“Now, children, I want you all to sit up just as straight and pretty as you can and give me all your attention for a minute or two. There -- that is it. That is the way good little boys and girls should do ..... I want to tell you how good it makes me feel to see so many bright, clean little faces assembled in a place like this, learning to do right and be good.”

Mark Twain - The adventures of Tom Sawyer
Chapter 4 Showing off in sunday school
(The superintendent commands attention...)

Can sclerochronology facilitate our understanding of ecosystem function?

Thomas Brey
Alfred-Wegener-Institut


Sunday, 26 May 13
Carbonate bio-archives ...

... are plenty in the sea ...

... but what are they good for in ecology?

Sunday, 26 May 13
Ecosystem function?
Ecosystem function!

External Drivers
- Climate & Environment
- Human Impact

Biota
- Biological Processes:
  - Mechanisms: Cause & Effect
- Ecological Processes:
  - Complexity & Variability in Space & Time

Ecosystem Functions
- Nutrient Recycling: N, P, Fe
- Carbon Metabolization: CO₂, C-org, CaCO₃
- Living Resources
- Biodiversity

Sunday, 26 May 13

The ecologist’s major challenges
The ecologist’s major challenges

- Understanding today’s aquatic ecosystems
The ecologist’s major challenges

- Understanding today’s aquatic ecosystems

Always trouble with system complexity

Antarctic Weddell Sea Food Web
(500 species - 16000 trophic links)
The ecologist’s major challenges

- Understanding today's aquatic ecosystems

Always trouble with system complexity spatial heterogeneity

Station Grid (taxonomy, numbers, biomass)

Benthic Production (new biomass)

Production Model & Geo-Statistical Model

Svalbard

Norway

Svalbard

Norway

Sunday, 26 May 13
The ecologist’s major challenges

- Understanding today's aquatic ecosystems
- Anticipating the future of aquatic ecosystems

Always trouble with system complexity spatial heterogeneity

SST Today
The ecologist’s major challenges

- Understanding today's aquatic ecosystems
- Anticipating the future of aquatic ecosystems

Always trouble with system complexity spatial heterogeneity

Food Web

Svalbard

Benthic Production

Norway

SST Today

SST Anomaly 2100 - Today

Future Global Change

Sunday, 26 May 13
The ecologist’s major challenges

- Understanding today’s aquatic ecosystems
- Anticipating the future of aquatic ecosystems

Always trouble with system complexity spatial heterogeneity

Food Web

Svalbard

Benthic Production

Norway

SST Today

SST Anomaly 2100 - Today

SST Anomaly Pliocene - Today

Future Global Change

Past Global Change

Sunday, 26 May 13
Where sclerochronology has a role:
Where sclerochronology has a role:

Environmental Archive
Where sclerochronology has a role:

Environmental Archive

Individual Growth

Sunday, 26 May 13
Where sclerochronology has a role:

Environmental Archive

Individual Growth

Shell Formation
Where sclerochronology has a role:

- Environmental Archive
- Individual Growth
- Shell Formation

Calcium Carbonate Polymorphs in *Laternula elliptica*

- Vaterite
- Calcite
- Aragonite

Nehrke et al. 2012

Sunday, 26 May 13
Where sclerochronology has a role:

- Environmental Archive
- Individual Growth
- Shell Formation
Where sclerochronology has a role:

- Environmental Archive
  - (Paleo-) Environment
  - High Resolution
  - Archive Diversity

- Individual Growth

- Shell Formation
Where sclerochronology has a role:

- **Environmental Archive**
  - (Paleo-) Environment
  - High Resolution
  - Archive Diversity

- **Individual Growth**

- **Shell Formation**

- **Ocean & Ecosystem Dynamics**

- **Pollution**

Sunday, 26 May 13
Where sclerochronology has a role:

- **Environmental Archive**
  - (Paleo-) Environment
    - High Resolution
    - Archive Diversity

- **Individual Growth**
  - Population Dynamics
    - Production
    - Energy Budget

- **Shell Formation**

- **Ocean & Ecosystem Dynamics**

- **Pollution**
Where sclerochronology has a role:

Environmental Archive

(Paleo-) Environment
- High Resolution
- Archive Diversity

Individual Growth

Population Dynamics
- Production
- Energy Budget

Shell Formation

Ocean & Ecosystem Dynamics

Food Web Living Resources

Pollution

Sunday, 26 May 13
Where sclerochronology has a role:

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  - (Paleo-) Environment
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  - Population Dynamics
  - Production
  - Energy Budget

- **Shell Formation**
  - Ecophysiology
  - Calcification
  - Energy Allocation

- **Ocean & Ecosystem Dynamics**
- **Pollution**
- **Food Web Living Resources**

Sunday, 26 May 13
Where sclerochronology has a role:

**Environmental Archive**
(Paleo-) Environment
- High Resolution
- Archive Diversity

**Individual Growth**
Population Dynamics
- Production
- Energy Budget

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Ecophysiology
- Calcification
- Energy Allocation

**Ocean & Ecosystem Dynamics**

**Pollution**

**Food Web Living Resources**

**Evolution & Biogeography**

Sunday, 26 May 13
Where sclerochronology has a role:

Environmental Archive
(Paleo-) Environment
- High Resolution
- Archive Diversity

Individual Growth
Population Dynamics
- Production
- Energy Budget

Shell Formation
Ecophysiology
- Calcification
- Energy Allocation

Ocean & Ecosystem Dynamics

Pollution

Food Web
Living Resources

Evolution & Biogeography

Sunday, 26 May 13
Case 1: Paleo - ecosystem dynamics: from growth to energy budget
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*
Ivany et al. 2011
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*

Ivany et al. 2011

Growth Model
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*

Ivany et al. 2011

Growth Model

Size - Mass - Relationship

(Recent Con-Species)

\[ M = 0.004 \times S^{2.844} \]
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*  
Ivany et al. 2011

**Growth Model**

\[ S_t = 82.867 \times (1 - e^{0.002 \times (1 - 0.274)}) \]

**Size - Mass - Relationship**  
(Recent Con-Species)

\[ M = 0.004 \times S^{2.844} \]

**Individual Production Model**

\[ \text{Production} P_{\text{ind}} \text{(g/ind/y)} \]

Sunday, 26 May 13
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene Cucullaea raea
Ivany et al. 2011

Growth Model

Size - Mass - Relationship (Recent Con-Species)

Body Mass M (g)

M = 0.004 * S^{2.844}

Size S (mm)

Individual Production Model

Production P_{ind} (g/ind/y)

Size S (mm)

Size - Frequency Data

Abundance N (Numbers/area)

Size S (mm)
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*
Ivany et al. 2011

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Sunday, 26 May 13
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*  
Ivany et al. 2011

**Growth Model**

Size $S$ (mm)  
Production $P_{ind}$ (g/ind/y)

**Size - Mass - Relationship**  
(Recent Con-Species)

Body Mass $M$ (g)  
Size $S$ (mm)  
$M = 0.004 \times S^{2.844}$

**Population Production**

Size $S$ (mm)  
Production $P$ (g/area/y)

**Similar approaches using present day proxies & empirical relationships:**

- Population Respiration
- Population Assimilation
- Population Consumption

$C \rightarrow A = P + R$

$C \rightarrow$ to predators  
$C \rightarrow$ to heat sink

Sunday, 26 May 13
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene Cucullaea raea
Ivany et al. 2011

Growth Model

Size S (mm)  Production P (g/area/y)

Individual Production Model

Size S (mm)  Production P (g/ind/y)

Size - Mass - Relationship

(Recent Con-Species)

Body Mass M (g) = 0.004 * S^{2.844}

Population Production

Similar approaches using present day proxies & empirical relationships:

Population Respiration
Population Assimilation
Population Consumption

The role of a population in its food web

Population Respiration → to predators
Population Assimilation → to heat sink
Population Consumption C → A = P + R

Size S (mm)  Production P (g/area/y)

Size S (mm)  Abundance N (Numbers/area)

Population R espiration

Sunday, 26 May 13
Case 1: Paleo - ecosystem dynamics: from growth to energy budget

Eocene *Cucullaea raea*

Ivany et al. 2011

**Growth Model**

**Size** $S$ (mm)  
**Production** $P_{ind}$ (g/ind/y)

**Size - Mass - Relationship**  
(Recent Con-Species)

$$M = 0.004 \times S^{2.844}$$

**Population Production**

$$P = \text{Production (g/area/y)}$$

**Size - Frequency Data**

**Size** $S$ (mm)  
**Abundance** $N$ (Numbers/area)

**Population**

- Respiration
- Assimilation
- Consumption

$$C = A = P + R$$

The role of a population in its food web

Food web dynamics

to predators

to heat sink

Similar approaches using present day proxies & empirical relationships:
Case 2: Organism response models
Case 2: Organism response models

Biogeochemical archive → Environment
Case 2: Organism response models

Biogeochemical archive

Environment

Morphological Archive

Life history
Case 2: Organism response models

Environment

Biogeochemical archive

Morphological Archive

Physiol. Performance
Energy budget
Biogeography

Life functions

Organism-Model

Mytilus edulis (Meyer & Möbius 1872)
Case 2: Organism response models

- Biogeochemical archive
  - Climate-Ocean model
    - Finite Element Sea Ice Ocean Model (FESOM)
- Environment
  - Mytilus edulis (Meyer & Möbius 1872)
- Organism-Model
  - Physiol. Performance
    - Energy budget
      - Biogeography
      - Life functions

Morphological Archive
Case 2: Organism response models

Bivalve Cerastoderma edule

Ecological niche - habitat dynamics in space & time

Today

2050

aquamaps.org
Case 2: Organism response models

**Ecological niche - habitat dynamics in space & time**

Bivalve *Cerastoderma edule*

Begum et al. 2010

**Organism performance - dynamics in space & time**

Bivalve *Arctica islandica*

Net Growth Efficiency

Begum et al. 2010
Case 2: Organism response models

Ecological niche - habitat dynamics in space & time

Bivalve *Cerastoderma edule*

Organism performance - dynamics in space & time

Bivalve *Arctica islandica*

“Reverse” modeling -> ecosystem dynamics

Begum et al. 2010
Case 3: Ecosystem parameter prediction
Case 3: Ecosystem parameter prediction

Environment → Model → Ecosystem

- Bioarchive Signature (Increment, Element, Isotope)
- Organism Performance (Growth, Metabolism)

\[ A = P + R \]

Sunday, 26 May 13
Case 3: Ecosystem parameter prediction

Bioarchive Signature (Increment, Element, Isotope)

Organism Model Output (Growth, Metabolism)

Ecosystem State

Primary Production Zooplankton Dynamics

Prediction

C = A = P + R
Case 3: Ecosystem parameter prediction

Arctica islandica

Increment Width

Water Temp.

Chl a

δ^{13}C

Ecosystem State

Primary Production

Zooplankton Dynamics

Schöne et al. 2005

Sunday, 26 May 13
Case 3: Ecosystem parameter prediction

Arctica islandica

Increment Width
58%

Water Temp.

Chl a

δ¹³C

Schöne et al. 2005

Diatom Numbers

Hi-res LA-ICP-MS
3 shells 975 spots

Ba/Ca

Mn/Ca

Hi-res LA-ICP-MS
3 shells 975 spots

Krause-Nehring in prep

Arctica islandica

Prediction

14

Schöne et al. 2005

Arctica islandica

Organism Model Output

Growth, Metabolism

Bioarchive Signature

Increment, Element, Isotope

Primary Production

Zooplankton Dynamics

Ecosystem State

Sunday, 26 May 13
Case 3: Ecosystem parameter prediction

Establishment of reliable relationships

Do we need a multi-archive / multi-proxy approach?

Ecosystem State Parameter

Prediction

Schöne et al. 2005

Krause-Nehring in prep

Sunday, 26 May 13
Case 4: Spatial & mobility patterns
Case 4: Spatial & mobility patterns

Habitat-specific Geochemical Signature (Element, Isotope)
Case 4: Spatial & mobility patterns

Habitat-specific Geochemical Signature (Element, Isotope)

Incorporation in Bioarchive
Case 4: Spatial & mobility patterns

Habitat-specific Geochemical Signature (Element, Isotope)

Incorporation in Bioarchive

\[ \delta^{13}C_{\text{DIC}} \]

\[ \delta^{18}O_{\text{Seawater}} \]

McMahon et al. 2013

Sunday, 26 May 13
Case 4: Spatial & mobility patterns

Habitat-specific Geochemical Signature (Element, Isotope)

Incorporation in Bioarchive

Caveats:
- Growth & Turnover Rates
- Tracer Fractionation Factor
- Physical & Chemical Conditions
- Metabolic effects

McMahon et al. 2013

Sunday, 26 May 13
Case 4: Spatial & mobility patterns

Habitat-specific Geochemical Signature (Element, Isotope)

Incorporation in Bioarchive

Caveats:
- Growth & Turnover Rates
- Tracer Fractionation Factor
- Physical & Chemical Conditions
- Metabolic effects

Identification & separation of stocks

Lates calcarifer

McCulloch et al. 2005

\( \frac{87}{86} \text{Sr} \)

\( \frac{\text{Sr}}{\text{Ba}} \)

Sunday, 26 May 13
Case 4: Spatial & mobility patterns

Habitat-specific Geochemical Signature (Element, Isotope) Incorporation in Bioarchive Caveats: Growth & Turnover Rates Tracer Fractionation Factor Physical & Chemical Conditions Metabolic effects

Identification & separation of stocks

Lates calcarifer

Life history of long-lived, large-distance roamers

Carcharodon carcharias

McCulloch et al. 2005

Sunday, 26 May 13
Case 5: Ocean acidification impact
Case 5: Ocean acidification impact

Change in Ocean Acidity 1700s to 1990s

Yool 2007
Case 5: Ocean acidification impact

Shell Growth

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \leftrightarrow \text{CaCO}_3 \]

Change in Ocean Acidity 1700s to 1990s

Yool 2007

Sunday, 26 May 13
Case 5: Ocean acidification impact

Shell Growth

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \leftrightarrow \text{CaCO}_3 \]

Energetic Costs?

\[ A = P_{\text{Body}} + P_{\text{Shell}} + R \]

Change in Ocean Acidity 1700s to 1990s

Yool 2007
Case 5: Ocean acidification impact

Shell Growth

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \iff \text{CaCO}_3 \]

Energetic Costs?

Shell Structure?

Change in Ocean Acidity 1700s to 1990s

Yool 2007
Case 5: Ocean acidification impact

Shell Growth

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \leftrightarrow \text{CaCO}_3 \]

Polyenes in *Arctica islandica*

Aragonite  
Polyenes  
Composite View

Stemmer et al. in prep

10 µm  
10 µm  
10 µm

Sunday, 26 May 13
Case 5: Ocean acidification impact

Shell Growth

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \Leftrightarrow \text{CaCO}_3 \]

Energetic Costs?

Shell Structure?

Geochemical Properties?

Yool 2007

Change in Ocean Acidity 1700s to 1990s

T. Brey 2013

Sunday, 26 May 13
An eternal evolutionary arms race
Case 5: Ocean acidification impact

An eternal evolutionary arms race

Naticid Gastropods (Moon snails) ... and their prey

Polinices sp.

drill to kill...
Case 5: Ocean acidification impact

An eternal evolutionary arms race

Naticid Gastropods (Moon snails) ... and their prey

Polinices sp.

Shell Growth

\[ \text{Ca}^{2+} + \text{CO}_3^{2-} \leftrightarrow \text{CaCO}_3 \]

Energetic Costs?

\[ \text{A = P Body} + \text{P Shell} + \text{R} \]

Geochemical Properties?

Shell Structure?

... and their prey

Crush to nosh...

Crabs

Drill to kill...

Hemigrapsus nudus - female

... and their prey
Case 5: Ocean acidification impact

An eternal evolutionary arms race

But the jury’s still out ... 

Shell dissolution in *Mytilus edulis*  
(Melzner et al. 2011)

ambient    | pCO2    | elevated

No effects in *Arctica islandica*  
(Stemmer et al. in press)

Crabs  
... and their prey

Shell growth: 

\[
\text{Ca}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{CaCO}_3
\]

Energetic Costs?

\[ \text{A} = \text{P}_{\text{Body}} + \text{P}_{\text{Shell}} + \text{R} \]

Geochemical Properties?

Shell Structure?

An eternal evolutionary arms race
Case 5: Ocean acidification impact

An eternal evolutionary arms race

Naticid Gastropods (Moon snails) ... and their prey

Modeling changes in predator - prey balance
Case 5: Ocean acidification impact

An eternal evolutionary arms race

Naticid Gastropods (Moon snails) ... and their prey

Modeling changes in predator - prey balance

Late Miocene -> Early Pliocene

Winners

Loosers

Global shifts in mollusk biodiversity

Hendy et al. 2009
... a look ahead - what deems important
... a look ahead - what deems important

THE trend in marine ecology:
building geo-referenced data bases

Norwegian-Russian joint Barents Sea Monitoring
... a look ahead - what deems important

THE trend in marine ecology: building geo-referenced data bases

Reference state for measuring future change

Norwegian-Russian joint Barents Sea Monitoring
The trend in marine ecology: building geo-referenced data bases

- Reference state for measuring future change
- Spatial modeling of ecosystem dynamics

Norwegian-Russian joint Barents Sea Monitoring

Sunday, 26 May 13
... a look ahead - what deems important

THE trend in marine ecology:
building geo-referenced data bases

Reference state for measuring future change
Spatial modeling of ecosystem dynamics

My intention:
to make sclerochronological data
a part of these initiatives
... a look ahead - what deems important

THE trend in marine ecology:
building geo-referenced data bases

Reference state for measuring future change
Spatial modeling of ecosystem dynamics

My intention:
to make sclerochronological data
a part of these initiatives

Enhanced spatial & temporal resolution
of environmental & ecosystem processes
Can sclerochronology facilitate our understanding of ecosystem function?
Can sclerochronology facilitate our understanding of ecosystem function?

Five cases

- Paleo-ecology
- Organism response
- Ecosystem parameters
- Spatial & mobility patterns
- Ocean acidification

\[ C \rightarrow A = P + R \]

to predators

to heat sink

Sunday, 26 May 13
Can sclerochronology facilitate our understanding of ecosystem function?

Five cases

- Paleo-ecology
- Organism response
- Ecosystem parameters
- Spatial & mobility patterns
- Ocean acidification

indicate: YES!
Coming soon at ISC 2013 ...
Session 1B:  Biology, Ecology & Ecosystems (2)  Session chair: Bryan Black

10:30 – 10:50  Una Matras  
Relationship between plankton characteristics and growth of the long-lived clam  
Arctica islandica on the Faroe Shelf

10:50 – 11:10  Julien Thébault  
Sclerochronology of benthic bivalves suggests major trophic shifts and stronger  
pelagic-benthic coupling in the Canadian Arctic

11:10 – 11:30  Michael Carroll  
Bivalve growth rate and isotopic variability across the Barents Sea Polar Front

11:30 – 11:50  Laure Pecquerie  
Understanding the impact of metabolism on δ¹³C patterns in bivalve shells and fish  
otoliths in the context of Dynamic Energy Budget (DEB) theory

11:50 – 12:10  Roger Mann  
Sclerochronology and bioenergetics: a combination to elucidate changes in growth  
environments at small temporal and spatial scales

12:10 – 12:30  Rhian Thomas  
Dead shell talking: investigating the impact of flow regulation on the endangered  
freshwater pearl mussel (Margaritifera margaritifera) using conservation  
palaeobiology and hydrology
Coming soon at ISC 2013 ...

Session 1B: Biology, Ecology & Ecosystems (2)
Session chair: Bryan Black

10:30 – 10:50 Una Matras
Relationship between
Arctica islandica
pelagic-benthic
interactions

10:50 – 11:10 Julien Thébault
Sclerochronology
of bivalves

11:10 – 11:30 Michael Carroll
Bivalve growth

Session 1C: Biology, Ecology & Ecosystems (3)
Session chair: Rob Witbaard

14:00 – 14:20 Gretchen Grammer
Evolution of an otolith-based marine chronology for the Southern Hemisphere
derived from a deep water fish species

14:20 – 14:40 Adam Rountrey
Otolith chronologies from the southeastern Indian Ocean reveal the effects of
temperature and current flow on the growth of fishes in a boundary current
ecosystem.

14:40 – 15:00 Alexander Arkhipkin
Annual and bi-annual life cycles in jumbo squid Dosidicus gigas as revealed from the
statolith microstructure

15:00 – 15:20 Clémence Royer
Sclerochronological and trace element investigations in Brittany populations of the
freshwater pearl mussel, Margaritifera margaritifera

15:20 – 15:40 Aurélie Jolivet
Is the great scallop recording upwelling events?

15:40 – 16:00 Melita Peharda
Glycymaris bimaculata (Poli, 1795) – a new sclerochronological archive for the
Mediterranean?
# Coming soon at ISC 2013 ...

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**Sunday, 26 May 13**

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**Thank you!**