*Clathromorphum* (a calcified ALGA!) meets requirements for climate archive

- Exhibit high temporal climate recording resolution
- Multicentury-scale lifespan
- Abundant in Arctic and Subarctic
- Accurately records climate information
Crustose coralline algal-based marine climate reconstructions

1. Bering Sea teleconnections
2. Crusty algae uncover sea-ice change
3. Coralline algae and ocean acidification
Clathromorphum nereostratum, Aleutian Islands

- Laterally continuous growth increments
- No apparent growth interruptions
- Life span ca. 151 years (based on annual growth increment counting)
How can we measure Mg/Ca ratio?

- Electron microprobe
- Electron beam spot size 5 μm
- 15 samples/year on average
Mg/Ca ratios – Temperature indicator

Hetzinger, Halfar et al. 2011, PPP
Algal Mg/Ca record

Hetzinger, Halfar et al. 2012, Climate Dynamics
Comparison of Mg/Ca and regional sea surface temperatures

Hetzinger, Halfar et al. 2012, Climate Dynamics

Bering Sea Teleconnections
Sea Ice Change
Ocean Acidification
Interbasin comparison: Bering Sea-Atlantic Teleconnection

(Teleconnection: Climate anomalies related to each other at large distances)

- Modeling studies have speculated on interbasin linkage
- Investigations hampered by limited length of reliable instrumental data
- Algal time series is first 150-year temperature record from Bering Sea
Interbasin comparison: Bering Sea-Atlantic Teleconnections

- Aleutian Mg/Ca Record - North Atlantic Oscillation

NAO: - Mode of natural climate variability in North Atlantic
    - Atmospheric pressure difference Icelandic Low and Azores High
Interbasin comparison: Bering Sea-Atlantic Teleconnections

- Aleutian Mg/Ca Record - North Atlantic Oscillation

**NAO:** - Mode of natural climate variability in North Atlantic
  - Atmospheric pressure difference Icelandic Low and Azores High
  - Controls strength of westerlies + storm tracks across North Atlantic

Large pressure difference (positive NAO) results in increased westerlies → mild and wet winters in Central Europe
Interbasin comparison: Bering Sea-Atlantic Teleconnections

Aleutian Mg/Ca Record - North Atlantic Oscillation
Multisample Mg/Ca record from Bering Sea

Williams et al., in prep.
Crusty algae uncover sea-ice change
- Sea-ice extent is declining faster than models predict!
- Improve models by calibrating them with long time series of past sea ice extent
Present knowledge about past sea ice distribution:

- Satellite data (since 1979)
- Observational information (sparse before ~1850)
Present knowledge about past sea ice distribution:

- Satellite data (since 1979)

- Observational information (sparse before ~1920)

- Sea Ice Proxies
  - Low-resolution marine sediment cores
  - Remote terrestrial archives – Ice cores

Need to search for high-resolution in situ marine sea-ice recorder
Characteristics of *Clathromorphum*

- Photosynthetic calcifier
- Can live under sea ice
Characteristics of *Clathromorphum*

- Photosynthetic calcifier
- Can live under sea ice
Growth Rates function of Light and Temperature
Growth rates – Indicator of length of ice cover + summer temperature
Mg/Ca ratios – Temperature indicator + length of summer growth season
Combination of

Growth rates – Indicator of length of ice cover + summer temperature and
Mg/Ca ratios – Indicator of temperatures + length of summer growth season

→ Ice cover proxy
Sea Ice Extent
Sep 2012

Total extent = 3.6 million sq km
Correlation to Satellite Data

- Baffinland: $r = -0.63$, $n = 28$, $p = 0.0003$
- Labrador: $r = -0.62$, $n = 30$, $p = 0.0001$
Relationship to Historical Data and Climate

- Algal Record
- Newfoundland Sea Ice Extent
- North Atlantic Oscillation

Halfar et al. 2013
- Longest continuous time series from live-collected coralline alga
- Onset of Little Ice Age coincides with expansion of Inuit
- 20th century sea-ice decline in NW Atlantic unprecedented in last 650 years

Halfar et al. 2013
Bering Sea Teleconnections

Sea Ice Change

Ocean Acidification

Algal growth and Mg/Ca anomalies

1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000

Year

RC3 1310-1440

0.0

-1.0

Little Ice Age

0.5

Laborador Inuit Southward Expansion

Newfoundland Sea Ice Extent

Less Ice

350

300

250

200

150

x1000 km²

RC2 1670-1840

RC1 1820-post 1950

A

MTM Spectrum 1365-1530 A.D.

Raw MTM

AR(1) 99%

AR(1) 95%

1365-1530

0.00 0.10 0.20 0.30 0.40 0.50

Frequency (Cycles/Year)

Spectral Power

Halfar et al. 2013
Halfar et al. 2013

Coralline algae as high-resolution environmental archives for sea-ice reconstructions in the Bering Sea, with a focus on the Little Ice Age (1400-1850) and more recent sea-ice change (1850-present). The graph illustrates algal growth and Mg/Ca anomalies, with notable periods of sea-ice extent change, such as the Labrador Inuit southward expansion and Newfoundland Sea Ice Extent. The MTM spectrum from 1860-2010 A.D. highlights spectral power across different frequency ranges.
- Interannual frequency dominates during cold intervals such as the LIA
- Multidecadal frequency dominates during warm intervals
Coralline algae and Ocean acidification
CO₂

Since 1700

Hoegh-Guldberg et al. 2007

Bering Sea Teleconnections
Sea Ice Change
Ocean Acidification

Hoegh-Guldberg et al. 2007
Are *Clathromorphum* carbonates susceptible to ocean acidification?

- Aragonitic corals may already show decrease in calcification rates

From De’ath et al 2009
Our question:

Do cold water coralline algae (High Mg-Calcite) show a similar decline?

Answer:
Ocean Carbon Chemistry

Carbonate Minerals

\[ \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \]

Increasing Solubility

Calcite  Aragonite  Mg-Calcite
High Mg-calcites exceed solubility of aragonite at ~12 mol% MgCO₃
Cold-water coralline algae have up to 18 mol% MgCO₃
Aragonite Saturation (~Mg-Calcite Saturation @ 12 mol% MgCO₃)

from Orr et al 2005
• Aragonite Saturation (~Mg-Calcite Saturation @ 12 mol% MgCO₃)

from Orr et al 2005
Calcification Rate (g/cm$^3$/yr) = Growth rate $\times$ Skeletal Density
Calcification Rate (g/cm³/yr) = Growth rate x Skeletal Density
• Micro Computer Tomography

• Resolution 20 microns

• Series of two-dimensional x-ray images

• Imaging + quantitative measurement of skeletal density

Calcification Rate (g/cm$^3$/yr) = Growth rate \times \text{Skeletal Density}
Bering Sea Teleconnections  Sea Ice Change  Ocean Acidification

Calcification Rate

n=8

Australia Coral Calcification

Year

1900  1950  2000

Chan, Halfar et al. subm.
Bering Sea Teleconnections

Sea Ice Change

Ocean Acidification

Calcification Rate

Arctic Oscillation

$r = 0.54; p = 0.01$

Chan, Halfar et al. subm.
- *Clathromorphum* buildups resilient to present-day effects of ocean acidification

- Resilience possibly due to metabolic control over calcification

- Until what pH can metabolic control be maintained?

Present

Future?