4TH INTERNATIONAL
SCLEROCHRONOLOGY
CONFERENCE
2016

Program and Abstracts

4th International Sclerochronology Conference

5th - 9th June, 2016
Portland, Maine

Program and Abstracts

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Abstract Volume

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Cover photo by Mike Retelle, Bates College, Maine

Dear Friends and colleagues,

On behalf of the organizing committee, welcome to beautiful and historic Portland, Maine (USA) home of the 4th International Sclerochronology Conference (ISC 2016). It has been a real pleasure to watch the field of sclerochronology develop so much since the first meeting in St. Petersburg, Florida in 2007. The high quality of the meetings in Florida (ISC 2007), Mainz, Germany (ISC 2010) and Caernarfon, North Wales (ISC 2013) made the organizing committee of ISC 2016 strive to also develop a world-class conference on sclerochronology. We especially want to welcome new members of the sclerochronology community to the conference!

For ISC 2016, we established topical sessions that we thought best reflected where the field of sclerochronology is now and where it seems to be moving. These include: Proxy Development: Problems and Opportunities, Scleroarchaeology, Growth and Bioenergetics, Deep-time Evolution and Ecology, Climate and Oceans: Past and Present, Environmental Monitoring and Conservation Paleobiology, Fisheries Ecology and Management, and Sclerochronology in the Classroom. It has become more and more evident by the number of high-quality peer reviewed journal articles that sclerochronology is an essential tool in the natural sciences. The interdisciplinary nature of sclerochronology along with its workers will help address many important problems facing the planet and our global society now and in the future. It is an exciting time to be a sclerochronologist.

The organizing committee is especially thankful to the keynote speakers, all of whom are internationally recognized experts, for bringing their unique experience and enthusiasm for sclerochronology to Portland. We also thank all of our authors for submitting their best work for this conference. Our single most important goal is that ISC 2016 will be a platform of discovery, debate, discussion, networking, collaboration, and a bit fun. Based on the contributions that we received, we are certain that we will meet this goal!

The venue for ISC 2016 is in the newly renovated Westin Portland Harborview Hotel in the heart of Portland, Maine. The waterfront, shops, eateries, and other local attractions are just a short walk away. If there is anything that the organizing committee can do to help make this conference more successful, please let us know. The organizing committee is thankful to our sponsors for providing financial support. Please be sure to visit with the vendors and sponsors during the meeting. They would be thankful for any future business that you may require. We are indebted to many people for helping this conference come to fruition. Of particular note, we thank Jennifer Vit from the Iowa State University Conference Planning Office for her huge amount of help and expert guidance. Additionally, we thank Madelyn (Maddie) Mette (PhD candidate, Iowa State University) for her immense commitment to ISC 2016 and for making the behind the scenes things work so well! We wish you a safe, enjoyable, and productive conference!

With warm regards,

Fred Andrus (University of Alabama), Bryan Black (University of Texas at Austin), Kristine Delong (Louisiana State University), David Gillikin (Union College), David Goodwin (Denison University), Linda Ivany (Syracuse University), Donna Surge (University of North Carolina), and Al Wanamaker (Iowa State University)

The organizers of ISC 2016 are very thankful for the generous support of the following sponsors. Please take time during the conference and visit these exhibitors.

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Schedule

4TH INTERNATIONAL
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Refreshment breaks sponsored by Electro Scientific Industries, Inc. (ESI)

SUNDAY, JUNE 5TH, 2016

17:30 – 19:30	Icebreaker and Registration (Ballroom pre-function space)

MONDAY, JUNE 6TH, 2016

09:00 – 09:20	Introductory Remarks and Welcome
SESSION	PROXY DEVELOPMENT: PROBLEMS & OPPORTUNITIES
	Session Chair: Donna Surge (morning) and Bryan Black (afternoon)
09:20 – 09:50	**Jochen Halfar (Keynote)** Coralline algal paleoclimatology – A review of current status and challenges
09:50 – 10:10	**Zita Kelemen** Reconstructing past variability in African hydrology using freshwater bivalve shell geochemistry: A multi-year calibration from the Oubangui and Niger Rivers
10:10 – 10:30	**Liza Roger** Geochemical and crystallographic study of two species of coolwater bivalves (*Fulvia tenuicostata* and *Soletellina biradiata*) from southwestern Australia
10:30 – 10:50	*Refreshment Break*
10:50 – 11:10	**Madelyn Mette** Using shell-based proxy records from northern Norway to evaluate high latitude impacts of the Atlantic Multidecadal Oscillation
11:10 – 11:30	**Merinda Nash** Understanding cellular-scale controls on Mg uptake in crustose coralline algae
11:30 – 11:50	**Phoebe Chan** Recent decline in skeletal density and calcification rates of subarctic crustose coralline algae
11:50 – 13:20	*Lunch (provided; Longfellow Room)*
13:20 – 13:40	**Michèlle LaVigne** Southeast Gulf of Mexico corals reveal annual barium cycles
13:40 – 14:00	**Stefania Milano** Mechanical and structural response of *Cerastoderma edule* shell to acidification
14:00 – 14:20	**Bernd Schöne** Bivalve Sr/Ca(shell) heterogeneity and microstructures – Are geochemical variations at the micrometer-scale masking potential environmental signals?
14:20 – 14:40	*Refreshment Break*

14:40 – 15:00	**Julien Thébault** Great scallop shells as geochemical archives of phytoplankton dynamics in the bay of Brest (France)
15:00 – 15:20	**Kohki Sowa** Spatial distribution of low molecular weight organic matter in micrometer skeletal structure of *Acropora* and *Porites* coral
15:20 – 15:40	**David Gillikin** Reconstructing hydrological changes over the past century in Central Africa using freshwater bivalve shells
15:40 – 15:50	*Refreshment Break (10 minutes)*

SESSION SCLEROARCHAEOLOGY

Session Chair: Kristine DeLong

15:50 – 16:20	**Marcello Mannino (Keynote)** The challenges of a high-resolution archaeology: Sclerochronological and isotopic approaches in perspective
16:20 – 16:40	**Meghan Burchell** Isotope sclerochronology and hunter-gatherer seasonality: Archaeological landscapes from the Pacific and Atlantic coasts of Canada
16:40 – 17:00	**Ryan Harke** Sclerochronology of a large predatory gastropod (*Busycon sinistrum*) to determine late prehistoric seasonality at St. Joseph Bay, Florida
17:00 – 17:10	*Refreshment Break (10 minutes)*
17:10 – 17:30	**Fred Andrus** Archaeological applications of molluscan nitrogen isotope analyses
17:30 – 17:50	**Peter Müller** Application of clumped isotopes in shell midden sclerochronology
17:50 – 18:10	**Donna Surge** Determining season of harvest in shells of the European limpet (*Patella vulgata*) from modern and medieval collections

TUESDAY, JUNE 7TH, 2016

08:55 – 09:00	Announcements
SESSION	GROWTH AND BIOENERGETICS
	Session Chair: David Gillikin
09:00 – 09:30	**Brian Helmuth (Keynote)** It's not all death and destruction: Thermal performance, energetics and the key role of monitoring growth responses to global climate change
09:30 – 09:50	**Ariadna Purroy** The interaction of reproduction and shell growth in the bivalve *Callista chione*
09:50 – 10:10	**Irene Ballesta Artero** Environmental factors driving the valve gape activity of the bivalve *Arctica islandica* in Northern Norway
10:10 – 10:30	**Michael Carroll** Shell growth and environmental control of methane-associated thyasirid bivalves from Svalbard cold seeps
10:30 – 10:50	*Refreshment Break*
SESSION	DEEP-TIME EVOLUTION AND ECOLOGY
	Session Chair: Fred Andrus
10:50 – 11:20	**Seth Finnegan (Keynote)** Paleobiology Needs Your Help
11:20 – 11:40	**Andrew Johnson** Evidence, cause and consequence of exceptionally rapid growth amongst Pliocene scallops of the US eastern seaboard
11:40 – 12:00	**David Moss** Latitudinal variation of lifespans and growth rates in modern marine bivalves
12:00 – 12:20	**Linda Ivany** Growing a sea monster: Isotope ecology of a giant heteromorph ammonite
12:20	Boxed lunches provided
(12:45)	Departure for "Southern Maine Quaternary Geology Field Trip" Excursion. Return by 18:00.
19:00 – 21:00	Poster Session (Eastland Grand Ballroom)

WEDNESDAY, JUNE 8TH, 2016

08:55 – 09:00	Announcements
SESSION	CLIMATE AND OCEANS: PAST AND PRESENT
	Session Chair: Al Wanamaker (morning) and Phoebe Chan (afternoon)
09:00 – 09:30	**Kim Cobb (Keynote)**
09:30 – 09:50	**Juan Estrella-Martínez** Evaluating the strength and temperature variability of the North Atlantic current for the second half of the last millennium using an *Arctica islandica*-derived increment series
09:50 – 10:10	**Melita Peharda** The bivalve *Glycymeris pilosa* as a multidecadal environmental archive for the Adriatic and Mediterranean Seas
10:10 – 10:30	**Nina Whitney** An annually resolved, shell-derived oxygen isotope record since the late Little Ice Age from the Gulf of Maine: Implications for ocean circulation changes in the western North Atlantic
10:30 – 10:50	*Refreshment Break*
10:50 – 11:10	**Fabian Bonitz** A 388-year *Arctica islandica* shell-based chronology from the Faroese Shelf: Implications for a better understanding of the natural climate variability of the Faroe Current
11:10 – 11:30	**Stella Alexandroff** Reconstructing Holocene temporal hydrographic variability in Scottish Shelf Seas using dog cockle shells (*Glycymeris glycymeris*)
11:30 – 11:50	**Branwen Williams** Impact of skeletal heterogeneity and treatment method on interpretation of environmental variability from the skeletons of deep-sea gorgonian corals
11:50 – 13:20	*Lunch (on your own)*
13:20 – 13:40	**James Scourse** Annually-resolved North Atlantic marine climate over the last millennium: the ULTRA series
13:40 – 14:00	**David Reynolds** An integrated spatial data-model approach to reconstructing and understanding Atlantic meridional overturning circulation
14:00 – 14:20	**Eric Otto Walliser** Short-term climate variability in Central Europe during the Oligocene – A story told by glycymerids
14:20 – 14:40	*Refreshment Break*

14:40 – 15:00	**Maria Pyrina** Test of North Atlantic sea-surface-temperature reconstructions with pseudo proxy experiments over the last millennium
15:00 – 15:20	**Kristine DeLong** Salinity shifts in the southwest tropical Pacific from the Little Ice Age to the 20th century
SESSION	ENVIRONMENTAL MONITORING AND CONSERVATION PALEOBIOLOGY
	Session Chair: Linda Ivany
15:20 – 15:50	**Greg Dietl (Keynote)** Conservation paleobiology meets sclerochronology
15:50 – 16:10	**Paul Butler** The regulatory context of the use of biochronologies for baseline environmental monitoring
16:10 – 16:20	*Refreshment Break (10 minutes)*
16:20 – 16:40	**Justin McNabb** Isotope sclerochronology and season of annual growth formation in the marine bivalve, *Astarte borealis*, from Arctic and cold-temperate seas
16:40 – 17:00	**Stephen Durham** Testing the effect of climate warming on oyster life history using geohistorical records
17:00 – 17:20	**Daan Vanhove** Do oxygen isotope ratios in unionid shells reflect continental African hydroclimate variability?
18:45	Walk to Peaks Island ferry for 19:15 departure. Return ferry embarks at 21:45. Ferry to Peaks Island takes 20 minutes.

THURSDAY, JUNE 9TH, 2016

08:55 – 09:00	Announcements
SESSION	FISHERIES ECOLOGY AND MANAGEMENT
	Session Chair: Meghan Burchell and David Goodwin
09:00 – 09:30	**John Morrongiello (Keynote)** Otoliths: From individuals to assemblages in a changing world
09:30 – 09:50	**Lisa Kerr** Reconstructing environmental histories of Atlantic cod in the Gulf of Maine
09:50 – 10:10	**Karin Limburg** Losing track of time: Is hypoxia in part to blame for Baltic cod aging problems?
10:10 – 10:30	**Beth Matta** Otolith biochronologies reveal latitudinal differences in growth of Bering Sea yellowfin sole *Limanda aspera*
10:30 – 10:50	*Refreshment Break*
10:50 – 11:10	**Peter van der Sleen** Low-frequency variability in a centennial-length biochronology of Bering Sea Pacific ocean perch (*Sebastes alutus*)
11:10 – 11:30	**Bryan Black** Crossdating and preservation of signal strength in growth increment chronologies
11:30 – 11:50	**Phil Hollyman** Micro-scale chemical analysis of statoliths from the whelk *Buccinum undatum*: validation of a novel age determination method for fisheries management
11:50 – 12:10	**Pierre Poitevin** A new method for age and growth rate determinations of the Atlantic surf clam (*Spisula solidissima*), based on internal growth lines in ligament cross-sections
12:10 – 14:00	**Lunch Banquet, Student Awards, Future Meeting Planning**

POSTER PRESENTATIONS

Presenting authors are listed below in alphabetical order with abstract titles.

Jared Ballew
Development of a species-specific oxygen isotope transfer function for *Arctica islandica* shells: Insights from a temperature experiment

Christine Bassett
Clams and climate: Implications for reconstructing paleoseasonality in southern Alaska

Fabian Bonitz
Temperature reconstructions based on $\delta^{18}O$ measurements in bivalve shells from the Faroese Shelf

Shibajyoti Das
Diet of fossil and modern bivalves and gastropods revealed by carbon and nitrogen isotopes of shell-associated organic matter

Kristine DeLong
Save our Marine Annually Resolved Proxy Archives (MARPA)!

Amy Featherstone
Multiproxy reconstruction of seawater temperature in the bay of Brest using shells of dog cockles, *Glycymeris glycymeris*

Teresa Franco
Seasonal patterns in shells of *Concholepas concholepas* and its application at the archaeological site of Camarones 14 (Camarones River Valley, Chile)

Megan Freiberger
Evidence for growth rate nonlinearity in bamboo corals

Pedro Freitas
Upwelling seasonality in the Iberian upwelling system from shell $\delta^{13}C$ records in the bivalve *Glycymeris glycymeris*

Thomas Geeza
Trace and major element ratios in *Elliptio dilatatus* shells as indicators of surface water quality in Western Pennsylvania

David Gillikin
Paleoclimate reconstruction from oxygen isotopes in a coral skeleton from East Africa

Lauren Graniero
Detecting seasonal variations in nitrogen and carbon sources to an impacted river and its estuary using bivalve shell $\delta^{15}N$ and $\delta^{13}C$ values

Steffen Hetzinger
Reproducibility of *Clathromorphum compactum* coralline algal Mg/Ca ratios and calibration to high-resolution sea surface temperature data

Alaina Hickey
Paleoecological implications of nitrogen and carbon isotopic data from organic material in Devonian rugose corals

Emily Judd
Seasonal variation in temperature and precipitation during Eocene cooling inferred from Antarctic bivalves

Daniel Killam
Geochemical evidence for the presence of photosymbiosis in Early Jurassic lithiotid bivalve

Natasha Leclerc
Shellfishing through the Holocene in British Columbia: Insights from oxygen isotope sclerochronology

Vilde Melvik
Marine climate variability of the Irminger Current based on growth increments in the bivalve *Arctica islandica*: A molluscan sclerochronological approach

Alexandra Németh
Sclerochronological comparison of two dog cockle (*Glycymeris glycymeris L.*) populations from the southeastern North Atlantic

Richard Patton
The impacts of ocean acidification and increasing temperature on shell properties of intertidal bivalve molluscs

Michael Retelle
Mid and Late Holocene marine paleoenvironmental reconstructions from Ingøya and Rolvsøya, northern Finnmark, Norway

Alejandro Román González
Advances in developing Antarctic sclerochronogical archives from the marine bivalve *Yoldia eightsi*

Bernd Schöne
The Mediterranean Sea during the Pleistocene - Bivalve shells and their potential to reconstruct decadal and seasonal climate signals of the past

Anna Sparrow
Tides & traditions: Insights into indigenous hunter-fisher-gatherer shellfishing with sclerochronology

Larry Taylor
Reconstruction of humpback whale migration via isotopic analysis of coronulid barnacle shells

Julien Thébault
Growth, longevity and stable isotope composition of European date mussels *Lithophaga lithophaga* from eastern Adriatic

Tamara Trofimova
Environmental variability revealed in sclerochronological records of *Arctica islandica* from the northern North Sea

Alan Wanamaker
Highly dynamic marine radiocarbon reservoir effect in the Gulf of Maine since AD 1685

Jacob Warner
Assessing seasonal variability and archaeological season of harvest in North-Central coastal Peru using the short-Lived bivalves *Donax obesulus* and *Mesodesma donacium*

Siobhan Williams
Comparing climate signals obtained from encrusting and free-living southwest Greenland coralline algae

Rob Witbaard
Seasonal timing of shell and tissue growth in *Arctica islandica*

Christiane Yeman
Continuous ^{14}C analysis of marine carbonates by laser ablation coupled with AMS

Liqiang Zhao
Effects of calcium availability on shell growth rate and element composition of *Corbicula fluminea* (*Bivalvia*)

Keynote Biographies and Abstracts

Congress Street, Arts District
Portland, Maine, USA

Session 1. Proxy Development: Problems and Opportunities

Jochen Halfar

Dept. of Chemical and Physical Sciences, University of Toronto, Mississauga, ON, Canada

Biography:
Dr. Jochen Halfar is an Associate Professor and Associate Chair in the Department of Chemical and Physical Sciences at the University of Toronto Mississauga (Canada). Dr. Halfar holds a B.S. in Geology and Paleontology from the University of Heidelberg (Germany) and a M.S. in Geology from the University of Göttingen (Germany). He obtained a PhD. in Geological and Environmental Sciences from Stanford University (USA). Dr. Halfar's research is focused on deciphering paleoclimates on different time scales ranging from the past centuries to the Neogene using geochemical, sedimentological, and oceanographic approaches. His recent work includes developing proxy records from information contained in calcified growth bands of long-lived coralline red algae to reconstruct sea surface temperatures of extratropical seas using state-of-the-art microanalytical geochemical techniques.

Abstract: Coralline algal paleoclimatology – A review of current status and challenges
Coralline algae are a globally distributed group of shallow marine benthic calcifiers that can form annual growth increments in a high-Mg calcite skeleton. Over the past 15 years a number of both free-living and encrusting coralline algal genera have been tested for their suitability as climate recorders and to date several multicentury long reconstructions of ocean climate have been generated. Coralline algal proxy studies span regions ranging from the tropics to arctic latitudes, with most studies focussing on mid- and high-latitude regions of the Northern Hemisphere. In high latitudes coralline algae are considered to be the single most abundant shallow benthic marine calcifier, sometimes covering up to 100% of the seafloor in the shallow photic zone. Proxy studies include both free-living rhodolith nodules and attached crusts forming build-ups on hard substrate. Environmental interpretation of rhodoliths, which are generally found on soft-substrate seafloor, is complicated by the fact that rhodoliths are overturned at infrequent intervals by water movement and benthic organisms, with opposite nodule sides receiving contrasting light conditions at any given time. This severely limits proxy reconstructions, since skeletal growth and trace element incorporation of the photosynthetic coralline algae is primarily controlled by light and temperature variability. In contrast, crusts of the massive growing coralline alga *Clathromorphum* sp., that forms abundant build-ups throughout the Subarctic and Arctic including regions seasonally covered by sea ice, remain in a fixed position throughout their up to 650 year long lifespan, while faithfully recording environmental conditions. With an absence of an ontogenetic growth decline and annual growth rates varying between 80-400 µm as a function of temperature and light variability, seasonal to annual resolution proxy reconstructions have been possible in regions as far as 73°N. To date, *Clathromorphum* sp. has yielded interpretations of past ocean temperature, cloud cover, freshwater influx, ocean pH and sea-ice conditions. The latter application is currently the focus of intense research, since the Arctic-wide occurring *Clathromorphum* is the only annual resolution marine sea ice proxy available to date. However, our understanding of *Clathromorphum* proxy recording has been hampered by an inability to achieve representative algal growth in controlled mesocosm experiments. Those experiments were designed to gain a better understanding of the relative influence of temperature and light on the photosynthetic proxy, evaluate interspecimen variability as well as to shed light onto calcification mechanisms, which to date are poorly understood. In addition to ongoing efforts of proxy calibration, basic questions such as distribution and occurrence of *Clathromorphum* buildups suitable for sclerochronological work are being addressed by upcoming expeditions to the core Arctic.

Session 2. Scleroarchaeology

Marcello Mannino
Dept. of Archaeology, School of Culture and Society, Aarhus University, Højbjerg, Denmark; Dept. of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany

Biography:
Dr. Marcello Mannino is an Associate Professor in the Department of Archaeology at Aarhus University (Denmark) and an Associate Scientist with the Department of Human Evolution at the Max Planck Institute for Evolutionary Anthropology (Germany). He holds a B.S. with Honors in Archaeology and obtained a PhD. in Archaeology from the University of London (United Kingdom). Dr. Mannino's research interests include human palaeoecology and the reconstruction of past environments, subsistence, diet, and mobility. He is currently investigating human dietary change from the late Middle Palaeolithic, through the Upper Palaeolithic, and to the early Neolithic by means of stable isotope analyses on skeletal remains of Neanderthals and Modern Humans

Abstract: The challenges of a high-resolution archaeology: sclerochronological and isotopic approaches in perspective
The palimpsest nature of archaeological deposits and their often coarse temporal resolution (e.g. in the order of decades, centuries or millennia) allow us to study phenomena and processes at broad scales of observation, which is useful to evaluate culture change over long periods of time. Sites, however, are also repositories of organic remains of past human actions, which constitute archives of past climates and environments inadvertently preserved for us by their occupants. Sclerochronology and isotope analyses on incremental skeletal structures, such as those of molluscan shells, offer us the possibility of attaining high-resolution environmental and archaeological data, on yearly, seasonal, monthly, weekly or even daily scales. High-resolution data is essential to assess whether, or in what way, changes in human behavior may have been linked to climate or changing environments, given that it is to short-term changes that humans would have adapted to. This lecture addresses how this is currently achieved by sclero-archaeology, as well as what methods and themes of inquiry should be developed in the future.

An immediate strategic goal is to establish as palaeo-seasonality proxies all mollusc taxa which are archaeologically common, by studying their living counterparts. These developments should not only be aimed at reconstructing season of mollusc collection, as is usually done, but at using shells as climatic and environmental records relevant for understanding past human behavior. Methodological progress should be made to improve radiocarbon dating projects based on shells and to expand the range of sclero-archaeological applications to provenancing shell artefacts. In fact, despite the fact that shell ornaments are proxies of past symbolism, languages or exchange networks, very little effort has been devoted to unravel the life histories of these shell artefacts, thereby limiting their potential as invaluable proxies of human behavior.

The rewards for embarking on targeted sclerochronological and isotopic studies of shells from a variety of archaeological periods and cultures are there for the taking. If similar strategies are pursued, high-resolution research may allow us to tackle the 'grand challenges for archaeology' (Kintigh et al. 2014) and contribute to our understanding of how people in the past responded to abrupt environmental change over the short term.

Session 3. Growth and Bioenergetics

Brian Helmuth

Department of Marine and Environmental Sciences, Northeastern University, Boston, MA, USA

Biography:
Dr. Brian Helmuth is a Professor of Marine and Environmental Sciences at Northeastern University in Boston, Massachusetts. He holds a B.S. in Biology from Cornell University and obtained an M.S. in Biology at Northeastern University. He earned a Ph.D. in Zoology from the University of Washington. Dr. Helmuth's research explores the effects of climate and climate change on the physiology and ecology of marine organisms. He uses thermal engineering techniques, including a combination of fieldwork, remote sensing and mathematical modeling, to explore the ways in which the environment determines the body temperatures of coastal marine animals such as mussels and seastars. His students study a wide range of topics and organisms, and in recent years the emphasis of his lab has shifted to include a large focus on the development of educational tools such as virtual reality environments and serious games to engage K-12 students and the general public in marine biology.

Abstract: It's not all death and destruction: Thermal performance, energetics and the key role of monitoring growth responses to global climate change
By definition, global climate change is affecting organisms and ecosystems worldwide, but these impacts often play out at incredibly local scales. For example, the ability of organisms to use microclimates can lead to differences in environmental stress over the scale of tens of cm that can exceed much larger-scale patterns observed over tens of degrees of latitude. An increasing number of studies are showing that rather than conforming to simple latitudinal gradients, many species live along what may best be considered as geographic mosaics of environmental stress. Moreover, non-climatic and climatic stressors do not always conform to the same geographic patterns, so that exposure to multiple stressors can be highly complex. Forecasting the likelihood of future responses to environmental change therefore requires not only that we understand the complicated ways in which multiple stressors affect organisms to create "winners" and "losers," but also that we gain a better understanding of how the temporal and spatial coincidence of these stressors will occur in nature. Energetics modeling provides an effective means of integrating the consequences of multiple stressors to organismal physiology. A primary finding of many of these studies is that the first observable impacts of climate change are not simply the result of rare but lethal extreme events, but also the cumulative effects of more chronic levels of stress on patterns of growth, reproduction and fitness. The production of hindcasting and nowcasting models of nonlethal responses to environmental change based on first principles, which can then be validated using cutting-edge sclerochronology methods in animals such as bivalves, offers new opportunities for interdisciplinary collaboration that will likely provide critical insights into climate change ecology.

Session 4. Deep-time Evolution and Ecology

Seth Finnegan

Department of Integrative Biology, University of California, Berkeley, CA, USA

Biography:

Dr. Seth Finnegan is an Assistant Professor of Integrative Biology at the University of California, Berkeley. He holds a B.S. from the University of Chicago and obtained an M.S. and Ph.D. in Geological Sciences from the University of California, Riverside. Dr. Finnegan's research integrates data from a variety of sources including field observations, lab work, and literature databases to study the nature of organism-environment interactions through time. He investigates patterns of extinction selectivity, environmental proxies, and methods to reconstruct the structure and function of marine ecosystems through time, with a recent focus on the Ordovician Period (488 to 444 million years ago).

Abstract: Paleobiology needs your help

The Phanerozoic marine fossil record presents many striking patterns that remain poorly understood despite decades of study. Many long-term macroevolutionary and paleoecological trends are thought to have been driven by organism-environment interactions, but understanding of these trends is hampered by lack of information about both the environments in which early animals evolved and the metabolisms of these animals. Because they focus on the intersection of organismal growth and environment, sclerochronological studies have enormous potential to bring clarity to these and other paleobiological controversies. My agenda in attending this meeting is, first, to learn from the sclerochronology community, and second, to bring some outstanding problems to your attention. I will focus on two broad problems, though there are many other areas in which sclerochronological studies can contribute to our understanding of deep-time paleobiological patterns. Our knowledge of deep-time climate changes comes primarily from the oxygen isotope record ($\delta^{18}O$) of biogenic carbonates and phosphates. Classic studies by Veizer and colleagues established that the average preserved $\delta^{18}O$ values of tropical-subtropical shallow-water calcifiers rose by ~6‰ from the Cambrian to the present. Taken as a record of sea surface temperatures this implies that early animals routinely survived temperatures in excess of 50˚C. Alternative interpretations include pervasive diagenetic alteration of ancient fossils and progressive $\delta^{18}O$ enrichment of the marine oxygen reservoir through time. The latter model is not supported by recent clumped isotope studies, but these studies themselves suffer from necessarily coarse sampling and consequent inability to resolve signals in single growth increments. Determining the proper interpretation of the Phanerozoic $\delta^{18}O$ trend is of first-order importance for understanding the nature of the environments in which early animals arose and evolved, and sclerochronology can play a critical role in resolving this debate. The mean body size of fossilized marine animals has also increased through the Phanerozoic. Along with concomitant increases in motility, proportion of predators, and the composition of primary producer communities this has been taken as evidence that mean per-capita metabolic rates have increased. On shorter timescales, many lineages exhibit reduced size in the aftermath of major mass extinction events. Changes in mean size can result from changes in lifespan or in growth rate, and these have quite different implications regarding the process(es) driving evolutionary trends. However, little is known about growth rates or lifespans in the great majority of extinct clades. Even in modern calcifying groups, comparatively little is known about the controls on growth rate: are growth rates more strongly determined by extrinsic environmental conditions such as temperature and productivity or by intrinsic aspects of physiology that may be conserved across broad phylogenetic groups? Such uncertainties hamper efforts to reconstruct ancient ecosystems and to understand the environmental drivers of macroevolutionary trends. Sclerochronologists have developed a mature set of tools that, carefully applied, can shed considerable light on the evolution of marine ecosystems through time.

Session 5. Climate and Oceans: Past and Present

Dr. Kim Cobb

School of Earth and Climate Sciences, Georgia Institute of Technology, Atlanta, GA, USA

Biography:
Dr. Kim Cobb's research uses corals and cave stalagmites to probe the mechanisms of past, present, and future climate change. She received her B.A. from Yale University in 1996, and her Ph.D. in Oceanography from the Scripps Institute of Oceanography in 2002. She spent two years at Caltech in the Department of Geological and Planetary Sciences before joining the faculty at Georgia Tech in 2004. Dr. Cobb has sailed on oceanographic cruises to the deep tropics and led caving expeditions to the rainforests of Borneo in support of her research. Dr. Cobb has received numerous awards for her research, most notably a NSF CAREER Award in 2007, and a Presidential Early Career Award for Scientists and Engineers in 2008. She is an Editor for Geophysical Research Letters, and sits on the international CLIVAR Pacific Panel, and the Advisory Council for the AAAS Leshner Institute for Public Engagement. As a mother to four, Dr. Cobb is a strong advocate for women in science. She is also devoted to the clear and frequent communication of climate change to the public through speaking engagements and social media.

Session 6. Environmental Monitoring and Conservation Paleobiology

Dr. Greg Dietl

Paleontological Research Institution, Ithaca, NY, USA

Biography:
Dr. Gregory P. Dietl is Curator of Cenozoic Invertebrates at the Paleontological Research Institution (PRI) and an Atkinson Center for a Sustainable Future Faculty Fellow at Cornell University in Ithaca, New York. Prior to coming to PRI and Cornell, he was a Gaylord Donnelley Environmental Fellow at Yale University. His innovative and cross-disciplinary research in ecology, paleontology, and conservation biology has been published in the leading peer-reviewed journals in science and environmental studies, as well as in popular magazines. His current research emphasis centers on efforts in the emerging field of conservation paleobiology, which applies paleontological data, theories and methods to understand and solve conservation problems.

Abstract: Conservation biology meets sclerochronology
Conservation paleobiology is a rapidly expanding discipline of conservation science that applies the theories and analytical tools of paleontology to conserve and restore biodiversity and ecosystem services. Sclerochronological records archived in the skeletal remains of organisms with accretionary growth are currently underutilized in the field. In this presentation I will focus on selected case studies that highlight the potential of sclerochronological records to give voice to a variety of past signals of change, which are as relevant to the many concerns, needs, and goals of conservation biology today as they are in navigating an uncertain, rapidly changing future. My overall goal is to raise awareness of the many opportunities that exist for closer collaboration between sclerochronologists and conservation paleobiologists. I will also offer practical advice to those wishing to develop conservation-relevant sclerochronological science.

Session 7. Fisheries Ecology and Management

Dr. John Morrongiello

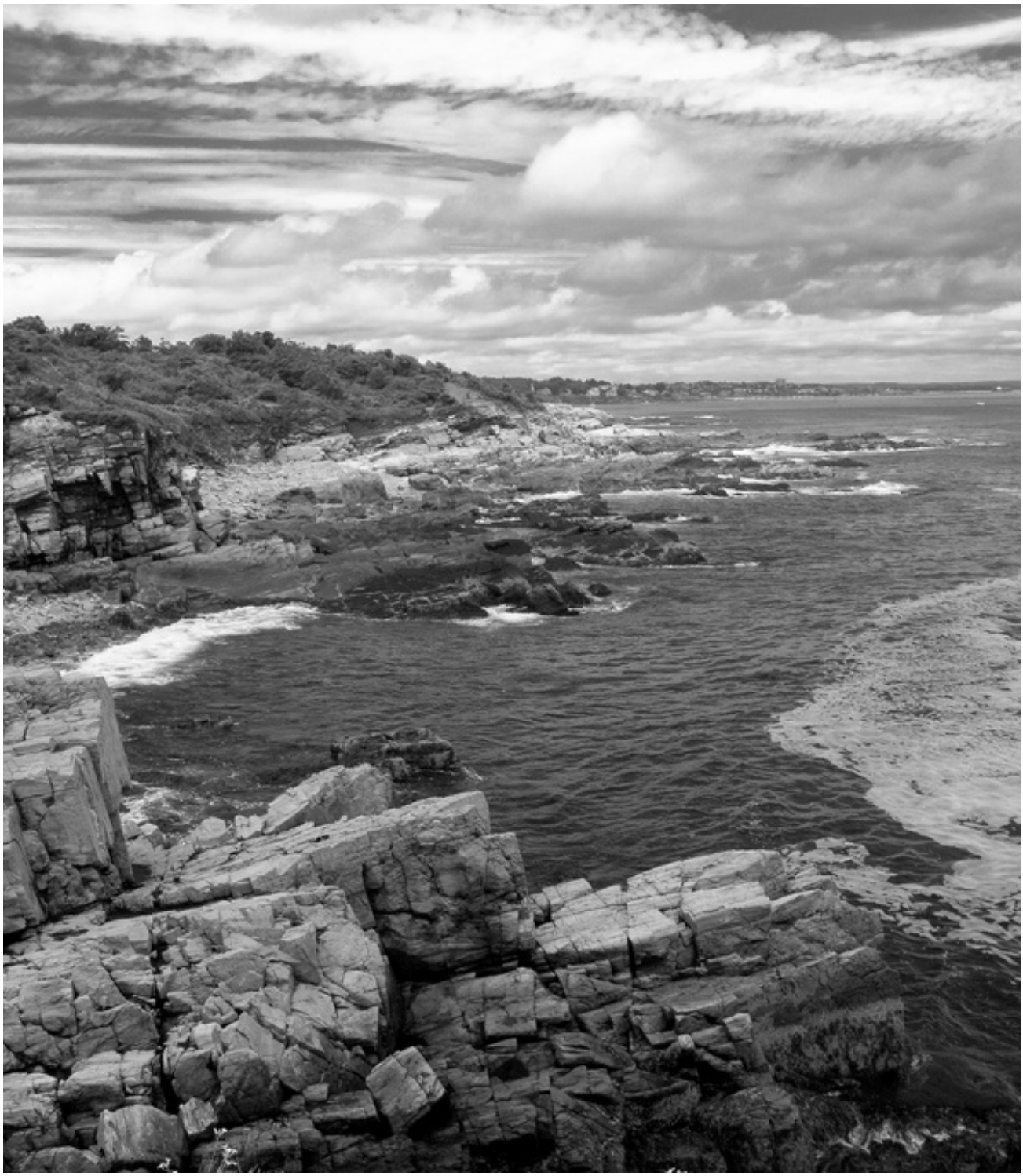
School of BioSciences, University of Melbourne, Melbourne, VIC, Australia

Biography:
Dr. John Morrongiello is a Lecturer in the School of BioSciences at the University of Melbourne (Australia). He holds a B.A./B.S. with Honors in Marine Ecology and Physical Geography from the University of Melbourne and obtained a Ph.D. in Zoology and Animal Biology at Monash University (Australia). After his PhD, Dr. Morrongiello completed a post-doc with CSIRO in Hobart, Australia where he worked with Dr Ron Thresher exploring the impacts of climate change and fisheries on marine productivity using otolith-based growth histories. Following this, he briefly worked as research scientist in freshwater ecology with the Victorian State Government before commencing his lectureship at Melbourne. Dr. Morrongiello works in marine and freshwater systems investigating how aquatic organisms, primarily fish, respond to environmental change on contemporary and evolutionary time scales using field-based and experimental techniques. He is also interested in the impacts of, and adaptations to, natural and human-induced flow variability, fishery activity, and climate change. He has an active research interest in the development of statistical methods and interpretation of data from biological hard-parts, primarily otoliths. Dr. Morrongiello uses this insight to provide a valuable long-term perspective to the causes and consequences of biological change in aquatic environments, ranging from individuals to assemblages.

Abstract: Otoliths: From individuals to assemblages in a changing world
Growth is a fundamental biological process, driven by a multitude of intrinsic (within-individual) and extrinsic (environmental) factors, which underpins individual fitness, population demographics, and assemblage productivity. Growth is not only responsive to ecological factors such as resource availability and environmental conditions, but is also a trait under contemporary evolutionary selection. Fish growth is therefore an ideal metric with which to study the impacts of natural and anthropogenic environmental change across all levels of biological organisation.

Otoliths provide fish ecologists and fisheries managers with an enviable source of biological data. Whilst we have long taken advantage of the periodically formed increments within otoliths to provide an estimate of fish age that can be readily used in stock assessment models, it is only more recently that we have begun to interpret the growth information that these increments represent. These aquatic biochronologies have enabled researchers to ask questions at daily to centennial time scales, in lakes to reefs to across large marine ecosystems, providing valuable ecological insight to fisheries ecology and management.

Here, I will discuss my recent work investigating the eco-evolutionary drivers of fish growth using information naturally archived in otoliths. I will highlight how this data can be used to explore a hierarchy of growth variation, ranging from within- and among-individual responses to temperature and fishing selectivity, to species-wide and assemblage-level assessments of fisheries, climatic, and oceanographic impacts. I will also present examples of how age information can readily be used to recreate recruitment indices and in data poor fisheries. Throughout, I will make reference to statistical models that facilitate the extraction and interpretation of biological insight from hardparts. I will finish by exploring exciting opportunities for the use of otolith-derived growth information, including the estimation of age at maturity and the development of improved predictions of fisheries productivity. Otoliths have, and will continue to play, a vital role in furthering our ecological and evolutionary understanding of aquatic systems, and thus the management of our marine and freshwater resources.



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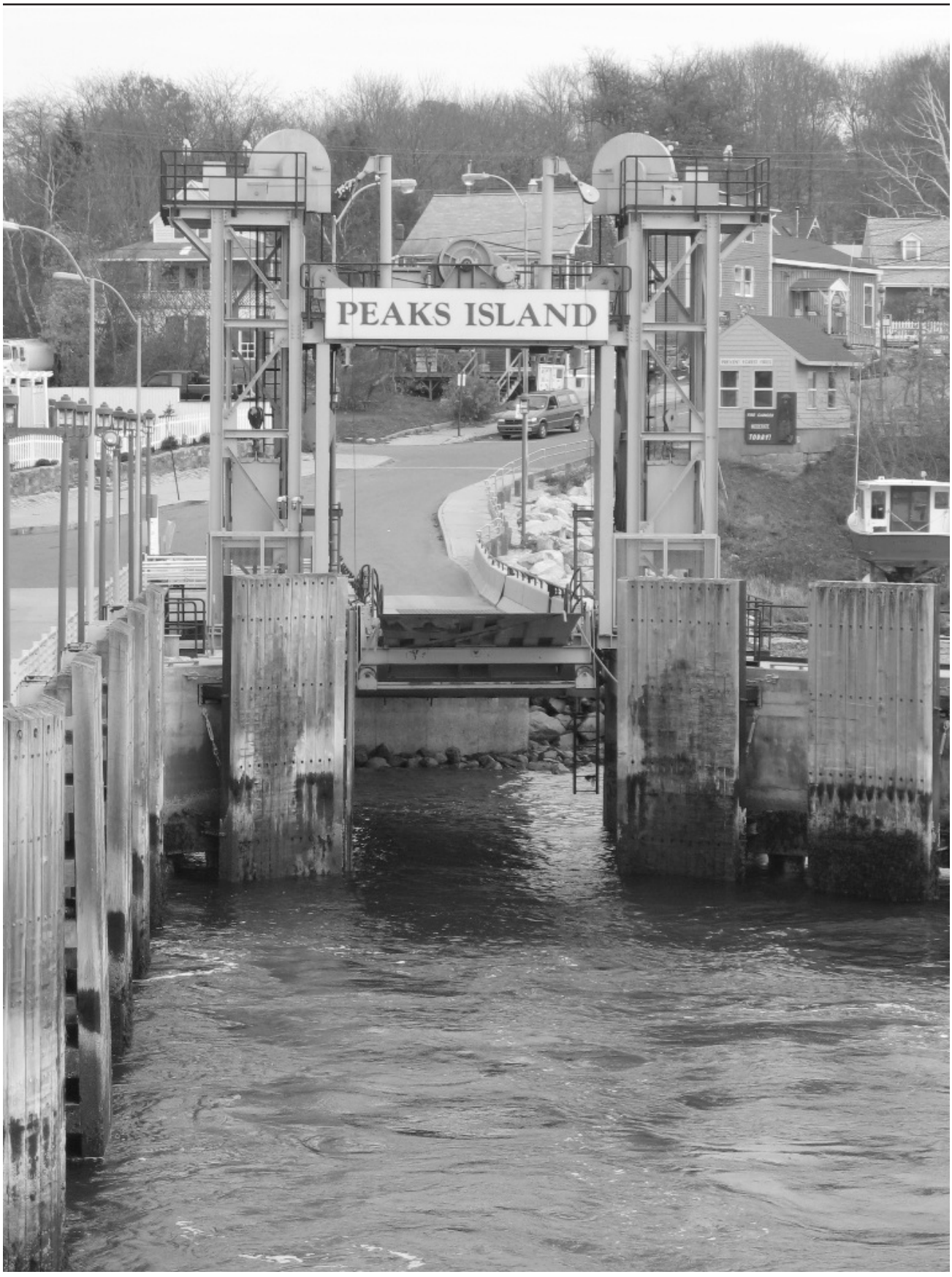
Abstracts



Peaks Island, Maine, USA

Reconstructing Holocene temporal hydrographic variability in Scottish Shelf Seas using dog cockle shells *(Glycymeris glycymeris)*

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The long-lived (>190 years) bivalve *Glycymeris glycymeris* is an annually resolved palaeoclimate archive for the eastern North Atlantic and adjacent shelf seas. *G. glycymeris* sclerochronologies have already been published for the Inner Hebrides, Scotland, and the Irish Sea, as well as other areas. The aim of this study is to detect a signal of Atlantic hydrographic variability in Scottish Shelf Seas that is as far as possible uncontaminated by other influences. In May 2014, we collected dead valves and young live specimens of *G. glycymeris* from St Kilda, Outer Hebrides, Scotland. This area is of particular interest as it is close to the Scottish shelf margin, has negligible freshwater input and is thought to represent open-ocean North Atlantic signals well. We here present two floating chronologies, each spanning >200 years, built from dead-collected *G. glycymeris* shells from St. Kilda. All the shells in these chronologies were assigned radiocarbon ages between 3700-3300 cal yr BP. The radiocarbon ages confirm our findings by grouping the shells into two distinct age bands consistent with our two floating chronologies. This archive provides the potential to compare hydrographic conditions between the present and earlier in the Holocene. We present sub-annual $\delta^{18}O$ data of these floating chronologies as well as of modern specimens from St. Kilda and instrumental data to compare changes in mean state and seasonality between the present and the fourth millennium BP.

Archaeological applications of molluscan nitrogen isotope analyses

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Measurements of nitrogen isotopes ($\delta^{15}N$) in the organic fraction of mollusk shells are increasingly used to assess temporal change in ecosystems related to anthropogenic impacts. The relative durability of molluscan organic matter preserved in archaeological middens permits analysis of $\delta^{15}N$ over longer time periods, however applications have been few. In part this is due to uncertainty concerning the effects of diagenesis and/or cooking on shell organic matrices and their nitrogen isotope records. Perhaps more significantly however, archaeologists are not familiar with this new tool, therefore its application to anthropologically-relevant questions have not been extensively explored. This presentation will describe the current state of knowledge regarding the impact of cooking and post-depositional processes on shell $\delta^{15}N$ records and describe some key questions that remain. Additionally, published and new $\delta^{15}N$ data measured in modern and ancient shells of eastern oysters (*Crassostrea virginica*) and quohog clams (*Mercenaria spp.*) will be compared between environments with different natural and human histories. These environments will range from the densely populated upper Chesapeake Bay region to the less developed northern Gulf of Mexico estuaries, and span the past 3000 years or more. Additionally, the potential utility of long-lived Unionid mussels as archives of $\delta^{15}N$ data in differing freshwater habitats will be compared to determine the likelihood of reconstructing anthropogenic impacts near interior archaeological sites. These data collectively suggest that even though shell organic material may be lost rapidly after deposition, the human impact to nitrogen loading in coastal ecosystems was detectable as early as pre-industrial historical time periods in some locales. This method may be developed to become a useful tool to aid understanding human population dynamics and economic activity over time.

Environmental factors driving the valve gape activity of the bivalve *Arctica islandica* in Northern Norway

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The bivalve *Arctica islandica* (Linnaeus 1767), also known as the ocean quahog, is the longest-lived non-colonial animal known at present. It inhabits coastal waters in the North Atlantic and its annual shell increments are widely used for paleoclimatic reconstructions. However, there is no consensus about the intra-annual timing of growth and length of the period over which growth increment formation takes place. Our research aims to identify the main environmental drivers of *A. islandica* activity patterns, in order to clarify the ambiguity surrounding its growth and to understand the seasonality of signals enclosed within the carbonate shell. A lander was deployed on the sea bottom at Ingøya in Northern Norway containing 16 living *Arctica islandica* specimens in individual containers. Each individual was wired with an electrode unit that measured gaping activity (distance between electrodes mounted on both valves) every minute. The lander was also equipped with instruments to simultaneously monitor environmental conditions (Temperature, Salinity, Chlorophyll-a, Turbidity, and Light conditions) and coincident with the valve gape activity. The seasonal activity of these bivalves were examined between February 2014 and September 2015. There were clear seasonal patterns of valve gape activity, with average values from 0.2 to 0.8. The population was inactive between October and January (valve gape <0.2). The main driver of this population activity appeared to be food availability (measured as Chlorophyll-a). This experimental setup provided insight into the variability of *A. islandica* activity patterns between individuals and over the seasons, key factors for paleoclimatic reconstructions.

Development of a species-specific oxygen isotope transfer function for *Arctica islandica* shells: Insights from a temperature experiment

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The geochemistry of aragonite shells of *Arctica islandica*, a long-lived marine bivalve native to the North Atlantic, is widely used as a proxy to reconstruct past marine conditions. Specifically, the oxygen isotope ($\delta^{18}O$) composition of the shell can be used to estimate hydrographic conditions, however like all biocarbonates the $\delta^{18}O$ of shell material is influenced by seawater temperature and the isotopic composition of seawater ($\delta^{18}O_{water}$ - related to salinity). Although several paleotemperature transfer functions have been developed for aragonitic taxa (e.g., Grossman and Ku, 1986), some of these functions have somewhat large errors (> ± 1 °C) and there can be fairly large differences in predicted temperatures (with identical shell and water isotope values) among these different paleotemperature equations. Despite its paleoceanographic potential, to date no species-specific transfer function has been developed to translate the $\delta^{18}O$ of the shell material to seawater temperature for *A. islandica*. In this study, we sought to develop a species-specific transfer function for *A. islandica*, which may potentially reduce the errors associated with seawater temperature reconstructions, and to further evaluate if the shells grew in oxygen isotopic equilibrium with ambient seawater. A total of 30 juvenile *A. islandica* clams (~3 yr. old; average shell height of 40 mm) were grown under temperature-controlled conditions during a 16-week period from March 27 to July 21, 2011. Seawater from the Darling Marine Center in Walpole, Maine, USA was pumped into temperature and flow controlled tanks that were exposed to ambient food and salinity conditions. Clams were grown at 10.3 ± 0.3 °C for six weeks and then at 15.0 ± 0.4 °C for an additional 9.5 weeks. Prior to the experiment, the clams were stained with calcein (a commonly used biomarker) and again when the temperature was changed from 10 to 15 °C. Salinity was monitored hourly, with average salinity values of 30.2 ± 0.7 and 30.7 ±0.7 for the first and second phases of the experiment, respectively. Water samples were taken approximately every two weeks to establish the $\delta^{18}O$ values of seawater. The average shell growth during the first phase of the experiment was 2.4 mm with a linear extension rate of 0.40 mm/week. The average shell growth during the second phase of the experiment was 3.2 mm with an extension rate of 0.34 mm/week. After the culture period, shell samples from the distinct temperature regimes were micromilled and measured for $\delta^{18}O$. A previously developed salinity/oxygen isotope mixing line was used to model daily $\delta^{18}O$ values of the seawater, and verified with actual seawater samples. Considering analytical and instrumental uncertainties, preliminary results suggest that *A. islandica* precipitates its aragonitic shell in oxygen isotopic equilibrium seawater. Additional shell material, including adult individuals, will be analyzed in the near future to refine this preliminary paleotemperature transfer function for *A. islandica*.

Clams and climate: Implications for reconstructing paleoseasonality in southern Alaska

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The archaeological record reflects fluctuating marine conditions from the Aleutian Islands to the Northwest Coast of North America during the Late Holocene. Though not widely tested, recent research suggests that conditions may have cooled enough during the Late Holocene to allow seasonal ice to accumulate as far south as Aleutian Islands. Zooarchaeological analysis supporting this claim relies on the presence of pagophylic mammalian remains in archaeological sites from Unalaska Island. However, disentangling behavioral changes from humans and the animals they hunt proves difficult in this case. Sclerochronological analysis of biogenic carbonates can provide additional paleoenvironmental information. Oxygen isotope analysis of bivalve shell yields information on the temperature of the water in which the organism grew. However, in coastal environments, variations in $\delta^{18}O$ of water may complicate the interpretation of shell isotope profiles. Measuring and comparing the length of seasonal shell growth in select species of bivalves may complement isotopic analysis, together providing a more precise paleoclimate reconstruction. This research utilizes the regular growth of Saxidomus gigantea, abundant both on modern and ancient coastlines, to provide information about the length of its growing season, which is temperature dependent. Modern samples of *S. gigantea* were collected from Alaska (n=20) and British Columbia (n=10) and the length of their respective growing seasons were measured by counting the number of lunar-daily growth increments (LDGI) imaged on acetate peels between consecutive isotopically identified periods of winter growth may indicate changes in seasonality in *S. gigantea.* Shells collected from Alaska exhibited shorter growing seasons than those collected in British Columbia. This method was then applied to five *S. gigantea* shells from four archaeological sites, Karluk (n=2) Rice Ridge (n=1), Settlement Point (n=1), and Uyak (n=1), to determine if the same methods are applicable to ancient shells. Preliminary results indicate that this method does work on ancient shells. Future analysis may potentially provide reconstructions of changes in seasonality in ancient shells abundant throughout Alaska's archaeological record and consequently confirm or refute findings from previous faunal analysis on Unalaska.

Crossdating and preservation of signal strength in growth-increment chronologies

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Proxies from the hard parts of fish, bivalves, corals, and trees are critical to establishing climate-growth relationships, identify linkages within and across ecosystems, reconstruct climate, and estimate population age structures. However, dating controls are necessary to ensure temporal precision and accuracy; simple counts cannot ensure that all layers are placed correctly in time. Originally developed for tree-ring data, crossdating is the only such procedure that ensures all increments have been assigned the correct calendar year of formation. In a simulation exercise, growth-increment data from two tree species, two marine bivalve species, and a marine fish species are used to illustrate sensitivity of environmental signals to modest dating error rates. When falsely added or missed increments are induced at one and five percent rates, errors propagate back through time and eliminate high-frequency variability, climate signals, and evidence of extreme events while incorrectly dating and distorting major disturbances or other low-frequency processes. These consecutive Monte Carlo experiments show that inaccuracies begin to accumulate in as little as two decades, though consequences may be even greater in real-world scenarios. We stress that, wherever possible, the fundamental tenets of crossdating must be applied to fully resolve environmental signals. Situations in which crossdating may not be readily applied are also addressed, as could be the case in sample sets with extremely low levels of interannual growth variability, limited sample replication, or short-lived species.

A 388-year *Arctica islandica* shell-based chronology from the Faroese Shelf: Implications for a better understanding of the natural climate variability of the Faroe Current

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In this study we aim to investigate the natural marine climate variability of the Faroe Current by building and analyzing a multi-centennial chronology from shells of the bivalve species *Arctica islandica* from the Faroese Shelf. The Faroe Current is one of the main inflow branches of warmer water masses into Northern Europe and the Arctic and is therefore of great importance for the climate development in these regions. The area around the Faroe Islands is an excellent study area because it is located in the middle of the Faroe Current and terrestrial and coastal interference is small. Since the species *A. islandica* is forming annual growth increments, its shells provide information of climate conditions on an annual scale. Here we present the first multi-centennial absolutely dated chronology from the Faroese Shelf covering the time period from 2013 – 1625 and discuss its potential for providing a reliable annually resolved paleo record in the this area. The chronology derives from shell material from the eastern side of the Faroe Islands from around 100 meter water depth and consists of 4 live-collected, 12 articulate and 18 sub-fossil specimens. All specimens cross-match well and radiocarbon dating of the sub-fossil specimens confirms their place in the chronology. The good cross-matching shows that the specimens share a common signal of an external forcing and that molluscan sclerochronological studies can be applied on the Faroese Shelf. The standardized growth indices of the chronology moderately anti-correlate with April – August sea-surface and air temperatures from this area for the last 100 years that indicates favorable conditions for growth when temperatures are lower. A comparison of the standardized growth indices with primary productivity data from the Faroese Shelf shows a strong positive relationship meaning that higher primary productivity rates result in wider growth increments. Since the main primary production event takes place in spring and summer the main growing season in *A. islandica* shells from the Faroese Shelf most likely occurs during this time. This is supported by several $\delta^{18}O$ measurements from the growth increments of the years 2013 – 2001 as the $\delta^{18}O$-based temperature reconstructions from these growth increments correlate best with spring and summer sea surface temperatures. Moderate correlations between the standardized growth indices and multi-decadal oscillations such as NAO and AMO can also be found especially for the last 100 years. In conclusion, our results suggest that the growth increments in *A. islandica* from the Faroese Shelf reflect changes in primary productivity and temperatures and also that the shells capture long-term signals. Further, $\delta^{18}O$ measurements in the shells lead to robust results and can potentially be used for temperature reconstructions for time periods beyond instrumental observations. Thus our chronology has the potential to contribute to a better understanding of the natural climate variability of the Faroe Current.

Temperature reconstructions based on $\delta^{18}O$ measurements in bivalve shells from the Faroese Shelf

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[1]*Uni Research Climate, Bjerknes Centre for Climate Research, Bergen, Norway*

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Annually resolved temperature records before instrumental observations are scarce in the marine realm, especially at higher latitudes. The geochemical analysis of growth increments in bivalve shells have the potential to close this gap and to provide past sea-surface temperature reconstructions on an annual time scale. In this study, we investigate the oxygen isotopic composition in annually-formed growth increments in the bivalve species *Arctica islandica* and apply $\delta^{18}O$-based paleo-thermometry. The analyzed shell material was collected east of the Faroe Islands from water depths of around 100m in 2014. The samples for the $\delta^{18}O$ analysis were extracted from 2 live-collected shells by micro-drilling. Depending on the size of the growth increment, between 4 and 10 samples were collected from every growth increment from 2002 – 2013. The reconstructed temperatures based on the $\delta^{18}O$ values range from about 6°C to 10°C in a single growth increment with lower temperatures at the beginning of the growth increment and higher temperatures towards the end of the growth increment. This indicates that a seasonal temperature signal is preserved in the $\delta^{18}O$ composition of the growth increments. Further, the reconstructed temperatures correlate best with observed sea-surface temperatures from around April to July. This is in agreement with the main growing season of phytoplankton on the Faroese Shelf and suggests elevated primary productivity to be one of the most important driving factors for the shell growth in *A. islandica*. The analysis of $\delta^{18}O$ values in the growth increments and the comparison with instrumental temperature data show that the bivalve species *A. islandica* captures the spring/summer temperature signal in its oxygen isotopic composition and has the potential to be used for time periods prior instrumental observations.

Isotope sclerochronology and hunter-gatherer seasonality: Archaeological landscapes from the Pacific and Atlantic coasts of Canada

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Stable oxygen isotope ($\delta^{18}O$) analysis of shell has been a component of understanding seasonal patterns of hunter-gatherer shellfish harvesting for almost 40 years, but only recently have archaeologists begun to use more sophisticated methods to derive seasonality estimates. The integration of high-resolution $\delta^{18}O_{shell}$ data with macro-growth features and fortnightly/lunar daily growth increments (F/LDGI) permits a precise seasonality estimate that can control for the opposing effects of temperature and salinity. This is critical for shell seasonality estimates from archaeological sites, since the majority of archaeological sites are in close proximity to seasonal freshwater sources that contribute to sub-annual fluctuations in temperature salinity.

This paper explores three case studies in Canadian archaeology from the Pacific and Atlantic coasts of Canada from ~4000 years BP to the 18th century with an emphasis on coastal British Columbia, Nova Scotia and Newfoundland. We argue that the analytical scale used to derive $\delta^{18}O_{shell}$ must ensure the precision of the seasonality estimate, while also considering the cultural, historical and temporal contingencies that shaped hunter-fisher-gatherer landscapes. In all three studies, both live-collected and archaeological specimens were micro-milled in 100-micron steps at the ventral margin to obtain $\delta^{18}O$shell values that were aligned to either F/LDGI or macro-growth structures. The study of *Saxidomus gigantea* from British Columbia provides an exemplary model of a regional and temporal scale study in seasonality through the alignment of F/LDGI with $\delta^{18}O_{shell}$ from 139 individual shells from nine shell midden sites. These sites, consisting of camps, villages and specialized shellfish camps are located in the traditional territory of the Heiltsuk First Nation, spanning over 4000 years. Moving east, *Mya arenaria* from Nova Scotia were analyzed from two sites in the traditional territory of the Mi'kmaq, dating from 1500 - 400 years BP. From Newfoundland, the analysis of *Mytilus edulis* from a 16th - 18th century Inuit winter sod house informed the interpretation of the seasonal range of landscape use. Coincidentally, in all three studies, the seasonal emphasis on shellfish harvesting falls in the spring and autumn. While understanding the spectrum of seasonal subsistence and settlement activities of a site cannot be achieved from shell analysis alone, the incorporation of shell seasonality data challenges notions about site use, and contributes to a nuanced understanding of subsistence and settlement patterns. The three studies illustrate how the precision of high-resolution sampling for $\delta^{18}O$ is negotiated with the number of individual shell samples to develop meaningful interpretations of past landscape use, site function, and seasonal patterns of shellfish harvest while further understanding the role of shellfish in hunter-fisher-gatherer societies.

The regulatory context of the use of biochronologies for baseline environmental monitoring

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The commercial application of sclerochronological techniques to environmental monitoring is intimately related to the regulatory framework, since such monitoring does not in itself add economic value to the final product. In turn, approaches to environmental regulation assume or propose particular desirable states, in the past, present or future, that are to be sustained or targeted. The goal of marine environmental monitoring in the commercial sector is the assessment of the extent to which these states are achieved in the contexts of (i) the impact of individual marine infrastructure developments and (ii) the integrated impact of all human activity in the marine environment. The unique selling point of sclerochronology is its potential for the reconstruction of long baselines of environmental variables and hence for the ability to compare pre- and post-industrial conditions. However, the identification of indicators of the pre-industrial condition of the environment does not in itself define a "pristine" environment that can be targeted for the achievement of "good" environmental status (in the context of the European Union's Marine Strategy Framework Directive). More realistically, the definition of such a status will require the identification of some acceptable degree of variability in the ecosystem response. It is this degree of variability that can be assessed with the help of biochronologies drawn from multiple sources (eg bivalve molluscs, fish otoliths, corals). Here, we will discuss the regulatory frameworks in which marine biochronologies can function as environmental monitors, especially those contexts related to baseline environmental monitoring and the concept of good environmental status.

Shell growth and environmental control of methane-associated Thyasirid bivalves from Svalbard cold seeps

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The analysis of molluscan shell material (sclerochronology) can provide information about an organism's age, growth history, and environmental conditions during its lifetime. Bivalve molluscs are common members of hydrothermal vents and methane cold seeps communities where, supported by chemosynthetic symbionts, they can reach high density and biomass. But little is known about methane-associated bivalve populations inhabiting high Arctic cold seeps, and sclerochronological analysis of methane-influenced bivalves is rare. We measured growth rates and chemical and isotopic shell signatures in a newly discovered species of bivalve (*Thyasiridae*) from cold seeps at 350-390m depth southwest of Svalbard. First discovered in 2014, shells of *Thyasira capitanea* sp.nov. were found at 2 seep systems in Storfjordrenna. Mean shell carbon isotopic ratios from inorganic $\delta^{13}C$ (-4.8‰) and organic $\delta^{13}C$ (-26.9‰) fractions indicate a methane influenced habitat and food source. Shell mineral ratios sampled along the axis of growth with laser-ablated ICP-MS exhibit variability through time and between sites, suggesting that concentrations of these elements that are affected by methane emissions. The mineralogical data also elucidates the internal pattern of shell deposition and growth checks, and combined with the isotopic and growth rate data, enables us to interpret the temporal history of methane release from these locations.

Recent decline in skeletal density and calcification rates of subarctic crustose coralline algae

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Warming surface ocean temperatures combined with the continued invasion of atmospheric CO_2 into seawater are increasing physiological stresses on calcareous marine organisms. Ocean acidification has been shown to have detrimental impacts on marine carbonate organisms in tropical and temperate localities. However, greater oceanic CO_2 uptake in higher latitudes suggests that calcareous organisms in the Arctic and Subarctic are even more susceptible to acidifying conditions than those residing in lower latitudes. This is especially true for coralline algae *Clathromorphum*, a dominant calcifier in Arctic/Subarctic hard-bottom communities that build their skeletons using high Mg-calcite, which is even more soluble than aragonite in corals. Here we present an annually-resolved growth, density, and calcification rate record from crustose coralline alga *Clathromorphum* collected from the Subarctic North Pacific, a region that has undergone a long-term decline of 0.08 ± 0.01 pH units since the late 19th century.

Coralline algal calcification rates display distinct multidecadal variability that is inversely related to the Arctic Oscillation Index (AO). Alternations between positive (negative) AO phases are closely linked with strengthening (weakening) of the Northern Hemisphere polar vortex, which regulates the frequency and intensity of storm events. During the positive AO phase, anomalously low pressure dominates the Polar regions, steering clouds and stormy weather northward. This induces wind mixing and upwelling, increasing surface water production (which intercepts solar insolation available for coralline algal photosynthesis), thereby resulting in reduced algal growth and calcification rates.

In contrast, while algal skeletal density also shows pronounced multidecadal variability, values have entered an unprecedented decline since 1980. The ecological benefits of sustained vertical growth in coralline algae may allow organisms to quickly heal and regenerate skeletal/thallus mass from damaging disturbance events such as wave action and herbivore grazing, both of which are common features of the Aleutian Island nearshore ecosystem. However, the metabolic trade-offs associated with maintaining algal calcification through continued growth may have translated into the production of weaker (less dense) skeletons resulting in a loss in structural integrity, and increasing susceptibility to erosional processes.

Diminishing algal density may also be associated to temperature stress resulting from increasing regional sea surface temperatures (SST) recorded in the Aleutian Island region. Regression analysis between algal density and Hadley Centre SST 1° x 1° reconstruction (HadISST) indicates a strong negative relationship, such that coralline algal skeletal density increases (decreases) with cooler (warmer) SST. While the exact mechanisms responsible for the here observed declines in algal growth parameters are uncertain, our study reveals that in addition to acidification, sunlight availability and temperature stress may also be factors that influence the ability of corallines to calcify.

Diet of fossil and modern bivalves and gastropods revealed by carbon and nitrogen isotopes of shell-associated organic matter

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The carbon and nitrogen isotopic compositions of an organism's tissues are representative of its diet (DeNiro and Epstein, 1978; DeNiro and Epstein, 1981). Hence, stable isotopic analysis has become a powerful tool to determine the diets of organisms with poorly understood ecologies (Peterson and Fry 1987; Hentschel 1998; Vander Zanden and Rasmussen 1999). This approach has been extended to the fossil record in a few cases (Ostrom et al., 1993), but the potential exists for a good deal more clarity on the diets of fossil animals and trophic relations among them. Preservation of organic matter from the extracellular matrix is possible in the shells of fossil mollusks, and this material can be used for stable isotopic analysis. Here we explore variation in the carbon and nitrogen isotopic composition of shell organic matter for several bivalve and gastropod taxa, both modern and fossil. Because organisms are known to change their feeding behavior over ontogeny, we will use sclerochronological techniques to assess both taxonomic and ontogenetic variation in the isotopic composition of shell organic matter. We test this approach on modern and Pliocene suspension-feeding bivalves and carnivorous gastropods. The techniques developed for these more recent materials will be applied to the reconstruction of ancient trophic strategies and ultimately food web reconstruction using specimens from the Late Cretaceous (Campanian/Maastrichtian) Lopez de Bertodano Formation exposed on the Antarctic Peninsula. Specimens were obtained from the Zinsmeister Collection housed at the Paleontological Research Institution in Ithaca, NY. The collection comprises of a broad group of near-shore organisms including bivalves, gastropods, ammonites, corals and calcareous worms, all co-occurring at one of several individual collection localities. The long-term goal of this project is to apply these techniques to examine how marine communities respond to significant environmental perturbations such as Oceanic Anoxic Events or the Paleocene-Eocene Thermal Maximum.

Salinity shifts in the southwest tropical Pacific from the Little Ice Age to the 20th century

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During the Little Ice Age, South Pacific SSTs were, on average, 1ºC colder than the 20th century with evidence of more saline surface waters in the southwest tropical Pacific from low-resolution coral $\delta^{18}O$ and Sr/Ca records. Here we present monthly-resolved coral $\delta^{18}O$ and Sr/Ca determinations from *Porites lutea* colonies offshore of Amédée Island, New Caledonia (22º28.8′S, 166º27.9′E) in the southwest tropical Pacific to investigate shifts in SST and sea surface salinity (SSS) from 1649 to 1999 CE. Coral Sr/Ca is a function of SST and coral $\delta^{18}O$ varies with SST and the $\delta^{18}O$ of seawater ($\delta^{18}O_{sw}$), which reflects changes in SSS, such that paired analysis of these two proxies allows us to quantify SSS shifts. Coral $\delta^{18}O$ variations from 1649 to 1900 CE contain interannual to bidecadal variations larger than those observed from 1900 to 1999 CE and in the coral Sr/Ca-SST reconstruction, suggesting large SSS shifts on those time scales. The coral Sr/Ca-SST reconstruction co-varies with the South Pacific Decadal Oscillation, for which SST anomalies in the southwest Pacific are linked to precipitation anomalies in the western equatorial Pacific. Furthermore, this decadal-scale SST variability changed in periodicity and strength before 1893 CE, suggesting a shift in natural SST variability for this location. Comparison of coral $\delta^{18}O$-SST and Sr/Ca-SST anomalies reveals a persistent +0.3‰ divergence in coral $\delta^{18}O$ or an ~0.8 psu shift to saltier SSS prior to ~1900 CE in which relatively ^{18}O-rich surface waters are present as the result of more evaporation than precipitation. The shift to saltier conditions coincides with the shift in coral Sr/Ca-SST decadal periodicity and strength suggesting a change in oceanic-atmospheric processes in the southwest tropical Pacific during the transition from the Little Ice Age to anthropogenic warming in the 20th century.

Save our Marine Annually Resolved Proxy Archives (MARPA)!

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Funding agencies, such as the National Science Foundation (NSF), require detailed Data Management Plans (DMP) for proposals that include plans for archiving data and physical samples yet there is no guidance on what is acceptable for a given community. Several groups are working on improving platforms for sharing data (NOAA Paleoclimate, Pangaea, EarthCube, and Linked Earth); however, no efforts are being made for curation of physical samples for our community. This is the time for the Sclerochronology community to join this initiative and to work on defining the standards needed for our field in order to curate physical samples, data derived from those physical samples, and metadata from both to promote the expansion of research while giving the original researchers credit and recognition for their work. Marine Annually Resolved Proxy Archives (MARPA) is a grass roots effort created under the EarthCube umbrella (http://earthcube.org) that is currently working on recommendations for physical samples to include in DMPs by identifying current resources that can be used by researchers.

There are several resources for curating physical samples currently in place that the MARPA working group reviewed. The System for Earth Sample Registration (SESAR; http://www.geosamples.org/) is a NSF-funded cyberinfrastructure that provides a registry for physical samples with their metadata. SESAR offers tools and services for users to manage their physical sample metadata and obtain International Geo Sample Numbers (IGSN; www.igsn.org) for citation of physical samples. The IGSN was developed by SESAR and has become an internationally recognized standard for sample identification. Several publishers, including AGU journals and Palaeogeography, Palaeoclimatology, Palaeoecology (Elsevier), are now requiring the use of IGSN in their publications. The MARPA working group is developing a web site (marpasite.wordpress.com/) with pertinent information for the community including a tutorial for entering physical sample metadata in SESAR, sample DMPs for proposals and grant reports, and our white paper reviewing of physical sample curation and geochemical data with recommendations. Additionally, we are seeking feedback on a template for data sharing for the sclerochronology community, likely in Excel format, complete with standardized vocabulary that could be stored locally offline with each researcher before submitting to a permanent repository (NOAA Paleoclimate and/or Pangaea). This effort will help the Sclerochronology community share their data with the wider community for data synthesis projects, such as Oceans2K and Iso2K, while receiving credit for their work.

Conservation paleobiology meets sclerochronology

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Conservation paleobiology is a rapidly expanding discipline of conservation science that applies the theories and analytical tools of paleontology to conserve and restore biodiversity and ecosystem services. Sclerochronological records archived in the skeletal remains of organisms with accretionary growth are currently underutilized in the field. In this presentation I will focus on selected case studies that highlight the potential of sclerochronological records to give voice to a variety of past signals of change, which are as relevant to the many concerns, needs, and goals of conservation biology today as they are in navigating an uncertain, rapidly changing future. My overall goal is to raise awareness of the many opportunities that exist for closer collaboration between sclerochronologists and conservation paleobiologists. I will also offer practical advice to those wishing to develop conservation-relevant sclerochronological science.

Testing the effect of climate warming on oyster life history using geohistorical records

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The metabolic theory of ecology (MTE) proposes that variations in metabolic rate—which scales with an organism's body mass and temperature—are responsible for many patterns in ecology, including covariations in lifespan, body size, and temperature. If temperature and mass estimates are available, predicting shifts in biological rates and times (e.g. lifespan) with temperature change is possible, making MTE a potentially powerful tool for examining LH responses to climate change in the fossil record. The MTE predicts that even modest increases in temperature (~1°C) can reduce ectotherm lifespans by between 3% and 19%. To test this prediction, we collected body size and lifespan data for 3,110 and 1,207 oysters (*Crassostrea virginica*) from Pleistocene fossil deposits and modern reef death assemblages, respectively, in South Carolina. Lifespans were estimated using models based on sclerochemical analyses of 55 fossil and 49 Recent specimens. The lithology, associated fauna, and information from the shells themselves (e.g., height-length ratios and attachment scar lengths) suggest that the fossil and Recent environments are similar. However, amino acid racemization dating suggests that the Pleistocene oysters lived during marine isotope stage 9 (MIS 9), when sea surface temperatures were ~2°C warmer and sea level was several meters higher than today, making this an opportunity to compare LH of oysters living in different climates. Our data show that the average size of the largest 50% of Pleistocene oysters was smaller than the average size of the largest 50% of Recent oysters ($t(5.97) = -2.36$, $p = 0.057$). Growth models (power functions) derived from the sclerochemical profiles were used to estimate size-at-age relationships for all measured oysters, and analysis of the oldest 50% of Pleistocene and Recent oysters suggests that Pleistocene oysters were also shorter-lived than Recent oysters in South Carolina ($t(5.5) = -1.94$, $p=0.105$). Finally, the slope of a plot of log average lifespan of Pleistocene and Recent oysters versus inverse temperature (assuming an average temperature difference of 2°C) was 1.005—within the MTE-predicted range of 0.2-1.2. Thus, the results are consistent with general expectations from MTE and LH theory, suggesting that studying LH changes in the fossil record may yield useful information for managing natural oyster populations in the coming decades as the climate warms.

Evaluating the strength and temperature variability of the North Atlantic Current for the second half of the last millennium using an *Arctica islandica*-derived increment series

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Although they are important for planetary climate modulation, the high latitudes are not well represented by high resolution palaeoceanography. Since the marine conditions in these latitudes are unsuitable for the development of natural archives like corals and varved sediments, much of the published literature consists of records with, at best, decadal resolution. The annually-deposited increments of the mollusk *Arctica islandica* can help fill this void, allowing us to study hydrographic conditions in greater detail. A strongly crossmatched increment series provides an absolute (no uncertainty) age model on which to base geochemical results obtained from the analysis of shell material. We present an extension back to 1543 of a previously-published *A. islandica* shell chronology for the Fladen Ground in the northern North Sea. Because it is subject to inflow of North Atlantic Current waters, this area is representative of the greater North Atlantic from the Labrador Sea to the Faroe Islands. Based on modelled results, we relate the width of the growth increments to the strength of the winter and spring inflow of North Atlantic waters into the North Sea through the Fair Isle Channel with a one-year lag from 1959 to 2001 ($r = -0.41$, $p<0.01$) which affects the distribution of nutrients over the Fladen Ground. We use these results along with geochemical analysis of shell material and publicly available 20th century oceanographic data to construct a local $\delta^{18}O$-carbonate to temperature calibration and develop a continuous annual temperature record from the mid-19th century until 2003, which will later be extended for the full length of the chronology. This reconstruction will be an excellent resource for climate model comparisons, enabling more tightly constrained projections of future climate variability.

Multiproxy reconstruction of seawater temperature in the Bay of Brest using shells of dog cockles, *Glycymeris glycymeris*

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Since the end of the 20th century, global climate change has become a major focus of politicians and scientists worldwide, the consensus being that human activities are influencing environmental changes and affecting the Earth's ecosystems. To establish the full extent of human influence, it is therefore necessary to reliably differentiate between natural variations in climate and anthropogenic influences. In order to do this, we must build a record of past long-term natural variability in the environment. In recent years bivalve mollusc shells have been successfully used as paleoenvironmental and paleoclimatic archives through the analysis of their growth increment patterns and their geochemical composition. *Glycymeris glycymeris* is a bivalve found in coarse-grained subtidal sediments, with a wide distribution from Cape Verde to Norway. Thanks to its remarkable longevity (up to 200 years in the northern part of its geographical distribution area), it has a strong potential for building chronologies extending over several centuries, making it a valuable resource for long-term climate reconstructions in temperate settings.

Here, we developed a cross-dated chronology of over 30 years based on internal growth increments in *G. glycymeris* specimens collected both live and dead from the Bay of Brest, Brittany, France. The Standardised Growth Increment (SGI) chronology, developed from thirty-five individuals (average age 20 years), was found to be statistically robust (Expressed Population Signal (EPS)>0.85). In addition to growth increment analysis, eighteen specimens were investigated for their stable isotope composition. Aragonite samples were micromilled in early ontogeny growth increments of several specimens with overlapping lifespans, and subsequently analysed for their oxygen isotope composition. The continuous time-series of oxygen isotope ratios was then compared to in situ temperature and salinity data from the SOMLIT monitoring station, which was established in 1998, in order to calibrate and build a localised paleotemperature equation. This specific equation was then used to estimate sea surface temperatures in the Bay of Brest from 1969 to 2011.

Overall, this study demonstrates that *G. glycymeris* can be used for decadal scale, high-resolution, reconstructions of past sea surface temperatures in the coastal waters of the Bay of Brest for periods before the availability of instrumental measurements.

Paleobiology needs your help

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The Phanerozoic marine fossil record presents many striking patterns that remain poorly understood despite decades of study. Many long-term macroevolutionary and paleoecological trends are thought to have been driven by organism-environment interactions, but understanding of these trends is hampered by lack of information about both the environments in which early animals evolved and the metabolisms of these animals. Because they focus on the intersection of organismal growth and environment, sclerochronological studies have enormous potential to bring clarity to these and other paleobiological controversies. My agenda in attending this meeting is, first, to learn from the sclerochronology community, and second, to bring some outstanding problems to your attention. I will focus on two broad problems, though there are many other areas in which sclerochronological studies can contribute to our understanding of deep-time paleobiological patterns. Our knowledge of deep-time climate changes comes primarily from the oxygen isotope record ($\delta^{18}O$) of biogenic carbonates and phosphates. Classic studies by Veizer and colleagues established that the average preserved $\delta^{18}O$ values of tropical-subtropical shallow-water calcifiers rose by ~6‰ from the Cambrian to the present. Taken as a record of sea surface temperatures this implies that early animals routinely survived temperatures in excess of 50˚C. Alternative interpretations include pervasive diagenetic alteration of ancient fossils and progressive $\delta^{18}O$ enrichment of the marine oxygen reservoir through time. The latter model is not supported by recent clumped isotope studies, but these studies themselves suffer from necessarily coarse sampling and consequent inability to resolve signals in single growth increments. Determining the proper interpretation of the Phanerozoic $\delta^{18}O$ trend is of first-order importance for understanding the nature of the environments in which early animals arose and evolved, and sclerochronology can play a critical role in resolving this debate. The mean body size of fossilized marine animals has also increased through the Phanerozoic. Along with concomitant increases in motility, proportion of predators, and the composition of primary producer communities this has been taken as evidence that mean per-capita metabolic rates have increased. On shorter timescales, many lineages exhibit reduced size in the aftermath of major mass extinction events. Changes in mean size can result from changes in lifespan or in growth rate, and these have quite different implications regarding the process(es) driving evolutionary trends. However, little is known about growth rates or lifespans in the great majority of extinct clades. Even in modern calcifying groups, comparatively little is known about the controls on growth rate: are growth rates more strongly determined by extrinsic environmental conditions such as temperature and productivity or by intrinsic aspects of physiology that may be conserved across broad phylogenetic groups? Such uncertainties hamper efforts to reconstruct ancient ecosystems and to understand the environmental drivers of macroevolutionary trends. Sclerochronologists have developed a mature set of tools that, carefully applied, can shed considerable light on the evolution of marine ecosystems through time.

Seasonal patterns in shells of *Concholepas concholepas* and its application at the archaeological site of Camarones 14 (Camarones River Valley, Chile)

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The Chinchorro culture of the north coast of Chile (7000-3500 BP) is best known for its maritime economy and mummification of the dead. Not known is how the Chinchorro people articulated with and managed both the maritime and desert coast of the region to develop their complex culture and whether these people had a sedentary lifeway. In this presentation I show the results of growth-ring analyses of the shells of the marine gastropod Concholepas concholepas that have been excavated from cultural deposits at the coastal site of Camarones 14 in the Camarones River Valley to document occupational seasonality and possible long-term occupation. The approach is based on seasonal patterns observed in the direction of the angles formed by the internal growth lines on modern shells of Concholepas concholepas and compared with the archaeological samples. Although this is a new approach it shows potential use to estimate seasonality of site occupation.

Evidence for growth rate nonlinearity in bamboo corals

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Bamboo corals, long-lived gorgonian octocorals living at depths of ~700-2000 m, represent unique archives of intermediate water conditions. These Isididae corals are characterized by alternating organic nodes and calcitic internodes, which give them an appearance reminiscent of a bamboo shoot. While coral internodes can be analyzed by LA-ICP-MS to obtain proxy data, constructing firm chronologies for these samples is difficult. The anthropogenic ^{14}C bomb spike recorded in coral organic nodes provides tie points for calculating radial growth rates, but low sampling resolution has led to the convention of applying a single growth rate to an entire bamboo coral record. In this study of radiocarbon-based chronologies in 6 bamboo coral samples from the California Margin, nodes were sampled at high enough resolution (<0.5 mm) to resolve the entire ^{14}C bomb spike (including three tie points linked to the initial ^{14}C rise in 1957, ^{14}C peak at 1970 and collection date at 2007) for four samples collected live, as well as a partial spike in two samples which were not collected live. Radial growth rates ranged from 10 μm $year^{-1}$ to 204 μm $year^{-1}$, with a growth rate decline between 1957-1970 and 1970-2007 indicative of declining growth rates with specimen age and size. This was confirmed by a strong negative correlation between growth rate and coral radius ($R^2 = 0.5$ for linear regression with corals with > 2 tie points). To provide a mechanistic basis for these observations, a simple mathematical model was used to predict radial growth rates as a function of radius under the assumption of limited food supply where a constant volume of organic material is deposited with time. Although the nonlinear, near exponential decline in growth rate illustrated by this model fell within the 95% confidence interval of the linear regression, reconstructing the ^{14}C bomb spike using nonlinear and linear growth rate models revealed that only the nonlinear model accurately reconstructed the expected ^{14}C curve. The implication of these findings for paleoceanographers interested in utilizing bamboo corals is that chronologies incorporating a nonlinear decline in growth rate with coral radius, driven by a constant increase in node volume with time, are likely more precise than those built on the assumption of constant radial growth rates.

Upwelling seasonality in the Iberian upwelling system from shell $\delta^{13}C$ records in the bivalve *Glycymeris glycymeris*

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Eastern Boundary Upwelling Systems (EBUS's) are among the most diverse and productive marine systems. Knowledge of past upwelling variability is essential to correctly predict the environmental and economic impacts of EBUS's in future climate change scenarios. The seasonally variable Iberian Upwelling System (IUS), the northern section of the Canary Current Eastern Boundary Upwelling Ecosystem (CUE), which albeit placed at a crucial climatic boundary position, lacks well-dated high-resolution proxy records of past environmental variability that can be extend to periods before instrumental records. Variability in the IUS is complex, with upwelling intensity and sea surface temperature shown to oscillate at sub-decadal to multi-decadal time scales in association with the Eastern Atlantic Pattern and the Atlantic Multi-Decadal Oscillation.

Bivalve shells contain annually- and sub annually-resolved records of shell growth (sclerochronology) that provide robust high-resolution archives of oceanographic and climatic data variability. However, sclerochronological studies have largely focused on shells from coastal waters in northern and temperate latitudes. Such studies in shells from southern European coastal shelf seas have been limited by the rarity of long-lived bivalve species (i.e. several decades to hundreds of years). The dog cockle, *Glycymeris glycymeris*, with a longevity >100 years, provides a novel sclerochronological archive for reconstructing past environmental variability in the CUE. In this study, carbon stable isotope ($\delta^{13}C$) profiles in *G. glycymeris* shells from the IUS were obtained at sub-monthly and annual resolutions to determine the potential of shell $\delta^{13}C$ as a proxy for changes in upwelling conditions in the IUS.

Profiles at sub-monthly resolution demonstrated that shell $\delta^{13}C$ variation is inversely synchronous to upwelling intensity and is likely explained by seasonal changes in upwelling-related ventilation of surface waters with lower $\delta^{13}C_{DIC}$ subsurface waters, i.e. higher upwelling during spring-summer lowers surface water $\delta^{13}C_{DIC}$, and thus lowers shell $\delta^{13}C$.

Profiles of annually-resolved $\delta^{13}C$ records from 1955 to 2013 CE showed a marked and stable ontogenetic decreasing trend. However, removal of the ontogenetic trend to extract higher frequency $\delta^{13}C$ variability produced a mean annual $\delta^{13}C$ index which had a similar variation to the inverted amplitude in upwelling intensity (AUI) between the high and low upwelling seasons (JAS-DJF). A potential mechanism is proposed where AUI changes the seasonal growth bias in the seawater $\delta^{13}C_{DIC}$ signal integrated by annual shell $\delta^{13}C$. Consequently, high (low) AUI would bias shell growth towards the high (low) upwelling season, and thus lower (higher) δ^{13}CDIC and ultimately lower (higher) shell $\delta^{13}C$. Replication and the extension of $\delta^{13}C$ records are needed, as well as validation of the mechanism linking shell $\delta^{13}C$ to UI and $\delta^{13}C_{DIC}$ seasonality, to confirm *G. glycymeris* shell $\delta^{13}C$ as a valid proxy for seasonality in the IUS.

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Trace and major element ratios in *Elliptio dilatatus* shells as indicators of surface water quality in western Pennsylvania

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Centralized waste treatment facilities in western Pennsylvania accept, treat, and discharge conventional oil and gas wastewaters. This wastewater contains elevated levels of Cl, Br, Ba, Sr, and Ra among other trace elements. Prior to 2012, these facilities also accepted unconventional flowback and produced water. While unit processes in these treatment plants are designed to remove many species, some elevated loads of Cl, Br, Sr, and Ra are discharged into waterways. Previous research on these waterways suggests that discharge from these facilities has led to accumulation of radium in sediments and has possibly contributed to habitat loss and further decline of multiple endangered mussel species including *Epioblasma torulosa rangiana* and *Lampsilis abrupta*. Mussels are used as a bio indicator species in waterways due to their ability to sequester and incorporate many trace metals into their biomass and shell. This work analyzes concentrations of metals in shells of mussels as an indicator of water quality and to determine if accumulation of elements present in the discharge of brine treatment facilities are bioaccumulating in the nearby environment. We measured major and trace element ratios by laser ablation inductively coupled plasma mass spectroscopy (LA-ICPMS) in shells of *Elliptio dilatatus*, a member of a common genus of mussel. Combining element ratios with $^{18}O/^{16}O$ ratios ($\delta^{18}O$) we can observe seasonal trends along the growth bands of the shells and more accurately date changes in concentration within the shells. We can also use $^{87}Sr/^{86}Sr$ ratios measured by multi-collector ICP-MS (MC ICP-MS) to indicate the likely origin of the strontium (e.g., mine drainage, oil and gas wastewater). Elevated ratios of Ba/Ca, Na/Ca, and Sr/Ca in the shells of *Elliptio dilatatus* collected downstream of one wastewater treatment facility correspond to periods of the highest reported discharge from that facility (2009-2012). Sediment cores collected from a lake downstream of a similar facility has confirmed both elevated strontium concentrations in the sediment deposited during the time period of highest discharge as well as exhibiting a $^{87}Sr/^{86}Sr$ indicative of unconventional oil and gas activity. Future work will look to more completely characterize the spatial extent and determine fate and transport of metals within the local ecosystem.

Reconstructing hydrological changes over the past century in Central Africa using freshwater bivalve shells

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Bivalve shell oxygen isotope ratios ($\delta^{18}O_s$) record both water oxygen isotope values ($\delta^{18}O_w$) and water temperature. However, in the tropics, temperature variations are minimal and variations in $\delta^{18}O_w$ values dominate the shell signal. Therefore shells can be used as archives of variations in $\delta^{18}O_w$ values. $\delta^{18}O_w$ values in turn predictably vary with changes in the hydrologic cycle – including precipitation and evaporation. We investigate $\delta^{18}O_s$ values of *Chambardia wissmanni* shells collected from the Oubangui River (Bangui, Central African Republic) over several years between 1908 and 2013 (one shell from 1908, two from 1914, one from the 1950s, and nine shells collected between 2011 and 2013). One *Aspatharia rochebrunei* shell from the Ibéléké River in the Ngotto rainforest about 160 Km west of Bangui (a tributary of the Lobaye, which meets the Oubangui downstream of Bangui) was also included in the analysis. Biweekly water samples and in-situ measurements collected over a period of 2 years (2010-2012) allowed a direct comparison with proxies recorded in shells. Seasonal minima and maxima in $\delta^{18}O_{shell}$ (-5.1 to +0.2 ‰) agreed well with predicted values calculated based on temperature and $\delta^{18}O_w$ (see Kelemen et al. in this abstract volume). Archived museum specimens from the Oubangui River cover the time periods between 1891 and the 1950s. $\delta^{18}O_s$ analyses on all pre-1950s specimens show that seasonal maxima in $\delta^{18}O_{shell}$ are significantly lower (~-2.5 ‰) than in recent shells (+0.2 ‰), while seasonal minima (-4.3 ‰) are in closer agreement with recent shells. This strongly suggests the dry season in the upper Oubangui basin has become drier in recent decades, which confirms decreased river discharge over this time. Interestingly, the shell collected just 160 Km to the west in the rain forest is similar to the pre-1950s shells. This suggests that the drier conditions in the Bangui region seen post 1950s is a regional phenomenon and is likely driven by precipitation-evaporation (P-E) budgets and not necessarily by changes in rainfall $\delta^{18}O$ values. Changes in P-E can be caused by land-use change or increased evaporation from warmer air temperatures. This suggests that land-use change and/or climate change is significantly threatening local water resources in Central Africa.

Paleoclimate reconstruction from oxygen isotopes in a coral skeleton from East Africa

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We present a lab activity that both illustrates how marine paleoclimate records are reconstructed from biological carbonates and strengthens student's spreadsheet and basic statistical skills. Students use published coral isotope data downloaded from the National Oceanographic and Atmospheric Administration Paleoclimate Database to develop a paleotemperature equation from oxygen isotope data paired with sea surface temperature (SST) data. They then use this equation to hindcast SST back to the beginning of the coral record in 1801. Students are exposed to isotope geochemistry (at a basic level), as well as error analysis, and how paleoclimate data are generated.

Detecting seasonal variations in nitrogen and carbon sources to an impacted river and its estuary using bivalve shell $\delta^{15}N$ and $\delta^{13}C$ values

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Estuaries are dynamic ecosystems susceptible to the combined effects of anthropogenic influence and global climate change. In particular, excess nutrient inputs cause eutrophication and overall water quality degradation. In the Neuse River Basin, NC, excess nutrients enter waters via effluent from several concentrated animal feeding operations (CAFOs), atmospheric deposition, fertilizer use, and wastewater treatment plants. These sources have distinguishable $\delta^{15}N$, $\delta^{13}C$, and C:N values due to predictable fractionations in N and C isotope ratios. The combined seasonal and spatial variations in the biogeochemistry of water and bivalve shells allows for chronological monitoring and assessment of these sources to the Neuse River and its estuary. Preliminary bivalve organic matter (muscle, mantle, gill, and stomach) data suggests that there is measurable spatial heterogeneity in nutrient sources to the Neuse River and its estuary. Average freshwater mussel tissue values from two Elliptio complanata indicate that upriver sites ($\delta^{15}N$=8.0±0.8‰, $\delta^{13}C$=-31.4±0.6‰) are isotopically distinguishable from downriver sites ($\delta^{15}N$=9.9±0.7‰, $\delta^{13}C$=-32.6±0.4‰). Average estuarine bivalve tissues from ten *Rangia cuneata* exhibit higher $\delta^{15}N$ (11.5±0.8‰) and $\delta^{13}C$ (-30.3±0.4‰) values compared to riverine sites. The C:N ratios between riverine and estuarine bivalve organic matter are indistinguishable. In *R. cuneata*, the range in mantle and gill $\delta^{15}N$ values for shells collected on the same day (n=5) are similar, whereas muscle tissues have notably higher $\delta^{15}N$ values and stomach tissues have lower $\delta^{15}N$ values. In *E. complanata*, there are not enough specimens to make a sufficient distinction. Further research will determine whether serially sampled bivalve shell $\delta^{15}N$ and $\delta^{13}C$ values record temporal and spatial variations in riverine and estuarine N and C sources and biogeochemical cycling.

Coralline algal paleoclimatology – A review of current status and challenges

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Coralline algae are a globally distributed group of shallow marine benthic calcifiers that can form annual growth increments in a high-Mg calcite skeleton. Over the past 15 years a number of both free-living and encrusting coralline algal genera have been tested for their suitability as climate recorders and to date several multicentury long reconstructions of ocean climate have been generated. Coralline algal proxy studies span regions ranging from the tropics to arctic latitudes, with most studies focussing on mid- and high-latitude regions of the Northern Hemisphere. In high latitudes coralline algae are considered to be the single most abundant shallow benthic marine calcifier, sometimes covering up to 100% of the seafloor in the shallow photic zone. Proxy studies include both free-living rhodolith nodules and attached crusts forming build-ups on hard substrate. Environmental interpretation of rhodoliths, which are generally found on soft-substrate seafloor, is complicated by the fact that rhodoliths are overturned at infrequent intervals by water movement and benthic organisms, with opposite nodule sides receiving contrasting light conditions at any given time. This severely limits proxy reconstructions, since skeletal growth and trace element incorporation of the photosynthetic coralline algae is primarily controlled by light and temperature variability. In contrast, crusts of the massive growing coralline alga *Clathromorphum* sp., that forms abundant build-ups throughout the Subarctic and Arctic including regions seasonally covered by sea ice, remain in a fixed position throughout their up to 650 year long lifespan, while faithfully recording environmental conditions. With an absence of an ontogenetic growth decline and annual growth rates varying between 80-400 µm as a function of temperature and light variability, seasonal to annual resolution proxy reconstructions have been possible in regions as far as 73°N. To date, *Clathromorphum* sp. has yielded interpretations of past ocean temperature, cloud cover, freshwater influx, ocean pH and sea-ice conditions. The latter application is currently the focus of intense research, since the Arctic-wide occurring *Clathromorphum* is the only annual resolution marine sea ice proxy available to date. However, our understanding of *Clathromorphum* proxy recording has been hampered by an inability to achieve representative algal growth in controlled mesocosm experiments. Those experiments were designed to gain a better understanding of the relative influence of temperature and light on the photosynthetic proxy, evaluate interspecimen variability as well as to shed light onto calcification mechanisms, which to date are poorly understood. In addition to ongoing efforts of proxy calibration, basic questions such as distribution and occurrence of *Clathromorphum* buildups suitable for sclerochronological work are being addressed by upcoming expeditions to the core Arctic.

Sclerochronology of a large predatory gastropod (*Busycon sinistrum*) to determine late prehistoric seasonality at St. Joseph Bay, Florida

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Recent archaeological investigations indicate that coastal Fort Walton cultures in the St. Joseph Bay region of northwest Florida emphasized marine and estuarine foraging. These late prehistoric, Mississippi-period (A.D. 1000-1500) peoples collected fish, shellfish, and other aquatic resources. At the Richardson's Hammock site (8Gu10), radiocarbon-dated to about A.D. 1300, large, predatory gastropods were a major subsistence component. This adaptation is in sharp contrast with that of contemporaneous inland Fort Walton societies, who relied on maize agriculture, and raises the question whether coastal groups were separate hunter-gatherer-fisher populations or migrated seasonally from inland farming villages. We perform stable oxygen and carbon isotope sclerochronology on lightning whelks (*Busycon sinistrum*) to determine the seasonality of Fort Walton foraging and to compare the environment of prehistoric St. Joseph Bay with that of the modern bay. Oxygen isotope profiles suggest that shellfish collecting was relegated primarily to the summer months, producing a scheduling conflict with the primary growing season for maize in northwest Florida. Thus, coastal and inland Fort Walton sites could represent separate culture groups. The relationship between $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ indicates similar environmental and climatic conditions between prehistoric St. Joseph Bay and today. However, modern whelks are depleted in ^{13}C compared to Fort Walton whelks, which reflects both twentieth century CO_2 emissions and years of dredging and wastewater pollution entering the bay.

It's not all death and destruction: Thermal performance, energetics and the key role of monitoring growth responses to global climate change

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By definition, global climate change is affecting organisms and ecosystems worldwide, but these impacts often play out at incredibly local scales. For example, the ability of organisms to use microclimates can lead to differences in environmental stress over the scale of tens of cm that can exceed much larger-scale patterns observed over tens of degrees of latitude. An increasing number of studies are showing that rather than conforming to simple latitudinal gradients, many species live along what may best be considered as geographic mosaics of environmental stress. Moreover, non-climatic and climatic stressors do not always conform to the same geographic patterns, so that exposure to multiple stressors can be highly complex. Forecasting the likelihood of future responses to environmental change therefore requires not only that we understand the complicated ways in which multiple stressors affect organisms to create "winners" and "losers," but also that we gain a better understanding of how the temporal and spatial coincidence of these stressors will occur in nature. Energetics modeling provides an effective means of integrating the consequences of multiple stressors to organismal physiology. A primary finding of many of these studies is that the first observable impacts of climate change are not simply the result of rare but lethal extreme events, but also the cumulative effects of more chronic levels of stress on patterns of growth, reproduction and fitness. The production of hindcasting and nowcasting models of nonlethal responses to environmental change based on first principles, which can then be validated using cutting-edge sclerochronology methods in animals such as bivalves, offers new opportunities for interdisciplinary collaboration that will likely provide critical insights into climate change ecology.

Reproducibility of *Clathromorphum compactum* coralline algal Mg/Ca ratios and calibration to high-resolution sea surface temperature data

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Crustose coralline algae are important shallow-marine calcifiers that grow attached to the seafloor. Their potential as high-resolution archives of past ocean variability has only recently been recognized. Coralline algae of the genus *Clathromorphum* form annual growth increments in their high-Mg calcite skeleton and have been successfully utilized to reconstruct paleoclimate in mid- to high-latitude oceans over multicentury time spans. However, few calibration studies of coralline algal proxies are available from these climatically important regions which have experienced drastic changes in recent decades, even rarer are well replicated records from individual sites. Of particular interest are records of temperature-dependent algal Mg/Ca ratios, which have previously been shown to track ambient sea surface temperature (SST) and thus can serve as a paleotemperature proxy.

Here we present new Mg/Ca records from a number of *Clathromorphum compactum* specimens (Gulf of Maine, North Atlantic). Sections from *C. compactum* algal mounds were analyzed using Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) yielding continuous individual Mg/Ca records of up to 30 years in length. We first assess signal reproducibility and show that algal Mg/Ca ratios are well reproducible both along several shorter transects within individual sample specimens and between different samples from the same study site on seasonal to interannual timescales. In addition to the testing of intra- and intersample signal replication, LA-ICP-MS-derived Mg/Ca ratios are compared to electron microprobe (EMP) analyzed algal Mg/Ca on the longest-lived sample specimens and were found to be within analytical error. Second, we calibrate our monthly resolved records with in situ oceanographic data in order to achieve a reliable assessment of the potential for paleotemperature reconstruction. We show that relationships to SST can be improved when using sample composites (averaging of multiple transects per sample) and by averaging of Mg/Ca records from multiple algal specimens. Sample composites and intersample averages generally yield stronger relationships to SST data than Mg/Ca records derived from individual samples.
In summary, this study shows that reproducibility of algal Mg/Ca ratios is high within the tested specimens of *C. compactum* and when comparing between individual samples. Thus, calibration of algal Mg/Ca ratios to SST data can be improved by using sample composites and by averaging data from several samples within a study site.

Paleoecological implications of nitrogen and carbon isotopic data from organic material in Devonian rugose corals

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The Rugosa, an extinct order of coral, were dominant reef builders from the Middle Ordovician to the Late Permian. There has been little research done on their paleoecology, particularly their feeding habits and growth rates, and the aim of our research is to investigate stable isotope signatures from both extracted organic material of Middle Devonian rugose corals and their calcium carbonate skeletons to provide insight into these unknowns. Corals were sampled from the Joshua Coral Bed in the Hamilton Group in Central, NY. These coral beds range in thickness form ~1 m to as many as 20 m and may have covered several hundred square kilometers of the sea floor. Represented genera include *Cystiphylloides*, *Siphonophrentis*, *Bethanyphyllum*, *Heliophyllum* and *Heterophrentis*. Corals were physically and chemically cleaned to ensure that exogenous organic matter from host shales was removed. Organic material is present in thin sections as thin filaments and remains as whispy organic filaments in acidified residuals. The nitrogen and carbon isotopic compositions of preserved organic material could provide substantial new insight into the diets and physiological processes of Paleozoic rugosans. I will also report on oxygen isotopic ratios sampled from the calcium carbonate shells for paleotemperature data, as well as carbon isotopic compositions to show the effects of climate variability on the mechanisms by which rugose corals construct their inorganic skeletons.

Micro-scale chemical analysis of statoliths from the whelk *Buccinum undatum*: validation of a novel age determination method for fisheries management

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The whelk *Buccinum undatum* is commercially important in the North Atlantic; however, monitoring populations has been problematic for fisheries scientists due to the lack of a robust age determination method. We validated the periodicity of dark growth rings present in the calcium carbonate statoliths located in the foot of field-collected and laboratory reared whelks using microscale measurements of trace element geochemistry. Analogous in function to the fish otolith, a statolith contains a high resolution archive of past growth. Whelk statoliths were sampled from 3 locations spanning the length of the UK (Shetland Isles = North; the Menai Strait (North Wales) = Mid; Jersey = South). Using Secondary Ion Mass Spectrometry (SIMS), annual trace element profiles were reconstructed at a 2 μm resolution. Clear cycles of 24 Mg concentrations are present with minimum values that correspond with the visible dark statolith rings. Statoliths from 1 and 2 year old laboratory cultured whelks of known age and life history contain 1 and 2 24 Mg cycles respectively. The reconstruction of seasonal seawater temperatures from oxygen isotope profiles from the matching shells show annual temperature cycles that match the numbers of statolith 24 Mg cycles. The timing of statolith ring formation appears to be during the winter season. The results obtained from the chemical analyses of the shells and statoliths confirm the robustness of the statolith rings in estimating whelk age and have allowed the construction of site specific growth curves using statolith age. μXRD at 2 μm spatial resolution show the statoliths are wholly aragonite in structure and thus trace element variation is not the result of possible variations in polymorphs of the statolith $CaCO_3$. The validation of the annual periodicity of statolith growth rings provides a robust and novel age determination technique that could potentially lead to improved management of *B. undatum* stocks.

Growing a sea monster: Isotope ecology of a giant heteromorph ammonite

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Diplomoceras maximum is a large, hamitcone heteromorph ammonite with a shell that resembles a giant paperclip. A 1.5 meter long specimen representing more than 3 meters of linear shell growth from the late Cretaceous Lopez de Bertodano Formation of Seymour Island, Antarctica, now resides at the Paleontological Research Institution (PRI) in Ithaca, NY. Its growth rate and ecology have been the subject of much discussion but are completely unknown. Stable carbon and oxygen isotope analysis of serially sampled shell material can provide insight into the growth and habitat of these peculiar cephalopods. A roughly half-meter section of shell containing a hook and both adjoining portions of shafts, with aperture diameter ~15 cm, was sampled at a resolution of 5 samples per sculptural rib on the shell (total of 145 analyses). $\delta^{18}O$ values vary between +1.9 to -1.7‰, roughly the same range expressed by co-occurring benthic mollusks. A 15-point moving average defines a broad sinusoid that likely reflects ~1.5 years of shell growth. If so, and if accretion were constant, the PRI animal would have been about 9 years old at death. Superimposed on this sinusoid is regular variation of up to 2‰ that corresponds to sculptural ribs and covaries with $\delta^{13}C$, suggesting the potential for disequilibrium effects during precipitation of ribs or, potentially, repeated vertical migrations through the water column. Carbon isotope values overlap those of typical benthic mollusks and other ammonites, but also include extremely negative values (+1.7 to -30‰). Values are low between ribs and higher on them; regular swings to low values become significantly more extreme in the hook than they are in the shafts. If related to disequilibrium and/or incorporation of metabolic CO_2, this suggests more rapid growth in the hook section. Exceedingly negative $\delta^{13}C$ values may also reflect precipitation in the presence of methane, as suggested in the literature by unusual carbonate precipitates, chemosymbiotic cold-seep bivalve taxa, and very low $\delta^{13}C$ values of cemented burrow fills. Taken together, the data suggest a pelagic habit near the bottom closely associated with methane seeps. Shell growth is fast, consistent with living coleoids, and large individuals are likely less than 10 years old at death.

Evidence, cause and consequence of exceptionally rapid growth amongst Pliocene scallops of the US eastern seaboard

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Scallops are amongst the fastest growing of bivalves, with many species growing in the order of 40 mm per annum in early ontogeny, and reliable evidence of early ontogenetic growth-rates up to 70 mm per annum in wild populations of certain species. From the evidence of oxygen isotope ($\delta^{18}O$) sclerochronology, modern examples of the western Atlantic genus *Placopecten* grow about 40 mm per annum in early ontogeny. The same approach reveals similar growth rates in Pliocene examples from Virginia and North Carolina. By contrast Pliocene examples of the extinct genera *Chesapecten* and *Carolinapecten* from Virginia grew at least 75 mm per annum, faster than has been recorded in any wild modern scallop, and examples of *Carolinapecten* from Florida grew up to 140 mm per annum, twice the maximum rate in wild modern scallops. The rapid overall growth of *Carolinapecten* is matched by exceptionally large microgrowth increments. In specimens with the fastest overall growth the number of increments approximately equals the number of days indicated by the oxygen isotopic data (e.g. c. 180 over half an oxygen isotope cycle), implying that deposition was daily. Specimens with slower overall growth do not have smaller increments but have substantially fewer than the number of days indicated by $\delta^{18}O$ evidence, showing that reduced overall growth was a consequence of periodic interruptions rather than permanently less favourable conditions. Since few individuals lived more than a year, rapid somatic growth must have been accompanied by gamete production, implying abundant food resources. Intervals of particularly rapid growth (largest microgrowth increments) are fairly closely correlated with increases in $\delta^{13}C$, as might have been caused by phytoplankton blooms. However, there is little evidence that these were stimulated by upwelling since there are few indications of a matching increase in $\delta^{18}O$ (i.e. colder water). Instead, primary productivity may have been enhanced by nutrient supply from the land. Whatever the cause of high primary productivity in the Pliocene of the US eastern seaboard, the subsequent demise of two scallop genera with exceptionally rapid growth seems as likely to relate to a decline in productivity as to a fall in temperature.

Seasonal variation in temperature and precipitation during Eocene cooling inferred from Antarctic bivalves

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Climate change is one of the most pressing issues facing societies around the globe, yet changes in seasonality and precipitation that accompany greenhouse conditions are still poorly understood. Because global warming is amplified at the poles, studying high-latitude settings during warm intervals in Earth's geologic past can provide insights about future conditions. Several recent studies have reported increased seasonal precipitation in high latitudes during the globally warm Eocene Epoch (55-34 Ma), suggesting the possibility of monsoon-like conditions near the poles during greenhouse climate regimes and hence a significant departure from the present-day climate system. Climate model results suggest that increased summer precipitation and runoff would create a brackish, isotopically negative lens on the surface of nearshore environments, prohibiting vertical mixing within the water column and keeping shallow marine waters warm. With cooling, precipitation and runoff would decrease, allowing for more consistent vertical mixing of cooler, deeper, marine water and resulting in a collapse in seasonal amplitude of temperature, with overall cooling. Such a hypothesis is only testable with the high temporal resolution afforded by a sclerochronological approach. We use seasonally resolved $\delta^{18}O_{aragonite}$ data from fossil bivalves from the La Meseta Formation, Seymour Island, Antarctica, a nearshore shallow-marine succession, to test for evidence of seasonal runoff of freshwater. Specimens from the genera *Cucullaea* and *Eurhomalea* are sampled on a MicroMill using software that allows for 3D digitizing and microsampling of growth increments on shell exteriors rather than polished cross sections, resulting in higher precision and larger sample sizes. To account for the variability in annual and ontogenetic growth rate, and to resolve the issues related to time averaging biases created when serially sampling clams at a fixed interval, we employ a synthetic clam growth model coupled with temperature. Samples from the late Eocene yield a more attenuated seasonal amplitude and higher average $\delta^{18}O$ value than those from the middle Eocene, consistent with the hypothesis that high-latitude marine seasonality decreases with decreasing mean annual temperature, with cooling mostly in summer. By augmenting these oxygen isotope data with seasonally resolved clumped isotope thermometry, we can determine water temperature during seasonal extremes and thereby calculate the composition of the water in both summers and winters, giving insights into runoff and hence precipitation regime.

Reconstructing past variability in African hydrology using freshwater bivalve shell geochemistry: a multi-year calibration from the Oubangui and Niger Rivers

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We examined if African freshwater bivalve shells can be used as a proxy of oxygen stable isotope signatures of river water ($\delta^{18}O_{water}$) and discharge. Daily discharge and sub-monthly $\delta^{18}O_{water}$ data were collected over several years from two contrasting African river systems: the Oubangui River at Bangui, Central African Republic, and the Niger River at Niamey, Niger. For the Oubangui, $\delta^{18}O_{water}$ data cover a period of five years at two-weekly to monthly resolution, while for the Niger our dataset covers two years at a two-weekly resolution. Nine specimens of Chambardia wissmanni, collected in the Oubangui, and five shells from the Niger River (one *Aspatharia chaiziana*, two *Chambardia wissmanni*, and two *Aspatharia dahomeyensis*,) were analyzed for both $\delta^{13}C$ and $\delta^{18}O$ values along their growth axis; all shells collected have at least partial overlap between their growth and the period of water sampling. In both river systems, water $\delta^{18}O$ values varied seasonally and were negatively correlated with discharge, with a logarithmic relationship ($R^2 \sim 0.75$), and with an overall large seasonal amplitude (-3.7 to +2.6 ‰ and -4.3 to +6.1 ‰ for the Oubangui and Niger, respectively), while water temperature variations remained small. Based on measured $\delta^{18}O$water values and water temperature, we calculated the $\delta^{18}O$ values for a 'model' shell assuming that carbonate is precipitated in oxygen isotope equilibrium with the river water. For both river systems, $\delta^{18}O_{shell}$ data matched model shell data very well, and different species and/or specimens of the same species closely matched each other. Some individuals, however, showed clear periods of growth cessation or reduction, and such growth gaps were observed during both high and low discharge periods. However, accurately reconstructing river discharge based on shell $\delta^{18}O$ data was only possible for periods of low discharge. $\delta^{18}O_{water}$ values shift significantly towards higher values during low flow conditions, resulting in a logarithmic relationship between discharge and $\delta^{18}O_{water}$ with little change in $\delta^{18}O_{water}$ above a certain threshold discharge.

While $\delta^{13}C_{shell}$ data typically show a similar seasonality as observed in $\delta^{18}O_{shell}$ data, $\delta^{13}C_{shell}$ data did not closely match values expected based on riverine $\delta^{13}C_{DIC}$ (dissolved inorganic carbon) data, and a decrease through ontogeny was also observed. This suggests that DIC is not the only source of C for the shell and that metabolic C is likely incorporated into the shells as has been noted in other studies. In conclusion, our extensive calibration study demonstrates that freshwater African bivalves secrete their shell in oxygen isotope equilibrium with the ambient water, but suggests that the reliability of $\delta^{18}O_{shell}$ values to reconstruct river discharge will depend on the local $\delta^{18}O_{water}$/discharge correlation. For the Oubangui and Niger River, our data suggest that freshwater shells should be sensitive recorders of long-term changes in low flow conditions, but are unlikely to accurately record changes in peak discharge regimes.

Reconstructing environmental histories of Atlantic cod in the Gulf of Maine

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The study of fish otolith chemistry can provide information on the environment experienced by a fish over its lifetime. Two major spawning complexes of Atlantic cod have been identified within the Gulf of Maine: 1) the spring spawning complex, which spawns primarily in Ipswich and Massachusetts Bay in the spring and, 2) the winter spawning complex which spawns in the same region in winter months. Winter and spring spawning fish are genetically distinct and may exhibit differences in the scale of their spatial behavior and habitat use. The goal of this research was to characterize differences in the environmental histories of the two major spawning complexes (winter and spring) of Atlantic cod in the Gulf of Maine. Spawning fish were collected in winter and spring in the Gulf of Maine from Ipswich and Massachusetts Bays. Otolith thin-sections were aged and analyzed across the longest growth axis of otoliths for a suite of isotopes, including ^{25}Mg, ^{55}Mn, ^{43}Ca, ^{138}Ba, ^{88}Sr, ^{63}Cu, and ^{68}Zn, using laser ablation inductively coupled plasma mass spectrometry. The analysis of transects across the growth axis of the otolith provided the opportunity to compare the chemical signature of the core (indicative of natal origin), the integrated transect across the whole otolith (fingerprint of lifetime habitat use), and the transect profile (providing a high resolution environmental chronology that can be related to both year and age of the fish). Significant differences in otolith elemental ratios were identified based on spawning time (winter and spring) as well as location of spawning (Massachusetts and Ipswich Bay) early in life and across the lifetime of fish. Significant differences in lifetime otolith growth were also identified between winter and spring spawners and spawners collected at different locations. Chemical chronologies were aligned with the age of the fish and year during which growth occurred and chemistry and growth patterns were compared across spawning groups. Differences in lifetime otolith elemental chronologies imply different environmental histories and consequently can serve as an indicator of stock identity or life history type. Increased understanding of differences in the spatial behavior of cod in the Gulf of Maine will provide information relevant to preserving within species diversity in the Gulf of Maine.

Geochemical evidence for the presence of photosymbiosis in Early Jurassic Lithiotid bivalve

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The Lithiotid bivalves (*Lithiotis*, *Cochlearites* and *Lithioperna*) were an aberrant bivalve group which arose during the Pliensbachian stage of the Early Jurassic, following a 10 million year post-Triassic extinction "reef gap". During this period of the near-complete eradication of reef-building corals, the Lithiotids became the dominant calcifiers in shallow tropical settings. Cochlearites and Lithiotis have been proposed to harbor photosymbionts because of their large size, flattened morphology, tropical distribution and aggregate lifestyle. We have gathered shells of each genus from the Trento Platform in Northern Italy and used stable isotopic sclerochronology to attempt to determine whether Lithiotis shows a photosymbiotic vital effect similar to the one displayed by known symbiotic groups such as the giant clams. If Lithiotis was photosymbiotic, we should see a $\delta^{13}C$ enrichment in summer months when its proposed symbionts would have been most active, as they preferentially fixing light ^{12}C through photosynthesis. This would manifest as a negative correlation between $\delta^{13}C$ and $\delta^{18}O$ sampling along a transect in shell carbonate (as $\delta^{18}O$ values are lower during times of high summer temperatures). Preliminary results suggest that Lithiotis does not display this negative relationship and does not have a highly accelerated growth rate, showing 2.5 cm/yr of growth, more in line with heterotrophic oysters than photosymbiotic giant clams. However, a longer transect needs to be collected along the longest axis of growth, collecting a longer isotopic transect in order to determine whether a phase lag is present between the C and O isotope results, and whether growth is faster in the vertical direction. When enough data is gathered, we will be able to determine whether Lithiotis, previously considered a strong candidate for symbiosis, actually displays a sclerochronological signal confirming this hypothesis.

Southeast Gulf of Mexico corals reveal annual barium cycles

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The coral skeleton barium to calcium ratio (Ba/Ca_{coral}) has been shown to reliably record dissolved barium concentrations (Ba_{SW}) in seawater. Ba/Ca_{coral} has been used as a tracer of upwelling based on the "nutrient like" Ba_{SW} depth profile, as well as a recorder of terrestrial runoff in some coastal locations. However, a fifteen year long *Siderastera siderea* coral record from Dry Tortugas National Park, FL (DRTO), a region of the Gulf of Mexico where upwelling and terrigenous influences are minimal, reveals large annual-scale variations in Ba/Ca_{coral} (~7-20 µmol/mol). The application of recently published Ba/Ca calibrations derived from Pacific *Porites* and *Pavona* corals to the DRTO *S. siderea* record suggests that these annual cycles correspond to changes in BaSW from ~60 nmol/kg (winter) to ~180 nmol/kg (summer). Although large in comparison to open ocean values, previous studies have explained Gulf of Mexico BaSW concentrations of this magnitude as a result of offshore drilling effluent discharge. The Ba/Ca maxima and minima lead those of SST by ~3 months (as inferred from Sr/Ca measurements of sample splits), and the magnitude of the Ba/Ca_{coral} cycles overwhelm any temperature influence, indicating that SST does not drive these changes. The timing of the Ba/Ca maxima and minima does, however, align with the timing of annual chlorophyll and $\delta^{13}C$ minima and maxima, respectively, suggesting that this annual barium cycle is linked to biological productivity. During the high productivity winter months, barium could be removed from the dissolved pool either via direct cellular uptake or indirectly via barite precipitation with the decomposition of large phytoplankton blooms. In addition to this biological cycling of barium, submarine groundwater discharge, estuarine barium sourced from the Mississippi River, and the release of drilling effluent on the Louisiana shelf could influence the Ba/Ca cycles recorded by these corals. Taken together, these results demonstrate the dynamic nature of barium cycling in surface waters and the utility of a multi-proxy approach to trace biogeochemical cycling in the past.

Shellfishing through the Holocene in British Columbia: Insights from oxygen isotope sclerochronology

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Shell middens from coastal British Columbia (BC), Canada, provide both cultural and biological insights into past human-environmental interactions, and the direct analysis of shells provides information about seasonality and local harvesting pressure. Previous analyses of macro-growth lines from butter clams (*Saxidomus gigantea*) distributed along 10,000 km of mainland and island coastline provided a foundation to interpret the role of shellfish in local and regional economies over a 6000-year period. Combined with high-resolution stable oxygen isotope ($\delta^{18}O_{shell}$) and fortnightly/lunar daily growth increment (F/LDGI) analysis revealed regional variation in seasonal shellfish harvesting.

This poster synthesizes $\delta^{18}O_{shell}$ from over 135 individual shells from 17 different sites, and growth increment analysis of over 5000 *S. gigantea* shell fragments from 37 archaeological sites on the BC coast. The results reveal region- and site-specific diachronic trends in shellfish harvesting strategies. Since the cultural and geographic scope of this study is so large, understanding different growth rates and salinity regimes is critical for applying stable oxygen isotope sclerochronology to understand patterns of seasonal shellfish collection. This will be critical as seasonality research using $\delta^{18}O_{shell}$ expands into new geographical and cultural areas of BC, specifically within Sechelt inlet since summer salinity values are as low as 15 PSU compared to other study areas on the coast where salinity ranged from 22-25 PSU.

The integration of new data from the southern region of BC, specifically from Sechelt inlet in the traditional territory of the shíshálh Nation, adds to our understanding of seasonal subsistence practices by comparing it with shellfish data from the traditional territories of the Coast Tsimshian, Haida Gwaii, Heiltsuk and Coast Salish peoples. The continued alignment of F/LDGI will ensure continuity in our methodology and contribute towards a pan-coastal understanding of shellfishing through the Holocene.

Losing track of time: Is hypoxia in part to blame for Baltic cod aging problems?

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Cod, a primary fishery species in the Baltic Sea since prehistoric times, has recently experienced marked declines in size and condition. This is due to a combination of worsening water quality conditions from hypoxia intensification, reduction in prey availability even as cod densities have risen, and increased occurrence of parasites and disease. One of the net results of this has been a decrease in formation of clear annual growth rings in otoliths of Eastern Baltic Cod. Otoliths (ear-stones) are part of the hearing and balance system in fishes, and grow incrementally as a fish grows. In seasonal environments, growth bands are laid down, much like tree rings. But in Eastern Baltic cod it has become increasingly difficult to "read" otoliths and determine ages. This is a serious problem, because age is a key variable used in stock assessment for the management of exploited populations, including quota-setting. In 2014 the situation became so dire that the stock assessment was not approved for this stock. Solutions are clearly needed. We are developing new methods to assist in solving the "aging problem" using a combination of otolith microchemistry, optical imagery and direct increment counts, and dynamic models. Developing novel ratios of trace elements and isotopes that enhance seasonal signatures appears promising. We are also tracking the intensity of hypoxia with a proxy (Mn:Ca ratios) as described in Limburg et al. 2015 (J. Mar. Sys. 141: 167-178). This study explicitly links hypoxia with a metric (otolith Mn:Ca ratios) that also has a physiological basis; preliminary results suggest our approach to deal with aging fishes badly impacted by hypoxia is broadly applicable across marine to freshwater ecosystems.

Otolith biochronologies reveal latitudinal differences in growth of Bering Sea yellowfin sole *Limanda aspera*

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Because they accrete continuously and deposit annual growth increments over the lifetime of a fish, otoliths ("ear stones") act as chronometers of a fish's life history. Growth-increment biochronologies are often related to factors in the physical environment such as temperature. The otoliths of yellowfin sole *Limanda aspera* are particularly suited to biochronology applications due to the general clarity of their growth increments and relatively long life span. In a previous study, a strong positive relationship was observed between a yellowfin sole otolith biochronology and bottom temperature in the southeastern Bering Sea. The aim of the present study was to determine whether this biochronology-growth relationship is maintained in yellowfin sole at higher latitudes. Two new biochronologies were developed from specimens collected near St. Matthew Island and the Bering Strait and compared with the previously developed Southeast Bering Sea biochronology. Despite large distances (600 km) apart, a high degree of synchrony was observed among all three biochronologies. However, subtle differences among biochronologies were observed upon closer examination. The St. Matthew chronology had the highest variability among individuals, possibly due to differences in oceanography and productivity in that region. The relative amplitude of otolith growth differed among the chronologies; stronger negative anomalies were observed in the south whereas stronger positive anomalies were observed in the north. Differences in average length at age were also detected, with fish growing slower to larger lengths with increasing latitude. The Bering Strait biochronology had the weakest and most localized relationship with climate variables, suggesting that effects of climate are not felt uniformly across the regions examined. Differences among the three chronologies are discussed with respect to ecological and physical factors in the three regions of interest.

The challenges of a high-resolution archaeology: sclerochronological and isotopic approaches in perspective

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The palimpsest nature of archaeological deposits and their often coarse temporal resolution (e.g. in the order of decades, centuries or millennia) allow us to study phenomena and processes at broad scales of observation, which is useful to evaluate culture change over long periods of time. Sites, however, are also repositories of organic remains of past human actions, which constitute archives of past climates and environments inadvertently preserved for us by their occupants. Sclerochronology and isotope analyses on incremental skeletal structures, such as those of molluscan shells, offer us the possibility of attaining high-resolution environmental and archaeological data, on yearly, seasonal, monthly, weekly or even daily scales. High-resolution data is essential to assess whether, or in what way, changes in human behavior may have been linked to climate or changing environments, given that it is to short-term changes that humans would have adapted to. This lecture addresses how this is currently achieved by sclero-archaeology, as well as what methods and themes of inquiry should be developed in the future.

An immediate strategic goal is to establish as palaeo-seasonality proxies all mollusc taxa which are archaeologically common, by studying their living counterparts. These developments should not only be aimed at reconstructing season of mollusc collection, as is usually done, but at using shells as climatic and environmental records relevant for understanding past human behavior. Methodological progress should be made to improve radiocarbon dating projects based on shells and to expand the range of sclero-archaeological applications to provenancing shell artefacts. In fact, despite the fact that shell ornaments are proxies of past symbolism, languages or exchange networks, very little effort has been devoted to unravel the life histories of these shell artefacts, thereby limiting their potential as invaluable proxies of human behavior.

The rewards for embarking on targeted sclerochronological and isotopic studies of shells from a variety of archaeological periods and cultures are there for the taking. If similar strategies are pursued, high-resolution research may allow us to tackle the ‘grand challenges for archaeology’ (Kintigh et al. 2014) and contribute to our understanding of how people in the past responded to abrupt environmental change over the short term.

Isotope sclerochronology and season of annual growth formation in the marine bivalve, *Astarte borealis*, from Arctic and cold-temperate seas

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Astarte borealis shells are well suited to investigate links between environmental change and biological consequences in high-latitude regions because of their long lifespans and abundance in boreal and arctic seas. These traits make *A. borealis* a useful tracker of the rapid climate changes in the Arctic, a region experiencing double the global rate of temperature change. Therefore, it is imperative to understand the isotope sclerochronology of these shells to quantify how factors, such as lifespan, are affected by climate change. Using isotope sclerochronology, we test the hypothesis that this mid- to high-latitude species form winter growth checks in their shells similar to other mid- to high-latitude venerid clams (*Mercenaria mercenaria*) and patelloid limpets (*Patella vulgata*). Specimens were collected alive from Kiel Bay, Germany (cold-temperate zone) and the White Sea, Russia (boreal zone). Oxygen isotope data show that shells from the Kiel Bay population of *A. borealis* slow growth in winter similar to other mid- to high-latitude molluscs most likely representing cold-temperature stress. In contrast, shells from the White Sea slow growth during the summer unlike other mid- to high-latitude molluscs. There are several factors that may contribute to the unexpected timing of slowed growth in the White Sea population, such as reproductive processes, food supply, temperature thresholds, and salinity. We can rule out reproduction as a contributing factor because *A. borealis* has fertile gonads all year round. Nutrient restriction is also unlikely because phytoplankton blooms occur from April to October. Summer temperatures would not trigger slowed growth because typical values for the White Sea do not exceed maximum temperature tolerances. The White Sea experiences pulses of meltwater during the early summers which drop salinity to less than 8 psu (practical salinity unites) in some areas. This decrease in salinity is below the tolerance threshold for *A. borealis* and is a likely cause for the observed slow summer growth.

Marine climate variability of the Irminger Current based on growth increments in the bivalve *Arctica islandica*: a molluscan sclerochronological approach

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The lack of high-resolution marine proxy records from higher latitudes limits our understanding of natural climate change in these areas. Systematic instrumental observations of the ocean is available from the last 50 years, only, and annually resolved climate archives such as corals are only sparsely available in higher latitudes. In this study, we will examine the annual resolved growth increments of specimens of the bivalve ocean quahog (*Arctica islandica*), aiming to decipher environmental change in the Irminger Current. The Irminger Current, a branch of the North Atlantic Current, transports relatively salty and warm water westward along the south coast of Iceland. The changes of the different environmental parameters, such as temperature, salinity and primary productivity that have occurred in the past will have had an impact on the living marine organisms in the northern areas, as well as various effects on the atmospheric climate. At northern latitudes, the changes in environmental parameters of the ocean are linked to the climatic conditions in the cryosphere. Consequently, sea ice cover and glaciers on Iceland will be affected by changes in the Irminger Current, and these fluctuations are possible to reconstruct using paleo archives from this area.

Synchronised response to changes in the environment within a population of *A. islandica* enables cross-matching of the growth increment patterns of live-collected and sub-fossil specimens from the same location. By implementing this method, it is possible to create a continuous multi-centennial master chronology, which can be compared with both instrumental records of e.g. temperature and primary productivity, and historical records. The growth increments will be measured along the ventral margin in the direction of the maximum shell height as well as in the umbo. So far, thirteen live-collected specimens of different sizes, collected from 104-meter water depth off the west coast of Iceland, have been processed. It remains to see if there is an adequate correlation between the specimens to create a master chronology. To extend this study it would be interesting to compare the specimens collected at deep water with specimens from more shallow water, to investigate to what extent the signals correspond between different water depths.

Using shell-based proxy records from northern Norway to evaluate high latitude impacts of the Atlantic Multidecadal Oscillation

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The Atlantic Multidecadal Oscillation (AMO) is thought to be a persistent feature of North Atlantic Ocean climate variability, switching between warm and cool periods on the order of 60-80 years. The lack of long-term, high-resolution surface ocean records, however, hinders a complete understanding of its persistence, interactions with other climate modes, and possible forcing mechanisms. Evidence for the AMO's influence and persistence at high northern latitudes is especially scarce (Drinkwater et al., 2014). *Arctica islandica* shell-growth and geochemical records from northern Norway show significant correlations with the AMO index over the past 112 years ($r^2 = 0.39$). Running correlations with the North Atlantic Oscillation vary in sign coincidently with AMO phases, suggesting complex air-sea interactions at high latitudes. Extending the shell-growth and geochemical records for several centuries will provide insight into the AMO's influence in the Barents Sea, and help establish the long-term dynamics and persistence of the AMO.

Mechanical and structural response of *Cerastoderma edule* shell to acidification

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Rising levels of carbon dioxide (CO_2) emissions to the atmosphere have resulted in an increased ocean pCO_2, lower seawater pH and decreased carbonate saturation state. This condition potentially represents a major thread to calcifying organisms such as mollusks. The present study focuses on the impact of elevated pCO_2 on shell microstructural and mechanical properties of the cockle, *Cerastoderma edule*. Specimens were collected in the Baltic Sea and kept in tanks at six different pCO2 levels ranging between 900 µatm (control) and 24,400 µatm. Extreme CO_2 levels were used to simulate the effects of potential leaks from the carbon capture and sequestration sites where considerable quantities of CO_2 are kept in sub-seabed geological formations. Two approaches were combined to determine the effects of the experiment: (1) Scanning electron microscopy (SEM) was used to analyze shell microstructures and dissolution damage and (2) nanoindentation was used to test shell hardness and wear resistance. Size and shape of microstructural units in the outer shell layer as well as shell hardness do not change significantly in response to acidified conditions. However, ontogenetically younger portions of the shell were more affected by dissolution pCO2 increased. Irrespective of pCO_2, strong negative correlations exist between prism size and shell mechanical properties (hardness and wear resistance) in natural and artificial conditions. An additional sample from the North Sea confirmed this result. Our findings suggest that the microstructures and mechanical properties of *C. edule* are not significantly influenced by pCO2 variations. Furthermore, our study indicates that shell mechanical properties depend on the shell architecture at the µm-scale.

Otoliths: from individuals to assemblages in a changing world

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Growth is a fundamental biological process, driven by a multitude of intrinsic (within-individual) and extrinsic (environmental) factors, which underpins individual fitness, population demographics, and assemblage productivity. Growth is not only responsive to ecological factors such as resource availability and environmental conditions, but is also a trait under contemporary evolutionary selection. Fish growth is therefore an ideal metric with which to study the impacts of natural and anthropogenic environmental change across all levels of biological organisation.

Otoliths provide fish ecologists and fisheries managers with an enviable source of biological data. Whilst we have long taken advantage of the periodically formed increments within otoliths to provide an estimate of fish age that can be readily used in stock assessment models, it is only more recently that we have begun to interpret the growth information that these increments represent. These aquatic biochronologies have enabled researchers to ask questions at daily to centennial time scales, in lakes to reefs to across large marine ecosystems, providing valuable ecological insight to fisheries ecology and management.

Here, I will discuss my recent work investigating the eco-evolutionary drivers of fish growth using information naturally archived in otoliths. I will highlight how this data can be used to explore a hierarchy of growth variation, ranging from within- and among-individual responses to temperature and fishing selectivity, to species-wide and assemblage-level assessments of fisheries, climatic, and oceanographic impacts. I will also present examples of how age information can readily be used to recreate recruitment indices and in data poor fisheries. Throughout, I will make reference to statistical models that facilitate the extraction and interpretation of biological insight from hardparts. I will finish by exploring exciting opportunities for the use of otolith-derived growth information, including the estimation of age at maturity and the development of improved predictions of fisheries productivity. Otoliths have, and will continue to play, a vital role in furthering our ecological and evolutionary understanding of aquatic systems, and thus the management of our marine and freshwater resources.

Latitudinal variation of lifespans and growth rates in modern marine bivalves

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Mean body size in marine animals has increased more than 100 fold since the Cambrian, a discovery that brings to attention the key life history parameters of lifespan and growth rate that ultimately determine the sizes attained by organisms. The longest lived non-colonial animal on the planet today, *Arctica islandica*, is a bivalve with a maximum reported lifespan of 507 years. In addition to Arctica, at least nine modern taxa are known to attain lifespans in excess of 100 years. What factors might be involved in this impressive longevity? A handful of mostly species-specific studies suggest that the longest lived individuals tend to be found at the highest latitudes of their geographic range – implying a role for the environment. However, the pattern across the Bivalvia has not been fully documented. Here, we present a new global database of maximum reported lifespan (MLSP) and shell growth for 1,381 populations of marine bivalves and show that 1) lifespan increases, and growth rate decreases, with latitude, both across the group as a whole and within individual well-sampled taxa, and 2) that growth rate, and hence metabolic rate, correlates inversely with lifespan. An environmental parameter related to latitude and therefore insolation, such as temperature or primary production/food availability, acting through its effect(s) on metabolic rate, likely explains the observed trends.

Our data set lays the ground work for testing hypotheses about relationships between life history traits and spatio-temporal macroevolutionary trends using the modern and fossil record. If cold temperatures at the poles is the main driver of today's observed latitudinal pattern, we would predict a change in intensity of that pattern in response to greenhouse versus icehouse conditions. Alternatively, if the suggestion that food and nutrient availability in marine settings has increased over the Phanerozoic is in fact true, we might expect to see an increase in von Bertalanffy k values (as a proxy for metabolic rate) as well. Despite the relative ease with which bivalve lifespans can be determined from their shells, the longevities of fossil bivalves have only been reported in a handful of studies. Discovering patterns of life history evolution in deep time using sclerochronology may be the next frontier of paleobiological research.

Application of clumped isotopes in shell midden sclerochronology

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Geochemical analyses of calcareous skeletal structures such as fish otoliths or mollusk shells from archeological sites provide sub-seasonally resolved records of paleoenvironmental conditions. However, many prehistoric settlements were located in coastal or estuarine environments in which biotic or abiotic seawater conditions underwent large seasonal fluctuations (e.g. primary production or salinity/$\delta^{18}O_{Water}$) which complicates the straight forward interpretation of most paleoenvironmental proxies. Carbonate clumped isotope thermometry represents a promising analytical approach as it represents a direct measure of carbonate precipitation temperature independent from the isotopic composition of the ambient water. However, recent studies have shown that in particular aragonite is characterized by fast re-equilibration rates of ^{13}C-^{18}O bonds due to closed systems isotope exchange reactions. Thus, clumped isotope thermometry might be susceptible to short-term heating events such as prehistoric cooking. To test this hypothesis, we measured the clumped isotopic composition of modern bivalve shells (*Mercenaria campechiensis*) which were experimentally exposed to different prehistoric cooking methods. Our data clearly show that prehistoric cooking causes a considerable alteration of clumped isotopes as a function of exposure time and cooking temperature. However, all cooking methods produced a characteristic clumped isotopic signature primarily dependent on the cooking temperature showing that clumped isotopes can be used to reconstruct prehistoric cooking methods in aragonitic shell midden constituents. This is of particular importance because our data also show that all cooking methods also caused a considerable alteration to other commonly used paleoenvironmental proxies even without any conversion of the initial aragonite into secondary calcite. Thus, clumped isotope thermometry represents a powerful tool to detect and reconstruct prehistoric cooking practices but should also be considered for assessing sample preservation to prevent misinterpretations of ancient climate conditions if samples were altered by prehistoric cooking methods prior to deposition.

Understanding cellular-scale controls on Mg uptake in crustose coralline algae

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Interpretations of past temperature are increasingly being made using changes in magnesium content together with annual growth banding of crustose coralline algae (CCA). However, these interpretations can be limited by the lack of understanding as to how magnesium is incorporated into the. Often published results for cold water CCA show unexplained spikes in Mg content that are above values found in tropical CCA. Our recent research shows that the strongest control on Mg incorporation is not temperature, but instead the Mg content is heavily dependent on the type of calcification and cell growth mode. Mg content is higher in cell walls than the interfilament (between cells). This offset has been found in both tropical and cold water CCA and the difference ranges from 5-8 mol% $MgCO_3$. Furthermore, wound repair and basal hypothallial cells can also have elevated Mg relative to the typical perithallial cells. These cellular scale controls can result in Mg contents in parts of cold water CCA being as high as tropical CCA. Prior to using CCA as a proxy, the different types of cell growth need to be identified so that analyses can be restricted to only one cell type area. Even within the one cell type, seasonal changes in relative amounts of cell wall to interfilament can influence the total measured magnesium content. These biological controls do not prohibit the use of Mg content in CCA as a paleo temperature proxy, but an understanding of the cellular scale controls is necessary in order to make reliable interpretations using Mg content. Our results to date show that the tightest correlations for Mg and temperature are for temperatures less than 10 degrees celsius. In contrast, the correlation weakens as temperatures increase to tropical. This shows the CCA can be reliably used for cold water temperature reconstruction, however the correlation does not consistently hold through temperatures up to the tropics.

Sclerochronological comparison of two dog cockle (*Glycymeris glycymeris* L.) populations from the southeastern North Atlantic

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The use of the abundant dog cockle (*Glycymeris glycymeris* L.) in sclerochronological studies is proven to be a valid method to reconstruct oceanographic variability in the North Atlantic Ocean, however, the sclerochronological potential of the species has not been investigated at the southern limit of its distribution. The aim of our study was to analyse growth patterns of *G. glycymeris* specimens from near the southern border of their species' distribution and to compare the synchronous annual growth indices from two environmentally different (sub-littoral and open marine) sampling localities to check whether the same environmental variables affected the shells' growth. The studied populations include a group of abandoned shells that were collected offshore of the Desertas Islands, Madeira in 2013 at 80-300 m water depth range together with two live-caught specimens and a second group of 13 shells that were collected alive in 2002 at 30 m water depth near Aveiro, Portugal. While these two collection sites represent two distinct habitats due to their depths, they are both situated in regions affected by the Canary Current System and seasonally variable upwelling systems.

The live collected shells from Aveiro were relatively young (the oldest specimen lived for 34 years). While the abandoned shells from the Madeiran group proved to have very high ontogenetic ages (the oldest specimen lived for 164 years). Both groups showed similar ontogenetic trends, however the average growth rate in the sub-littoral environment was three times higher in the first four years of their lives than it was in the deeper collection site.

Subsets of the Madeira (n=18) and the Aveiro samples (n=6) could be collected into robust site chronologies and negative exponential fitting was applied to derive standardized growth indices from the raw increments. A good agreement was found (EPS>0.8 during 1950-2000) for the Madeira-group which suggests an external effect on their growth. Their composite chronology exhibited negative correlation ($r=0.4\text{-}0.5$, $p < 0.1$.) with the April-May HadISST1 SST fields around Madeira. The Aveiro composite chronology (EPS>0.85 between 1981 and 2001) also exhibited negative correlation with the May-June HadISST1 SST fields near the Portugese shores ($r=0.4\text{-}0.6$, $p < 0.1$). Earlier studies reported positive correlation between the growth indices of *G. glycymeris* shells and seawater temperature, however our results suggests that in these southern sample locations lower water temperature was not a limiting environmental variable and other external effect could affect the shells growth.

Due to the seasonal variability of the Canary Current System the direction and strength of local currents and the chlorophyll-a content of the surface seawater change during the year. The latter exhibits a maximum in April when the currents from the NE direction become stronger and deliver cooler, nutrient rich water to Madeira. According to this, the positive correlation found between the Madeira composite chronology and the interannual variations in regional mean meridional current velocity during the early summer months between 1993 and 2003 can point to a physiologically plausible relationship.

The impacts of ocean acidification and increasing temperature on shell properties of intertidal bivalve molluscs

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The progressive increase in atmospheric carbon dioxide in the Anthropocene is causing potentially catastrophic changes in coastal marine systems. The world's oceans have absorbed over 30% of emitted CO_2 since the beginning of the industrial revolution, thus mitigating part of the warming effect, but resulting in a continuous decline in surface-ocean pH. Current models predict a reduction in surface-ocean pH from 8.1 to 7.68 by the end of the century, with a simultaneous increase in mean surface-ocean temperatures of 2-4°C. As a result of increasing seawater pCO_2, saturation states of the major calcium carbonate polymorphs (e.g. calcite and aragonite) are becoming lower, leading calcifying organisms such as bivalve molluscs to be potentially vulnerable to the effects of ocean acidification. We report on laboratory studies into the effects of ocean acidification and increases in ambient seawater temperature on the incremental growth, shell thickness, shell microstructure, and physiological condition of juvenile blue mussel, *Mytilus edulis* and European common cockles, *Cerastoderma edule* held under controlled conditions of tidal emersion and OA under a seasonal temperature cycle.

The bivalve *Glycymeris pilosa* as a multidecadal environmental archive for the Adriatic and Mediterranean Seas

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We evaluated the potential of *G. pilosa* as an environmental indicator for the Mediterranean region by applying sclerochronological techniques. A sample set of shells (N=50) was live-collected from Pašman Channel in the middle Adriatic Sea with individuals ranging in age from 24 to 69 years (N=44, x=45.6±11.4 years), 5 of which were older than 60. There was strongly synchronous growth among individuals, though increments in 18 samples were not clear enough for crossdating and were discarded from further analysis. Once visual crossdating was completed, growth-increment widths in the remaining 26 individuals were measured. Mean sensitivity was 0.178, mean segment series length was 37.3 years, and interseries correlation, representing the mean correlation between each sample and the average of all others, was 0.592. A master chronology was developed by detrending each measurement time series with a negative exponential function (N=23) or 50-year 50% frequency cutoff cubic spline (N=3). A running EPS calculated over a 30-year window indicated the chronology was robust from 1969 - 2013, though the oldest *G. pilosa* was measured back to 1948.

The chronology significantly and negatively correlated with local summer sea temperatures (ST), especially between August (r=-0.464, p=0.017) and September (r=-0.442, p=0.024). There was also a correlation with a multivariate index of circulation (cyclonic vs. anticyclonic patterns) in the northern Ionian Sea (r=-0.536, p=0.012). In summary, reduced growth tends to occur under warm, saline, periods typical of cyclonic regimes. There was also an apparent terrestrial influence in which growth significantly and positively correlated with November precipitation (r=0.410, p=0.020). This is typically the wettest period of the year during which terrestrial inputs would be at a maximum and most likely to influence nearshore processes.

Live and dead *G. pilosa* shells were also collected from the northern Adriatic Sea, and preliminary analysis indicates the longevity of dead-collected individuals is > 100 yr. Given this longevity, clarity of annual increments, and broad geographic distribution, *G. pilosa* has considerable potential to test hypotheses relating to environmental variability and biological response in the Mediterranean. Indeed, the power of such analysis could be further expanded if chronologies from the closely related *Glycymeris bimaculata* and *Callista chione*, for which preliminary data are promising, can be incorporated.

A new method for age and growth rate determinations of the Atlantic surf clam (*Spisula solidissima*), based on internal growth lines in ligament cross-sections

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The Atlantic surf clam (*Spisula solidissima*) is an economically valuable burrowing bivalve widely distributed along the northeastern coast of the United States and Canada. However, stock assessment surveys of Atlantic surf clams in the Middle Atlantic Bight continental shelf show a trend of decreasing maximum shell length over the past 30 years. This trend can be driven by fishery truncation (size selection), increasing bottom water temperature or some combination of both. A prerequisite for any attempt to manage the fishery or monitor the environmental effects on this species is an understanding of *Spisula solidissima* growth rate.

Growth rates of bivalves not only differ among specimens, but they also vary throughout the growing season and from year to year. This strongly suggests that shell growth of bivalves is partly governed by common external drivers. Moreover, many studies have already focused on the potential of marine carbonate skeleton compositions, especially bivalve hard parts to record environmental conditions. Examination of growth lines and increments preserved in hard structures is a relatively fast and cheap method to compare shell growth rates in different localities. Annual lines ("annuli") that are counted and used to age *Spisula solidissima* are clearly visible in surf clam shell cross-sections (both in the outer shell layer and in the well-developped spoon-shaped chondrophore). However, in some cases or in some localities, disturbance lines are undistinguishable from annual lines, thus leading to unreliable results. Further limitations occur in older specimens because the most recently formed lines may be very close to each other, and/or the umbonal region may be eroded thus hampering an accurate age determination. In view of these uncertainties, additional methods for accurately interpreting these annual lines must be investigated. The internal ligament (resilium), which is protected from damage or erosion by the valves and where distinct lines are clearly visible seems to be a good candidate for accurate growth rate studies.

The purpose of the present communication is focused on the analysis of the surf clam population of Saint-Pierre and Miquelon (SPM), located 25 km off the south coast of Newfoundland, for which no growth studies has ever been conducted. The objectives are: (i) to compare the growth lines present on the outer layer of the shell, the chondrophore, and the resilium and (ii) to describe annual growth variations using three different hard parts of *Spisula solidissima* in SPM over the past 25 years. The results obtained from 30 individuals aged from 8 to 27 years old collected in 2015, showed strong correlations between resilium growth lines and the two other shell parts "annuli", especially with the chondrophore ($r > 0.9$). Those first results about surf clam resilium growth lines, will provide a new reliable tool for fishery management of an economically important species. Moreover, the associated knowledge related to the growth of this new archive (resilium) composed of oriented aragonite crystals in an elastic protein matrix, will open new fields of sclerochronological and sclerochemical studies related to *Spisula solidissima* environment and biology along the northeastern coast of America.

The interaction of reproduction and shell growth in the bivalve *Callista chione*

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It is widely accepted that bivalve shell growth responds to environmental factors, however, few studies analyze the influence of biological drivers on growth, including reproduction. We evaluated the reproductive cycle of *Callista chione* as a potential driver of shell formation rate. *C. chione* is a commercially important species and due to its longevity (> 20 years) is an interesting target for sclerochronological studies. Sampling was conducted in two different environmental settings along the eastern Adriatic coast: Pag – a semi-enclosed bay, and Cetina – a coastal site near a river mouth. The monthly collection was carried out for a 18-month period from May 2014 until October 2015. Temperature was measured hourly, whereas Chl a and $\delta^{13}C_{POM}$ were determined monthly. Satellite data for Chl a was also included in the study. The Gonadosomatic Index (GSI) was used as a unit of measure for variation in gonadal mass. The oxygen isotope composition of several shells ($\delta^{18}O_{shell}$), once converted into seawater temperature, was used to determine the duration of the main growth season.

Minimum monthly temperatures differed by ca. 4°C between Pag and Cetina (8.9°C and 12.7°C, respectively), whereas maximum temperatures were similar. Chl a and $\delta^{13}C_{POM}$ values showed distinct temporal trends. A clear seasonal cycle in GSI was observed, however, it was not synchronous between sites. In Pag, GSI started to increase in early spring and reached maximum values during the summer, with a main spawning peak in July. In Cetina, increasing GSI values were observed during winter reaching maximum values in early spring, whereas spawning took place on several occasions during late spring and summer. Based on $\delta^{18}O_{shell}$ values, the fastest shell growth occurred between the winter and summer (> 70%). The difference in temperature ranges may explain the spawning lag observed between sites. The highest temperatures in Pag in 2015 coincided with the main spawning peaks, while in Cetina temperature was inversely related to the GSI throughout the year. A correlative allocation of energy to growth and reproduction was observed at both sites, with a decline in growth after spawning. The highest peaks in Chl a concentration occurred mostly between November and April, a period with an increase in production of gonads. During this period, an inverse relationship of Chl a and $\delta^{13}C_{POM}$ values was observed. More positive $\delta^{13}C_{POM}$ values, indicative of fresh material, were related to periods following the main spawning peaks when the GSI was low; conversely, more negative values were observed during the most ripe stages and maximum spawning peaks. This suggests that the allocation of energy to growth was higher during earlier reproductive stages when nutrients were more abundant, followed by a shift of energy investment toward gonad production and a decrease in nutrients.

Test of North Atlantic sea-surface-temperature reconstructions with pseudo proxy experiments over the last millennium

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We test a Climate Field Reconstruction Method to reconstruct past sea-surface temperature in the North Atlantic Ocean (NA) over the last 1000 years with a sparse network of proxy locations. We use a set of climate model simulations (CMIP5 Earth System Models) and COBE2 reanalysis data in a pseudo proxy approach. With our approach we want to mimic records of an extremely long-lived bivalve shell, *Arctica islandica*, and test whether this local proxy information can be used to make inferences about the SST field of the whole North Atlantic Ocean.

For this test we use the so called Principal Component Regression analysis as one example of a Climate Field Reconstruction (CFR). We carry out a set of calculations with pseudo-proxy locations based on *Arctica islandica*'s collection sites. Practically, the pseudo proxies are the (undisturbed) simulated or reanalyzed grid points co-located with the collection sites of the shells. Since one of the main assumptions of CFR techniques relates to the temporal and spatial stationarity of the relationships between proxy indicators and large-scale climate patterns we tested the reconstructed SST field evolution against different calibration periods.

We found that the evaluation of the CRF reconstruction (in terms of calibration statistics, spatial co-variability structure etc) strongly depends on the individual model simulation used. The correlation between the original and the reconstructed evolution of the SST anomalies is higher close to the proxy locations reaching values of between +0.6 and +1 over the eastern NA. In addition, the calibration period exerts an influence on the reconstruction with the main structure of the spatial correlation pattern between the original and the pseudo-proxy based SST field remaining the same. Subtracting the trend of the SST anomalies in the calibration period during the 2nd half of the 20th century does not affect the results. In future work, in contrast to the ideal pseudoproxies used here, we will use noisy pseudoproxies for which the grid point temperatures will be contaminated with proxy-specific noise based on the characteristics of *Arctica islandica*.

Mid and Late Holocene marine paleoenvironmental reconstructions from Ingøya and Rolvsøya, northern Finnmark, Norway

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Mid and late Holocene *Arctic islandica* shells from raised marine deposits were examined to reconstruct patterns in growth history related to marine conditions in northernmost coastal Norway. *Arctica* shells were collected from two main sites in raised marine deposits on Ingøya (71°05 N 24°03E) and Rolvsøya (70°98 N 24°03 E). Shell-rich mid to late Holocene marine terraces and raised beaches are found from current sea level to the upper limit of the mid-Holocene Tapes Transgression (9 meters asl on Ingøya). The mid-Holocene shells (ca. 6,000 B.P.) were collected from reworked sandy marine and eolian deposits above a raised beach complex at Nordhamna on northeastern Rolvsøya. The late Holocene (ca. 1,500 B.P.) shell samples were collected from a 3 meter high coastal bluff exposure at Østerbotn on central Ingøya in stratified gravelly and sandy shallow marine deposits. Prior to undertaking detailed analyses, shell ages at each site were surveyed using low precision ^{14}C AMS then calibrated (CALIB 7.1, with ΔR of 72 ±18 years) to find shells with overlapping ages that could be used to provide crossdated records of growth increments. The collections from Rolvsøya did not yield specimens of overlapping ages however 5 shells with overlapping ages collected from the bluff section on Ingøya produced a 409 year shell growth series ca. 1,400-1,800 calendar years BP.

Annual growth increments from two mid-Holocene *A. islandica* specimens, dated at 6,245 and 6,011 years B.P, and subsampled for interannual $\delta^{18}O$ analysis establish an annual seasonality and display a narrower range in summer to winter temperatures than currently exist in the region, which is approximately 8°C. Furthermore, the older of the two specimens shows lower overall annual temperatures and a greater seasonal temperature differential than the younger. The inversion of temperature and seasonal amplitude may be a result of diminished vertical water column mixing during warmer conditions.

Trends from both the 400-year late Holocene shell growth series and the detailed $\delta^{18}O$ records indicate substantial variability in the sub-decadal to multi-decal range, possibly related to large-scale ocean-atmosphere dynamics. The late Holocene shell records display a pronounced seasonal signal, with a mean seasonal variation of 4.7°C. These seasonal variations indicate an increase in seasonality through the Holocene, with mid-Holocene (~6,000 calendar year BP) shells having the smallest range in seawater temperature seasonality. Although seasonality increased in the late Holocene shells, modern shell values demonstrate an even larger range in seasonal temperatures.

An integrated spatial data-model approach to reconstructing and understanding Atlantic meridional overturning circulation

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Despite numerous lines of evidence there is still a great deal of uncertainty surrounding our understanding of what drives variability in the Atlantic Meridional Overturning circulation (AMOC) and what influence this variability has on the wider climate system. Here we present analyses of annually-resolved absolutely-dated sclerochronological records spanning past centuries to millennia, from across the western British Isles and north Iceland, along with the PMIP3 (Paleoclimate Model Intercomparison Project phase 3) last millennium climate model simulations, to provide novel insights into past AMOC variability. In contrast to recent AMOC records, these data highlight there is significant multi-decadal to centennial scale variability in AMOC strength throughout the last millennium and that a subtle reduction in AMOC strength was likely a driving force behind the transition between the Medieval Climate Anomaly-Little Ice Age transition (along with solar and volcanics). These data further suggest that a significant proportion of AMOC variability is externally forced. This work highlights the potential power of large spatial networks of sclerochronological records and proxy-model integrated approaches at reconstructing and understanding past ocean variability. These approaches will help to constrain uncertainties in the numeric climate models and ultimately facilitate more accurate predictions of future climate variability.

Annually-resolved North Atlantic marine climate over the last millennium: The ULTRA series

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Numerical climate models predict a significant weakening (~30%) in Atlantic Meridional Overturning Circulation (AMOC) over the 21st century in response to anthropogenic climate forcings. However, the lack of absolutely dated oceanographic information prior to the modern instrumental period limits the direct assessment of the mechanistic role played by North Atlantic Ocean dynamics in previous climate transitions (e.g., Medieval Climate Anomaly-Little Ice Age, MCA-LIA). Here we present analyses of the first millennial-length, annually resolved and absolutely-dated marine archive from the ocean (ULTRA series). Our record of oxygen isotope ratios in the shell of the long-lived marine bivalve *Arctica islandica* (δ^{18}O-shell) from the North Icelandic shelf demonstrates that solar and volcanic forcing coupled with ocean circulation dynamics are key drivers of climate variability. This absolutely-dated series from the North Atlantic provides the opportunity for comparisons with annually-resolved Northern Hemisphere atmospheric series (tree-rings, ice cores) and provides a key, and unique, observational dataset for integration with coupled ocean-atmosphere model simulations.

Geochemical and crystallographic study of two species of cool-water bivalves (*Fulvia tenuicostata* and *Soletellina biradiata*) from southwestern Australia

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This multi-modal study focuses on the structure and composition of two species of marine bivalves endemic to southwestern Australia (*Fulvia tenuicostata* and *Soletellina biradiata*) to gain insight into the physio-chemical processes involved in molluscan calcification and provide a benchmark for monitoring global change in biogenic carbonate. Such studies of temperate Australian marine bivalves are few despite the absence of coral and the need to use other faunal records. X-ray diffraction and Raman spectroscopy analyses reveal that the shells of both species are composed mainly of aragonite with minor calcite and not purely aragonitic as previously documented. Ionic substitution of Mg^{2+} for Ca^{2+} is identified in calcite in *F. tenuicostata* and anisotropic distortions (stretching and shrinking) are consistent with other molluscan species. Electron probe microanalysis and laser ablation mass spectrometry reveal correlations between Mg, S and P in *F. tenuicostata*, and Sr, S and Ba in *S. biradiata*. These results may give insight into the composition of the organic matrix and its impact on elemental composition of the crystalline structure. The combination of P- and S-containing organic macromolecules appears to be facilitating Mg^{2+} substitution in calcite, which might also explain greater lattice distortion in *F. tenuicostata*. The organic macromolecules that constitute the organic shell matrix require further investigation. Although the study of trace element incorporation in biogenic carbonate is important, the composition of the organic molecules is also significant considering it may exert a control on the fine-scale composition and structure of bivalves and other biogenic carbonate.

Advances in developing Antarctic sclerochronogical archives from the marine bivalve *Yoldia eightsi*

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A strong warming trend in west Antarctic has been measured over at least the last 50 years, this is associated with a shortening of the winter season, increased deglaciation and meltwater runoff and warming and freshening of surface waters. These environmental responses are very likely to affect Antarctic ecosystems from shallow habitats to deeper communities. However, investigation of these changes is limited because of a lack of long-term environmental records endemic for Antarctica due to the isolation of the continent and for technical and economic reasons. Annually-resolved sclerochronological archives have now the potential to fill some of the gaps in the instrumental record and even to extend back beyond the establishment of the scientific stations. *Yoldia eightsi* is an infaunal marine bivalve found in shallow waters (mostly down to 100 m) and it is believed to have a circum-Antarctic distribution. We present five chronologies from two Antarctic locations: South Orkney Islands (Signy station) and West Antarctic Peninsula (Rothera station). *Yoldia eightsi* shell growth showed a negative relationship with winter duration ($r = -0.52$, $N=24$, $P \leq 0.01$) and fast-ice duration ($r = -0.41$, $N= 24$, $P \leq 0.05$) and a positive relationship with mean annual sea surface temperature (SST; $r = 0.48$, $N= 24$, $P \leq 0.05$) winter SST ($r = 0.57$, $N= 24$, $P \leq 0.01$) and summer SST ($r = 0.46$, $N= 24$, $P \leq 0.05$) between 1965 and 1988 at Signy. Chronologies developed from adjacent sampling locations at Rothera may offer insights into the local hydrography.

Bivalve Sr/Ca(shell) heterogeneity and microstructures – Are geochemical variations at the micrometer-scale masking potential environmental signals?

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It is still controversially debated if the trace and minor elements of (aragonitic) bivalve shells serve as environmental proxies or largely reflect changes in bivalve physiology and/or crystal kinetics. For example, in controlled tank experiments, Sr/Ca ratios in shells of *Corbicula fluminea* are positively and linearly correlated to Sr/Ca of the ambient water and negatively to temperature (Zhao et al., 2016) – which is in agreement with abiogenically precipitated aragonite. However, the Sr/Ca(shell) values remain ca. four times below that of Sr/Ca(water), and the temperature sensitivity is only -0.02 mmol/mol/1°C as opposed to -0.04 in synthetic aragonite (Dietzel et al., 2004) and, on average, -0.06 in tropical, shallow-water corals (Corrège, 2006). In wild populations of many other bivalve species, distribution coefficients also deviate significantly from that of abiogenic aragonite suggesting that Sr is not incorporated into the crystal lattice of $CaCO_3$ in equilibrium with the ambient water. Furthermore, Sr levels near annual growth lines were much higher than in portions between adjacent growth lines (= growth increment), yet lower than those expected for chemical equilibrium. Surprisingly, no uniform temperature sensitivity seems to exist in wild-grown bivalves, and some authors were unable to identify any clear relationship between Sr/Cashell and temperature.

To study what these discrepant findings may explain, we have conducted an ultra-high resolution mapping (electron microprobe, NanoSIMS) of strontium and sulfur (as a proxy for certain organics) in shells of Cerastoderma edule collected alive from the intertidal zone of the North Sea. Sr levels were strongly heterogeneously distributed at the lower micrometer scale and strongly coupled to the prevalent microstructure (crystal fabrics, shell ultrastructure). In the outer portion of the outer shell layer for example, Sr/Ca ratios were significantly higher at circatidal growth lines (irregular simple prismatic structure; 2.9 ± 0.4 mmol/mol) and lower within circatidal increments (nondenticular prismatic structure; 2.5 ± 0.2 mmol/mol). Shell sulphur-to-calcium ratios showed the opposite distribution patterns, i.e., high values in circatidal increments (2.4 ± 0.3 mmol/mol), low values at circatidal growth lines (2.1 ± 0.5 mmol/mol). Both Sr/Ca(shell) and S/Ca(shell) were at maximum values at annual growth lines (4 and 4.6 mmol/mol, respectively). The intimate link between Sr/Ca(shell), S/Ca(shell) and shell architecture likely indicates that microstructures or the processes controlling their formation exert a strong control over the incorporation of strontium into shells of C. edule. Analytical techniques with lower sampling resolution, e.g., LA-ICP-MS, cannot resolve such fine-scale Sr variations. As a result, the signal-to-noise ratio decreases and the data generated by such techniques do not seem to provide useful paleotemperature data. Future studies should therefore employ a combined analysis of Sr/Ca(shell) and shell microstructures. Sr/Ca(shell) values of shell portions consisting of different microstructures should be interpreted separately.

Spatial distribution of low molecular weight organic matter in micrometer skeletal structure of *Acropora* and *Porites* coral

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Coral skeletons consist of aragonite and organic matter (1–3 wt%) (e.g. Falini et al., 2014). Microstructures in coral skeletons comprise two microstructural components: centers of calcification (COC), and fibers (>96 vol%) (Allison, 1996). Previous studies have focused on elemental distribution (e.g., S, Sr, $\delta^{11}B$, and $\delta^{18}O$) in coral microstructures. Although organic matter is one of the important chemical components for coral biomineralization, only few studies have examined its distribution in micrometer skeletal structure (e.g. Cuif et al., 2005; Mass et al., 2014). The information will resolve the enigma of forming different crystallographic texture of COCs and fibers. Here, we report the first result of the spatial distribution of low molecular weight organic matter (m/z 100–1500) in coral skeletal microstructures using matrix-assisted laser desorption/ionization MS imaging by iMScope TRIO (Shimzau Corporation) at JAMSTEC, Japan. We used branching *Acropora* sp. and massive *Porites* sp. skeletons, collected from Okinawa and Kagoshima, Japan, for the analysis. Coral skeletons were immersed in hydrogen peroxide and sodium hypochlorite solutions to remove coral tissues and organic matters on the surface of coral skeletons. After washing the coral samples via MQ, the samples were embedded in epoxy resin (E205, Nichika.Co.Ltd, Japan). Thin sections of <0.1 mm thickness were then prepared. A matrix of 2,5-dihydroxybenzoic acid (DHB) was vapor-deposited onto the thin section. Measurement pitch and laser diameter of the iMScope were set at <5 μm. Except for the strong peak of resin and glue, specific peaks for each coral specimen were different. The prominent peaks below m/z 450 were observed in positive ion mode for *Acropora* coral specimens. On the other hand, prominent peaks at m/z 300–900 and m/z 650–900 were observed in positive and negative ion modes, respectively, for *Porites* coral specimens. There were no distinct differences observed between COC and fibers in both coral types examined. Further results will be discussed regarding the m/z and composition of organic matter.

Tides & traditions: Insights into indigenous hunter-fisher-gatherer shellfishing with sclerochronology

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Hunter-fisher-gatherers on the Pacific Northwest Coast of North America are renowned for their complex fishing strategies that sustained a storage-based economy for over 6000 years. However, the role of shellfish has often been overlooked in archaeological interpretations. Hunter-fisher-gatherers living on coastal landscapes incorporated shellfish into their diets throughout the course of human history, and in turn, shellfish became incorporated not only as a dietary staple but also as a culturally significant component of their everyday lives. Shellfish were gathered for consumption, construction of shell middens, creation of artifacts, and have been included in many oral traditions, myths, songs, and dances.

Using macro-growth line analysis, the deliberate management of butter clam (*Saxidomus gigantea*) has been identified on the central coast of British Columbia in the traditional territory of the Heiltsuk First Nation. In addition, 'clam gardens' have also been identified in several regions of the Pacific Northwest Coast, providing further evidence for sophisticated intertidal resource management. There is a saying amongst the Tlingit of Alaska and northern British Columbia that 'When the tide is out, the table is set' – in this poster, we explore traditional myths, stories, songs, and art to investigate the cultural significance of shellfish to the peoples on the Pacific Northwest Coast. Integrating sclerochronological analysis alongside Indigenous knowledge and tradition can help to refine archaeological understandings of past shellfish use and the continuity of shellfish harvesting over Holocene.

Determining season of harvest in shells of the European limpet (*Patella vulgata*) from modern and medieval collections

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Shells of the European limpet, *Patella vulgata*, are common constituents in late Holocene archaeological middens along eastern North Atlantic coastlines. Thus, they potentially serve as valuable records of paleoclimate information and human activity. Oxygen isotope sclerochronology is a powerful tool for deciphering seasonal changes in growth temperature (a proxy for seawater temperature) and season of death. A previous calibration study on modern *P. vulgata* demonstrated its utility for reconstructing seawater temperature after correcting for a predictable offset from oxygen isotope equilibrium. Ultra high-resolution microsampling of *P. vulgata* shells at submonthly scale can potentially capture the entire range of seasonal variability assuming growth rates are greater than 1 mm per year. Using isotope sclerochronology, we evaluate the potential of archaeological *P. vulgata* shells to accurately record information on season of harvest. Modern shells were collected alive from Rack Wick Bay off Westray in the archipelago of Orkney, Scotland on 16 August 2006, the warmest month of the year, and eight were selected for isotopic analysis. Five of the modern shells recorded actual seawater temperature at the time of harvest within error, and six shells reflected summer season along the growth margin. Estimated temperature along the growth margins of the other two shells were more similar to mid-spring temperature, likely reflecting a time-averaging bias due to slowed growth with increasing ontogenetic age. Therefore, it is critical to take growth rate into account when estimating season of harvest. Ten archaeological shells from a nearby midden dating to the 12th Century were selected for isotopic analysis, and all specimens had well-preserved margins that lacked signs of abrasion. Estimated temperature from oxygen isotope ratios recorded in the last year of growth suggest harvesting occurred year round.

Reconstruction of humpback whale migration via isotopic analysis of coronulid barnacle shells

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The ecology of the modern great whales is defined by migration, as their immense nutritional needs demand that they traverse thousands of miles to reach the seasonally productive waters on which they rely. Understanding the impact that external pressures have had on migratory behaviors through time would offer new insight into cetacean natural history, yet little is known about whale migration prior to the advent of whaling. A potential proxy for reconstructing whale migration may be found, however, within the calcitic shells of coronulid barnacles (Killingley, 1980). Coronulids – the epizoic crustaceans which live attached to baleen whales – grow their shell plates in measureable daily increments that are each deposited in isotopic equilibrium with the surrounding seawater. Thus a barnacle attached to a migrating whale will preserve within its shell growth bands a high-resolution isotopic signature of the water through which the whale was moving, with progressive changes in oxygen-18 values largely reflecting changes in latitude. Here we present initial isotopic analysis of coronulid shells collected from humpback whales stranded on the coast of California. Eastern Pacific seawater isotope and temperature gradients were used in conjunction with the shell oxygen isotope ratios to interpret the movement of the barnacles' cetacean hosts. Preliminary results indicate that the host whales wintered in waters south of Baja California and migrated to northern California to feed in the summer, a trajectory consistent with the migration patterns of California coast humpbacks. Application of this method has potential use as a means of reconstructing cetacean migration in both modern oceans and in the prehistoric past, allowing us to pursue questions of how previous changes in climate, ocean nutrient distribution, or other extrinsic pressures may have impacted cetacean migratory behavior.

Growth, longevity and stable isotope composition of European date mussels *Lithophaga lithophaga* from eastern Adriatic

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Bivalve mollusc shells are widely used as archives of past variability in aquatic environments. Long-lived species are particularly useful for long-term reconstructions of climatic and environmental signals over decades to centuries. However, most of these species are living in cool marine waters under temperate settings. No equivalent of northern quahogs *Arctica islandica* (>500 years old) or dog cockles *Glycymeris glycymeris* (>200 years old) has ever been found in the Mediterranean. The European date mussel *Lithophaga lithophaga* (Mytilidae) is an endolithic bivalve species boring into calcareous substrates all around the Mediterranean coasts. Although under-investigated, this protected species (listed in the CITES Appendix II) has been suggested to live more than 50 years in the Aegan Sea, and therefore appears as a good candidate for paleo-ecological and paleo-environmental studies.

Here, we analyzed shell growth of 71 specimens collected in July 2013 off Split (Croatia) by counting ridges on the external shell surface. High variations in growth rates between individuals were noted and age of analyzed shells (based on the assumption of an annual periodicity of formation of external ridges) varied from 10 to 54 years (for a shell length of 30.6 to 93.6 mm). According to results of growth modelling using a generalized von Bertalanffy growth function, asymptotic shell length was 107.6 mm while growth coefficient was 0.03 year-1. Both parameters were used to calculate an overall growth performance index that was found to be similar to the one previously calculated in a Greek date mussel population (2.54 vs. 2.42, respectively). In addition, we analysed the oxygen and carbon isotope composition of one shell, randomly selected amongst medium-sized shells. A total of 147 discrete carbonate samples were collected on the shell surface using a micromilling device (2-8 samples per growth increment). Obtained $\delta^{18}O$ results strongly suggest that growth ridges visible on the external shell surface of *L. lithophaga* are formed annually as we counted as many growth increments as $\delta^{18}O$ cycles. The $\delta^{18}O$ values ranged from -0.2 to 2.7 ‰, which equates to a temperature range of 13°C. The reconstructed seawater temperatures varied from 12 to 25ºC, a range in good agreement with measured temperature. Stable carbon isotope values decreased through ontogeny and ranged between -2.05 and 2.32‰. Results of this study provide first stable isotope data for *Lithophaga lithophaga* shells and show potential of this species as geochemical sclerochronological archive.

Great scallop shells as geochemical archives of phytoplankton dynamics in the Bay of Brest (France)

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It is now widely accepted that human activities affect the structure and functioning of coastal ecosystems. One of the most significant consequences are related to changes in nutrient input that can induce changes of trophic conditions (up to eutrophication) and disturbances of phytoplankton dynamics, keystone of the functioning of coastal ecosystems. This includes changes in primary production levels, in bloom frequency, and in the composition of microalgal communities.

However, this global outlook conceals major temporal and spatial disparities. As conventional monitoring time-series are quite sparse and scattered, biological records of environmental variability are relevant tools to gain insight into phytoplankton dynamics over larger temporal and spatial scales. In this context, bivalve mollusk shells, and especially scallops (Pectinidae), appear as valuable biogenic archives as they form their external calcium carbonate skeleton periodically, leading to the formation of concentric growth lines that can be used as chronological landmarks.

Here, we present results of a interdisciplinary project dealing with geochemical information archived in shells of the great scallop Pecten maximus in the Bay of Brest (France). This species is known to form daily growth lines between March and November visible on its calcitic shell surface. An extensive 1-year environmental survey of physical, chemical and biological parameters was carried out in 2011 with a weekly resolution, at the exact location of a large scallop population. Several scallops were then collected at the end of this survey and analyzed for their shell geochemical composition. We focus here on results dealing with lithium and molybdenum concentration of seawater, soft tissues and shells.

Our results highlight that phytoplankton dynamics can explain the incorporation of these elements in shells, both through trophic (Mo) and dissolved (Li) pathways, that can in turn be used as proxies and archives for ecological processes in coastal waters.

Environmental variability revealed in sclerochronological records of *Arctica islandica* from the northern North Sea

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The shortness of the instrumental records and the lack of high resolution marine paleo records limit our understanding of climate dynamics and climate change in the North Sea. For extratropical marine reconstructions bivalves have been shown to provide a useful archive with high temporal resolution. The species, *Arctica islandica* is unique due to its exceptional longevity combined with sensitivity to changes in environmental conditions. It also has a wide geographical distribution, and previous investigations have successfully shown that sclerochronological records of this species from both sides of the North Atlantic can be used for the climatic reconstructions.

In this study we investigate the impact of climate variability on sclerochronological records of *A. islandica* from the northern North Sea - the major gateway for the inflow of Atlantic water in the North Sea. We use shells of *A. islandica* collected by dredging along the seabed on the Viking Bank (North Sea) at depth around 100 meters. The growth patterns of living and subfossil specimens were analysed using acetate replicas made from polished and etched cross-sections of individual shells. The annual growth bands were determined and growth increments widths were measured. By cross-matching 28 individual increment-width time series we build an absolutely dated 187-year long shell-growth chronology. The relatively high Rbar (>0.5) and EPS (>0.85) values suggest strong environmental forcing on the shell growth within the population. Therefore, ongoing work mainly focuses on comparing the shell-growth chronology with existing observational time series of climatic parameters to determine controlling factors and test the use of growth chronologies for climate reconstruction in this area. For reconstructing seasonality we analyse the stable isotope ($\delta^{18}O$, $\delta^{13}C$) composition of the shell carbonate by milling individual growth increments. Future work includes the development of an annually resolved oxygen isotope record and subsequent temperature reconstruction.

Low-frequency variability in a centennial-length biochronology of Bering Sea Pacific ocean perch (*Sebastes alutus*)

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Productivity and functioning of Bering Sea marine ecosystems are tightly coupled to decadal-scale environmental variability as exemplified by the profound changes in community composition that followed the 1976/77 shift from a cool to a warm climate regime. Longer-term ecosystem dynamics, including the extent to which this regime shift was exceptional in the context of the past century, remain poorly described due to a lack of multi-decadal biological time series. To address this issue, we applied dendrochronology (tree-ring science) techniques to the otolith growth-increment widths of Pacific ocean Perch (*Sebastes alutus*; POP) in the eastern Bering Sea. Two chronology development techniques were applied: i) a regional curve standardization (RCS) approach designed to retain as much low-frequency variability as possible, but at the expense of adding uncertainty, and ii) a "negative exponential" approach that maximized ability to detect interannual variability. The RCS chronology spanned the years 1923–2006, significantly ($p < 0.001$) and positively correlated with sea surface temperature, and was characterized by a profound, sustained shift from relatively slow to relatively fast growth beginning at 1976/77. The years following 1976/77 were characterized by the highest levels of growth on record, which was corroborated by the negative exponential chronology. Ultimately, these chronologies underscore the susceptibility of fish biology to extreme and uncommon low-frequency events, and provide clues on how future global warming may alter growth rates of POP.

The Mediterranean Sea during the Pleistocene – bivalve shells and their potential to reconstruct decadal and seasonal climate signals of the past

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Understanding the climate of the past, in particular seasonal temperature amplitudes, is essential to evaluate the effects of future climate change on marine ecosystems. The Mediterranean is of particular importance, because of its crucial role in modern ocean atmosphere phenomena such as the North Atlantic Oscillation (NAO). We analyzed fossil shells of the bivalve *Arctica islandica* collected from Pleistocene successions in Central and Southern Italy (i.e., Rome, Lecce and Sicily). According to preliminary biostratigraphic data the studied deposits belong to the middle Calabrian, between 1.2-0.9 Ma for the Sicily outcrop and 1.4-1.2 Ma for the Rome and Lecce outcrops. Prior to isotope geochemical analysis confocal Raman microscopy measurements were conducted to detect potential diagenetic alterations (e.g., from aragonite to calcite). The seasonal water temperature amplitude was reconstructed using stable oxygen isotope ($\delta^{18}O$) values, which were derived by micro-milling and Isotope Ratio Mass Spectrometry. Analysis of the growth patterns (on-going research) revealed ontogenetic ages of up to 210 years. These time series are used for the identification of multi-year (i.e., decadal) patterns, such as the NAO. First results of our study indicate that seasonality was remarkably low during the studied geological epoch. This is in sharp contrast to previous assumptions according to which the simultaneous occurrence of boreal (*A. islandica*) and warm-water species in the Mediterranean Sea during the Pleistocene can be explained by high seasonality. Different links and scenarios on a regional as well as a bigger scale will be discussed.

Do oxygen isotope ratios in unionid shells reflect continental African hydroclimate variability?

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Freshwater bivalves (unionids) are ubiquitous in many different types of river ecosystems. In their shell carbonate, in situ changes in riverine stable isotope signatures and element abundances are recorded. Microsampling of the growth increments in the shells allows high-resolution reconstruction of intra-annual changes in ambient river water geochemistry. Our study evaluates if the oxygen isotope composition in unionids can be used as proxy for variability and changes in African river hydrology and precipitation, on a local to continental scale. Between 2010 and 2015, bivalve specimens were collected from various rivers and small lakes across the African continent (Niger, Mali, Central African Republic, D.R. Congo, Kenya, Botswana, Zimbabwe, Namibia, and South Africa). Oxygen stable isotope ratios in the shells ($\delta^{18}O_{shell}$) were measured in order to reconstruct those in ambient water ($\delta^{18}O_{water}$). Values are compared to a published model of isotopes in precipitation ($\delta^{18}O_{precipitation}$), and to measured $\delta^{18}O_{water}$ at monitoring stations (GNIP and GNIR data from the IAEA, Vienna; own data). A continental-scale isoscape of the amplitude of $\delta^{18}O_{shell}$ was constructed and evaluated against amplitude of $\delta^{18}O_{precipitation}$. We find that the amplitude of bivalve $\delta^{18}O_{shell}$ tends to correlate with the amplitude of $\delta^{18}O_{precipitation}$ along a cross-continental transect through sampling locations. Intra-annual variability of $\delta^{18}O_{shell}$ in central Africa is relatively low, between -4.0 ‰ and -2.0 ‰ around the equator and between -4.0 and 0.0 ‰ at 5° N. Towards southern Africa, the seasonal range increases to 6.9‰, reflecting both temperature and $\delta^{18}O$-water variability. By contrast, specimens from Niger show a 12‰ range, from -8.0 to +4.0‰, and specimens from an ephemeral lake tributary in Mali show previously unrecorded $\delta^{18}O$ values ranging up +11.3‰, reflecting contrasting humidity and highly evaporative conditions. Positive departures from $\delta^{18}O_{precipitation}$ reflect evaporation during dry season (Sahel region) or lake evaporation (e.g. Nile downstream Lake Victoria). Small negative departures probably relate to rainfall quantity during wet-season (tropics). Secondly, we find that shell $\delta^{18}O$ accurately reflects river water $\delta^{18}O$ and can be used to quantitatively reconstruct periods of low discharge (<6000 m^3s^{-1}) and qualitatively reconstruct periods of high discharge, if the relationship between river $\delta^{18}O$ and discharge is known. Our data provide evidence that freshwater bivalve $\delta^{18}O$ is an extremely valuable proxy for the reconstruction of local to continental-scale variability in African hydroclimate.

Short-term climate variability in Central Europe during the Oligocene – A story told by glycymerids

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The Oligocene was a geological epoch during which dramatic changes occurred in the Earth system, amongst others the onset of the Antarctic glaciation that gave rise to the present Icehouse world climate, and the largest extinction event of the Cenozoic, the Grande Coupure. The present study used shells of *Glycymeris planicostalis* and *G. obovata* from Lower (Rupelian) and Upper (Chattian) Oligocene strata of Germany and Belgium to shed light on the short-term climate variability of Central Europe during this time interval, an aspect, which remained poorly studied until now. Glycymerids are one of the most common fossil bivalves of Cenozoic shallow water deposits of Europe. Particularly during the Oligocene, they developed into thick-shelled and long-lived forms that inhabited the coasts of epicontinental seas.

As indicated by seasonally resolved stable oxygen isotopes data, the studied bivalves grew their shells during both seasonal extremes, whereas a growth cessation occurred in fall. Reconstructed temperatures suggest environmental conditions similar to the modern northwestern Mediterranean, with temperatures ranging between 10°C in winter and 24°C in summer. According to annual growth patterns, the studied specimens lived for up to 155 year (on average, 70 years). Spectral analyses of standardized growth index chronologies revealed statistically significant signals on quasidecadal time scales, mainly around 5 years, closely resembling the interannual frequencies of the El Niño – Southern Oscillation. This points to an enhanced Pacific climate teleconnection to Europe during the Oligocene. We further investigated the extent and the pathways of this teleconnection using numerical climate models. Simulations indicate that the Aleutian Low and Icelandic Low were stronger linked with each other than today, which is likely related to a wider North Pacific Basin. As a result European SST were stronger synchronized to the Pacific equatorial climate variability at that time.

Highly dynamic marine radiocarbon reservoir effect in the Gulf of Maine since AD 1685

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Based on a multicentury, crossdated master shell growth chronology derived from annual increments in *Arctica islandica* shells collected from the central coast of Maine in the Gulf of Maine (- 38 m), we developed a continuous time-series of the marine radiocarbon reservoir effect to assess the variability in the local marine radiocarbon reservoir offset (ΔR). Labrador Slope Water (LSW) and Warm Slope Water (WSW; derived from Gulf Stream waters) likely represent end-member source waters to the Gulf of Maine. Based on 33 radiocarbon samples over a 250-year interval, this decadal scale record reveals abrupt and frequent changes in source waters to the Gulf of Maine. The median ΔR value was 68 years with an average value of 77.8 ± 70 years, perhaps representing a typical admixture of LSW and WSW in the Gulf of Maine. Maximum and minimum ΔR values were 222 years and -59 years, respectively, with a total range of 281 years. From AD 1685 to AD 1850 ΔR values decreased gradually with decadal variability indicating a larger contribution of WSW into the Gulf of Maine. After AD 1850, ΔR values increased rapidly suggesting a renewed influence of LSW until AD 1900. From AD 1900 to AD 1935, ΔR values were generally around 100 years. Ongoing work is investigating the potential relationships among the ΔR record in the Gulf of Maine and large-scale ocean circulation dynamics in recent centuries. Finally, these results from the absolutely dated master shell growth chronology indicate that using a constant ΔR value to constrain marine sediment age/depth models via radiocarbon in the Gulf of Maine is invalid.

Assessing seasonal variability and archaeological season of harvest in north-central coastal Peru using the short-lived bivalves *Donax obesulus* and *Mesodesma donacium*

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Archaeologically, bivalves provide information about not only local environment but also human behavior. Some long-lived bivalves (e.g., *A. islandica*, *P. generosa*, *S. gigantea*) have also been used to provide paleoclimatic reconstructions as a time series of variability. However, long-lived organisms are rare in coastal Peru requiring the use of short-lived organisms to reconstruct seasonal variability for select time intervals. Monte Carlo simulations suggest short-lived bivalves are better poised to record seasonal variability than single foraminifers (2–3 month life span) due to their longer life span (1–3 years). *Mesodesma donacium* (a short-lived bivalve) has been used to reconstruct season of harvest, which is crucial to understanding prehistoric human subsistence systems, and the variability of past seasonal cycles. Studies in central and southern coastal Peru using $\delta^{18}O$ seasonal cycles in *M. donacium* reveal similar variability between modern and 2900 BP ($\delta^{18}O$ seasonal cycle = ~1‰). However, *M. donacium* is vulnerable to die offs from warmer sea surface temperatures (SST) during El Niño events, possibly biasing its seasonal $\delta^{18}O$ cycle towards La Niña conditions. Furthermore, *M. donacium* is functionally extinct north of ~14°S, making modern calibrations biased toward colder surface waters. Lastly, spatial and temporal gaps exist in previous reconstructions as they lack archaeological sites north of 10°S and *M. donacium* specimens from 2900 to 800 BP. We assess the ability of *M. donacium* and *Donax obesulus*, a short-lived bivalve with warm water temperature preference, to record season of harvest and seasonal $\delta^{18}O$ variability on the north-central coast of Peru (9°11'30.38" 78°23'30.97") in archaeological (2400 ±100 BP) and modern contexts. Initial $\delta^{18}O$ results from an archaeological *M. donacium* specimen (MA266-1) reveal a $\delta^{18}O$ seasonal cycle of 1.1‰ confirming seasonal variability similar to modern conditions noted by previous studies. We interpret the $\delta^{18}O$ value from the ventral margin of MA266-1 as austral spring (~25% of cycle) for seasonal of harvest. *D. obesulus* (life span 1–3 years) is an intertidal clam found in both modern and archaeological contexts at our study site. The mean seasonal cycle of $\delta^{18}O$ (0.9 ±0.46‰, 1σ) from 12 *D. obesulus* (6 modern, 6 archaeological) specimens confirm this species' ability to record seasonal cycles. Season of harvest for modern specimens was austral winter (July 2012), but varies in archaeological specimens. *D. obesulus* exhibit a -0.77‰ change in mean $\delta^{18}O$ value (modern = 1.02‰, archaeological = -0.25‰) suggesting a shift in salinity and/or temperature. The greater mean $\delta^{18}O$ seasonal cycle range recorded by *D. obesulus* archaeological specimens (1.6±0.5‰, 1σ, n=6) compared to previous studies using only *M. donacium* (~1‰) indicates that climatic conditions ~2400 BP may have been more variable than previously understood. Our results confirm *M. donacium*'s cold bias, necessitating combination of these two proxies for a complete picture of climate and human activity in prehistoric coastal Peru.

An annually resolved, shell-derived oxygen isotope record since the late Little Ice Age from the Gulf of Maine: Implications for ocean circulation changes in the western North Atlantic

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Recent studies have suggested that Gulf of Maine waters are warming faster than 99.9% of the global ocean. However, despite the fact that it is one of the longest (110 years) on the east coast of North America, the instrumental record in the region is relatively short and therefore limits our ability to evaluate whether this recent warming is outside of the range of natural variability of regional water temperatures. Additionally, the short instrumental record impedes our understanding of which major climate parameters may be influencing these changing hydrographic conditions.

In order to address these challenges in evaluating recent Gulf of Maine warming, we have developed an annually resolved oxygen isotope ($\delta^{18}O$) record from the Gulf of Maine that spans the past 250 years. This record was developed from crossdated *Arctica islandica* shells collected in the western Gulf of Maine in 38 meters water depth. The $\delta^{18}O$ record has a strong inverse relationship with sea surface temperatures (SSTs) recorded at Boothbay Harbor, Maine (~17 km distance) for the time period during which the two records overlap (1906-2013), with 51% of the variance in the $\delta^{18}O$ being explained by the instrumental SST record. Therefore, $\delta^{18}O$ from *A. islandica* shells appears to be a suitable proxy for Gulf of Maine SSTs.

The $\delta^{18}O$ record reveals that the Gulf of Maine had been cooling for the 150 years before the start of the instrumental record and that recent warm seawater temperatures are not unique in the last 250 years. This record has strong correlations with the Florida Straight (related to surface Atlantic Meridional Overturning Circulation - AMOC) instrumental record ($r = 0.92$, $p<.015$, 4 year lag, 3-yr running average) and modeled AMOC ($r = 0.70$, $p<.015$, 5 year lag, 3-yr running average, October) indicating that AMOC may be a primary driver of Gulf of Maine hydrographic dynamics. Therefore, it seems likely that recent warming in the Gulf of Maine is due, at least in part, to a weakening of AMOC strength, which may be related to anthropogenic climate change.

Comparing climate signals obtained from encrusting and free-living Southwest Greenland coralline algae

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Coralline algae have been widely used for sclerochronological studies throughout the last decade. These studies have focused on two different growth morphologies of the photosynthetic coralline algae, including massive crusts forming small buildups on hard substrate, and free-living branching algal nodules, known as rhodoliths. The latter are generally found on soft-substrate, where they are frequently overturned by water movement and bottom feeding organisms, leaving one side of the rhodolith partially buried in the sediment at any given time. The purpose of this project is to test whether one of the two growth morphologies is more suitable for proxy reconstructions. For our test we have chosen to analyse specimens of the long-lived alga *Clathromorphum compactum*, a commonly used proxy archive, from Nuuk Fjord, Greenland, which is the only location known to date where this species forms both encrusting and free-living morphologies. In addition , *Lithothamnion glaciale*, a shorter lived rhodolith proxy archive was also collected in Nuuk Fjord. Two to three transects of laser ablation ICP-MS measured Mg/Ca ratios separated by at least 3mm and spanning 18 years of growth were analysed on sections of two encrusting *C. compactum* specimens and along different sides of five *C. compactum* and three *L. glaciale* rhodoliths. Monthly values from multiple transects within each individual were compared and significant correlations were found in 3 of 4 encrusting *C. compactum* transect comparisons, 8 of 13 *C. compactum* rhodolith comparisons, and 5 of 9 *L. glaciale* rhodolith transects. Averaged transects from each sample were compared with other samples of the same algal morphologies. Significant correlations were found between both of the two encrusting *C. compactum* samples, 6 of 10 *C. compactum* rhodoliths, and all three of the three *L. glaciale* rhodoliths. Finally, all of the transects from each of the three types of coralline algae were annually averaged and the encrusting C. *compactum* and *L. glaciale* transects correlated significantly with a sea surface temperature record (HADSST) from Nuuk Fjord, while the *C. compactum* rhodolith record did not. In summary, while individual coralline algal transects show high intertransect and interspecimen variability, averaging of multiple records reduces variability and produces a record more consistent with regional temperature observations.

Impact of skeletal heterogeneity and treatment method on interpretation of environmental variability from the skeletons of deep-sea gorgonian corals

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The proteinaceous skeletons of deep-sea gorgonian corals hold a wealth of information about past ocean conditions. These long-lived corals form hard skeletons with alternating concentric growth bands of calcite and gorgonian skeleton. They act like living sediment traps, preserving isotopic records of their food, particulate organic matter originating in surface waters, in their skeletons. To realize the full potential of deep-sea gorgonian corals as bioarchives of past ocean conditions, we must better understand the preservation of isotopic signals in the coral material. Here, we use a suite of gorgonian corals collected from four sites in the NE Pacific Ocean to quantify effects of acidification treatment to remove the calcite skeleton and intrinsic biological variability on the carbon and nitrogen stable isotope composition of coral tissue and gorgonin skeleton. We found that the stable carbon isotopic composition ($\delta^{13}C$) was significantly higher in acidified material due to the removal of calcite with an isotopic composition influenced by ambient dissolved inorganic carbon at depth. The $\delta^{13}C$ values were significantly lower in the tissue relative to the skeleton in samples with the calcite removed. Based on compound specific isotope analyses of the individual amino acids (AAs) in the tissue and skeleton, this difference cannot be explained by differences in the essential and non-essential AAs $\delta^{13}C$ values between the material types but could reflect differences in AA composition. We found that the stable nitrogen isotopic composition ($\delta^{15}N$) significantly differed between acidified and non-acidified material, indicating a pretreatment effect of acidification on the geochemistry of the coral skeleton. With either treatment, the $\delta^{15}N$ values were significantly lower in the skeleton than the tissue, which reflects differences in the AA composition and their respective isotopic signatures between the material types. The average standard deviation from the acidified skeletons of multiple specimens located at one site was 0.9‰ for $\delta^{13}C$ and 0.8‰ for $\delta^{15}N$, which is significantly higher than typical instrumental uncertainty of ±0.2‰ reported by many stable isotope laboratories. Taken together, these results indicate caution must be taken when interpreting the bulk stable isotope values of coral material, particularly when comparing values across treatment methods and material types. Quantifying these isotopic offsets inherent to the coral animals will significantly improve our ability to interpret deep-sea coral stable isotope values as paleoproxies of past ocean conditions.

Seasonal timing of shell and tissue growth in *Arctica islandica*

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The bivalve *Arctica islandica* is a well appreciated biochronicle on basis of which climate reconstructions are made for the shelf seas bordering the North Atlantic. The basis of these reconstructions are the annually deposited growth lines and growth increments.

Resolution and interpretation of these studies can be improved if there is a better understanding of timing of shell growth, tissue growth and timing of the growth line deposition.

To obtain this knowledge, we performed a series of simple growth experiments in semi natural conditions. In the first experiment shell size of juvenile Arctica was monthly re-measured over a period of three years. In the second experiment shell growth, tissue growth and the period of growth line formation were estimated by monthly random sampling of specimens of which shell size was known at the start of the experiment and of which the change in body condition could be estimated on basis of a reference group of animals. Latter shell samples were sectioned to check in which month and what percentage of animals had formed the growth line.

The results show that highest shell and tissue growth rates are found in the spring bloom and early summer period (March-June). In this period about 50% of the annual achieved shell growth is attained. In this period the animals obtain their highest body mass condition. The sectioning of monthly taken samples showed that at the end of summer (August) 100% of the animals had formed the annual growth line.

Continuous ^{14}C analysis of marine carbonates by laser ablation coupled with AMS

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A new method for direct and continuous ^{14}C analysis of carbonates is presented, where a laser ablation (LA) cell is coupled to the gas ion source of an accelerator mass spectrometer (AMS). By focusing a pulsed laser beam (ArF excimer laser 193 nm, 200 – 250 Hz) on the sample surface, CO_2 is produced, which is directly and continuously introduced into the gas ion source and analyzed for radiocarbon. A positioning system allows precise movement of the sample relative to the laser beam. Hence, scanning along the growth axis of a sample allows recording a continuous ^{14}C profile. In contrast to conventional methods that require discrete sampling, such as drilling and subsequent graphitization, minimal sample preparation is required with the novel method, thus making an exceptional sample throughput possible. This new method is a potent tool for establishing a quick overview of the ^{14}C signature of a sample. Accuracies on the order of 1 % for a modern sample and a spatial resolution down to 100 µm can be achieved. The mean blank level $F^{14}C$ of 0.013±0.004 of the setup is determined by scanning a marble sample, enabling to measure samples as old as 35000 years.

LA-AMS can be used for the analysis of terrestrial and marine carbonate samples, such as stalagmites, corals, shells and otoliths. Here, we present the analysis of a shell section of the species *Arctica islandica*. Its ^{14}C profile covering 50 mm could be established within 40 min. Initially it was assumed that the shell contained the bomb ^{14}C peak. The LA-AMS analyses revealed that the shell must be substantially older, which was afterwards also confirmed by one graphite sample. Furthermore, the otolith of a red snapper (*Lutjanus campechanus*) -only a few hundred micrometers thick- was analyzed by LA-AMS and the ^{14}C signature recorded for the lifespan of the fish. Pre-bomb and peak ^{14}C were detected, indicating the fish was more than 50 years old.

Effects of calcium availability on shell growth rate and element composition of *Corbicula fluminea* (*Bivalvia*)

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Element impurities in bivalve shells potentially record physicochemical changes of the ambient environment during growth. Of particular interest are divalent cations that can substitute Ca^{2+} in the crystal lattice. However, the underlying mechanisms responsible for their incorporation into the shells have not yet been fully elucidated. It is commonly assumed that Ca^{2+} and other divalent ions may share the same transport mechanisms because of similar ionic radii and electrochemical properties. So far, little effort has been devoted to support this hypothesis. To disentangle the role of Ca^{2+} in shell formation and elemental incorporation, specimens of the Asian clam (*Corbicula fluminea*) were reared for four weeks in three sets of experiments: (1) different aqueous Ca^{2+} levels (3, 4, 5 and 6 mM); (2) the presence of Ca^{2+}-channel blockers (lanthanum: 1 and 10 mM; Verapamil: 0.1 and 1 mM), and (3) the presence of a Ca^{2+}-ATPase inhibitor (ruthenium red: 0.1 and 1 mM). Our findings demonstrate that different Ca^{2+} levels in the water did not significantly affect the rate of shell growth. Likewise, the two Ca^{2+}-channel blockers had little effect on shell production. However, exposure to 1 mM ruthenium red led to ca. 32 % reduction of the shell growth rate. On the other hand, with increasing water Ca^{2+} level, the amounts of Mn, Cu and Sr incorporated into the shells decreased, whereas the Zn, Ba and Pb contents remained relatively constant. Blocking the Ca^{2+}-channels significantly reduced the incorporation of Mn, Cu, Zn and Pb into the shells and Mn/Ca_{shell} and Cu/Ca_{shell} decreased simultaneously when inhibiting Ca^{2+}-ATPase. Nevertheless, neither Sr/Ca_{shell} nor Ba/Ca_{shell} were changed implying intracellular Ca^{2+} transport mechanisms are not responsible for their incorporation into the shells. Findings of the present study may help to better understand the mechanisms responsible for the element partitioning between the ambient water and the shells.

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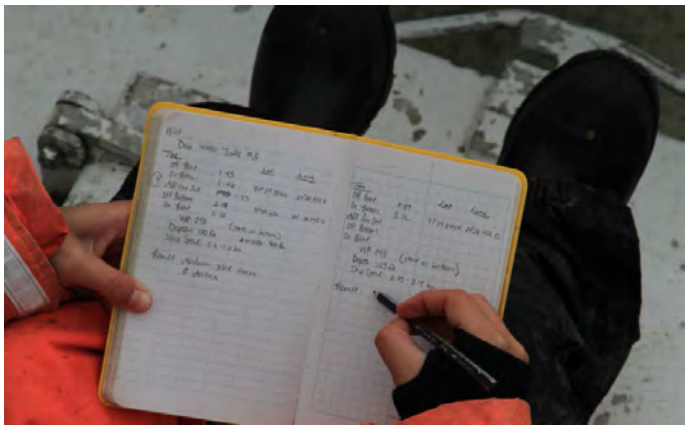

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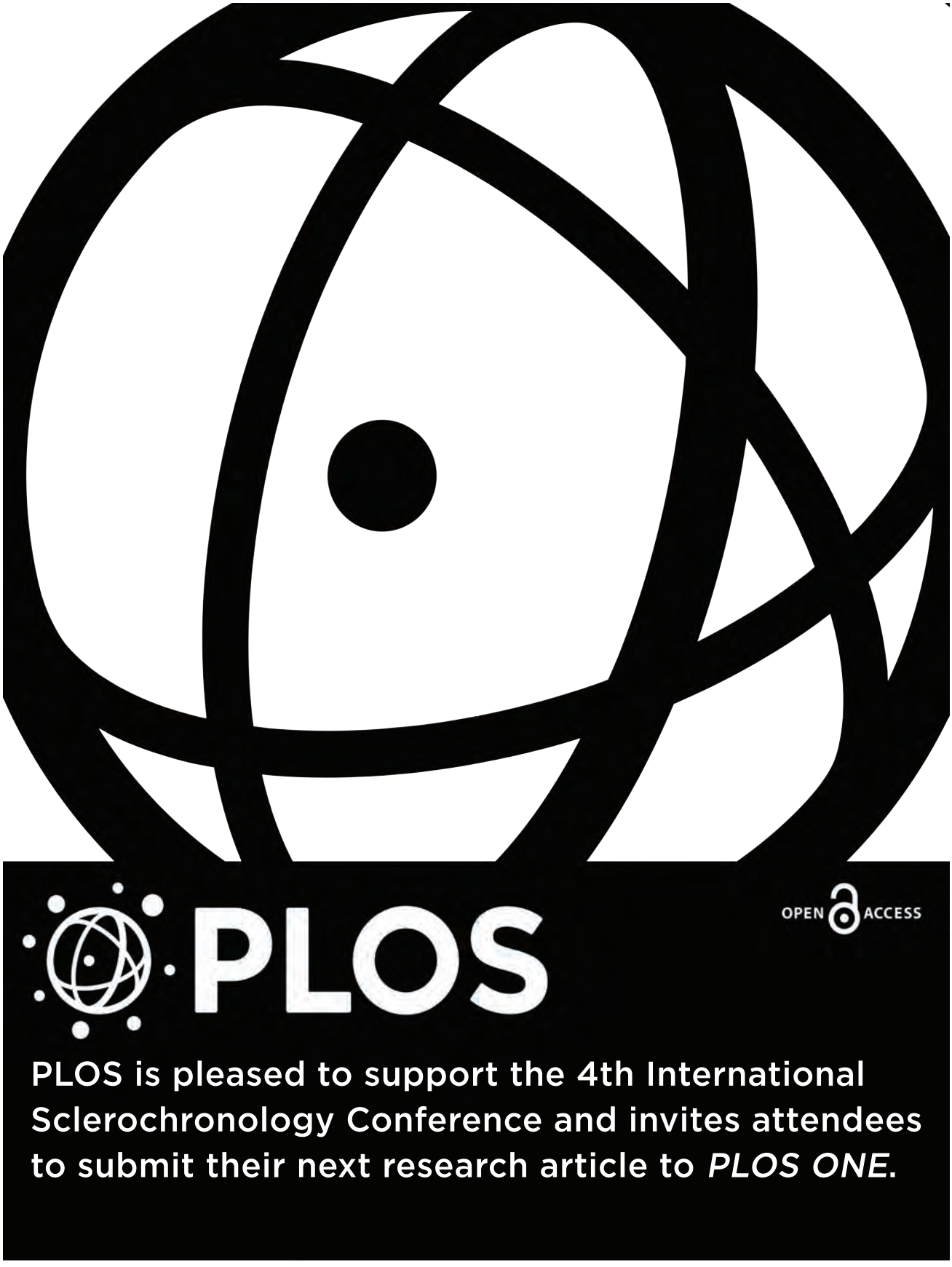
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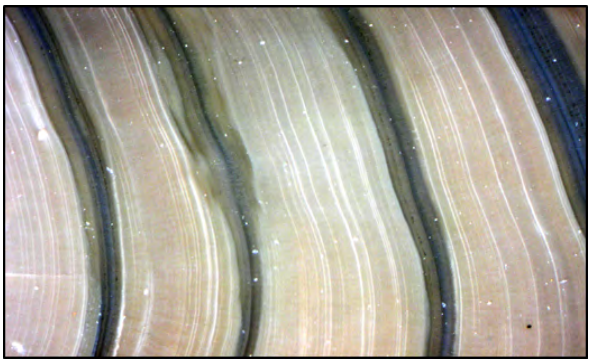

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