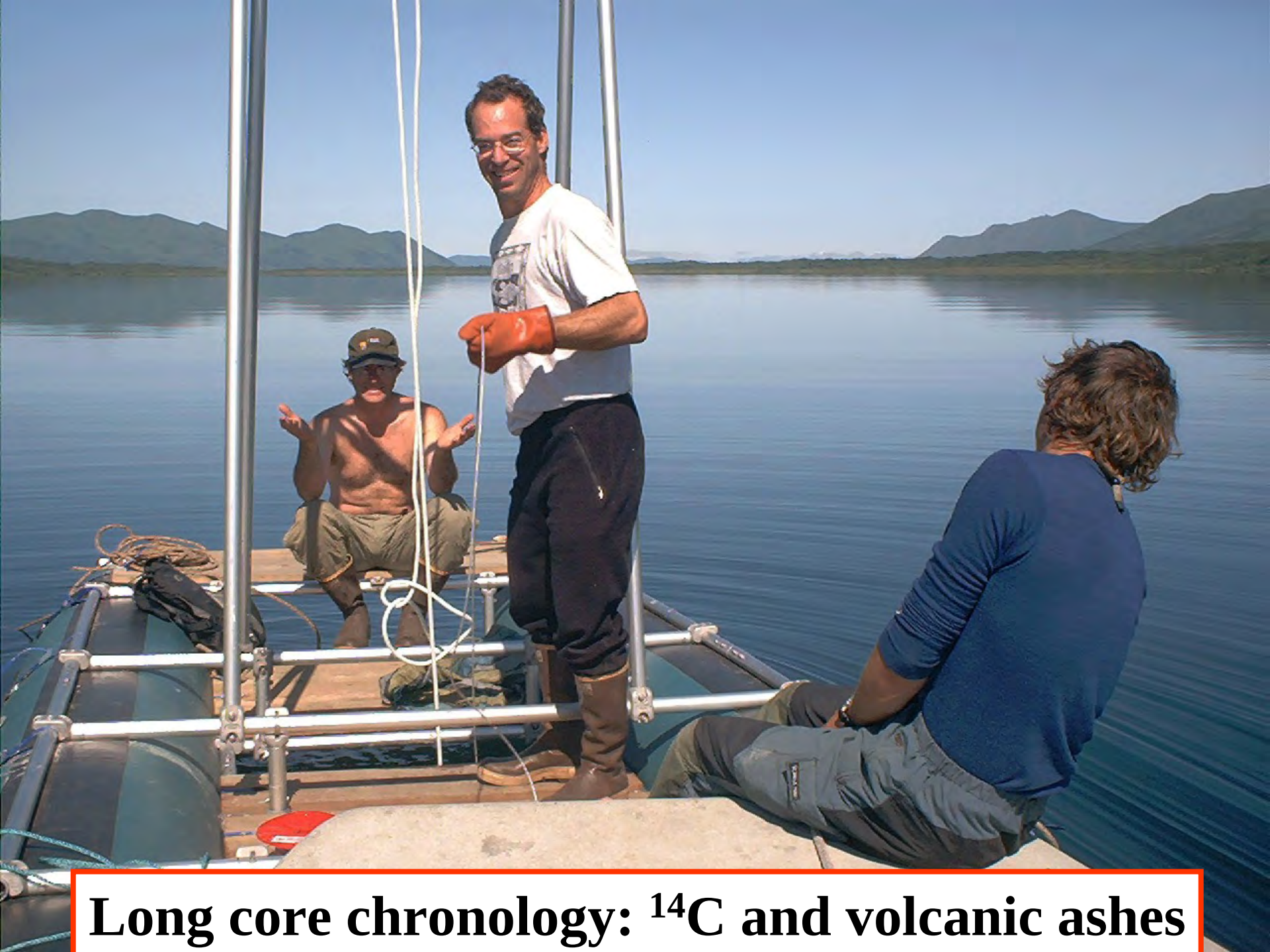
# Dating of Recent Sediments:

# $^{210}Pb$

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

# Dating of Sediments:Tephrochronology

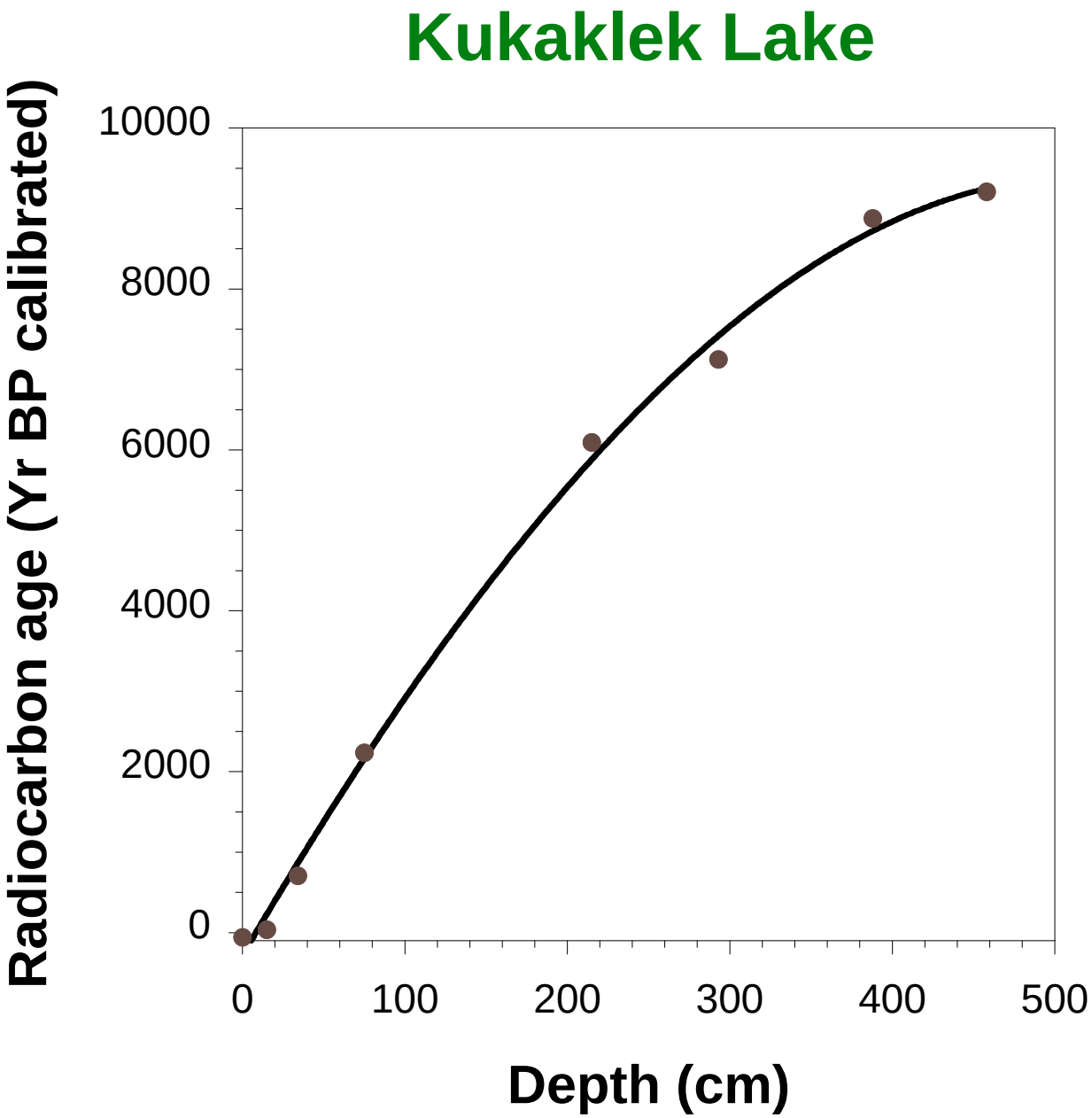
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



# Long core chronology: $^{14}C$ and volcanic ashes

**Dating of older (~250 - 40,000 years BP) Sediments:**

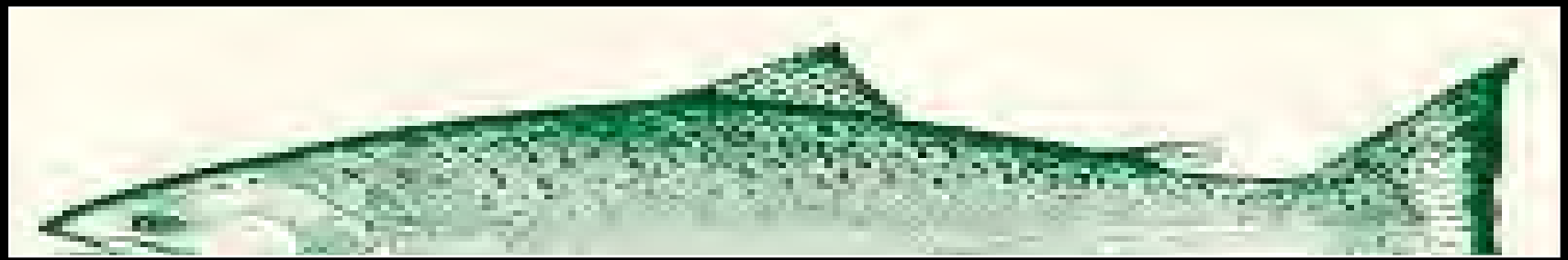
**Radiocarbon ($^{14}C$)**



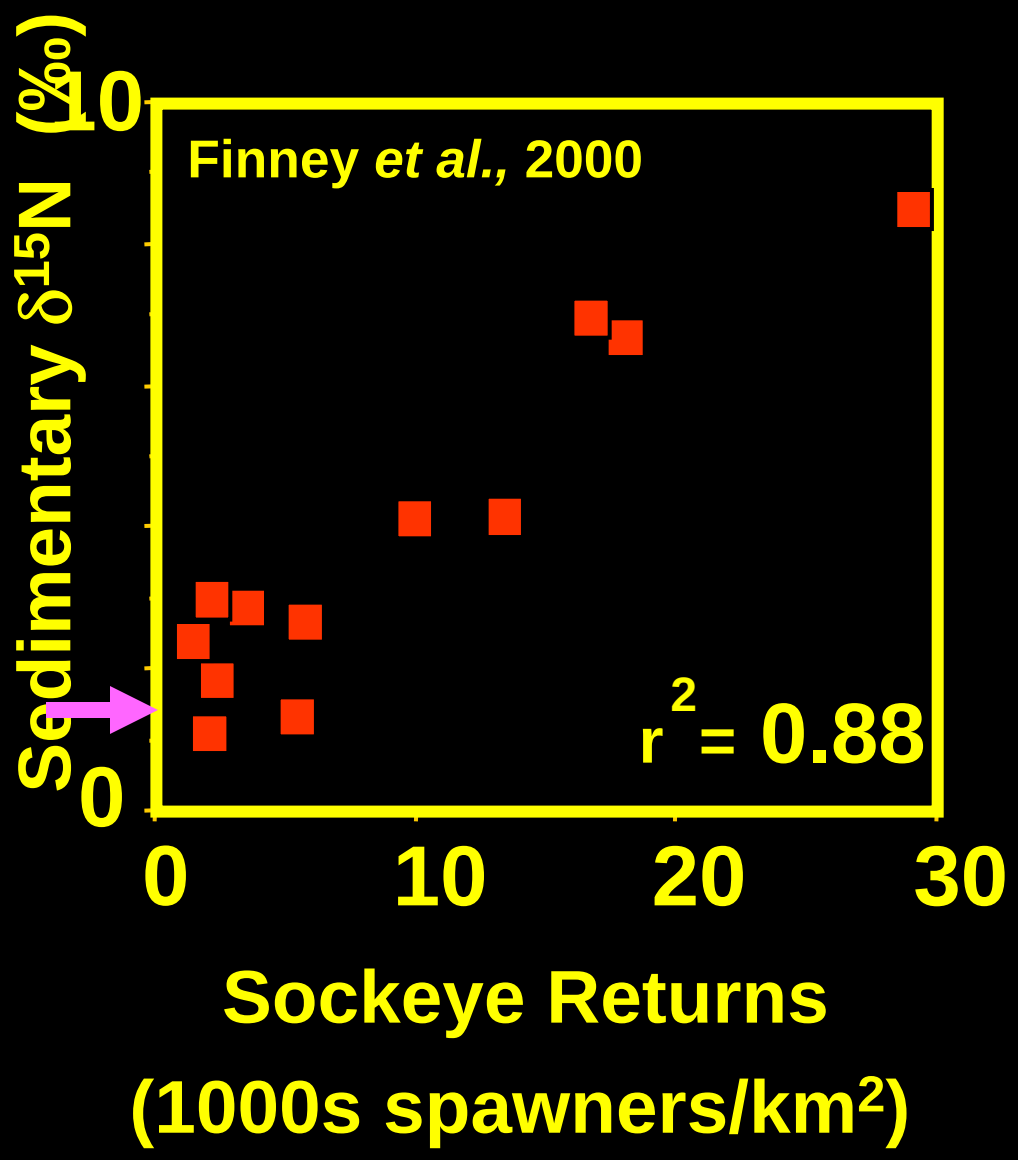
# Paleoecological Perspective on Pacific Salmon

## Sockeye salmon

- 1 - 3 years Freshwater Lake
- 1 - 3 years Marine
- Return to freshwater, spawn and die



# Stable Isotopes:



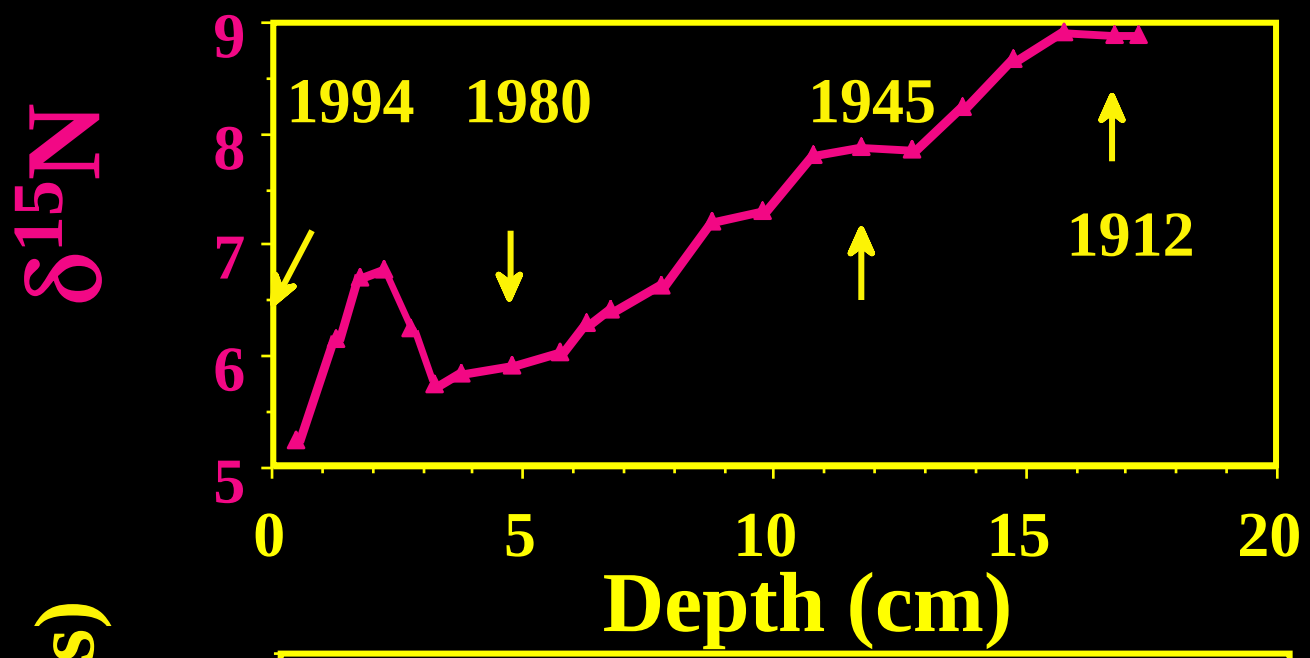

- Adult sockeye obtain > 99 % of biomass in ocean

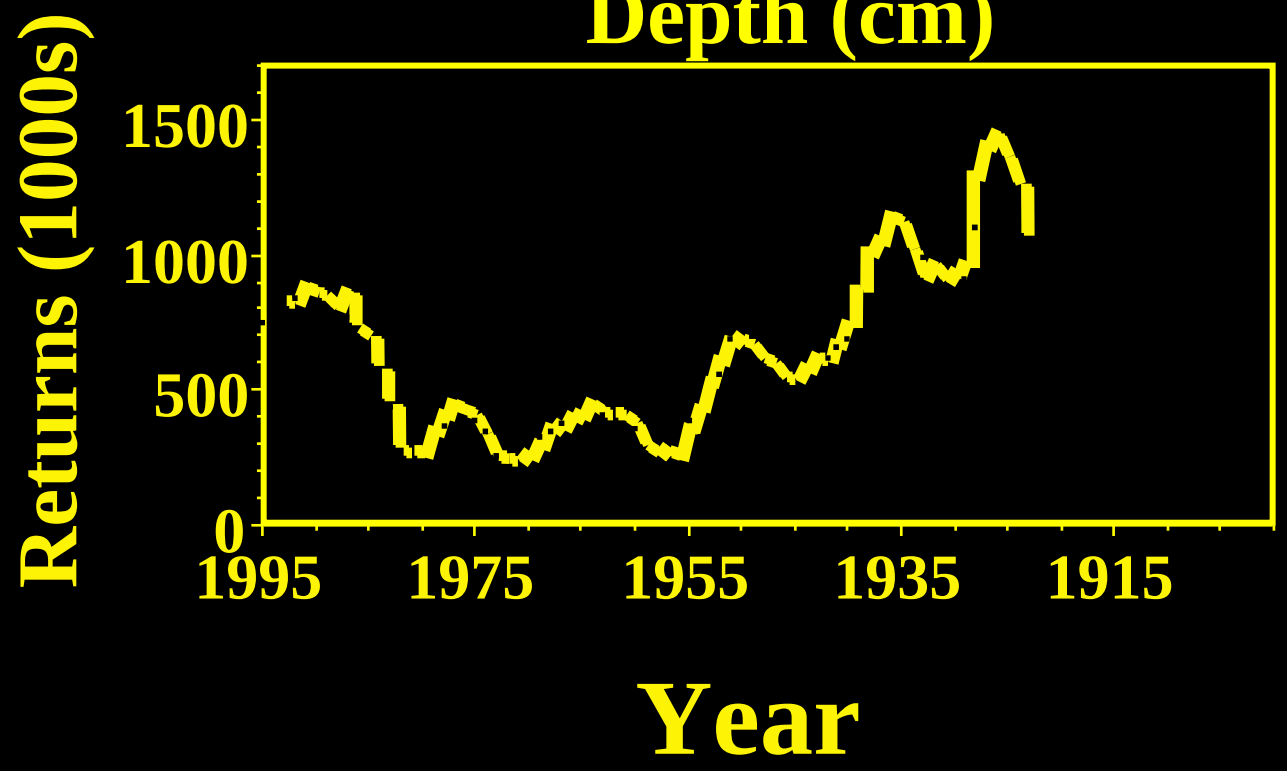
- Adults transport marine nutrients to freshwater

- Salmon carcasses enriched in $\delta^{15}N$

- Sediment $\delta^{15}N$ tracer of past salmon abundance

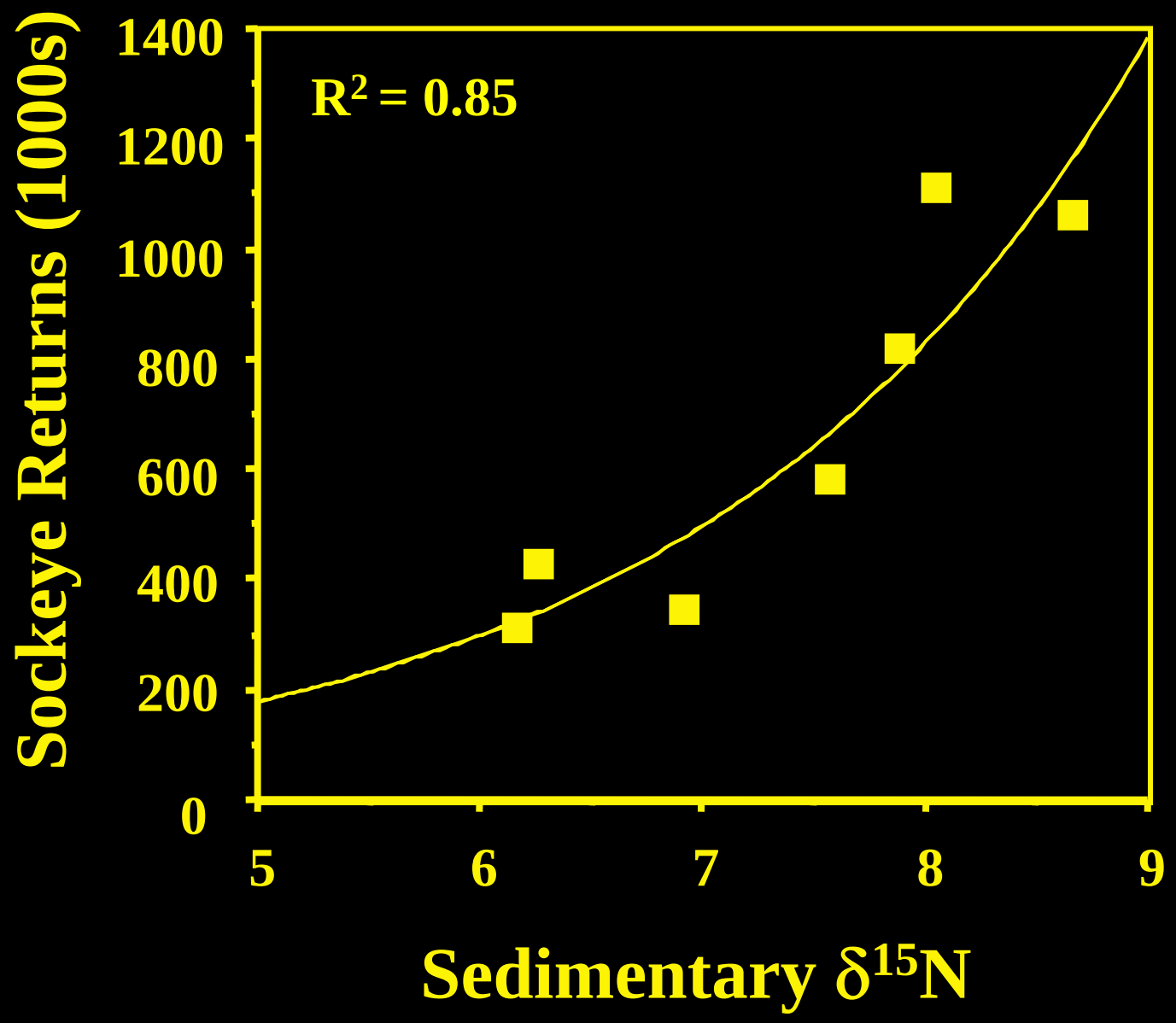
**Karluk Lake**
**Kodiak Island Alaska**


$\delta^{15}N$
9
8
7
6
5
1994
1980
1945
1912
0
5
10
15
20
Depth (cm)


Returns (1000s)
1500
1000
500
0
1995
1975
1955
1935
1915
Year

# Karluk Lake

# Karluk Lake: Salmon - $\delta^{15}N$ Calibration

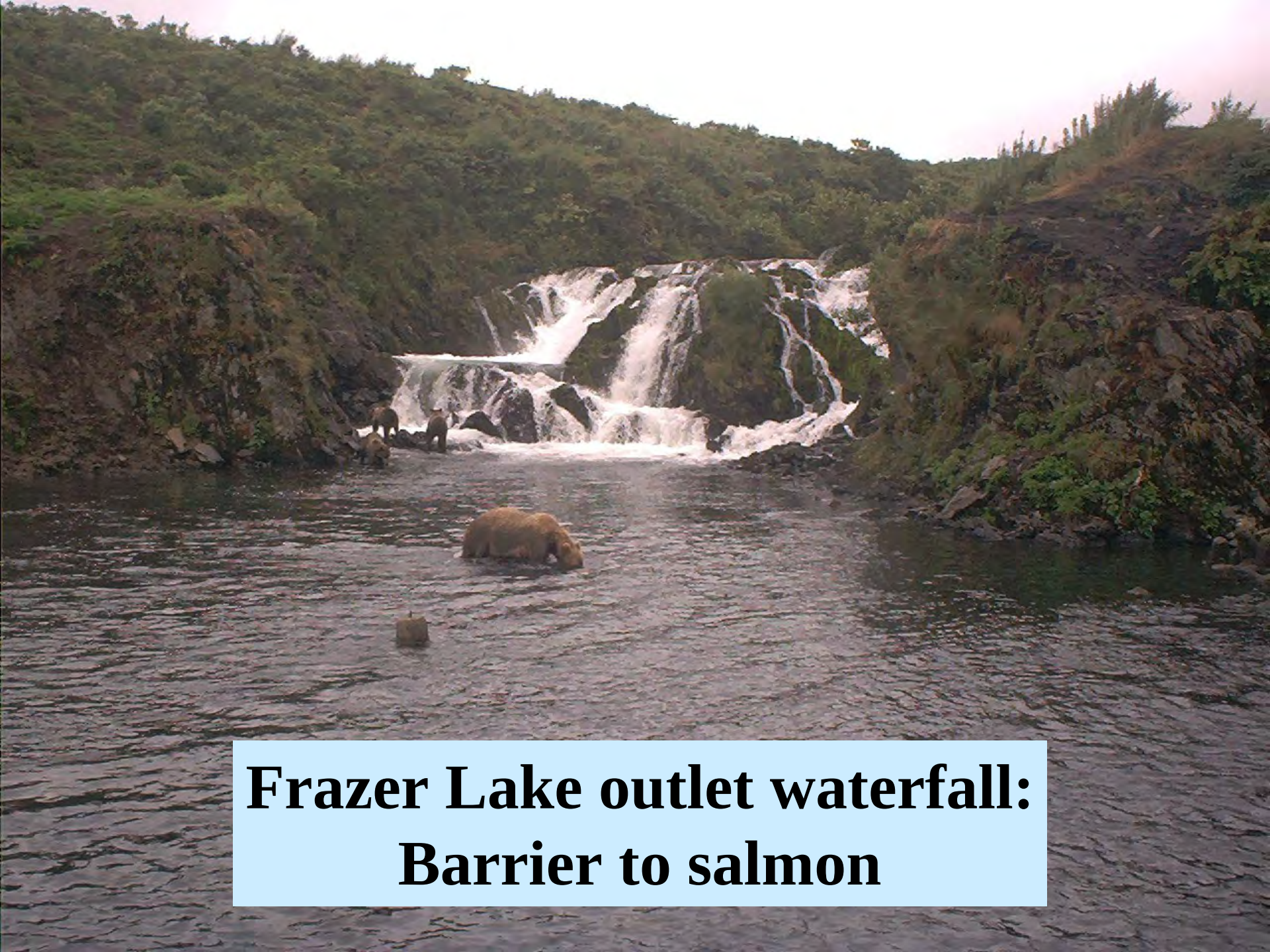


# Controls: Sedimentary $\delta^{15}N$

- Nutrient source (salmon vs. terrestrial/Atmosphere)
- Nitrate utilization
- Ammonia volatilization
- Denitrification
- Diagenesis
- Organic matter source (terrestrial vs. aquatic)

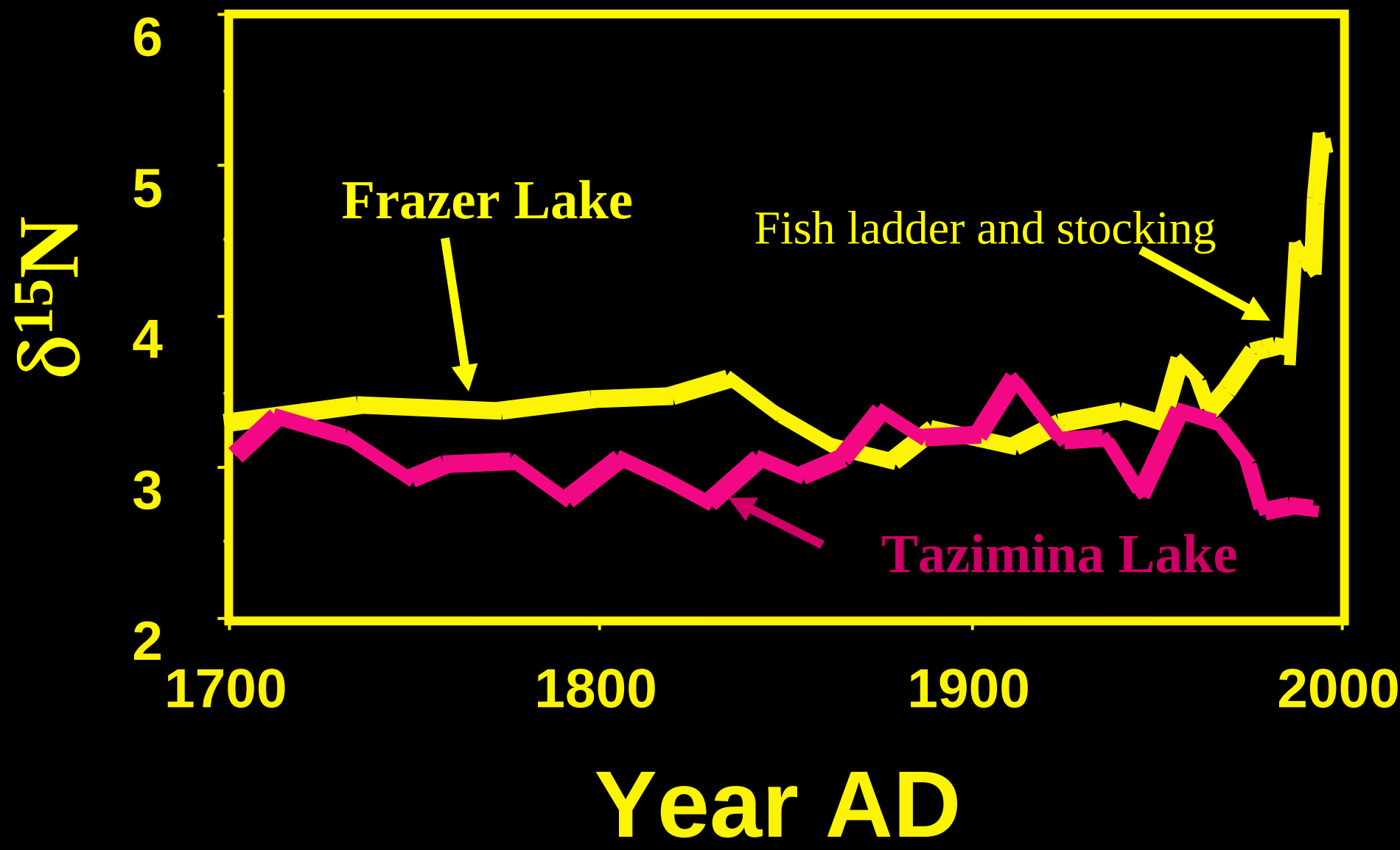
## Assess via:

- Limnological data
- Control (non-salmon) lakes



**Frazer Lake outlet waterfall: Barrier to salmon**

# Alaska "Control" Lakes



# Estimating Past Salmon Abundance

Use $\delta^{15}N$ to reconstruct magnitude of salmon-nitrogen nutrient source

In salmon lakes, 2 main nitrogen sources: (1) salmon carcasses and (2) watershed / soils (ultimately from atmosphere: $\delta^{15}N = 0$)

**Mass Balance:** $\delta^{15}N$ sediment sample at time x =

$$\delta^{15}N_{watershed} * Input_{watershed} + \delta^{15}N_{salmon} * Input_{salmon}$$

Control lakes critical in evaluating watershed input

# Karluk Lake, Alaska
# Nitrogen Sources

| Source | N input ($10^3$ kg/yr) |
|---|---|
| Rivers (w/o salmon contribution) | 43.2 |
| Rain | 0.8 |
| Nitrogen Fixation | ? (low) |
| Sockeye Salmon (1 million) | 64.1 |

- Salmon average ~ 60% of annual N and P input
- 5X change in total annual nutrient input, based on estimated changes in salmon returns

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

# Control (i.e., non-salmon) Lakes

**Brian Cohn UAF M.S. Thesis (2009)**

$\delta^{15}N$ - Spatial variability (2-3 o/oo)

Related to watershed characteristics

Climate

In-lake processes

$\delta^{15}N$ - Temporal variability (<1 - 2 o/oo)

Related to climate and environmental change

$\delta^{15}N$ and watershed nutrient loadings have changed over time in relation to climate (with feedback from vegetation change). Key times of change: late 20th century (1976 regime-shift), beginning and end of Little Ice age, Neoglaciation, early Holocene

Control lakes are key in accounting for changes in nitrogen input and cycling due to non-salmon processes

Match salmon lake: lake and watershed characteristics, climate, etc.

# Estimating Past Salmon Abundance

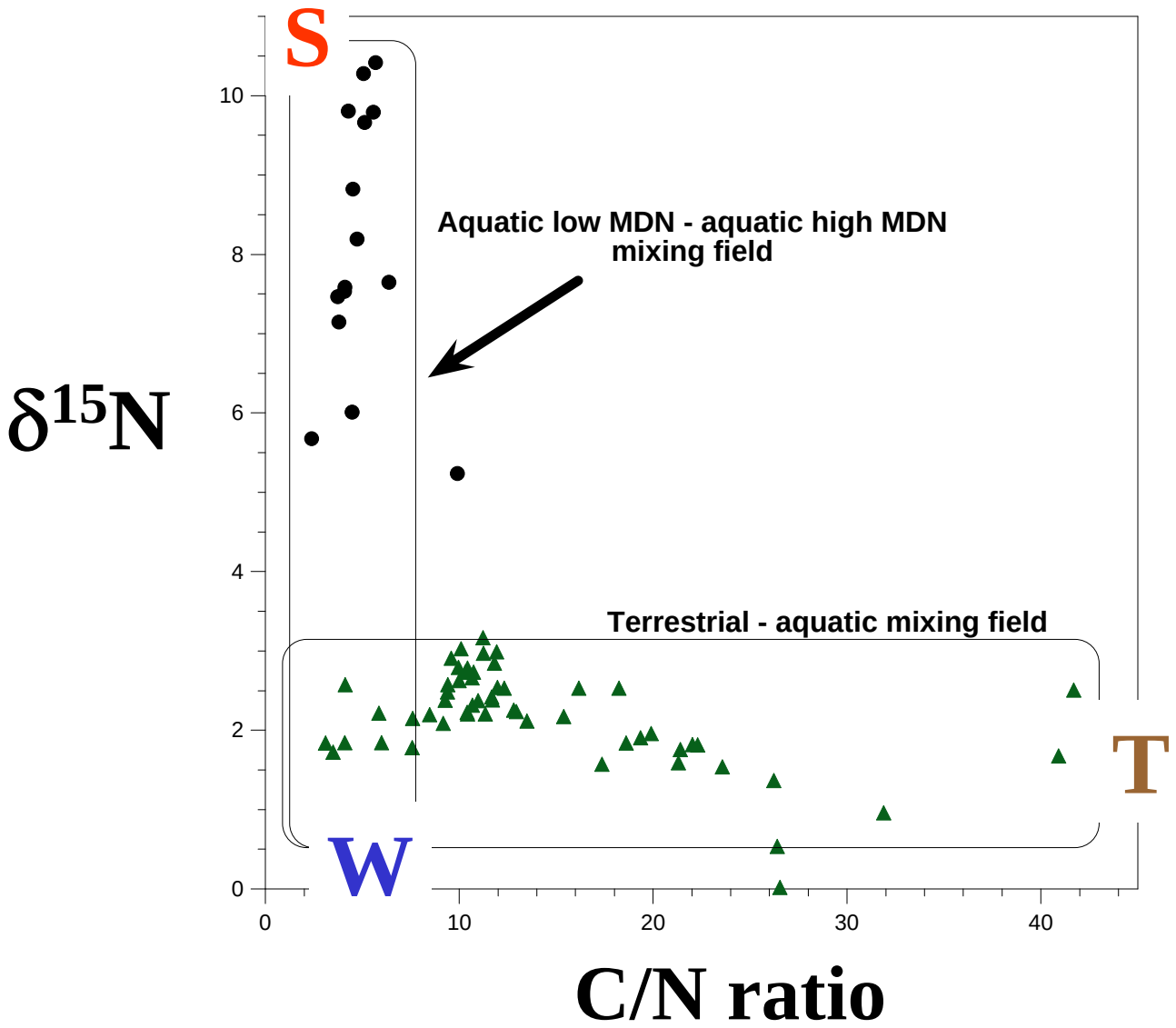
Using $\delta^{15}N$ to reconstruct magnitude of salmon nitrogen source

Assumes that sediment organic matter is derived from aquatic sources (i.e., phytoplankton), and thus its $\delta^{15}N$ reflects nitrogen-nutrient source contributions

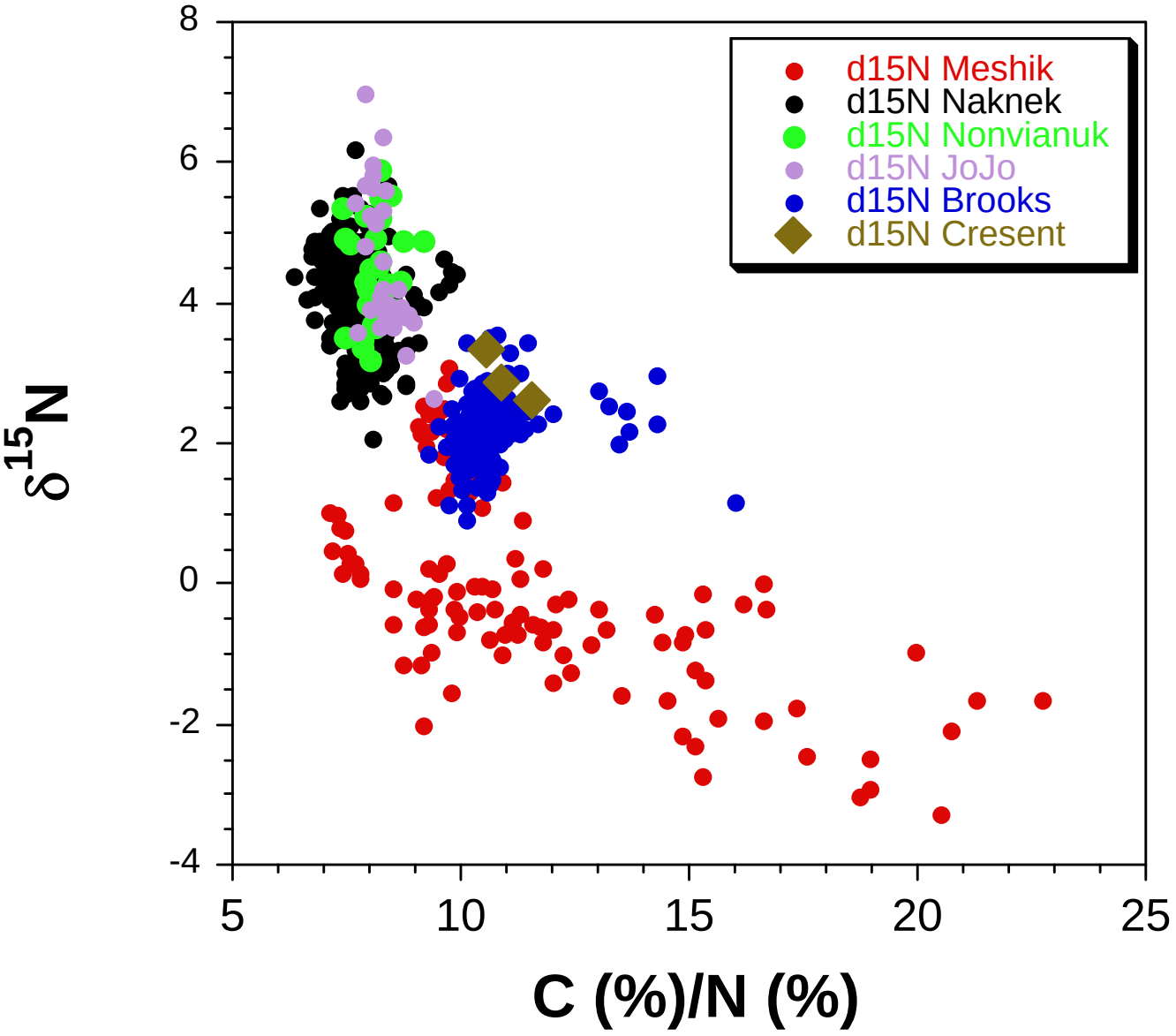
In some lakes and during some types of sedimentation processes, significant contributions of organic matter of terrestrial origin occur

These are evaluated by examining sediment characteristics, and composition (i.e., C/N ratios)

# Three “end-member” mixing concept



# SWAN Salmon Lakes



# SWAN Project Objectives:

1. Reconstruct past changes in salmon abundance (current and and systems that may have had salmon in the past). Time frame of reconstructions from detailed decadal-scale variability over the last 500 years, to long-term changes since the end of the last ice age.
2. To determine past changes in lake primary productivity and nutrient status, for both salmonid and barriered systems.
3. Compare to records of past environmental change to determine how factors such as climate change, volcanic eruptions, geomorphologic change and human impacts influence these freshwater systems.

## SWAN Project Objectives (continued):

4. Describe long-term trends in sockeye abundance, assess recent levels from a long-term perspective, and compare trends to those determined for other Alaskan systems.
5. Determine role of lake primary productivity and carcass-derived nutrients in influencing sockeye production.

# SWAN Study Lakes

***Salmon:***

Brooks
Naknek
Nonvianuk
Kukaklek
Hammersley
Murray
Jo-Jo (?)
Devils Cove (?)

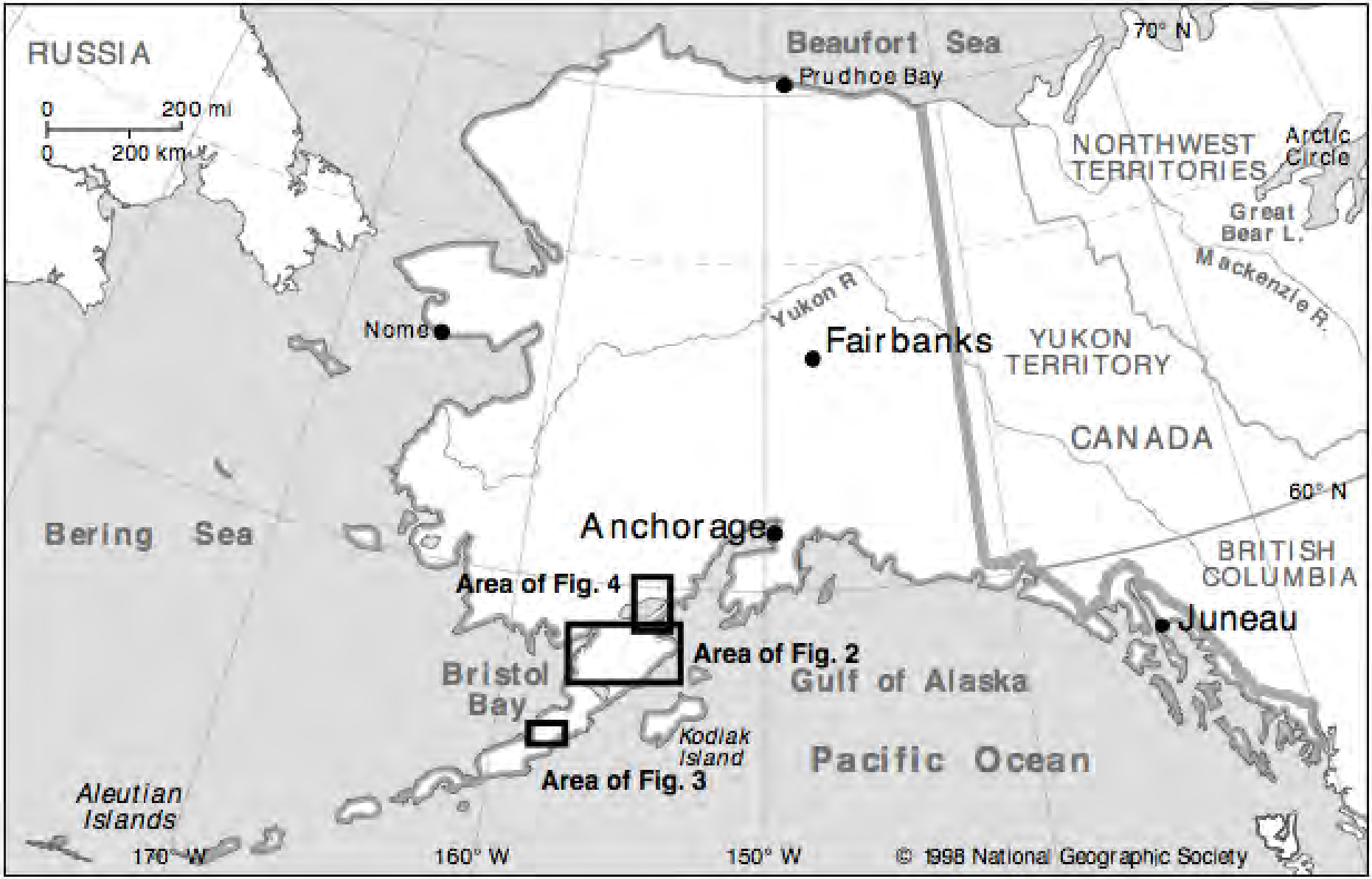
Surprise
Meshik

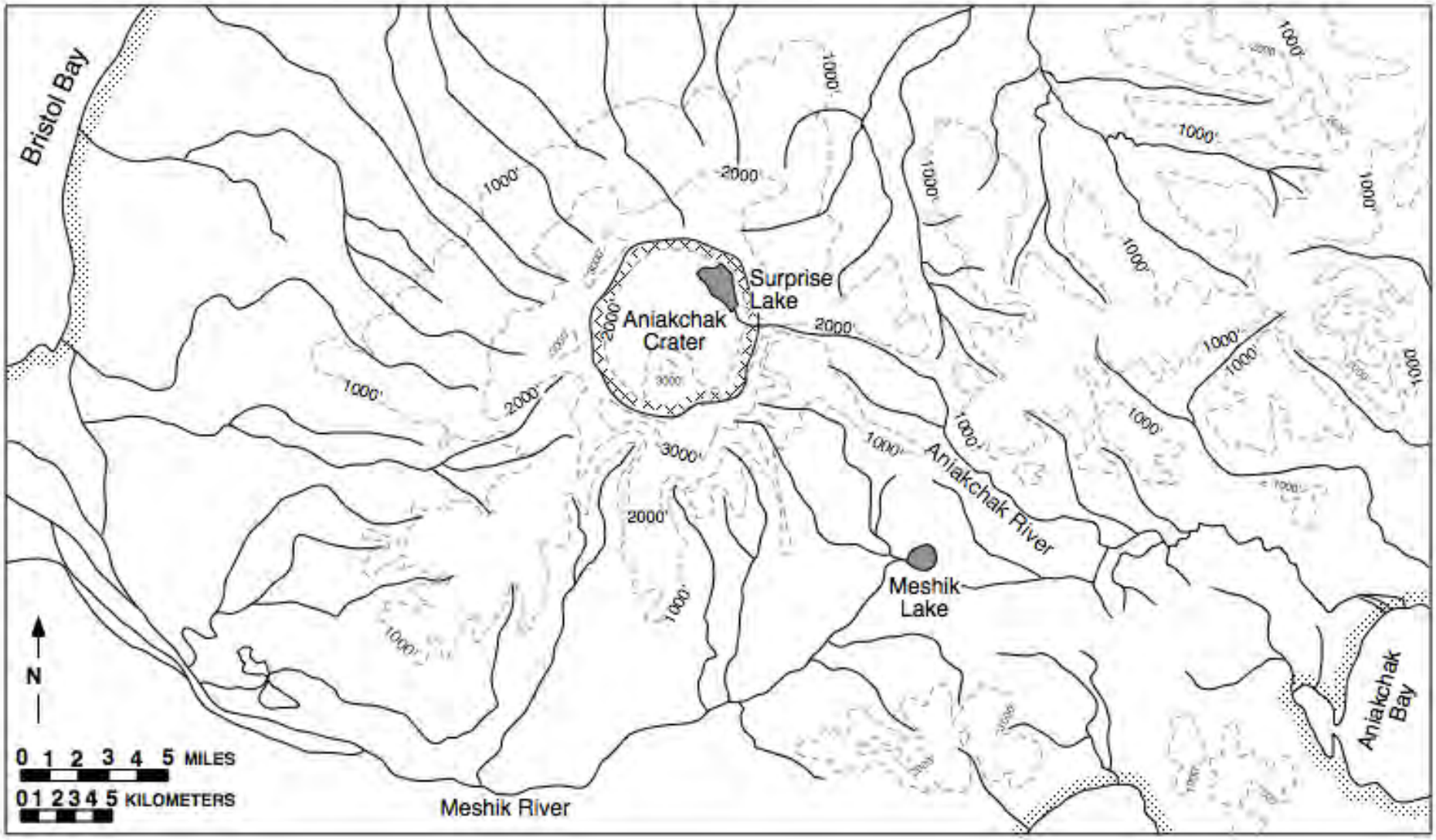
Kijik Lake
Lake Clark
Crescent
(Telaquana, Lower Twin)

***Non-Salmon (control):***

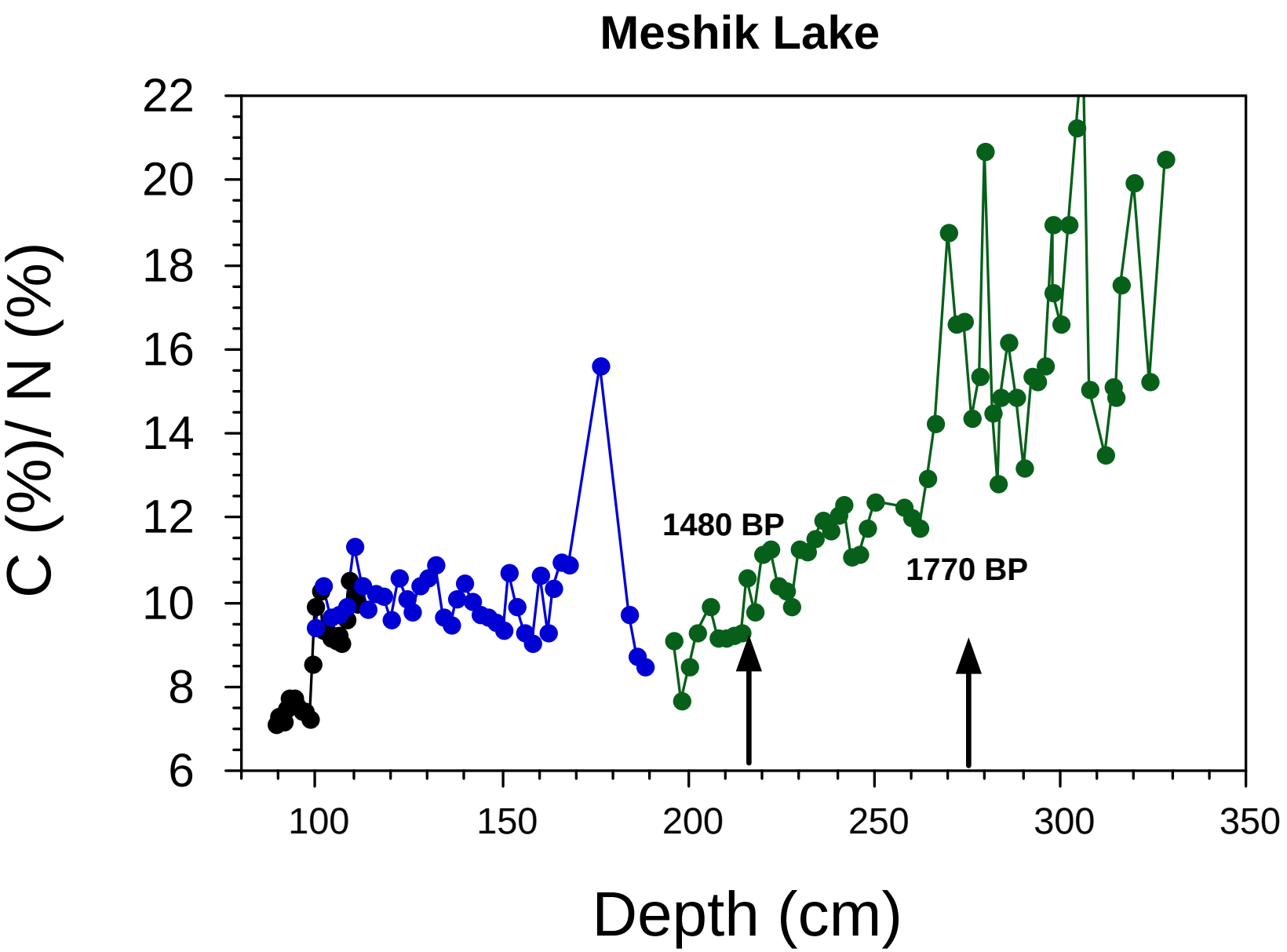
Idavain
Klosterman
Pringle

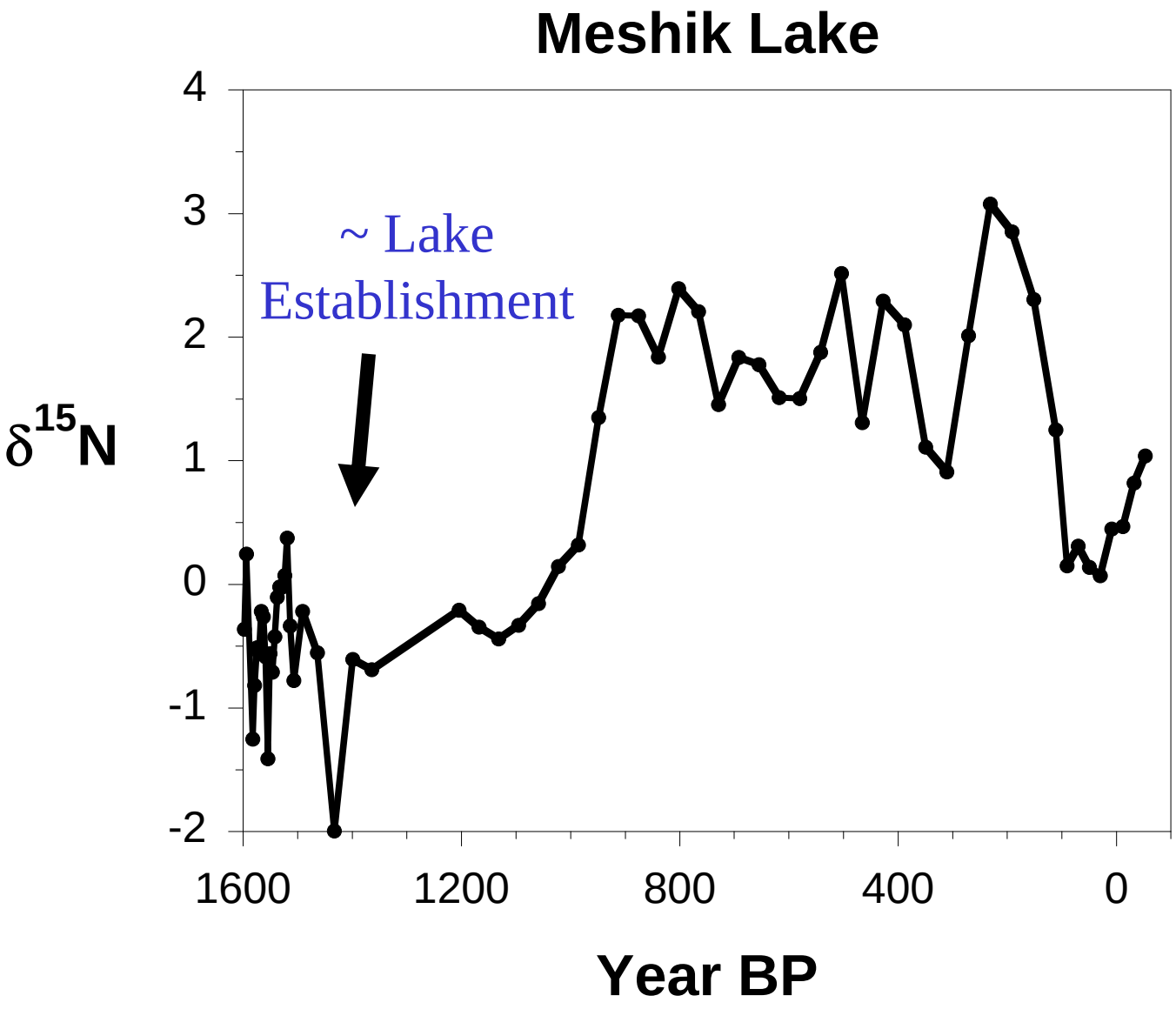
Kontrashibuna
Hickerson
Portage
(Lower Tazimina)


RUSSIA
0 200 mi
0 200 km
Beaufort Sea
Prudhoe Bay
70° N
NORTHWEST TERRITORIES
Arctic Circle
Great Bear L.
Mackenzie R.
Yukon R
Nome
Fairbanks
YUKON TERRITORY
CANADA
60° N
Bering Sea
Anchorage
BRITISH COLUMBIA
Area of Fig. 4
Juneau
Area of Fig. 2
Bristol Bay
Gulf of Alaska
Kodiak Island
Pacific Ocean
Area of Fig. 3
Aleutian Islands
170° W
160° W
150° W
© 1998 National Geographic Society

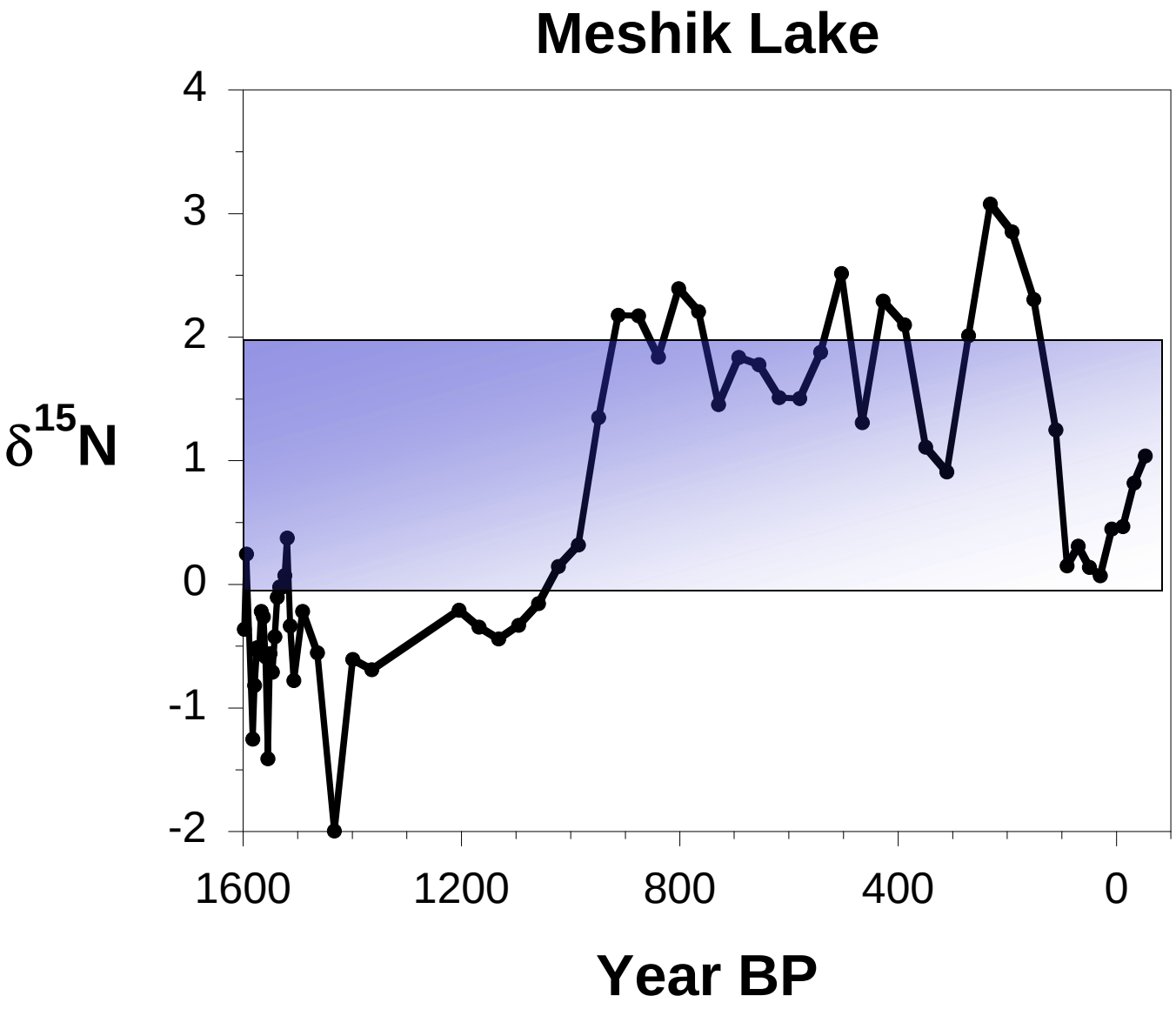

Bristol Bay
Surprise Lake
Aniakchak Crater
Aniakchak River
Meshik Lake
Aniakchak Bay
Meshik River
N
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
1000'
2000'
3000'

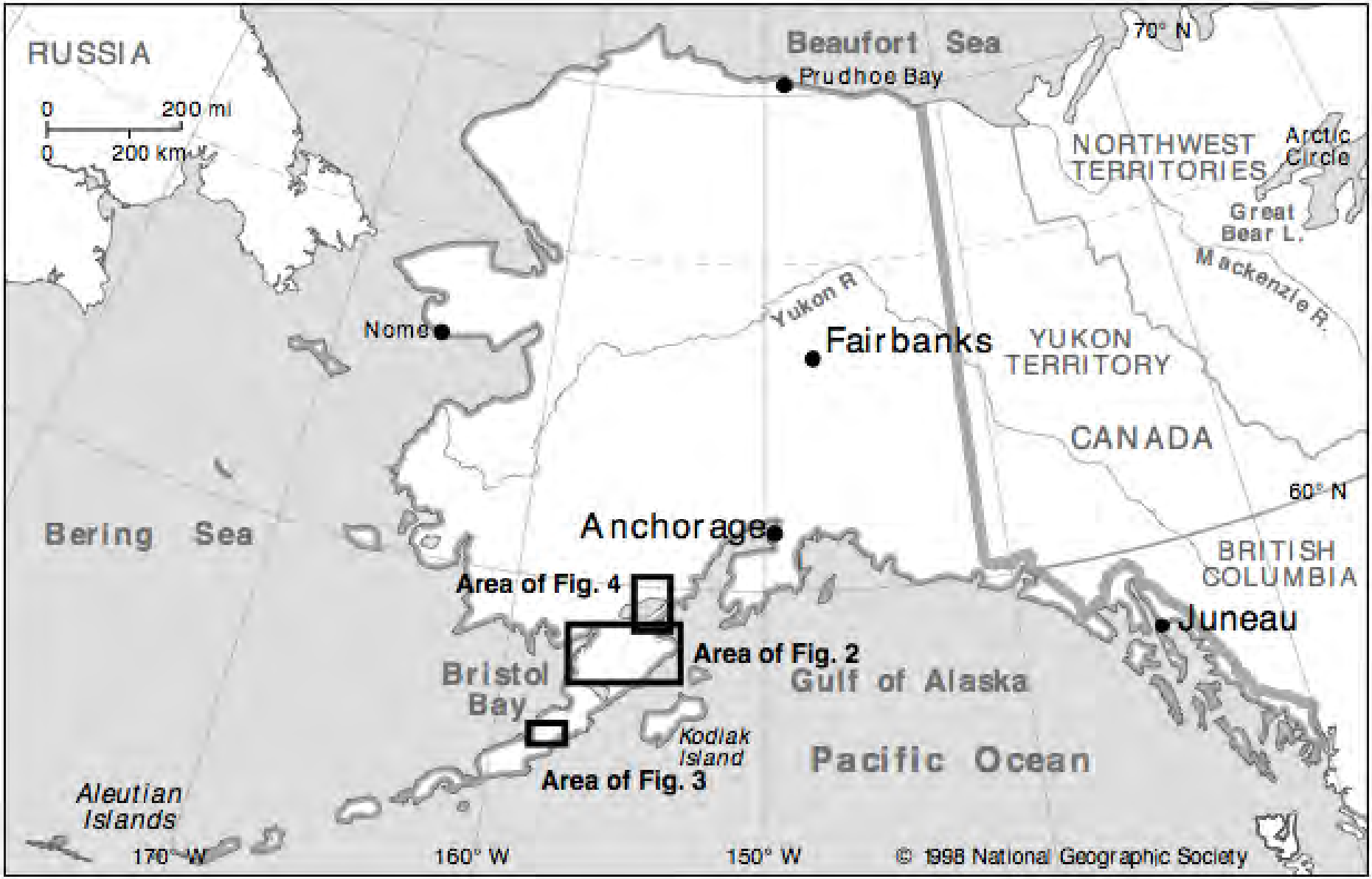
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.


Meshik Lake
C (%)/ N (%)
22
20
18
16
14
12
10
8
6
100
150
200
250
300
350
Depth (cm)
1480 BP
1770 BP


Meshik Lake
~ Lake Establishment
δ15N
4
3
2
1
0
-1
-2
1600
1200
800
400
0
Year BP

# Establishment of Salmon Run?




RUSSIA
0 200 mi
0 200 km
Beaufort Sea
Prudhoe Bay
70° N
NORTHWEST TERRITORIES
Arctic Circle
Great Bear L.
Mackenzie R.
Yukon R
Nome
Fairbanks
YUKON TERRITORY
CANADA
60° N
Bering Sea
Anchorage
BRITISH COLUMBIA
Area of Fig. 4
Juneau
Area of Fig. 2
Bristol Bay
Gulf of Alaska
Kodiak Island
Pacific Ocean
Area of Fig. 3
Aleutian Islands
170° W
160° W
150° W
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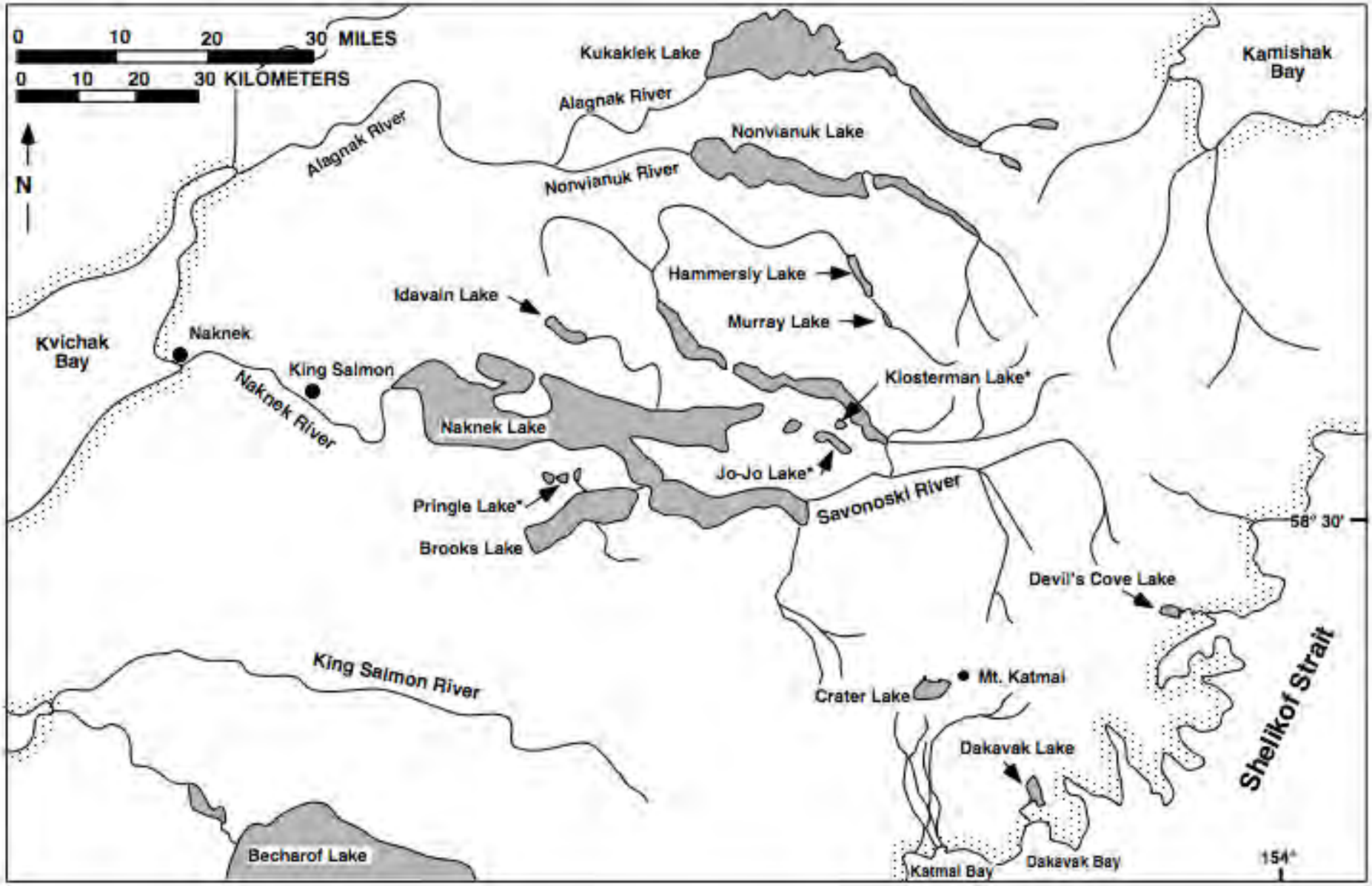
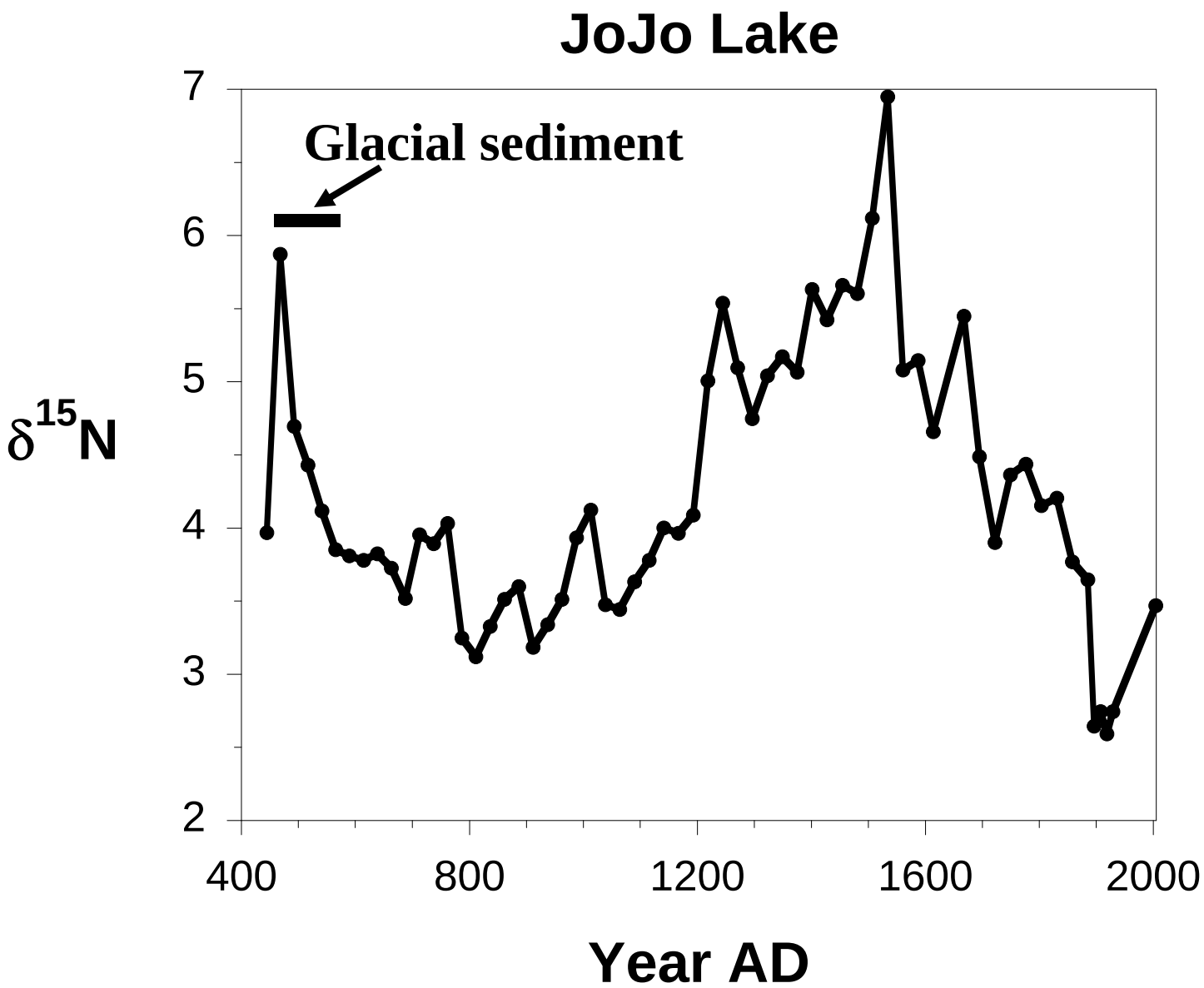
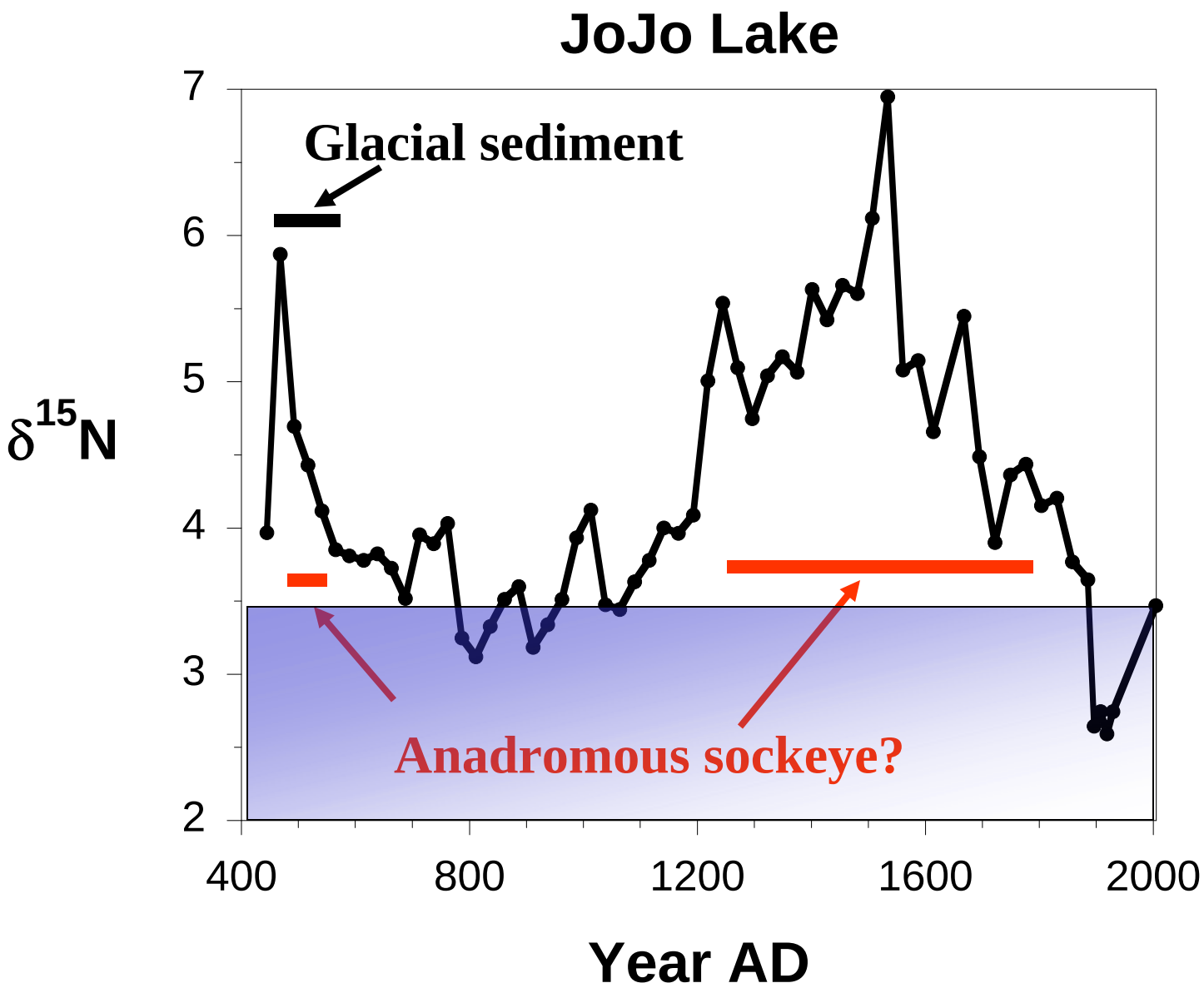
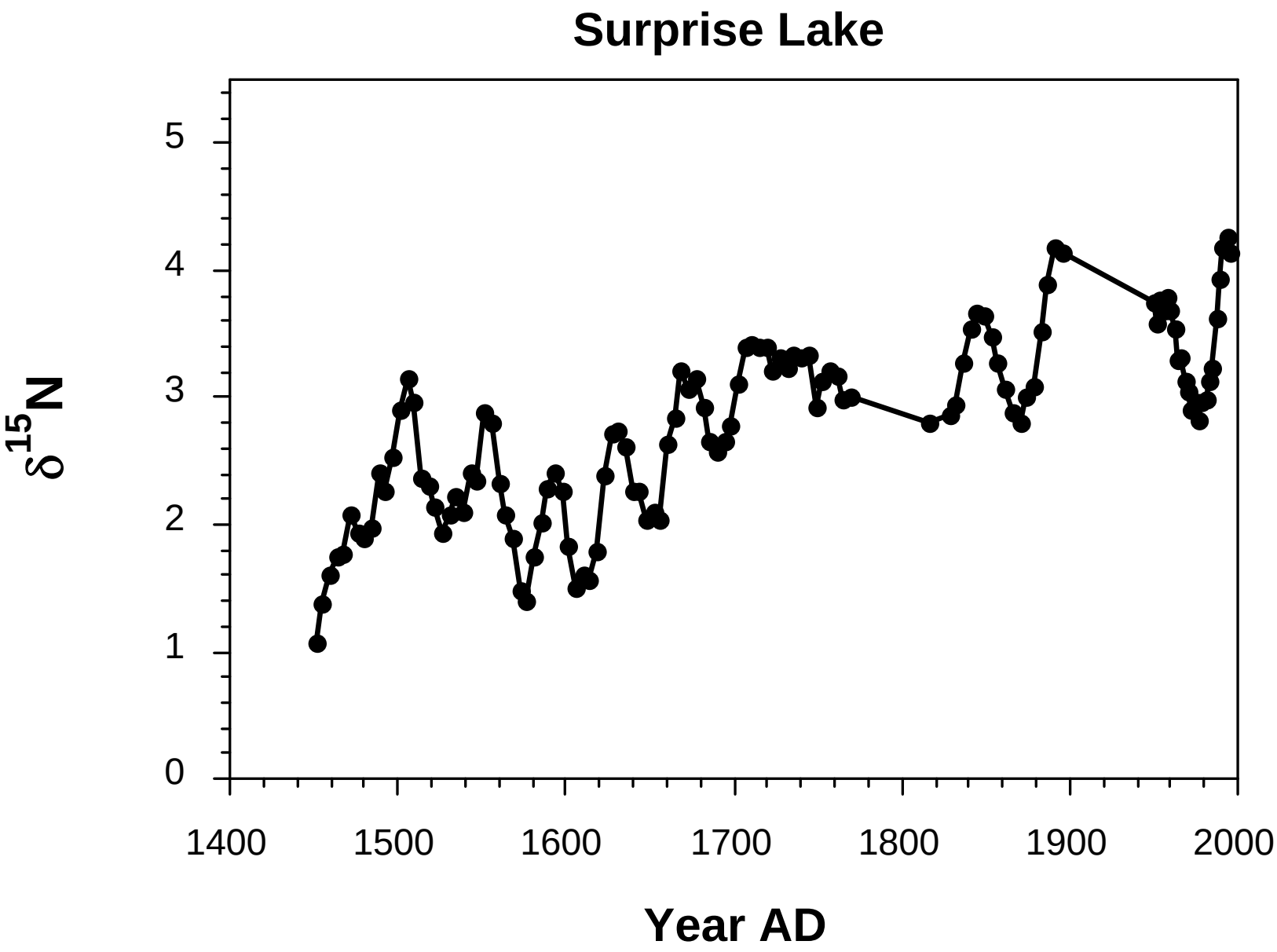

0 10 20 30 MILES
0 10 20 30 KILOMETERS
N
Kukaklek Lake
Alagnak River
Alagnak River
Nonvianuk Lake
Nonvianuk River
Kamishak Bay
Hammersly Lake
Idavain Lake
Murray Lake
Kvichak Bay
Naknek
King Salmon
Naknek River
Klosterman Lake*
Naknek Lake
Jo-Jo Lake*
Pringle Lake*
Brooks Lake
Savonoski River
58° 30'
Devil's Cove Lake
Shelikof Strait
King Salmon River
Mt. Katmai
Crater Lake
Dakavak Lake
Becharof Lake
Katmai Bay
Dakavak Bay
154°

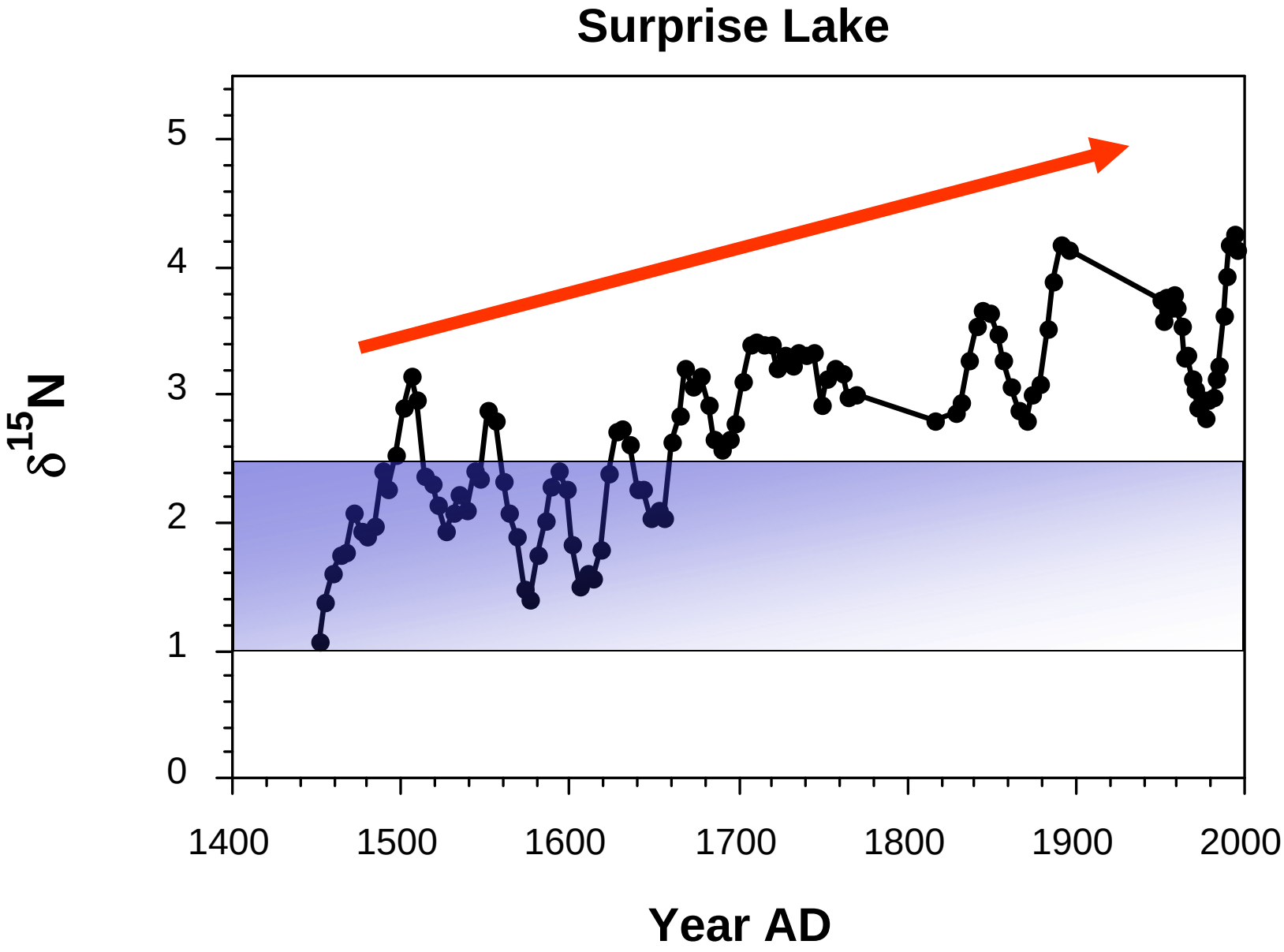

JoJo Lake
Glacial sediment
δ15N
7
6
5
4
3
2
400
800
1200
1600
2000
Year AD

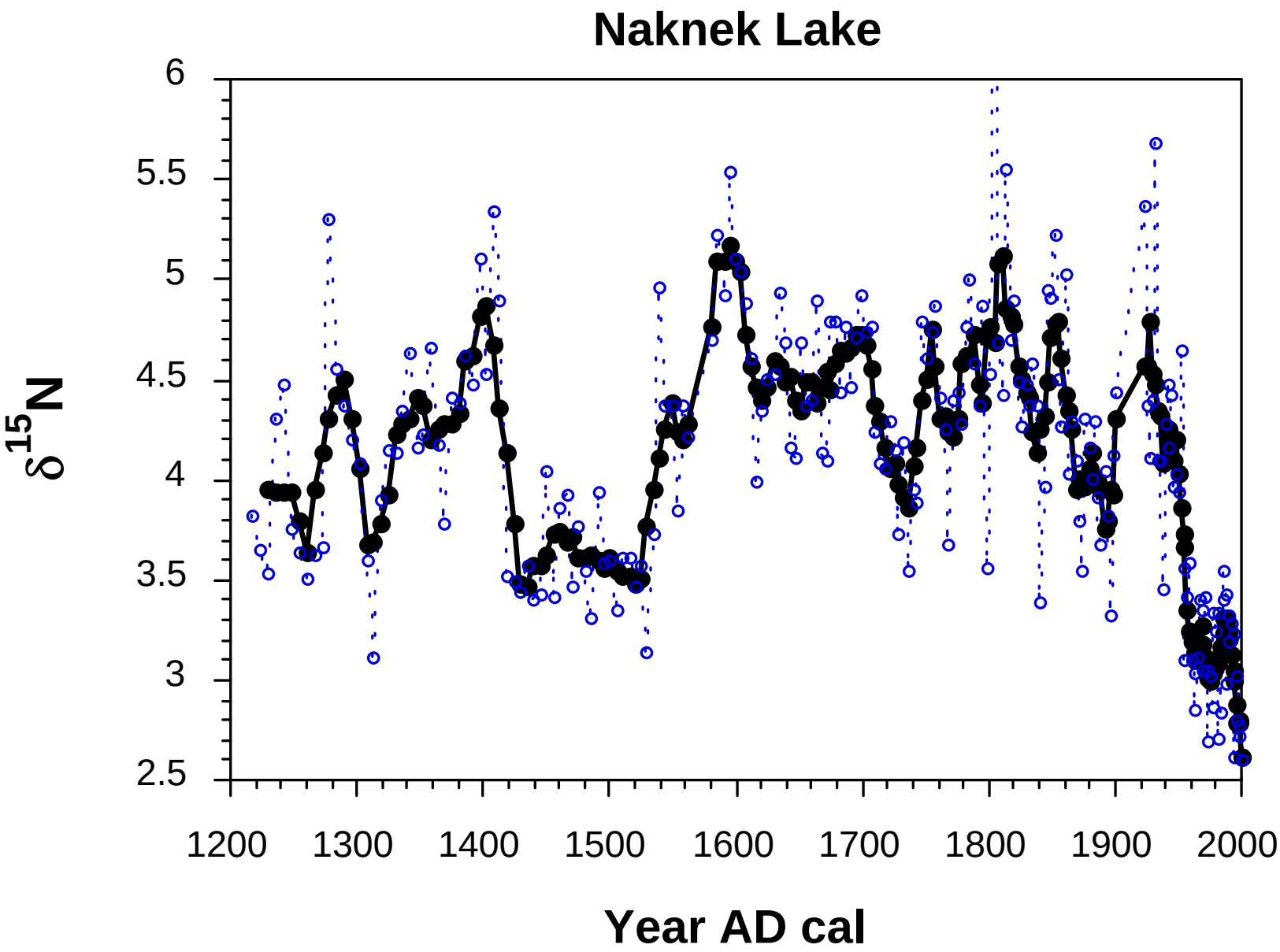
# Evidence for Anadromous Connections in Past?

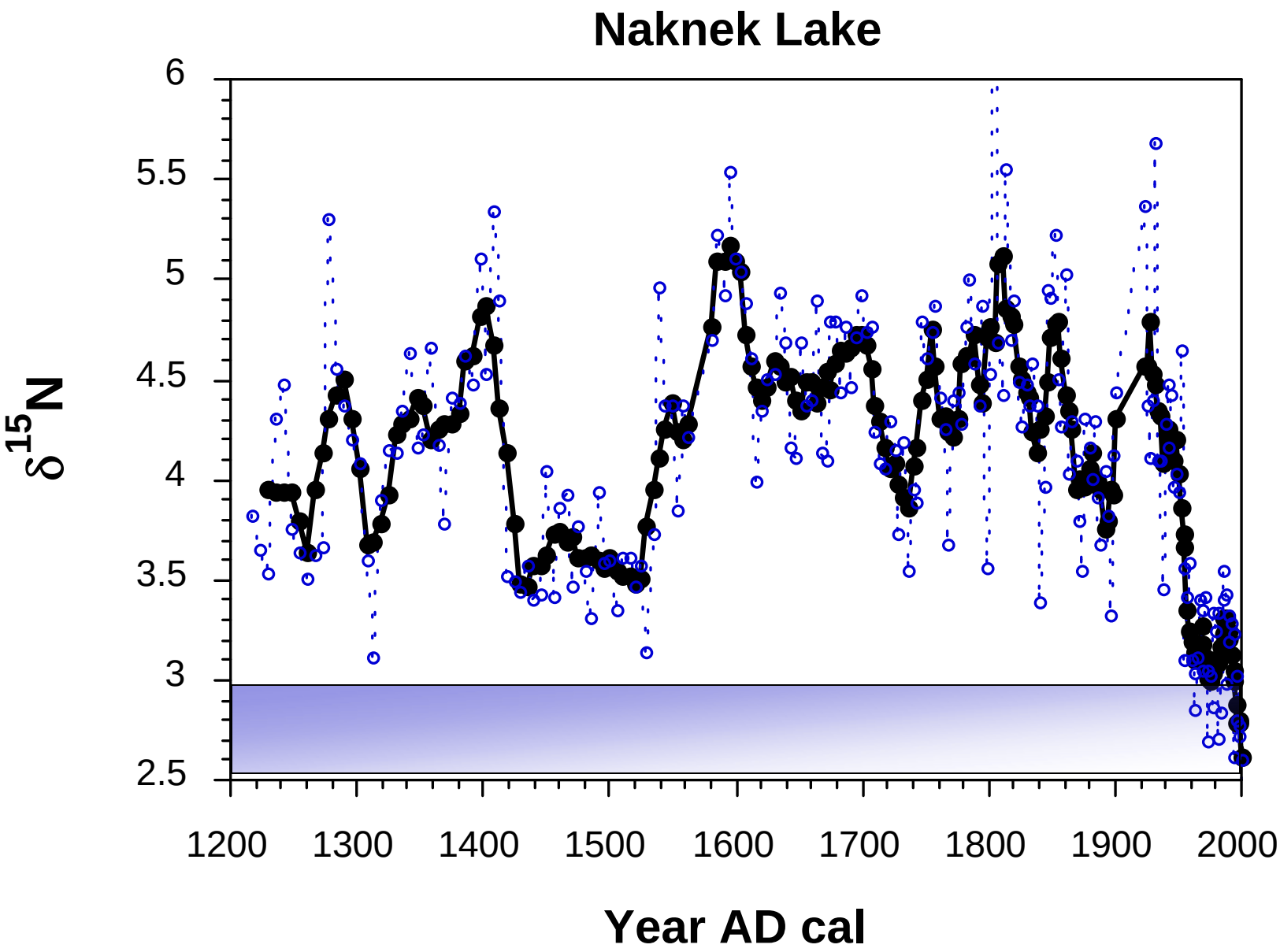


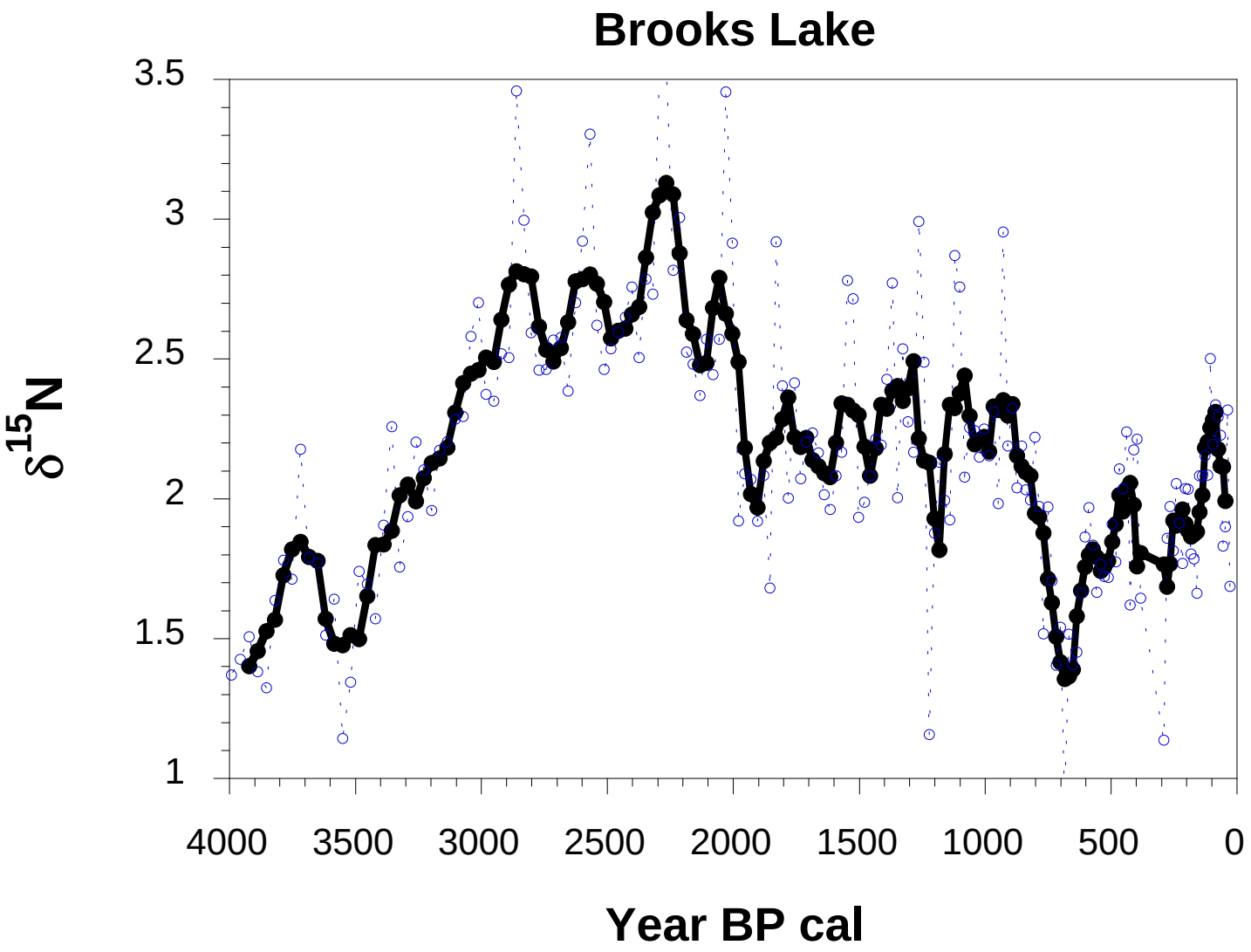

Surprise Lake
δ15N
0
1
2
3
4
5
1400
1500
1600
1700
1800
1900
2000
Year AD

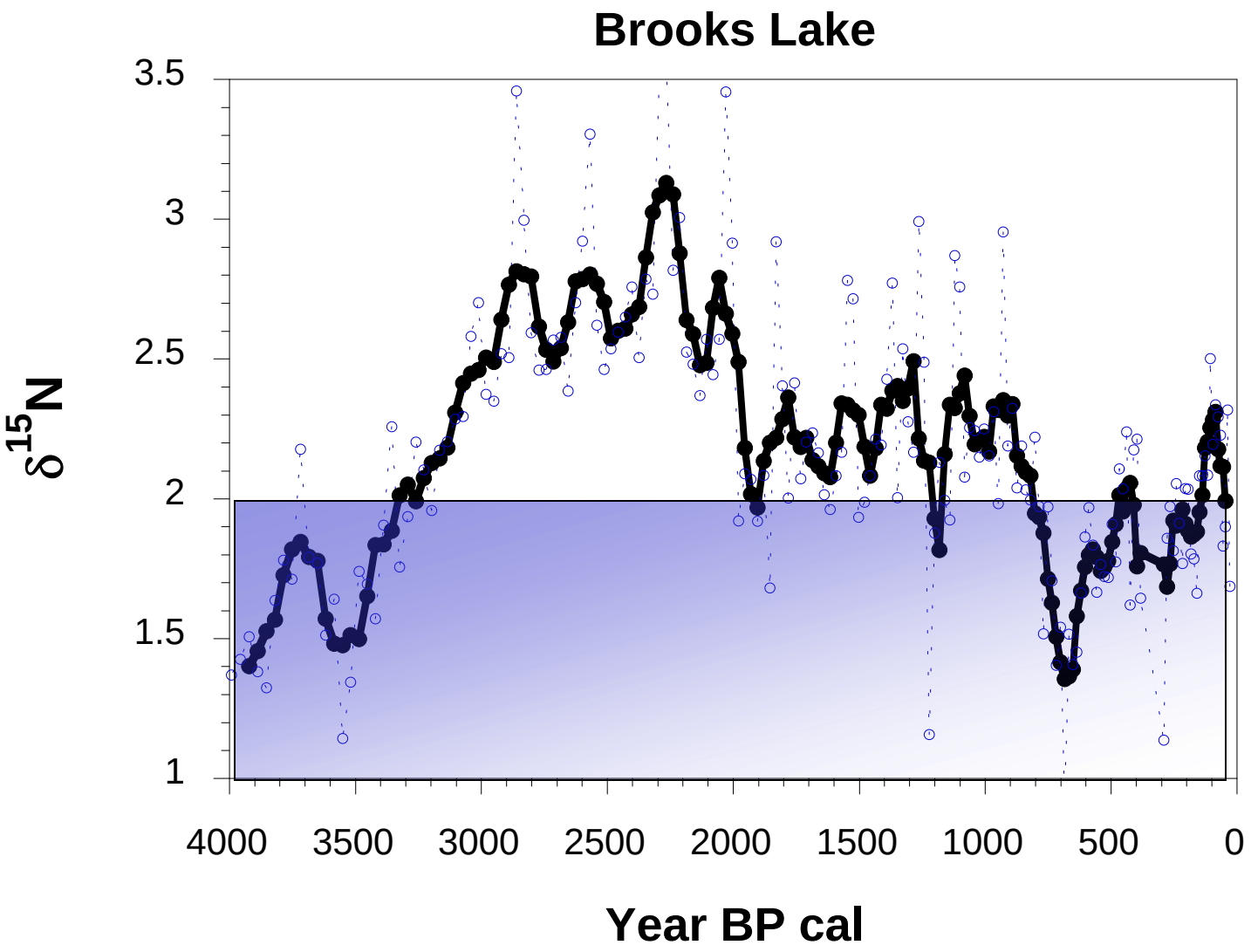
# Ramp up of Salmon Population?

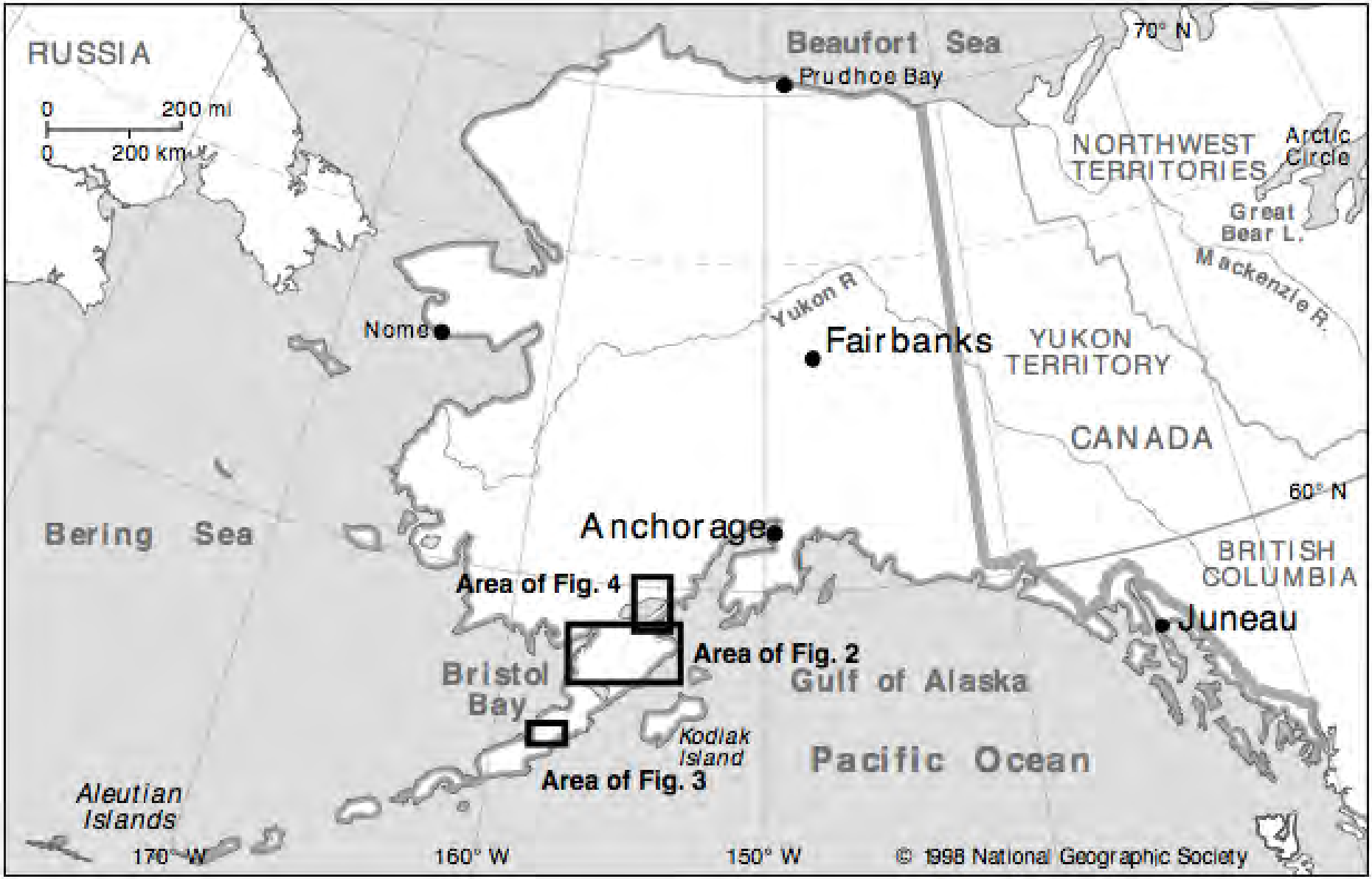


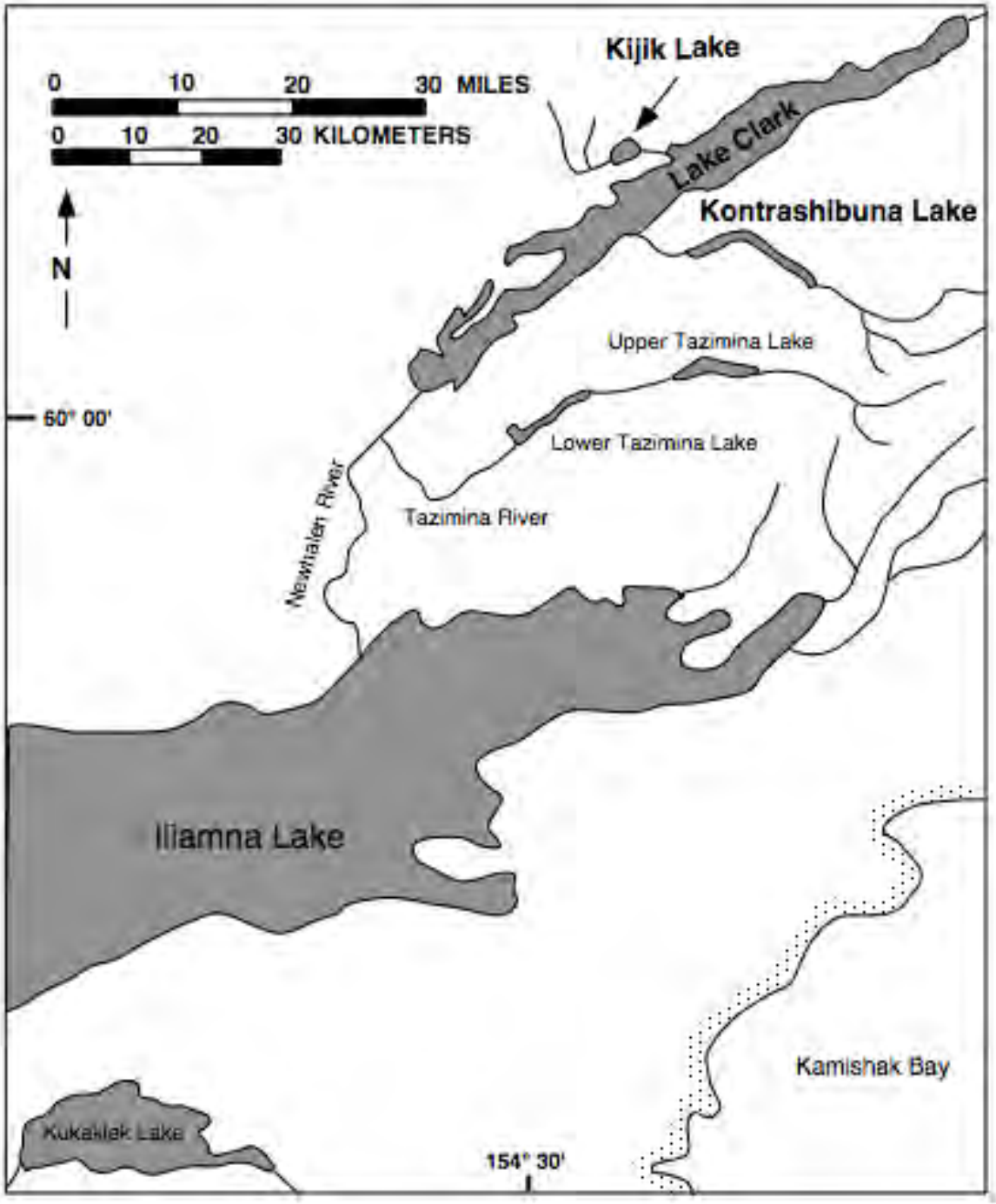

Naknek Lake
6
5.5
5
4.5
4
3.5
3
2.5
δ15N
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year AD cal


Naknek Lake
6
5.5
5
4.5
4
3.5
3
2.5
δ15N
1200
1300
1400
1500
1600
1700
1800
1900
2000
Year AD cal


Brooks Lake
3.5
3
2.5
2
1.5
1
δ15N
4000
3500
3000
2500
2000
1500
1000
500
0
Year BP cal

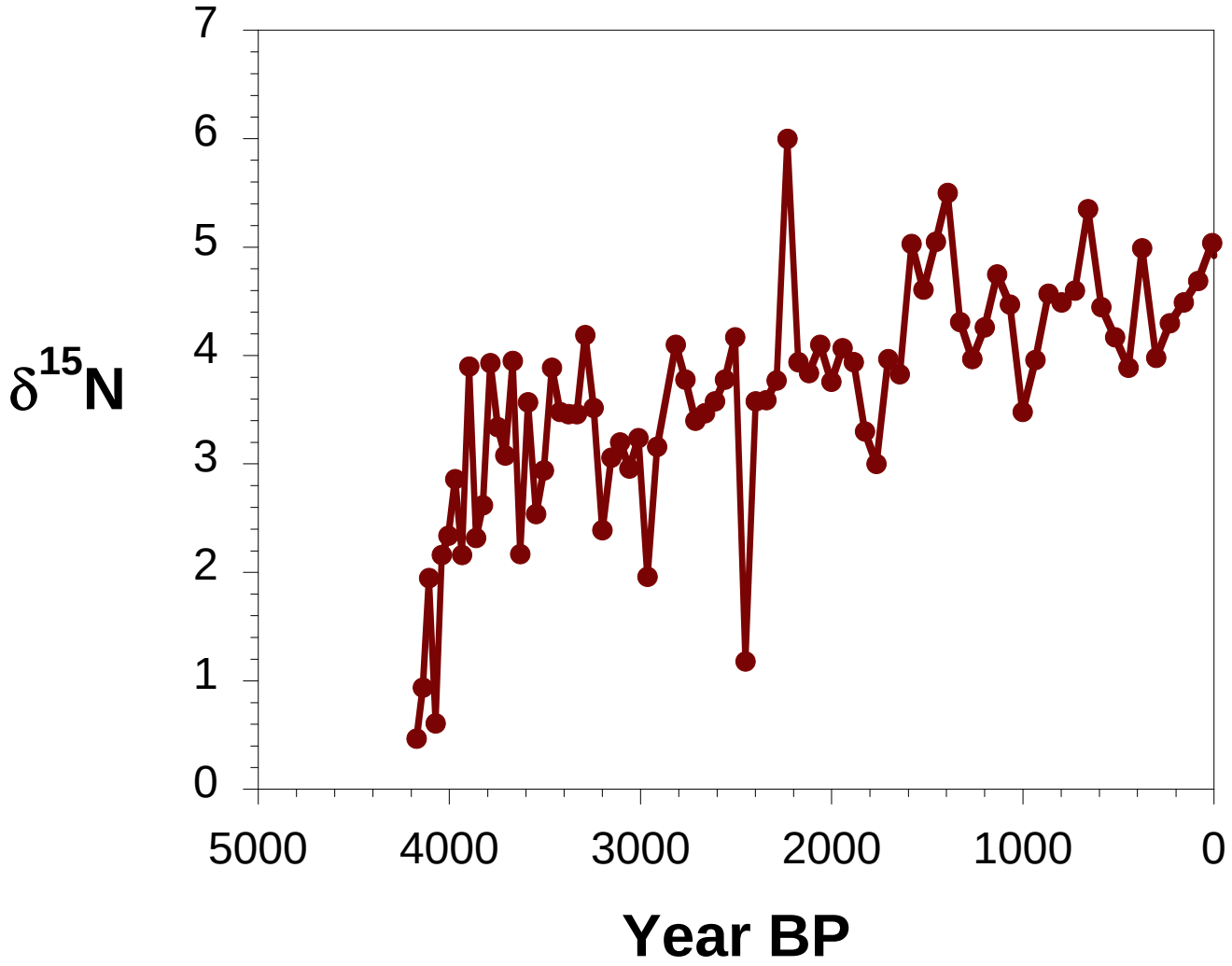

Brooks Lake
3.5
3
2.5
2
1.5
1
δ15N
4000
3500
3000
2500
2000
1500
1000
500
0
Year BP cal


RUSSIA
0 200 mi
0 200 km
Beaufort Sea
Prudhoe Bay
70° N
NORTHWEST TERRITORIES
Arctic Circle
Great Bear L.
Mackenzie R.
Yukon R
Nome
Fairbanks
YUKON TERRITORY
CANADA
60° N
Bering Sea
Anchorage
BRITISH COLUMBIA
Area of Fig. 4
Juneau
Area of Fig. 2
Bristol Bay
Gulf of Alaska
Kodiak Island
Pacific Ocean
Area of Fig. 3
Aleutian Islands
170° W
160° W
150° W
© 1998 National Geographic Society

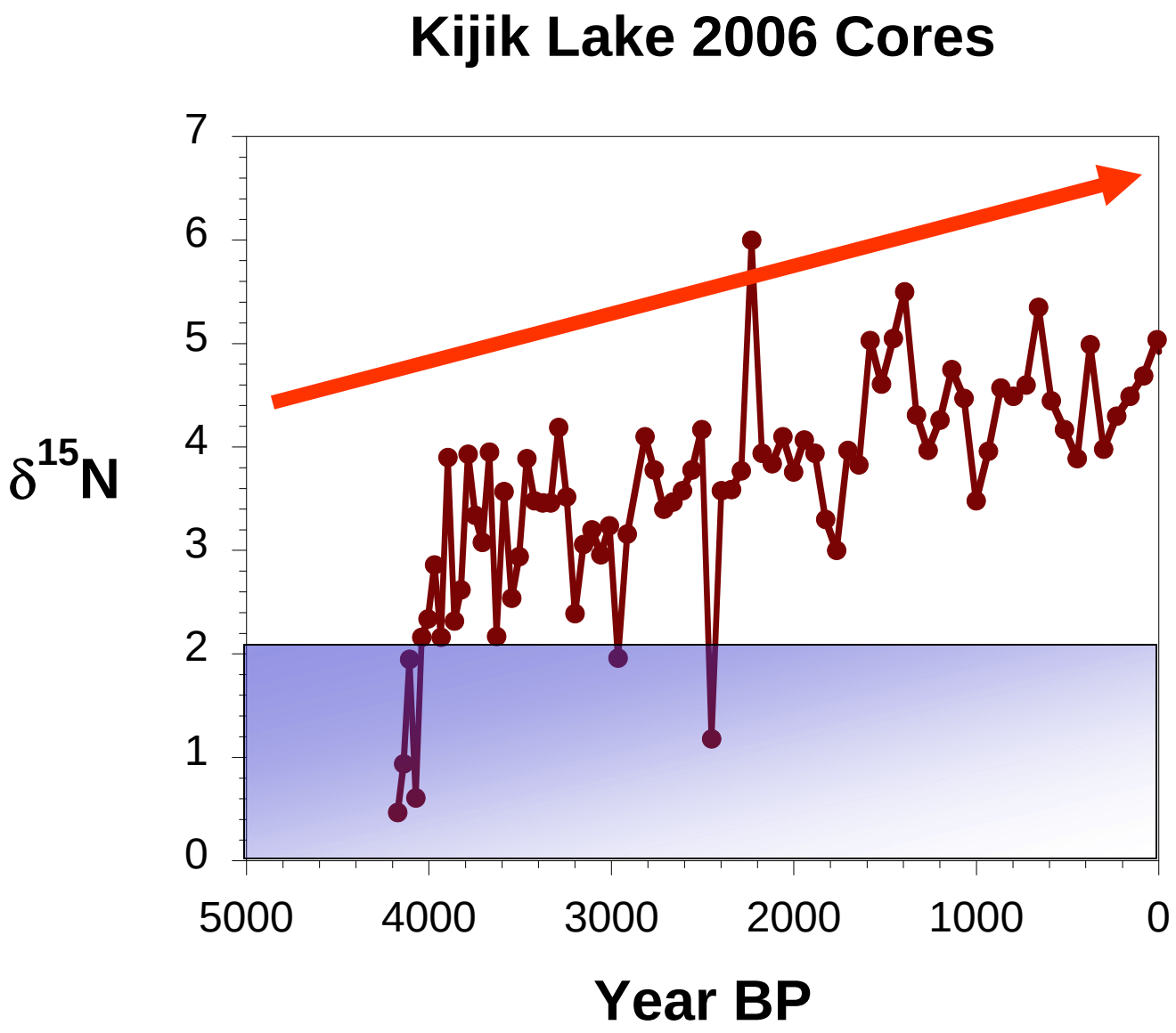

Kijik Lake
0 10 20 30 MILES
0 10 20 30 KILOMETERS
N
Lake Clark
Kontrashibuna Lake
Upper Tazimina Lake
60° 00'
Lower Tazimina Lake
Newhalen River
Tazimina River
Iliamna Lake
Kamishak Bay
Kukaklek Lake
154° 30'

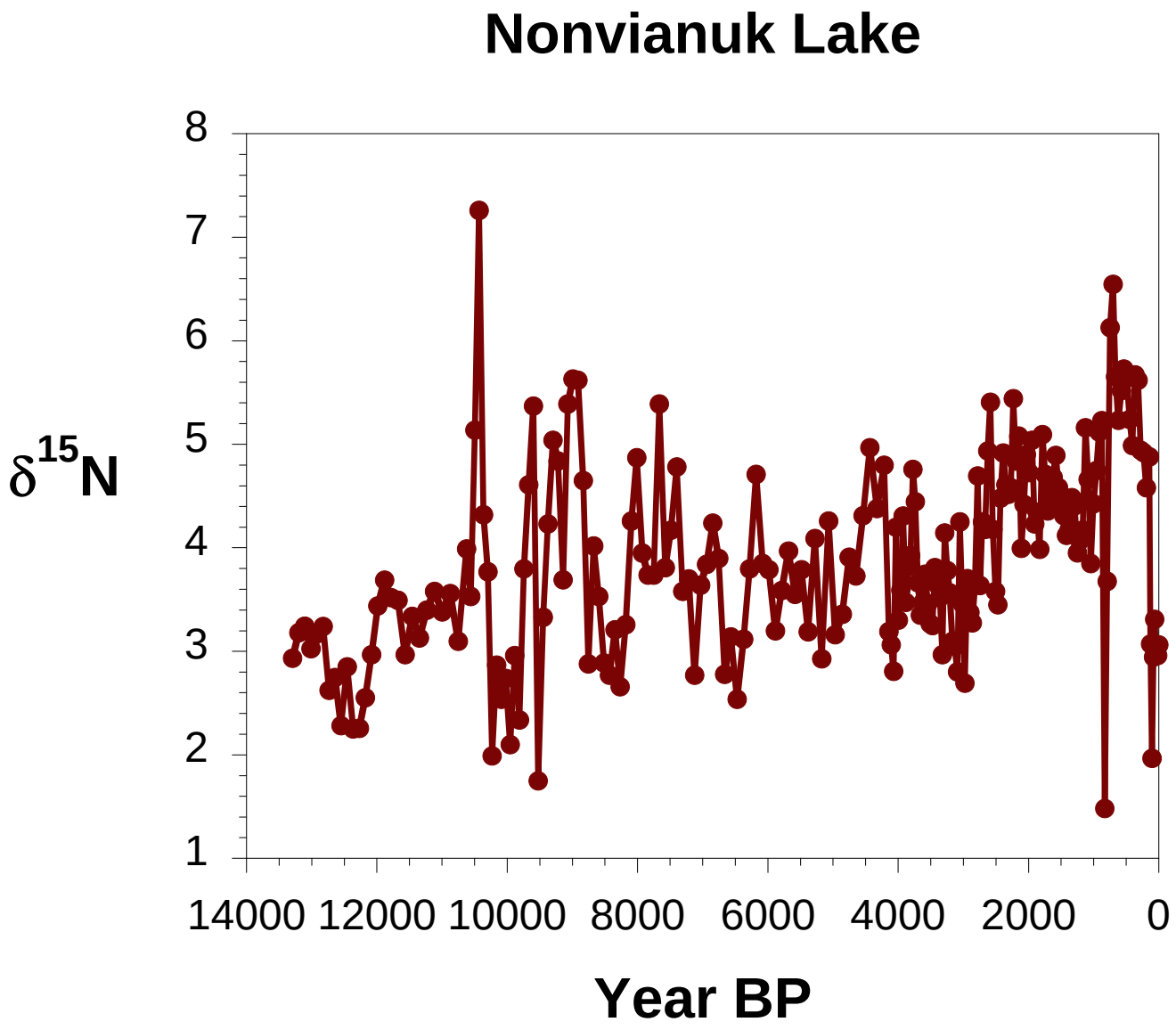
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

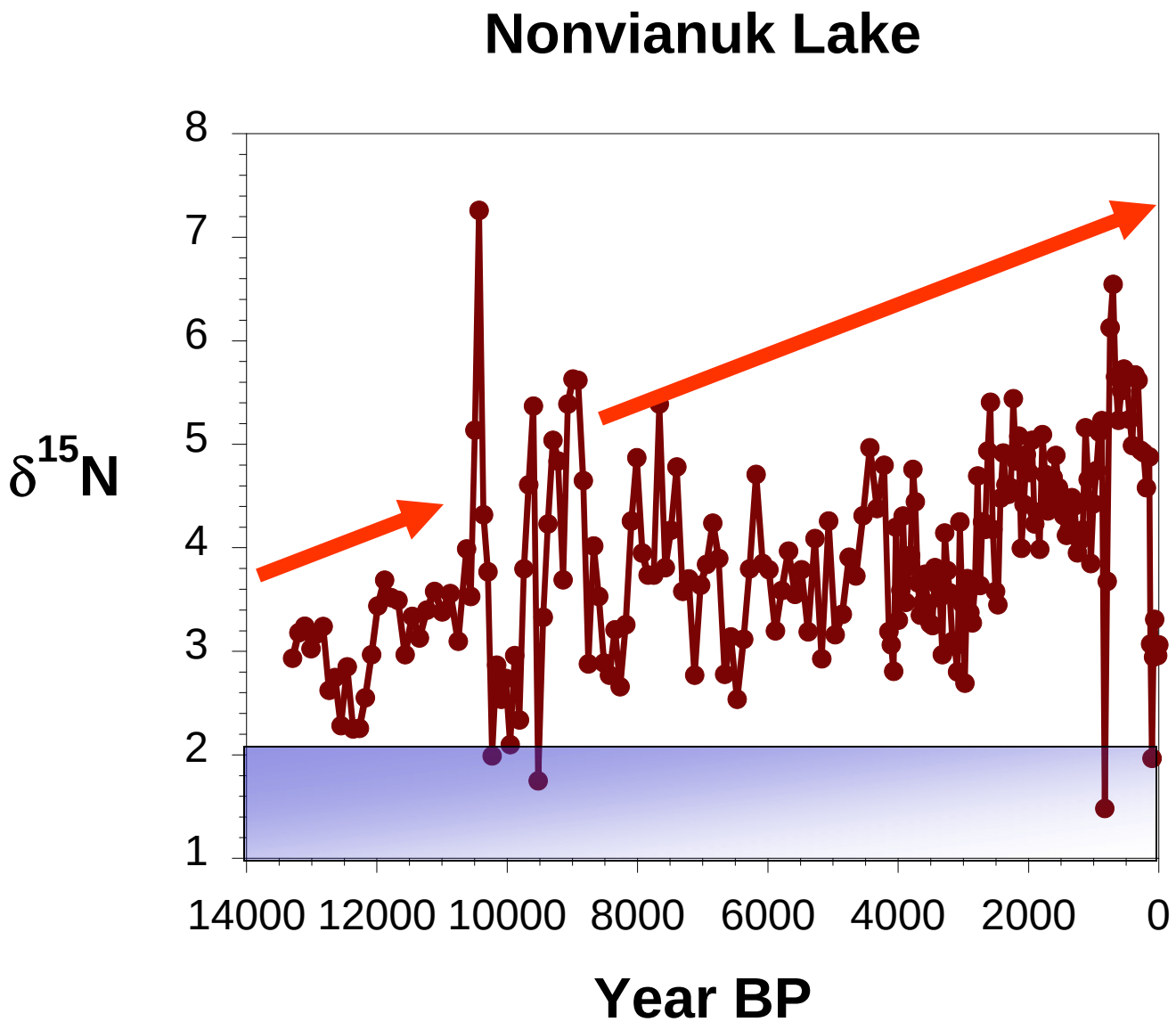
# Kijik Lake 2006 Cores



# Ramp up of Salmon Population?




Nonvianuk Lake
8
7
6
5
4
3
2
1
δ15N
14000
12000
10000
8000
6000
4000
2000
0
Year BP

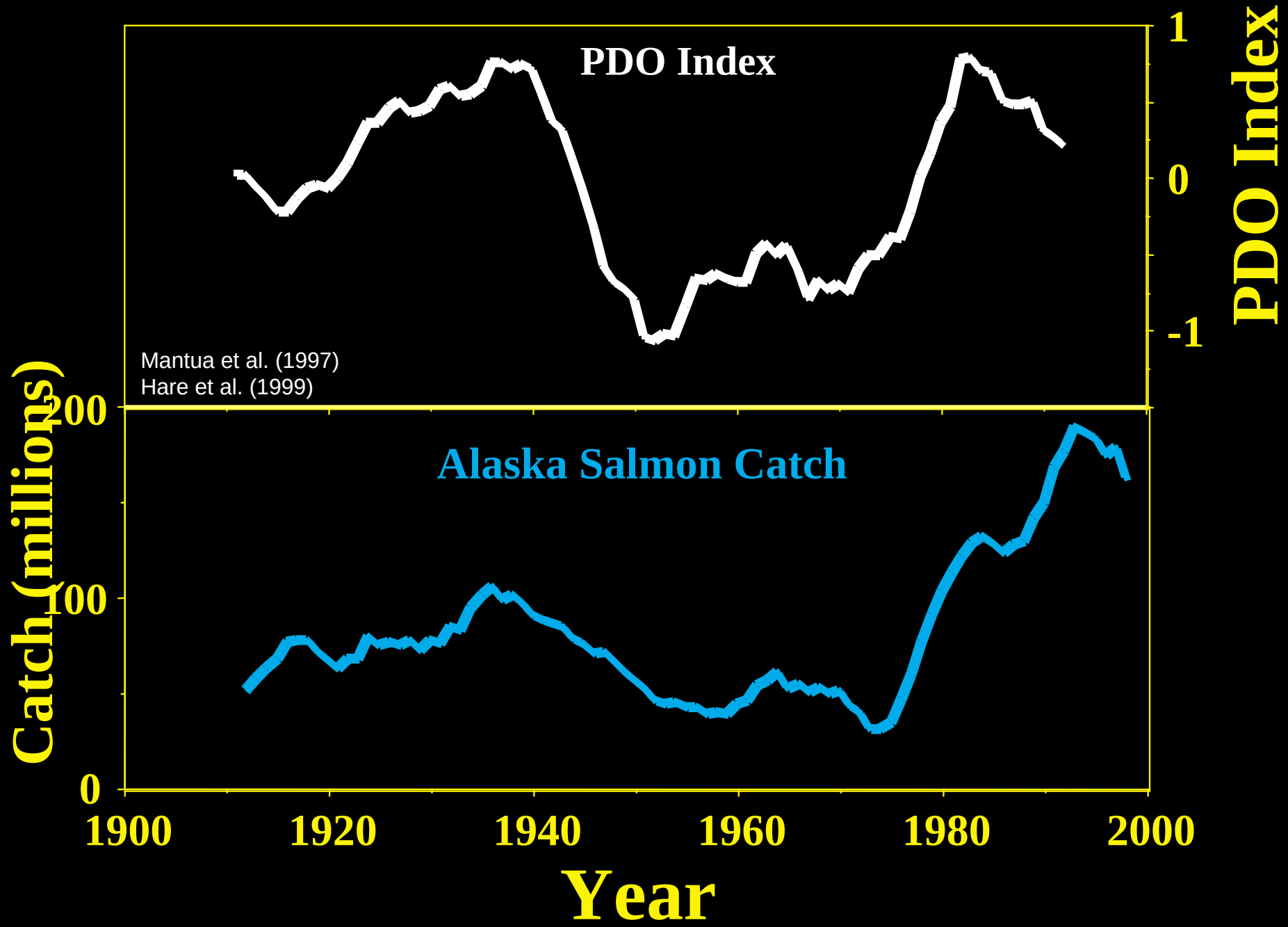

Nonvianuk Lake
δ15N
8
7
6
5
4
3
2
1
14000
12000
10000
8000
6000
4000
2000
0
Year BP

# Common Patterns or Random Madness??

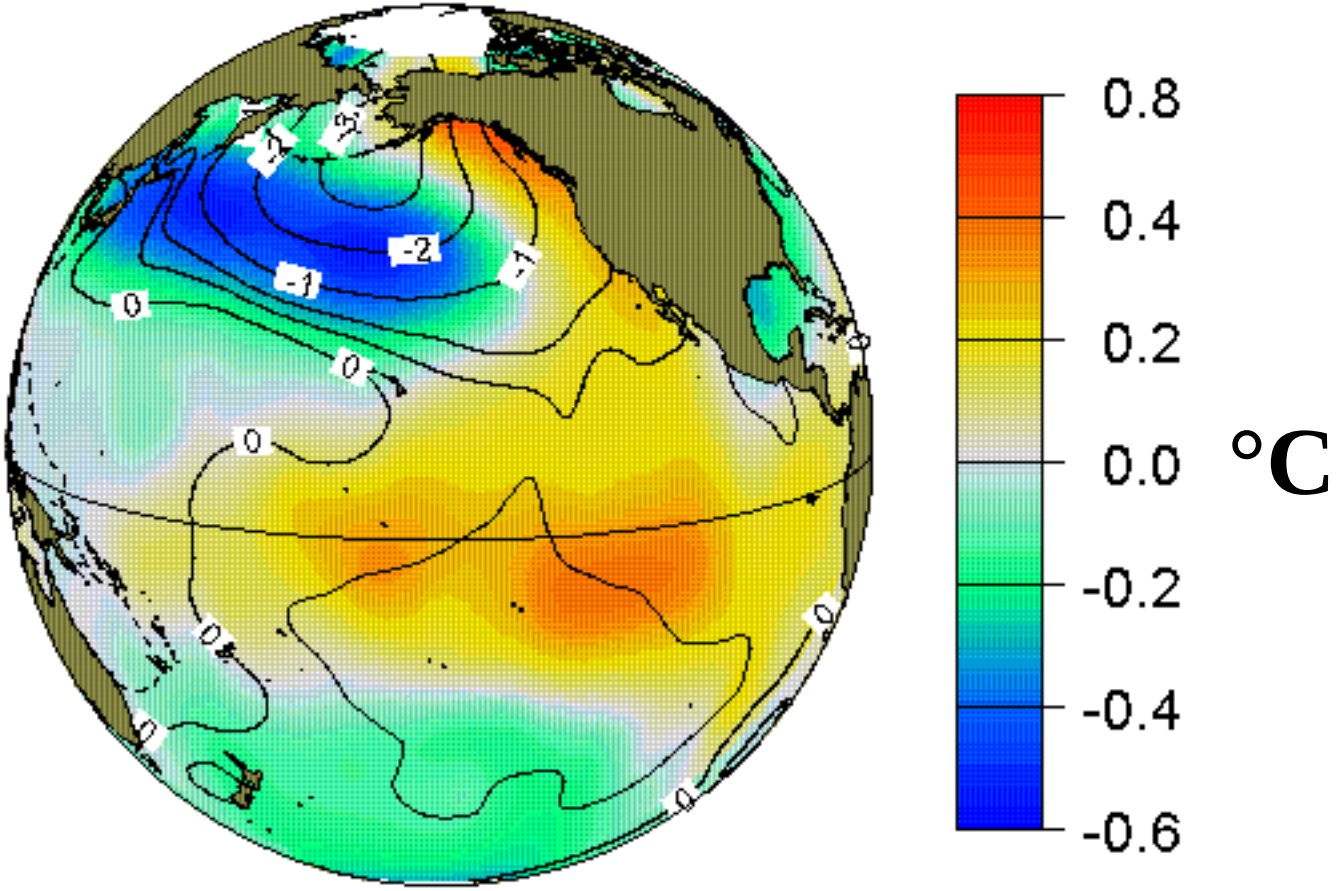
Long-term increase since deglaciation, with some abrupt “steps”:

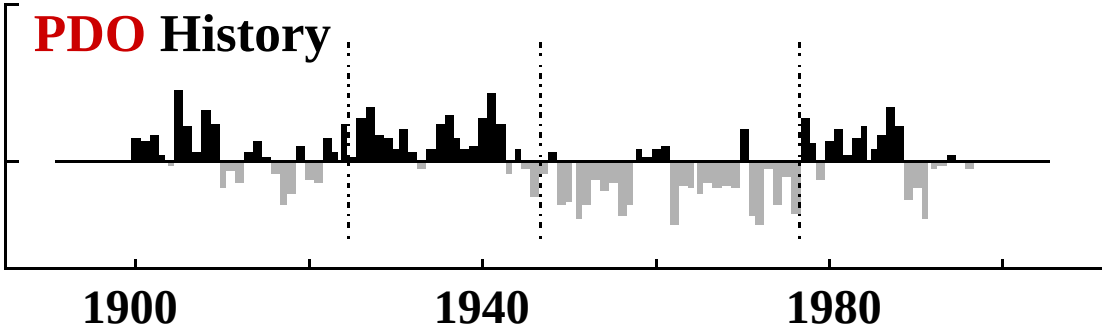
- Early Holocene peak?
- Neoglacial increase (3,000 - 4,000 yr BP)
- Decrease ~ 2,000 yr BP
- Peak during Little Ice Age (1200 - 1900 AD)
- Decline during 20th century (commercial fishing)

# Historical Climate and Salmon Catch Data



# Pacific InterDecadal Oscillation SST Pattern

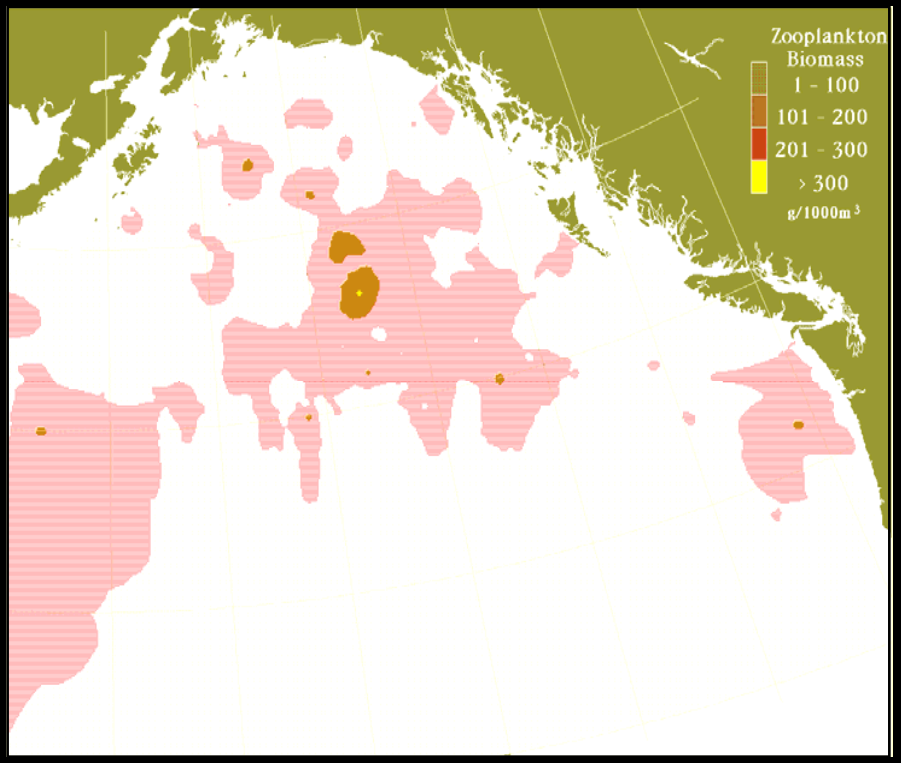


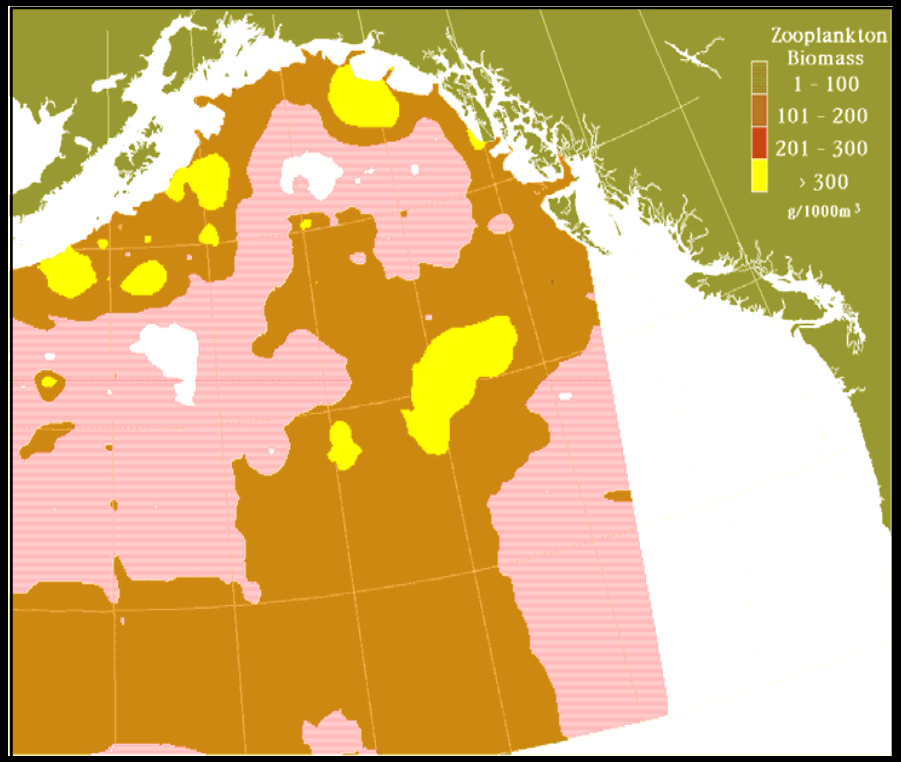

Mantua et al. (1997)

# Gulf of Alaska Zooplankton Biomass

1956-1962

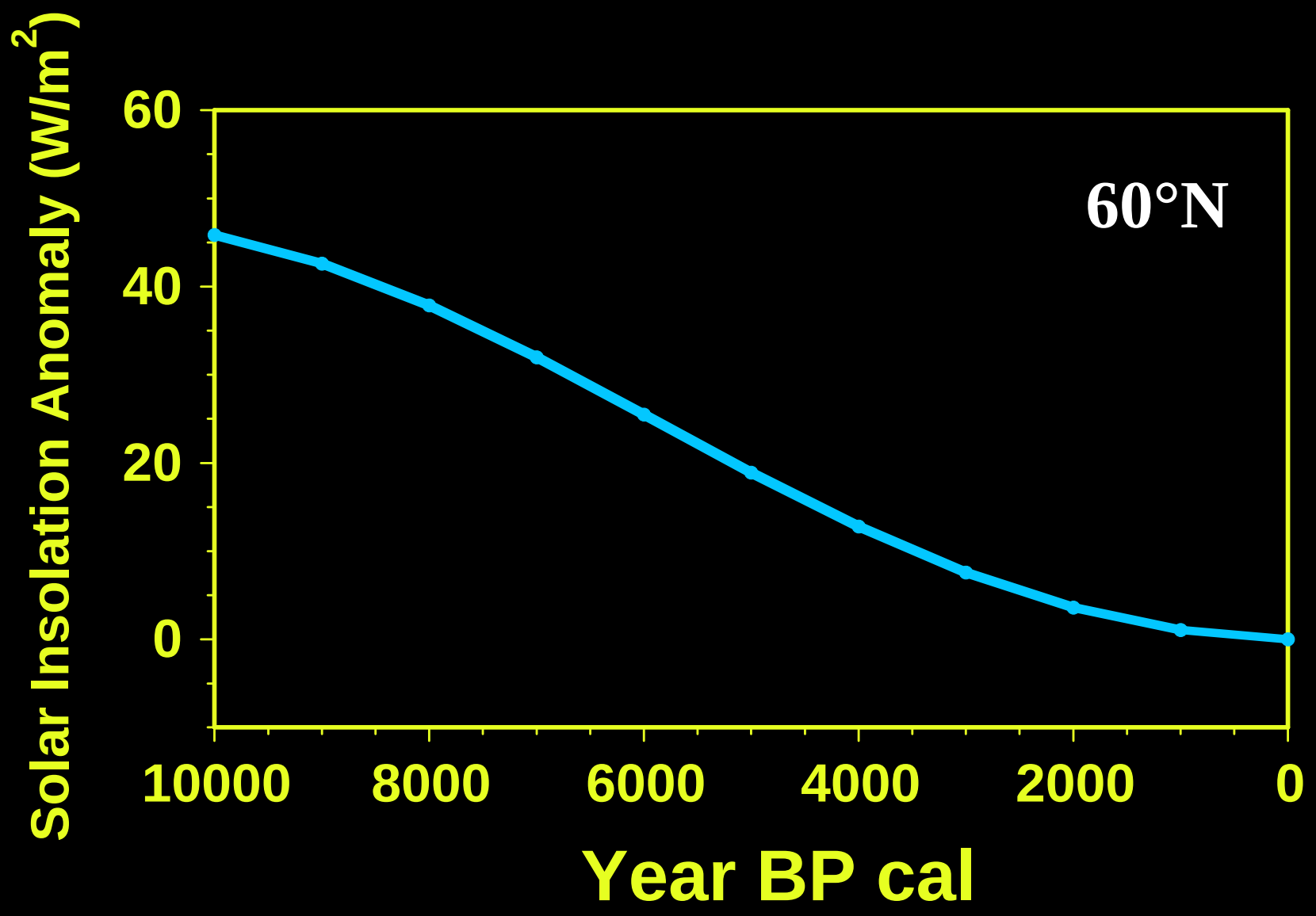



1980-1989

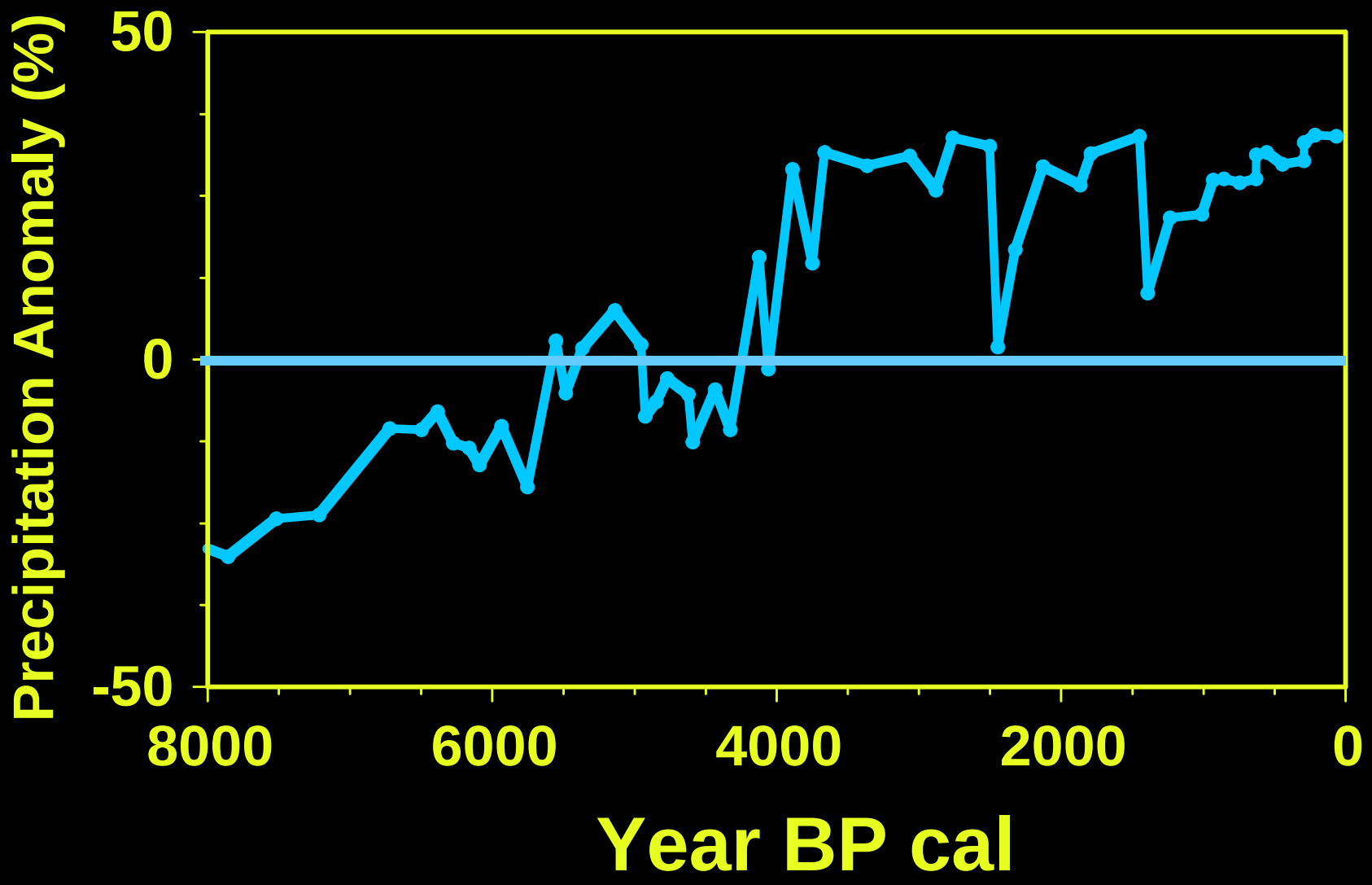



From: Brodeur and Ware (1992) Fish. Oceanogr. 1: 32-38

# Millennial Climate Forcing: Holocene

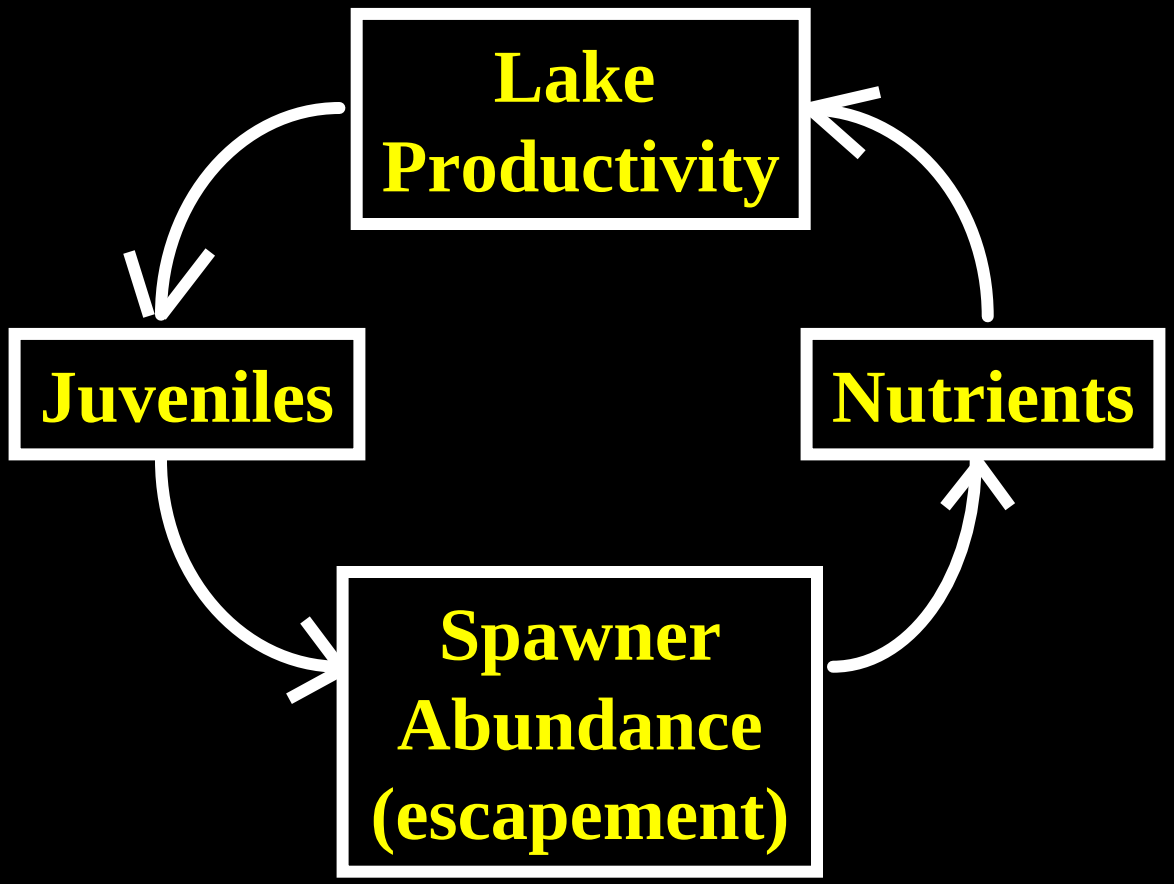


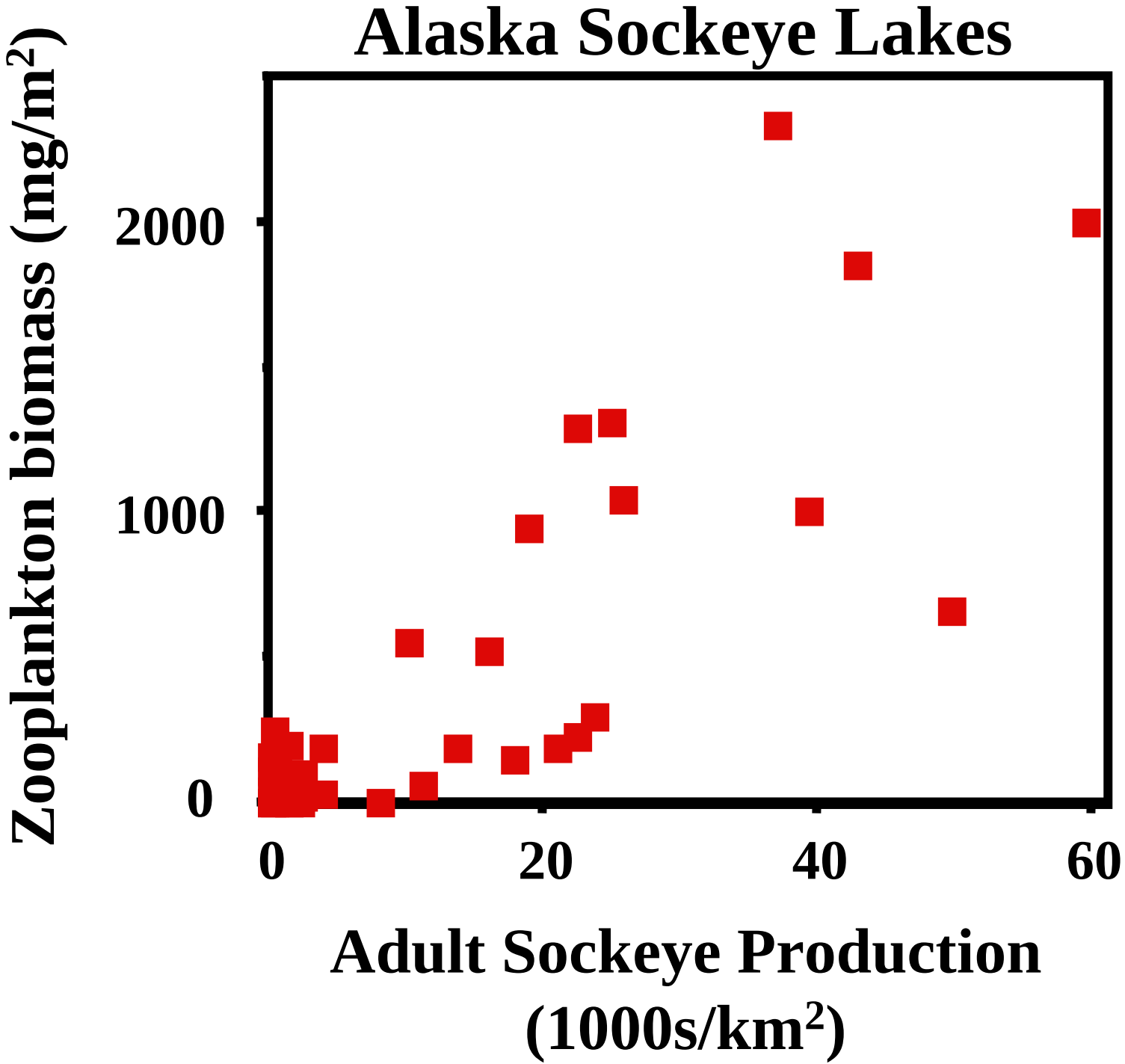
# Holocene Coastal Precipitation
# South Central Alaska

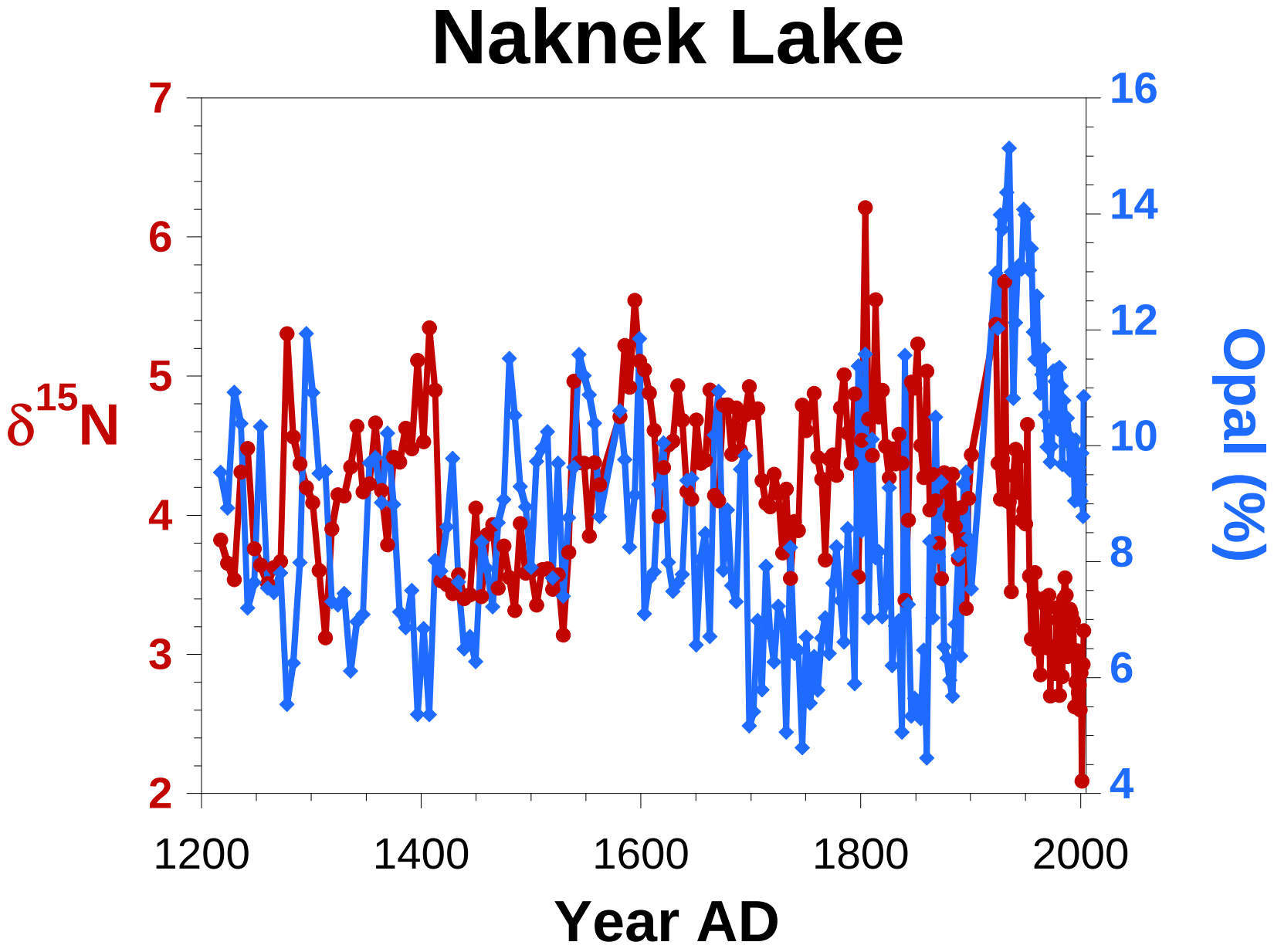


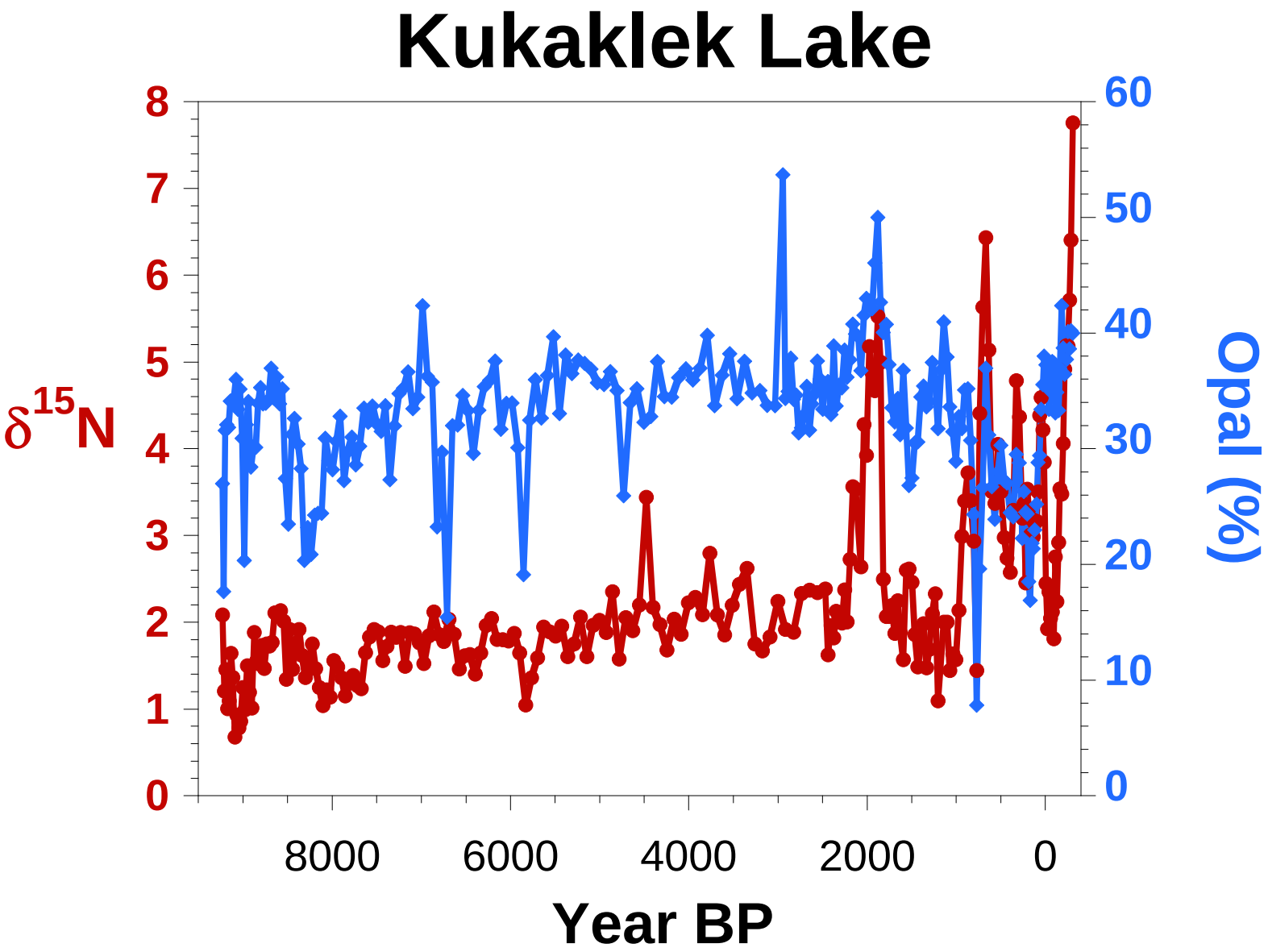

Heusser et al. 1985

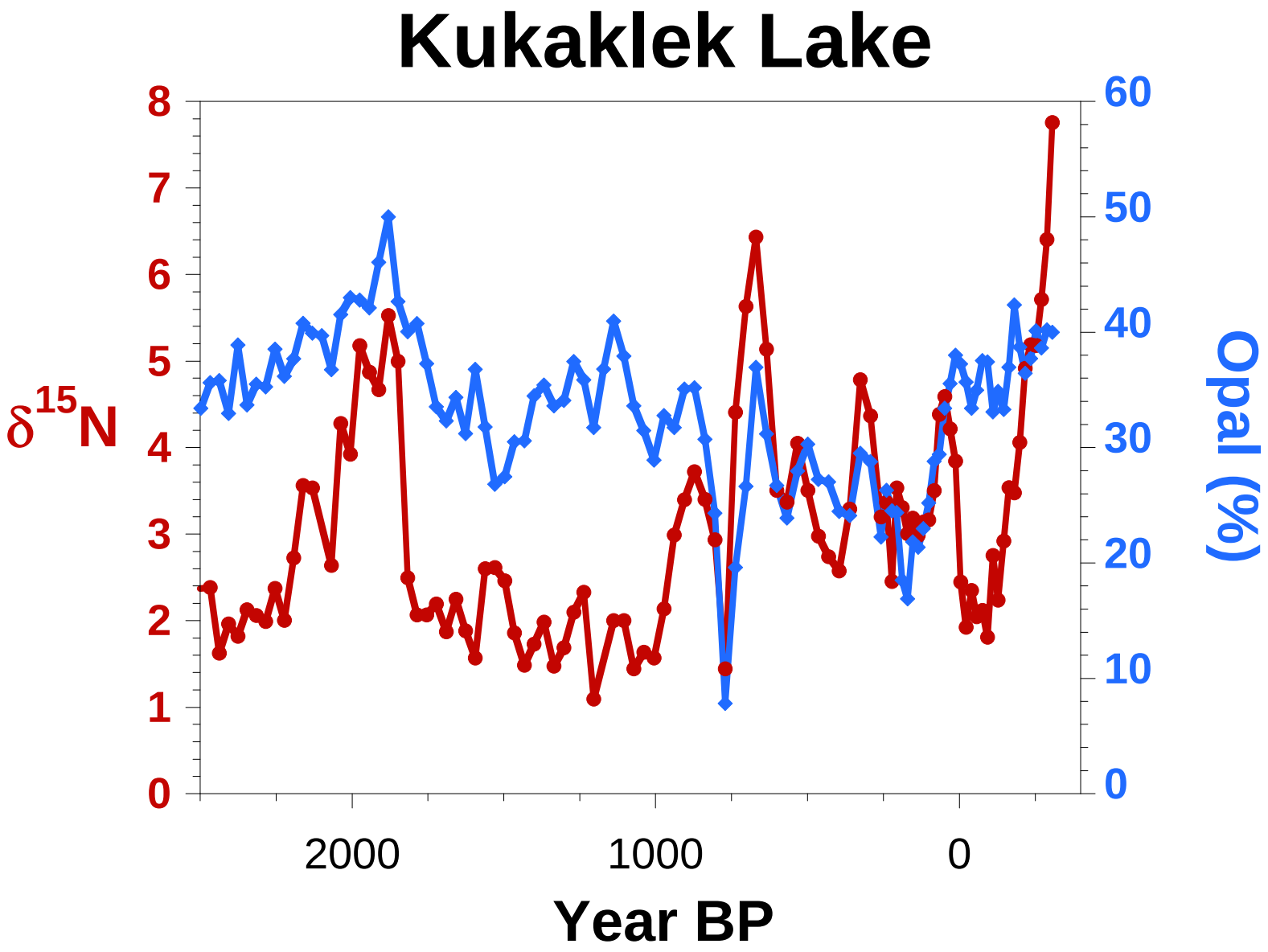
# Salmon-Derived Nutrients - Productivity Feedback




Alaska Sockeye Lakes
Zooplankton biomass (mg/m2)
2000
1000
0
0
20
40
60
Adult Sockeye Production
(1000s/km2)


Naknek Lake
δ15N
7
6
5
4
3
2
16
14
12
10
8
6
4
Opal (%)
1200
1400
1600
1800
2000
Year AD


Kukaklek Lake
δ15N
Opal (%)
Year BP
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
8000
6000
4000
2000
0


Kukaklek Lake
δ15N
Opal (%)
Year BP
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
2000
1000
0

## Paleolimnology in SWAN: Future Directions

Better understanding of nutrient cycling and isotopic variability: couple limnological monitoring with paleo

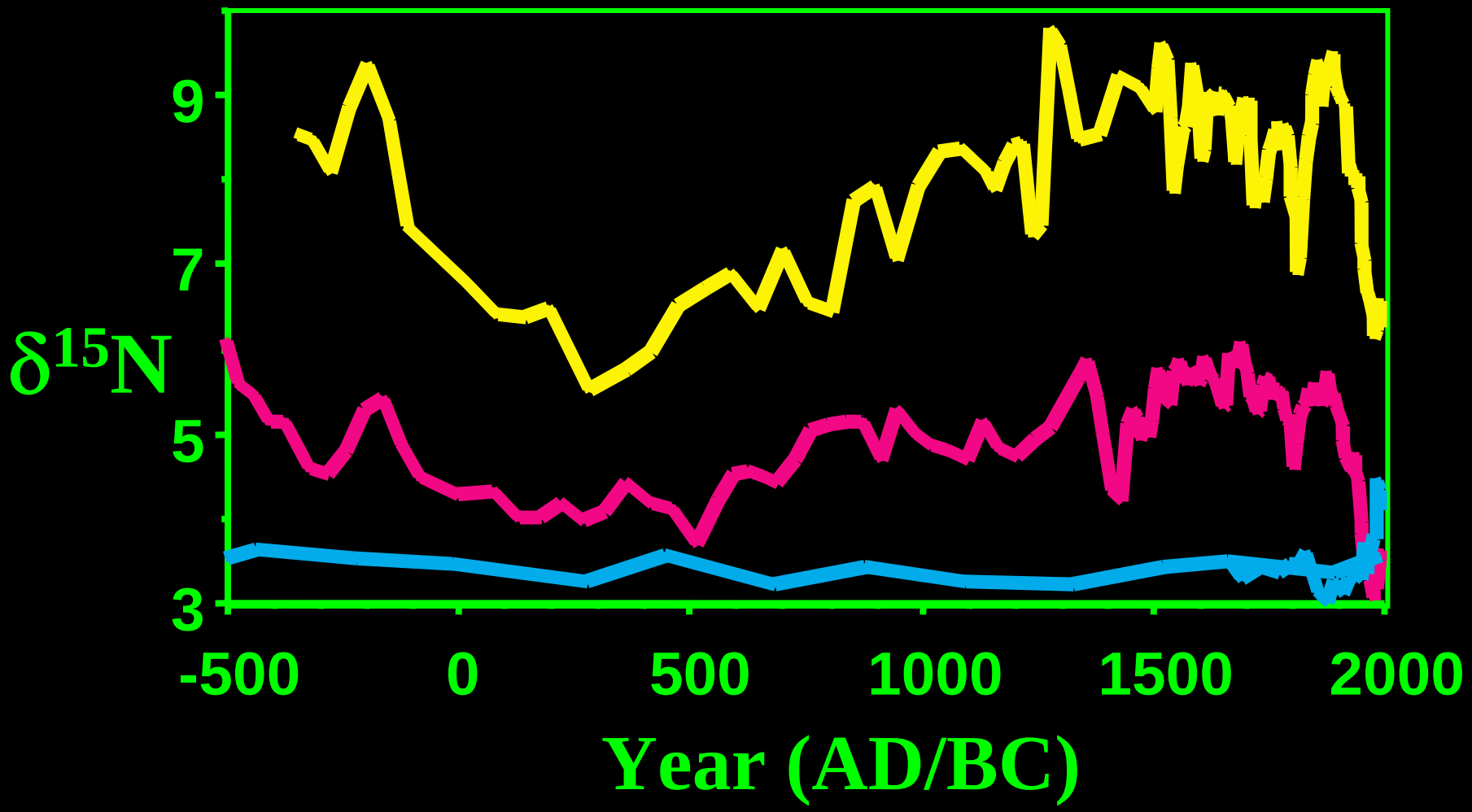
- Control Lakes

Integrate results with:

- Archeology
- Other AK and other salmon studies
- Paleoceanography

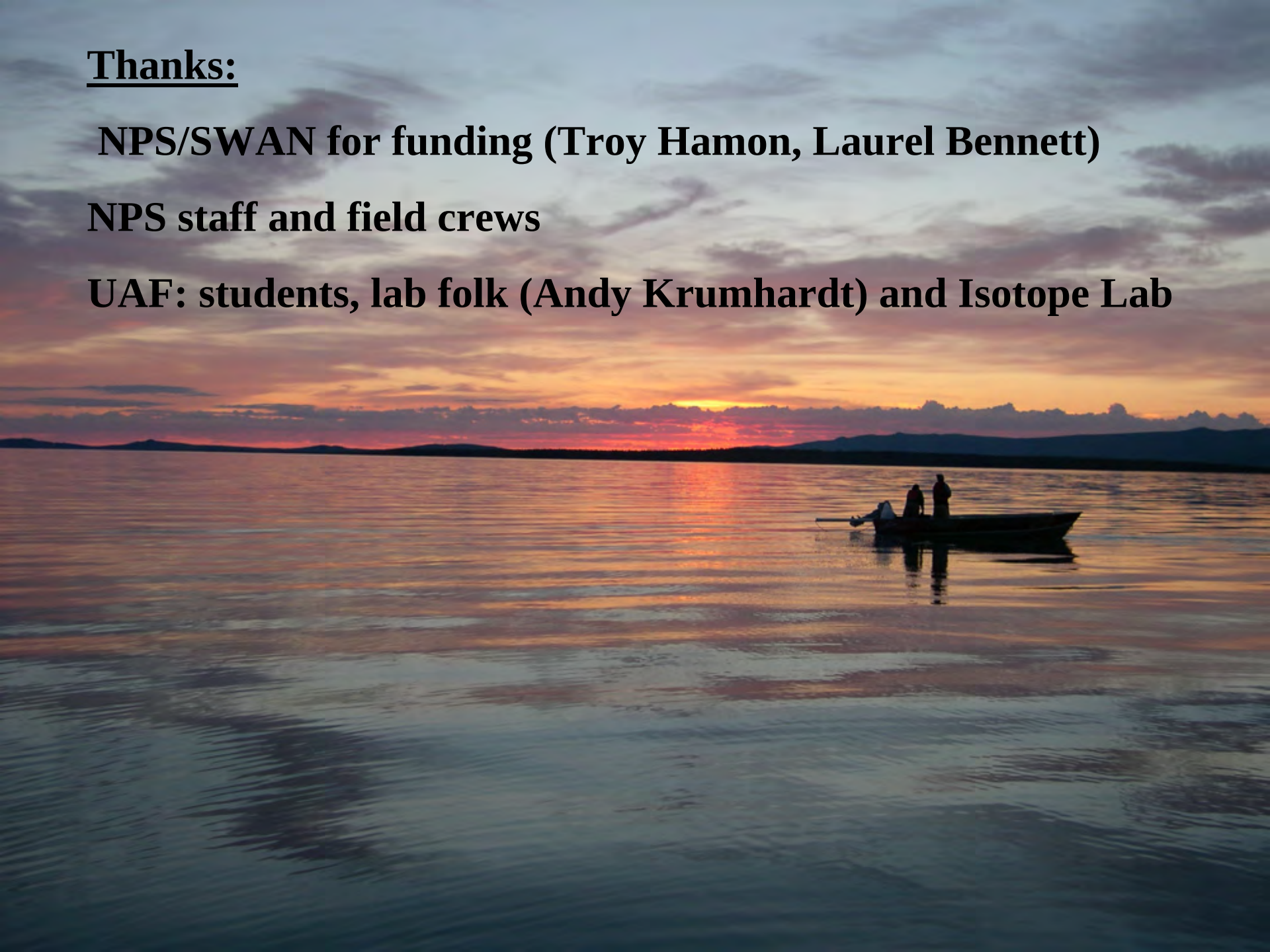
Use existing cores to add other proxies:

- Metals
- Other ecosystem components (zooplankton)



# Kodiak Archeology

Finney et al. (2002)



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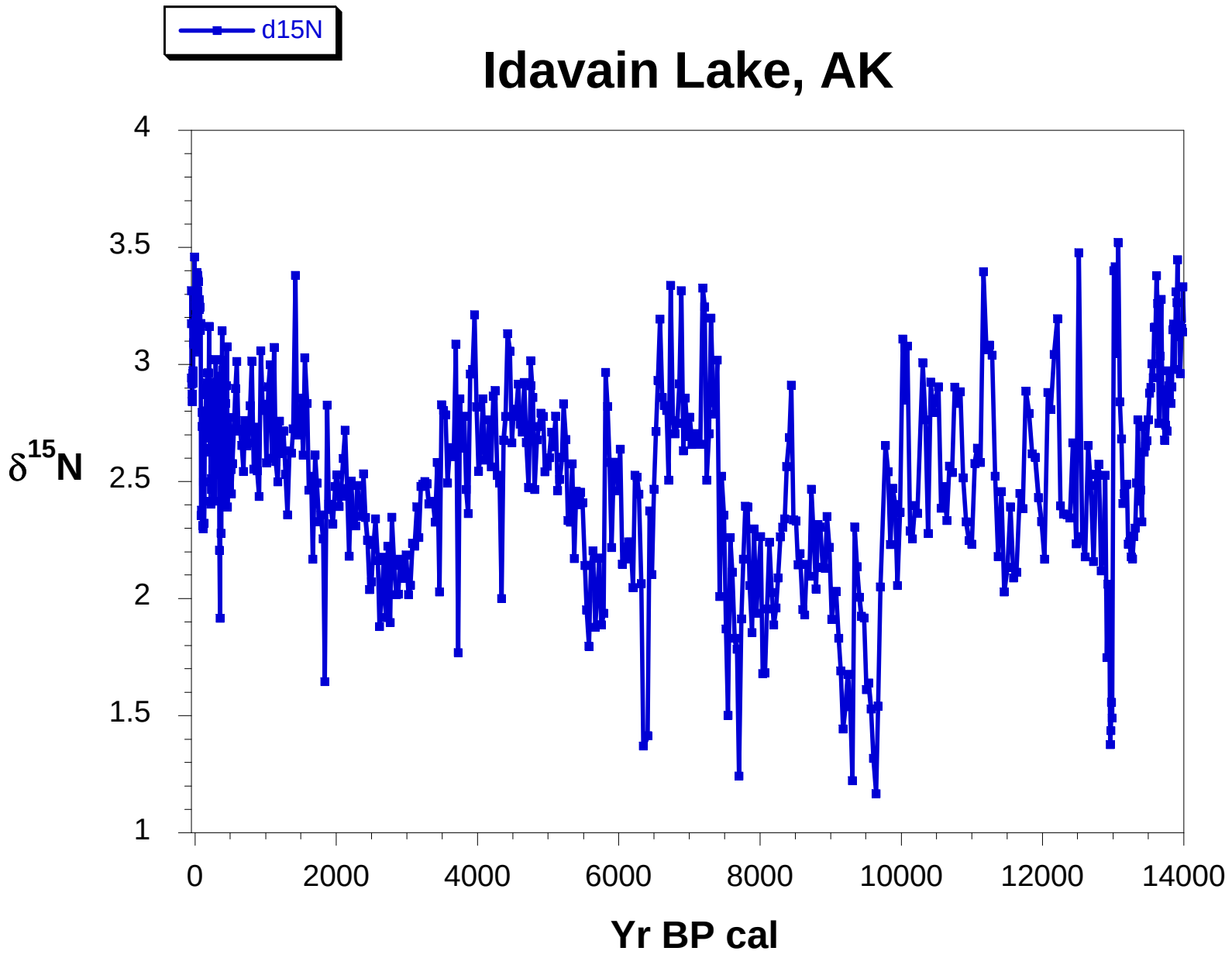
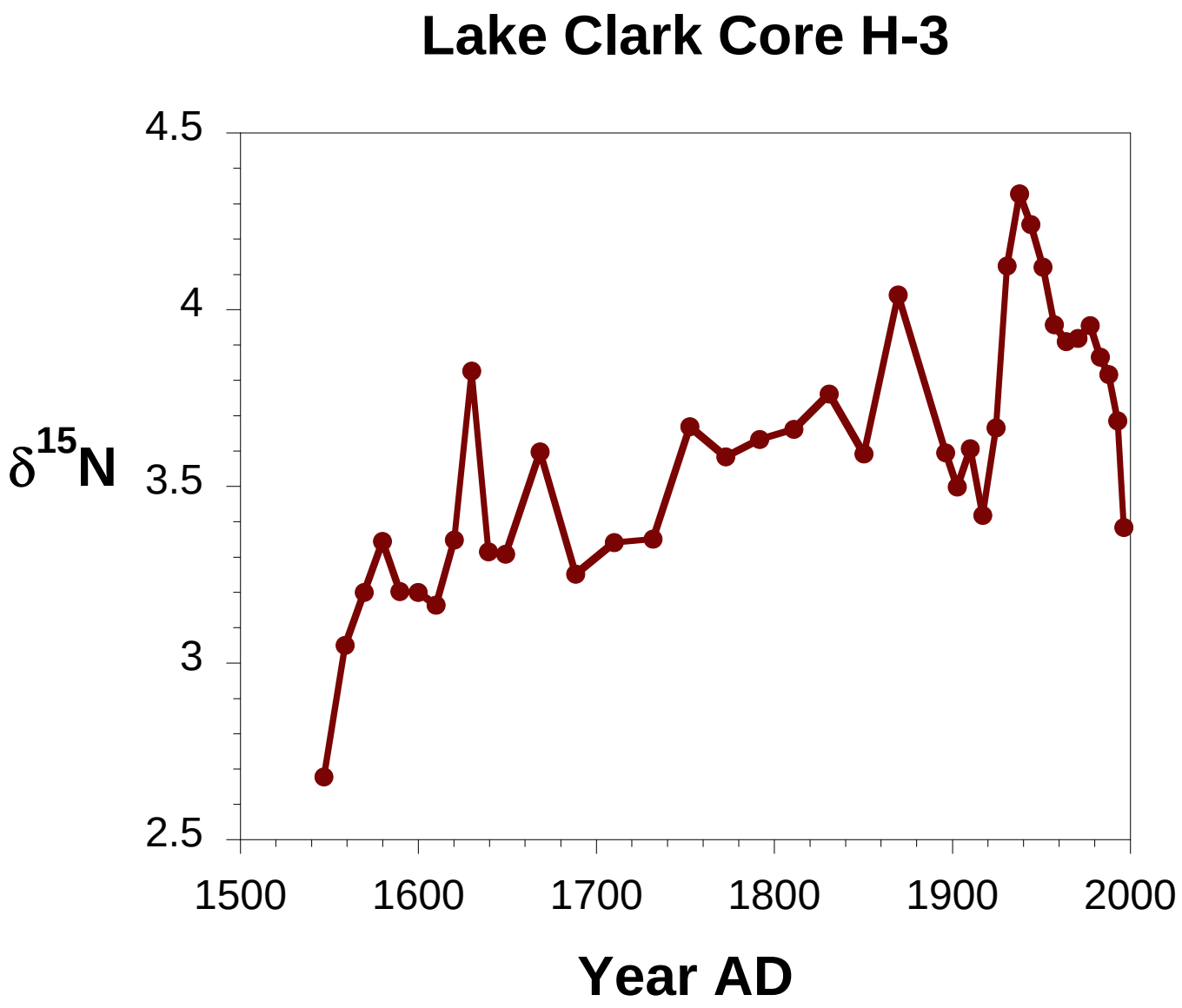
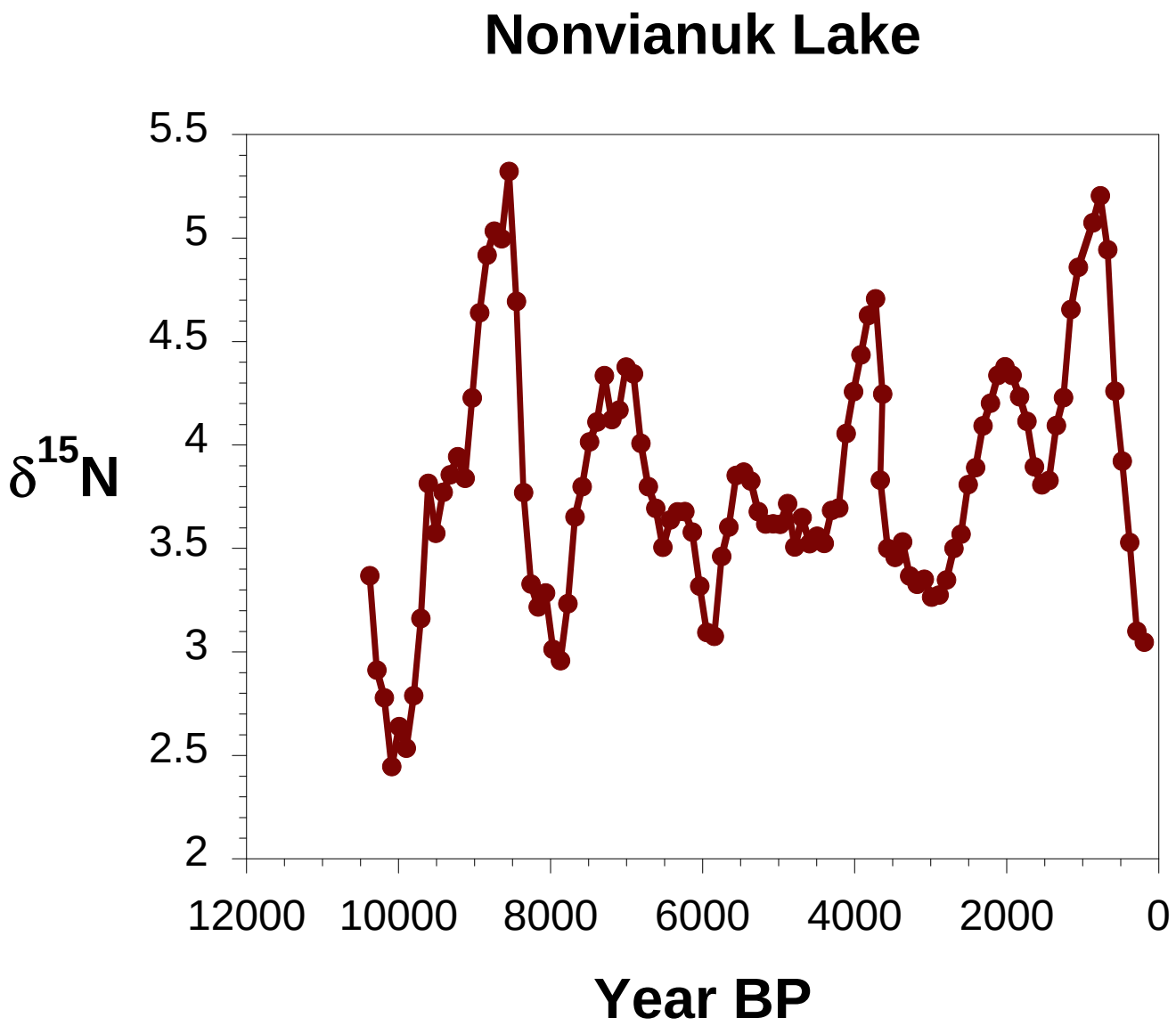
**NPS/SWAN for funding (Troy Hamon, Laurel Bennett)**

**NPS staff and field crews**

**UAF: students, lab folk (Andy Krumhardt) and Isotope Lab**


d15N
Idavain Lake, AK
4
3.5
3
2.5
2
1.5
1
δ15N
0
2000
4000
6000
8000
10000
12000
14000
Yr BP cal

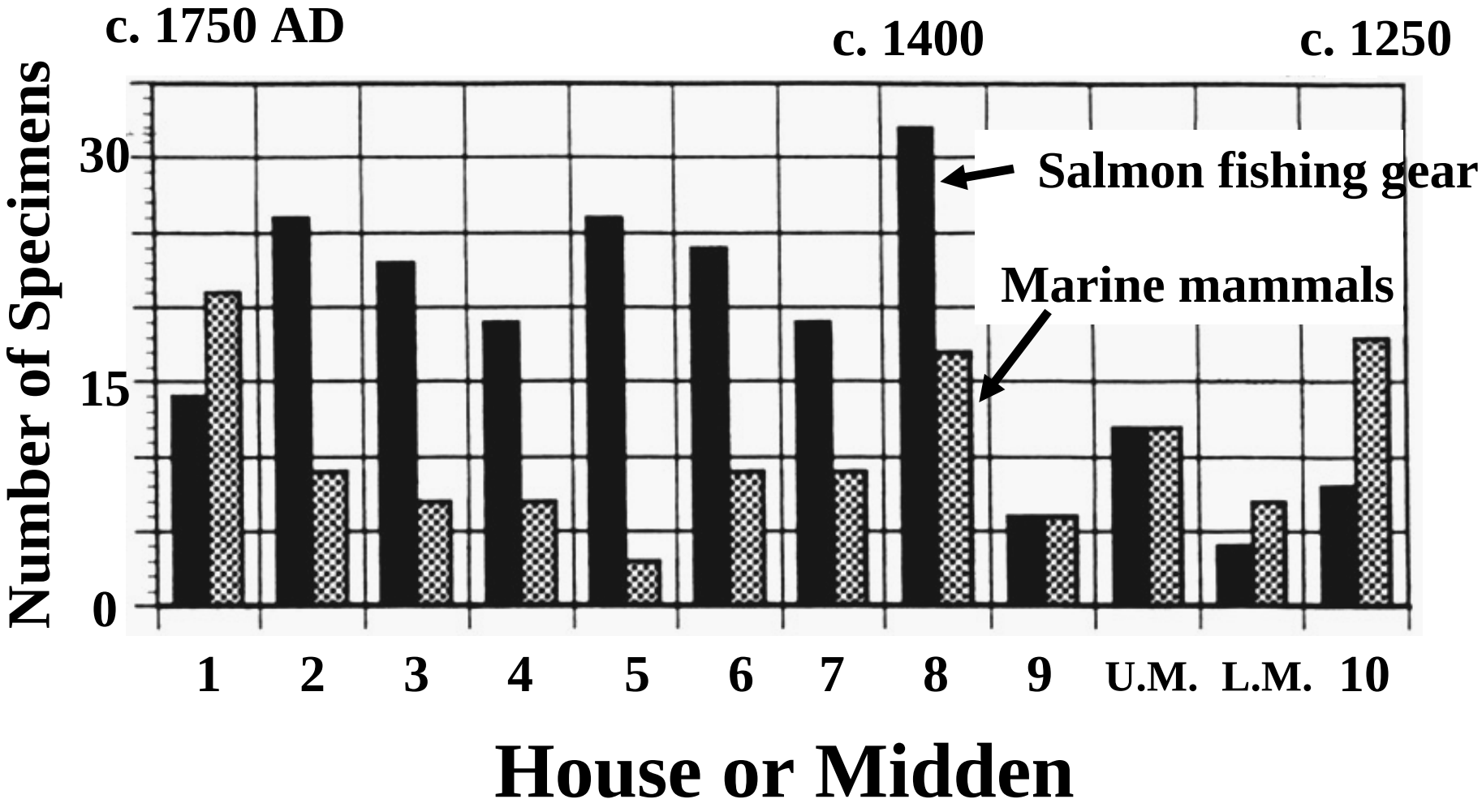

Lake Clark Core H-3
4.5
4
3.5
3
2.5
δ15N
1500
1600
1700
1800
1900
2000
Year AD


Nonvianuk Lake
5.5
5
4.5
4
3.5
3
2.5
2
δ15N
12000
10000
8000
6000
4000
2000
0
Year BP

# Kodiak Human Population

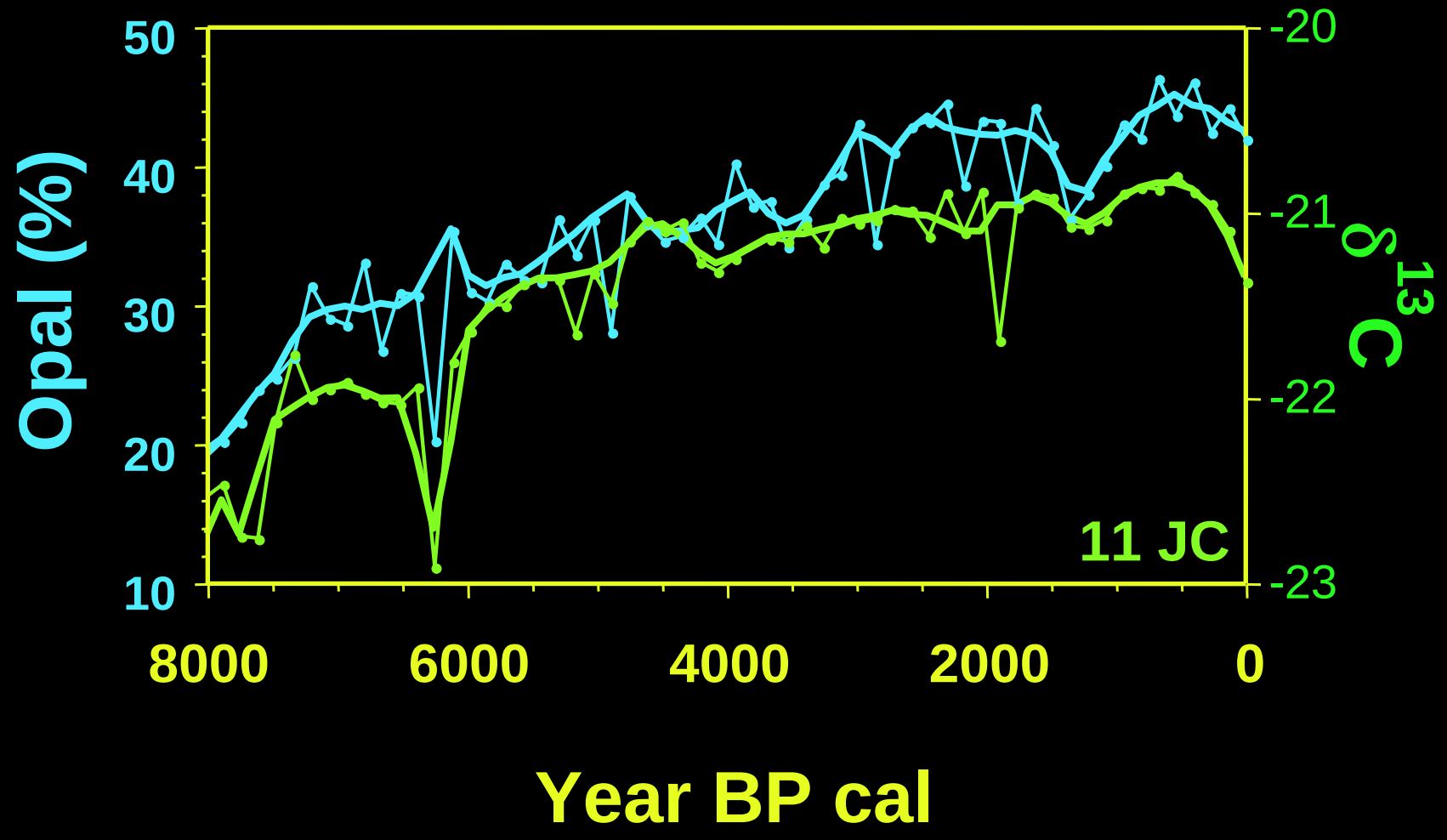
Saltonstall and Steffian (2004)

# Karluk One - Artifacts

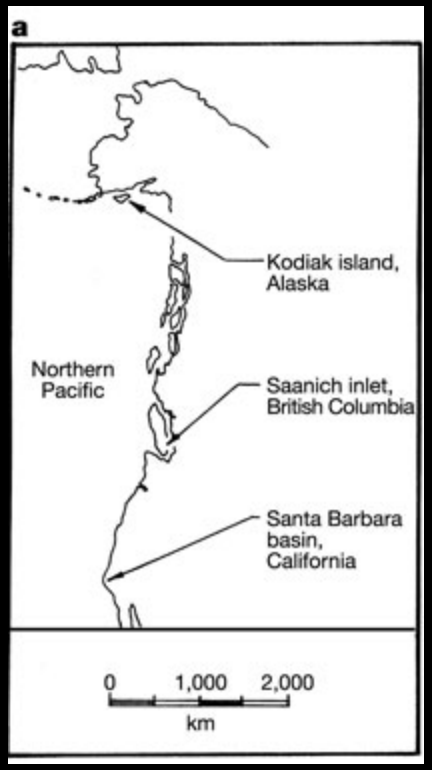



Knecht (1995)

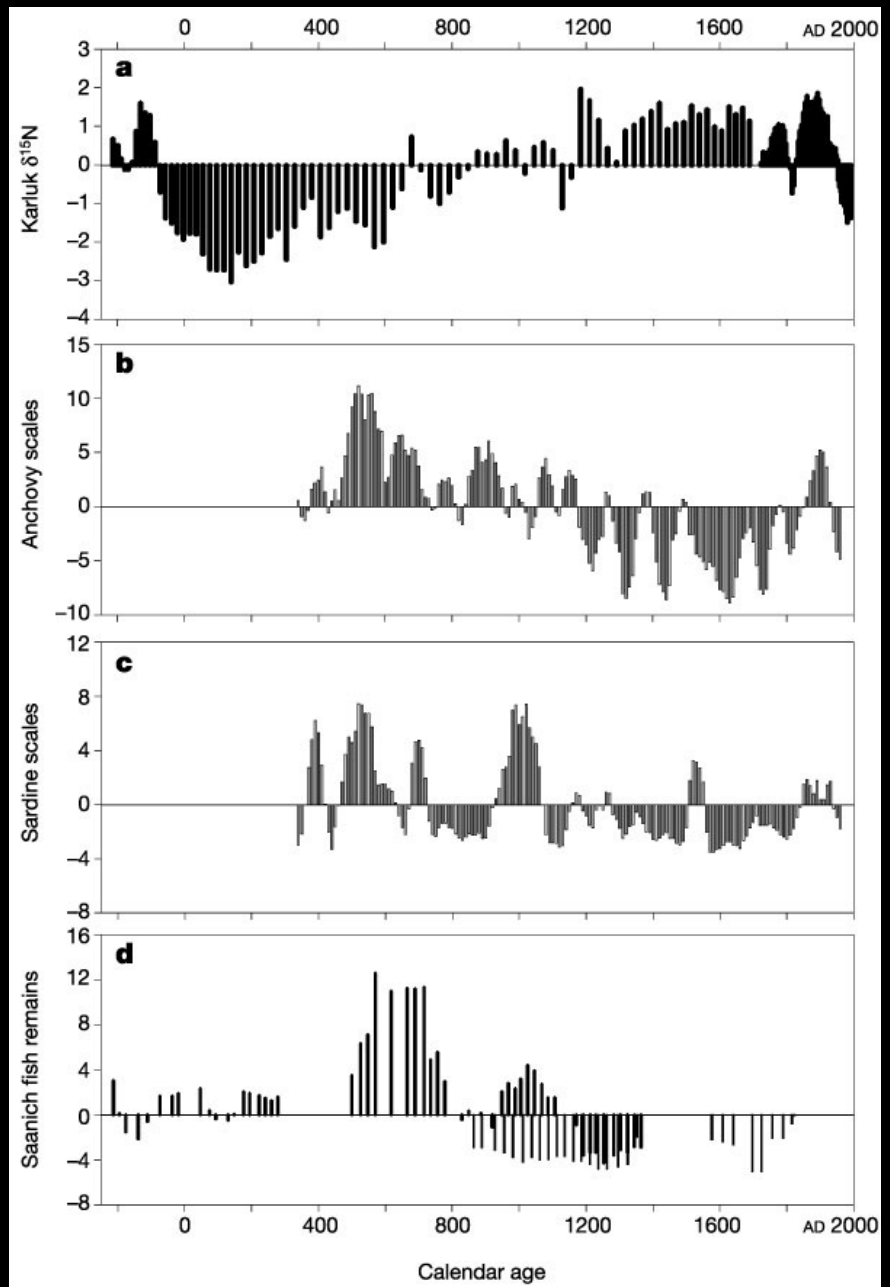
# Gulf of Alaska - Paleoproductivity



# NE Pacific fisheries over the last 2000 years




Finney et al. 2002




Kodiak Island sockeye

California anchovy

(Baumgartner et al. 1992)

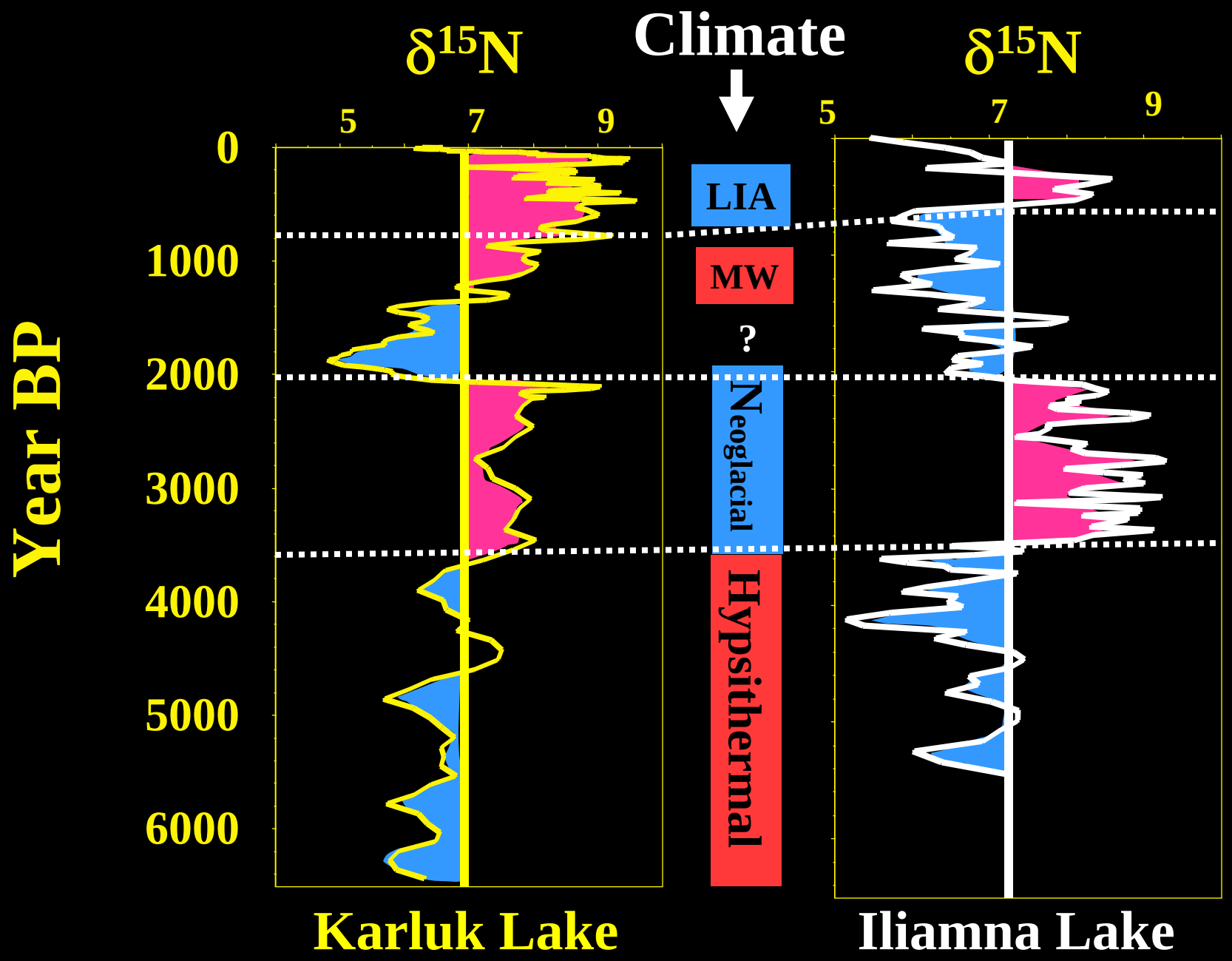
California sardine

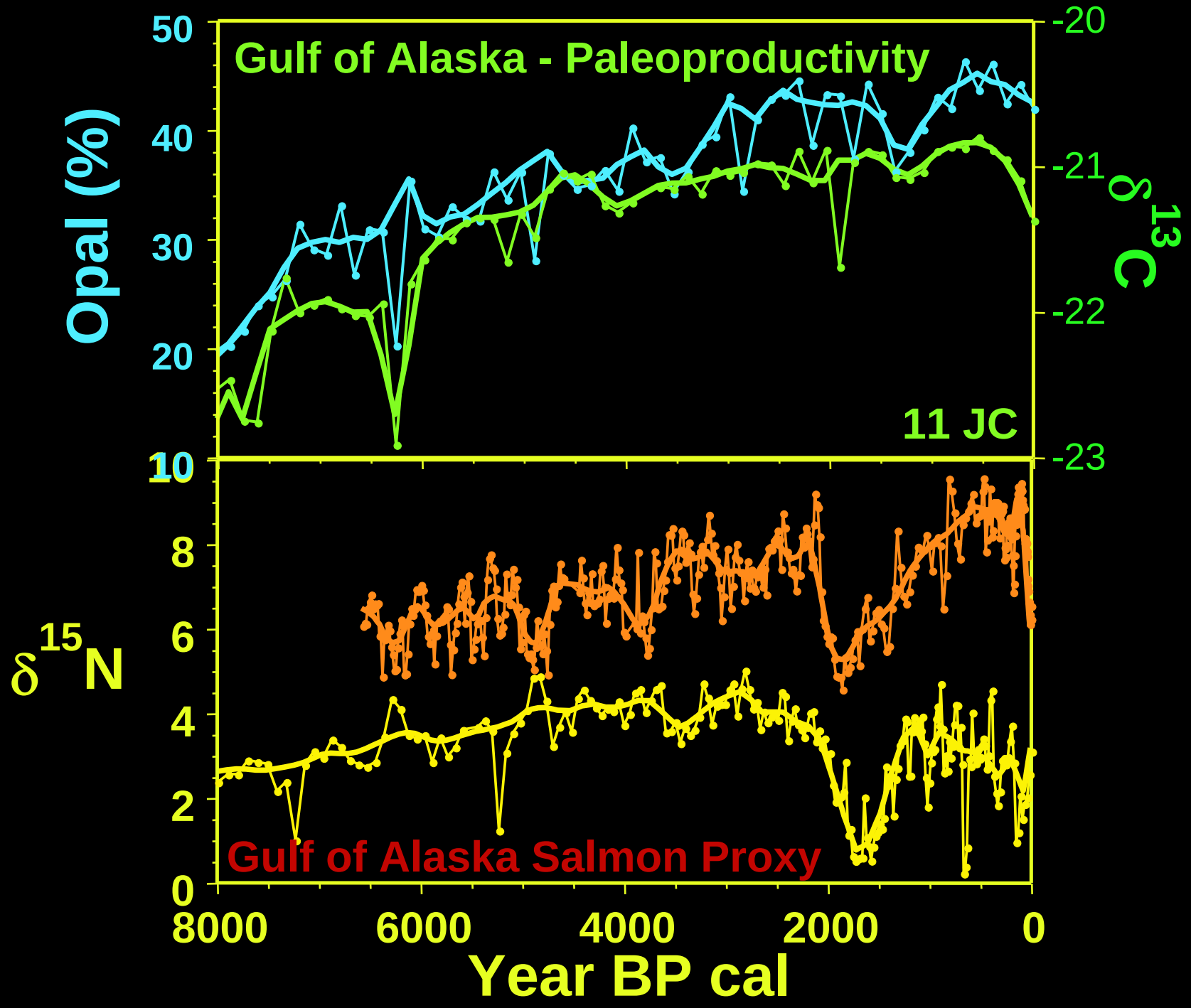
(Baumgartner et al. 1992)

BC total fish

(Tunnicliffe et al. 2001)

# Holocene Trends in Alaska Salmon and Climate




Gulf of Alaska - Paleoproductivity
Opal (%)
50
40
30
20
10
-20
-21
-22
-23
δ13C
11 JC
δ15N
8
6
4
2
0
Gulf of Alaska Salmon Proxy
8000
6000
4000
2000
0
Year BP cal