Book of Abstracts

5th International Sclerochronology Conference

16-20th June 2019 Split, Croatia

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16-20th June 2019 Split, Croatia

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Abstract Volume

Editors: Melita Peharda, Daria Ezgeta-Balić, Hana Uvanović
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Dear Friends and Colleagues,

On behalf of the Conference Organising Committee we would like to welcome you to the beautiful City of Split and to the 5th International Sclerochronology Conference (ISC2019) organized by the Institute of Oceanography and Fisheries (www.izor.hr).

This Conference marks a small jubilee – scientists and students interested in sclerochronology gathering together for the fifth time. Since the first International Sclerochronology Conference in St. Petersburg, Florida in 2007, our sclerochronology community has grown both in numbers and geographically. This conference in Split covers research conducted on all the continents, from the traditionally well represented Europe and North America, to Asia, Australia, Africa, South America, and even Antarctica. We wish a warm welcome to all of you traveling from near and far, and thank you for taking the time to participate in ISC2019.

Special thanks to our keynote speakers: your experience and viewpoints give direction to our eight conference sessions. Coming from a research institute with a strong fisheries component, we are especially pleased that the session on Fisheries Ecology and Management has generated such great interest and that fish-based research has also been included in several other conference sessions. The need for organising a conference that would gather scientists interested in bivalve shells and fish otoliths, arose at the ISC2013 in Wales, and we are proud to have achieved this. Based on your submissions and interest, one of the main challenges faced by the sclerochronology community is the commercial application of our research, and this is certainly something that we should address in the future. The research presented at the ISC2019 is highly diverse with respect to topics and taxa and we hope that you will have a productive meeting resulting in new international and interdisciplinary collaboration.

Work hard, play hard. And Split is a great place for all this. The conference venue is Faculty of Medicine, University of Split, located about 10 minutes from the nearest beach (possible lunch break swim) and just under 30 minutes to the city centre by foot (of course, public transportation and taxis are available). Split has a rich history and cultural heritage – with the 1700-year old magnificent Diocletian's Palace at its very heart. Riva - the seafront promenade in the centre, Peristil Square in front of St. Domnius' Cathedral and the Bačvice sandy beach are just a few of the spots you should certainly visit while in Split. Croatia has excellent olive oil, cheeses, fish - so do not forget to enjoy your evenings in town and take home some of these flavours. We have a great conference and social programme set up for you and hope that your time in our city will have unforgettable.

Preparations for this conference were conducted within the framework of SCOOL and NurseFish projects financed by the Croatian Science Foundation.

We would especially like to thank our sponsors and the members of the Scientific Committees who contributed to the conference organisation and made this possible.

Hvala,

Organising Committee

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Photo by Mišo Pavičić

Keynote Abstracts

Towards an integrated synthesis of Earth's coupled marine-terrestrial systems

Bryan A. Black[1*]

[1]Laboratory of Tree-Ring Research, University of Arizona, USA

**presenting author: bryanblack@email.arizona.edu*

The pace of sclerochronological research has dramatically accelerated over the past two decades, culminating in an increasingly global network of absolutely dated, well-replicated archives from the calcified structures of bivalves, fish, and corals. These records provide uninterrupted multi-decadal to millennial histories of ocean climate and ecological processes that can be readily integrated with observational physical or biological records. As such, the discipline is positioned for unprecedented synthesis across spatial scales, trophic levels, habitats, and functional types to establish climate-biology relationships, test hypotheses of ecosystem functioning, conduct multi-proxy reconstructions, and provide constraints for numerical climate models. Combining these annually-resolved marine records with the global network of tree-ring chronologies will enable unprecedented synthesis of ocean-atmosphere trends and interactions at hemispheric scales. In the coming years, these 'present-past-future' perspectives will provide multi-faceted, broad-scale insights into ocean climate, its role in marine ecosystem functioning, and interactions with the atmosphere and terrestrial ecosystems.

Session: Climate and Oceans: Past, Present and Future

A view into the abyss; have we seen the limits of sclerochronology?

Steven Campana[1*]

[1]Life and Environmental Sciences, University of Iceland, 101 Reykjavik, Iceland

**presenting author: scampana@hi.is*

Sclerochronology has achieved mainstream acceptance in science, with the use of everything from climate chronologies based on coral banding, to the millions of fish otoliths used as the basis for global fisheries management. Indeed, it now seems that all animals can be aged using periodic growth increments, if given the appropriate funding and research. Or can they? There is a troubling minority of species that seem to resist all attempts at age determination, at least to a reasonable level of precision. Are we now limited by our poor understanding of the processes responsible for annual growth increment formation in organisms? In this talk, I will avoid talking about the great successes of sclerochronology as applied to fish and fisheries, and instead focus on its limitations and the reasons for its occasional failure. I will conclude by attempting to answer the question: at what point does the elegance of sclerochronology need to be pushed aside in favour of 'brutish', but more accurate, alternate approaches?

Session: Fisheries Ecology and Management

Direct cellular activity drives the fabrication of some invertebrate microstructures

Antonio Checa[1*]

[1]Departamento de estratigrafía y Paleontología, Universidad de Granada, 18071 Granada, and Instituto Andaluz de Ciencias de la Tierra, CSIC-Universidad de Granada, 18100 Armilla, Spain

**presenting author: acheca@ugr.es*

In biomineralization, microstructures can be defined as aggregates of biocrystals with recurrent 3D arrangements and morphologies. Microstructures consist of a mineral phase associated with a minority organic phase. The resulting biocomposite possesses biomechanical properties well above those of its individual components. Microstructures produced by invertebrates are made by calcite and/or aragonite. They are highly diverse and well-ordered and most usually look very different from inorganic aggregates. Molluscs are by far the group with the widest variety of microstructures, followed by other groups like brachiopods and bryozoans. How microstructures are fabricated by these animals is a central theme in biomineralization. A common tenet is that the organic phase is able to control most, if not all, aspects of microstructures. Nevertheless, in recent years, there is increasing evidence that physical processes, such as crystalline competition or physical self-organization processes may explain the internal arrangements of crystallites and organic membranes. In other instances, the morphologies and/or distributions of such components cannot be the result of such physical operators. This study will focus on three different microstructures: the calcitic/aragonitic columnar prismatic and the aragonitic helical fibrous microstructures of molluscs, and the calcitic fibrous microstructure of brachiopods. In all three instances, either the morphologies/dimensions of the organic networks, the non-crystalline shapes of crystals or the presence of some associated nanostructures strongly suggest that the cells of the underlying mantle act in a coordinated fashion in order to detect the organic and mineral component elements and continue their secretion. Direct cellular activity on the fabrication of such microstructures is also consistent with what is known about the mantle-shell relationship in those invertebrate groups. This indicates that the mantles of some molluscs and brachiopods have unsuspected sensorial and secretional sub-cellular abilities. The unveiling of fabricational strategies of microstructures has relevance in adaptive morphology and evolution, and is crucial in biomimetics.

Session: Biomineralization

Bivalve sclerochemistry: challenges and opportunities

David P. Gillikin[1*]

[1]Geology Department, Union College, Schenectady, NY 12308, USA

**presenting author: gillikid@union.edu*

Since the seminal works of Epstein and co-workers in the early 1950s, bivalve shell geochemistry has been used as proxy of environmental conditions. Bivalves live in nearly every aquatic environment, have a global distribution, and are well represented in the Phanerozoic fossil record making them an excellent target organism for environmental reconstruction. Early work focused on oxygen isotopes which proved to be a faithful recorder of both water temperature and water oxygen isotopes. Since then a multitude of studies have confirmed this in both marine and freshwater bivalve shells – which closely match results from inorganic calcite and aragonite. Carbon isotopes are more complex due to inputs of multiple sources of carbon including dissolved inorganic carbon and metabolic carbon. Some bivalve species exhibit a strong ontogenic trend in $\delta^{13}C$ values, whereas others do not. Nevertheless, while carbon isotopes are less straightforward than oxygen isotopes, they certainly provide some level of information about the environment. More recently, nitrogen isotopes in the organic material bound within the carbonate shell have been explored as a proxy of environmental nitrogen dynamics. Several papers have illustrated that this new proxy has much promise. Shell $\delta^{15}N$ values can be used in a similar fashion to soft tissue $\delta^{15}N$ values – but the possibility exists to obtain higher resolution data (down to weekly). Similar to stable isotopes, elemental ratios in bivalve shells have also been explored as environmental proxies since the 1950s – but since the start researchers noted strong vital effects. Some elemental ratios have shown to be reliable temperature proxies in corals and foraminifera (e.g., Sr/Ca and Mg/Ca), but this is not the case in bivalve shell carbonate. Other elements such as Ba/Ca or Li/Ca ratios in bivalve shells have shown promise, but more work is needed. Nevertheless, general transfer functions have only been developed for oxygen isotopes despite more than 50 years of research on bivalve shell geochemistry. While we can find new proxies to test, and new ways to use proxies – we should move away from attempting to apply proxies that have been shown not to be reliable recorders of environmental conditions.

Session: Proxy Development: Challenges and Opportunities

Elements, isotopes and banding patterns – Sclerochronogical approaches to the study physiological performance in fishes

Peter Grønkjær[1*]

[1]Deptment of Bioscience, Aarhus University, Ole Worms Allé 1, Dk-8000 Aarhus C, Denmark

**presenting author: peter.groenkjaer@bios.au.dk*

Sclerochronological studies of a wide range of organisms, including corals, molluscs and fish, have contributed substantially to our knowledge of historical and contemporary ocean conditions and the life history of the organisms. In fishes, otoliths have provided a wealth of knowledge on fish growth patterns, habitat use and more recently also of trophic relationships. However, otoliths may also be the new tool to investigate the physiology of fishes through studies of physiologically controlled incorporation of elements and isotopes into the otolith aragonite. In this talk, I will provide examples and ideas of how the combination of classic visual otolith analysis and microchemical analysis of elements and isotopes may yield new insights into the impact of environment conditions on the physiology of the individual. Direct coupling of e.g. growth variations to indicators of physiological performance may allow for tests of several unresolved topics in marine and freshwater science, including current disputes of oxygen limitation in fishes. These analyses can also be used to improve predictions of future macroecological patterns of fish distribution and productivity under environmental change, as they may reveal behavioral, physiological and genetic adaptation that modify the impact of ocean change. The use of otoliths as recorders of physiological performance is still in its infancy. Exploitation of their potential will require a major cross-disciplinary research effort encompassing long-term controlled experiments, new ways of combining the information from data storage tags with otolith based performance indicators and the collaboration between physiologists, chemists and fish ecologists.

Session: Growth, Bioenergetics and Ecosystems

How low can you go? Seasonal resolution in 300-million-year-old aragonite mollusks and the insights they provide

Linda C. Ivany[1*], Marie Y. Jimenez[1], Emily J. Judd[1], Gregory Henkes[2]

[1]Department of Earth Sciences, Syracuse University, Syracuse NY 13244, USA
[2]Department of Geosciences, Stony Brook University, Stony Brook, NY 11794, USA

**presenting author: lcivany@syr.edu*

Seasonally resolved isotopic sclerochronological studies have become almost commonplace in the Pleistocene and Recent, and examples in the Cenozoic are proliferating. Pushing such datasets back farther into the rock record becomes increasingly complicated with age, as the specter of diagenesis looms larger and the global and regional context into which to place the data become more progressively more unfamiliar and unconstrained. Nonetheless, careful work peering through the glass darkly can allow for unique insights into very ancient environments and the ecologies and life histories of long-extinct organisms.

We share seasonally resolved stable isotope data from Pennsylvanian mollusk shells collected in the Appalachian Basin of tropical North America. X-ray diffraction and scanning electron microscopy indicate an aragonite mineralogy with retention of primary microtextures, elemental chemistry is consistent with the shells of living mollusks, and $\delta^{18}O$ data reveal regular cyclic variation over ontogeny, together suggesting that original shell carbonate is preserved and records environmental conditions over the life histories of the animals. Cyclic variation allows determination of lifespan estimates for these Paleozoic animals, the first to be reported. Myalinid bivalves, lophospiridid gastropods, and bellerophont monoplacophorans measuring under 2 cm exhibit at least 3 years of growth, suggesting slower growth and longer lifespans than seen in many modern groups. Despite their inferred marine setting, oxygen isotope values are quite low, centering around -4.6‰, and intraannual variation is much higher than expected for the tropics, spanning up to 2.2‰. We invoke runoff of fresh water to the basin, concentrated in the summertime and significantly depleted by Rayleigh distillation of water vapor along the adjacent high-elevation Central Pangaean Mountains. These data extend a documented trend toward more depleted carbonate values eastward across the midcontinent sea, reflecting a decreasing salinity gradient with increasing distance from Panthalassa, and highlight the problems with calculating paleotemperatures from $\delta^{18}O$ values of carbonates precipitated in epicontinental seas by assuming a marine seawater composition. While carbonate clumped isotope paleothermometry is a potential solution to this seawater $\delta^{18}O$ 'problem', we demonstrate that such data from these aragonitic samples are related to burial diagenesis and not the Pennsylvanian paleoenvironment. The bias toward samples from such settings in the Paleozoic, because continental margins are more likely to be deformed, suggests that postulated warm regional and global temperature histories from the Paleozoic should be treated with caution until epeiric oxygen isotope seawater values can be better constrained.

Session: Paleoecology and Evolution

Environmental biomonitoring – challenges for sclerochronologists

Karin Limburg[1,2*]

[1]Department of Environmental and Forest Biology, State University of New York College of Environmental Science & Forestry, Syracuse, NY, USA
[2]Department of Aquatic Resources, Swedish University of Agricultural Sciences, Lysekil, Sweden

**presenting author: klimburg@esf.edu*

The structures discussed at this conference – the clams, corals, otoliths, bones, and so forth – possess the wonderful attribute of "time-stamped chemistry". As observers, sclerochronologists make careful measurements and do their best to interpret various trace elemental and isotopic data. Because of the uptake properties of these hard structures, it is logical to propose that many could potentially be used for long- or short-term biomonitoring. Yet as many researchers have shown, the interplay of environmental exposure (exogenous supply) and physiological regulation (endogenous controls) may confuse and confound. In addition, I propose that many potentially useful biomarkers may simply be undiscovered or currently inaccessible. Here I review current examples from a range of hard, chronometric structures (principally otoliths), show the value of combined approaches, and end with a challenge to our community to think creatively and broadly about future applications.

Session: Environmental Biomonitoring & Entrepreneurship

Sclerochronology and archaeology in the Mediterranean: seasonal foraging patterns, environmental change, and human-environment interaction

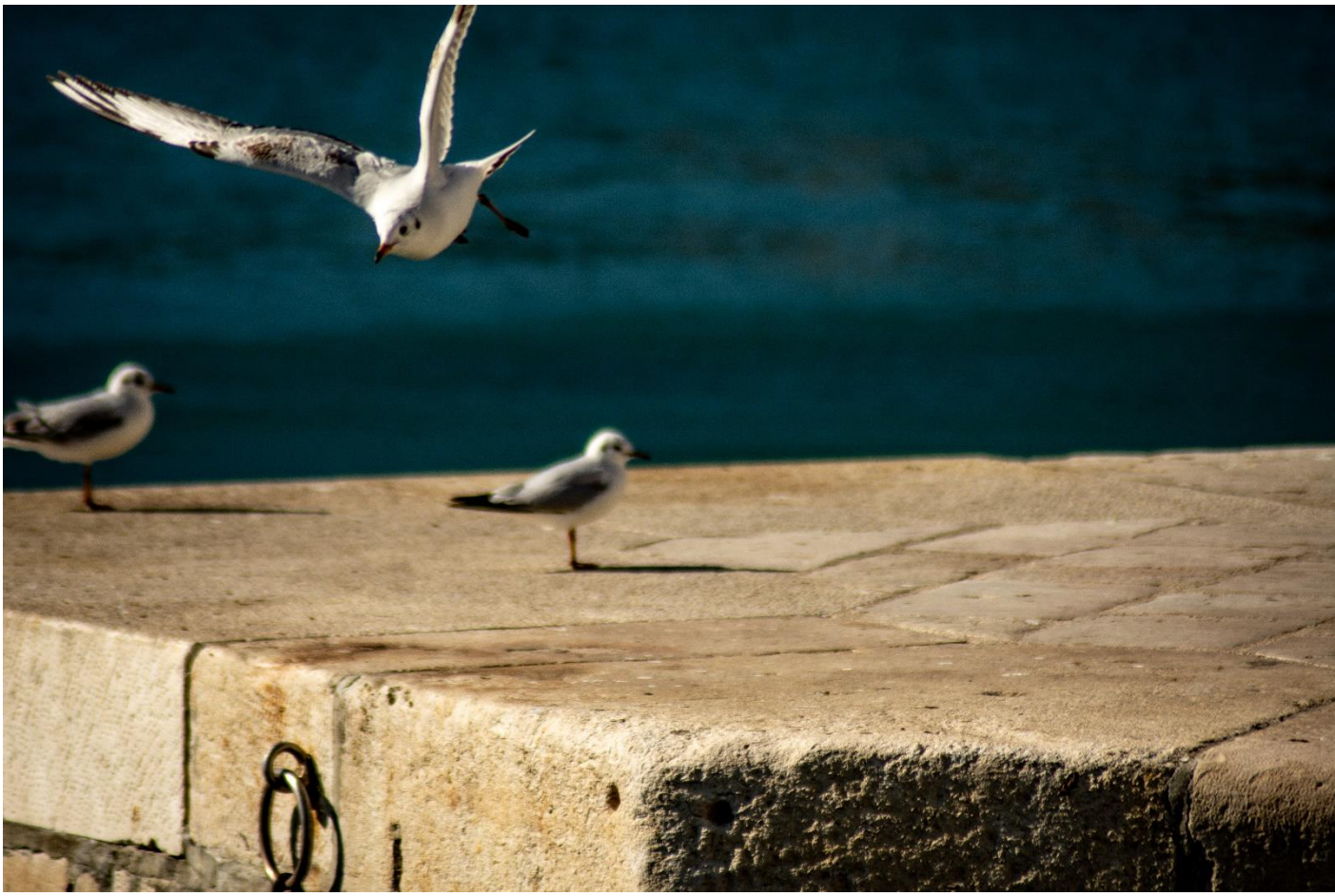
Amy Prendergast[1*]

[1]School of Geography, University of Melbourne, Australia

**presenting author: amy.prendergast@unimelb.edu.au*

Humans respond to changes in their local environment on daily to seasonal timescales. Therefore, robust assessments of the impact of environmental change on human behaviour requires an understanding of local environmental change at seasonal to sub-seasonal resolution. Sclerochronology has much to add to the study of human-environment interaction as mollusc shell growth and chemistry provide some of the few sub-seasonal resolution palaeoenvironmental proxies in the mid to high latitudes. Obtaining these records from food-refuse archaeological specimens enables the reconstruction of a more detailed picture of how humans responded to changing climatic regimes in the past and also allows an assessment of shellfish foraging seasonality. Here we present sub-monthly resolved environmental reconstructions from stable isotope analyses of marine and terrestrial mollusc shells from the Middle to Upper Palaeolithic archaeological sites in the Levant. These highly resolved environmental records, coupled with well-dated archaeological sequences provide a framework for assessing the complex interplay between early modern humans and their local environments. We found evidence for fluctuating temperature, rainfall and seasonality regimes throughout marine isotope stage 3, some of which appear to be linked to northern hemisphere millennial-scale climate oscillations. The archaeological records show human occupation of these sites occurred during both warmer and cooler phases and during both high and low seasonality regimes, and that shellfish were foraged during all seasons. This indicates that modern human populations were somewhat resilient to the resource uncertainty that would have accompanied these changing temperature and seasonality regimes. These paired cultural-environmental records have enabled an examination of hominin-environment interactions during critical periods of the late Pleistocene in a region with comparatively few high-resolution climate records.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present



Seagulls, Split, Croatia
Photo by Filip Grubišić

Oral presentation abstracts

Hydrographic and climate variability at St Kilda, Scotland, since the late 19th century

Stella J. Alexandroff[1,2*], James D. Scourse[1], Paul G. Butler[1], Martin Sayer[3], Bernd R. Schöne[4], Melanie Leng[5,6]

[1]*Geography - College of Life and Environmental Sciences, Exeter University, TR10 9EZ Penryn, United Kingdom*
[2]*School of Ocean Sciences, Bangor University, LL59 5AB Menai Bridge, United Kingdom*
[3]*Tritonia Scientific Ltd, Dunstaffnage Marine Laboratories, Oban, Scotland*
[4]*Department of Applied and Analytical Paleontology, Institute of Geosciences, University of Mainz, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany*
[5]*NERC Isotopes Geosciences Facilities, British Geological Survey, Keyworth, NG12 5GG Nottingham, United Kingdom*
[6]*School of Biosciences, Centre for Environmental Geochemistry, The University of Nottingham, Sutton Bonington Campus, LE12 5RD Leicestershire, United Kingdom*

**presenting author: s.alexandroff@bangor.ac.uk*

The main aim of this study is to construct centennial records of the hydrographic variability in the late Holocene at St Kilda, West Scotland. St Kilda is a sampling site of high importance, as its offshore location close to the shelf margin makes it highly valuable for palaeoceanographic reconstructions. Being practically unaffected by freshwater input and other onshore influences, and being located just south of the North Atlantic Current (NAC), it is thought to represent the open-ocean North Atlantic signal well. The NAC is a key component of the Atlantic Meridional Overturning Circulation (AMOC), which is crucial to heat and moisture transport to northwest Europe and influences global climate. Furthermore, the lack of freshwater input at St Kilda facilitates a clear interpretation of stable isotope data at this location. Live and dead *A. islandica* were collected in May 2016 at Village Bay, St Kilda, at 26 m depth. So far, a chronology spanning the years 1888-2015 CE has been constructed. A ten-year record of sub-annual $\delta^{18}O_{shell}$ for 1888–1898 CE was obtained by microdrilling the juvenile increments of two shells. In addition to the seasonal $\delta^{18}O_{shell}$ data, we present an annually resolved 127-yr $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ series based on the shell chronology. Both growth patterns and isotope data are compared to instrumental data and other proxy data from the eastern North Atlantic. Shell growth at St Kilda correlates positively with the Atlantic Multidecadal Oscillation (AMO) and the regional phytocolour index, while it correlates negatively with summer NAO (SNAO). The stable isotope data show the local Suess effect as well as a warming trend from 1888 to 2015, and match regional instrumental and reanalysis data. The main growth season of *A. islandica* at this location is spring and summer, with more than 80% of the shell being built May–July. We conclude that (1) this *A. islandica* chronology reflects North Atlantic climate patterns of the last century, (2) $\delta^{18}O_{shell}$ is an accurate proxy for regional sea surface temperatures at this location, and (3) temperature and $\delta^{13}C$ trends at St Kilda since the late 19th century coincide with trends reported for the North Atlantic.

Session: Climate and Oceans: Past, Present and Future

Challenges and applications of oxygen isotope analysis of season of capture of freshwater mollusks

C. Fred T. Andrus[1*], Christine N. Bassett[1], Barbara Voohies[2], Joe D. Collins[3], Evan Peacock[4]

[1]Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama, USA
[2]Department of Anthropology, University of California Santa Barbara, Santa Barbara, California, USA
[3]Department of Geosciences, Middle Tennessee State University, Murfreesboro, Tennessee, USA
[4]Department of Anthropology and Middle Eastern Cultures, Mississippi State University, Starkville, Mississippi, USA

**presenting author: fandrus@ua.edu*

Season of capture has been measured using oxygen isotope profiles in mollusk shells from archaeological sites for nearly 50 years. The vast majority of these studies utilize estuarine and marine taxa. Freshwater snail and mussel shells have been analyzed for season of capture to a far lesser extent, due in part to complications that arise from poor preservation, irregular seasonality of climate parameters, growth rate variation, shell abrasion, and related concerns. We present data from modern and ancient North American freshwater bivalves; the river mussels *Quadrula pustulosa*, *Fusconaia flava*, and *Ptychobranchus occidentalis*, and from the Central American gastropod *Pachychilus* spp. to illustrate these challenges and demonstrate how resulting data can be useful to archaeologists. These bivalve species are commonly found in archaeological sites in much of the Mississippi River drainage, while the snail is found in a variety of Maya sites. In both cases, the shells were exceptionally well-preserved due to the unique properties of the sites, namely carbonate-rich middens and protected cave deposits. Nearly all shells suffered some degree of abrasion during growth, and required different sampling strategies to accommodate the resulting challenges in data interpretation. Seasonal oxygen isotope oscillations measured in the mussel shells were primarily caused by temperature variation, and show limited evidence of growth cessations, thus proved useful for season of capture determination. The oxygen isotope profiles of the snail shells appear predominantly influenced by precipitation variation, but clear seasonal oscillations were not evident in all shells.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Fact or fiction? Exploring the possibility of Neoglacial sea ice off the coast of Unalaska

Christine N. Bassett[1*], Fred T. Andrus[1], Catherine F. West[2], Michael Etnier[3]

[1]*University of Alabama, Tuscaloosa, Alabama, USA*
[2]*Boston University, Boston, Massachusetts, USA*
[3]*Western Washington University, Washington, USA*

**presenting author:* cbassett@crimson.ua.edu

The annual cycling of sea ice expansion and retreat is an integral part of the climate system, which subsequently affects a wide range of biota from micro- to macroscopic scales, including human populations. A study published in 2007 suggested the presence of seasonal sea ice east of Unalaska, Alaska, USA at Unimak Pass from approximately 4,700 to 2,500 years ago. There is no historical record of sea this far south. If sea did exist here, it likely produced observable changes in the distribution and behavior of flora and fauna in the region and may have had a profound impact on humans living in the region. While global climate widely fluctuated during the Late Holocene, the extent of these changes and how they manifested regionally and locally is poorly constrained. This research is part of the Unalaska Sea Ice Project, which seeks to address uncertainties of local climate and environmental change in Unalaska in response to global change throughout the Middle to Late Holocene. Recent work with bivalve sclerochronology and sclerochemistry on shellfish remains from archaeological contexts has significantly contributed to understandings of past relationships between humans and their environments, especially where environmental reconstructions can be combined with associated archaeological evidence. Here we present data from stable isotope paleothermometry and growth increment analysis of shellfish remains (*Saxidomus gigantea*) from the Margaret Bay site (UNL-048) and the Amaknak Spit site (UNL-055). Results from this study provide key environmental information to which zooarchaeological analyses can be compared to produce higher confidence interpretations of human-environment interactions, as well as taxonomic changes in response to local climate changes (or lack thereof) during this time.

Session: Climate and Oceans: Past, Present and Future

Seawater paleotemperature and paleosalinity evolution in neritic environments of the Mediterranean margin during the Miocene: insights from combined $\delta^{18}O$-$\Delta47$ analyses of bivalve shells

Justine Briard[1,2]*, Romuald Jaillet[2], Emmanuelle Pucéat[2], Marc de Rafélis[1], Emmanuelle Vennin[2], Mathieu Daeron[3], Didier Merle[4]

[1]*Géosciences Environnement Toulouse (GET), Université de Toulouse, CNRS, IRD, UPS, 14 avenue Edouard Belin F-31400 Toulouse, France*
[2]*Biogéosciences, UMR 6282, UBFC/CNRS, Université Bourgogne Franche-Comté, 6 boulevard Gabriel, F-21000 Dijon, France*
[3]*Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS UVSQ, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*
[4]*Muséum National d'Histoire Naturelle, UMR CRNS 7207 (CR2P-MNHN, CNRS,UPMC-Paris 6), Sorbonne Universités, 8 rue Buffon F-75005 Paris, France*

**presenting author: justine.briard@get.omp.eu*

A major climate evolution during the Cenozoic is the transition from the "greenhouse" conditions of the late Early Eocene (~50 Ma) to our modern "icehouse" conditions with its much lower CO_2 levels and significant polar glaciation. This transition occurred through a series of steps, including Oligo-Miocene cooling (Mi-events), the last mid-Miocene warming (MMCO) and terminal cooling (MMCT). The identification of these phases of the Antarctic ice-sheet instability strongly relies on $\delta^{18}O$ and Mg/Ca benthic foraminifera records from ODP / DSDP sites, and few records currently exist from shallow environments. Reconstruction of shallow water temperatures (SST) in coastal environments using bivalve $\delta^{18}O$ can be impeded by variations in local seawater $\delta^{18}O_{sw}$ linked to fluctuations in local hydrological cycle. One way to circumvent this limitation is to combine $\delta^{18}O$ with clumped isotope (Δ_{47}) analyses of bivalve to decipher the evolution of SST and local $\delta^{18}O_{sw}$. We tested in this work the potential of this combined approach to reconstruct the evolution of SST and salinity over the latest Oligocene to Middle Miocene interval (~10 Ma). Two outcrops have been selected, at Carry-le-Rouet and Castillon-Du-Gard within the Liguro-Provencal Basin (SE of the Mediterranean Sea) that present sediments deposited in shallow open marine environments with bivalve fauna. Our dataset provides new information on both SST and salinity evolution within a still understudied region and as such contributes to increase our knowledge of the regional environmental response to global climatic changes during this key interval of Antarctica ice-sheet instability. SSTs oscillate between 15 and 20°C for the Aquitanian with a large estimated salinity range (18-34‰) pointing to the occurrence of sporadic freshwater inputs during this interval. For this stage, combined $\delta^{18}O$ and Δ_{47} analyses within the largest bivalve samples provide for the first time an estimation of seasonal SST and salinity variations. Our data highlight limited seasonal temperature variations but larger seasonal salinity variations with dry winters and wet summers, in agreement with the palynological data in this region during the Miocene. Burdigalian SSTs are generally warmer by ~ 5°C with higher salinities (38-39‰). The Langhian samples display surprisingly low SSTs (15-20°C) from Δ_{47} data for this time interval, described as a climatic optimum, which in combination to $\delta^{18}O$ values lead to low calculated salinities (32-33‰). These data may point to a local discharge of cool submarine groundwaters, that would be in agreement with the concomitant proliferation of bryozoan observed in the Castillon-Du-Gard area.

Session: Climate and Oceans: Past, Present and Future

Corals reveal a cooler and fresher tropical Atlantic during the mid-last interglacial

William M. Brocas[1]*, Thomas Felis[1], Manfred Mudelsee[2,3]

[1]MARUM - Center for Marine Environmental Sciences, University of Bremen, Bremen, Germany
[2]Climate Risk Analysis, Heckenbeck, Bad Gandersheim, Germany
[3]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

**presenting author: wbrocas@marum.de*

The last interglacial (LIG, Marine Isotope Stage 5e, 127-117 ka) is widely cited to have experienced globally warmer than modern temperatures, however the regional differences that occurred during this time are poorly understood. This challenge must be addressed if the LIG is to continue to offer a test-bed for quantifying natural climate variability relevant to the assessment of future climate change scenarios. To better constrain the natural response, variability and spatiotemporal evolution of the climate system during a warmer climate background, tropical Atlantic sea surface temperatures (SST) and hydroclimate reconstructions are required. We achieve this by extracting paleoclimate records contained within the annually banded skeletal structure of Diploria strigosa corals. These fossil corals thrived in shallow waters environments and are now preserved upon the uplifted reef terraces of the southern Caribbean island of Bonaire (Caribbean Netherlands). Using precise ^{230}Th/U dating methods we present eight snapshots, from between 130 and 118 ka ago, of monthly resolved coral Sr/Ca records to reconstruct tropical Atlantic mean annual SST changes. Coral $\delta^{18}O$ was measured on the same samples and the Sr/Ca derived SST component removed in order to reconstruct simultaneous $\delta^{18}O_{seawater}$ records, from which hydroclimate changes are revealed.

During the early LIG, at 129 ka, we reconstruct modern-like SST and hydroclimate. This was then followed by cooler than modern SST at ~125 ka, a finding that provides new independent evidence, in support of tropical Atlantic sedimentary records, for a cooler than modern tropical Atlantic during a period of globally warmer SST. We contribute to the paucity of LIG hydroclimate records by also revealing that less saline surface waters accompanied cooler SST at that time. Taken together our corals indicate an altered oceanic system that promoted the advection of colder and fresher waters during the mid-LIG. Our corals then reconstruct, between ~124 ka and 118 ka, modern-like SST and salinities suggesting the late-LIG experienced a return to an oceanic regime similar to modern. While the prominent insolation forcing associated with the LIG has been previously shown to strongly influence the seasonality of SST and hydroclimate, our findings suggest mean annual values were indirectly affected. We also discuss error estimations and the importance of incorporating uncertainties related to modern inter-colony offsets and the calibration of coral Sr/Ca and $\delta^{18}O$ to SST. This study highlights the climate instabilities and regional complexities that occur within the natural climate variability of interglacials periods.

Session: Climate and Oceans: Past, Present and Future

Reconstructing growth histories across multiple fish species in the Celtic Sea using multidecadal otolith collections

Deirdre Brophy[1]*, Amanda Egan[1], Yéléna Brison Bika Bika[1], Deirdre Lynch[2], Cóilín Minto[1]

[1]Marine and Freshwater Research Centre, Galway Mayo Institute of Technology, Galway, Ireland
[2]Marine Institute, Renville, Oranmore, Co Galway, Ireland

**presenting author: deirdre.brophy@gmit.ie*

Archived fish otoliths, collected for the purposes of age-determination and stock assessment hold a wealth of individual-based information collected over multi-decadal time scales. Sclerochronological techniques can be used to reconstruct past growth histories from annual otolith increments in order to investigate temporal trends in growth at an individual and population level. Coupling this data with environmental and biological time-series can help to elucidate drivers of observed change. This study used archived collections of otoliths to investigate multi-decadal (1980's to 2010's) variability in the growth of three species from the Celtic Sea: plaice (*Pleuronectes platessa* L.) herring (*Clupea harengus* L.) and haddock (*Melanogrammus aeglefinus* L.). Otoliths were imaged under a stereo-microscope and the distances between annual growth bands (annuli) were measured across the entire growth history of each individual. Linear mixed effects modelling was used to partition environmentally driven inter-annual growth variability from age-related, sex-related or cohort specific trends. The resultant trends were further analysed in relation to environmental conditions (temperature, food availability, meteorological conditions) and abundance (recruitment, spawning stock biomass). Sources of variability in growth, and their relative importance, differed substantially between species. In plaice, within cohort growth patterns were indicative of sampling effects and/or size selective fishing (increase in proportion of faster growing fish overtime) while in haddock there was evidence of size dependant mortality (removal of slower growing fish over time). Growth of herring and plaice showed small scale interannual fluctuations while a strong directional increase in the growth of haddock was detected. Annual growth patterns linked primarily with bottom temperature (plaice), mean AMO (herring) and sea surface temperature (haddock). The relative importance of population specific and broad scale ecosystem level change in the Celtic Sea are examined.

Session: Growth, Bioenergetics and Ecosystems

Shell midden archives, climate change and human response in Barkley Sound, British Columbia

Meghan Burchell[1*], Nadine Hallmann[2], Greg Monks[3], Marisa Dusseault[4], Bernd R. Schöne[5]

[1]Department of Archaeology, Memorial University, 310 Prince Philip Drive, St. John's, NF A1C 5S7, Canada
[2]Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement, Aix-Marseille Université, Aix-en-Provence, 13545, France
[3]Department of Anthropology, University of Manitoba, 32 Fletcher Argue Building, 15 Chancellor Circle, Winnipeg, MB R3T 2N2, Canada
[4]Department of Physics and Physical Oceanography, Memorial University, St. John's, NF A1C 5S7, Canada
[5]Institute of Geosciences, University of Mainz, Mainz, 55128, Germany

**presenting author: mburchell@mun.ca*

Shell midden sites on Canada's Pacific Northwest Coast provide an ideal opportunity to apply sclerochronology (stable oxygen isotopes and growth patterns) to refine interpretations of changes in local sea-surface temperature and hunter-fisher-gatherer subsistence practices. In this presentation, we examine a 3000-year shell midden archive from the west coast of Vancouver Island to examine how, and if, two climatic anomalies, the Little Ice Age (LIA) and Medieval Warm Period (MWP) can be detected in the archaeological record, and if local environmental changes affected human subsistence and settlement. Zooarchaeological analysis of fish remains recovered from the T'ukw'aa village site and the smaller site of Ma'acoah near mouth of Toquart River, demonstrated a shift from salmon to rockfish in assemblages dated to the LIA and MWP, respectively. This change in fishing practices, combined with other faunal data, suggests there may be other changes in subsistence practices, such as seasonal shellfish harvesting. To further understand subsistence practices in relation to local environmental changes, we conducted sclerochronological analysis and stable oxygen isotope ($\delta^{18}O$) analysis on *Saxidomus gigantea* (butter clam) from two sites from the traditional territory of the Nuu-chah-nulth, specifically the Toquaht of Barkley Sound, British Columbia. Through the analysis of monthly-collected live *S. gigantea* and archaeological specimens, we also evaluate the effects of sampling between modern and fossil assemblages. We integrate new $\delta^{18}O_{shell}$ data with direct radiocarbon dates to improve site chronologies, and demonstrate how bivalve shells can be used to refine interpretations of human-response to environmental change from ancient and historic shell midden assemblages.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

An ecological perspective of age and growth in *Mullus surmuletus* Linnaeus, 1758 from South-West Adriatic Sea

Pierluigi Carbonara[1*], Loredana Casciaro[1], Alessandro Cicolella[2], Francesco De Franco[2], Marilena Donnaloia[1], Giuseppe Lembo[1], Maria Teresa Spedicato[1], Walter Zupa[1], Paolo Guidetti[3]

[1]COISPA Tecnologia & Ricerca, Stazione Sperimentale per lo Studio delle Risorse del Mare, Via dei Trulli 18/20 70126 Torre a Mare (BA), Italy
[2]Consorzio di Gestione di Torre Guaceto Via Sant'Anna 6 - 72012 Carovigno (BR), Italy
[3]Université Nice Sophia Antipolis Parc Valrose 28, avenue Valrose 06108 Nice Cedex 2, France

**presenting author: carbonara@coispa.it*

The growth rate is a peculiar trait of the life history for each species. The amount of energy allocated to growth and the other physiological activities (e.g. reproduction, predation, migration etc.) depends on a number of factors, some of them are intrinsic (e.g. genetic and physiological), other are environmentally driven (e.g. temperature, food availability). Thus, a compromise on energy balancing must exist reflecting the specific growth and other physiological activities in the life of an individual fish. Moreover, fisheries remove individuals at various trophic levels in the ecosystem, affecting the distribution of energy and hence the amount of energy available. In this way, fishery activities influence fish growth and maturation dynamics. This might also explain the high growth variability among populations of several species, despite their relatively high genetic homogeneity and/or nearness. Growth, therefore, characterizes the species from a biological point of view (trait of life history), but also it has an ecological implication because in turn it is influenced by the environment in terms of energetic flow.

The objective of this study is to compare the growth of a costal species, the stripped red mullet (*Mullus surmuletus*), under two levels of anthropogenic pressure (fishing) in South Adriatic Sea (Central Mediterranean). The two study locations are the Marine Protected Area (MPA) of Torre Guaceto and the unprotected coast around Monopoli (South-West Adriatic Sea). These two locations are about 60 km away from each other and have similar bottom/biocenosis characteristics. M. surmuletus is an important target species mostly for the small-scale fishery in both locations.

For the purpose of this study, the otoliths of 50 female specimens were collected in each area and analysed. Then a transparent rings back-calculation was performed. The specimens in the two locations were selected with the same frequency of transparent rings number in order to avoid any sampling bias. Through the back-calculation the growth curves of *M. surmuletus* were estimated in each study location. The two curves were significantly different, mostly from the age 2 onward and *M. surmuletus* specimens from the MPA displayed a higher growth rate. These results suggest that, from an ecological perspective, intraspecific (e.g. density) and interspecific (e.g. energy flow through the food web) relationships could change depending on the level of protection against fishing exploitation.

Session: Fisheries Ecology and Management

Cerastoderma edule as a new proxy of historical liquid releases from European nuclear reprocessing plants

Maxi Castrillejo[1*], Marcus Christl[1], Rob Witbaard[2], Rob Dekker[2], Christopher A. Richardson[3], Jose-Luis Mas Malbuena[4], Núria Casacuberta[1], Christiane Yeman[1], Lukas Wacker[1], Caroline Welte[1,5], Hans-Arno Synal[1]

[1]*Laboratory of Ion Beam Physics, ETH - Zurich, Switzerland*
[2]*NIOZ Royal Netherlands Institute for Sea Research and Utrecht University, The Netherlands*
[3]*School of Ocean Sciences, Bangor University, United Kingdom*
[4]*Departamento de Física Aplicada I, Universidad de Sevilla, Spain*
[5]*Biogeosciences, ETH - Zurich, Switzerland*

**presenting author: maxic@phys.ethz.ch*

Nuclear reprocessing plants of La Hague (France) and Sellafield (England) have been legally discharging liquid radioactive waste to the sea for more than 5 decades. As a consequence, the seawater flowing through the English Channel and the Irish Sea is labelled with several artificial radionuclides that can be used to investigate the downstream transport of water into the Arctic and North Atlantic oceans. One of these radionuclides is the long-lived ^{236}U ($T_{1/2}$=23.4 Ma), which recently has been made available to the oceanographic community as a tracer of water circulation. So far, the ^{236}U tracer cannot be fully exploited because of a substantial gap of knowledge on its release history from Sellafield and La Hague. Therefore, the main goal of this study is to create the very first observational-based reconstruction of historical ^{236}U releases from La Hague using *Cerastoderma edule* as a recorder of sea water $^{236}U/^{238}U$ levels. So far, we measured the uranium content in the shells of 2-year-old *C. edule* collected alive every 1-2 years as part of a long term (1960-present) fauna sampling program in Balgzand (main inlet to Wadden Sea, Netherlands). The archived shell material is ideal because the location is under the direct influence of the coastal water carrying the isotopic signature of La Hague discharges, and the time coverage of the available shells represents the period of documented main ^{236}U discharges from the nuclear facility (1966 to present). Preliminary results show that the contemporary shell material consistently records the $^{236}U/^{238}U$ atom ratios in overlying seawater and that there is no significant exchange with the surrounding sediments. Furthermore, the shell-based reconstruction of past $^{236}U/^{238}U$ atom ratios compares well to modelled uranium ratios in the coastal water on basis of documented ^{236}U discharges. The time series of $^{236}U/^{238}U$ measured in the shells agrees with the model output for most of the ^{236}U release period suggesting that *C. edule* is a suitable candidate for reconstructing past uranium levels in seawater. This study is being extended to reconstruct the release of ^{14}C and ^{129}I circulation tracers from La Hague and Sellafield reprocessing plants.

Session: Environmental Biomonitoring & Entrepreneurship

Modern-day decline in skeletal density of subarctic crustose coralline algae

Phoebe T.W. Chan[1]*, Jochen Halfar[2], Christopher J.D. Norley[3], Steven I. Pollman[3], David W. Holdsworth[3], Walter H. Adey[4], Phillip A. Lebednik[5], Douglas Rasher[6], Robert Steneck[7]

[1]University of Bergen & Bjerknes Centre for Climate Research, Jahnebakken 5, Bergen 5007, Norway
[2]University of Toronto, 3359 Mississauga Rd. North, Mississauga, Ontario L5L 1C6, Canada
[3]University of Western Ontario, 1151 Richmond St. North, London, Ontario N6A 5B7, Canada
[4]Smithsonian National Museum of Natural History, 1000 Constitution Ave. NW, Washington D.C. 20560, USA
[5]Lebcon Environmental Services, 3043 Naranja Drive, Walnut Creek, California, 94598, USA
[6]Bigelow Laboratory for Ocean Sciences, 60 Bigelow Dr., East Boothbay, ME 04544, USA
[7]University of Maine, Darling Marine Center, 194 Clarks Cove Rd., Walpole, ME 04573, USA

**presenting author: phoebe.chan@uib.no*

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 high latitudes suggests that calcareous organisms residing in the Arctic and Subarctic are even more susceptible to acidifying conditions than those in lower latitudes. This is especially true for *Clathromorphum* sp. crustose coralline algae, 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 skeletal density record from crustose coralline alga collected from the Aleutian Islands in the subarctic North Pacific, a region that has undergone significant environmental changes over the last century.

Coralline algal skeletal densities were determined using micro-computed tomography (micro-CT) as described in Chan et al., (2017). Results show that shallow-collected (8-10 m) and deep-collected (25 m) specimens exhibit very different trends in skeletal density, with shallow samples exhibiting a more gradual decline, whereas in deep samples, density increased before decreasing sharply near the end of the record. This decline in modern-collected specimens (in 2008 and 2014) is not evident in museum specimens (collected in 1969), which suggests that the decline is not an artifact of a slowdown of growth rates over time. In addition to declining pH in the Aleutian region, diminishing algal density may also be associated to temperature stress resulting from increasing sea surface temperatures (SST) recorded in the region. This is demonstrated by a significant negative relationship between algal density and the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) data set - such that increasing (decreasing) algal skeletal density is associated with cooler (warmer) SST.

The ecological benefits of sustained vertical growth and calcification 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 tradeoffs associated with weakening algal skeletons may offset the benefits of continued growth and calcification, and expose skeletons to both physical and biological erosional processes, with anticipated consequences for the diverse reef-like communities associated with algal structures.

Session: Climate and Oceans: Past, Present and Future

Impact of global change on cold-water coral growth: threats to deep-sea ecosystems

Leila Chapron[1*], Erwan Peru[1], Alexandra Engler[1], Pierre Galand[1], Franck Lartaud[1]

[1]Sorbonne Université, CNRS, Laboratoire d'Ecogéochimie des Environnements Benthiques, LECOB, F-66650, Banyuls-sur-Mer, France

**presenting author: leila.chapron@obs-banyuls.fr*

Skeletal growth is a key physiological function, which in the case of calcifying organisms, provides structure and protection for internal soft tissues. Additionally, the skeleton of engineer species such as scleractinian corals, form three dimensional structures that support the local biodiversity. Questions regarding how the environment impacts the growth of calcifying pieces are thus of paramount importance for various ecosystems, particularly in a changing ocean. This is typically the case for cold-water corals (CWC) reefs and their key ecological functions in the deep-sea. But shortly after their discovery, it has been demonstrated that CWCs are facing several serious anthropogenic threats, including deep-sea fishing, waste discharges, global ocean warming and acidification.

Plastic contamination, such as macro- and microplastics debris which accumulate in surface and deep waters, is now recognized as one of the most serious environmental issues for oceans. Also, the warming of deep marine waters as a result of climate change is known to affect physiological functions, such as skeletal growth. This danger has become all the more relevant considering that (1) scleractinian CWCs live at the uppermost of their thermal tolerance range in the Mediterranean Sea and (2) Mediterranean submarine canyons are highly contaminated by plastic wastes. Thus, the aim of our study was to investigate whether plastics and temperature could affect growth of the main deep engineer specie, Lophelia pertusa.

Based on experimental aquarium approaches, the coral growth rates were measured using a chemical marker, calcein, that is incorporated into the skeleton. Our studies show, in one hand, that growth rates of L. pertusa are affected by both macro- and microplastics debris, likely related to a barrier effect for macroplastics and energy costs during ingestion and/or egestion processes for microplastics. On the other hand, skeletal growth changes with temperature, leading to maximum growth rates at 13°C (i.e., the present temperature in the habitat) and a significant decrease at 15°C (i.e., expected temperature by the end of the century). Considering the high accumulation of plastic debris on the seafloor and the ongoing global climate change, our results suggest that these combined stressors constitute major threats for reef aggradation, and thus jeopardise the resilience of cold-water coral reefs and their associated biodiversity.

Session: Growth, Bioenergetics and Ecosystems

Plasticity of field metabolic rate between genetically distinct and coexisting cod populations

Ming-Tsung Chung[1*], Kris-Emil Mose Jørgensen[1], Clive N. Trueman[2], Rasmus Hedeholm[3], Sara Bonanomi[4], Einar E. Nielsen[5], Thomas Brændgaard[1], Peter Grønkjær[1]

[1]Department of Bioscience, Aarhus University, Denmark
[2]Ocean and Earth Science, University of Southampton, UK
[3]Department of Fish and Shellfish, Greenland Institute of Natural Resources, Greenland
[4]Institute of Marine Sciences, Italian National Research Council, Italy
[5]National Institute of Aquatic Resources, DTU Aqua, Denmark

**presenting author: mingtsungchung@bios.au.dk*

Metabolic rate is a fundamental property setting daily energy requirements for individuals, and knowledge of metabolic costs associated with maintenance, foraging, growth and reproduction under natural conditions is important for understanding the energetic consequences of environmental change at population, community and ecosystem levels. If we want to understand how animals perform in the wild and operate within a complex environment, time-integrated individual-level field metabolic rate is the ecologically and evolutionarily relevant trait to study, and it can be investigated through natural stable carbon isotope tracers in otoliths. Isotopic composition of carbon in otolith aragonite can be used as a proxy field-based for oxygen consumption rates in Atlantic cod (*Gadus morhua*), as the otolith $\delta^{13}C$ value is a weighted average of the $\delta^{13}C$ values of water and metabolic carbon. We describe the mechanistic relationship between otolith inorganic $\delta^{13}C$ values and oxygen consumption under laboratory conditions and use this proxy to evaluate spatial, temporal and genetic influences on metabolic performance of Atlantic cod in natural habitats. The otolith metabolic proxy provides evidences to support existing ecological assumptions or hypotheses. (1) The metabolic rate of fish varies among individuals that is linked to phenotypic plasticity and is expressed in the life history and personalities. (2) Fish living in the cold water respond to an environmental temperature increase by reducing metabolic rates and energy costs. (3) Selective pressure from fishing activity not only changes the population size but also shapes the population metabolism. Current theory predicting the performance of fish under different climate change scenarios and environments, typically does not take into account individual behavioural and physiological responses and adaptation, or altered metabolic costs associated with changing foraging and predation dynamics. Otolith-based measurements of individual-level field metabolic rates could provide data needed to enhance ecological models and could provide more accurate and precise predictions of fish population dynamics, behaviour and adaptation under a long-term environmental change.

Session: Growth, Bioenergetics and Ecosystems

Otolith analysis and particle drift modelling to investigate variation in early life connectivity for the gilthead sea bream in the Gulf of Lions

Audrey M. Darnaude[1*], Maylis Labonne[1], Christophe Lett[2], Chloé Vagnon[1], Cécile Petit[1], Sophie Hermet[1], Sadjia Belkacemi[1]

[1]*MARBEC (CNRS, Univ. Montpellier, Ifremer, IRD), Montpellier, France*
[2]*IRD (UMI 209 UMMISCO), Sète, France*

**presenting author: audrey.darnaude@cnrs.fr*

Effective management of fish resources requires a good knowledge of the local connectivity patterns responsible for the genetic structure of the exploited stocks, especially for species with a life cycle that involves migration at varied life stages. Yet, this information is still lacking for many target species and parts of the world. In the Gulf of Lions (NW Mediterranean) for example, little is known about the offshore spawning sites of the gilthead sea bream (*Sparus aurata*) or the origin of the post-larvae that colonize the varied lagoon used as nursery sites by the species. In this work, we investigated the number and location of these spawning grounds and their respective contribution to the juvenile sub-populations of four varied lagoons (Mauguio, Thau, Salses and Bages) recognized as the main local nursery sites for *S. aurata*. For this, we used both the left and the right otoliths (sagittae) of >200 early juveniles from three different cohorts. Right otoliths were used to evaluate the variability in hatching dates among lagoon sites and years. We then modeled potential larval drift at sea for all years and hatching dates, using two discrete zones in the Gulf of Lions where adults are known to aggregate during the winter as presumed spawning sources. The possible migration routes obtained were then matched with concomitant environmental data (temperature, salinity, Chl *a*) for the entire area, and compared with the environmental (ratios in B, Ba, Ce, Cr, Mg, Mn, Pb, Sr, Zn and Y) and physiological (daily growth rates) information stored in the left otoliths of the fish during the first 60 days of larval life. This allowed identifying fish origin for all years and nursery sites and characterizing the differences in larval life history among them. The results suggest that the sea bream juveniles of the four lagoons originate from both spawning areas, with different larval migration routes from both sites according to fish spawning date. These temporal differences explain differences in spawning origin among lagoons and years, bringing new insights on the early life connectivity of *Sparus aurata* and its consequences for population structure and stock maintenance in this area.

Session: Fisheries Ecology and Management

Corals are not thermometers – How to extract a geochemical time series from a complex skeleton

Kristine L. DeLong[1,2*], Gilman Ouellette[1], Jacob Warner[1], Deborah Loke[1], Marissa Vara[1]

[1]*Louisiana State University, Louisiana, USA*
[2]*Coastal Studies Institute, Louisiana State University, Louisiana, USA*

**presenting author: kdelong@lsu.edu*

For the past ~30 years, the geochemical variations in coral skeletons have provided many multi-century long reconstructions of temperature, salinity, and other environmental variables. As this field matures, there are discussions that some coral proxies are not as reliable, reproducible, and/or difficult to interpret. Geochemical methods have improved with advances in technology but the methods used to extract samples from the coral skeleton include hand-held rotary tools, drill presses, and advanced computer-aided micro-milling systems. Furthermore, the methods used for time assignment to coral samples has not improved. Our work reveals that sampling and time assignment can have a large impact on coral proxy calibration and the resultant reconstruction. Slabs removed from a coral core must transect the extending corallite walls so the user can extract samples along a continuous growth-time skeletal feature. Computer-aided micro-mills are preferred for sampling to control the sample location and penetration depth into the coral skeleton, which is needed to avoid non-target skeletal elements, especially for corals with larger polyps (e.g., *Siderastrea, Orbicella, Diploria*, and *Diploastrea* spp.). Micro-mills allow for sampling increments to be smaller than the diameter of the bit since movement can be lateral whereas the up-down drilling sets increment size to bit diameter. For complex coral skeletons, laser ablation can be used to extract ~weekly samples from coral skeletons but require the coral to be cut into 1–2 cm pieces; however, advances in laser ablation large chamber technology will help resolve this issue. Time assignment is difficult, particularly for weekly laser ablation records, where users assigned years by-hand with guidance from x-radiographs to establish each year and/or use QAnalyseries software (https://sites.google.com/site/geokotov/software) to assign years and months. We find the number of "tie points" used per year changes calibration slopes. Our recent study with gridded and interpolated SST (HadISST and ERSST) reveals non-systematic biases at the single grid level that can significantly change calibration slopes. We recommend using in situ SST or satellite-derived SST (AVHRR SST) for a single location. We find that the Atlantic coral, *Siderastrea siderea*, has the ~same Sr/Ca-SST calibration equation for 44 coral colonies at different sites in the Gulf of Mexico and Tropical Atlantic when using these improved sampling and calibrating methods.

Session: Proxy Development: Challenges and Opportunities

Investigating long term temporal stability of otolith morphometry of Northeast Arctic cod (*Gadus morhua*) in the Barents Sea

Côme Denechaud[1,2*], Szymon Smolinski[2], Jane A. Godiksen[2], Audrey J. Geffen[1,2]

[1]*Department of Biology, University of Bergen, Norway*
[2]*Institute of Marine Research, Bergen, Norway*

**presenting author: come.denechaud@hi.no*

Otolith shape analysis provides a robust tool for the stock discrimination of many fish species, often substituting to more time and resource-heavy methods. Separating these populations is useful in improving fisheries management because fishing may affect different stock components disproportionately. However, differences in otolith morphometry are caused by a complex array of genetic and environmental factors, making it difficult to develop a consensus on their interpretation. While stock discrimination using otolith shape is increasingly seen as a useful tool, the reasons for shape variations are rarely understood. Notably, there has been little research to examine the within-stock stability of otolith morphometry over long periods of times, in relation to large changes in the environment and fish condition. In this study, we aim to investigate the potential changes in the shape of Northeast Arctic cod otoliths during the period 1932-2015 and its main drivers. Otoliths contours descriptors will be extracted from archived material of mature fish of similar age classes. These descriptors will then be related to several exploratory factors trying to explain this variability. We expect this study to not only give new insights on the stability of shape over time, but to also draw new conclusions regarding the importance of environmental factors on otolith morphometry and its reliability as a stock discriminant.

Session: Fisheries Ecology and Management

Asymmetry of otolith chemical composition from 2D mapping: relationship with biomineralization mechanisms and implications for microchemistry analyses

Helene de Pontual[1*], Helene Tabouret[2], Kelig Mahé[3], Emilie Le Luherne[1,4], Françoise Daverat[4], Christophe Pecheyran[2]

[1]*IFREMER Centre de Bretagne, Plouzané, France*
[2]*UMR 5254, Université de Pau et des Pays de l'Adour-CNRS, Pau, France*
[3]*IFREMER, Boulogne-sur-Mer, France*
[4]*IRSTEA Bordeaux, Cestas, France*

**presenting author: helene.de.pontual@ifremer.fr*

Although otoliths are widely used as archive to infer life history traits and habitat use in fishes, their biomineralization process remains poorly understood. This lack of knowledge is problematic as it can lead to misinterpreting the different types of signals (e.g. optical or chemical) that provide basic data useful for research in fish ecology, fisheries management and conservation. Otolith calcification relies on a complex system involving a pericrystalline fluid, the endolymph. Its composition has been shown to be heterogeneous for some organic and inorganic constituents. This property stems from the particular structure of the calcifying saccular epithelium. In this study, we explored the heterogeneity of elemental incorporation in otoliths of two species with high economical interest, European hake (*Merluccius merluccius*) and European sea bass (*Dicentrarchus labrax*). Two-dimensional mappings of chemical elements were obtained by UV-fsLA-HR-ICPMS analyses on transverse sections of sagittae. Results highlighted a clear proximo-distal asymmetry for some elements such as magnesium Mg, phosphorus P, manganese Mn and potassium K with concentration gradient directions that varied depending on the analyzed element. Chemical imaging revealed that elements such as strontium Sr, barium Ba and rubidium Rb were symmetrically distributed between proximal (sulcus) and distal (antisulcus) sides of the otolith. These results are discussed in the light of current knowledge on endolymph composition (organic and inorganic) and mechanisms that drive its compartmentalization, resulting in asymmetrical incorporation of some of the chemical elements that cross the saccular epithelium. In addition, these findings highlight the need 1) for further research on otolith biomineralization mechanisms, 2) for rigorous sampling schemes in order to avoid analytical biases when using otolith chemical signatures as proxies of fish life traits or environmental parameters, and 3) for thorough analyses of analytical setting before comparing otolith signatures between species or geographical areas.

Session: Biomineralization

Reconstructing paleoseasonality in the Late Cretaceous greenhouse world: A multi-proxy approach

Niels J. de Winter[1*], Clemens V. Ullmann[2], Anne M. Sørensen[3], Nicolas Thibault[3], Martin Ziegler[4], Steven Goderis[1,5], Stijn Van Malderen[5], Frank Vanhaecke[5], Philippe Claeys[1]

[1]*AMGC research group, Vrije Universiteit Brussel, Brussels, Belgium*
[2]*Camborne School of Mines and Environment and Sustainability Institute, University of Exeter, UK*
[3]*Faculty of Science, IGN, University of Copenhagen, Denmark*
[4]*Stratigraphy and Paleontology group, Faculty of Geosciences, Utrecht University, The Netherlands*
[5]*A&MS research group, Department of Chemistry, Ghent University, Belgium*

**presenting author: niels.de.winter@vub.be*

Studies of past climate change provide modelers with data required to calibrate models for climate forecasting and yield valuable insights into greenhouse climates**(1)**. The Late Cretaceous was characterized by much warmer global temperatures and reduced land ice volumes compared to the present**(2)**, and therefore serves as an interesting analogue for future climate. While long-term climate trends in this period are frequently studied, studies of short-term (seasonal to decadal) climate dynamics are rare, especially in higher latitudes. This study adds vital information about temperature seasonality in the Campanian (Late Cretaceous) age from excellently preserved oyster (*Rastellum diluvianum* and *Acurostrea incurva*) and radiolithid rudist bivalves from the coastal Kristianstad Basin in southern Sweden (50°N paleolatitude).

Our work combines records of a range of proxies (e.g. stable isotope, clumped isotope and trace element ratios) from the shells of these bivalves. This multi-proxy, multi-species approach allows us to disentangle the effects of temperature, water composition and physiology which often complicate seasonality reconstructions in bivalves. It also provides independent control on the interpretations made from multi-proxy records**(3)**, and allows us to extend the nearest living relative approach to study the expression of climate proxies in rudist shells, which are very common in the Cretaceous**(4)**.

The excellent shell preservation in the Kristianstad Basin makes it possible to apply conventional oxygen isotope analysis together with clumped isotope analysis to reconstruct both water temperature and salinity. As one of the first applications of clumped isotope thermometry in fossil bivalve shells, this study tests the method for reconstructing absolute surface water temperature seasonality in Late Cretaceous oceans. The combination of these methods yields a seasonal temperature range of 22-26°C for Campanian high-latitudes with low seasonal variability in seawater oxygen isotope composition (±0.3‰) even in this coastal setting.

Finally, a detailed comparison between trace element and stable isotope proxies provides insight in the application of controversial trace element ratios for climate reconstructions. Given the high spatial resolution that can be reached using modern techniques for *in situ* trace element analyses (e.g. LA-ICP-MS and µXRF), the use of these proxies could bring about a significant increase in the resolution of sub-annual climate records from bivalve shells.

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Session: Paleoecology and Evolution

Ba/Ca as a potential proxy for phytoplankton dynamics in *Arctica islandica* shells from Saint-Pierre and Miquelon (Northwest Atlantic Ocean)

Justine Doré[1*], JulienThébault[1], Pierre Poitevin[1], Laurent Chauvaud[1], Philippe Archambault[2], André Poirier[3], Simon Bélanger[4], Virginie Roy[5], Gwenaëlle Chaillou[6]

[1]Université de Brest, Institut Universitaire Européen de la Mer, Laboratoire des sciences de l'environnement marin (UMR6539 CNRS/IRD/UBO), Plouzané, France
[2]Département de Biologie, Québec-Océan, Takuvik, Université Laval, Québec-Océan, QC G1V 0A6, Canada
[3]Centre de recherche en géochimie et géodynamique (Geotop), Département des sciences de la terre et de l'atmosphère, Université du Québec à Montréal, Succursale Centre-ville, Montreal, QC H3C 3P8, Canada
[4]Département de biologie, Chimie et géographie, groupe BORÉAS et Québec-Océan, Université du Québec à Rimouski, Québec G5L 3A1, Canada
[5]Département des sciences benthiques, Institut Maurice-Lamontagne, Pêches et Océans Canada, Québec G5H 3Z4, Canada
[6]Institut des Sciences de la Mer, Université du Québec à Rimouski, Rimouski, Québec G5L 2Z9, Canada

**presenting author: justine.dore@univ-brest.fr*

Global change is affecting oceans and particularly phytoplankton dynamics in coastal areas, modifying the species composition of microalgae communities, the level of primary production and the global biogeochemical carbon cycle. It is therefore crucial to get insights about past and present spatial and temporal dynamics of phytoplankton blooms. However, no relevant geochemical, high resolution, proxies for these ecological processes have yet been found in marine biogenic archives.

The temporal variations of barium-to-calcium ratio in bivalve shells (Ba/Ca_{shell}) are not yet fully understood but there is a consensus among the scientific community about the fact that they are primarily induced by the environment. Some studies went further and suggested a relationship between phytoplankton dynamics and the incorporation of barium in these shells.

In order to test this assumption, Ba/Ca_{shell} was measured by LA-ICP-MS along the hinge plate of *Arctica islandica* (Ocean Quahog) specimens collected alive at a depth of 14 meters around Saint-Pierre and Miquelon islands in the Gulf of St. Lawrence (Northwest Atlantic Ocean). The Ba/Ca_{shell} time-series covers the period 2006-2018, and shows flat background levels interrupted by erratic sharp peaks. The date of each of these peaks was identified to the nearest year using growth increment analysis. In parallel, estimates of sea surface chlorophyll concentration were calculated from remote-sensing data collected around these islands by SeaWIFS and Aqua MODIS sensors.

The comparison of these two time-series let us assess the potential of this geochemical ratio as a paleo-environmental proxy for the phytoplankton dynamics in the Northwest Atlantic Ocean.

Session: Environmental Biomonitoring & Entrepreneurship

Deep-water octocoral sclerochronology and microgeochemistry in cold waters of Atlantic and Arctic Canada

Evan Edinger[1,2,3*], Sam Davin[4], Bárbara de Moura Neves[2,5], Krista Greeley[6], Claude Hillaire-Marcel[4], Graham D. Layne[3], Owen Sherwood[7], Vonda Wareham-Hayes[5]

[1] *Geography Department, Memorial University, St. John's, Canada*
[2] *Biology Department, Memorial University, St. John's, Canada*
[3] *Earth Sciences Department, Memorial Universit, St. John's, Canada*
[4] *GEOTOP, Université de Québec à Montréal, Montréal, Canada*
[5] *Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada, St. John's, Canada*
[6] *Environmental Science Program, Memorial University, St. John's, Canada*
[7] *Earth Sciences Department, Dalhousie University, Halifax, Canada*

**presenting author: eedinger@mun.ca*

Many species of deep-sea octocorals, including members of both 'gorgonians' (Alcyonacea) and the 'sea pens' (Pennatulacea) produce mineralized skeletons, and can record oceanographic conditions in their skeletons. Gorgonians, especially Primnoidae and Isididae, build composite skeletons of protein and magnesian calcite, potentially recording surface and ambient conditions, respectively. The most common gorgonian species in the NW Atlantic can live hundreds of years. Differences in bomb radiocarbon between the protein and calcite portions of their skeletons record deep water radiocarbon ventilation. Stable isotopes of C and N in the proteinaceous portions of their skeletons record variations in currents and nutrient dynamics, transferred to the corals via phytodetritus in their diets. Mg/Ca ratios in gorgonian calcites appear to record seawater temperature. Although the corals form annual growth rings, the gorgonian calcites reflect seawater temperature variation at a decadal scale more reliably than at an annual scale. Bulk δ^{15}N measurements of the organic portions and Pb/Ca ratios in the calcite portions of *Keratoisis* skeletons from the SW Grand Banks slope, Newfoundland record Labrador current strength, and anthropogenic lead contamination, respectively. Positive correlations between skeletal Ba/Ca ratios and δ^{13}C measurements support the use of skeletal Ba concentrations in Keratoisis as a proxy for productivity. *Keratoisis* from SE Baffin Bay, growing in Irminger current waters at about 1˚C apparently display much slower growth rates than their Newfoundland congeners in 4˚C Labrador slope water.

Northwest Atlantic sea pen skeletons are composed of 70-85% magnesian calcite and 15-30% protein. Proteins appear to be distributed within the skeleton, rather than found in discrete layers. Sea pen growth is recorded in annual growth rings, which may form by seasonal variations in protein vs. magnesian calcite content. Sea pen growth rates are much faster in the shorter-lived boreal species and *Halipteris finmarchica* and *Pennatula* spp. than in the Arctic sea pen *Umbellula encrinus*, which can live more than 65 years. Despite their shorter lifespan than gorgonians, sea pen skeletons may be useful in paleoceanographic reconstructions due to their broad distributions, especially in regions without gorgonians or other long-lived skeletal archives. Reliable correlation of height to age in sea pens allows estimation of age-frequency distributions in sea pens based on by-catch collections and video analysis. Both gorgonians and sea pens in the NW Atlantic and Arctic Canada provide important long-lived physical structure in deep-sea ecosystems that contribute importantly to local biodiversity.

Session: Climate and Oceans: Past, Present and Future

Provenance and stock structure of capelin in Greenland using microchemistry

Peter Fink-Jensen[1,2*], Karin Hüssy[1], Teunis Jansen[1,2], Tonny Bernt Thomsen[3], Simon Hansen Serre[3]

[1]Technical University of Denmark, Institute of Aquatic Resources, Kemitorvet building 201, 2800 Kgs. Lyngby, Denmark
[2]Greenland Institute of Natural Resources, Kivioq 2, 3900 Nuuk, Greenland
[3]Geological Survey of Denmark and Greenland, Oester Voldgade 10, 1350 Copenhagen K, Denmark

**presenting author: pefi@aqua.dtu.dk*

In this study, we investigate movement and structure of capelin (*Mallotus villosus*) stocks in Greenland by otolith microchemistry. Capelin is an essential species in the food chains of many marine ecosystems, but little is known about its stock composition and migratory behavior in Greenland. Such knowledge is crucial for proper management of the species, both in terms of sustainability and economy. During late spring and early summer, large schools aggregate in Greenland fjords all along the coastline, where they spawn in shallow water. However, their spatial movement the rest of the year is largely unknown, with some residing in the fjords while others may migrate offshore. In this study, we tested for the following: 1. If separate capelin stocks exist and, if so, to what degree mixing between them occurs; 2. If individual fish exhibit natal homing for spawning; 3. If migration between fjords and offshore environments occurs. In preparation for this study, 50-80 spawning capelin were caught at each of 21 different localities along Greenland's West-, South- and East coast. From each locality, otoliths were removed from ~35 fish that predominantly belonged to the 2013 year class. To discriminate between stocks at different localities, microchemical patterns in the otoliths were analyzed using LA-ICP-MS on core-to-edge transects. Otolith microchemistry depends amongst others on ambient water chemistry, and can be used to trace parameters such as temperature, salinity and local geological discharge. We tested for patterns in element-to-calcium ratios of the elements Sr, Ba, Mg, Mn, Li, Cu, P, K, Ti, Zn and Pb. Two of the involved localities were situated near previously active lead-zinc-mines, which could allow for a Pb-Zn signal to be traced in fish from these and adjacent localities. Results indicate that different localities can be discriminated based on otolith chemistry, both for individual localities and on a larger scale, by which Greenland's coastline can be divided into different zones with distinct geochemical signatures, allowing us to track migration and identify different stocks.

Session: Fisheries Ecology and Management

Shell sclerochronology and stable oxygen isotope ratios from the limpet *Patella depressa* Pennant, 1777: Implications for palaeoclimate reconstruction and archaeology in northern Spain

Asier García-Escárzaga[1,2*], Igor Gutiérrez-Zugasti[3], Manuel R. González-Morales[3], Javier Fernández-Eraso[2], Patrick Roberts[1]

[1]Max Planck Institute for the Science of Human History. Kahlaische Strasse 10. D-07745 Jena, Germany
[2]Department of Geography, Prehistory and Archaeology, University of the Basque Country, C/ Tomás y Valiente s/n, 01006, Vitoria-Gasteiz, Spain
[3]Instituto Internacional de Investigaciones Prehistóricas de Cantabria (Universidad de Cantabria, Gobierno de Cantabria, Grupo Santander), Edificio Interfacultativo de la Universidad de Cantabria, Avda. Los Castros s/n. 39005. Santander, Spain

**presenting author: a.garcia.escarzaga@gmail.com*

Palaeoclimate studies in archaeology are increasingly focusing on methodologies that enable high-resolution insights into seasonality, a primary parameter dictating human foraging strategies and resilience. In areas such as Spain, where hunter-gatherers have utilised coastal resources throughout the Pleistocene and Holocene, stable oxygen isotope ratios of mollusc shells found in archaeological sites offer the possibility of reconstructing coastal resource exploitation patterns and changing in marine conditions of direct relevance to past hominin. However, this method relies on the fact that 1) shell carbonate is deposited by the molluscs in equilibrium with the surrounding environment and that 2) actualistic investigation of modern specimens validate that selected species can be used as accurate palaeoclimate indicators. While previous investigations in the Cantabrian region (northern Spain) have focused on topshells *Phorcus lineatus* (da Costa, 1778) and limpets *Patella vulgate* Linnaeus, 1758 as effective seawater palaeothermometers, the limpet *Patella depressa* Pennant, 1777, one of the most represented mollusc species in the archaeological assemblages during the Holocene in the Atlantic Europe, has been very scarcely studied as a climate proxy. Here we explore the possibility that this species can be used as an effective climate proxy in this region. We collected modern samples of the limpet *P. depressa* from Cantabria throughout the course of a year. A sclerochronological investigation combining stable oxygen isotopes and growth pattern analysis was conducted in order to determine if $\delta^{18}O_{shell}$are mainly temperature dependent and also to accurately establish *P. depressa* annual growth patterns.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Using hard structure chemistry and growth increment chronologies to investigate partial migration: implications for fisheries management

Bronwyn M. Gillanders[1*], Christopher Izzo[2]

[1]*School of Biological Sciences, University of Adelaide, SA, Australia*
[2]*Fisheries Research and Development Corporation, Adelaide, SA, Australia*

**presenting author: bronwyn.gillanders@adelaide.edu.au*

Migration shapes the distribution of animals in space and time and is widely seen in the animal kingdom. As animals strive to survive and maximise their fitness, a number of strategies have evolved including partial migration, or intrapopulation variation in migratory tendency. Under such a scenario a component of the population migrates and a component remains resident within a single habitat throughout the year. Although ubiquitous among many animals, partial migration remains relatively understudied with little empirical research addressing its consequences. The chemical patterns in hard structures and the temporal context in which they have formed provide an opportunity to not only elucidate individuals within a population that migrate versus those that remain resident, but also to investigate potential consequences, for example on growth. Our aim, focusing on fish, is to use elemental signatures in ear bones (otoliths) to categorize fish as either resident or migratory and then to determine continuous seasonal or annually resolved growth histories of each contingent type. All three species (black bream, mulloway, greenback flounder) investigated showed differences in proportion of fish categorized as migratory versus resident based on chemical chronologies. Although average growth was often similar between resident and migrant fish, year to year variation varied significantly. Migration type (resident versus migratory) often significantly improved model fit compared to models with just year- and age-related growth trends. Results suggest potential population level bet hedging for some species with dynamism in growth likely driving persistence of both life-history types. Such complex relationships in growth between resident and migratory contingents suggests that management of species exhibiting partial migration will be challenging, especially in a world subject to a changing climate.

Session: Fisheries Ecology and Management

Developing subannual isotope records from fingernail-sized shells from Antarctic coastal waters

Alejandro Román González[1*], Ian Hall[1], James Scourse[1], Paul Butler[1], Lloyd Peck[3], Michael Meredith[3], Hugh Venables[3], Caroline Lear[2]

[1]University of Exeter, Penryn Campus, Penryn, Conrwall TR10 9FE, UK
[2]School of Earth and Ocean Sciences, Cardiff University, Main Building, Park Pl, Cardiff, CF10 3AT, UK
[3]British Antarctic Survey, High Cross, Madingley Rd, Cambridge, CB3 0ET, UK

**presenting author: a.roman-gonzalez@exeter.ac.uk*

Stable oxygen and carbon isotope records ($\delta^{18}O$ and $\delta^{13}C$) are a commonly used proxies in sclerochronology to understand environmental drivers of shell growth. These proxies become especially important to stablish baselines when instrumental data is sparse or non-existent. The Southern Ocean is a clear example of this, where collecting instrumental data series is challenging, expensive and often they are carried out only during short periods of time. In particular, the West Antarctic Peninsula (WAP) region has been the focus of scientific interest since has been experiencing the strongest warming in the southern hemisphere over the last half of the 20th century. We present here the first multiannual stable oxygen and carbon isotope records with seasonal resolution of the shallow Antarctic bivalve *Aequiyoldia eigthsii* collected from the South Orkney Islands and from the WAP from modern and historical collections. Since this is the first time that these records have been developed for this species we present the annual and subannual variability and uncertainties in the records. In addition, we present the technique used for drilling this particularly fragile and thin shells, which may help colleagues working with similar specimens. A detailed comparison of the stable isotope records with the long-term Rothera Biological Instrumental Series (RaTS) is presented. $\delta^{13}C_{shell}$ records capture major ecological changes that occurred in Ryder Bay (WAP) between 2007/8, when a shift from high to low yielding blooms occurred. An offset between the seasonal averaged $\delta^{18}O_{shell}$ and the $\delta^{18}O_{water}$ was identified, a linear model was used to produce a synthetic $\delta^{18}O_{shell}$ record to calculate the differences in temperature and salinity for such offset. A possible explanation of the cause of this offset is the influence of coastal meltwater runoff in the coastal salinity by the creation of surface hyposaline water lenses.

Session: Climate and Oceans: Past, Present and Future

Sclerochronological study in the Arabian Peninsula: growth pattern calibrations on modern bivalves and archaeological application from shell middens

Marc Gosselin[1*], Catherine Dupont[1], Sophie Méry[1], Jean-François Berger[2]

[1]CNRS, UMR 6566 CReAAH « Centre de Recherche en Archéologie Archéosciences Histoire » Université de Rennes, 35000 Rennes, France
[2]CNRS, UMR 5600 EVS, IRG, Université Lyon 2, 69676 Bron, France

**presenting author: a.roman-gonzalez@exeter.ac.uk*

Numerous mollusc shell middens exist along the coasts of the Arabian Peninsula. It is the consequence of human occupations during Mid-Holocene and suggests that resources from marine environment played a significant part in their diet and/or daily activities. However, uncertainty remains about the perennial or seasonal occupation of such coastal sites. Sclerochronology can assess such hypothesis by studying the season of catch of those bivalves. To this end, three Veneridae species regularly found in shell middens of United Arab Emirates and Sultanate of Oman were selected. As the biology of those species is poorly known, we first conducted *in situ* experiments on modern specimens in order to access their respective growth rhythms and thus to understand their shell growth patterns within their surrounding environment. Those findings were then applied to archaeological specimens from different Arabian shell middens (6.200-4.300 BC) as a way to investigate spatial-temporal patterns of human occupation as well as insight into environmental variability. This work was supported by the ANR project NéoArabia (ANR-16-CE03-0007) and the French Archaeological Mission to the UAE.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Unravelling the biology of conodonts (early vertebrates) through sclerochronology of their skeletal tissues

Bryan Shirley[1], **Madleen Grohganz[1*]**, Michel Bestmann[1], Emilia Jarochowska[1]

[1]GeoZentrum Nordbayern, Friedrich-Alexander Universität Erlangen-Nürnberg, Germany

**presenting author: madleen.grohganz@web.de*

Conodonts are extinct jawless, eel-like vertebrates common in marine facies from the Cambrian to the Triassic periods. Despite their wide use in biostratigraphy and paleoclimatology, little is known about their actual biology. Conodonts were the first vertebrates to produce mineralized skeletal tissue. Their microscopic teeth analogues, called elements, are composed of an apatite-organic composite biomineral and grew through outer periodical accretion of new growth lamellae. To analyze physical and chemical variations across their accretionary lamellar tissue, thin sections through individual conodont elements were prepared. With the help of our high-resolution BSE imaging technique, alternations of dark and light bands forming the conodont growth lamellae were made visible. This technique provides a new way to analyze conodont growth dynamics and determine distinct growth stages. Additionally, geochemical EDX analyses were carried out across the lamellar tissue of the different growth stages. These stages are linked to distinct geochemical changes, mainly of the element strontium. Sr concentration relative to Ca acts as an indicator of the trophic position, on which an organism is situated. The higher an organism is situated in the trophic network, the more depleted its tissue will become in Sr. This relationship is mainly observed in terrestrial mammals, but is also hypothesized for marine organisms. Therefore, the observed changes in Sr might reflect a transition in the conodont's mode of feeding and/or living. The early life stage of the conodont is characterized by a thin, elongated morphology, the lack of wear patterns and high Sr values. These observations lead to the interpretation as the first, larval stage, during which the conodont fed on lower trophic levels. Based on the observation of following patterns of wear and periodic repair, as well as low Sr values, a drastic change in the conodont's mode of living towards a more mature type of feeding, possibly as a predator or scavenger, is proposed. This study shows that applying sclerochronological methods to analyze the succession of growth lamellae in conodonts can provide valuable information about the biology, especially the mode of living and/or feeding, of these enigmatic animals.

Session: Paleoecology and Evolution

Seeking the true time: Exploring otolith chemistry as an age-determination tool

Yvette Heimbrand[1*], Karin Limburg[1,2], Karin Hüssy[3], Rajlie Sjöberg[1], Anne-Marie Palmén Bratt[1], Svend-Erik Levinsky[3], Anastasia Karpushevsky[4], Krzysztof Radtke[5], Jill Öhlund[6], Eva Kylberg[6]

[1]Swedish Institute of Marine Research, Swedish University of Agricultural Sciences, Turistgatan 5, Lysekil 453 30, Sweden
[2]SUNY College of Environmental Science and Forestry, United States
[3]National Institute of Aquatic Resources, Technical University of Denmark, Jaegersborg Alle 1, Charlottenlund 2920, Denmark
[4] Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO).5 Dm. Donskoy Street, Kaliningrad, Russia
[5]National Marine Fisheries Research Institute, Ul. Kollataja 1, 81-332 Gdynia, Poland
[6]Swedish Museum of Natural History, Stockholm, Sweden

**presenting author: yvette.heimbrand@slu.se*

Otoliths are calcified structures in bony fishes' sensory and balance system with chronometric properties, often used for age and growth rate estimation in fisheries management. Unclear seasonal growth zones in otoliths of the Eastern Baltic Sea cod stock have resulted in unreliable age determination and impaired analytical assessment. An age estimation experiment was set up to compare conventional age reading with a new micro-chemical method, assessing seasonal patterns in trace elemental otolith uptake. We examined chemical profiles of various elemental ratios that were expected to display seasonal peaks and valleys, either due to differences in growth (higher in summer) or environment (e.g., movement into colder, saltier, less hypoxic water in winter). Images of transverse cross sections of otoliths from the Baltic and North seas, collected during the last four decades were uploaded into the age reading platform SmartDots. Six experts at reading cod otoliths used visually recognizable features in the otolith images to annotate annuli along a pre-drawn transect from the core to the dorsal edge. Three chemical readers annotated annuli based primarily on chemical profiles which were provided separately. A ranking scale was developed to assess both otolith image readability and how well the chemical profiles reflected seasonality. The outcome of the age experiment revealed higher precision (coefficient of variation) and percentage agreement for the chemical method than for the conventional method. The highest ranked trace elements for reflecting seasonality i.e. age were Mg and P, both proxies for growth. The image opacity of the three first annotated annuli on each otolith also varied between methods. Conventional readers tended to select darker translucent areas whereas chemical readers placed the annuli on brighter, opaque parts of the otoliths, suggesting inverse formation of growth zones. These promising results show potential to validate age and growth rate estimations, improve the certainty and quality of the analytical assessment, and hence management of the Eastern Baltic cod stock.

Session: Fisheries Ecology and Management

A novel study combining sclerochronology and biogeochemical modelling to understand mechanisms controlling bivalve growth on the North West European shelf

Sarah Holmes[1*], Paul Halloran[1], Paul Butler[3], Johan van der Molen[2], John Aldridge[3], Chris Perry[1]

[1]*Department of Geography, University of Exeter, UK*
[2]*Royal Netherlands Institute for Sea Research (NIOZ), NL*
[3]*Center for Environment, Fisheries and Aquaculture Science (CEFAS), UK*

**presenting author: s.holmes@exeter.ac.uk*

Of all marine proxies available, sclerochronology (the study of the growth bands on long-lived marine clams) is the only one that provides absolutely-dated, multi-centennial, annually-resolved archives of past ocean environment, analogous to dendrochronology. Shell growth has been shown to be a function of temperature and food availability and many studies have demonstrated that these records are also capturing a number of related environmental variables including SSTs, air temperature, productivity and wider-scale climate patterns such as AMO (Atlantic Multidecadal Oscillation) and NAO (North Atlantic Oscillation); however, the exact mechanisms of shell growth are yet to be fully understood.

Recent *in situ* and laboratory experiments have been fundamental in disentangling these mechanisms but the factors that drive or hinder growth within the ecosystem and the wider environment still need to be studied in greater detail and across the vast habitat range of species such as *Arctica islandica*. However, attempts to do so are hampered by scarce long-term instrumental records. Bottom water time series (where clams live) are extremely rare and moreover, only a limited number of variables are measured - important biogeochemical parameters are often omitted. Other options must be explored.

For the first time, this PhD research is attempting to use biogeochemical models alongside sclerochronology records to explore the mechanisms behind shell growth. Ecosystem models such as the European Regional Seas Ecosystem Model (ERSEM) contain a vast number of hydrographical, chemical and biological variables and have been shown to simulate the shelf sea environment with a good degree of accuracy. This research compares multiple sclerochronologies across the North Sea with 1D hindcasts of ERSEM and works towards understanding their relationships by running novel experiments within the 1D model such as controlling (or even blocking) meteorological inputs.

This talk will present results of these experiments. For example, a key finding has been that using the model, we have been able to mechanistically attribute bivalve growth variability to wind speed variability. From this we can infer that the primary control on the ecosystem (as represented by modelled bivalves) is still of natural climate variability rather than anthropogenic change. It is clear that in addition to furthering the field of sclerochronology, the proxy-model fusion approach can give us greater insight into the shelf sea environment where instrumental data is lacking. Finally, the project also has potential to provide improved predictions of future shelf sea change allowing policy-makers to manage this vital ecosystem more effectively.

Session: Climate and Oceans: Past, Present and Future

The "who, when and where" of cod migrations in the Kattegat

Karin Hüssy[1*], Christoffer Moesgaard Albertsen[1], Tonny Berndt Thomsen[2], Simon Hansen Serre[2], Jakob Hemmer-Hansen[1]

[1]National Institute of Aquatic Resources, Technical University of Denmark, Kemitorvet, Building 202, DK-2800 Kgs. Lyngby, Denmark
[2]Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K., Denmark

**presenting author: kh@aqua.dtu.dk*

The prerequisites for sustainable management of fish stocks is knowledge about the stocks geographic distribution and the extent of migration between adjacent management units. In recent decades the use of otolith chemical fingerprints for stock identification purposes has gained increasing interest. Owing to their time-keeping properties and their lifelong record of environmental history, otoliths are a useful tool for studying stock affiliation and individual fish's migration patterns. The Kattegat is a transition area between the North Sea and the Baltic Sea, where environmental conditions are dominated by a pronounced horizontal salinity gradient and a coastal-type environment in the Kattegat compared to the North Sea. The cod stock in the Kattegat consists of a mix of genotypes from both the North Sea and the Kattegat, with a decreasing frequency of North Sea cod with age. We used LA ICP-MS based data with combined standard stock identification analyses and a regime-switching state-space model to test the hypotheses that 1) North Sea cod are spawned in the North Sea and drifted into the Kattegat during the early life stages, and 2) Adult North Sea cod remain in the Kattegat without return migrations during that time. The regime-switching state-space model filters noise from signal in the data and includes four areas of attraction to describe the migration patterns depicted in the chemical fingerprints. All parameters are estimated by maximum likelihood using an approximate deterministic filter and smoother. Results show that North Sea cod are spawned in the North Sea and enter the Kattegat before the end of their first winter. Elements separating the fingerprints of the two cod genotypes are Sr, Ba and Mn. North Sea samples were characterized by higher levels of Sr and lower levels of Ba and Mn, consistent with the different environmental conditions in the two areas. Consistent return-migrations on an annual basis could not be detected neither during the juvenile nor during the adult stages. However, a small number of individuals did undertake migrations to the North Sea and back to the Kattegat. However, there was no consistent pattern in these migrations with respect to fish age or time of the year. These results demonstrate the need for a stock assessment that takes these complex drift/migration patterns into account in order to avoid over-exploitation of the endemic Kattegat cod stock.

Session: Growth, Bioenergetics and Ecosystems

Growth rate, extinction and survival among late Cenozoic marine bivalves of the US eastern seaboard

Andrew L.A. Johnson[1*], Annemarie M. Valentine[2], Bernd R. Schöne[3], Donna Surge[4], Melanie J. Leng[5], Hilary J. Sloane[5]

[1]*School of Environmental Sciences, University of Derby, Derby DE22 1GB, UK*
[2]*School of Geography and Environmental Science, Nottingham Trent University, Southwell NG25 0QF, UK*
[3]*Institute of Geosciences, University of Mainz, 55128 Mainz, Germany*
[4]*Department of Geological Sciences, University of North Carolina, Chapel Hill, NC 27599, USA*
[5]*NERC Isotope Geoscience Facilities, British Geological Survey, Keyworth NG12 5GG, UK*

**presenting author: A.L.A.Johnson@derby.ac.uk*

The Plio-Pleistocene saw a mass extinction of marine bivalves in the western Atlantic, with some 65% loss of species. Two important pectinid genera (*Carolinapecten* and *Chesapecten*) became extinct. These probably had a 'siege' strategy towards predators, favoured by rapid growth. The evidence of microgrowth-increment size and/or oxygen-isotope ratios shows that growth occurred rapidly in Plio-Pleistocene examples of both, in *Carolinapecten* at rates up to to 60% higher than have been recorded in any other pectinid, extinct or extant. Another important pectinid genus (*Placopecten*) of the US eastern seaboard survived from the Pliocene to the present. This has a 'flight' strategy towards predators, not favoured by rapid growth. In accordance with this, growth in Pliocene examples was no faster than in modern forms, despite conditions of high primary production (indicated by the vertebrate assemblage) which would have enabled rapid growth. While the Plio-Pleistocene decline in primary production on the US eastern seaboard would have had no effect on the growth rate and ability of *Placopecten* to avoid predation, it would have impacted on *Carolinapecten* and *Chesapecten*, and may account for their extinction. Detailed analysis of growth-rate variation in *Carolinapecten* in relation to production and temperature (Johnson et al. 2019; PALAIOS 34:1-22) indicates that exceptionally fast growth required high production but was possible at quite low temperatures. Slow growth never occurred under high production but was common at low temperatures. These findings suggest that while production decline was contributory to the extinction of *Carolinapecten*, Plio-Pleistocene temperature decline also played a part. However, the latter is implicated only if the low oxygen-isotope temperatures associated with late, slow-growing examples of *Carolinapecten* are accurate. They are contradicted by the assemblage composition of co-occurring molluscs and ostracods and by the rapid growth of the co-occurring glycymeridid bivalve, *Glycymeris americana,* modern examples of which appear to grow at a comparable rate only under conditions of high temperature (combined with 'average' production). Available evidence therefore suggests that Plio-Pleistocene extinction of marine bivalves on the US eastern seaboard was largely due to production decline.

Session: Paleoecology and Evolution

Sclerochronological and geochemical approach for paleo typhoon seasonality reconstruction using giant clam fossils in Kikai Island, Japan

Taro Komagoe[1*], Tsuyoshi Watanabe[1,2], Keiichi Sasaki[3], Kotaro Shirai[4], Atsuko Yamazaki[1,5]

[1]KIKAI institute for coral reef sciences, Kikai town, Japan
[2]Department of Natural History, Graduate School of Science, Hokkaido University, Sapporo, Japan
[3]Department of Cultural Properties and Heritage, Kanazawa Gakuin University, Kanazawa, Japan
[4]Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan
[5]Faculty of Sciences, Kyushu University, Fukuoka, Japan

**presenting author: komataro@kikaireefs.org*

Giant clam (Tridacnidae) widely distributes over the coral reefs in Indo-Pacific Ocean and has symbiotic algae, facilitating fast growth and forming daily shell growth pattern (daily growth increment). Thus, giant clam shell could be useful tool for high temporal resolution analysis for past environment.

Kikai Island located in the northern Ryukyu archipelago has the well-developed coral reef terraces with the highest uplift rate (1.8 m/ka) in Japan tracking back to that formed in marine isotope stage (MIS) 5e (Ota *et al*., 2000). With this feature, late Pleistocene to Holocene giant clam shell fossil are continuously available through the period. Especially, MIS 3 has been the subject of intense study in deep-sea cores and in ice records as it shows unusual high frequency climate variability. Therefore, giant clam fossil in Kikai Island can provide the high temporal resolution environment changes information through the period.

We sampled modern giant clam specimen (*Tridacna maxima*), Late Pleistocene MIS 3 (55ka, *T. Squamosa*), and Holocene (3.9ka, and 7.2ka, *T. maxima* and *T. Squamosa*, respectively) fossil specimens from Kikai Island. Each fossil specimen was well preserved from diagenesis alternation. After checking diagenesis alternation, stable isotope ratio ($\delta^{18}O$, $\delta^{13}C$), Barium Calcium concentration (Ba/Ca), and sclerochronological analysis were performed in each shell specimens. The shell samples were milled with 300 µm width using hand drill. $\delta^{18}O$, and $\delta^{13}C$ in shell specimen were analyzed using stable isotope ratio mass spectrometer. Ba/Ca was analyzed using Laser Ablation Inductively Coupled Plasma Mass Spectrometry andInductively Coupled Plasma Atomic Emission Spectrometry.

$\delta^{18}O$ and growth increment thickness in the modern shell specimen well reflected annual SST cycles. The Ba/Ca peaks and growth reduction which characterized by disturbed growth lines in summer coincided with the typhoons approached to Kikai Island in modern specimen. As well as modern specimen, $\delta^{18}O$ and growth increment thickness in fossil specimen showed annual cycles. Also, fossil specimen had growth reductions, especially, MIS 3 specimen had Ba/Ca peaks at summer season. Growth reduction and Ba/Ca peaks in giant clam shell possibly reflects typhoon approaches (Komagoe *et al*., 2018). Thus, these results suggest that Holocene and MIS 3 fossil giant clams in Kikai Island could reveal the changes in timing and frequency of typhoons approaching Kikai Island from Late Pleistocene to Holocene. We will discuss the relationship between the typhoon signature suggested from giant clam records and mean climate at MIS3 and Holocene in the presentation.

Session: Environmental Biomonitoring & Entrepreneurship

Geochemistry and sclerochronology of *Mercenaria stimpsoni* collected from the western North Pacific

Kaoru Kubota[1*], Kotaro Shirai[1], Naoko Murakami-Sugihara[1], Koji Seike[3], Kazushige Tanabe[4], Masayo Minami[5], Toshio Nakamura[5]

[1]*Japan Agency for Marine-Earth Science and Technology, Japan*
[2]*Atmosphere and Ocean Research Institute, The University of Tokyo, Japan*
[3]*Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology, Japan*
[4]*The University Museum, The University of Tokyo, Japan*
[5]*Institute for Space-Earth Environmental Research, Nagoya University, Japan*

**presenting author: kaoryu0129@gmail.com*

Bivalve shell is one of the most important archives of past environmental changes because some species can live more than several decades and distribute broadly (e.g., from high to low latitude, fresh/brackish/sea water). We have investigated potential of long-lived cold water bivalve, *Mercenaria stimpsoni* (Stimpson's hard clam) living in the western North Pacific (especially, coastal area of North East Japan). In this presentation we will show sclerochlonological and geochemical records (e.g., oxygen isotopes and radiocarbon) of both live-caught and dead specimens collected from the seafloor of NE Japan (5–20 m). From both sclerochlonology and nuclear bomb-derived radiocarbon (bomb-^{14}C), it was found that this animal can live for more than 100 years, thus very useful for paleoeanograpic studies. It was also found that a lot of *M. stimpsoni* were killed by huge tsunami that hit NE Japan in March 2011, which is likely caused by disturbance of marine sediment, including seabed liquefaction.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Sclerochronology beyond the deep

Franck Lartaud[1*], Karine Nedoincelle[1], Marc de Rafelis[2], Olivier Bruguier[3], Nadine Le Bris[1]

[1]Sorbonne Université, CNRS, Laboratoire d'Ecogéochimie des Environnements Benthiques, LECOB, Observatoire Océanologique de Banyuls, F-66650 Banyuls-sur-mer, France
[2]Géosciences Environnement Toulouse, UMR 5563 CNRS,UR 234 IRD,UM 97 UPS,Observatoire Midi-Pyreńeés, CNES, 14 avenue Édouard Belin, 31400 Toulouse, France
[3]Géosciences Montpellier, Université de Montpellier – CNRS, 2 Place E. Bataillon, 34090 Montpellier Cedex 5, France

**presenting author: franck.lartaud@obs-banyuls.fr*

Sclerochronology is widely used in marine coastal environments but still in its infancy in the deep-sea, although biogenic carbonates are classically the only support for characterization of climate and oceanographical changes in theses habitats. The difficulties of accessing to deep-sea ecosystems and the lack of temporal calibration in skeleton biomineralization of species living in the deep-sea explain partly this gap. But the use of underwater vehicles allows now *in situ* experimentation facilities. Through the shell growth and geochemical signal analysis of chemosynthetic mussels from mid-oceanic hydrothermal systems, we demonstrate the paramount contribution of sclerochronological approaches to investigate both the ecology of vent species and the environmental dynamic.

(1) Mussel growth is related to semi-diurnal and spring-neap fluctuations of abiotic conditions exposing the organisms to the alternance of oxic and sulfidic conditions. Periods associated with the absence of hydrodynamic fluctuations strongly limit growth, suggesting that periodical changes in the habitat conditions are essential for those species.

(2) The carbon isotopic signature of the shells is primarily controlled by the local dissolved inorganic carbon, but the types of chemosynthetic pathways (i.e., methanotrophic or thiotrophic) produce a ^{13}C fractionation in the shell with respect to seawater. Mussels associated to sulfide-oxidizing symbiosis display higher $\delta^{13}C$ than expected by the isotopic equilibrium. This suggests that shell carbon isotopes are a reliable proxy in the symbiosis activity, including at micro-habitat scale, and can be used to reconstruct the trophic pathways in fossil hydrothermal systems.

(3) As Mg/Ca in hydrothermal fluids are severely depleted in magnesium, mussels used a stable content of Mg from seawater to form their shells making the shell Mg/Ca ratio a promising thermometer proxy in hydrothermal vent ecosystems.

Deep-sea ecosystems constitute thus new opportunities and challenges for sclerochronological works giving atypical environments to test the applicability of geochemical proxies.

Session: Proxy Development: Challenges and Opportunities

Can otolith $\delta^{18}O$ of tagged fish informed about migration behaviors and population structure of European sea bass in the North East Atlantic?

Emilie Le Luherne[1,2*], Françoise Daverat[2], Mathieu Woillez[1], Hélène De Pontual[1]

[1]IFREMER Brittany Center, Plouzané, FRANCE
[2]IRSTEA Bordeaux, Cestas, FRANCE

**presenting author: Emilie.Le.Luherne@ifremer.fr*

European sea bass, *Dicentrarchus labrax*, is – especially in France – a key species for both recreational and commercial fisheries. Recent stock assessments have shown a decline of sea bass wild population. For a better understanding of the population structure, IFREMER has carried out since 2014 a large-scale electronic tagging programs targeted on adult fish that have already provided more than 30 % of recovery in late 2018. From Dunkirk to Cap Breton, 1 220 sea bass were equipped with data storage tags (DSTs), with temperature and pressure sensors and a typical battery life of 2 years. Individual migration histories reconstructed from the recovered DSTs have yield evidence of sea bass fidelity to winter spawning areas in the northern region (English Channel/Celtic Sea) and in the Bay of Biscay. This finding raises new questions on the underlying mechanism of fidelity to spawning areas: is that behavior associated to natal homing or social learning mechanisms? The aim of the present study is to clarify the underlying mechanism of fidelity to spawning areas from coupling for the same fish, migration histories obtained from DSTs and the analysis of individual histories retrieved from otoliths. The isotopic composition of oxygen ($\delta^{18}O$) in otoliths has been largely used as a proxy of temperature. Therefore, it was chosen as a relevant tool to differentiate the English Channel/Celtic Sea stock and the Bay of Biscay stock. To assess both the spatial and analytical precisions required for these analyses, $\delta^{18}O$ were measured using Secondary Ion Mass Spectrometry. $\delta^{18}O$ signatures were analyzed at three life periods : (1) the larval period, (2) the spawning periods with corresponding temperatures from DSTs and (3) the spawning periods without corresponding temperatures from DSTs (i.e. before tagging and post tagging for fish with more than 2 year at liberty).The coupling of temperatures from DSTs and otoliths oxygen isotope signatures allows us (i) to calibrate the relation between sea temperature and oxygen stable isotope in otoliths of sea bass and then (ii) to explore the underlying mechanism of sea bass fidelity to spawning areas. Improvement in the understanding of sea bass fidelity to spawning areas and potential exchanges between these two stocks will provide relevant information for sea bass assessment and management.

Session: Fisheries Ecology and Management

Stable isotope investigations of Later Stone Age shellfishing and local climate shifts on the South African west coast

Emma Loftus[1*], Julia A Lee-Thorp[2], Judith Sealy[3]

[1]McDonald Institute for Archaeological Research, University of Cambridge, Cambridge, UK
[2]Research Laboratory for Archaeology, University of Oxford, Oxford, UK
[3]Department of Archaeology, University of Cape Town, Cape Town, South Africa

**presenting author: el485@cam.ac.uk*

Coastal hunter-gatherer occupation of southern African shores spans tens of thousands of years, and has accumulated valuable repositories of seasonal climate and human behavioural data, in the form of long-sequence archaeological shell-middens. We present a modern geochemical study (serial stable carbon and oxygen measurements) of the limpet *Cymbula granatina*, from locations upstream and downstream of a large, summer upwelling cell, demonstrating the utility of this species for palaeoclimate and seasonality studies. We also investigate the appropriate scale of sampling for this relatively fast-growing species, given the temporal span and archaeological research questions. Regional shifts in sea surface temperature and upwelling activity are reconstructed from several radiocarbon-dated sites across the Holocene, and correlated with shifts in the cultural record from the region. We examine the scheduling of hunter-gatherer shellfishing, including from both rockshelter and open-air "megamidden" contexts, and demonstrate a persistent pattern of winter shellfish harvesting, similar to that observed along the southern coast during the Holocene Later Stone Age, in spite of marked ecological differences between the regions.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

High-resolution oxygen isotope records from fish and shell remains, Lake Kutubu, Papua New Guinea

Kelsie Long[1,2*], Simon Haberle[1,2], Larissa Schneider[1,2], Rachel Wood[2,3], Stewart Fallon[2,3]

[1]*School of Culture, History and Language, ANU, Australia*
[2]*ARC Centre of Excellence for Australian Biodiversity and Heritage, ANU, Australia*
[3]*Research School of Earth Sciences, ANU, Australia*

**presenting author: kelsie.long@anu.edu.au*

Lake Kutubu is a thermally stratified freshwater lake, situated in the southern highlands province of Papua New Guinea. The lake is oligomictic, exhibiting thermal and chemical stratification with rare periods of circulation at irregular intervals. The region derives its high annual rainfall from the Northwest Monsoon and Southeast Trade Winds throughout the year and is sensitive to changes in the strength of Indian Ocean Dipole and El Niño-Southern Oscillation.

Here we focus on exploring the potential for deriving a long-term and continuous stable isotope record from fish remains preserved in Holocene sediments cores from Lake Kutubu. The main aim of the project is to expand our understanding of past palaeoclimate drivers, landscape dynamics and lake system productivity, all of which would have influenced patterns of human occupation, dispersal and environmental interactions through time.

The first part of the project explores the relationships between isotopic changes in modern fish remains and known lake conditions. We measured oxygen isotopes across the age increments of modern fish otoliths collected from Lake Kutubu, using the Sensitive High Resolution Ion Microprobe (SHRIMP). Freshwater snail shells from the upper layers of the lake sediment cores have also been analysed for oxygen isotope ratios, to determine if any past fluctuations in ambient conditions are preserved. Here I will present the results of these initial oxygen isotope measurements and discuss their relationship to ambient lake conditions, known climatic events and the possibilities of extending the record further back in time using fish scales and bones preserved in lake sediment cores.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

A 250 year chronology of *Arctica islandica* in the Mid-Atlantic region of the US continental shelf

Roger Mann[1*], Eric Powell[2], John Klinck[3], Sara Pace[2], Matthew Long[1], Theresa Redmond[1], Khalil Russell[4]

[1]Virginia Institute of Marine Science, Gloucester Point VA 23062, USA
[2]Gulf Coast Research Laboratory, University of Southern Mississippi, 703 East Beach Drive, Ocean Springs, MS 39564, USA
[3]Department of Ocean, Earth, and Atmospheric Sciences, Center for Coastal Physical Oceanography, 411 Monarch Way, Old Dominion University, Norfolk, VA 23529, USA
[4]Department of Biology, College of William and Mary, P.O. Box 8795, Williamsburg VA 23187-8795, USA

**presenting author: rmann@vims.edu*

The presence of the ocean quahog *Arctica islandica* in the Mid-Atlantic region of the US continental shelf represents the most southerly extension of the species distribution. The region is notable for the presence of both a large annual surface temperature range that reaches subtropical summer maxima in combination with an intense seasonal thermocline that overlays a "cold pool" of water. *A. islandica* is restricted to the depths of the cold pool, and its biology is both intimately related to and records the dynamics of this oceanographic feature. Additionally, the population, with a standing stock estimated at several million tonnes, is subject to a sustainably managed fishery. Herein we review a near decade of effort examining population age structure, mortality, and recruitment of this extraordinary population in addition to the large terminal size of many individuals, in some instances exceeding 130 mm shell length. The Mid-Atlantic is warming, as noted by the changing distributions of both finfish and benthic dominants including *A. islandica*. We describe the response of the population to changing climate from the end of the Little Ice Age through the present, and note a continuing increase in growth rates over the past century in combination with a gradual retreat into greater depths as summer warming impacts the shallow, inshore limit of the Mid Atlantic seasonal cold pool.

Session: Climate and Oceans: Past, Present and Future

Glycymeris pilosa - spatial and temporal insight into differences of trace element records

Krešimir Markulin[1*], Melita Peharda[1], Regina Mertz-Kraus[2], Hana Uvanović[1], Bernd R. Schöne[2]

[1]Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia
[2]Institute of Geosciences, Johannes Gutenberg University, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany

**presenting author: markulin@izor.hr*

Investigation of the geochemical composition of bivalve shells can provide information on changes in the marine environment occurring during the organism's lifespan. High spatial and temporal resolution element records can be obtained through laser ablation inductively coupled plasma mass spectrometry (LA–ICP–MS). *Glycymeris pilosa* was chosen as target species as it has a lifespan exceeding 50 years and presents a potential archive of decadal climate variability. These shells contain annual growth increments which are visible in cross-sections enabling temporal positioning of geochemical data obtained from different shell portions. Bivalves were collected alive by SCUBA diving at six localities along the Eastern Adriatic coast including Barbariga, Istria in the North Adriatic Sea, Pag Island, Pašman Island, at the mouth of the river Cetina in the Central Adriatic as well as Živogošće and Drače in the Southern Adriatic.

In this study we applied LA–ICP–MS in line scan mode to determine the trace element composition along the major growth axis in the hinge area of the shell to obtain high-resolution profiles of Na/Ca, Mg/Ca, Sr/Ca, and Ba/Ca. From each locality, a minimum of three similar-sized specimens were selected for the chemical analysis. To study how trace element patterns compare among individuals from the same locality and among different sites along the Eastern Adriatic coast in more recent times, three ontogenetically young (<15 years) specimens were chosen. For the more distant past, three larger, ontogenetically older (>50 years) specimens from localities near Istria and Drače were studied.

Time-series of Na/Ca_{shell}, Mg/Ca_{shell} and Sr/Ca_{shell} display characteristic cyclic variations with Na/Ca_{shell} minima and Mg/Ca_{shell} and Sr/Ca_{shell} maxima occurring near annual growth lines. Ba/Ca_{shell} time-series show noncyclic sharp peaks that vary between years and among localities. Furthermore, time-series of Na/Ca_{shell}, Mg/Ca_{shell} and Sr/Ca_{shell} can be used to validate the presence of annual growth lines used to build chronologies, while Ba/Ca_{shell} time-series vary along the Eastern Adriatic coast and probably reflect local environmental changes.

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Session: Proxy Development: Challenges and Opportunities

Daily growth chronologies in a marine flatfish during estuarine colonization

Filipe Martinho[1*], Ana Vaz[1], Ana Lígia Primo[1], Miguel A. Pardal[1], Bronwyn M. Gillanders[2], Rita P. Vasconcelos[3], Susanne E. Tanner[4], Patrick Reis-Santos[2,4]

[1]Centre for Functional Ecology - CFE, Department of Life Sciences, University of Coimbra, Calçada Martins de Freitas, 3000-456 Coimbra, Portugal
[2]Southern Seas Ecology Laboratories, School of Biological Sciences, The University of Adelaide, SA 5005, Australia
[3]IPMA – Instituto Português do Mar e Atmosfera, Rua Alfredo Magalhães Ramalho, 6, 1495-006 Lisboa, Portugal
[4]MARE - Marine and Environmental Sciences Centre, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal

**presenting author: fmdm@ci.uc.pt*

Marine fishes display among the most extreme spatial and temporal variability in population dynamics, given that several transitions during their ontogenic development co-occur with changes in habitat use. This is the case of many marine flatfishes, whose early life cycle involves the transition between coastal areas as larvae, metamorphosis and then benthic settlement in estuaries, during which growth is driven by both intrinsic and extrinsic conditions. While the development of growth chronologies has greatly increased our understanding of the effects of climate on fish growth over large temporal scales, this methodology has not yet been implemented to assess daily growth variations on fish early life history stages, during which migrations, metamorphosis and other ecological changes may further hamper our understanding of species-environment relationships. In this work, we used otolith daily increment widths (as a proxy for individual growth) of a juvenile marine flatfish - European flounder *Platichthys flesus*, from the Mondego estuary nursery (Portugal). We used increasingly complex mixed models to partition intrinsic (age and early life stage – pelagic, benthic) and extrinsic (environment: temperature, river flow) factors to explore the importance of different environmental and physiological drivers to individual growth in different life stages and over five recruitment cohorts (2011-2015). Additionally, we included otolith chemical composition (Sr:Ca and Ba:Ca ratios) as a natural proxy for habitat use, and whose incorporation of elements in the otolith matrix is also influenced by the environment and physiology. Unraveling these processes is particularly complex in estuarine environments where environmental conditions vary on small spatial and temporal scales. Results contribute to disentangling environmental and life stage driven growth patterns, which can contribute to a better understanding of juvenile fish habitat use patterns and estuarine nursery role.

Session: Growth, Bioenergetics and Ecosystems

Reconstructing the upper-ocean ^{13}C Suess-effect using high-resolution sclerosponge records and implications for the oceanic CO_2 sink

Malcolm McCulloch[1*], Amos Winter[2], Manuel Rigo[3], Clark E. Sherman[4], Julie Trotter[1]

[1]*Ocean Graduate School and Oceans Institute, The University of Western Australia, Crawley, Australia*
[2]*Earth and Environmental Systems Department, Indiana State University, Terre Haute, Indiana, USA*
[3]*Dipartimento di Geoscienze, Università degli Studi di Padova, 35131 Padova, Italy*
[4]*Department of Marine Sciences, University of Puerto Rico at Mayaguez, Mayaguez, Puerto Rico*

**presenting author: Malcolm.McCulloch@uwa.edu.au*

Here we use the distinctive $d^{13}C$ *Suess-effect* signature from fossil-fuel burning preserved in the aragonite skeleton of long-lived Caribbean sclerosponges (*Ceratoporella nicholsoni*) to constrain the efficacy of the oceanic sink for CO_2 over the Anthropocene. The oceans play a key role in determining the habitability of our planet, absorbing nearly 30% of the CO_2released by fossil-fuel burning and other human activities. However, their ability to continue to absorb anthropogenic CO_2 at historic rates is under increasing question as atmospheric concentrations continue their seemingly inexorable rise. Furthermore, the oceans carbonate ion concentration, and hence buffer capacity, is declining due to ocean acidification, compounded by the reduced solubility of CO_2 in seawater as upper-ocean temperatures rise.

Sclerosponges are an ideal archive for reconstructing the oceanic uptake of anthropogenic CO_2 since they are long-lived organisms whose carbonate skeleton is precipitated with a near constant $d^{13}C$ fractionation factor relative to the dissolved inorganic carbon of seawater (e.g. Böhm et al., EPSL 1996). Here we also utilise sensitive high-resolution MC-ICPMS U-series dating enabling precise, absolute chronologies to be determined. For high U sclerosponges (4-6 ppm), accurate chronologies are mainly limited by uncertainties in corrections for non-radiogenic ^{230}Th incorporated during calcification (e.g. Rosenheim, et al., GCA, 2007). To overcome this limitation, we also extracted samples from the uppermost 2-3 mm of growth surface for which ages can be independently inferred by the date of sample collection. This now enables reliable corrections for initial $^{230}Th/^{232}Th$, facilitating near-annual resolution in skeletal chronologies.

Using these highly accurate sclero-chronologies we find that, regardless of water depth (30-90 m), the combined sclerosponge $d^{13}C$ records closely mirror changes expected from the oceanic uptake of isotopically distinctive $d^{13}C$ released into the atmosphere over the Anthropocene. From 1750 to 1850, when atmospheric CO_2 concentrations were only marginally above pre-industrial levels (i.e. ~280±5 ppm), $d^{13}C$ ratios show relatively little change, consistent with natural variability (i.e. ±5 ppm). However, from the 1850's to present-day (2010), there is an excellent correlation (r^2 = 0.995) between declining sclerosponge $d^{13}C$ and rising atmospheric levels of CO_2, indicative of a constant rate of uptake by the oceans of isotopically distinctive anthropogenic-derived carbon. This contrasts to the more disparate ice-core records of changing atmospheric $d^{13}C$. Our findings thus provide a rare 'good-news' story, implying that the oceanic sink for anthropogenic CO_2 is still relatively stable, with uptake remaining proportionate to increasing atmospheric pCO_2.

Session: Climate and Oceans: Past, Present and Future

Endolithic cyanobacteria: a complication for the study of ecology and sclerochronology

Christopher McQuaid[1*], Aldwyn Ndhlovu[1], Cristian Monaco[1], Gerardo Zardi[1]

[1]Dept of Zoology and Entomology, Rhodes University, Grahamstown 6140, South Africa

**presenting author: c.mcquaid@ru.ac.za*

Sclerochronology is an invaluable tool in marine ecology that depends on shell structure that is largely uncorrupted. Endolithic organisms, including photosynthetic cyanobacteria, are a ubiquitous problem for marine organisms with calcified shells as they can cause extensive shell damage. This can introduce problems as bioerosion can interfere with the determination of growth lines. In intertidal mussels, endolithic infestation can lead to shell collapse and mortality and even in less extreme cases, endoliths can cause a range of sub-lethal effects as energy must be re-routed to deal with shell damage. We examined the effects of endolithic infestation on mussel energy budgets and thermal biology. We found that, while infestation did not affect ammonium excretion, feeding rates or tolerance of heat stress, it reconfigures the overall energy budget by increasing metabolic rates while reducing growth and gonad production. At the same time, deposition of excavated $CaCo_3$ on the outside of the shell alters the shell albedo or reflectivity, leading to reduced body temperatures and, under extreme conditions, decreased mortality through heat stress.

Levels of infestation depend on a wide range of factors ranging from large to small scales. These include factors affecting cyanobacterial community composition, such as latitude and biogeography, as well as cyanobacterial biology, such as shore aspect with respect to insolation and topographic shading. Because initial infestation depends on damage to the periostracum of the shell through wave or sand abrasion, levels of infestation are also affected by height on the shore, the degree of wave action and host age, while differences among host species in periostracum thickness and structure are reflected in their susceptibility to endolithic infestation. In the case of invasive species, immunity to endoliths can offer an example of enemy-free space in the invaded locality. Overall, endoliths have complex relationships with their host species, affecting their ecology and introducing complications to the application of sclerochronology to their hosts.

Session: Growth, Bioenergetics and Ecosystems

Temperature-induced mineralogical transformations of aragonitic mollusc shells

Stefania Milano[1,2*], Gernot Nehrke[2]

[1]*Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, 04103 Leipzig, Germany*
[2]*Alfred Wegener Institute for Polar and Marine Research, Am Handelshafen 12, 27570 Bremerhaven, Germany*

**presenting author: stefania_milano@eva.mpg.de*

Mollusc shells are complex biomineralized structures mostly composed of calcium carbonate ($CaCO_3$) and organic macromolecules. Their hierarchical organization and the coexistence of an inorganic and an organic phase make the shells particularly resistant to mechanical and chemical stress. For this reason, mollusc shells are abundant in geological and archaeological contexts and they are often used as paleoenvironmental records. However, despite a general elevated preservation potential, shells can be subjected to diagenetic alterations. These processes can alter their mineralogical, structural and chemical properties potentially undermining the paleoclimate reconstruction reliability. In particular, aragonite, being a metastable $CaCO_3$ polymorph, is especially prone to transform into calcite. The aim of this study is to shed light on the mechanisms involved in aragonite-to-calcite transformation in response to high temperatures exposure. Mineralogical and structural changes in the shell of the marine gastropod *Phorcus turbinatus* are observed by means of Confocal Raman Microscopy, Scanning Electron Microscopy and Atomic Force Microscopy. The results show a different thermal behaviour among the two aragonitic shell layers, which transform into calcite at different temperatures. Such a heterogeneous response is likely related to the different types of microstructures and organic content of the two shell portions. Overall, our data suggest that carbonate structural properties might be an extremely important factor to take into consideration when studying diagenetic alteration dynamics.

Session: Biomineralization

Exploring illicia microchemistry: a new tool for fish age determination?

Sílvia Pérez-Mayol[1], **Beatriz Morales-Nin[1*]**, Audrey J. Geffen[2], Roxanne Duncan[3], Deirdre Brophy[3]

[1]*IMEDEA CSIC/UIB, Miquel Marques 21, 07190 Esporles, Spain*
[2]*Department of Life Sciences, Imperial College London, Imperial College Road, London SW7 2AZ, UK*
[3]*Marine and Freshwater Research Centre, Galway Mayo Institute of Technology, Dublin rd, Galway, H91 T8NW, Ireland*

**presenting author: beatriz@imedea.uib-csic.es*

The microchemical composition of calcified tissues of marine organisms is a well developed tool to unravel life history events, assess migrations and determine stocks. Most studies in fish are based on otoliths and more infrequently on scales and bones (vertebra, spines or fin rays). The illicium is the most antero-dorsal spine present in fish of the genus *Lophius*, it appears as a long filament movable in all directions that these predators use to attract other fish to their jaws. Illicia are calcium phosphate structures, mainly composed of hydroxyapatite ($Ca_5(PO_4)_3(OH)$) and a protein matrix, that are metabolically active and subject to elemental mobilization and resorption, and are used, as otoliths, for age determination. They are the structure of choice for age determination of *Lophius piscatorus* due to the lack of distinct bands in their otoliths that makes them very difficult to interpret.

In this pilot study we develop the methodology to analyse illicia using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS), a highly sensitive analytical technique that allows a high spatial resolution. The aim is to validate seasonal trends in microchemistry and relate them to the visual growth marks usually employed in age determination using illicia.

For this purpose we used white anglerfish (*L. piscatorus*) collected in winter, spring, summer and autumn (2017/2018) at the Southern Celtic Seas and the Bay of Biscay. Lithium, Na, Mg, Al, P, K, Ca, Mn, Fe, Zn, Sr, Ba and Pb were quantified by LA-ICPMS on the identified growth marks and on a radial continuous line of 20 illicia transverse sections, and used to compare between fish collected in each season. The evaluation of the data determines if there are annual cycles in microchemistry that could be used to estimate age. Moreover, the comparison of the results between the transects along the illicia radius and in the identified growth marks provide supplementary information about the characteristics of illicia and anglerfish life history events.

Session: Growth, Bioenergetics and Ecosystems

Anomalous ^{18}O-depletions of Madeiran *Glycymeris* growth increments – A new tool to trace meridional shifts of the Azores Front

Alexandra Németh[1,2*], Zoltán Kern[1,2], Ronny Boch[3]

[1]*Isotope Climatology and Environmental Research Centre (ICER), MTA ATOMKI, Debrecen, Hungary*
[2]*Institute for Geological and Geochemical Research, MTA Research Centre for Astronomy and Earth Sciences, Budapest, Hungary*
[3]*Institute of Applied Geosciences, Graz University of Technology, Graz, Austria*

**presenting author: nemethalexandra89@gmail.com*

Despite the positive results obtained using saltwater clam *Glycymeris* spp. for palaeoenvironmental reconstructions in the extratropical North Atlantic domain, its potential has not been investigated in the subtropical North Atlantic region. The aim of this study was to investigate cockles (*G. vanhengtsumi*) as archives for climate perturbations from the subtropical region by measuring the oxygen isotope compositions from the annual growth increments. The shells' habitat ranging from 150-160 m depth offshore Madeira is exposed to relatively minor seasonal contrasts in terms of temperature compared to higher latitudes. The region itself, however, is exposed to the highly dynamic system of the Azores Current and its associated front on the north-eastern boundary of the North Atlantic Subtropical Gyre.The three analysed shells were collected (one alive and two as sub-fossil specimens) near the Desertas Islands, Madeira in 2014. They were selected from a set of synchronized increment series of a robust site chronology for the 1950–2012 period which was used to explore shell growth responses to environmental parameters in an earlier study. As the three increments series are overlapping in time, the collected carbonate samples cover the period between ~1957 and 2010. Annual increments were sampled at seasonal resolution (min. 3 max 7 sample points per increment) using a computer-controlled micromill device (ESI New Wave Research, Portland). Stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope compositions of the carbonate samples were analysed by an IRMS. Oxygen isotopic ratios measured from the shells' carbonate and regional seawater $\delta^{18}O$ were used to calculate water temperatures on a seasonal resolution based on isotope equilibrium relationships. The results mostly coincided with the expected seasonal temperature range (17-19°C) of the shells habitat, except from a few anomalously high temperature values inferred (20-23°C), e.g. for 1986-1988 and in the late 70's. During these years, the modelled position of the Azores Front shifted southward unexpectedly (~31° N) compared to its usual position situated between 33° and 35° N. This relationship suggests that anomalous $\delta^{18}O$-depletions of the Madeiran cockle increments are not necessarily connected to real water temperature anomalies as the upper layer of the water column has prominently lower $\delta^{18}O$ values north of the Azores Front than south of it. Our results suggest that sclerochronological analysis of *Glycymeris* spp. shells combined with high-resolution stable oxygen isotope measurements could be used to track regional changes of this subtropical current system.

Session: Proxy Development: Challenges and Opportunities

Evaluating *Porites* microatolls for climate reconstructions: Records from French Polynesia

Nicholas Farley[1*], Elias Samankassou[1], Guillaume Antonioli[1], Nadine Hallmann[2], Gilbert Camoin[2], Anton Eisenhauer[3], Claude Vella[2], Glenn A. Milne[4]

[1]University of Geneva, Rue des Maraîchers 13, CH-1205 Geneva, Switzerland
[2]Aix-Marseille Université, CNRS, IRD, Collège de France, CEREGE, Europôle Méditerranéen de l'Arbois, BP80, 13545 Aix-en-Provence cedex 4, France
[3]GEOMAR Helmholtz-Zentrum für Ozeanforschung, Wischhofstraße 1-3, 24148 Kiel, Germany
[4]University of Ottawa, Department of Earth and Environmental Sciences, Ottawa, Ontario K1N 6N5, Canada

**presenting author: nicholas.farley@unige.ch*

Through a collaborative project we have a succession of *Porites* microatolls throughout the mid to late Holocene. In order to carry out paleoclimate reconstructions we have first scrutinized how suitable *Porites* microatolls are at recording sea-surface temperatures by comparing modern microatolls against instrumental (MeteoFrance) and satellite temperature data.

Based on the classical Sr/Ca and $\delta^{18}O$, and additionally Sr-U (DeCarlos et al., 2015, 2016) and Li-Mg (Montagna et al., 2014), we tested sample material from Bora Bora and Maupiti in the present study. We further measured the elemental ratios of Ba/Ca to monitor changes in environment and investigate possible vital effects. Congruent with the recent literature on massive *Porites*, the Sr/Ca ratios of individual corals show offsets which can be attributed to vital effects. When we combine three records, we can reconstruct the temperature record accurately with an r^2 of 0.80 and producing a final calibration for French Polynesian *Porites* microatolls Sr/Ca = -0.0675(±0.004) SST + 10.887(±0.059) which is coherent to massive *Porites* corals previously published (e.g., Cahyarini et al., 2008 with a gradient of -0.0663(±0,004) and r^2=0.74. The $\delta^{18}O$ record, although still well correlated with temperature (r^2 of 0.77) has a much larger range of values between the records so is not nearly as precise. The Sr-U corrects to some extent for vital effects however it is then not suitable for time series analysis. The Li/Mg data are currently being compiled and quantitively compared against the Sr/Ca record but so far qualitatively they do not seem to be as effective as a composite of multiple Sr/Ca records.

The current results indicate that microatolls can be a valuable record of past sea-surface temperatures, easily as good as massive *Porites*. Final conclusions on the reliability of the latest geochemical paleothermometers will be available for our samples

Session: Climate and Oceans: Past, Present and Future

Microscale stable isotopic analytical system (MICAL3c) reveals high-resolution temperature history of fish otoliths

Kozue Nishida[1,2*], Tatsuya Sakamoto[2,3], Tomoya Aono[1,3], Saburo Sakai[4], Toyoho Ishimura[1]

[1]National Institute of Technology, Ibaraki College, Japan,
[2]The Japan Society for the Promotion of Science (JSPS), Japan
[3]Atmosphere and Ocean Research Institute, The University of Tokyo, Japan
[4]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan

**presenting author: nishida@gm.ibaraki-ct.ac.jp*

Since the 1950's, stable carbon and oxygen isotope ($\delta^{13}C$ and $\delta^{18}O$) of biological carbonate have been used for paleoenvironmental and paleoecological studies, and, in particular, $\delta^{18}O$ is a powerful tool for estimating environmental history (such as temperature, seawater $\delta^{18}O$). Recently, we have been developed the method of high resolution stable carbon and oxygen isotope analysis by using customized microscale isotopic analytical system (MICAL3c with IsoPrime100: Ishimura et al. 2004, 2008). MICAL3c enabled us to determine $\delta^{13}C$ and $\delta^{18}O$ values for small amounts of carbonate, as low as 0.2 μg, which is less than 1/100 of the amount required by conventional methods, with analytical precision less than 0.1‰. Recently, we have reported micro-volume stable isotopic data by using MICAL3c system of various carbonate, such as the single foraminiferal specimens (Ishimura et al., 2012; Takagi et al., 2015), the single grain of the international reference materials (Ishimura et al., 2008; Nishida and Ishimura, 2017) and fish otoliths (Kitagawa et al., 2013; Sakamoto et al., 2017, 2018). In this study, we introduce our recent studies using the microscale isotopic analytical system which is applicable for sclerochronology of various calcifiers.

To track the movements of fish in open oceans is of great importance for efficient fisheries management to understand population structures and the environmental cause of recruitment variabilities, and, recently, fish otolith has been focused on for understanding of fish ecology. Otolith $\delta^{18}O$ is known to reflect ambient water temperature through fish growth; however, it has been difficult to obtain time-series stable isotope data because of the limits of milling technique of small-sized specimens and carbonate weight for isotopic analysis. To solve these issues, we have applied our MICAL3c system in combination with the high precision micro-milling system (Geomill326, Izumo-web, Japan) for realizing high-resolution time-series stable isotope data of fish otolith. By using this milling system, we can obtain about 40 samples from a 1 mm-length otolith, and the milling line width is 10 to 50 μm. This resolution is close to the reported resolution of Secondary Ion Mass Spectrometry analysis (e.g. Shiao et al., 2014). We will present our challenges including the evaluation of the otolith-$\delta^{18}O$ thermometer of Japanese sardine, *Sardinops melanostictus* through the temperature-controlled culture experiment for rigorous temperature calculation (Sakamoto et al., 2017), and the estimation of high-resolution migration history of Japanese sardine in the North West Pacific by using microvolume isotope analysis and numerical simulation (Sakamoto et al., 2018).

Session: Proxy Development: Challenges and Opportunities

Drivers of synchrony among deep-water snappers

Joyce Ong[1*], Corey Wakefield[2], Malin Pinsky[1], Stephen Newman[2]

[1]Department of Ecology, Evolution and Natural Resources, Rutgers University, 14 College Farm Road, New Brunswick, New Jersey 08901, USA
[2]Western Australian Fisheries and Marine Research Laboratories, Department of Primary Industries and Regional Development, Government of Western Australia, PO Box 20, North Beach, WA, 6920, Australia

**presenting author: joyce.ong.jl@rutgers.edu*

Marine fisheries contribute significantly to food security, nutrition, employment and trade of many countries. Hence, the sustainability and vulnerability of marine fisheries is a critical concern, especially given the increased risks related to climate changes and the potential for overfishing. Synchrony of population fluctuations has become an important lens for understanding fisheries because of its negative effects on the stability of aggregate properties such as total biomass production and yield. In addition, synchrony points to major drivers of population dynamics such as climate, trophic interactions or anthropogenic factors. Most fisheries studies detecting synchrony from ecological timeseries data use correlation-based methods, however, these methods do not take non-stationarity, temporal autocorrelation, lags and timescale-specific changes into account. Here, we use wavelet analysis, which can account for such issues, to detect timescale-specific synchrony within populations of two deep-water snappers along the northwest coast of Australia. We constructed otolith biochronologies from 113 fishes of the species *Pristipomoides zonatus* and *Lutjanus bohar*. These timeseries spanned a 37 year series from 1970 to 2006. Population synchrony within and between species was investigated followed by an examination of potential drivers of synchrony. Examples of potential drivers included strength of the major boundary current and several large-scale oceanographic processes such as the Pacific Decadal Oscillation, Indian Ocean Dipole and ENSO. We identify the dominant timescales at which synchrony occurs, time-specific changes in synchrony and the phase relationships (in-phase, phase lagged and anti-phase) between the population dynamics of these deep-water snappers and potential drivers of synchrony. Preliminary analyses reveal that both species are not responding synchronously to each other. *Lutjanus bohar* has a dominant timescale pattern of 6-8 years and seems to be related to the Pacific Decadal Oscillation and the Indian Ocean Dipole. *Pristipomoides zonatus* has a shorter dominant timescale pattern of around 4 years and is strongly related to the strength of the major boundary current and ENSO. Detecting synchrony and lags, both within populations and between potential drivers, is helpful for understanding how to mitigate and prepare for future populations responses to climate and anthropogenic changes.

Session: Fisheries Ecology and Management

Biomineralization in *Spirula spirula*: first proteomic data and new microstructural inputs

Morgane Oudot[1*], René Hoffmann[2], Emmanuel Fara[1], Pascal Neige[1], Frédéric Marin[1]

[1]Biogéosciences, UMR CNRS 6282, Université Bourgogne Franche-Comté, 6 boulevard Gabriel, 21000, Dijon, France
[2]Department of Earth Sciences, Institute of Geology, Mineralogy, and Geophysics, Branch Paleontology, Ruhr-Universität Bochum, Universitätsstrasse 150, 44801 Bochum, Germany

**presenting author: morgane.oudot@u-bourgogne.fr*

The ram's horn squid *Spirula spirula* (Linné 1758) is an enigmatic small-sized mesopelagic cephalopod (Coleoidea, Decabrachia) with a specific anatomy, made of a mosaic of plesiomorphic characters and synapomorphies, and resulting in a predominantly head-down swimming position. In contrast to the highly abundant shells that can be collected on the beaches of the Atlantic, Indian and west Pacific Oceans, the life habits of *Spirula* remains poorly known. A few studies have investigated the shell microstructure but the shell biochemistry has never been examined so far. Yet, considering the enigmatic anatomy and the differing microstructure of the *Spirula* shells, it appears quite interesting to characterize the organic matrix responsible for the shell formation and compare it with other cephalopods (such as cuttlefishes or nautiloids), or other shell-bearing marine molluscs. Accordingly, this study aims at bringing the first biochemical characterisation of the spirulid organic matrix and novel microstructural inputs, and at confronting the biochemical/proteomic data with the morphological one. Our main results show that the organic matrix is sugar-rich and protein-rich, with macromolecules ranging from low to high molecular weights. Nevertheless, low molecular weights proteins may be more abundant. We also noticed the presence of a putative calcium-binding component around 17 kDa. The saccharides of the organic matrix are predominantly represented by mannose, galactose and acetylglucosamine. The first proteomic analyses performed on diverse shell extracts of *S. spirula* identified numerous peptides. However, few of them actually match with already known mollusc skeletal proteins, suggesting that the shell matrix of the ram's horn squid is quite different from that of other shell-bearing molluscs studied so far. In parallel, SEM observations reveal some structures rarely described in the literature: at the junction of the septa with the shell wall, the lamello-fibrillar structure of the septa is inserted between two sub-layers of the internal microstructure of the wall, in the form of a bevel. Besides illustrating the complexity of *S. spirula*'s shell microstructures, our study provides the first exhaustive characterization of the shell organic matrix of this species.

Session: Biomineralization

Separating seasonality in temperature and the oxygen isotopic composition of water: Sub-annual clumped isotope analysis of gastropods

Sierra V. Petersen[1*], Jade Z. Zhang[1], Serena R. Scholz[1], Rebecca C. Heaman[1], Niels J. de Winter[2], Johan Vellekoop[2,3]

[1]University of Michigan, Ann Arbor, Michigan, USA
[2]AMGC, Vrije Universiteit Brussel, Belgium
[3]KU Leuven, Belgium

**presenting author: sierravp@umich.edu*

High-resolution oxygen isotope records from fossil marine mollusks are an important archive of past sub-annual climate change. However, the oxygen isotopic composition of shell carbonate is influenced by both growth temperature and changes in the oxygen isotopic composition of local waters ($d^{18}O_{water}$). Mollusk species targeted for sclerochronology studies commonly live in coastal regions where changes in $d^{18}O_{water}$ are likely occurring, which would interfere with interpreted temperature seasonality in unquantified constructive or destructive ways. In contrast, the clumped isotope paleothermometer (D_{47}), based on the ordering of heavy isotopes of both carbon and oxygen within the carbonate lattice, can determine growth temperature independent of $d^{18}O_{water}$. When combined with simultaneously-measured $d^{18}O$ of carbonate, can additionally determine past $d^{18}O_{water}$ values themselves. It has been difficult to apply this powerful new paleothermometer at sub-annual scales due to large sample size requirements. Although technological advances continue to reduce sample sizes, typical sclerochronological micromilling methods are still generally out of reach of the clumped isotope proxy, or require pooling of many adjacent samples. Large, fast-growing marine gastropod species produce enough shell material per year to easily allow for sub-annual sampling for D_{47}. However, published clumped isotope calibration efforts targeting any marine gastropod species (i.e. modern specimens collected from known environments) are limited to five individual shells representing only two species (*Cittarium pica and Conus ermineus*), each sampled at one point per shell.

In this study, we expand this small marine gastropod calibration dataset with the addition of many more species (*Campanile symbolicum, Busycon carica, Busycon (Sinistrofulgur) sinistrum,* and others) from a variety of modern localities and apply both bulk and sub-annual isotopic sampling strategies. We use high-resolution $d^{18}O$ analyses to define seasonal structure and growth rate, then take larger samples at sub-annually spaced intervals for D_{47}. We compare D_{47}-derived temperature and $d^{18}O_{water}$values to known environmental conditions to determine whether these species reliably record climate conditions or whether 'vital effects' cause offsets from the expected D_{47}-Temperature relationship founded on analysis of synthetic carbonates. We investigate sub-annual changes in $d^{18}O_{water}$ and estimate the impact observed changes would have on $d^{18}O$-based paleoclimate reconstructions if not considered. Overall, this study serves to demonstrate the potential of a combined $d^{18}O$-D_{47}measurement scheme to eliminate potential biases caused by changing $d^{18}O_{water}$ and reveal more accurate sub-annual paleoclimate information.

Session: Proxy Development: Challenges and Opportunities

Coupling individual natural tracers to assess the connectivity within a flatfish metapopulation

Marine Randon[1*], Le Pape Olivier[1], Bruno Ernande[2], Kélig Mahé[2], Filip Volckaert[3], Eric Petit[1], Gilles Lassalle[1], Thomas Le Berre[1], Nathan Martin[1], Elodie Réveillac[1]

[1]ESE, Ecology and Ecosystem Health, Agrocampus Ouest, INRA, 35042 Rennes, France
[2]Fisheries Laboratory, IFREMER, 150 Quai Gambetta, BP 699, 62321, Boulogne-sur-Mer, France
[3]Laboratory of Biodiversity and Evolutionary Genomics, Charles Deberiotstraat 32, box 2439, 3000 Leuven, Belgium

**presenting author: marine.randon@agrocampus-ouest.fr*

In marine exploited populations, precise understanding of population structure and connectivity is required to ensure sustainable fisheries. The common sole (*Solea solea*) of the Eastern English Channel (EEC) stock is currently assessed and managed as a single and homogeneous population and has been overexploited over the past decade. The existence of three subpopulations (with different levels of exploitation by fisheries) has been recently suggested but has not been deeply investigated so far. Whereas the connectivity induced by early life stages was assessed as low inside the EEC stock, sub-adult and adult mixing between putative subunits remains unknown.
Here, we hypothesized that the common sole of the EEC stock presents a metapopulation structure of three sub-populations. We assessed both genetic and demographic connectivity within the common sole metapopulation of the EEC stock by analyzing, on the same adult individuals, three complementary natural tracers: otolith microchemistry, otolith morphometry and genetic markers. First, we assessed demographic connectivity between the juvenile and adult stages by introducing the otolith composition in trace elements into a Bayesian model to assign adults to their nurseries of origin. Specifically, we implemented an atlas of nurseries otolith compositions based on a reference data set comprised of juvenile individuals. Comparing adult otolith composition with the juvenile signatures allowed the allocation of adults to their nurseries of origin. In parallel, we investigated, on the same adult individuals, genetic connectivity and population structure using up to date genetic markers (Single Nucleotide Polymorphism from RAD sequencing). Also, we tested for spatial segregation of sub-populations using the adults' otolith shape (elliptical Fourier descriptors) as integrative tracer of life history. Finally, we compared and discussed the synergy and discrepancies between individual tracers. Otolith microchemistry indicated that a large part of adults were assigned to a nursery close to the spawning grounds where they were sampled, which means that adults mainly reproduced in a local sub-population, thus supporting a metapopulation functioning. Genetic assignments and otolith shape analyses also suggested a metapopulation structure and especially highlighted the isolation of a sub-population located in the South West from the rest of the EEC. Our findings support the hypothesis of a metapopulation structure of three sub-populations with relatively low connectivity and isolation of a southwestern subunit. Congruence and complementarity between otolith microchemistry, otolith shape and genetic analyses were found and highlighted the interest of a holistic approach in connectivity studies.

Session: Fisheries Ecology and Management

Influence of El Niño Southern Oscillation events on otolith growth and chemical chronologies in dusky grouper

Patrick Reis-Santos[1,2*], Mario V. Condini[3], Alexandre Garcia[4], Cristiano Q. Albuquerque[3], Bronwyn Gillanders[2], Susanne E. Tanner[1]

[1]MARE — Marine and Environmental Sciences Centre, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Campo Grande, Lisboa, Portugal
[2]Southern Seas Ecology Laboratories, School of Biological Sciences, The University of Adelaide, SA 5005, Australia
[3]Departamento de Ciências Animais, Universidade Federal Rural do Semi-Árido, CEP: 59625-900, Mossoró, RN, Brasil
[4]Laboratório de Ictiologia, Instituto de Oceanografia, Universidade Federal de Rio Grande, Av. Itália Km 08, Carreiros, CEP: 96.201-900, Rio Grande, RS, Brasil

**presenting author: pnsantos@fc.ul.pt*

Dusky grouper *Epinephelus marginatus* is the only large Epinephelidae species commonly found along subtropical latitudes, and is listed as 'Endangered' (IUCN Red List) due to a combination of overfishing and complex life history strategy (slow growth rate, late maturation, aggregative spawning behavior and sequential hermaphroditism). Here we develop otolith growth and chemical chronologies spanning a 30-year period for dusky grouper collected in the coastal region adjacent to the Patos Lagoon - a major estuarine system in the Southwest Atlantic and one of the most productive fishing areas in Brazil. In this region, variations in the El Nino Southern Oscillation (ENSO) are renowned for modifying rainfall and estuarine biogeochemical cycles, and such dynamism in environmental conditions likely influences individual fish growth. Therefore, we used increasingly complex mixed models to partition intrinsic and extrinsic factors (including SST, salinity, chlorophyll a, multivariate ENSO index, prey availability), evaluate their relative importance to individual growth and otolith chemical composition, as well as to identify climate- or environment-driven variations, namely how cold (La Niña) and warm (El Niño) episodes of ENSO influence grouper population dynamics. Ultimately, understanding how local and regional environmental variability drive grouper population productivity is key for management and conservation of this endangered species.

Session: Fisheries Ecology and Management

Northern Hemisphere ocean atmosphere interactions over the last 500 years

David Reynolds[1*], Bryan Black[1], Ian Hall[2], Freya Garry[3], Paul Halloran[3], James Scourse[4]

[1]Laboratory of Tree Ring Research, University of Arizona, Bryant Bannister Tree Ring Building, 1215 E Lowell St, Tucson, AZ, 85721, USA
[2]School of Earth and Ocean Science, Cardiff University, Main Building, Park Place, Cardiff, CG10 3AT, UK
[3]School of Geography, College of Life and Environmental Science, University of Exeter, North Park Road, Exeter, EX4 4QE, UK
[4]Centre for Geography and Environmental Science, College of Life and Environmental Science, University of Exeter, Penryn Campus, Treliever Road, Penryn, Cornwall, TR10 9FE, UK

**presenting author: davidreynolds@email.arizona.edu*

Pre-industrial Northern Hemisphere climate variability is driven by the interplay between external climate forcings (solar variability and volcanic aerosols) and internal mechanisms, such as atmospheric and oceanic feedbacks. Over the last 500 years the Northern Hemisphere transitioned from the relatively cold interval of the Little Ice Age into the industrial era characterised by the modern anthropogenic warming. These intervals are also characterised by significant variability in total solar irradiance, volcanic aerosols and greenhouse gases. Hitherto the lack of absolutely-dated marine reconstructions that extend over this period has precluded the investigation of the role the oceans play in mediating Northern Hemisphere climate variability. We utilise a hemispheric suite of absolutely dated sclerochronologies and dendrochronologies to investigate the mechanisms that drive inter-annual to centennial scale Northern Hemispheric climate variability over the last 500 years. The absolutely dated nature of the records facilitates the identification of coherent patterns of variability across large spatial scales on inter-annual to multi-centennial timescales. These analyses suggest there is significant coherence between North Atlantic Ocean and North Pacific Ocean variability over the last 500 years mediated by atmospheric circulation patterns (Polar Jet stream, Pacific North America Pattern [PNA] and the North Atlantic Oscillation [NAO]). Comparison of the spatial network with external forcing timeseries highlights that solar variability and explosive volcanic eruptions play a significant role in driving both the oceans and atmosphere. These analyses highlight the power of integrating sclerochronology and dendrochronology archives to reconstruct coupled ocean-atmosphere system dynamics, external forcings, and internal mechanisms at a hemispheric scale.

Session: Climate and Oceans: Past, Present and Future

Hindcasting for forecasting. Disentangling the impact of environment and fishing in Flemish Cap Atlantic cod dynamics

Raquel Ruiz-Díaz[1*], Rosario Domínguez-Petit[2], Fran Saborido-Rey[3]

[1]University of Gent, Marine Biology Research Group, 9000 Gent, Belgium
[2]Spanish Oceanographic Institute, (IEO), 36390 Vigo, Spain
[3]Marine Research Institute, (IIM-CSIC), 36208 Vigo, Spain

**presenting author: raquel.ruiz103@gmail.com*

The Flemish Cap (FC) Atlantic cod (*Gadus morhua*) population experienced a sharp decline that ended up with the collapse of the stock by mid 1990s and, as consequence, the stock was on fishing moratorium from 1999 to 2009. The goal of this study is to ascertain the environmental variables that have influenced growth in a long time series that includes several decades of important shifts in environmental conditions and fishing regime. In this study, sclerochronology is applied to develop a multidecadal growth chronology from the increment widths of Atlantic cod otoliths. Cod samples were collected in the Flemish Cap (FC), a seamount located in the Northwest Atlantic (NAFO division 3M) at 200 m depths. A scientific survey is carried out by the Institute of Marine Research and the Spanish Institute of Oceanography in this area since 1988. Otoliths are selected base in the year of capture and the age of the individuals (+10 years). Otoliths are sectioned, polished and mounted on resin. High resolution digital pictures of the section are taking with the Leica stereomicroscopy M205 C at the highest magnification. Annuli are measured by the software Fiji with the plugin ObjectiveJ from transversal section of aged otoliths. Finally, total length and width as well as growth increments are measured. These measures of growth increment are crossdated with COFECHA software. The detrended series are averaged with respect to calendar year and a master biochronology is generated with the ARTSAN software. The quality of the chronology is quantified using the Expressed Population Signal (EPS) statistic. Finally, General Linear and Additive Mixed Models (GLMM and GAMM) are used to relate population growth variability with indexes of exploitation, food availability (prey abundance index and condition), climate (NAO and bottom temperature) and denso-dependency (cod abundance and cohort effect). Based on these results, growth trends could be[r1] forecasted under different climatic scenarios to assess the potential impact of climate change on cod growth performance and hence in productivity at mid and long term.

Session: Fisheries Ecology and Management

The "jewel of Mediterranean" *Spondylus gaederopus*: insights into the biomineralization through biomolecular analysis

Jorune Sakalauskaite[1,2*], Beatrice Demarchi[1], Frédéric Marin[2]

[1]*Department of Life Sciences and Systems Biology, University of Turin, Turin, Italy*
[2]*UMR CNRS 6282 Biogéosciences, University of Burgundy-Franche-Comté, Dijon, France*

**presenting author: jorune.sakalauskaite@unito.it*

Mollusc shells are one of the most fascinating systems for studying the fundamental processes of biomineralization. Despite the great attention that this field has attracted over the years, our knowledge on the mechanisms controlling biomineralization is still limited. This is due to the diversity of shell structural architectures and the size of the phylum. In-depth analysis is usually carried out on model systems, hence the amount of information available for non-model systems, especially with regard to the skeletal matrix, is even more scarce.

The thorny oyster *Spondylus gaederopus* is such an example. Considered as "the jewel of Mediterranean", it was used in rare occasions as climate archive but not for biomineralization purpose, in spite of its peculiar evolution: on the basis of morphological arguments, spondylids are supposed to have diverged from a pectinid ancestor in the middle Jurassic. But molecular genetics suggests that the spondylid clade is rather a sister group of pectinids. This evolutionary question is intriguing because Pectinidae shells are fully foliated (calcitic) whereas *Spondylus* is mostly crossed-lamellar (aragonitic). Even though this microstructure is the most common among bivalves, very few studies have targeted the biomineralizing organic matrices of these shells.

We aim to get a deeper insight into the formation of *Spondylus* shells, which would extend our knowledge on the mechanisms of biomineralization for "non-model" systems. Approaching this from a biomolecular angle, we focus on studying the organic shell matrix and compare our new molecular data with closely related taxa, i.e., Pectinidae and Ostreidae. We present preliminary data that reveal the peculiarities of the "biomolecular toolkit" controlling *Spondylus* shell biomineralization: this is one of the first studies attempting to probe the whole set of biomolecules (proteins, sugars, lipids and pigments) occluded in the shell skeleton. We discuss possible methods for "big data" analysis and interpretation, given the paucity of comparative 'omics datasets for non model system. Our work sheds light on the complexity and rapid evolution of molluscan skeletal matrices.

Finally, our work emphasizes an important question for the future: what drives the selection of model organisms for biomineralization studies? Many studies have focused on commercially important species. Our starting point is cultural: *Spondylus* has been an iconic shell since Prehistory, and the presence of *Spondylus* ornaments can be used by archaeologists as an effective "tracker" for the movements and cross-cultural interactions of prehistoric communities. Our biomolecular data will contribute to important archaeological projects.

Session: Biomineralization

Assessing geochemical seawater temperature proxies in the deep sea bivalve *Acesta excavata*

Nicolai Schleinkofer[1*], Jacek Raddatz[1], Max Wisshak[2], Axel Gerdes[1], Jens Fiebig[1], Sascha Flögel[3], Sebastian Streng[1], Alexander Wacholz[1], Silke Voigt[1]

[1]Goethe University Frankfurt, Institute of Geosciences, Altenhöferallee 1, 60438 Frankfurt am Main, Germany
[2]Senckenberg am Meer, Marine Research Department, Südstrand 40, 26382 Wilhelmshaven, Germany
[3]GEOMAR Helmholtz Zentrum für Ozeanforschung Kiel, Wischhofstr. 1-3, 24148 Kiel, Germany

**presenting author: nicolai.schleinkofer@live.com*

Cold-water coral reef communities provide a valuable source of proxy material for intermediate water-depths. Unfortunately, strong vital effects and difficult growth patterns make environmental reconstructions on cold-water corals, like *Lophelia pertusa*, rather difficult. Organisms that inhabit the same habitat, such as the bivalve *Acesta excavata* could provide a proxy-source which is less affected by vital effects and exhibits easier growth patterns.

Here we present solution based ICP-OES elemental ratios (Mg/Ca, Sr/Ca, Li/Mg, Mn/Ca, Fe/Ca) and stable isotope ($\delta^{18}O$ & $\delta^{13}C$) measurements on *A. excavata* from two Norwegian cold-water coral reefs (Sula & Nordleksa). Environmental parameters for proxy calibration are provided by three landers that were deployed in close proximity to the observed reefs over the period of 13 months.

Our results reveal a significant correlation between Mg/Ca ratio and temperature in the high-Mg calcite of *A. excavata* with a very high sensitivity that has not been observed so far in any other marine carbonate or inorganic calcite. The calculated temperatures deviate from the in-situ measured temperatures by a maximum of 0.5°C. Mg/Ca ratios in *A. excavata* therefore holds promise to serve as a temperature proxy for intermediate water mass reconstructions with relatively low variations. Furthermore, Li/Mg, measured by LA-ICP-MS, and Mg/Sr ratios also show promising results as temperature proxies, by reducing the temperature deviations between different specimens that are visible when using Mg/Ca ratios. This is presumably caused by similar vital effects on Mg/Ca, Sr/Ca and Li/Ca ratios (e.g., changes in the rate of skeletogenesis, nutrient availability, etc.) which are minimized by using the elemental ratios in combination.

The $\delta^{18}O$ ratio appears to be only partly controlled by temperature, but reveals a similar seasonal cyclicity as the Mg/Ca ratio. The calculated temperatures however deviate by up to 2°C from the in-situ and the Mg/Ca temperatures. We propose that this is caused by kinetic effects that are due to rapid calcification or changes in the hydrology either caused by freshwater influence or ascending/descending water masses with concomitant changes of the ambient water $\delta^{18}O$ signal. Additionally, the high magnesium content in the skeleton could also cause increasing $\delta^{18}O$-values which would lead to an underestimation of calculated temperatures.

Session: Proxy Development: Challenges and Opportunities

Brachiopods – faithful recorders of ocean properties?

Bernd R. Schöne[1*], Eric O. Walliser[1], Carsten Lüter[2]

[1]Institute of Geosciences, University of Mainz, Joh.-J.-Becher-Weg 21, 55128 Mainz, Germany
[2]Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Invalidenstraße 43, 10115 Berlin, Germany

**presenting author: schoeneb@uni-mainz.de*

Phanerozoic trends of ocean temperature were largely estimated from brachiopods. Respective studies were triggered by Lowenstam (1961) according to which brachiopod shells preserve well and form in equilibrium with $\delta^{18}O_{water}$. However, this long-standing view was rivaled in the mid-1990s demonstrating that species-specific isotopic disequilibrium occurs and certain shell portions are affected by vital/kinetic effects. Auclair et al. (2003) and Yamamoto et al. (2011) also identified growth rate-related isotopic offsets from expected thermodynamic equilibrium as well as ontogenetic changes in modern cold-water terebratulids. Here, we followed in the footsteps of these authors and tested if the same applies to another modern, live-collected terebratulid, *Neothyris lenticularis* from Chatham Rise (134 m water depth), New Zealand. Data of fossil atrypids (Devonian) and rhynchonellids and terebratulids (Cretaceous) were then compared to Veizer's isotope compilation. We also tested a variety of different illumination techniques and contrasting methods in conjunction with polished, stained and etched cross-sections to identify shell growth patterns in modern brachiopods. Findings on the latter were compared to concepts reported by Ye et al. (2018).

Serial sampling from the posterior to the anterior margin was completed in the outer secondary shell layer. Results of the modern brachiopod were contrasted to $\delta^{18}O_{shell}$ time-series of a coeval bivalve mollusk, *Glycymeris* sp., collected at the same locality. Whereas the glycymerid $\delta^{18}O_{shell}$ data fluctuated in a narrow range of +1.58 to +2.45 ‰ which closely reflects the seasonal water temperature range (8-10°C), the $\delta^{18}O_{shell}$ of *N. lenticularis* were more than -2.00 ‰ offset (considering the different isotopic fractionation between glycymerid aragonite and low-Mg calcite of the brachiopod) and showed seasonal fluctuations with an amplitude of up to 2.59 ‰ as well as an ontogenetic shift to higher $\delta^{18}O_{shell}$ (lifespan ca. 10 years). During the first six years of growth, $\delta^{18}O_{shell}$ fluctuated around ca. -0.50 to -1.00 ‰ followed by a gradual increase. However, oxygen isotopic equilibrium was never reached, i.e., even the highest $\delta^{18}O_{shell}$ values (likely representing winter) were still ca. 0.70 ‰ more negative than expected. Following these findings, temperatures reconstructed from $\delta^{18}O_{shell}$ of *N. lenticularis* can at most provide a rough estimate of winter temperatures, and only the most positive values determined at the anterior edge of old-grown specimens are least affected by kinetic and vital effects. Although terebratulids are typically not used for paleotemperature estimates, existing Paleozoic temperature estimates are most likely far too high. Initial data from fossil brachiopods confirm this hypothesis.

Session: Climate and Oceans: Past, Present and Future

Atlantic herring recruitment in the North Sea for the past 455 years based on the $\delta^{13}C$ from annual shell increments of *Arctica islandica*

Juan Estrella-Martínez[1], Bernd Schöne[2], Ruth Thurstan[3], Elisa Capuzzo[4], Paul Butler[5], **James Scourse[5*]**

[1]*School of Ocean Sciences, Bangor University, Bangor, Wales, UK*
[2]*Institute of Geosciences, Johannes Gutenberg University, Mainz, Germany*
[3]*Centre for Ecology and Conservation, University of Exeter, Penryn, Cornwall, UK*
[4]*Centre for Environment, Fisheries and Aquaculture Science (Cefas), Lowestoft, UK*
[5]*Centre for Geography and Environmental Sciences, University of Exeter, Penryn, Cornwall, UK*

**presenting author: j.scourse@exeter.ac.uk*

Understanding the recruitment variability of the Atlantic herring (*Clupea harengus*) North Sea stock remains a key objective of stock assessment and management. Although efforts have been undertaken linking climatic and stock dynamic factors to herring recruitment, no major attempt has been made to estimate recruitment levels before the 20th century. Here we present a novel annually-resolved, absolutely dated herring recruitment reconstruction, derived from carbon stable isotope geochemistry ($\delta^{13}C$) of *Arctica islandica* shell increments from the Fladen Ground (northern North Sea). Our age model is based on a standardised growth increment chronology obtained from fourteen shells. Ten of these were micromilled at annual resolution for $\delta^{13}C$ analysis. Our results indicate that the anthropogenically-driven relative depletion of ^{13}C, the oceanic Suess effect (oSE), became evident in the northern North Sea in the 1850s. We calculated a regression line between the oSE-detrended $\delta^{13}C$ results ($\delta^{13}C\dot{S}$) and phytoplankton primary production in the North Sea, which is modulated by the effect of the latter on the $\delta^{13}C$ of the ambient dissolved inorganic carbon. We used this regression to build an equation mediated by a nutritional link to reconstruct herring recruitment using $\delta^{13}C\dot{S}$. The reconstruction suggests that there were five extended episodes of low recruitment levels before the 20th century. These results are supported by measured recruitment estimates and historical fish catch and export documentation. This work demonstrates that molluscan sclerochronological records can contribute to the investigation of ecological baselines and ecosystem functioning impacted by anthropogenic activity with implications for conservation and stock management.

Session: Fisheries Ecology and Management

Ecological responses of coral reef under different seawater conditions inferred from mid-Holocene coral reefs at the central Ryukyu Islands, Japan

Kohki Sowa[1*], Chuki Hongo[2], Saburo Sakai[1], Kosei E Yamaguchi[3,4]

[1]JAMSTEC, 2-15 Natsushima-cho, Yokosuka-city, Kanagawa, Japan
[2]University of the Ryukyus, 1 Senbaru, Nishihara-cho, Nakagami-gun, Okinawa, Japan
[3]Toho University, 2-2-1 Miyama ,Funabashi-shi ,Chiba, Japan
[4]NASA Astrobiology Institute

**presenting author: sowak@jamstec.go.jp*

The Kuroshio Current provides favorable environmental conditions for the coral reef ecology of the Ryukyu Islands, Japan, where one of the highest coral species diversities in the world is found. Currently, coral reefs are threatened by both global and local environmental changes. To assist with effective coral ecology restoration plans, data on coral species and cover and environmental data on the "pre-industrial era" conditions are essential. However, most of the existing coral reefs have been affected by global and local environmental stresses, as a result of which, data from modern monitoring would not reflect conditions of the "pre-industrial era." The Holocene up-lifted coral reefs emerge around the Ryukyu Islands coastal area. Studies of the sediment cores show that sea surface temperatures of the Kuroshio Current have been persistent during the past 7500 years. Therefore, an integrated analysis of coral geochemistry using coral skeletons and paleontology of the up-lifted Holocene coral reef at the Ryukyu Islands would provide valuable data on the "pre-industrial era" coral reef conditions. Previous studies have been limited to the Kikai Island, situated along the higher latitudes of the Ryukyu Islands, whereas the current study scrutinizes the central part of the Ryukyu Islands. We show an integrated analysis of coral geochemistry and paleontology of up-lifted Holocene coral reefs at the central Ryukyu Islands, Japan. The ^{14}C age of the fossil *Porites* coral estimated to be 5400±140 cal. yr BP. The seasonal $\delta^{18}O$ of the fossil *Porites* coral (~26-year, N=1) averages -4.36‰, which is ~+0.54‰higher than that of the modern coral (~5-year, N=2). XRD analyses and SEM observation show good preservation of the fossil coral skeletons. The averaged extension rates of the fossil/modern coral cores have been calculated at >6 mm/year, indicating a minor kinetic isotopic effect related to skeletal growth. Fossil and modern coral skeletal $\delta^{18}O$ values imply that the Kuroshio Current was saltier in the mid-Holocene than it is today. Despite higher salinity, the fossil coral species were no different than those found in the modern coral reefs. Research results also show that coral coverage in the Holocene was higher than that observed in the modern coral reefs (14.4% vs. 10.5%). Coral cover diminution has been likely caused by recent negative impacts of global and local environmental stress. We have further discussed the effects of reconstructed local-SST and sediment loading/upwelling using coral skeletons.

Session: Paleoecology and Evolution

How do deep-sea fish respond to environmental change: Patterns and drivers of growth variation among space, time and taxonomy

Susanne E. Tanner[1*], Eva Giacomello[2], João Neves[2], John R. Morrongiello[3], Patrick Reis-Santos[1,4], Rita P. Vasconcelos[1,5], Ana Rita Vieira[1]

[1]MARE - Marine and Environmental Sciences Centre, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
[2]IMAR/Okeanos/MARE, Rua Prof. Dr. Frederico Machado 4, 9901-862 Horta, Portugal
[3]School of Biosciences, University of Melbourne, Victoria 3010, Australia
[4]Southern Seas Ecology Laboratories, School of Biological Sciences, The University of Adelaide, SA 5005, Australia
[5]IPMA – Instituto Português do Mar e Atmosfera, Rua Alfredo Magalhães Ramalho, 6, 1495-006 Lisboa, Portugal

**presenting author: setanner@fc.ul.pt*

The deep ocean remains the least explored biome on Earth and is inhabited by many organisms that are highly vulnerable to human pressures and environmental change due to their life histories characterized by long lives, late reproduction and low fecundity. Here, we use growth as a proxy to measure organisms' response to environmental change as growth is sensitive to a range of drivers including temperature effects on physiology, changes in food webs and fishing intensity, as well as playing a fundamental role in determining fitness. Growth rate information naturally archived within otoliths of a set of deep-sea fish species (*Helicolenus dactylopterus*, *Pontinus kuhlii*, *Pagellus bogaraveo*) is used to develop chronologies documenting growth variations in a wide marine region (Iberian Atlantic coast and oceanic islands of Azores and Madeira). We use among and within species mixed effects models capturing both intrinsic (e.g. age, sex, age at capture, species) and extrinsic sources (e.g. temperature at depth, climatic indices, fishing pressure) of variation in growth to assess the relative importance of drivers as well as the temporal and spatial patterns in population productivity. These models are also used 1) to investigate transferability of temporal patterns and drivers of growth variation between fish species in the deep-sea; and 2) to evaluate spatial upscaling of identified patterns of growth variation and drivers for individual species from 10s to 1000s of kms. The integrated assessment of growth variation across species and over wide temporal and spatial extents provides a means to better understand how human-induced and climate driven effects impact understudied systems, such as the deep-sea.

Session: Fisheries Ecology and Management

Investigating scale trace element microchemistry as a tool to track adult North Atlantic salmon populations

Elizabeth Tray[1,3*], Quentin Crowley[2], Niall O'Maoileidigh[3], Deirdre Brophy[1]

[1]Marine and Freshwater Research Centre, Galway Mayo Institute of Technology, Co. Galway H91 T8NW, Ireland
[2]Trinity College Dublin, Geology, Dublin 2, Co. Dublin, Ireland
[3]Marine Institute, Furnace, Co. Mayo F28 PF65, Ireland

**presenting author: Elizabeth.Tray@gmit.ie*

Despite ongoing global conservation measures for north Atlantic salmon, the species has experienced recent population declines. Marine habitat use of salmon is still widely unknown. Non-invasive and robust methods are needed to monitor salmon marine habitat use on large temporal and spatial scales. Microchemical analyses of scales and otoliths can provide insight into the environmental history of migrating salmon. Scales are an advantageous sample type because they can be easily and non-lethally obtained. Reconstruction of environmental histories from analyses of scale growth trajectories may however be confounded by metabolic re-working of scale calcium after deposition. The mechanism controlling post-depositional chemical exchange in fish scales is underexplored, and further investigation is needed to determine the extent of compromised material. In addition, many scale microchemistry studies report trace elements as ratios (element: calcium), assuming calcium is constant through the hydroxyapatite (HAP). There is a lack of published data on salmon scale calcium variability within a single sample and between individuals. Understanding HAP calcium variability is important when reporting elemental concentrations, because small changes in calcium could greatly impact trace element ratio values. Recently, advances in material science technologies have provided new (non-destructive) methods that allow for more precise measurement of fish scale structure and composition. The aims of the study were to: 1) use new tools to measure salmon scale HAP calcium variability and re-evaluate the significance of post-depositional exchange, 2) determine if trace element profiles from adult salmon scales can be used to characterize feeding grounds inhabited by returning migrants.

Scanning electron microscopy (SEM) and white light interferometry were used to characterize scale HAP, and energy dispersive spectrometry (EDX) was used to measure scale calcium. Laser ablation inductively coupled mass spectrometry (LA-ICP-MS) was used to investigate trace elements within salmon scale HAP. Scales were sampled (n=59) from salmon actively feeding from the Greenland fishery (marine), and from an Irish population of returning adults (river). Scale growth marks were used to partition the freshwater (FW) and saltwater (SW) portions of the microchemistry transect. Trace element profiles were compared between fish collected from the feeding grounds and fish collected in the rivers on their return migration, to evaluate the extent to which over-plating or resorption affects the feeding ground signature. In addition, trace element data was analysed for variability between individuals, to determine if adult individuals in the same habitat record similar trace element profiles.

Session: Fisheries Ecology and Management

Inferring movement tracks of individual baleen whales from chemical records combined with coupled simulation models

Clive Trueman[1*]

[1]Ocean and Earth Science, University of Southampton, UK

**presenting author: trueman@noc.soton.ac.uk*

Movement ecology has been revolutionised by the development of animal-based telemetry. Smart tag deployment remains relatively expensive, however, and is not suitable for a wide range of organisms, and seldom records individual behaviour for periods greater than a year. Chemical records contained in incrementally grown tissues provide the only retrospective records of animal movements, but inferring location from tissue chemistry can be complex. Stable isotope compositions are especially promising chemical proxies for location as the isotopic composition of tissues can be referred to spatial models of isotopic distribution (isoscapes).

Many marine organisms possess incrementally-grown tissues suitable for recording migration and movement, but the isotopic composition of the marine environment is complex, temporally dynamic and difficult to sample at sufficient spatio-temporal resolution. Consequently, few studies have attempted to reconstruct marine animal movement paths based on chemical records from incrementally-grown tissues.

In this talk I will outline how coupled simulation models can be used to infer individual animal movement tracks from stable isotope records in incrementally grown tissues. I focus on baleen as an incrementally grown tissue and stable carbon isotopes as my environmental tracer. I simulate the isotopic composition of baleen plates expected under different migration trajectories by coupling a simple agent-based movement model with a temporally-explicit global model of carbon isotope composition of phytoplankton at 1 degree and monthly resolution. The simulation model framework can then be used to generate multiple potential baleen isotope chronologies which can then be compared to measured baleen data and most likely movement trajectories selected. I will show how this approach has been used to infer probable movement trajectories in historic and modern blue whales in the Atlantic and Pacific Ocean, and show how the conceptual approach can be extended to any animal-isotope system where a suitable predictive isoscape model is available.

Session: Growth, Bioenergetics and Ecosystems

Linking sclerochronology to fish population dynamics

Peter van der Sleen[1*], Bryan A. Black[2]

[1]*Department of Wetland Ecology, Karlsruhe Institute of Technology, 76437 Rastatt, Germany*
[2]*Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ 85721, USA*

**presenting author: j.p.vandersleen@gmail.com*

The population dynamics of fish are often characterized by conspicuous low-frequency variability at multi-annual to multi-decadal scales. Understanding the origin of this variability is an urgent need for fisheries management and allows to disentangle the effects of climate and human activity. Here, we propose that much of the low-frequency variability in fish populations can arise from the "buffering" of higher-frequency climate signals through fish vital rates (e.g. growth, mortality and recruitment) and the species' lifespan. The longer the lifespan, or the slower the vital rates, the greater the climate is "buffered", which can be modeled by adding autocorrelation to climate variables closely associated to fish biology. A key feature of higher autocorrelation is the emergence of low-frequency variability, which would therefore be more likely in longer-lived species. To test this hypothesis, we used an extensive, global-scale dataset on life-history traits of fishes to demonstrate that the life span of fish is roughly related to trophic position and temperature. We show how relatively simple models can be used to quantify low-frequency variability in fish species from different trophic positions. Lastly, we added autocorrelation to gridded global sea surface temperature data to modeled the level of "buffering" (autocorrelation) we expected at each trophic level. In so doing, we quantify the patterns of low-frequency variability we expect in fish populations, and identify regions where fish population may be more prone to large-amplitude state transitions. These results provide context with which to distinguish potential anthropogenic ecosystem change from "natural" population dynamics. Furthermore, we show that sclerochronology can provide the information necessary to model and understand the population dynamic of fish.

Session: Fisheries Ecology and Management

Relating patterns in annual growth of a Western Irish European eel *Anguilla anguilla* Linnaeus, 1758 population to habitat and climatic conditions

Louise Vaughan[1,2*], Deirdre Brophy[2], Russell Poole[1], Ciar O'Toole[1], Conor Graham[2], Niall Ó Maoiléidigh[1], Elizabeth Tray[1,2]

[1]*Marine Institute, Furnace, Newport, Co. Mayo, Ireland*
[2]*Marine and Freshwater Research Centre, Galway-Mayo Institute of Technology, Galway, Ireland*

**presenting author: louise.vaughan@marine.ie*

The European Eel (*Anguilla anguilla*) is a facultative catadromous species living in fresh, brackish and coastal waters. Recruitment has been declining since the early 1980s at a European wide scale. The collapse in recruitment and its catadromous lifestyle leaves the species vulnerable to climatic influences. The Burrishoole catchment is situated on the North West Coast of Ireland. Lough Feeagh and Lough Bunaveela are the two largest freshwater lakes in the catchment both containing stocks of European Eel. Full trapping facilities have been in place between the Lough Feeagh and the estuarine Lough Furnace since 1970 allowing for the sampling of downstream migrating silver eels. Individual growth trajectories of silver eels collected on their outward migration were examined using otoliths (1987, 1988, 2007, 2012, 2013 and 2017). Eels in the Burrishoole catchment are particularly long lived with many eels achieving ages of 35 plus giving growth trajectories spanning over 6 decades of growth. This study examined the use of mixed effects models to account for both intrinsic and extrinsic effects on eel growth. The best fitting model of intrinsic growth showed an age and sex dependent pattern of growth declining as the fish aged. This varied among individuals, year and cohort year. The models showed a difference in growth between male and female eels with females growing larger. Both sexes showed a decline in growth with age.

Historically water temperatures in Irish systems were considered suboptimal for eel growth. Lake water temperature data available from the 1960's showed an increase in water temperature across all seasons particularly from the mid-1990's onwards. Rising temperatures in Irish systems could be expected to positively affect growth and survival of European eel. In this study the mean temperature experienced by an individual fish over its lifetime was shown to have a positive effect on eel growth. Increasing water temperature in the Burrishoole system may have a positive effect on eel survival however further investigation is needed.

Future work will look to extend the modelling approach to other environmental variables and extreme events associated with climatic change. An in-depth examination of the microchemistry of otoliths will also be carried out to identify habitat usage of the eel population within the Burrishoole catchment.

Session: Fisheries Ecology and Management

sclero: an R package to measure growth patterns and align sampling spots in chronologically deposited materials

Mikko Vihtakari[1*]

[1]Institute of Marine Research, Fram Centre, Tromsø, Norway

**presenting author: mikko.vihtakari@gmail.com*

Visible growth lines can be used as time markers in chronologically deposited materials (i.e. proxy records) to reconstruct growth patterns of the material back through time. In general, proxy records do not deposit linearly through time and along the material complicating the dating of geochemical signatures from proxy records, sampled using techniques such as milling, laser burning, or particle bombarding. Consequently, to relate the samples to the time of deposition, it is critical to identify the location of sampling spots in relation to the adjacent growth lines rather than to measure a distance from a defined point along the proxy record. Further, sampling spots introduce a time-averaging error, which varies depending on the area of the sampling spot, curvature of growth lines and growth rate of the material.

An open-source package, *sclero*, was developed to solve the above-mentioned issues when relating the location of sampling spots to the time of deposition. The package is written in R, a popular statistical programming language, and uses ImageJ for image analysis. This presentation describes how to use the package to align sampling spots consistently to growth lines and how to estimate the time-averaging error in proxy records with complex inconsistently curved growth lines.

Session: Proxy Development: Challenges and Opportunities

Temperature association and exposure of Icelandic cod (*Gadus morhua*) over the last 100 years

Gotje von Leesen[1*], Ulysses Ninnemann[2], Ásta Guðmundsdóttir[3], Steven E. Campana[1]

[1]University of Iceland, Faculty of Life and Environmental Sciences, Sturlugata 7, 101 Reykjavik, Iceland
[2]University of Bergen, Department of Earth Science and Bjerknes Centre for Climate Research, Allegaten 41, 5007 Bergen, Norway
[3]Marine and Freshwater Research Institute, Skúlagata 4, 101 Reykjavik, Iceland

**presenting author: gotjevonleesen@gmail.com*

Increasing water temperatures are predicted around the globe with high amplitudes of warming in Subarctic and Arctic regions where Atlantic cod (*Gadus morhua*) populations currently flourish. To determine if cod will move or migrate to avoid increasing water temperatures, we have reconstructed oxygen isotope and temperature chronologies from otoliths of one of the largest cod stocks in the world. Samples of the last 100 years were collected reflecting the environmental conditions of the Icelandic waters. For $\delta^{18}O_{otolith}$ analysis, individual annual growth increments from immature and mature stages were micromilled. Preliminary data show differences in temperature association and exposure between different life stages. Higher oxygen isotope values were measured for mature cod suggesting that mature cod lives in deeper, colder water masses relative to immature cod. Oxygen isotope values suggest that substantial temperature variations occurred across the past century.

Session: Fisheries Ecology and Management

Paleoseasonality in the benthic environment of the Tethys during the Late Cretaceous

Eric O. Walliser[1*], Bernd R. Schöne[1]

[1]Institute of Geosciences, University of Mainz, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany

**presenting author: walliser@uni-mainz.de*

Following the Cenomanian/Turonian event (OAE 2), the Late Cretaceous world experienced a time interval of significant global cooling, which mainly affected intermediate and deep waters in tropical oceans. In the Tethyan realm, this climate transition coincides with a positive shift of ca. 1 ‰ in bulk carbonate $\delta^{18}O$ values, which reflects a relative decline of ca. 4°C in bottom water temperatures. However, precise information on the absolute water temperatures during this time interval is still lacking. Novel sclerochronological data ($\delta^{13}C$ and $\delta^{18}O$) of a well-preserved *Inoceramus*sp. shell from the Turonian-Coniacian deposits of the Scaglia Rossa Formation (Trento Plateau, Italy) suggest a mean annual temperature of ca. 15°C and seasonal oscillations of ca. 1°C at the seafloor (ca. 150 m water depth) in the northwestern region of the Tethys. According to the results, shell $\delta^{13}C$ were positively correlated to shell $\delta^{18}O$ values suggesting that the process governing temperature fluctuations also affected food availability in the water column. The reconstructed benthic temperatures, however, were consistently lower than those estimated for the upper ocean layers in previous studies (21 to 35 °C). Such discrepancy likely indicates a thermal decoupling of the two habitats which can possibly be explained by the influence of deep and cold water masses on the benthic environment of the Trento Plateau likely promoted by upwelling.

Session: Climate and Oceans: Past, Present and Future

Local perspectives on ENSO mean states ~2300 B.P. and now: $\delta^{18}O$ reconstructions from the short-lived bivalves *Donax obesulus* and *Mesodesma donacium*

Jacob Warner[1*], Kristine L. DeLong[1], David Chicoine[1], C. Fred T. Andrus[2], Kaustubh Thirumalai[3], Alan Wanamaker, Jr.[4]

[1]*Department of Geography and Anthropology, Louisiana State University, 227 Howe-Russell Geoscience Complex, Baton Rouge, LA 70803, USA*
[2]*Department of Geological Sciences, University of Alabama, 2003 Bevill Building, Tuscaloosa, AL 35487, USA*
[3]*Department of Earth, Environmental, and Planetary Sciences, Brown University, Box 1846, 324 Brook St, Providence, RI 02912, USA*
[4]*Department of Geological & Atmospheric Sciences, Iowa State University, Ames, IA 50011, USA*

**presenting author: jwarn11@lsu.edu*

Some areas lack long-lived organisms suitable for sclerochronological studies, creating a need for novel archives. The presence of short-lived (<5 years) bivalves in archaeological contexts fills this need by allowing for the examination of "snapshots" of past climatic conditions rather than the creation of continuous time series. *Mesodesma donacium*, a short-lived intertidal bivalve, is an established paleoclimate archive for coastal Peru. However, modern populations are functionally extinct north of ~14°S, restricting the possibility for modern analog studies to southern Peru. *M. donacium* is vulnerable to extreme El Niño events, which are increasingly common and strongly impact the north coast of Peru. We use *Donax obesulus*, a short-lived surf clam, to compliment *M. donacium*. *D. obesulus* populations survive the warmer sea surface temperatures (SSTs) of El Niño events, though they are vulnerable to colder SSTs, especially those associated with extreme La Niña events. The internal banding of *D. obesulus* is often difficult to distinguish, requiring the use of alternative age-determination methods alongside band counting to time-assign geochemical data. Our method supplements band counting with a Von Bertalanffy growth curve for *D. obesulus* determined by the Instituto del Mar del Peru from near our collection site adjusted to daily growth along the axis of maximum height. We collected live *D. obesulus* from the Nepeña Valley, department of Ancash, Peru in 2012 (La Niña), 2014 (ENSO-neutral), and 2016 (El Niño) for modern analog studies. We compared forward models of $\delta^{18}O_{shell}$ (a proxy for SST and $\delta^{18}O_{water}$) created from SST and SSS measurements to $\delta^{18}O_{shell}$ values obtained by subsampling modern shells that were time assigned by daily growth along the axis of maximum height. Our results indicate that *D. obesulus* $\delta^{18}O_{shell}$ captures on average 55±21% of modeled SST range (RMSE = 2.8°C), with seasonal upwelling affecting the influence of $\delta^{18}O_{water}$ on the overall signal. We sampled one *M. donacium* and six *D. obesulus* from a Nepeña Valley archaeological site (Caylán) to test the two species as complimentary paleoclimate archives. *M. donacium* mean $\delta^{18}O_{shell}$ is enriched ~0.8‰ compared to preceding periods and ~1.1‰ compared to modern on the south coast of Peru, while Caylán *D. obesulus* mean $\delta^{18}O_{shell}$ is enriched ~0.7‰ compared to modern. Both shell species suggest La Niña-like (~2–4 °C cooler) mean conditions or a shift in $\delta^{18}O_{water}$ compared to modern ~2300 B.P. These results suggest *D. obesulus* is a suitable compliment to *M. donacium* for paleoclimate reconstruction.

Session: Climate and Oceans: Past, Present and Future

A 150 years *Margritifera* shell record reveals that summer air temperature in northern Japan is linked to Atlantic Multidecadal Oscillation

Tsuyoshi Watanabe[1*], Mayumi Suzuki[1], Kotaro Shirai[2], Atsuko Yamazaki[3]

[1]*Faculty of Science, Hokkaido University, N10W8, Kita-ku, Sapporo 060-0810, Japan*
[2]*Atmosphere and Ocean Research Institute The University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba, 277-8564 Japan*
[3]*Faculty of Science, Kyushu University, 744 Motooka Nishiku, Fukuoka 819-0395 Japan*

**presenting author: nabe@sci.hokudai.ac.jp*

We demonstrate the possible link of summer air temperature in northern Japan to Atlantic multidecadal oscillation (AMO) using by sclerochronological and geochemical approaches on long lived fresh water mussels *Margritifera laevis,* collected from Hokkaido, northern part of Japan. We used the total 75 specimens from Shiribetsu and Teshio rivers in the side of Japan sea and from Obetsu and Abira rivers in the side of Pacific Ocean, respectively. Observation of daily growth lines and high-resolution analysis of trace elements (Sr/Ca, Mg/Ca, and Ba/Ca ratios) and stable oxygen and carbon isotopes suggest that distinct annual growth lines observed in each increments formed in winter season. We calculated the standard growth index (SGI) for each river using annual growth patterns in individual shell specimens and found that the SGI for Japan sea side was correlated to winter snow volume and the SGI for Pacific side to summer air temperature. Here, we concentrate to demonstrate SGI and geochemical records from Obestu river of Pacific side where the longest lived shell of 150 years old was found. The sharp peaks of trace elements were observed in the shell increments of 1960. These indicate that the salt water inflow to the river induced by Tsunami of Chili earthquake were recorded in corresponding shell deposition and confirm the fidelity of age model of our shell records. A 150 years sclerochronological and geochemical records reveal the positive correlation between AMO and SGI and negative between AMO and Ba/Ca ratio. We discuss the possible climatic and environmental mechanisms such as the linkage between Pacific and Atlantic oceans through atmospheric interaction.

Session: Climate and Oceans: Past, Present and Future

Insights on AMOC dynamics over the last 300 years using multiple geochemical proxies from an *Arctica islandica* record in the western North Atlantic

Nina M. Whitney[1*], Alan D. Wanamaker[1], Beverly J. Johnson[2], Caroline Ummenhofer[3], Shelly M. Griffin[1], Erin Lower-Spies[1], Karl J. Kreutz[4], Philip T. Dostie[2], Katherine Luzier[1], Douglas S. Introne[4]

[1]Department of Geological and Atmospheric Sciences, Iowa State University, 2237 Osborn Drive, Ames, Iowa, 50011, USA
[2]Geology, Bates College, 44 Campus Avenue, Lewiston Maine, 04240, USA
[3]Woods Hole Oceanographic Institution, 86 Water Street, Woods Hole, Massachusetts, 02543, USA
[4]School of Earth and Climate Sciences, University of Maine, 5790 Bryand Global Sciences Center, Orono, Maine, 04469, USA

**presenting author: nwhitney@iastate.edu*

Several recent studies, including both modeling and paleoceanography studies, have suggested that the Atlantic Meridional Overturning Circulation (AMOC) has weakened in recent years as a result of an anthropogenic freshening of the northern North Atlantic. However, there is no current consensus on the timing of this weakening and the extent to which it is exceptional. More high resolution, absolutely dated paleoceanography records from locations strongly influenced by AMOC variability are therefore necessary in order to help put recent changes in AMOC strength into a broader context.

The Gulf of Maine, a semi-enclosed sea on the east coast of North America, is one such location thought to be influenced by the AMOC. The Gulf of Maine hydrographic properties are affected by changes in AMOC strength via the AMOC's influence on the position of the Gulf Stream relative to the entrance to the Gulf of Maine. These shifts in current position impact the composition of waters entering the Gulf of Maine and therefore can be recorded by geochemical proxies.

Here we present three different water mass proxies measured from *Arctica islandica* shells collected near Seguin Island in the western Gulf of Maine and crossdated into a chronology that extends back to 1762. Shell carbonate was sampled to obtain a decadally resolved radiocarbon reservoir age record and an annually resolved oxygen isotope record. Shell periostracum was sampled to obtain a decadally resolved nitrogen isotope record.

All three water mass proxies indicate more Gulf Stream derived waters entering the Gulf of Maine recently, suggesting a weakening AMOC in agreement with other recently published paleoceanography records. Proxies presented in this study suggest that this weakening began around the beginning of the 20th century but that, unlike conclusions drawn by other studies, this weakening is not anomalous over the last 250 years as AMOC also appears to have been weak at the end of the Little Ice Age.

This multi-proxy approach derived from a shell-based record therefore contributes a high-resolution, absolutely dated reconstruction to the current understanding of how the AMOC has behaved in the last several hundred years. Given the complexity of the AMOC system, no one paleoceanography reconstruction can be expected to fully capture how the AMOC has changed over this time period. However, by developing multiple records such as this one from locations throughout the North Atlantic, a better understanding of past AMOC behavior and potential future changes can be gained.

Session: Climate and Oceans: Past, Present and Future

Seasonal patterns in shell gape activity of *Arctica islandica*

Rob Witbaard[1*], Michael Carroll[2], Irene Ballesta-Artero[3]

[1]*NIOZ; Netherlands Institute for Sea Research and Utrecht University, Department of Estuarine and Delta Systems, PO Box 140, 4400 AC Yerseke, The Netherlands*
[2]*Akvaplan-niva, FRAM-High North Centre for Climate and the Environment, 9296 Tromsø, Norway*
[3]*NIOZ; Netherlands Institute for Sea Research and Utrecht University, Department of Coastal Systems, PO Box 59, 1790 AB Den Burg, Texel, The Netherlands*

**presenting author: rob.witbaard@nioz.nl*

Arctica islandica (bivalvia) has a prominent role in the study of past ocean climate. Shell growth patterns as well as the geochemical composition of the shell are used to reconstruct past temperatures and study the interaction between atmospheric and oceanic climate. In this approach, the bivalve biology is in most cases approached as a black box. There is insufficient knowledge on the behavior of these animals despite this information being crucially important to understand how and what aspects of the environmental signal is actually recorded in its shell.

Between February 2014 and September 2018 we deployed a lander frame in a shallow Arctic bay in northern Norway. This lander was equipped with an array of self-logging instruments, among which were 2 so-called valve gape recorders. With the latter the shell gape activity of 16 animals was monitored at a time resolution of one minute over more than 4 years.

Analyses of these data showed that there are marked seasonal patterns in activity, i.e. wide open valves in spring and summer and closed valves in winter. PCA analyses of this time series corroborated the dominant relationship between valve gape and the concentration of Chlorophyll previously observed over a shorter (19 month) interval. Temperature however, has a minor role in the gaping activity patterns.

Comparison of the seasonal activity cycles showed that there are significant differences in the timing and duration of valve gape among years. For example, at a valve gape threshold of 50%, the difference in length of the active period between years is as long as 8 weeks. This suggests that the duration of the active period in this shallow arctic bay is variable among years and, might partially control the observed inter-annual differences in shell growth observed in this species.

Session: Environmental Biomonitoring & Entrepreneurship

Linkage between climate condition and coral reef development on Holocene uplifted terraces in Kikai Island, Japan

Atsuko Yamazaki[1,2,3*], Wataru Kobayashi[3], Kevin Garas[3], Tsuyoshi Watanabe[2,3]

[1]Faculty of Science, Kyushu University, Motooka 744, Nishi-ku, Fukuoka, Japan
[2]KIKAI institute for Coral Reef Sciences, Shiomichi 1508, Kikai-town, Kagoshima, Japan
[3]Faculty of Science, Hokkaido University, N10W8, Kita-ku, Sapporo, Japan

**presenting author: yamazakiatsuko@geo.kyushu-u.ac.jp*

Decline of coral reefs have been concerned due to recent climate change and sea level rise. However, the relationship between climate conditions and coral reef development is still unknown. In this study, we reconstructed the composition of coral communities, coral carbonate production, and climate condition (sea surface temperature; SST and salinity) from Holocene uplifted terraces in Kikai Island, Japan, and discussed the relationship between reef growth potential and climate change during mid to late Holocene.

Kikai Island is located at the central Ryukyus and on border between East China Sea and Pacific Ocean. The coast of Kikai Island is composed by four terraces (Terrace Ⅰ - Ⅳ) developed from 8.1 ka to 1.4 ka. We measured topographic profiles and coral genus composition along four transects crossed over from Terrace Ⅱ to Ⅳ (6.3 ka to 1.4 ka) around the Island. Coral carbonate production (CCP) in each terrace was calculated from the coverage, the skeletal density and the growth rate in each coral genus. Seasonal variation of SST and salinity were reconstructed by oxygen isotopes and strontium/calcium ratios in fossil *Porites* corals sampled from each terrace.

The composition of coral community showed that *Acropora* sp., powerful reef builder, was generally dominant in each site. The coverage of *Acropora* sp.was small on terrace Ⅲ at east coast and *vice versa* at west coast. The diversity of coral genus was increased with decreasing *Acropora* sp. among each terrace. Average of CCP in four sites was 7.3 kg $CaCO_3$ m^{-2} yr^{-1} at terrace Ⅱ and decreased to 5.5 and 4.6 kg $CaCO_3$ m^{-2} yr^{-1} at terrace Ⅲ and Ⅳ, respectively. CCP values were generally correlated with the coverage of *Acropora* sp. The seasonal variation of reconstructed SST and salinity suggested the strength of east Asian monsoon.

These results revealed the relationship between climate and coral reef developments. Terrace Ⅱ was highly developed under warm climate (Holocene climatic optimum) and strong summer monsoon. On terrace Ⅲ at east coast, cooling climate decreased distribution of *Acropora* sp.and CCP, however, coral diversity was increased to keep the reef growth. On terrace Ⅲ at west coast, strong winter monsoon (north west wind) developed coral reef. On terrace Ⅳ, the cover of *Acropora* sp.and CCP were recovered with the transition to modern warm climate. Reef Corals changed their diversity and have kept the reef growth through the Holocene in Kikai Island.

Session: Paleoecology and Evolution

Large-scale mapping of $^{143}Nd/^{144}Nd$ ratios in bivalve shells for geographical traceability

Liqiang Zhao[1*], Kentaro Tanaka[1], Hirofumi Tazoe[2], Tsuyoshi Iizuka[3], Kaoru Kubota[4], Naoko Murakami-Sugihara[1], Kotaro Shirai[1]

[1]Atmosphere and Ocean Research Institute, The University of Tokyo, Chiba 277-8564, Japan
[2]Institute of Radiation Emergency Medicine, Hirosaki University, Aomori 036-8564, Japan
[3]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Tokyo 113-0033, Japan
[4]Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology, Nankoku 783-8502, Japan

**presenting author: lzhao@aori.u-tokyo.ac.jp*

Geographical traceability of marine bivalves is critical to guarantee their quality and safeguard the interest of both consumers and producers. The neodymium isotopic ratio ($^{143}Nd/^{144}Nd$) of the coastal water mainly reflects the geology of its neighboring watershed, displaying the distinct and systematic variability at high level of geographical detail and thereby shedding light on its potential as a geochemical tracer. For the first time, the present study investigated the utility and robustness of $^{143}Nd/^{144}Nd$ archived in mytilid mussel shells for geographical traceability purposes. The consistency of $^{143}Nd/^{144}Nd$ ratios maintained in mussels shells from the same cohort demonstrates that the Nd isotopic ratio meets the major requirement for an ideal geochemical tracer, i.e., the biologically induced variation should be rather minimal. The distribution and variability of mussel shell $^{143}Nd/^{144}Nd$ patterns were subsequently mapped along the Japanese and Chinese coastal waters. Neodymium isotopes of mussel shells record $^{143}Nd/^{144}Nd$ variations among local regions and between the two countries, which are rather compatible with the ages and lithology of the continental bedrocks. These findings highlight the great potential of $^{143}Nd/^{144}Nd$ for tracing the geographical origin of marine bivalves.

Session: Fisheries Ecology and Management

Evidence that coralline red algae are tougher than we thought - Industrial era pH seasonality and long-term trends in the Canadian Arctic Archipelago

Meghan Zulian[1*], Jan Fietzke[2], Jochen Halfar[1]

[1]*Department of Chemical and Physical Sciences, University of Toronto Mississauga, Mississauga, ON, Canada*
[2]*GEOMAR Helmholtz Zentrum für Ozeanforschung Kiel, Wischhofstr. 1-3, D-24148 Kiel, Germany*

**presenting author: meghan.zulian@mail.utoronto.ca*

As anthropogenic carbon emissions reduce ocean pH, marine ecosystems will experience adverse effects from acidification. Ecosystem models predict faster acidification rates for the Arctic ocean due to their low alkalinity waters and near calcium carbonate under-saturation. In lower pH waters calcification will require more energy, leading to declines in the survival of carbonate secreting organisms. Despite the projected impacts of acidification, no high-resolution, continuous, historical data exist for high Arctic Ocean pH.

The coralline red algae *Clathromorphum compactum* is the only established high-resolution, continuous, paleoclimate pH proxy inhabiting the shallow high Arctic seafloor. Their growth is a function of temperature and light availability. As *C. compactum* form annual growth increments, they incorporate boron into their high magnesium calcite skeleton. Skeletal boron concentrations and boron isotopic composition depend on environmental pH conditions. Throughout the multi-centennial lifespan of *C. compactum,* it records seasonal pH dynamics and long-term trends.

Here, we examine seasonal and century scale pH dynamics in multiple locations from the Canadian Arctic Archipelago (CAA), where sea ice duration limits annual growth of *C. compactum* to less than 100 µm. *C. compactum* boron concentration and isotopic composition were analyzed at 25 µm resolution, using laser ablation multi-collector inductively coupled mass spectrometry (LA-MC-ICPMS).

Our results indicate that throughout the CAA, B/C ratios and boron isotopes document distinct changes in pH during the Industrial Era. Lower algal boron concentrations and lighter boron isotopic composition indicate a strong pH decline post-1930, likely driven by anthropogenic carbon emissions. The seasonal amplitude of recorded pH also increases by 50% post-1930, with summer pH higher, and winter pH lower than any values in the 250-year algal record. Summer pH highs and winter lows are likely a result of intensified primary productivity and the subsequent decay of organic matter. Our data suggest that declining sea ice extent increases light availability, permitting greater bulk primary production that sequesters CO_2, and drives up ocean pH. In winters when the organic material decays, CO_2 is released to the environment, drawing down pH. Despite the long-term acidification trend, annual growth of *C. compactum* continues to increase. Thicker annual growth increments indicate that increased photosynthetic rates are compensating for lower pH conditions, suggesting *C. compactum* maintains strong control over calcifying fluid pH and may be less vulnerable to acidification than previously predicted.

Session: Climate and Oceans: Past, Present and Future

Fishing vessel, Kaštela Bay, Croatia
Photo by Mišo Pavičić

Poster presentations

Increment microstructure of the gladius in recent squid helped to assess duration of ontogenetic phases in Jurassic belemnites (Mollusca: Cephalopoda)

Alexander Arkhipkin[1*], Robert Weis[2], Zhanna Shcherbich[1]

[1]Falkland Islands Fisheries Department, Bypass Road, Stanley, FIQQ 1ZZ, Falkland Islands
[2]Palaeontological Department, National Museum of Natural History, 25 Rue Münster L-2160 Luxembourg, Luxembourg

**presenting author: aarkhipkin@fisheries.gov.fk*

Belemnites originated in the Lower Jurassic and quickly became one of the most abundant coleoid cephalopods that inhabited the shelves of Mesozoic seas. They had the functional phragmocone in the internal shell with counterweighted calcitic rostrum, giving them neutral buoyancy in the water. The structure of the internal shell with the dorsal plate (proostracum) formed to the anterior side of their phragmocone left free the ventral part of the muscular mantle, enabling belemnites to produce jet propulsive movements in analogy to modern cuttlefish. The shape of the rostrum of Jurassic belemnites, varying from short conical to long conical (sometimes with developed posterior part called epirostrum) indicated that their swimming abilities were not as strong as in their Cretaceous successors. Despite frequent occurrence of belemnite shells in Mesozoic deposits, very little is known about their life cycles including duration of ontogenetic phases and growth rates.

We have investigated microstructure of the rostra in the gladius of recent squid *Onykia ingens* and *O. robusta* (Onychoteuthidae) and *Illex argentines* (Ommastrephidae) and compared it with that of the guards (rostra) of Jurassic belemnites. Those included *Dactyloteuthis semistriata*and *Acrocoelites riegrafi* that formed an elongated epirostrum anteriorly to their orthorostrum in adult animals, as well as several species of large *Megateuthis* that increased their rostral growth by forming non-dense aragonite layers in the inner part of their otherwise calcitic epirostrum. Growth increments within the rostra of both recent squid and extinct belemnites had similar features that made it possible to date the formation of various zones within the rostrum microstructure by counting growth micro-increments. Assuming daily nature of growth micro-increments, it was possible to date ontogenetic stages that putatively correspond to the periods of late embryonic stage, hatching and formation of the orthorostrum and epirostrum and estimate their growth rates and life span. It was found that belemnites lived generally longer than modern squid, from 2 years in small *D. semistriata* and *A. riegrafi* to 3-4 years in large *Megateuthis* spp. Taking into account ontogenetic changes in the microstructure and shape of the rostra, a new hypothesis on possible ecological role of tail formation in adult of Jurassic belemnites has been suggested.

Session: Paleoecology and Evolution

Unravelling native nanostructured details in high resolution scanning electron microscopy (HRSEM) of wasted marine biomaterials

Lucian Barbu-Tudoran[1,2*], Maria Suciu[1,2], Fran Nekvapil[1,2], Simona Cinta Pinzaru[2], Branko Glamuzina[3]

[1]*National Institute For Research and Development of Isotopic and Molecular Technologies, 67-103 Donat, Ro-400293 Cluj-Napoca, Romania*
[2]*Babes-Bolyai University, Kogalniceanu 1, RO-400084 Cluj-Napoca, Romania*
[3]*University of Dubrovnik, Department for Aquaculture, Ćira Carića 4, 20000, Dubrovnik, Croatia*

**presenting author: lucianbarbu@yahoo.com*

Ultrastructural approach for native biomaterials analysis with scanning electron microscopy implies a series of smart sampling steps to be able to preserve the native details at nanoscale. Organic scaffolds like chitin-protein fibrils in biomaterials exhibiting Bouligand pattern are particularly difficult due to their sensitivity to the electron beam. Their real-time movement during HR-SEM imaging makes the experimental data difficult to collect when nanoscale details are aimed. Here we demonstrate using several marine biomaterials that their nanomorphology could be imaged and unexpected particularities drives to novel bioinspired applications. Skeletons fragments of sea creatures aimed for HR-SEM of their structural layers are very similar from the chemical point of view (calcium carbonate polymorphs) and extremely different and diverse from morphological point of view. The differences were born from their different needs and adaptations. HR-SEM in conjunction with EDX and guided by preliminary Raman spectroscopy analysis are crucial to approach down to nanometer size the delicate morphological details. For example, sea urchins have a spongy calcite stereom with high magnesium content and with spines that contain glycoproteins. Pores are micron-sized and have an arranged spongy order with porosity of much interest for new biocomposites. Crabs' exoskeleton is much more compact, with nanometer-sized pores and with a considerable amount of protein content, in the form of orderly layered protein foils between compact calcite sheets, all connected in a fabric-like structure of organic and inorganic network. Understanding the complex formation of skeleton structures and function can provide valuable information about their possible applications and novel 3d-ordered structures or their ability to capture and host certain pollutants.

Comparative nanometer scale HR-SEM images from biomaterials harvested from marine organisms are discussed. Derived from their morphology and chemical properties, several applications of sea urchins and crab skeletons porous biomaterial are highlighted.

Session: Biomineralization

Examining the potential of Pacific abalone as a novel high-resolution archive of seasonal upwelling in the Channel Islands, CA, USA

Christine N. Bassett[1*], C. Fred T. Andrus[1]

[1]*The University of Alabama, Tuscaloosa, Alabama, USA*

**presenting author: cbassett@crimson.ua.edu*

Upwelling is an important seasonal oceanographic process that brings up cold, nutrient-rich waters to the surface. These nutrients encourage the growth of phytoplankton and seaweed, which form the foundation of most coastal food webs as well as the fisheries that depend on them. Consequently, the occurrence of upwelling directly affects the health of coastal ecosystems, as well the ability of human populations to depend on them for dietary resources. An array of proxies from sediment cores inform the bulk of upwelling reconstructions throughout Earth's history. More recently, organisms which precipitate calcium carbonate skeletons have also provided invaluable information from stable oxygen and carbon isotopes from which upwelling conditions can be inferred. This study explores the potential of using stable isotope analysis of shells from Pacific black abalone, *Haliotis cracherodii* (Leach 1817), in the Channel Islands. We present high-resolution time-series stable nitrogen isotope data ($\delta^{15}N$) that, together with table oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopes, reflect seasonal variability that is closely linked to upwelling and propose a more comprehensive study that would measure seasonal variations in water properties and nutrient availability in order to more confidently interpret variations recorded in abalone shells. The implications of this research are twofold: The ability to reconstruct seasonal upwelling patterns from abalone shell may provide more detailed knowledge on the cycling of nutrients during times of upwelling, and perhaps more importantly, during its absence. Furthermore, in the Channel Islands, shell middens contain an abundance of both black and red abalone date back to the early Holocene, meaning that reconstructions of upwelling can potentially span the entire Holocene.

Session: Proxy Development: Challenges and Opportunities

Climate variability of North Atlantic water masses along the Irminger Current: Insights from *Arctica islandica* shells from SW Iceland

Fabian Bonitz[1*], Carin Andersson[1], Tamara Trofimova[1], Vilde Melvik[1], Madelyn Mette[1]

[1]Norwegian Research Centre, Bjerknes Centre for Climate Research, Bergen Norway, Jahnebakken 5, 5007 Bergen, Norway

**presenting author: fabian.bonitz@norceresearch.no*

The shells of the marine bivalve mollusc *Arctica islandica* have proven to be a valuable paleo proxy for climatic and environmental conditions in the northern North Atlantic. In this study, we use shell growth variability and stable oxygen isotope variability in *A. islandica* shells from the Faxaflói area close to Reykjavik, SW Iceland to gain insights into the dynamics of northward flowing North Atlantic water masses along the Irminger Current. The area SW of Iceland has not been targeted for sclerochronological investigations so far. Thus, our results will enhance the network of sclerochronologically-derived paleoclimate reconstructions in the North Atlantic. Further, our study enables for the first time comparisons between sclerochronological data from northern Iceland and SW Iceland, allowing for a detailed comparative study of two geographically similar yet oceanographically distinct regions.

So far, 19 live-collected and 5 sub-fossil shells have been successfully cross-matched and have been used to construct a statistically robust master chronology spanning the last two centuries. The chronology was compared to various instrumental data to determine the main forcing for the shell growth in this area as well as to other sclerochronological data from the northeastern North Atlantic. Frequency analyses were applied to reveal recurrent modes of climate variability such as the Atlantic Multi-decadal Variability and the North Atlantic Oscillation. In addition, annual $d^{18}O_{shell}$ samples were taken from two specimens, providing a $d^{18}O_{shell}$record covering 1890-2008. Currently, more $d^{18}O_{shell}$ samples are being collected to extend the isotope chronology further back in time. The preliminary $d^{18}O_{shell}$ record is negatively correlated with instrumental temperature data from the area and a field correlation between the $d^{18}O_{shell}$ record and SST data reveals strongest correlations along the main inflow branches of North Atlantic Waters into the Arctic. This indicates that the temperature signal recorded in the chemical composition of the shells ($d^{18}O_{shell}$) is a reliable proxy for water temperature estimates in the Iceland area.

Session: Climate and Oceans: Past, Present and Future

Coral calcification during the geological past – why was it so different?

Thomas C. Brachert[1*], Philipp Spreter[1], Christine Perrin[2], Markus Reuter[1]

[1]*University of Leipzig, Institute of Geophysics and Geology, Talstraße 35, 04103 Leipzig, Germany*
[2]*SETE UMR5321, 2 Route du CNRS, 09200 Moulis, France; and: Centre Européen de Recherches en Préhistoire Muséum National d´Histoire Naturelle HNHP UMR 7194 CNRS-MNHN, France*

**presenting author: brachert@uni-leipzig.de*

The present increase in atmospheric carbon dioxide (pCO_2) due to the burning of fuels is unprecedented in earth history. As a result, ongoing ocean acidification increasingly endangers marine calcareous biota such as reef corals. For testing predictions on the carbonate saturation state of the surface ocean in reef settings over geological time, we present the first comprehensive set of reef-coral sclerochronological records and calcification data from specimens being between 23 and 1 million years old. The sclerochronological data document environmental variability at annual and inter-annual time-scale compatible with the Recent. The calcification patterns of the fossil corals differ from corals in present-day reef settings (warm and oligotrophic), but are indistinguishable from those in oceanic low carbonate supersaturation (CS) environments. This finding may indicate to low seawater CS during the geological past. By now it is not clear, however, whether low CS was an effect of globally high pCO_2, or local environmental stressors (low temperature, siltation stress, upwelling, etc.). We also find that investing calcification resources preferentially in skeletal extension rather than skeletal density is a conservative evolutionary trait of the scleractinian reef corals. It reflects an adaption to colonizing space on a reef in low CS environments of the past and likely was an essential pre-adaption to compete with rapid, deglacial sea-level rises.

Session: Climate and Oceans: Past, Present and Future

Sclerochronology and stable isotope records ($\delta^{18}O$) of Lower Jurassic lithiotid bivalves from the Trento Platform (Southern Alps, Italy)

Valentina Brandolese[1*], Hideko Takayanagi[2], Davide Bassi[1], Thuy Thi Nhu Ha[2], Yasufumi Iryu[2], Renato Posenato[1]

[1]Department of Physics and Earth Sciences, University of Ferrara, via Saragat 1, 44122 Ferrara, Italy
[2]Institute of Geology and Paleontology, Graduate School of Science, Tohoku University, Aobayama, Sendai, Japan

**presenting author: valentina.brandolese@unife.it*

Lithiotids are Lower Jurassic, mainly Pliensbachian, larger thick-shelled bivalves characterized by aberrant and frame-building morphologies. They include several gregarious taxa with a wide geographical distribution in the Tethyan and Panthalassa shallow-water carbonate platforms, where they built considerable biogenic accumulations. Since the large shell size has been so far related to longevity or photosymbiosis, here we performed a sclerochronological study based on a high-resolution oxygen isotope records ($\delta^{18}O$). Carbon isotope data ($\delta^{13}C$) testing the photosymbiosis hypothesis are in progress.

In the present study, the specimens with a complete and possibly almost complete original aragonitic shell composition were analysed. The material was collected from the Rotzo Formation (Trento Platform, northern Italy) and includes following species: *Cochlearites loppianus*, *Lithioperna scutata, Lithiotis problematica*, *Opisoma excavatum*, and *Pachyrisma durga*. Beside the growth patterns, the study provided palaeoenvironmental and palaeoclimatic information. Diagenetic screening (SEM and XRD analyses) were conducted on polished slabs, while thin sections were used for sclerochronological assessement.

In the feather-like areas of the cardinal area, *Lithiotis* and *Cochlearites*show growth periodicity characterized by prominent regular intervals. These intervals were interpreted as annual growths. *Lithioperna* usually shows thin dense and not well-defined ribs. *Opisoma* and *Pachyrisma* do not display growth pattern on shell surface. In *Cochlearites* and *Opisoma* the $\delta^{18}O$ shell profiles show distinct sinusoidal oscillations related to regular seasonal growth cycles. In *Cochlearites*, the $\delta^{18}O$ profile confirms an annual periodicity of the first order growth lines occurring on the feather-like areas. *Lithioperna* and *Pachyrisma* are characterized by less defined regular $\delta^{18}O$ cycles presumably due to the lower sampling resolution related to a lower growth rate.

Session: Paleoecology and Evolution

Analysis of the persistence of seasonal stratification in the northern North Sea using a $\delta^{18}O_{shell}$ - based bottom water temperature reconstruction for the last 455 years

Juan Estrella-Martínez[1], Bernd R. Schöne[2], James D. Scourse[3], **Paul G. Butler[3*]**

[1]*School of Ocean Sciences, Bangor University, Bangor, Wales, UK*
[2]*Institute of Geosciences, Johannes Guttenberg University, Mainz, Germany*
[3]*College of Life and Environmental Sciences, University of Exeter, Penryn, Cornwall, UK*

**presenting author: p.butler@exeter.ac.uk*

The development of seasonal stratification in epicontinental seas Is a first-order hydrographic phenomenon with physical, biological, biogeochemical and geological impacts. Instrumental series of stratification dynamics are of very high resolution but they are limited to the very recent past. Millennial-length proxy records, on the other hand, lack the temporal resolution required to assess the persistence of stratification under the influence of high frequency atmospheric forcings. Here we present a c.500-year, annually-resolved, absolutely-dated bottom water temperature (BWT) reconstruction for the Fladen Ground, northern North Sea, based on the stable oxygen isotope geochemistry of *Arctica islandica* shells ($\delta^{18}O_{shell}$). Micromilling of samples from annual increments yielded an annually resolved and precisely dated $\delta^{18}O_{shell}$ record for the period 1551-2004 CE. Sub-annual sampling suggests that the average growing season of *A. islandica* in the Fladen Ground extends from February to October. The reconstruction shows an average temperature of 7.20°C for the past c. 500 years, with warming trends of 0.05 ± 0.02°C decade^{-1} for the years 1640-1740 and 0.08 ± 0.02 °C decade^{-1} for the years 1880-2001, and a cooling trend of -0.11 ± 0.02°C decade^{-1} for the years 1810-1910. These trends cannot be attributed to North Atlantic sea surface temperatures (SST). 9-54 % of variability in average Feb-Oct BWT can be attributed to low frequency changes in the winter North Atlantic Oscillation (NAO). Higher frequency NAO variability does not show a consistent effect for any season. A BWT/SST regression analysis suggests that the thermal stratification in the northern North Sea can be overturned by local storm activity, but that it persists under calmer conditions and when the storm tracks pass through the central and southern North Sea.

Session: Climate and Oceans: Past, Present and Future

Growth and age validation of thornback ray in the West-Central Mediterranean basin

Pierluigi Carbonara[1*], Andrea Bellodi[2], Francesca Capezzuto[3], Cristina Follesa[2], Giuseppe Lembo[1], Porzia Maiorano[3], Michele Palmisano[1], Paola Pesci[2], Maria Teresa Spedicato[1], Letizia Sion[3]

[1]COISPA Tecnologia & Ricerca, Stazione Sperimentale per lo Studio delle Risorse del Mare, Via dei Trulli 18/20, Torre a Mare (BA), Italy
[2]Dipartimento di Biologia Animale ed Ecologia, Universita di Cagliari, Cagliari, Italy
[3]Department of Biology, University of Bari, Bari, Italy

**presenting author: carbonara@coispa.it*

Despite their evolutionary success, many chondrichthyans are increasingly threatened with extinction as a result of human activities and the conservative life history traits of this group of fishes. In Mediterranean basin, the thornback ray (*Raja clavata*), represents among the Rajids the most commercially utilized species and it is actually included in the IUCN-RedList as Threatened species. In particular, in the West-Central Mediterranean basin, where the fishing activity is well-developed, *R. clavata* represents one of the most important by-catch species mostly for the bottom trawl and long line fishery. Despite being a very widespread species, some gaps still exist on its biology mostly on the growth pattern. The lack of biological data constitutes, for the Mediterranean, one of the impediments in order to assess and take appropriate management measures for this species. Indeed, stock-assessment models, particularly the analytical ones, require growth parameters as important input data. The aim of the present study is to fill this knowledge gap. Specimens of *R. clavata* were collected during the experimental trawl surveys, commercial landings and discard monitoring in Sardinia, Central-Southern Tyrrhenian, West Ionian and South Adriatic Sea. Thin sections of vertebrae were performed in order to determinate the age and calculate the parameters of the von Bertalanffy growth function for both sexes in each study area. Moreover, on specimens captured in Adriatic, Sardinia and West Ionian, the marginal analysis of the vertebrae was also carried out as a semidirect ageing analysis validation. In the Adriatic, a mark-recapture experiment, marking by both external (spaghetti tags) and chemical (oxytetracycline injection) tags, 98 specimens of *R. clavata* was also realized. In total two recaptures after 11 and 14 months were recorded with an increment in total length respectively of 11.4 cm (from 49.5 to 60.9 cm) and 10.3 cm (from 63.5 to 73.8 cm). In both specimens recaptured the oxytetracycline mark together with the subsequent deposition of a completed *annulus* (one transparent and opaque ring) was observed on the sections of vertebrae.

The marginal analysis highlighted the deposition of one *annulus* (one opaque ring and one transparent ring) per year. Moreover, the results from tag-recapture experiment seems validate the age criteria adopted in this study to read the vertebrae of thornback ray in the West-Central Mediterranean basin, although they are related to only two specimens.

Session: Fisheries Ecology and Management

Ring deposition patterns in common sole otoliths from the Adriatic Sea

Pierluigi Carbonara[1*], Enrico Arneri[2], Petra Bratina[3], Loredana Casciaro[1], Sabrina Colella[4], Ilija Cetković[5], Fortunata Donato[4], Robert Grgičević[6], Nicoletta Milone[2], Tomaz Modic[3], Giulio Pellini[4], Stefan Ralević[5], Nedo Vrgoč[6], Giuseppe Scarcella[4]

[1]COISPA Tecnologia & Ricerca, Via dei Trulli 18/20, Torre a Mare (BA), Italy
[2]FAO-AdriaMed Project, Viale delle Terme di Caracalla, 00153 Roma, Italy
[3]Fisheries Research Institute of Slovenia, Sp. Gameljne 61, SI-1211 Ljubljana-Šmartno, Slovenia
[4]Istituto per le Risorse Biologiche e le Biotecnologie Marine (CNR-IRBIM) Largo Fiera della Pesca, 1 60125, Ancona, Italy
[5]University of Montenegro - Institute of Marine Biology of Kotor, PO Box 69--85330 Kotor, Montenegro
[6]Institute of Oceanography and Fisheries, Š. Ivana Meštrovića 63, 21000 Split, Croatia

**presenting author: carbonara@coispa.it*

Common sole (*Solea solea*) represent one of the most commercially important fishery resources for the Mediterranean basin and in particular for the Adriatic Sea. As for other exploited resources, age and growth estimations are essential to study life-history traits, and in turn to understand the population dynamics thus providing indication to proper manage the stocks. Fish ageing analysis relies on the presence on calcified structures (e.g. otolith, vertebrae, scale) with a structural pattern of growth rings in terms of succession of opaque and translucent zones, as well on knowledge of the periodicity of the deposition and growth pattern. The seasonal appearance of opaque and translucent rings in the whole otolith of flatfish shows a reversal pattern for otoliths as regards fishes of temperate and cold water. However, the deposition pattern of the opaque/translucent area for the *S. solea* in the Adriatic is poorly known or based on studies from the 80s. Therefore, the aim of the present work is to investigate the deposition pattern on sole otoliths by qualitative (marginal analysis, MA) and quantitative (marginal increment analysis, MIA) methods as a semi-direct age validation approach. The otoliths analyzed are part of a common set of otoliths shared by the research institutions of five countries in the Adriatic Sea. Indeed, the deposition pattern shall be determined as the first step to understand whether the increments are laid down according to a periodicity related to a regular time scale. The results obtained show that one transparent and opaque area per year are laid down in *S. solea* in the Adriatic Sea. The transparent zone is laid down between July and December, while the opaque between January and June. The marginal increment analysis shows a significant otolith growth higher in the winter/early-spring months. Moreover, these results are compared with previous data to understand if the increase of Adriatic water temperature has influenced the growth/deposition of the common sole otoliths. The results of the MA and MIA are strategic for the defininition of the number of *annulus/i* laid down per year; the margin type represents a key element to obtain a clear age scheme that improve the standardization of age analysis, by increasing the reproducibility between age readers.

Session: Fisheries Ecology and Management

Extended chronology of the bivalve *Serripes groenlandicus* from a high-Arctic fjord in Svalbard, Norway

Michael Carroll[1]*, William Ambrose[2], Colin Eimers[3], Amanda Eller[4]

[1]Akvaplan-niva, Fram Centre for Climate and Environment, 9296 Tromsø, Norway
[2]Coastal Carolina University, School of the Coastal Environment, Conway, South Carolina, 29528, USA
[3]University of Maine, School of Marine Sciences, Orono, Maine, 04469, USA
[4]Bates College, Department of Biology, Lewiston, Maine, 04240, USA

**presenting author: mc@akvaplan.niva.no*

Knowledge of how marine organisms are influenced by past climate may help us better understand how they will respond to climate change. Climate change is occurring rapidly in the Arctic, so observing the links between change and biological effects there can provide key information on the ecosystem consequences of climate change in the world's oceans. Analysis of shell-based records of mollusks (sclerochronology) provides an approach to reconstructing environmental-ecological linkages. We explored the relationship between large-scale climate regimes, local environmental conditions, and the growth of the Greenland Cockle (*Serripes groenlandicus*) from Rijpfjorden, a high-arctic fjord in Svalbard, Norway (80°10'N, 22°15'E). Ambrose et al. (2006, Global Change Biology 12, 1595-1607) published a 22-year growth chronology, spanning 1981 through 2002, based on samples collected in 2003. Here we extend the growth chronology through 2017 (based on samples collected in 2007, 2010, 2012, 2013, and 2017), increase the sample size to 80 individuals, and examine the influence of environmental variables on the extended 37-year chronology.

Individuals ranged in age from 5-29 years, and raw shell increment series were detrended with the von Bertalanffy growth function to obtain a Standard Growth Index (SGI) for all samples. SGI ranged from a low of 0.6 in 1988 to a high of 1.6 in 1994. From the peak SGIs in the mid-1990s, there has been a steady downward trend despite smaller-magnitude oscillation cycles of 5-6 years. Temperature of the West Spitsbergen Current (WSC) explained the most variability in shell growth (R^2 = 0.33), while the WSC, the Arctic Climate Regime Index (ACRI) and maximum arctic-wide sea ice cover explained a total of 62% of the interannual growth variability. We will also explore temporal trends within the environmental regulation of the growth chrononology, i.e. variation in the environmental factors most strongly associated with shell growth in the original chronology from Ambrose et al. 2006 and in the updated master chronology. These results suggest that the Greenland Cockle is quite sensitive to environmental changes over annual to decadal scales and therefore can serve as a proxy of climate change effects on ecosystem processes in the Arctic.

Session: Growth, Bioenergetics and Ecosystems

Micro-chemical and micro-mineralogical techniques for sclerochronological studies – which one should I choose?

Simon Chenery[1*], Charlotte Colvin[2], Pedro Freitas[3,4], Phil Hollyman[2,5], Konstantin Ignatyev[6], Ion Microprobe Facility[7], Andy Marriott[1], Ian McCarthy[2], Chris Richardson[2]

[1]Centre for Environmental Geochemistry, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK
[2]School of Ocean Sciences, College of Environmental Sciences and Engineering, Bangor University, Menai Bridge, LL59 5AB, UK
[3]Danish Shellfish Centre, Technical University of Denmark, Øroddevej 80, 7900 Nykøbing M, Denmark
[4]Instituto Português do Mar e da Atmosfera (IPMA), Rua Alfredo Magalhães Ramalho, 1495-006 Lisboa, Portugal
[5]British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK
[6]Diamond Light Source, Harwell Campus, Didcot, Oxon, OX11 0DE, UK
[7]Ion Microprobe Facility, Edinburgh University, Edinburgh, EH9 3JW, UK

**presenting author: srch@bgs.ac.uk*

Our multi-institute research group have been using micro-chemical and micro-mineralogical techniques as investigative tools for sclerochronological studies of shells, statoliths and fish otoliths for more than two decades. The primary technique used, has been point analysis by laser ablation-ICP-MS. This provided spatial trace element concentrations and Sr isotopic data on several hundred points per day, typically at 20-50 micron resolution. Considerable valuable information has been gained, but has been limited due to the small fraction of the total area of a shell measured or insufficient fine-scale resolution for chemical banding in small structures, such as statoliths. Our recent investigations have made use of the ion-probe for precise small spot analysis (2 micron) and synchrotron micro-XRF to map Sr concentrations at a similar scale. The synchrotron provides mineralogical information on which calcium carbonate polymorphs exist, using micro-XRD and molecular structural information via XANES and EXAFS. With limited access to a synchrotron Raman spectroscopy has been investigated as an alternative for providing mineralogical information. Laser ablation as a technique has not stood still, with recent advances in the laser ablation systems coupled with increasingly sensitive ICP-MS is revolutionizing trace element mapping in terms of data acquisition speed. In this presentation we will briefly explore and review, using examples, what each technique has to offer sclerochronology and their advantages and limitations, with the aim of helping others to best choose from this menu of techniques for their own applications.

Session: Biomineralization

Determining spatial and temporal compositional variation in *Buccinum undatum* shells

Charlotte Colvin[1*], Philip Hollyman[2,3], Simon Chenery[3], Chris Richardson[1], Konstantin Ignatyev[4], Ian McCarthy[1]

[1]School of Ocean Sciences, College of Natural Science, Bangor University, Menai Bridge, Anglesey LL59 5AB, UK
[2]British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK
[3]Centre for Environmental Geochemistry, British Geological Survey, Keyworth, Nottingham, G12 5GG, UK
[4]Diamond Light Source, Harwell Science and Innovation Campus, Didcot, Oxfordshire, OX11 0DE, UK

**presenting author: ospa5d@bangor.ac.uk*

Trace element variations in mollusc shells are studied as proxies for historical conditions, e.g. seawater temperature. These proxies may also vary due to animal physiology and shell mineralogy. The commercially important whelk *Buccinum undatum*, frequently experiences damage from anthropogenic activities and unsuccessful predatory attacks. As an example of this, the process of removing under-sized animals for release can cause damage to shells as they are passed through a series of metal bars called a "riddle". All of these damage incidences combine to delay normal shell growth and thicken the shells through re-growth. The shells of *B. undatum,* form as a solid calcareous exoskeleton are formed of 4 distinct layers of aragonite around the central columella.

LA-ICP-MS was used to determine concentrations of key trace elements (Sr, Mg, U, Ba, Fe, Mn and Na) both within and between shell layers. Crystallographic (μXRD), fluorescence (μXRF) and absorption (μXANES/EXAFS) techniques on the Diamond I-18 microspectroscopy beamline were then used to further establish differences in shell mineralogy and crystal structure in response to laboratory-controlled shell damage and re-growth.

Results from LA-ICP-MS have shown concentrations of trace elements to significantly change during periods of rapid growth between the newly formed shell layers, with differing chemical compositions amplified in areas of rapid growth and shell repair. Mapping using the μXRF confirmed the Sr elemental distributions whereas the μXRD show mineralogical changes between layers to be minimal.

Session: Biomineralization

Deciphering high resolution structural and geochemical signals present in Stromatoporoids from the upper Cretaceous

Thierry Corrège[1*], Laurent Londeix[1], Josue Polanco-Martinez[2], Luc Feuillerat[1], Badr Bennani[1], Mériadec Le Pabic[1]

[1]UMR 5805 EPOC, Université de Bordeaux, Pessac, France
[2]Econometrics Research Group (ERG), Institute of Public Economics (IEP), University of the Basque Country, Bilbao, Spain

**presenting author: thierry.correge@u-bordeaux.fr*

Stromatoporoids flourished during the Paleozoic and the Mesozoic, but are now extinct. Their taxonomic classification is still debated, although they are generally considered as Porifera. *Actinostromaria stellata* (Stromatoporoids) collected from the southwest of France (Ile Madame, Charente) and dating from the Cenomanian (Upper Cretaceous) possess an extremely dense and well-preserved low-Mg calcitic skeleton. The skeleton is composed of fine laminae and pillars, and show conspicuous banding, several mm wide. The banding is an alternance of light and dark bands, similar to the density banding present in most massive corals. The growth rate of Stromatoporoids has been studied by various authors, with no consensus being reached. Some consider that the laminae may be annual, while others consider that it is the colour banding which is annual. To assess the origin of these bands, and their potential as paleoclimatic and paleoenvironmental archives, their nature was investigated using high resolution scans of polished sections, thin sections, scanning electron microscopic observations, and geochemical analyses.

Three specimens of *Actinostromaria stellata* were slabbed and polished. The slabs were scanned at high resolution (typically 8 µm), and the distance between laminae was measured across several transects. This distance ranges from 153 to 180 µm. Grey levels were also measured on the transects. Spectral analyses were conducted on both the inter-laminae distance and the grey level. Two specimens reveal a periodicity of 24 to 27 laminae, which is consistent with the number of laminae present in a couplet of light and dark bands. The third specimen yielded a periodicity of 33 laminae, slightly higher than the two others.

Geochemical analyses of Mg/Ca and Sr/Ca were conducted at high resolution (i.e. every 400 µm) along the same transects. They reveal a variability linked to the colour banding, and similar to annual cycles of sea surface temperature seen in corals.

It seems therefore likely that the colour banding present in *Actinostromaria stellata* is annual. The cause for this difference in colour is still being investigated, as SEM observation did not yield any clue. The number of laminae per year is unusual, ranging from 24-27 to 33. A possibility could be that laminae deposition was linked to the tidal cycle.

Session: Proxy Development: Challenges and Opportunities

Bivalve shells as archives of seasonality during the early Pleistocene in the Mediterranean Sea

Gaia Crippa[1*], Lucia Angiolini[1], Fabrizio Felletti[1], Melanie Leng[2], Gianluca Raineri[3]

[1]Università degli Studi di Milano, Dipartimento di Scienze della Terra 'A. Desio', via Mangiagalli 34, Milano, 20133, Italy
[2]NERC Isotope Geosciences Facilities, British Geological Survey, Keyworth, Nottingham NG12 5GG, UK
[3]Parco Regionale dello Stirone e del Piacenziano, Loc. Millepioppi, Salsomaggiore Terme, 43039, Italy

**presenting author: gaia.crippa@unimi.it*

The early Pleistocene is characterised by several climatic oscillations linked to glacial/interglacial cycles. The Mediterranean area was strongly affected by these climatic oscillations in both marine and continental settings; in the marine environment the most important biotic event is represented by the appearance of the "northern guests" – such as the bivalve *Arctica islandica* – at the beginning of the Calabrian, suggesting a progressive climatic deterioration (i.e., cooling) in the Mediterranean region.

The lower Pleistocene (Calabrian) Arda River marine succession, cropping out in Northern Italy, deposited continuously during this time interval; it represents an ideal site to study the climatic oscillations of the early Pleistocene using pristine bivalve shells as geochemical archives to understand if and how seasonality varied in this interval. The marine succession represents the subaqueous extension of a fluvial system, originated during phases of advance of fan deltas affected by high-density flows triggered by river floods, which are an expression of early Pleistocene climate changes. The top of the succession is bounded by conglomerates indicating a sea level drop and the establishment of a continental environment, testifying the approaching of the Middle and Upper Pleistocene continental glaciations.

249 fossil bivalve shells belonging to species of *Glycymeris, Aequipecten* and *Arctica*, collected from 141 beds were analysed for bulk shell isotopic compositions ($\delta^{18}O$, $\delta^{13}C$), after having checked their preservation. Ten pristine bivalve shells (*A. islandica* and *Glycymeris* spp.) collected from six discrete intervals along the section were sclerochemically analysed ($\delta^{18}O$, $\delta^{13}C$) to reconstruct seasonality.

The sclerochemical analyses indicate an increase in seawater temperature seasonality through the early Pleistocene. However, the isotope data from the bulk shells do not indicate cooling of overall sea surface temperatures throughout the interval, except for a significantly cold and seasonal event at the first occurrence of *Arctica islandica*. Strong seasonality and low winter palaeotemperatures were assumed to be the main drivers for the widespread establishment of the "northern guests" populations in the Palaeo-Adriatic Sea around 1.80 Ma. This study indicates that the variations in seawater temperature seasonality was the main variable of climate change within the study area, preparing the ground for the onset and establishment of the Middle and Upper Pleistocene continental glaciations.

Session: Paleoecology and Evolution

Highlighting inter-individual variability in *Patella vulgata* shell growth: what consequences for paleo-environmental proxies?

Jean-François Cudennec[1*], Yves-Marie Paulet[1]

[1]Institut Universitaire Européen de la Mer, Technopôle Brest-Iroise, Rue Dumont d'Urville, 29280 Plouzané, France

**presenting author: JeanFrancois.Cudennec@univ-Brest.fr*

To achieve reliable paleoenvironmental reconstructions from biogenic carbonates of marine molluscs, growth model of the studied species must be well known. In mollusc shells, growth marks produced in response to different rhythmicities (lunar-daily, fortnightly, annual) are used as milestones for estimating and measuring growth patterns, from the daily scale to the whole life of the individuals. For this purpose, it is necessary to develop a toolkit based on present-day shells to understand the recording of environmental variables in the carbonates.

Several recent studies are using sclerochemical analyzes of oxygen isotopes in shells of the intertidal gastropod *Patella vulgate* to perform paleo-SST reconstructions. We have studied growth in this species through several approaches, including population studies on the shore, calcein marks experiment and the study of different growth rings in the shells.

The results highlight a very strong inter-individual variability, questioning the size/age relationship in this species. Various environmental factors (SST, tidal coefficients) have been taken into account in an attempt to explain this variability and its impact on the high-resolution $\delta^{18}O$ profiles used for paleo-environmental reconstructions. This variability rises the question of the interest of classical methods of growth rings studies in *Patella vulgata*, which cannot for the moment be used to enlighten growth cessation periods on $\delta^{18}O$ profiles.

Session: Proxy Development: Challenges and Opportunities

Structural order in biogenic carbonates: Screening for diagenesis with FTIR

Marisa Dusseault[1*], Meghan Burchell[2], Kristin M. Pouduska[1]

[1]Department of Physics and Physical Oceanography, Memorial University, St. John's, NF A1C 5S7, Canada
[2]Department of Archaeology, Memorial University, 310 Prince Philip Drive, St. John's, NF A1C 5S7, Canada

**presenting author: mad872@mun.ca*

Fourier Transform Infrared spectroscopy records the chemical composition and crystal structure of a material by probing a sample with infrared radiation, which is absorbed by the sample's vibrational modes. This method is useful for distinguishing between polymorphs – substances that have the same chemical composition but different crystal structures. The two most common polymorphs of calcium carbonate ($CaCO_3$) are calcite and aragonite – also the most common minerals composing mollusk shells. In addition to being useful for identifying the crystals of calcite and aragonite, FTIR can also be used to analyze amorphous substances which allows us to assess the degree of structural disorder within a sample. Studies implementing analyses and methods that provide such information have been applied to archaeological calcite samples but have not been used previously to analyze bivalve mollusks from shell midden sites. The data obtained from FTIR analyses can provide information on chemical composition, crystal structure, and diagenesis; providing critical information to evaluate the diagenesis and the suitability of the sample for stable isotope and radiocarbon analysis. To illustrate this, we show that comparing relative peak intensities in FTIR spectra can be used to understand the degree of structural disorder within samples of aragonite from archaeological mollusks. We use samples from three distinct archaeological and geographic contexts to explore variability in shell structure and preservation: 1) *Saxidomus gigantea*, from British Columbia (~4000-2000 years BP); 2) *Mya Arenaria* from Nova Scotia (~1500-1000 years BP); 3) *Pomecea palludosa* from Cuba (~1700 years BP). To further understand cultural and environmental post-depositional alteration in shell, we tested shells from controlled boiling and roasting experiments, and also selected sun-bleached specimens with visible outer damage to the shell surface. The inner and outer layers of all shell samples are distinguishable when analyzing the relative peak intensities of multiple FTIR spectra, which indicates differing degrees of structural disorder. These differences are not detectable when analyzing individual spectra. Further research will combine these methods with growth data, radiocarbon and stable oxygen and carbon isotope analyses to study how sample preservation and diagenesis is linked to radiocarbon variability.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Sclerochronology of oyster shells – differences in trace and minor element composition between native *Ostrea edulis* and invasive *Magallana gigas*

Krešimir Markulin[1], Hana Uvanović[1], **Daria Ezgeta-Balić[1*]**, Regina Mertz-Kraus[2], Melita Peharda[1], Ivan Župan[3]

[1]Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia
[2]Institute of Geosciences, Johannes Gutenberg University, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany
[3]Department of Ecology, Agronomy and Aquaculture, University of Zadar, Trg Kneza Višeslava 9, 23000 Zadar, Croatia

**presenting author: ezgeta@izor.hr*

In the northern Adriatic Sea, European flat oyster *Ostrea edulis* and invasive Pacific oyster *Magallana gigas* coexist in the same area. Growth performance of oysters is one of the most important parameters in terms of *O. edulis* aquaculture and in terms of *M. gigas* invasion success. As both species do not have clear periodic growth lines on their outer shells or in shell cross sections they are both a challenging species for ontogenetic age determination.

Objectives of this study were: (i) to estimate the potential of LA-ICMP-MS analysis for ontogenetic age determination of oyster shells, (ii) to compare trace and minor element composition within and between shells of two species, (iii) to compare results obtained for oysters with geochemical results previously obtained for other bivalve species in the Adriatic Sea, (iv) to evaluate the potential of oyster shells as environmental archives.

Oysters shells were collected alive in November 2017 from the aquaculture farm in the Lim channel, in the North Adriatic Sea. Three similar sized specimens of each species were prepared for the analysis. Analyses were performed at the Institute of Geosciences, JGU, Mainz, Germany, using LA-ICP-MS. Analyses yielded high resolution time-series of Na/Ca_{shell}, Mg/Ca_{shell}, Mn/Ca_{shell}, Sr/Ca_{shell}, Zn/Ca_{shell} and Ba/Ca_{shell}. Since oysters do not have clear periodic growth lines in shell cross sections of their hinge area, obtained chemical data could not directly associate to certain calendar years. Furthermore, time series of trace and minor element composition to calcium ratios had low reproducibility among different individuals and between different species. Evidence of yearly cyclicity in Na/Ca_{shell}, Mg/Ca_{shell}, and Sr/Ca_{shell} ratios, previously found for shells of *Glycymeris pilosa*, *Callista chione*, and *Venus verrucosa* from the Adriatic Sea (Markulin et al., unpublished data), were only hinted for Mg/Ca_{shell} time series obtained from oysters indicating its potential use in estimating age and growth. Na/Ca_{shell} time-series showed higher values in *M. gigas* than in *O. edulis*. Oyster species showed higher values of Zn/Ca_{shell} and Mn/Ca_{shell} and lower values of Ba/Ca_{shell} in comparison to other analyzed bivalve species from the Adriatic Sea (Markulin et al., unpublished data). Uneven and irregular growth of oysters could be the reason of low reproducibility among different individuals, and future data should aim to find and study shell parts that are comparable among different individuals.

Session: Proxy Development: Challenges and Opportunities

Bivalve mollusk sclerochronology in a changing world: Environmental controls on the growth of *Mercenaria mercenaria* from North Carolina, USA

David H. Goodwin[1*], David P. Gillikin[2], Alan D. Wanamaker Jr.[3]

[1]*Department of Geosciences, Denison University, Granville, OH 43023, USA*
[2]*Geology Department, Union College, Schenectady, NY 12308, USA*
[3]*Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA 50011, USA*

**presenting author: goodwind@denison.edu*

Bivalve mollusks shells archive environmental conditions in the form of biogeochemical variations and periodic growth lines and increments. When calibrated with observed environmental records, these archives become valuable sources of (paleo)autecological information. Here we present new information of the growth of *Mercenaria mercenaria* from Jarrett Bay, in the Cape Lookout region of North Carolina, USA. Environmental records were collected between August 2016 and June 2018. Hourly water temperatures were recorded with multiple in situ loggers in Jarrett Bay (±0.2°C). Weekly water samples were collected from the same site between August 2016 and June 2018 (n = 89), to determine water oxygen isotope ($d^{18}O_W$) variation (analytical uncertainty ±0.07‰). In addition, regional water sample transects collected in April 2017; October 2017; and, June 2018 document $d^{18}O_W$ spatial variability in the spring, summer, and autumn seasons, respectively. Daily maximum and minimum temperatures, together with interpolated daily $d^{18}O_w$ values from Jarrett Bay, were used to calculate the predicted carbonate oxygen isotope ($d^{18}O_C$) envelope (i.e., the daily range of potential $d^{18}O_C$ values). Multiple specimens of *M. mercenaria* were grown under natural conditions at the same site between 2016-2018. Clams were stained with calcein, which fluoresces under UV light, on three dates: 8/13/16; 4/8/17; and, 7/13/17. Shells were then collected on 10/21/17. Carbonate samples were collected from thick-sections using a computer-controlled XYZ micromill. Analytical uncertainty of measured $d^{18}O_C$ samples was ±0.07‰. Measured $d^{18}O_C$ samples were fit within the oxygen isotope envelope using the stained samples and known collection date to calibrate the timing of shell growth. Our results suggest *M. mercenaria* in Jarrett Bay grow essentially throughout the year. Surprisingly, the dark annual bands, thought to form between May and October, were deposited between early April and October. These bands likely reflect heat stress and may reflect earlier warming of Jarrett Bay waters in the spring. Placement of the measured $d^{18}O_C$ samples in the oxygen isotope envelope suggests these specimens grew preferentially during the warm hours of the day. Finally, our results suggest these specimens stopped growing during the extreme precipitation event, Tropical Storm Julia (September 2016). If these storm-induced growth cessations can be recognized it may provide a new tool for reconstruction of prehistoric tropical storms.

Session: Growth, Bioenergetics and Ecosystems

The carpet shell *Ruditapes decussatus* in archaeological context: insights on season of collection and coastal paleo-temperature

Marc Gosselin[1*], Catherine Dupont[1], Céline Poulain[2], Xavier Le Coz[3], Gregor Marchand[1], Jean-Marie Munaron[2], Christine Paillard[2], Yves-Marie Paulet[2], François Plustoc'h[1], Julien Thébault[2]

[1]CNRS, UMR 6566 CReAAH « Centre de Recherche en Archéologie Archéosciences Histoire » Université de Rennes, 35000 Rennes, France
[2]LEMAR, UMR 6539 CNRS/UBO/IRD/IFREMER, Institut Universitaire Européen de la Mer, Place Nicolas Copernic, 29280 Plouzané, France
[3]Géosciences Rennes Atelier Géomatériaux, UMR 6118 CNRS, OSUR, Université de Rennes 1, 35042 Rennes cedex, France

**presenting author: mar.gosselin@gmail.com*

Specimens of carpet shell *Ruditapes decussatus* from the Mesolithic shell midden (6th millennium BC) of Beg-an-Dorchenn (Brittany, France) were studied in order to access their period of collect as well as some insight on Paleo-temperature reconstructions. Cross sectioned shells display very clear growth structures free from diageneses allowing to assess a growth rhythm of 2 increments per lunar day. From this temporal framework, daily growth increments, fortnightly ridges, winter annual growth break and spawning events were characterized. The *R. decussatus* studied shells collected in late autumn and/or early spring period. Chemical analyses of shell carbonates were also conducted to access a preliminary range of potential sea temperature data from oxygen isotopes values ($\delta^{18}O_{shell}$). $\delta^{18}O_{shell}$ shows seasonal variations but do not displays the whole range of temperature as *R. decussatus* have a growth break during winter. However, the range of reconstructed SST did not show nonsensical values and suggest sea temperatures slightly higher than the current ones. Thus, *R. decussatus* is particularly suited to address paleo-environmental issue at high temporal resolution such as the seasonal periodicity. To conclude additional sclerochronological and chemical researches on other mollusk species from Beg-an-Dorchenn or other Mesolithic shell middens along the European Atlantic façade will contribute to the problematics of seasonal occupation as well as climate variability at the Mesolithic-Neolithic transition.

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Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Reconstruction of Arctic Oscillation driven sea ice variability in Lancaster Sound, Canadian Arctic, using the long-lived coralline alga *Clathromorphum compactum*

Jochen Halfar[1*], Annelotte Van der Linden[2], Kent Moore[1], Sarah Shana[1], Sasha Tsay[3], Zoltan Zajacz[3]

[1]Department of Chemical and Physical Sciences, University of Toronto at Mississauga, 3359 Mississauga Rd. N, Mississauga, ON, L5L 1C6, Canada
[2]Department of Earth Sciences, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, Netherlands
[3]Department of Earth Sciences, University of Toronto, 22 Russell Street, Toronto, ON, M5S 3B1, Canada

**presenting author: jochen.halfar@utoronto.ca*

Arctic sea ice cover has been rapidly declining since the beginning of satellite observations in the 1970s. However, limited length satellite records do not allow for an assessment of the long-term behaviour of sea ice. Recently, the shallow benthic coralline alga *Clathromorphum compactum* has been shown to archive annual resolution proxy information of sea ice cover. *C. compactum* is found throughout the Arctic and can exhibit a life-span of up to 650 years while depositing annual growth increments in a High-Mg calcite skeleton. Annual growth increment widths and Mg/Ca ratios in this photosynthesizing marine plant are strongly dependent on light availability on the shallow seafloor, where low growth rates and Mg/Ca ratios are related to long duration sea-ice cover. Here, we have analyzed Mg/Ca ratios in two specimens of *C. compactum* live-collected from Lancaster Sound, Nunavut, Canada in summer 2016. Mg/Ca ratios exhibit annual cyclicities, which were used to calculate annual growth increment widths and generate an age model extending back to 1863. The sea-ice proxy was constructed by averaging of annual growth increment width and Mg/Ca anomalies of both samples. Proxy strength was tested by comparison with satellite derived regional summer sea ice concentration data between 1979-2015 yielding significant negative relationships (western Lancaster Sound $r=-0.8$, $p<0.0001$; central Lancaster Sound $r=-0.4$, $p<0.03$). Spatial comparisons with satellite-derived sea-ice concentrations across the Canadian Arctic Archipelago exhibit highest correlations in the western-central Lancaster Sound and Barrow Strait region, further confirming the suitability of *C. compactum* for regional scale sea-ice reconstructions. The algal time series prior to satellite observations indicates a long-term sea-ice decline which was most pronounced between 1910-1950 followed by a period high sea-ice cover from the 1960s to 1980s. Lancaster Sound sea ice anomalies have previously been related to variability of the Arctic Oscillation (AO) - a measure of Northern Hemisphere sea-level pressure differences determining the exchange of atmospheric mass between the Arctic and mid-latitudes. The AO influences Lancaster Sound through wind patterns, where a positive AO results in strong winds driving ice out of the Sound. Variability of the algal sea ice reconstruction is closely related to an AO index ($r_{annual}=0.67$, $p<0.0001$, 1899-2000) demonstrating the long-term stability of the sea-ice – AO relationship in Lancaster Sound. However, from 2000 onwards algal anomalies indicate a steep decline in sea ice unrelated to the AO, suggesting that Lancaster Sound sea-ice variability has started to respond to other drivers, such as increasing Arctic temperatures.

Session: Climate and Oceans: Past, Present and Future

Annually resolved NE Atlantic Ocean variability through the 8.2K cold event

Ian Hall[1*], David Reynolds[2], Sophie Slater[1], James Scourse[3], Paul Halloran[4], Freya Garry[4]

[1]School of Earth and Ocean Science, Cardiff University, Main Building, Park Place, Cardiff, CG10 3AT, UK
[2]Laboratory of Tree Ring Research, University of Arizona, Bryant Bannister Tree Ring Building, 1215 E Lowell St, Tucson, AZ, 85721, USA
[3]Centre for Geography and Environmental Science, College of Life and Environmental Science, University of Exeter, Penryn Campus, Treliever Road, Penryn, Cornwall, TR10 9FE, UK
[4]School of Geography, College of Life and Environmental Science, University of Exeter, North Park Road, Exeter, EX4 4QE, UK

**presenting author: hall@cardiff.ac.uk*

The 8.2K event is regarded as one of the largest climate perturbations of the Holocene, which brought generally widespread, especially wintertime, cold and dry conditions to northern-hemisphere regions, in response to a very large outburst flood that freshened the North Atlantic. As a result, it is suggested that the Atlantic Meridional Overturning Circulation (AMOC) significantly weakened. Understanding the response of the AMOC to rapid freshening in the subpolar North Atlantic Ocean is of significant interest due to the role AMOC plays in heat transport from the tropics to the mid and polar latitudes as well as the potential for significant socioeconomic impacts if, as numeric climate models predict, the AMOC weakens over the 21st century in response to increased fresh water input from melting ice due to anthropogenic warming. Here we report the stable isotopic composition ($d^{18}O_{shell}$ and $d^{13}C_{shell}$) of live and fossil *G. glycymeris* shells collected from the Tiree Passage in northwest Scotland. These shells spanned two distinct intervals from ca. 8900 BP to 8000 BP (i.e. spanning the 8.2K event) and 800 CE to 2011 CE. The isotopic data, from both intervals, are characterised by significant inter-annual to centennial scale variability with the coldest temperatures over the last millennium occurring between 1500 CE and 1800 CE and, for the 8.2K event shells, between 8300 BP and 8400 BP. The timing of the cold interval over the last millennium coincides with the Little Ice Age, whilst the coldest interval from the 8k shells is broadly consistent with the timing of the 8.2K event. The comparison of the $d^{18}O_{shell}$ data with the corresponding $d^{13}C_{shell}$ data, which is sensitive to changes in salinity, suggest there were likely large shifts in both sea water temperature and salinity during the 8.2K event in this region. Given the proven sensitivity of hydrographic variability in Northwest Scotland to changes in North Atlantic Ocean circulation patterns, and the fortunate timing of the shell collections that capture the 8.2k event and variability over the last millennium, these data may facilitate the attribution of the role of the AMOC in driving climate variability over the last millennium and help constrain uncertainties associated with quantifying the current state of AMOC variability.

Session: Climate and Oceans: Past, Present and Future

Age estimation and corroboration of four-spot megrim (*Lepidorhombus boscii*) on the Porcupine Bank (west of Ireland)

Carmen Hernández[1*], Jorge Landa[1]

[1]Instituto Español de Oceanografía (IEO), Centro Oceanográfico de Santander, Promontorio de San Martín s/n, 39004 Santander, Spain

**presenting author: carmen.hernandez@ieo.es*

Age and growth of four-spot megrim (*Lepidorhombus boscii)* on the Porcupine Bank, a relevant European fishing area for the demersal fleet, is estimated based on the analysis of otolith (sagittae) annuli. The state of the stock in Celtic Seas (including Porcupine Bank) and northern Bay of Biscay, has not been assessed in ICES so far, and biological information for a forthcoming stock assessment process is required. In this study, the age was estimated by counting translucent bands (annuli) of the sagittal otoliths following internationally standardized protocols. Otoliths were obtained from specimens caught in five annual bottom trawl surveys (2008-2012) carried out in Porcupine Bank.

The consistency of the age interpretation of *L. boscii* is demonstrated by analyzing the regularity of the distances of the (supposed) annuli to the otolith primordium and by the back-calculation of the annuli. The growth patterns obtained from direct otolith age estimation and from back-calculation are also compared.

The age estimation is corroborated by tracking year-class abundance indices from the surveys. The strength of the year-classes was well tracked in the first abundant age groups, highlighting the very abundant 2008 year-class.

Furthermore, the von Bertalanffy growth parameters are also estimated and compared with those from other stocks. The parameters obtained here are available for the upcoming analytical stock estimation.

Session: Fisheries Ecology and Management

Northeast Atlantic chub mackerel (*Scomber colias*): growth pattern and age validation in Northern Iberian waters

María Rosario Navarro[1], Jorge Landa[1], Begoña Villamor[1], **Carmen Hernández[1*]**, Rosario Domínguez[2]

[1]*Instituto Español de Oceanografía (IEO), C.O. Santander, Promontorio de San Martín s/n, 39004 Santander, Spain*
[2]*Instituto Español de Oceanografía (IEO), C.O. Vigo, Subida a Radio Faro, 50, 36390 Vigo, Spain*

**presenting author: carmen.hernandez@ieo.es*

During the last years, chub mackerel has increased its abundance at its northernmost distribution limit (Northern Iberian waters), possibly influenced by oceanographic shifts, with potential impact on other important pelagic fisheries and the ecosystem. Fishery advice has been recently recommended within ICES to be performed in the near future. Based in samples from commercial catches and scientific surveys between 2011 and 2017, this study shows the growth pattern and paramenters of chub mackerel in Northern Iberian waters. Absolute and relative otolith marginal increment analyses and otolith edge nature analysis, based on speciemens from two consecutive years, are performed to validate the periodicity of growth increments of this population. With the purpose of corroborating the growth pattern, length-frequency analyses are also peformed. In addition, the consistency of the age interpretation is tested by the regularity of the otoliths increments formation and with back-calculation analysis. The growth parameters obtained from direct age estimation and back-calculation are also compared between them and with those from other areas. Our parameters could be used as input in fisheries assessment models.

Session: Growth, Bioenergetics and Ecosystems

Automation of bivalve microstructure analysis: Making a new proxy feasible

Nils Höche[1*], Eric O. Walliser[1], Melita Peharda[2], Bernd R. Schöne[1]

[1]University of Mainz, Institute of Geosciences, Joh.-J.-Becher-Weg 21, 55128 Mainz, Germany
[2]Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia

**presenting author: nhoeche@uni-mainz.de*

As recently demonstrated, shell microstructure properties can potentially serve as a proxy for ambient water temperature. For example, *Cerastoderma edule* forms larger and more elongated biomineral units (BMUs) in warmer waters. Before this method can be broadly applied, it needs to be validated in different species with the same microstructure and tested for different microstructures and environments. Furthermore, some analytical challenges require attention: (1) Proper etching techniques are needed for unequivocal BMU recognition; (2) Image analysis is currently done in only two dimensions, whereas BMUs are three-dimensional objects; (3) Algorithms are required that can faithfully recognize BMU outlines without manual correction. Here, we present preliminary results from *Glycymeris* spp. (Croatia) and *Arctica islandica* (Iceland and Baltic Sea) for homogenous, crossed-acicular and crossed-lamellar microstructures.

Best results to study BMUs of homogeneous microstructures were achieved by gently etching polished cross-sections under constant stirring for 2h in 0.0001vol% formic acid. Crossed-acicular microstructures required shorter immersion and higher concentration, i.e., 20s in 0.5vol% formic acid. Crossed-lamellar microstructures turned out best when oxidized for 30m in 3.5% H_2O_2. Subsequent O_2-plasma-etching removed superfluous organics and improved image quality.

SEM micrographs were automatically processed and analyzed with ImageJ. Preprocessing with suitable filters removes noise (median filter) and sharpens BMU contours (Laplacian filter). To quantify BMU properties, the use of an automatic mean threshold combined with a distance transform watershed algorithm performed best. Bias induced by differing cutting angles was counteracted by considering only the sample surface and the 10% largest BMUs. Furthermore, only lamellae cut perpendicular to their longest axis were analyzed in crossed-lamellar and crossed-acicular microstructures. Microstructures of the hinge plate of *A. islandica* (cross-acicular, fine complex crossed-lamellar) offered more numerous morphometric features suitable for analysis than the homogenous microstructure of the outer shell layer.

In agreement with the seasonal temperature ranges, BMUs of *A. islandica* from Iceland showed considerably lower variability in size and shape than specimens from the Baltic Sea.

The new methods hold great promise to reliably and automatically generate morphometric BMU data in short time, which is crucial to further calibrate and establish the new microstructure-based temperature proxy.

Session: Proxy Development: Challenges and Opportunities

Mapping and quantification of sub-annual trace element variation in otoliths of toothfish (*Dissostichus eleginoides*) using µXRF and LA-ICP-MS

Phil Hollyman[1,2], **Simon Chenery[2*]**

[1]*British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK*
[2]*Centre for Environmental Geochemistry, British Geological Survey, Nottingham NG12 5GG, UK*

**presenting author: srch@bgs.ac.uk*

Trace element concentrations within fish otoliths can be used as proxies for reconstructing several aspects of environmental and ecological histories. The efficacy of these proxies varies across species groups and environmental contexts but with appropriate validation, they remain a powerful tool for retrospective studies. The Patagonian toothfish (*Dissostichus eleginoides*) supports several fisheries in Southern latitudes, notably around the island of South Georgia, which has a fishery that is widely acknowledged as well managed and sustainable. Due to their longevity, otoliths from South Georgia toothfish toothfish have the potential to contain long time series of elemental information of up to 60 years, roughly 3x longer than existing in-situ environmental datasets from the same location. Whilst micro-chemistry of *D. eleginoides* otoliths has been undertaken in the past, this has been for the purpose of stock discrimination and until now, no sub-annual or full growth axis analysis has been performed. This poster will outline the findings from an exploratory LA-ICP-MS and synchrotron µXRF study to identify potential proxies and investigate spatial distributions of trace elements contained within these otoliths. Distinct annual cycles in key trace elements (e.g. Sr) were observed along with clear ontogenetic changes in trace element incorporation. These findings are being developed to answer important fisheries related and ecological questions. These include the timing of ontogenetic depth migrations, the timing and drivers of growth line formation and the timing of apparent pre-maturation migrations to the South Sandwich Islands, an archipelago roughly 550 km East of South Georgia. This project will form a basis of understanding, allowing us to approach these key life history questions and improve the long-term management of this species.

Session: Fisheries Ecology and Management

Using anually-resolved bivalve records and biogeochemical models to understand and predict climate impacts in coastal oceans

Sarah Holmes[1*], Paul Halloran[1], Paul Butler[1], Johan van der Molen[2], John Aldridge[3], Chris Perry[1]

[1]Department of Geography, University of Exeter, UK
[2]Royal Netherlands Institute for Sea Research (NIOZ), Netherlands
[3]Center for Environment, Fisheries and Aquaculture Science (CEFAS), UK

**presenting author: s.holmes@exeter.ac.uk*

Projected to warm at substantially greater rates than those in the open ocean, the shelf seas are extremely vulnerable to the effects of climate change. These highly productive coastal ecosystems are therefore of great socio-economic significance and understanding how they will change in the future is of major importance to decision-makers. However, attempts to do so are hindered by insufficient observational data. Long-term, highly spatially- and temporally-resolved datasets of the marine environment simply do not exist.

Simulating the shelf seas with biogeochemical models can provide valuable data and huge efforts across the modelling community are invested into developing and increasing the reliability of these models. However, in the current state of knowledge, these are typically validated using (at best) the aforementioned sparse observational datasets, and often against climatological observational fields. With increasing pressures on coastal ecosystem services, we need to do better. For the first time, this research is attempting to assess model skill with the use of marine proxies. Of all marine proxies available, sclerochronology (the study of the growth bands on long-lived marine clams) is the only one (at mid-to-high latitudes) that provides absolutely-dated, multi-centennial, annually-resolved archives of past ocean environment, analogous to dendrochronology in terrestrial environments.

This PhD project is attempting to demonstrate the benefits of proxy-model fusion by combining the European Regional Seas Ecosystem Model (ERSEM) with the sclerochronologies of bivalve molluscs (clams) *Glycymeris glycymeris* and *Arctica islandica* on the North West European Shelf (NWES). The research aims to better parameterise the "filter feeder" component of ERSEM (using 1D hindcasts) and give insight into the factors controlling bivalve growth in order to better interpret these proxy records. A key finding has been that by controlling meteorological inputs into the model, we can mechanistically attribute bivalve growth variability to wind speed variability. This novel research will contribute to a better understanding of the NWES sea environment with potential to improve predictions of future climate change in this region and beyond.

Session: Climate and Oceans: Past, Present and Future

Extracting seasonality signals from Late Albian bivalve shells: A multiproxy multispecies approach

Stefan Huck[1*], Niels de Winter[2], Rute Coimbra[3], Philippe Claeys[2], Ulrich Heimhofer[1]

[1]Institut für Geologie, Leibniz Universität Hannover, Germany
[2]AMGC research group, Free University of Brussels (VUB), Brussels, Belgium
[3]3GeoBioTec, Dpt. of Geosciences, University of Aveiro, Portugal and MARE, Earth Sciences Dpt., University of Coimbra, Portugal

**presenting author: huck@geowi.uni-hannover.de*

Cretaceous rudist bivalve shells have been shown to faithfully record inverse cyclic changes of oxygen isotope ratios and Mg contents, which are interpreted to represent seasonal temperature changes of the ambient sea water (Steuber, 1999). Estimating the impact of salinity changes on the rudist shell oxygen isotope composition at a given setting, however, is still problematic and calls for a calibration of oxygen-isotope based sea surface temperatures by means of additional palaeothermometers (e.g. clumped isotopes or TEX_{86}). Moreover, a metabolic control on the isotopic composition of the low-Mg calcite rudist shell cannot be completely ruled out, as no modern analogues of these extinct bivalves exist.

In order to disentangle the influence of palaeoenvironment, diagenesis and 'vital effects' on the rudist shell geochemistry, the current study compares highly resolved multi-proxy (stable isotopes, trace elements) sclerochronological records of different Late Albian bivalve taxa (requieniid and radiolitid rudists, pectinids, chondrodonts and oysters) derived from the same proto-North Atlantic palaeoenvironmental setting in Portugal (Lusitanian Basin, Horikx et al., 2014). In contrast to classical methods such as ICP-OES, the here applied micro-XRF scanning technique allows to simultaneously measure a variety of elements, which help to (i) distinguish between natural and diagenetic enrichments of indicative elements such as iron and manganese and to (ii) identify the influence of palaeoenvironmental changes (SST, nutrients, salinity etc.) on bivalve shell growth (see de Winter et al., 2017). A multivariate statistical approach is presented to identify the influence of differential diagenesis on these multi-proxy records.

In particular, the comparison of rudist and pectinid sclerochronological records is a very promising approach, as pectinids have living analogues and therefore much more is known about the metabolic control on the shell geochemistry. This in turn will help to better understand the palaeoecology of rudist bivalves and how these animals recorded palaeoceanographic signals in their shells.

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Session: Proxy Development: Challenges and Opportunities

Recent ENSO Evidence from Fiji: Climate Archives in Middens (REEFCLAM)

Eleanor H. John[1*], Elia Nakoro[2]

[1]School of Earth and Ocean Sciences, Cardiff University, Park Place, Cardiff CF10 3AT, UK
[2]Fiji Museum, Suva, Fiji

**presenting author: johne11@cardiff.ac.uk*

Giant clam shells are highly valuable archives of past climate data: they are fast-growing, long-lived, and their dense shells have annual growth bands that can be subsampled and analysed to produce sub-annually resolved climate proxy records spanning multiple decades. Moreover, they are common in the tropical Pacific, where paleoclimate data is particularly valued as sub-annual to decadal-scale changes in this region have been linked to dramatic global temperature and rainfall anomalies with far-reaching socioeconomic and environmental effects. The challenge in using them is finding material of suitable age and quality to investigate pre-industrial climate variability. Giant clams have been (and are) a common food and tool supply in the tropical Pacific and are abundant in Lapita-age (~3500–2500 cal BP) shell middens, providing unique opportunities for paleoclimate research that have not yet been exploited. I plan to use shells from a Lapita-age shell midden in southwest Viti Levu, Fiji, to generate the first pre-industrial *Tridacna*-based record of climate variability in Fiji. This will provide a snapshot of past seasonal to decadal variability in sea surface temperature and salinity in an important yet understudied region and test the hypothesis that the first major pulse of eastward human migration into the Pacific by the Lapita people was associated with an interval of more frequent El Niño events.

Session: Climate and Oceans: Past, Present and Futuere

Microgrowth-increment and isotopic data from sub-thermocline *Aequipecten opercularis*: recognition of setting and fidelity of temperature records

Andrew L.A. Johnson[1*], Melita Peharda[2], Bernd R. Schöne[3], Ivica Janeković[4], Annemarie Valentine[5]

[1]*School of Environmental Sciences, University of Derby, Derby DE22 1GB, UK*
[2]*Institute of Oceanography and Fisheries, 21000 Split, Croatia*
[3]*Institute of Geosciences, University of Mainz, 55128 Mainz, Germany*
[4]*UWA Oceans Institute, University of Western Australia, Crawley, WA 6009, Australia*
[5]*School of Geography and Environmental Science, Nottingham Trent University, Southwell NG25 0QF, UK*

**presenting author: A.L.A.Johnson@derby.ac.uk*

The shell $\delta^{18}O$ of benthic marine molluscs is commonly an accurate reflection of seafloor temperature. Ontogenetic profiles from organisms that lived in continuously well-mixed settings can be read as a record of surface temperature but those from depths below the summer thermocline cannot: the maximum benthic temperature recorded will always be less than the surface temperature. For the purposes of interpreting palaeoclimate (i.e. surface temperature) from the $\delta^{18}O$ of fossil shells it is important to be able to tell whether the organism lived in a supra- or sub-thermocline setting and, if the latter, whether even benthic temperature is accurately represented. We investigated ontogenetic variation in $\delta^{18}O_{shell}$, $\delta^{13}C_{shell}$ and microgrowth-increment size in three modern specimens of the pectinid bivalve *Aequipecten opercularis*, collected live on 13thSeptember 2016 from a seasonally stratified setting (38 m depth) in the northern Adriatic Sea. Fluctuations in $\delta^{18}O$ (undoubtedly due to seasonal temperature variation) indicate that two shells started post-larval life in winter 2013-14 and one in winter 2014-15. Shell $\delta^{13}C$ does not parallel $\delta^{18}O$, contradicting a model for variation of this parameter in seasonally stratified settings (Arthur et al. 1983; Geology 11:655-659), but microgrowth-increment size shows substantial seasonal variation (out of phase with $\delta^{18}O$) in two of the shells, in accordance with a model for this parameter (Johnson et al. 2009; Palaeogeography, Palaeoclimatology, Palaeoecology 284:164-179). The $\delta^{18}O$ of material apparently deposited during winter 2013-14, summer 2014 and winter 2014-15 in general closely matches predicted values based on modelled temperatures and salinities (hence water $\delta^{18}O$) for the location, depth and interval. However, the minimum shell $\delta^{18}O$ values (corresponding to the warmest temperatures) recorded during summer 2015 are substantially above the values predicted for this unusually warm summer, when benthic temperature reached 23°C. Temperatures approaching this are recorded in the shell $\delta^{18}O$ of *A. opercularis* from elsewhere in the Mediterranean (Malaga area and Gulf of Tunis). Their absence for summer 2015 in northern Adriatic shells probably reflects cessation of growth, not due to high benthic temperature but perhaps because of low oxygen availability associated with a stable (stratified) water column and high benthic respiration. Physical evidence of growth cessation in summer 2015 is scant so while sub-thermocline examples of *A. opercularis* can be identified (from microgrowth-increment data) and provide a faithful isotopic record of benthic temperature in winters and some summers, extremely warm summers are neither recorded nor suggested.

Session: Proxy Development: Challenges and Opportunities

Understanding growth variation and life history diversity in a migratory salmon population using otolith microstructural and microchemical analysis

Brian P. Kennedy[1,2*], Jensen Hegg[1], Katherine Gilles-Rector[1]

[1]Department of Fish and Wildlife Sciences, University of Idaho, Moscow, Idaho 83844-1136, USA
[2]Department of Biology and Geology, University of Idaho, Moscow, Idaho 83844-1136, USA

**presenting author: kennedy@uidaho.edu*

Understanding the conditions that create and maintain a portfolio of salmon migration strategies is challenging in large river systems where life history diversity can be the product of many factors. Here, we paired a long-term otolith dataset of life history expression with a bioenergetic analysis of early growth opportunity in a salmon population to identify how growth conditions related to life history expression for individual fish for which we isotopically reconstructed migratory paths. In the Snake River, Idaho, USA, populations of fall Chinook salmon (*Oncorhynchus tshawytscha*), appear to be exhibiting novel life history strategies in response to the widespread alteration of mainstem migratory corridors. Using otolith microchemistry and microstructure analysis, we have studied spatially-explicit variation in migratory timing and its implications for how water resources are stored and managed throughout the Columbia River system. Our laboratory has explored the application of novel data acquisition techniques, such as Laser Ablation Split Stream ICPMS, as well as data analysis methods, such as Dynamic Time Warping, to optimize the resolution and efficiency of our life history reconstructions. Our combined bioenergetics and life history analyses have demonstrated differences in mainstem reservoir use and early life history growth that are based upon natal rearing locations as well as annual differences in climate. Specifically, our findings indicate that delayed migration of some individuals is correlated with larger sizes at ocean entry, but that this strategy is not expressed evenly across the species' distribution. In source habitats where delayed migration is more common, its prevalence in any given year is significantly affected by annual variation of flow in the basin. Our long-term dataset has improved our understanding of the selection for migratory timing across an altered landscape and its implications for population resilience.

Session: Fisheries Ecology and Management

Giant clam growth in the Gulf of Aqaba is accelerated compared to fossil populations: The role of nitrate aerosol fertilization

Daniel Killam[1*], Tariq Al-Najjar[2], Matthew Clapham[3]

[1]University of Haifa, Department of Marine Geosciences, Israel
[2]University of Jordan, Aqaba Branch, Jordan
[3]University of California, Santa Cruz; Department of Earth and Planetary Sciences, USA

**presenting author: daniel.e.killam@gmail.com*

The giant clams are globally distributed reef-dwelling bivalves which use the same photosymbiotic partnership characteristic of reef-building corals. But while the declining health of corals in the face of climate change and human pollution are the topic of intensive research, comparatively little work has been dedicated to understanding trends in the health of giant clams in relation to environmental change. We have collected fossil and modern specimens of three species of *Tridacna* from reefs fringing the Gulf of Aqaba in the Northern Red Sea. After calibrating the daily/twice-daily growth bands from the outer layer of their shells, we have determined that all three species are growing more quickly in the modern day compared to fossil specimens from Holocene and Pleistocene reefs. We found that giant clam shell organic $\delta^{15}N$ of modern specimens show a 4.5‰ lower average value compared to fossil specimens, an offset which we propose is most likely attributable to increased deposition of isotopically light nitrate aerosols in the modern era. As nitrate is a known accelerant of giant clam growth, it may play a role in the faster growth seen in modern populations. We found that that growth is positively correlated to temperature as measured by oxygen isotope paleothermometry of their shell carbonate, and discuss how lower winter cold temperatures in the past may have depressed giant clam growth compared to the relatively small seasonal availability seen today. Giant clams can serve as isotopic and physiological sentinels of reef environmental change, both to determine their own comparative health and that of the coral reefs they inhabit.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Dramatic growth anomalies and isotopic disequilibrium characterize the shell portion of oysters formed during the juvenile period

Damien Huyghe[1,2], Marc de Rafelis[3], Mathieu Daëron[4], Laurent Emmanuel[5], Vincent Mouchi[5], Michel Ropert[6], Nathalie Labourdette[5], Maurice Renard[5], **Franck Lartaud[1*]**

[1]Sorbonne Université, CNRS, Laboratoire d'Ecogéochimie des Environnements Benthiques, LECOB, Observatoire Océanologique de Banyuls, F-66650 Banyuls-sur-mer, France
[2]Centre de Géosciences, MINES Paris tech, PSL University, 35 rue St Honoré, 77305 Fontainebleau cedex, France
[3]Géosciences Environnement Toulouse, UMR 5563 CNRS, UR 234 IRD, UM 97 UPS, Observatoire Midi-Pyrénées, CNES, 14 avenue Edouard Belin, 31400 Toulouse, France
[4]Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-USVQ, Université Paris-Saclay, Orme des Merisiers, F-91191 Gif-sur-Yvette Cedex, France
[5]Sorbonne Université, CNRS-INSU, Institut des Sciences de la Terre Paris, ISTeP, F-75005 Paris, France
[6]Ifremer, Laboratoire Environnement Ressource de Normandie, Avenue du Général de Gaulle, BP 21, 14520 Port-en-Bessin, France

**presenting author: franck.lartaud@obs-banyuls.fr*

Biomaterials are now widely used as an archive of past and present environmental conditions. The development of sclerochronology and sclerochemistry provides clues in the characterization of both long-term and high frequency environmental changes (e.g., infra-seasonal). But in many cases, interpretations are limited by the metabolism impact on growth increment formation and the geochemical signal they hold. To solve this limitation, a multi-proxy approach can be useful together with a better insight into skeleton growth processes, particularly at high-resolution. The lack of a chronological constraint in the accretion of hard tissues is a major obstacle for the use of proxy, which needs to be clearly defined for each studied species.

Based on monthly mark and recapture techniques applied in the field over two years, we conducted an insightful study on oyster shell growth and the potential use of isotopic proxies (oxygen stable isotopes and clumped-isotopes). The cathodoluminescence microscopy of shells previously stained with manganese reveals two distinct patterns depending on the age of the organism. After one year old (i.e., reaching the sexual maturity), the formation of growth increments follows a tide-related model, leading to the mineralization of ~2 incr. per day. Also, growth rate changes at lunar and semi-lunar periodicities are recorded during this period, as well as a seasonal trend interrupted by growth breaks when temperature decreases below 6°C. But in the shell portion younger than one year old, although the general growth rate is higher, growth increments analysis reveals unconventional patterns. We observe either up to five growth increments formed per day or less than one yet large increment per day, associated with frequent growth cessations. These juvenile patterns have considerable consequences on the use of isotopic proxies. Although oxygen stable isotopes ($\delta^{18}O$) and clumped-isotopes (Δ_{47}) match well with the seasonal trend during most part of the shell mineralization (i.e., oysters aged of ≥ 1 year old), during the juvenile period (i.e., < 1 year old), both $\delta^{18}O$ and $\Delta_{47}$are out of isotopic equilibrium. For these two proxies, the estimated temperatures are ~10°C higher compared to the environmental monitoring, likely related to kinetic effects in the incorporation of isotopes. We thus recommend to carefully consider this potential bias during the juvenile mineralization prior to use biomaterials as (paleo)environmental archive from geochemical proxies.

Session: Proxy Development: Challenges and Opportunities

A multi-decade record of increasing growth rates in a Mid Atlantic population of ocean quahogs

Matthew Long[1*], Sara Pace[2], Roger Mann[1], Eric Powell[2], Theresa Redmond[1]

[1]*Virginia Institute of Marine Science, Gloucester Point, VA 23062 USA*
[2]*Gulf Coast Research Laboratory, University of Southern Mississippi, 703 East Beach Drive, Ocean Springs, MS 39564; USA*

**presenting author: mclong@vims.edu*

The Mid Atlantic continental shelf of the United States east coast is a highly productive region for commercially important fish and shellfish species. A cold pool of water persists below an intense seasonal thermocline in this region with annual water temperature ranges more reflective of higher, boreal latitudes. An extensive population of the ocean quahog, *Arctica islandica* (Linnaeus 1767), occurs throughout the bathymetry of this cold pool region. Large ocean quahogs (>100mm shell length) collected from this region have recently been demonstrated to exhibit increased growth rates over two centuries from 1775 to 1975. An examination of growth increments for a collection of immature and small mature ocean quahogs from the same location provided evidence of a continued trend of increasing growth rates between 1975 and the present. Examination of growth in immature animals required the development of methods, described herein, to address the unique challenges posed by erosive loss of early growth lines in the outer shell material of ocean quahogs; specifically, for estimation of missing or incomplete internal growth lines in other hard-shelled marine organisms. Application of this approach demonstrated an acceleration of the increase in growth rate within the most recent decade.

Session: Climate and Oceans: Past, Present and Future

Otolith morphometry relations of *Trachurus picturatus* (Bowdich, 1825) from two different areas: the Canary Islands and the Ligurian-Northern Tyrrhenian Seas

Alba Jurado-Ruzafa[1], **Andrea Massaro[2*]**, Alessandro Ligas[3], María Teresa García Santamaría[1]

[1]Spanish Oceanographic Institute (IEO), Canary Oceanographic Centre, Vía Espaldón, Dársena Pesquera 8, 38180, Santa Cruz de Tenerife, Spain
[2]APLYSIA, via Menichetti 35, 57121, Livorno, Italy
[3]CIBM, viale Nazario Sauro 4, 57128, Livorno, Italy

**presenting author: andrea.massaro@aplysia.it*

Relationships between otolith morphometry and fish size of *Trachurus picturatus* (Bowdich, 1825) from the Canary Islands (CI, CE Atlantic) and the Ligurian-Northern Tyrrhenian Seas (LNT, Mediterranean Sea) were investigated. The blue jack mackerel is a benthopelagic species occurring from the Bay of Biscay to Mauritania (including Azores and the Canary Islands), and in the Mediterranean. In the CI, this species is caught exclusively by the artisanal purse-seine fleet and represents the second-most important species of small pelagic fish in terms of landings, accounting for approximately 700 tonnes in 2017. In LNT, this species is landed together with *T. trachurus* and *T. mediterraneus*, therefore it is not possible to gather accurate estimates of their landings. Anyway, the abundance of blue jack mackerel is lower than the other two species.

A total of 153 specimens were collected: 58 individuals from LNT, ranging from 8.0 to 42.5 cm total length (TL) and 95 individuals from CI (10.4-40.5 cm TL). The analysis of covariance (ANCOVA) was used to test the effect of the categorical factor area in the fish length-weight relationship, in the relationship between fish TL and otolith length, and in the otolith morphometric relationships (i.e. length, width, radius, perimeter). The factor splits the relationship between dependent and independent variables into two equations (one for each area). Regression lines were compared by studying the interaction of the factor with the independent variable. If the interaction is significantly different from zero, the regression lines have different slopes, thus there is significant difference between the two areas.

The results of the analyses showed no significant effect of the factor area in the fish length-weight relationship. In contrast, significant differences were found in the otolith morphometric relationships due to the effect of the factor area, supporting the hypothesis of a possible segregation between Atlantic and Mediterranean populations of the blue jack mackerel.

Session: Fisheries Ecology and Management

Inferring the population dynamic from otolith phenotypes

Alba Jurado-Ruzafa[1], Víctor Manuel Tuset[2], José Luis Otero-Ferrer[3], **Andrea Massaro[4*]**, María Teresa G. Santamaría[1]

[1]Spanish Oceanographic Institute (IEO), Canary Oceanographic Centre, Vía Espaldón, Dársena Pesquera 8 (38180), Santa Cruz de Tenerife, Spain
[2]Institute of Marine Sciences (CSIC), Department of Renewable Resource, Passeig Marítim 37-49 (08003), Barcelona, Spain
[3]University of Vigo, Departament of Ecology and Animal Biology, Fonte das Abelleiras (36310), Vigo, Spain
[4]APLYSIA, via Menichetti 35 (57121), Livorno, Italy

**presenting author: andrea.massaro@aplysia.it*

The polymorphism is commonly unexplored in studies on fish dynamic population despite its relationship with the life histories and spatial distributions. Considering the phenotypic variability of otolith contour, we provide a new perspective on the population of *Trachurus picturatus* (Bowdich, 1825) inhabiting the Canary Islands (eastern central Atlantic Ocean). Our findings revealed the presence of three otolith phenotypes (M1, M2 and M3) in similar proportions, which are not linked to sex, age and fish size. They showed temporal variations associated to life cycle: spawning, recruitment and feeding. The best model to explain this population structure could be the "contingency theory" where a population is composed by migrants and residents. In addition, each fish group showed significant differences in the Von Bertalanffy growth parameters. Both results revealed that the insular population of the Canary Islands would be more complex than a priori was expected.

Session: Fisheries Ecology and Management

Fish and sclerochronology research in the Mediterranean – challengies and opportunities

Sanja Matić-Skoko[1*], Melita Peharda[1], Dario Vrdoljak[1], Hana Uvanović[1], Krešimir Markulin[1]

[1]*Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia*

**presenting author: sanja@izor.hr*

Over the past two decades, field of sclerochronology has been rapidly developing and scientists are devoting significant efforts studying physical and chemical variations in hard tissues of different marine organisms. Most of this research has been limited to certain taxa and geographic areas. Although growth increments in fish otoliths are being used for sclerochronological purposes, very little has been done in the Mediterranean Sea. The main reasons include following: (i) the longevity of very few fish species in the Mediterranean Sea extends over several decades, (ii) there are almost no otolith samples available prior to 1950s, (iii) there are problems associated with reliable age determination for certain long-lived fish species (e.g. Sparidae, Scorpaenidae, Serranidae), (iv) efforts to model the impact of climate change on fish growth have been hampered by a lack of long-term (multidecadal) data needed to understand the effects of temperature on growth rates in natural environments and (v) funding, expertise and instrumentation is limited. Despite these challenges, fish sclerochronology research does have the potential in the Mediterranean, and adjacent Seas. Recent studies in the Adriatic Sea resulted in construction of bivalve chronologies as well as geochemical analysis of shells and provide important time-series data for comparative analysis and multispecies approach. Furthermore, studies conducted in other parts of the world have demonstrated potential for use fish otolith as monitors of environmental variability and the effects of pollutants and disturbance. In a framework of NURSE fish project, financed by the Croatian Science Foundation, we recently started geochemical analysis of otoliths from Sparidae family and are investigating ways and possibilities for developing this line of research at the Institute of Oceanography and Fisheries in Split.

Session: Fisheries Ecology and Management

An otolith biochronology provides evidence for species interactions in the Aleutian Islands ecosystem

Mary Elizabeth Matta[1*], Kimberly Rand[2], Morgan Arrington[3], Bryan Black[4]

[1]*Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 7600 Sand Point Way NE, Seattle, WA 98115, USA*
[2]*Lynker Technologies, LLC, 202 Church Street SE #536, Leesburg, VA 20175, USA*
[3]*School of Aquatic and Fishery Sciences, University of Washington, 1122 NE Boat Street, Seattle, WA 98105, USA*
[4]*Laboratory of Tree-Ring Research, University of Arizona, 1215 E Lowell Street, Tucson, AZ 85721-0045, USA*

**presenting author: beth.matta@noaa.gov*

Fish otolith increment chronologies developed using mixed effects models can reveal factors contributing to growth. These annually resolved, multi-decadal chronologies have been used to identify temporal and spatial patterns in growth variability. Here, we used a mixed modeling approach to determine the relative importance of intrinsic factors (e.g., sex, age) and extrinsic factors (e.g., temperature, abundance of con-specifics and competitors) to growth of Atka mackerel, a commercially important groundfish dominant in the Aleutian Islands ecosystem. A yearly alternating pattern of wide and narrow increments was observed, and was negatively correlated with abundance of pink salmon, suggesting possible competition over shared food resources such as copepods (which were positively correlated with the otolith chronology). We also contrast the otolith chronology with a body condition index to examine the relationship between otolith and somatic growth.

Session: Fisheries Ecology and Management

Depth-dependent environmental factors control *Arctica islandica* shell growth variability in SW Iceland

Madelyn Mette[1*], Fabian Bonitz[1], Paul Halloran[2], Vilde Melvik[1], Tamara Trofimova[1], Carin Andersson[1]

[1]Norwegian Research Centre, Bjerknes Centre for Climate Research, Bergen, Norway
[2]Department of Geography, University of Exeter, Exeter, United Kingdom

**presenting author: mame@norceresearch.no*

Cross-dated sclerochronologies are the foundation of absolutely dated, annually resolved proxy reconstructions using growth and geochemical measurements of bivalve shells. Synchronous shell growth patterns indicate the presence of a common environmental forcing, however, it is not always possible to determine the combination of factors controlling shell growth in different settings due to limited environmental data. The present study investigates differences between shell growth chronologies from two sites, one at 50m depth and one at 100 m depth, located 50 km apart in Flaxafloi, SW Iceland. Instrumental and model data reveal significant differences in the annual temperature cycle and thermocline dynamics between the two study sites. Hypotheses will be presented to explain the prevalent environmental forcings at each site and their resulting influences on shell records.

Session: Climate and Oceans: Past, Present and Future

Determination of age and growth in fish of the Pacific pomfret (*Brama australis*) in south central and southern off Chile

Guillermo Moyano[1*]

[1]*Instituto de Fomento Pesquero, Calle Blanco 839, Valparaíso, Chile*

**presenting author: guillermo.moyano@ifop.cl*

The main life history parameters of the Pacific pomfret (*Brama australis*) of samples from the industrial (trawl) and artisanal vessels (longline and gillnet) that operate in south-central and southern off Chile (35°00'S and 57°16'S) during the period 2012 to 2016, represented by individuals between 25.0 to 58.0 cm fork length (FL). The growth parameters were obtained from the annuli reading in *sagittal* otoliths, where the location of the first annulus was verified through daily microincrements analysis. The highest growth rates occurred during the first year of life, reaching a size of 30.13 cm FL at a daily rate of 0.55 mm*day^{-1}. The catches of the different fishing gears were mostly represented by individuals of 4 years of age. The average length of sexual maturity ($L_{50\%}$), corresponding to 37.7 cm FL was reached at age 3. Finally, otolith shape indexes analisys showed 3 different morpho-types, which are not associated with capture zones, fishing gears, sex or length of the individual

Session: Growth, Bioenergetics and Ecosystems

Stereoscopic vision of otoliths by microphotogrammetry

Lizandro Muñoz[1*], Luis Cid[1]

[1]*Instituto de Fomento Pesquero, Blanco 839, Valparaíso, Chile*

**presenting author: lizandro.munoz@ifop.cl*

Microphotogrammetry of otoliths is a technique that consists of obtaining 3D models from 2D images, which considerably broadens the possibilities of morphometric studies of otoliths in various fishing resources with specific applications such as stock differentiation among others. It is possible through the sequential acquisition of images to obtain digital reconstructions in three dimensions. The objective of this work is to develop a working methodology for obtaining otoliths images 3d with materials and tools available in the age and growth laboratory of the Instituto de Fomento Pesquero and that can be replicated in other laboratories. Otoliths of some of the main species that make up the commercial fisheries of Chile were used, as well as an image analysis device with Image Pro Premier, Agisoft, VSCD softwares and an adjustable speed cutting machine. By means of this procedure, several measurements can be obtained in both two-dimensional and three-dimensional planes that can be used in various inter and intraspecific characterization studies. As a final result three-dimensional images of otoliths are obtained that offer possibilities for further studies, mainly of morphometric characterization and species differentiation.

Session: Growth, Bioenergetics and Ecosystems

The trace element composition of mussel shells reflected the tsunami-induced environmental changes inherent in individual bays

Naoko Murakami-Sugihara[1*], Kotaro Shirai[1], Hiroshi Ogawa[1]

[1]Atmosphere and Ocean Research Institute, The University of Tokyo, Chiba, Japan

**presenting author: nsugihara@aori.u-tokyo.ac.jp*

Coastal zones are one of the most important habitats for organisms, but vulnerable to be natural disasters or manmade event. On 11 March 2011, the eastern coast of Japan was seriously damaged by a massive tsunami following the 2011 Tohoku Earthquake. This devastating tsunami altered the coastal ecosystems and biogeochemical cycles. To accurately understand the impact of such natural disaster on the coastal environment, continuous environmental information from before to after the event is essential. However, data before the event is often lacking and field observations are also difficult during and immediately after such event.

High-resolution reconstruction of the past environment using biological hard tissues, such as bivalve shells, is a promising method for solving such a problem. During their growth, bivalve shell geochemical compositions reflect the external environment. Here we investigated the impact of the tsunami on the coastal environment based on trace element analysis of mussel shells. On September 2011, Mediterranean mussels (*Mytilus galloprovincialis*) were collected alive from seven intertidal locations along the northeastern Pacific coast from Iwate to Fukushima. Shells were cut along the maximum growth axis. Trace element compositions on the polished shell cross section were analyzed along the growth direction using LA-ICP-MS. Prior to this study, Sugihara et al. (in review) analyzed trace element composition of a mussel shell from the Otsuchi Bay. We found that changes in oxygen isotopic ratio was synchronous with the shell Mg/Ca ratio, indicating seasonal cycles. We also revealed that the shell Mn/Ca ratio rapidly increased just after the tsunami, of which age model was established by growth line counting. Increased shell Mn/Ca ratio just after the tsunami was likely attributed to suspended terrestrial soil and seafloor sediment in the water column caused by the huge tsunami waves. In this study, five more locations were additionally investigated. Mn/Ca ratios were increased at the timing when Mg/Ca decreased at the timing of the tsunami occurred (winter, March). The height and duration of the Mn/Ca peak were different for each bay. This may be attributed to a different characteristic between the bays, such as the amount of inflow of terrestrial soils, seawater exchange, and residence time of each bay.

Session: Environmental Biomonitoring & Entrepreneurship

Stable isotope study of a *Glycymeris glycymeris* population from the Iberian Shelf

Alexandra Németh[1,2*], Zoltán Kern[1,2], Victor Quintino[3]

[1]*Isotope Climatology and Environmental Research Centre (ICER), MTA ATOMKI, Debrecen, Hungary*
[2]*Institute for Geological and Geochemical Research, MTA Research Centre for Astronomy and Earth Sciences, Budapest, Hungary*
[3]*Department of Biology & CESAM–Research Center Environmental and Marine Research, University of Aveiro, Aveiro, Portugal*

**presenting author: nemethalexandra89@gmail.com*

Glycymeris species have a known potential in reconstructing past seawater temperatures as several studies have reported that shell aragonite is precipitated in isotopic equilibrium with the ambient seawater and most of the seasonal oxygen isotope signature is recorded in the shell carbonate. The extent of the seasonality these shells can record, however, is still discussed and most studies focused on collection sites in the Adriatic and the northern temperate regions of the North-Atlantic.

The aim of this study was to investigate the driving factors for shell growth in *Glycymeris* bivalves by analysing the growth patterns and stable oxygen- and carbon-isotope composition of *Glycymeris glycymeris* shells collected from the Atlantic coast of the Iberian Peninsula. Subsets of the Aveiro (n=10) samples could be arranged into a robust site chronology covering the 1991-2001 period and were used to explore shell growth responses to environmental parameters. The chronology displayed a positive correlation ($r=0.82$, $p < 0.05$) with the regional January-March sea surface temperature (SST). The results suggest that at this collection site, lower winter SST was a directly limiting environmental variable. Comparing sub-annually resolved oxygen isotope ratios from three specimens with overlapping lifespans (1984-1993) to satellite-derived temperature data proved that summer seawater temperature maxima were recorded within the shell carbonate, whereas annual minima are not reflected.

Session: Proxy Development: Challenges and Opportunities

Temperature seasonality as recorded in shell microstructure of genus *Scapharca* (Mollusca: Bivalvia): new insights into the age determination and paleoenvironmental study

Kozue Nishida[1,2*]

[1]National Institute of Technology, Ibaraki College, Japan
[2]The Japan Society for the Promotion of Science (JSPS), Japan

**presenting author: nishida@gm.ibaraki-ct.ac.jp*

Shell microstructures in Bivalvia have been studied predominantly in relation to taxonomy (Taylor, 1963; Kobayashi, 1971; Carter, 1990; Sato et al., 2013), phylogeny (Taylor et al., 1969, 1973; Shimamoto, 1986], and crystallography (Ubukata, 2000, 2001; Checa et al., 2009, 2013). As shown in these studies, some bivalve species crystallize shells with a single constituent mineral whereas others form a shell composed of both calcite and aragonite (e.g., a calcitic outer prismatic layer and an aragonitic inner nacreous layer in pearl mussels). Moreover, the shell microstructures made by a single individual can differ, depending on the environmental conditions it experiences during biomineralization (Carter, 1980; Nishida et al., 2012).

Cyclical changes in the shell microstructure within a single shell layer have been observed in various taxa of Bivalvia (Nishida et al., 2011). In family Arcidae, both modern and fossil specimens in genera *Scapharca* and *Anadara* showed the changes (Kobayashi and Kamiya, 1968; Kobayashi, 1976a,b; Nishida et al., 2012; Nishida and Sasaki, 2018). I will present my recent studies of the shell microstructure of genus *Scapharca* evaluating the relationship between water temperature and shell microstructural formation by geochemical and culture experimental approaches to contribute to paleoecological and paleoenvironmental studies.

In genus *Scapharca*, the outer shell layer of this species is characterized by composite prismatic structure on the exterior side and crossed lamellar structure on the interior side. By comparing cyclical microstructural changes of *S. broughtonii* with the temperature records calculated by stable oxygen isotopes of the shells of field-collected specimens, the relative thickness of composite prismatic structure is greater at cooler temperatures (Nishida et al., 2012; Nishida and Sasaki, 2018). Moreover, Nishida et al. (2015) revealed the thermal dependency on shell microstructural formation by a rigorous culture experiment at the five different temperature treatments, and this result was consistent with the trend observed in field-collected specimens. The temperature seasonality in shell microstructure can be applied to age determination and the characterization of the summer and winter seasons which helps the milling of shells for geochemical analysis as same as a soft X-ray observation.

Session: Proxy Development: Challenges and Opportunities

Life history patterns of modern and fossil *Mercenaria* from the US Mid Atlantic Coastal Plain during cold vs. warm climate conditions

Kylie L. Palmer[1*], Donna Surge[1], David K. Moss[2]

[1]*University of North Carolina-Chapel Hill, Department of Geological Sciences, Chapel Hill, NC, USA*
[2]*Sam Houston State University, Department of Geography & Geology, Huntsville, TX, USA*

**presenting author: kylaine@live.unc.edu*

Given the current trend of global warming, the biological consequences of increasing water temperature on economically and ecologically important bivalves are uncertain. One way to assess such impacts is to evaluate changes in life history across space and time in the context of warm vs. cold climate conditions. This assessment can be accomplished using sclerochronlogy. Today, marine bivalves exhibit a consistent latitudinal pattern in their life history. Bivalves from mid to high latitudes tend to grow slower and have longer lifespans than those from low latitudes. This pattern may be related to environmental conditions, such as water temperature and seasonal availability of nutrients. Growth patterns in shells of the northern and southern hard clams (*Mercenaria mercenaria* and *M. campechiensis*, respectively) are well-documented throughout their geographic range. However, most of this work focuses on modern and archaeological specimens and fossil specimens remain to be investigated. How has the life history of *Mercenaria* changed during climate conditions colder than today? Here, we provide life history data recorded in *Mercenaria* shells from two time intervals (modern and early Pleistocene) at similar latitudes in the US Mid Atlantic Coastal Plain of North Carolina. The differences in lifespan and growth rates between these populations will be assessed using the von Bertalanffy growth equation. We hypothesize that fossil shells from the early Pleistocene Waccamaw Formation (cold climate) will have longer lifespans and slower growth rates compared with modern specimens (warm climate). Future work will examine *Mercenaria* shells across a latitudinal gradient from Florida to Virginia. Results from this study will contribute to our understanding of how this bivalve species may respond to rising seawater temperature projected for the end of the 21st century.

Session: Paleoecology and Evolution

Age determination of the short-finned squid *Illex coindetii* using statolith analysis

Mirela Petrić[1*], Svjetlana Krstulović Šifner[1]

[1]University of Split, Department of Marine Studies, Ruđera Boškovića 37, P.O. Box 190, 21000 Split, Croatia

**presenting author: mpetric@unist.hr*

Statolith analysis is widely used method for investigating age and growth of cephalopods, especially squids. Statoliths are paired calcareous structures mostly composed of aragonite and a small percentage of organic matter, located in cephalopod equilibrium organs called statocysts. Statoliths are result of biomineralization, with dark rings deposited during daylight and light rings during darkness. It is suggested that statolith increments are formed daily, therefore one increment represents one day. A total of 500 *Illex coindetii* individuals, with dorsal mantle length range from 55 to 216 mm, were sampled in the eastern part of the central Adriatic Sea to study statolith microstructure. Statoliths were surgicaly extracted from the cephalic cartilage and stored dry in plastic vials. Before grinding, concave side of statoliths were mounted on microscope slide using thermoplastic resin. Grinding procedure consisted of proper grinding and polishing both sides of statolith, using lapping film sheets with 30,12, 5 and 0,05 µ grades. The total number of increments visible in the statolith microstructure were counted under a light microscope at 200 and 400x magnification, starting from the natal ring in the direction from statolith nucleus to the edge of the dorsal dome. The hatching dates of each squid was back-calculated from date of capture and increments counts. The life span of the Adriatic *Illex coindetii* was estimated at around six months. The youngest male had a total of 52 days (77 mm DML) and youngest female a total of 56 days (82 mm DML). The maximum counted age was 186 days (162 mm DML) for males and 180 days (188 mm DML) for females. No statistically significant difference in statolith increment counts was found between the sexes (p = 0.657), with mean values of 108 days (SD = 22.44) and 109 days (SD = 25.66) for males and females, respectively. The oldest individual was caught in spring and youngest during the summer season. Obtained results indicate the existence of seasonality in squid hatching time in the eastern Adriatic Sea.

Session: Fisheries Ecology and Management

Raman spectroscopy and imaging tools for correlative analyses in otoliths sclerochronology

Simona Cinta Pinzaru[1*], Sanja Matić-Skoko[2], Melita Peharda[2], Dario Vrdoljak[2], Hana Uvanović[2], Calin Firta[1,3], Geza Lazar[1], Fran Nekvapil[1,3], Lucian Barbu-Tudoran[1,3], Maria Suciu[1,3], Branko Glamuzina[4]

[1]*Babes Bolyai University, Kogalniceanu 1, RO-400084 Cluj-Napoca, Romania*
[2]*Institute of Oceanography and Fisheries, Šetalište I. Meštrovića 63, 21000 Split, Croatia*
[3]*National Institute for Research and Development of Isotopic and Molecular Technologies, 67-103 Donat, Ro-400293 Cluj-Napoca , Romania*
[4]*University of Dubrovnik, Department for Aquaculture, Ćira Carića 4, 20000 Dubrovnik, Croatia*

**presenting author: simona.cinta@phys.ubbcluj.ro*

Although tracking the otoliths development as veritable life history capsule for sclerochronology studies appeared increasingly attractive in the past decade [1], the complexity and variability in otoliths biomineral formation in various species is far from being understood. Few studies employed Raman micro-spectroscopy for getting insight into the organic-inorganic fractions and their spatial distribution in otoliths for several fish species. Significant reported drawbacks regarding the otoliths sampling protocol, particularly resins fixation, which can interfere with the original organic matter Raman signal, as well as high variability within individual biomaterial, poor understanding of biomineralization characteristics for various environmental conditions, or lack of correlative data via scanning electron microscopy and energy dispersive X-ray (EDX) spectroscopy, place the sclerochronology approach yet in early stage.

Here we present comprehensive Raman micro-spectroscopy and imaging data combined with SEM-EDX line tracking to correlate non-destructively the chemical composition and its high resolution spatial distribution in aragonite otoliths harvested from *S. aurata* in four regions from Adriatic Sea. Line scan single point Raman spectra have been recorded using a Renishaw InVia Reflex Raman system and a DPSS laser emitting at 532 nm for excitation. Spectra were collected either in short mode, employing just 1 s exposure time, sufficient for inorganic fraction signal, or in extended mode, in the 100-3200 cm^{-1} range, using 10 s exposure, to complementary assess the organic fraction Raman characteristics attributed to proteins and amino acids. Different collecting optics has been employed to assess the influence of the native anisotropy of otoliths on the Raman signal and imaging data. We show how daily rings are developed with sub-micrometer spatial resolution and further use the information with controlled scan step of the whole sagittal otolith sections. Meaningful common structural characteristics assigned for various otoliths groups as well as variability within individuals are discussed based on the correlated Raman, SEM and EDX data and prospect their linkage with the existing environmental parameters.

1. Beierlein, L., G. Nehrke, and T. Brey (2015), Confocal Raman microscopy in sclerochronology: A powerful tool to visualize environmental information in recent and fossil biogenic archives, Geochem. Geophys. Geosyst., 16, 325– 335, doi:10.1002/2014GC005547.

Session: Biomineralization

Mediterranean limpets and Mg/Ca ratios - using LIBS to screen for SST changes and physiological effects

Niklas Hausmann[1,2*], **Amy Prendergast[3]**, Demetrios Anglos[1,4]

[1]*Institute of Electronic Structure and Laser, Foundation for Research and Technology - Hellas, Heraklion, Greece*
[2]*BioArCh, University of York, York, UK*
[3]*School of Geography, University of Melbourne, Australia*
[4]*Department of Chemistry, University of Crete, Heraklion, Greece*

**presenting author: niklas@palaeo.eu*

Elemental analysis of biogeochemical archives is an established technique used to study climate in a range of applications, including ocean circulation, glacial/interglacial climates, and anthropogenic climate change.

Data from mollusc archives are especially important because of their global abundance and sub-annual resolution. Despite this potential, they are underrepresented among palaeoclimate studies, due to enigmatic physiological influences skewing the elemental record. Understanding the patterns behind these influences will improve data interpretation and lead to the development of new climate proxies.

Here, we apply extensive mapping of multiple mollusc specimens using the rapid method of Laser Induced Breakdown Spectroscopy (LIBS) across a wider region to compare and resolve enigmatic patterns within the elemental record caused by physiological influences.

2D elemental (Mg/Ca) maps of whole limpet shells (*Patella caerulea*) from across the Mediterranean revealed patterns of variability within individual mollusc records as well as within isochronous parts of specimens. By registering and quantifying these patterns, we established previously uninterpretable correlations with sea surface temperature (SST): R^2>0.8.

We additionally found that the resulting SST equations were specimen specific and would require additional calibration using other methods (i.e. $\delta^{18}O$). We thus present a combined approach of fast and cheap LIBS screening and subsequent isotopic analysis of seasonal minima and maxima only.

This approach thus presents the means to assess annual temperature ranges using oxygen isotope analysis requiring only 2 samples per shell and season of capture, important for archaeological studies, entirely without oxygen isotope analysis.

Session: Proxy Development: Challenges and Opportunities

Pipi shells: a new high-resolution palaeoenvironmental archive for south-eastern Australia

Amy Prendergast[1*], Vincent Chea[1], Michael Godfrey[1]

[1]School of Geography, University of Melbourne, Australia

**presenting author: amy.prendergast@unimelb.edu.au*

Oxygen isotope ratios from marine mollusc shells have been widely used to reconstruct sea surface temperature (SST) and seasonal shellfish foraging records from archaeological sites worldwide. However, the application of this technique to the Australian archaeological record has so far been limited to a few sites. Pipi shells (*Donax deltoides*) are common components of many archaeological sites in south-eastern Australia. One pioneering study in the 1980s (Godfrey 1988) employed oxygen isotope analyses of pipi shells to study the Holocene archaeological record of Discovery Bay in Victoria. However, this study was constrained by the technology and techniques of the time. Recent advances in mollusc shell growth increment analysis (sclerochronology) and high-resolution geochemical sampling as well as improvements in mass spectrometry technology have enabled the reconstruction of sub-monthly sea surface temperature records from intertidal mollusc shells, thus enabling more robust and reliable reconstructions. In light of these recent advances, we reassess the utility of *Donax deltoids* shells as archives for SST and seasonality information in south-eastern Australia.

To validate whether this species is a faithful year-round palaeoenvironmental recorder, we collected live *D. deltoids* from Discovery Bay, Victoria each month for a year. We analysed the intra-annual variability of $\delta^{18}O$ in modern live-collected shells and sea water and compared $\delta^{18}O$-derived SST reconstructions with instrumental SST records. Shell-derived SSTs were highly correlated with instrumental SST records over the period of collection. This suggests that these shells are reliable palaeothermometers. This study demonstrates the utility of applying advanced sclerochronological techniques to Australian shell middens and shows that pipi shells hold great potential for reconstructing monthly-resolved SST records and seasonal foraging practices in south-eastern Australia.

Session: Sclerochronology and Human-Environmental Interactions: Past and Present

Exploring the potential of Arctic coralline algae as a paleosalinity proxy

Lina M. Rasmusson[1*], Jochen Halfar[2], Jason M. Hall-Spencer[3], Hans W. Linderholm[1]

[1]Regional Climate Group, Department of Earth Sciences, University of Gothenburg, SE-40530 Gothenburg, Sweden
[2]Department of Chemical and Physical Sciences, University of Toronto at Mississauga, L5L 1C6 Mississauga, Canada
[3]Marine Biology and Ecology Research Centre, School of Marine Science and Engineering, Plymouth University, PL48AA Plymouth, UK

**presenting author: lina.rasmusson@gu.se*

As Arctic glaciers and ice sheets are melting rapidly, ocean salinity is declining. Salinity determines water density and strongly influences the strength and direction of currents and ocean circulation. It thus has great impacts on regional and global climate as it drives the transport of heat and energy. Establishing if salinity shifts are occurring naturally or if we are facing extreme events can help us predict the future impact of lowered salinity on climate patterns and ecosystems. As existing salinity reconstructions of Arctic waters are few, short and of low temporal resolution, new reliable salinity proxies are needed. For instance, the Intergovernmental Panel on Climate Change (IPCC) reported on the lack of such proxies in their report on the impacts of climate change on the oceans. A promising way to go for this purpose is Rhodochronology, the methodology examining how calcifying red algae, also referred to as coralline algae, are capturing environmental fluctuations within their annually banded structures. By analysing the trace element- and isotopic composition in the growth layers of these algae, it might be possible to trace salinity variability hundreds of years back in time. *Clathromorphum compactum*, the species of interest in this project, has a geographic distribution throughout the high Arctic, where most other organisms suitable for sclerochronological surveys are absent. Algae have and will be collected around the coastlines of Svalbard and Greenland; samples will be collected along a natural salinity gradient in a fjord system in Greenland summer 2019. The trace elements Ca, Mg, Ba, Mn, Li, Na and Sr will be determined using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) and the levels of $\delta^{18}O$ using mass spectrometry with the aim to investigate how the signal changes in accordance to salinity. All these elements have given slight indications, but not yet proven, salinity related responses in other organisms. Moreover, *C. compactum*will be kept in a laboratory set-up consisting of aquaria with different salinities in order to detect the incorporation of the elements and $\delta^{18}O$ in controlled salinity settings. This project focuses on calibrating and evaluating the use of this method for making salinity reconstructions, hence validating the huge potential calcareous algae have as a historical salinity archive. The reconstructions will provide highly needed data and serve as a framework for future climate modelling, useful for researchers and policymakers when assessing salinity related effects of climate change in the marine environment.

Session: Proxy Development: Challenges and Opportunities

Coral calcification and sclerochronology during the Middle Miocene Climate Transition

Markus Reuter[1*], Philipp Spreter[1], Regina Mertz-Kraus[2], Thomas C. Brachert[1]

[1]Institute of Geophysics and Geology, University of Leipzig, Talstraße 35, 04103 Leipzig, Germany
[2]Institute for Geosciences, Johannes Gutenberg-University Mainz, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany

**presenting author: markus.reuter@uni-leipzig.de*

The rise of atmospheric pCO_2 due to anthropogenic burning of fossil fuels is unprecedented in the last 300 million years (Ma). In addition to ocean warming, rising pCO_2 causes ocean acidification, which endangers calcification in many marine calcareous biota such as reef corals. Nevertheless, coral reefs were more widespread-than-present during periods with high pCO_2 in the geological past, because pCO_2 changes were likely slow allowing the oceanic carbonate system to maintain high saturation with calcium carbonate. For testing model predictions on the long-term carbonate buffering capacity of the oceans coral calcification data from such periods are mandatory, but detailed coral calcification records from deep geological time are still lacking because the porous aragonitic skeletons of scleractinian corals, as a general rule, quickly undergo biological and diagenetic degradation. Here we present high resolution (0.1 mm sampling distance) stable isotope ($\delta^{18}O$, $\delta^{13}C$) and calcification (skeletal density and extension) data from two fossil *Porites*corals of late Langhian – early Serravllian age (ca 14 – 13 Ma) that were discovered at Pötzleinsdorf and Drasenhofen in the Vienna Basin (Austria). According to careful screening procedures (SEM, XRD, X-radiography), the corals under study are in a rather pristine state of preservation retaining their original skeletal aragonite, pore space and microstructural details. This exceptional state of preservation makes them the oldest scleractinian corals known so far suited for combined stable isotope sclerochronology and radiodensitometry. The corals investigated represent the Middle Miocene Climate Transition (MMCT), a phase of major global cooling at ca 15 – 13 Ma following the Middle Miocene Climatic Optimum (MMCO), which was the warmest episode of the Neogene. Climate models assume atmospheric CO_2 concentrations of 400 ppmv during the MMCO, which decreased to 200 ppmv at the end of the MMCT. The sclerochronological records presented by us offer a rare opportunity to study the responses of reef coral calcification during this time of global pCO_2 and climatic turnover.

Session: Climate and Oceans: Past, Present and Future

Do scales and otoliths tell the same shad story?

Elodie Réveillac[1*], Jean-Luc Baglinière[2], Elise Sola[3], Emilien Lasne[2], Anthony Acou[4], Christophe Pécheyran[3], Eric Feunteun[5]

[1]Agrocampus Ouest, UMR 0985 ESE Agrocampus Ouest-INRA, 65 rue de St Brieuc 35000 Rennes, France
[2]INRA, UMR 0985 ESE Agrocampus Ouest-INRA, 65 rue de St Brieuc 35000 Rennes, France
[3]MNHN, UMR BOREA 7208 MNHN-CNRS-Sorbonne Université-IRD 207-UCN-UA, CRESCO Station marine de Dinard, 38 rue du Port Blanc, 35800 Dinard, France
[4]AFB, UMS Patrinat AFB-MNHN-CNRS, CP41, 36 rue Geoffroy Saint-14 Hilaire, 75005 Paris, France
[5]IPREM/LCABIE UPPA-CNRS, 2 avenue Angot, Hélioparc Pau Pyrénées, 64053 Pau cedex 9, France

**presenting author: elodie.reveillac@agrocampus-ouest.fr*

Do fish scales and otoliths tell the same story regarding the events marking out the life history? Anadromous Twaite *(Alosa fallax*) and Allis *(Alosa alosa*) shads are good examples to answer this question. These species undergo successive migrations at different periods of their life cycle into very contrasted environments. Spawning and juvenile growth occur in freshwater and juveniles stay some months at sea before migrating sea back to freshwater. Allis shad is generally considered as a semelparous species while Twaite shad is a multi-spawner species. Then, during their life cycle, physiological, morphological and environmental changes are recorded in hard structures as scales and otoliths.

In anadromous fish, life history traits are often described using scales reading. This non-lethal method is commonly used to estimate traits such as the growth, total age and age at reproduction and number of spawning events. Particularly during pre- and spawning events there is a remobilization of calcium carbonate stored in scales because they ensure a source of minerals used during sexual maturation. This results in a resorption process in the scale, in an erosion phenomenon of the edge and the formation of a spawning mark if the fish survives.

In shads, otoliths are less commonly used to estimate life traits history than scales. Otolith inert structure is considered unaltered by internal physiological nor biochemical processes once formed (crystallized). Otolith structure is only modulated by ongoing processes (decreasing or increasing growth, metamorphosis etc...). Likewise, the chemical composition of otoliths is modified along all the life cycle by migrations in environments of different chemical composition like the sea and freshwater where both shad species spawn.

Taking into account these findings, shad spawning events are assumed to be printed in scales structure and in otoliths chemical composition. Allis shad is hypothesized to exhibit only one ultimate spawning record whereas the Twaite shad may show several ones.

Our study analyzes the match or mis-match between scale structure and otolith chemical composition in recording spawning events in Allis and Twaite shads. Results should provide guidelines for using hard structures as proxy of fish life history events.

Session: Proxy Development: Challenges and Opportunities

An integrated carbon and oxygen isotope approach to reconstructing past environmental variability in the northeast Atlantic Ocean

David Reynolds[1*], Ian Hall[2], Sophie Slater[2]

[1]Laboratory of Tree Ring Research, University of Arizona, Bryant Bannister Tree Ring Building, 1215 E Lowell St, Tucson, AZ, 85721, USA
[2]School of Earth and Ocean Science, Cardiff University, Main Building, Park Place, Cardiff, CG10 3AT, UK

**presenting author: davidreynolds@email.arizona.edu*

The combined influence of temperature and the isotopic composition of the seawater [$d^{18}O_w$] often precludes the use of oxygen isotope ($d^{18}O$) records, derived from marine carbonates, to reconstruct absolute seawater temperatures, without the application of an independent $d^{18}O_w$ proxy. Here we investigate the application of carbon isotope records ($d^{13}C_{shell}$), derived from the long-lived marine bivalve *Glycymeris glycymeris*, as a proxy for $d^{18}O_w$ variability. Our analyses indicate *G. glycymeris* $d^{13}C_{shell}$data derived from growth increments >20 years of age contain strong ontogenetic trends (-0.013‰ yr^{-1}, R^2=0.97). These analyses demonstrate that, coupled with the ontogenetic trends, 54% of the variability in *G. glycymeris* $d^{13}C_{shell}$ records can be explained by a combination of the marine Suess effect, physical (salinity and riverine input) and biological processes (primary production). The application of these $d^{13}C_{shell}$ data in conjunction with co-registered $d^{18}Os_{hell}$ and growth increment width series, each of which have been shown to be sensitive to seawater temperature and primary productivity respectively, can therefore provide new insights into past environmental variability and help constrain uncertainties in reconstructions of past seawater temperature variability.

Session: Proxy Development: Challenges and Opportunities

Stylasterids: a new paleoceanographic archive?

Ana Samperiz[1,2*], Laura Robinson[2], Melanie Leng[3], Nadia Santodomingo[4], Brad Rosenheim[5], Katharine Hendry[2], Veerle Huvenne[6]

[1]*School of Earth and Ocean Sciences School, Cardiff University,Cardiff, UK*
[2]*School of Earth Sciences, University of Bristol, Bristol, UK*
[3]*NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, UK*
[4]*Natural History Museum, London, UK*
[5]*College of Marine Science, University of South Florida, Florida,USA*
[6]*National Oceanography Centre, Southampton, UK*

**presenting author: samperizvizcainoa@cardiff.ac.uk*

Stylasterids are a commonly found deep-sea coral taxon that build their skeletons from either calcite or aragonite (or both). Their potential as paleoceanographic archives remains unexplored and robust geochemical proxy data collected from modern specimens is very limited. Ninety-three stylasterids were selected from locations including the Southern Ocean, Equatorial Atlantic, North Atlantic and Galápagos Islands spanning a range of depths from 63 to 2894 m and temperatures from 0 to 17°C. Samples were identified up to species level when possible. They included 20 species belonging to 7 genera. These were *Adelopora* sp*., Cheiloporidion* sp*., Conopora* sp., *Errina* sp*., Errinopsis* sp*., Inferiolabiata* sp*.* and *Stylaster* sp*.* Fifty-six specimens were analysed for skeletal mineralogy. Sixteen samples were calcitic, and 40 were aragonitic. Oxygen and carbon ($\delta^{18}O$ and $\delta^{13}C$) isotopic composition was measured in all the specimens. Five specimens were sub-sampled in the main trunk, secondary branches and growing tips. All data were below equilibrium, with the tips of the colonies having the lightest values, and the trunk being the heaviest. The $\delta^{18}O$ and $\delta^{13}C$ range within a single specimen is lower compared to published values in deep-sea scleractinian corals. All the specimens were subsampled in the main trunk. Their $\delta^{18}O$ and $\delta^{13}C$ was measured and compared to local hydrographic data to gain insight into calcification mechanisms and test their use as paleotemperature archives. Different isotopic values were found between aragonitic and calcitic samples. Calcitic corals showed less depleted values from equilibrium for $\delta^{18}O$ but a higher depletion for $\delta^{13}C$. The data indicate that environmental temperature is recorded in the skeletal chemistry of stylasterid corals. A global $\delta^{18}O$:temperature calibration for aragonitic stylasterids was produced. This calibration showed a mean depletion of 0.97‰ from equilibrium. This work highlights the potential application of stylasterid coral $\delta^{18}O$ data to reconstruct ancient seawater temperature.

Session: Proxy Development: Challenges and Opportunities

High resolution analysis of bivalve shell by NanoSIMS

Yuji Sano[1*], Kotaro Shirai[1], Naoto Takahata[1], Akizumi Ishida[2]

[1]*Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Chiba 277-8564, Japan*
[2]*Institute for Excellence in Higher Education, Tohoku University, Aobaku, Sendai 980-8576, Japan*

**presenting author: ysano@aori.u-tokyo.ac.jp*

We developed a method to measure Mg/Ca, Sr/Ca and Ba/Ca ratios of natural carbonates with supper-fine structure using high lateral resolution secondary ion mass spectrometer, NanoSIMS [1]. This method was successfully applied into geochemical analysis of foraminifera test [2] and coral skeleton [3]. Previous high resolution analysis of cultivated giant clam shell with 2 micro-meter spot [4] showed a diurnal variation in the Sr/Ca ratio, which may reflect the daily light cycle. Based on the calibration between the insolation and Sr/Ca ratios, we reconstructed solar radiation of Middle Holocene using a fossil giant clam shell [5]. In order to apply state-of-the-art analytical method to other bivalve shell, we measured Mg/Ca, Sr/Ca and Ba/Ca ratios of a Mediterranean mussel (*Mytilus galloprovincialis*) collected at the Otsuchi bay, on the Pacific coast of northeastern Japan. This bivalve was living at intertidal zone and colletected on September 6th 2011, that may have suffered by a great tsunami induced by the 2011 magnitude 9.0 Tohoku earthquake on March 11th. Soft tissues were removed from mussel and the shell was cut along the maximum growth axis and mounted in Araldite disk together with a carbonate standard. This species is known to form a growth line with organic matter daily or bidaily at the air exposure time, which may facilitate age-model with tidal record by counting the etched-stained lines. After polishing and gold coated, we analyzed trace elements of the shell by low resolution (10-micro-meter spot at 100-micro-meter interval) and high resolution (2-micro-meter spot at 3-micro-meter interval) using NanoSIMS installed at The University of Tokyo. Annual variations of Mg/Ca ratios, high in winter and low in summer, are clearly visible at low resolution, smilar to those of caltivated giant clam shell [4]. Mg/Ca ratios of the inner edge, corresponding to most recent date (September 2011) together with data of December 2010 estimated by the age-model, show daily or bidaily cyclic changes at high resolution. High Mg/Ca ratios are probably derived from the time of air exposure at low tide when the Ca transportation is blocked. Ref: [1] Sano et al. *Anal. Sci.* 21, 1091, 2005. [2] Kunioka et al. *G-Cubed* 7, Q12P20, 2006. [3] Shirai et al. *Geochim. Cosmochim. Acta* 72, 5386, 2008. [4] Sano et al. *Nature Commu.* 3, 761, 2012. [5] Hori et al. *Scientific Reports*, 5, 8734, 2015.

Session: Proxy Development: Challenges and Opportunities

8.2 ka event North Sea hydrography determined by bivalve shell stable isotope geochemistry

Juan Estrella-Martínez[1], Philippa Ascough[2], Bernd Schöne[3], Paul Butler[4], **James Scourse[4*]**

[1]School of Ocean Sciences, Bangor University, Askew St., Menai Bridge LL59 5AB, UK
[2]NERC Radiocarbon Facility, Scottish Universities Environmental Research Centre, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, G75 0QF, UK
[3]Institute of Geosciences, Johannes Guttenberg University, J.-J.-Becher-Weg 21, D-55128, Mainz, Germany
[4]Centre for Geography and Environmental Sciences, University of Exeter, Penryn, Cornwall, TR10 9EZ, UK

**presenting author: j.scourse@exeter.ac.uk*

The abrupt 8.2 ka cold event has been widely described from Greenland and North Atlantic records as a response to a perturbation in the Atlantic Meridional Overturning Circulation arising from freshwater outburst from the terminal Laurentide Ice Sheet. The expression of this event is poorly documented from the Atlantic shelf seas. We present an annually-resolved temperature and water column stratification reconstruction based on stable isotope geochemistry of *Arctica islandica* shells from the Fladen Ground (northern North Sea) temporally coherent with Greenland ice core records. Our age model is based on a growth increment chronology obtained from four radiometrically-dated shells covering the 8286-8105 cal BP interval. Our results suggest that a sudden sea level rise event (SSLR) recognised in southwest Scotland forced water column stratification between 8320 and 8220 cal BP. Thirty years later, cold conditions associated with the 8.2 ka event inhibited water column stratification but an eventual incursion of sub-Arctic waters into the North Sea re-established density-driven stratification. The water temperatures reached their minimum of ~3.8 °C 55 years after the SSLR. Intermittently-mixed conditions were later established when the sub-Arctic waters receded.

Session: Climate and Oceans: Past, Present and Future

Mussel periostracum as a high-resolution archive of soft tissue $\delta^{15}N$ records in coastal ecosystems

Kotaro Shirai[1*], Kentaro Tanaka[1], Quang Dung Le[2], Naoko Murakami-Sugihara[1], Kaoruko Mizukawa[3], Liqiang Zhao[1]

[1]*Atmosphere and Ocean Research Institute, The University of Tokyo, Japan*
[2]*Institute of Oceanography and Environment, Universiti Malaysia, Terengganu, Malaysia*
[3]*Department of Environmental Science on Biosphere, Tokyo University of Agriculture and Technology, Japan*

**presenting author: kshirai@aori.u-tokyo.ac.jp*

To understand sources of the anthropogenic nitrogen inputs along coast, the development a new and more efficient tool for monitoring is needed. Given filter feeding bivalves are considered as ideal bioindicator for environmental pollution, including nitrogen enrichment, since the isotopic composition in their soft tissues often reflects isotopic composition of POMs in water bodies. Recently we have also demonstrated that the carbon isotopic ratio of mussel periostracum can also be used as a proxy for time series fluctuation of POM isotopic composition. Hence, it is an attempt to test the periostracum of mussel as proxy for nitrogen monitoring in along the coastal waters based on stable isotopic approach.

Mussel samples were quarterly or seasonally collected from coastal areas of Japan in 2015/2016. Seaweed samples (*Ulva* sp.) were also collected when available. Nitrogen isotopic compositions were analyzed by standard methods using IRMS. Nitrogen isotopic composition of muscle and periostracum showed strong correlation, indicating that the composition of periostracum reflects soft tissue composition. Nitrogen isotope ratios of muscle and seaweed showed positive, but weak, correlation. This indicates that the isotopic composition of mussel tissue is affected by isotopic composition of nitrate available for seaweed, through compositional changes in POM containing phytoplankton that also assimilate the nitrate. These results suggested that the mussel periostracum is a useful proxy for elucidating the coastal nitrogen geochemical cycle.

Session: Proxy Development: Challenges and Opportunities

Sclerochronology and ^{14}C dating applied on bivalve *Glycymeris pilosa* from the Adriatic Sea

Andreja Sironić[1*], Krešimir Markulin[2], Slaven Jozić[2], Hana Uvanović[2], Damir Borković[1], Carin Andersson[3], Melita Peharda[2]

[1]*Ruđer Bošković Institute, Bijenička cesta 54, 10 000 Zagreb, Croatia*
[2]*Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21 000 Split, Croatia*
[3]*NORCE Norwegian Research Centre, Bjerknes Centre for Climate Research, Jahnebakken 5, 5007 Bergen, Norway*

**presenting author: asironic@irb.hr*

This study combines radiocarbon analysis and sclerochronology research, an approach that to the best of our knowledge, has not yet been applied using bivalves from the Mediterranean Sea. We analysed shells from the North Adriatic Sea: live- and dead-collected specimens of the infaunal bivalve *Glycymeris pilosa* (Linnaeus, 1767) and two dead-collected specimens of *Glycymeris* sp. According to crossdating results, growth increment time series obtained from acetate peels of the dead-collected *G. pilosa* (S3FP11) indicate the potential for creating longer chronologies from live and dead-collected specimens. Based on the radiocarbon results obtained from a growth increment assigned to AD 1950 in a live-collected shell, the reservoir age (R) and reservoir correction (ΔR) are 264 ± 23 years and -6 ± 32 years, respectively. One of the three sub-fossil shells reflected ^{14}C bomb peak and could be assigned to a time period from AD 1965 to AD 2013. The other two sub-fossil specimens were dated with reservoir age correction calculated as mean from AD 1950 increment growth and ΔR reported by Siani et al. (2000; Radiocarbon 42:271-80) and, by use of Bayesian analysis, were placed in periods from 15th to 17th century (S3F5) and from 17th to 19th century (S3F3). The greatest longevity was seen in the dead-collected *Glycymeris* sp. specimen S3F3, estimated to be ~130 years (started growing AD 1678-1742 and died AD 1826-1860), indicating the potential to extend *Glycymeris* growth increment chronologies to past centuries. The highest $\Delta^{14}C$ values obtained correspond to the calendar year 1974. The ^{14}C record obtained from *G. pilosa* correlates well with the modelled surface ocean (mixed-layer) bomb pulse curve (Reimer et al. 2009; Radiocarbon 51:1111-50) and with model developed for Mediterranean Sea by Ayache et al. (2017; Biogeosciences 14: 1197-213). Research has been conducted in a framework of the project SCOOL (IP-2014-09-5747) supported by the Croatian Science Foundation.

Session: Climate and Oceans: Past, Present and Future

Constraining palaeo-CO_2 reconstructions though B isotopes in marine carbonates using the NU Plasma II MC-ICP-MS

Sophie Slater[1*], Caroline Lear[1]

[1]School of Earth and Ocean Sciences, Cardiff University, UK

**presenting author: SlaterS3@cardiff.ac.uk*

Carbonate organisms are a useful archive for a variety of palaeoclimatic proxies, including the boron isotope ($\delta^{11}B$) proxy for seawater pH. Boron is fractionated into different species in its aqueous state: boric acid and borate ions; the ratio of boric acid to borate in seawater is strongly pH-dependent. Isotopic fraction between the species therefore means that the $\delta^{11}B$ of either dissolved species is a function of both pH and the $\delta^{11}B$ of the total B dissolved in seawater. Because foraminiferal B content is derived from the borate species only, foraminiferal $\delta^{11}B$ is a powerful archive to reconstruct past variations in pH and hence CO_2. However, on geological (several millions of years) timescales, uncertainties in the estimates of the $\delta^{11}B$ of the total B dissolved in seawater limit reconstructions of absolute pH, and hence pCO_2 from foraminiferal $\delta^{11}B$. It is hoped that this uncertainty may be reduced by using other carbonate materials as a boron archive. For example, it has been suggested that biomineralization of some molluscs, brachiopods, and otoliths may occur within a self-regulated fluid with respect to pH. Such biogenic carbonates may be less sensitive to ambient seawater pH, and hence may have potential as recorders of long-term changes in the $\delta^{11}B$ of total B dissolved in seawater.

To date, the vast majority of $\delta^{11}B$ records derived from small biogenic carbonate samples (e.g. foraminifera) have been generated using either thermal ionisation mass spectrometry (TIMS) or Thermo Neptune multi-collector inductively-coupled plasma mass spectrometers (MC-ICP-MS). Cardiff University's CELTIC Laboratory recently installed a NU Plasma II MC-ICP-MS. Our initial aim was therefore to determine whether this instrument can achieve the required precision and accuracy to enable investigations of a range of biogenic carbonate using the $\delta^{11}B$ proxy. We tested its precision and accuracy using 3 concentrations (100ppb, 50ppb and 10ppb) of the standard SRM NIST951a (boric acid). We used standard-sample bracketing to offset drift during the course of a run. At the target concentration of 50ppb, the ±1SD precision for the standard was 0.10‰ when treated as a sample in triplicate. This is similar to that reported for the Thermo Neptune MC-ICP-MS, and indicates that the NU Plasma II MC-ICP-MS will be capable of exploiting the $\delta^{11}B$ proxy in a range of biogenic carbonates, including molluscs, brachiopods and foraminifera. We also discuss our immediate sampling strategy, which includes a combination of culture study, modern, and fossil material.

Session: Proxy Development: Challenges and Opportunities

Variation of carbon isotopic composition in otoliths of Northeast Arctic cod (*Gadus morhua*)

Szymon Smoliński[1*], Côme Denechaud[1,2], Gotje von Leesen[3], Jane A Godiksen[1], Audrey J. Geffen[1,2], Peter Grønkjær[4]

[1]*Institute of Marine Research, Bergen, Norway*
[2]*Department of Biology, University of Bergen, Norway*
[3]*Faculty of Life and Environmental Sciences, University of Iceland, Reykjavik, Iceland*
[4]*Aquatic Biology, Department of Bioscience, Aarhus University, Denmark*

**presenting author: szymon.smolinski@hi.no*

The isotopic composition of carbon in otoliths of fish may be a useful tracer of metabolic rates and help to reconstruct the marine food web structure in the past. However, proper interpretation of isotopic fluctuations requires understanding of their physiological and environmental drivers. The aims of this work will be to evaluate different sources of variations in the carbon isotopic signals of Northeast Arctic cod (*Gadus morhua*) otoliths, including environmental (e.g. temperature) or physiological controls (e.g. changes of growth rate of individual fish), and to investigate their long-term temporal variability. Multidecadal archival collection of otoliths from fish sampled in the Lofoten area (Norway), which constitutes the main spawning site of this stock, will be used in the study. For $\delta^{13}C$ analysis of otolith aragonite, individual annual growth increments from immature and mature stages will be micromilled and measured by isotope-ratio mass spectrometry. Simultaneously, all annual ring increments of the otoliths will be measured as a proxy of fish somatic growth. Series of mixed-models will be developed in order to analyse different intrinsic and extrinsic sources of variation in carbon isotopes and fish growth. This statistical technique can also help to explore relationships between composition of carbon isotopes and growth changes during a lifetime of an individual fish estimated with biochronology. Synchronous fluctuations in the isotopic composition over time will be further explored considering information on the isotopic composition of potential prey in the feeding area (the Barents Sea), data on dissolved inorganic carbon and other physical properties of water masses. Otolith carbon isotopic analysis has the potential to provide a direct link revealing how environmental conditions are affecting cod metabolic activity. Identification of these responses to the changing environment can support sustainable management of the Northeast Arctic cod, which constitutes the largest cod stock in the world.

Session: Growth, Bioenergetics and Ecosystems

Otolith shape variations between artificially stocked and autochthonous pikeperch (*Sander lucioperca*)

Allan T. Souza[1*], Katerina Soukalová[1], Vilém Děd[1], Jan Kubečka[1]

[1]Institute of Hydrobiology, Biology Centre of the Czech Academy of Sciences, Na Sádkách 7, 370 05 České Budějovice, Czech Republic

**presenting author: allan.souza@hbu.cas.cz*

Fish stocking (i.e. introduction of allochthonous individuals into the ecosystem) is one of the most widespread and frequent management strategy adopted by stakeholders in freshwater systems, which usually spend relatively large part of their budget in this activity. However, the contribution of stocked fish to the population is seldom investigated, and hence the effectiveness of this strategy is virtually unknown for many populations. Understanding the contribution of stocked fish into the population is crucial because it allows the estimation of survival and growth rates and the contribution of stocked fishes to the population. The differentiation between stock and non-stocked fish can be done using different techniques, which include fin clipping, otolith staining and micro wire tags, but the results are not always satisfactory, often leading to a decreased survival rate of marked fish, biasing the stock assessment. Otoliths are conservative structures in which their shape often vary according to several ecological and environmental factors, thus serving as an excellent tool for ecologists and fishery scientists. To evaluate the shape differences on sagittal otoliths of stocked and autochthonous fish, 40 sagittal otoliths of stocked pikeperch (*Sander lucioperca*) and 40 sagittal otoliths originating from a rearing facility were compared using 4 shape indexes (circularity, ellipticity, roundness, rectangularity). Results indicated slight differences among stocked and non-stocked fish suggesting that this technique can be used to discriminate the natal origin of fish in a much faster and cheaper way than commonly used techniques.

Session: Fisheries Ecology and Management

EDX in Bouligand pattern sclerochronology

Maria Suciu[1,2*], Lucian Barbu-Tudoran[1,2], Fran Nekvapil[1,2], Simona Cinta Pinzaru[2], Branko Glamuzina[3]

[1]*National Institute for Research and Development of Isotopic and Molecular Technologies, 67-103 Donat, Ro-400293 Cluj-Napoca, Romania*
[2]*Babes-Bolyai University, Kogalniceanu 1, RO-400084 Cluj-Napoca, Romania*
[3]*University of Dubrovnik, Department for Aquaculture, Ćira Carića 4, 20000, Dubrovnik, Croatia*

**presenting author: maria.suciu5@gmail.com*

Elemental composition of natural biomaterials is determined by the genetic inheritance of individuals and by the physical-chemical characteristics of the inhabiting environment and/or its stressful changes. To track such changes, we describe here advances in Energy-dispersive X-ray spectroscopy (EDX) analysis of crustacean skeletons which are crucial for correct correlation of the chemical composition, morphology and biological functions. The crustacean wildlife is famously renown and admired for the species colours and their shell structure and arrangement. Line scan EDX combines scanning electron microscopy imaging with cross-section elemental spectroscopy technique. Through these combined methods we analyzed the elemental minute differences in the growth of the exoskeletons and infer from that, meaningful seasonal environmental influences on the crustacean development. Comparative EDX datacollected from *C. sapidus*, one invasive [1] crab species in Mediterranean area, as well as from *C. aestuarii* green crab cuticles revealed that the generally known "universal" Bouligand pattern in crustacean skeletons showed completely distinct elemental composition. *C. sapidus* revealed the lowest Ca level in epicuticle, further increasing in exocuticle and showing an unusually high amount (up to 71.6 wt%) in endocuticle. Lowest C, O and Mg level in endocuticle and highest P content in exocuticle completely differentiate the elemental pattern in blue compared to green crab cuticle. Such feature, could suggest distinct protective role of endocuticle as the first mineralized load-bearing layer after crab molting. In line scan of elemental composition, EDX data constantly showed higher content of C associated to corresponding lower content of Ca, Mg and P, particularly in epicuticle, which mostly contains amorphous minerals and waxy lipoproteins. The present data infirm the previous report [2] on the presence of Br or Sr in blue shell and their influence in *C. sapidus* coloration as well as their incorporation in cuticle from heavy metals polluted water of their Adriatic environment.

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Session: Biomineralization

Assessing seasonality and life history of Baltic Sea *Astarte borealis* (Bivalvia) using oxygen isotope ratios measured by high-precision SIMS

Donna Surge[1*], David K. Moss[2], Ian J. Orland[3], Michael L. Zettler[4]

[1]*University of North Carolina-Chapel Hill, Department of Geological Sciences, Chapel Hill, NC, USA*
[2]*Sam Houston State University, Department of Geography & Geology, Huntsville, TX, USA*
[3]*University of Wisconsin-Madison, Department of Geoscience, Madison, WI, USA*
[4]*Leibniz-Institute for Baltic Sea Research, Rostock, Germany*

**presenting author: donna64@unc.edu*

The bivalve *Astarte borealis* (Schumacher, 1817) is an important component of the biomass in arctic-boreal seas and oceans and has a relatively long lifespan, living for several decades. Therefore, it is potentially a useful recorder of environmental information. Our recent sclerochronologic studies of this relatively small bivalve species in the Baltic Sea have found some populations exhibiting easily identifiable annual growth increments, while annual increments in other populations are less clear. This morphological difference in shell growth records is likely related to local environmental conditions. Because of their small size and narrow or complex growth increments, micromilling of *A. borealis* shells from the Baltic Sea was not possible. Here, we present a high-resolution submonthly resolved record of oxygen isotope variability from one Baltic Sea *A. borealis* shell using secondary ion mass spectrometry (SIMS; WiscSIMS lab at UW-Madison). We report oxygen isotope ratios from 307 spots (10 mm diameter) in a transect that follows growth direction. Along this transect, variation of oxygen isotope ratios is quasi-sinusoidal and reflects an estimated 17+ years of growth (shell height = 12.5 mm). The average range of of oxygen isotope ratios is 2.4‰ (VPDB; max = −3.24±0.43‰, n = 18; min = −5.62±0.29‰, n = 17), suggesting a seasonal temperature variation of ~11°C. This seasonal range is similar to the average range of bottom water temperature measured at a nearby site (~10°C). Note, however, that the oxygen isotope ratio of water cannot be well constrained or assumed to be constant to precisely calculate temperature using the oxygen isotope ratio of shell carbonate. Our interpretation of of oxygen isotope time series shows that annual growth checks occur during winter. Comparison with water monitoring data will allow us to better understand the life history and environmental/ecological records contained in this new bio-archive.

Session: Growth, Bioenergetics and Ecosystems

Microscale magnesium distribution in shell of *Mytilus galloprovincialis*: An example of multiple factors controlling Mg/Ca in biogenic calcite

Kentaro Tanaka[1*], Nobuyuki Okaniwa[2], Tsuzumi Miyaji[3], Naoko Murakami-Sugihara[1], Liqiang Zhao[1], Kazushige Tanabe[4], Bernd R. Schöne[5], Kotaro Shirai[1]

[1]*Atmosphere and Ocean Research Institute, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa-shi, Chiba, 277-0882, Japan*
[2]*Rural Environment Division, Rural Policy Department, Rural Development Bureau, Ministry of Agriculture, Forestry and Fisheries, 1-2-1 Kasumigaseki, Chiyoda-ku, Tokyo, 100-8950, Japan*
[3]*National Ainu Museum, 2-3-4 Wakakusa-cho Shiraoi-cho, Hokkaido, 059-0902, Japan*
[4]*University Museum, The University of Tokyo, 7-3-1 Hongo, Tokyo 113-0033, Japan*
[5]*Institute of Geosciences, University of Mainz, Johann-Joachim-Becher-Weg 21 55128 Mainz, Germany*

**presenting author: kentaro.tanaka@aori.u-tokyo.ac.jp*

Since magnesium concentration in biogenic calcite is considered to reflect water temperature during precipitation, the magnesium-to-calcium ratio (Mg/Ca) has been examined as a proxy for water temperature in paleoclimate research, although factors other than temperature may also influence Mg/Ca in biogenic calcite, thereby introducing a potential bias in the relationship between Mg/Ca and temperature observed in inorganic systems. To better understand factors controlling Mg incorporation into the calcitic shells of bivalves, the distribution of Mg in the Mediterranean mussel *Mytilus galloprovincialis* was studied, being compared with ambient sea surface temperature (SST), shell growth rate and the distribution of organic matter. Although a positive relationship between Mg/Ca and SST was observed, Mg/Ca had been influenced by additional factors such as organic-bound Mg. In fact, organic-rich growth lines contained more Mg than the adjacent growth increments. Furthermore, Mg/Ca was relatively enriched in the undulated shell portions, i.e. those with higher curvature. Variations of shell Mg/Ca ratios could neither be solely explained by SST, growth rate or organic matter. We hypothesize that zoning of Mg^{2+}/Ca^{2+} within the extrapallial fluid at the time of formation of the undulated shell portion may have occurred, and the heterogeneous Mg distribution in contemporaneously formed shell portions thus limits the usability of Mg/Ca in shells of *Mytilus* sp. as a proxy for water temperature.

Session: Proxy Development: Challenges and Opportunities

Highly synchronous shell growth records in *Laternula elliptica* from Adelie Land (East Antarctica)

Julien Thébault[1*], Hana Uvanović[2], Laurent Chauvaud[1], Erwan Amice[1], Melita Peharda[2]

[1]*Université de Brest – CNRS, 29280 Plouzané, France*
[2]*Institute of Oceanography and Fisheries, 21000 Split, Croatia*

**presenting author: julien.thebault@univ-brest.fr*

The scientific community recognizes that global change is affecting all the Earth's ecosystems. Polar settings are among those that will be most impacted because they are very sensitive to small increases in the annual mean temperature. Whereas there are strong lines of evidence that the Arctic is warming much faster than any other biome worldwide, the situation is more complex for the Antarctic. The Peninsula and Western Antarctica are warming at a rate about 10 times faster than the global average but other parts of the White Continent did not experience large temperature changes over the past 50 years. Predicting the future of Antarctica and its sensitive ecosystems in a warming world is still tricky because of the lack of robust environmental data and because scientists do not really well understand the mechanisms underlying snowfall, ice sheet stability, and sea-ice dynamics in these remote areas.

Changes in the phenology of physical and ecological variables associated with climate change are likely to have significant effects on many aspects of the polar benthic ecosystems. Here, we focused on a circum-antarctic bivalve species, *Laternula elliptica*, living up to four decades. The main goal was to assess the potential of these shells as archives of zoobenthic response to environmental variability. Most of informations previouly published on this species were based on specimens from the Antarctic Peninsula and nearby islands, where impacts of climate change are already significant. Conversely, we worked on a population from East Antarctica in order to get a baseline of normal conditions before the effects of global warming become too strong. In January 2016, 29 live specimens were collected at a depth of 21 m close to the French station Dumont d'Urville (Adelie Land). Shells were processed using standard sclerochronological procedures to investigate inter-annual shell growth dynamics. Once detrended, individual shell growth trajectories (standardized growth indices) were highly synchronous, with an alternance of negative and positive anomalies over the period 1998-2015 (EPS > 0.85).

This strongly suggests that a common environmental factor is driving shell growth dynamics. Unfortunately, the lack of long time-series of environmental parameters prevented us to identify this factor. The main feature changing at an inter-annual time-scale is sea-ice dynamics, i.e. timing of freeze-up and break-up, ice thickness, etc. Sea-ice impacts underwater light availability and, therefore, primary production dynamics by phytoplankton, microphytobenthos and ice-algae. This could be the driving force underlying inter-annual variations in SGI shell chronology.

Session: Climate and Oceans: Past, Present and Future

Unlocking the archive: a biochronology repository

Elizabeth Tray[1*], Deirdre Brophy[1], Adam Leadbetter[2], Niall O'Maoileidigh[2]

[1]Marine and Freshwater Research Centre, Galway Mayo Institute of Technology, Galway H91 T8NW, Ireland
[2]Marine Institute, Furnace, Mayo F28 PF65, Ireland

**presenting author: Elizabeth.Tray@gmit.ie*

The aim of the ARCHIVE project is to consolidate existing collections of fish scales, otoliths (ear bones), associated images, and data into a single biochronology repository. Growth marks, genetic material, and chemical constituents of fish scales and otoliths produce data that can be used to reconstruct temporal trends in biological responses of fish populations. These biological time series can be combined with long-term environmental data to develop robust statistical models that predict species-specific population responses to a changing climate.

A common problem associated with biological collections is that while sample intake grows exponentially, long-term storage is rarely a priority. Material is often collected to meet short-term objectives and resources are seldom committed to maintaining and archiving long-term collections. As a consequence, precious samples are frequently stored in many different and unsuitable locations, and may become lost or estranged from associated data.

The Marine Institute, Ireland (MI) holds over 10,000 scales and otoliths from salmon, trout and eel, with some collections dating back to the 1920's. Samples are in different stages of image and data processing. To consolidate these collections a multi-functional Drupal (open-source) database is under development. The database contains two main schemas: (1) an archive fish scale and otolith inventory and (2) a data analysis catalogue for researchers. Work-flows, data entry sheets, and vocabulary lists that match the database will standardize the collection and storage of fish scale and otolith samples. Biological material will be held within a sample repository and accessed according to standard procedures for sample analysis and archive deposition. A public view of the database will feature within the MI's data catalogue, which is developed by the MI's Information Services & Development team. The ultimate aim is to produce Ireland's first repository that is centered around fish sclerochronology samples, paired with a database of individual growth records and scale and otolith images.

Unlocking the archive: using scale and otolith chronologies to resolve climate impacts (the ARCHIVE project) is a collaboration between the Marine and Freshwater Research Centre at the Galway-Mayo Institute of Technology and the Marine Institute in Ireland. The project (Grant-Aid Agreement No. PBA/FS/16/03) is carried out with the support of the Marine Institute and is funded under the Marine Research Programme by the Irish Government.

Session: Fisheries Ecology and Management

Oxygen isotope composition of *Arctica islandica* aragonite in the context of shell architectural organization

Tamara Trofimova[1*], Stefania Milano[2], Carin Andersson[1], Fabian G. W. Bonitz[1], Bernd R. Schöne[3]

[1]NORCE Norwegian Research Centre AS, Bjerknes Centre for Climate Research, Jahnebakken 5, Bergen, Norway
[2]Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Deutscher Platz 6, Leipzig, Germany
[3]University of Mainz, Institute of Geosciences, J.-J.-Becher-Weg 21, Mainz, Germany

**presenting author: tatr@norceresearch.no*

Stable oxygen isotope composition of shell carbonate is one of the most studied and widely applied proxy in bivalve sclerochronology. Stable oxygen isotope values are commonly used to study paleotemperature and paleosalinity changes at high temporal resolution. Yet, the reproducibility of the results and the effect of microstructural organization on the isotopic signature and measurements have not been extensively studied. In this study, we examine the architectural changes within *Arctica islandica* shells, specifically if samples from microstructurally different shell layers typically used to produce paleorecords, differ in respect to stable oxygen isotope values. The oxygen isotope profiles of two microstructurally different shell layers, each sampled at different temporal resolution, were compared to each other. Our results demonstrate that shell aragonite, collected from an inner portion of the outer shell layer (crossed-acicular/lamellar microstructures), tends to be enriched in heavier oxygen isotopes compared to samples from the outer portions (homogeneous microstructure). In some cases, this difference exceeded 0.3‰, which may translate to 1.3°C difference in reconstructed temperatures. This indicates that sampling from different microstructural layers can significantly affect the reproducibility of the records and the interpretation of a recorded environmental signal. Observed differences in stable oxygen isotope data may be associated with the physiology of the mollusk and the physical and chemical composition of studied shell layers.

Session: Proxy Development: Challenges and Opportunities

Isotope chemistry of scales reveals continent-scale variation in at-sea foraging in European populations of Atlantic salmon

Clive Trueman[1*], Kirsteen MacKenzie[2], Jean-Marc Roussel[3]

[1]*Ocean and Earth Science, University of Southampton, UK*
[2]*Havforskningsinstituttet, Tromsø, Norway*
[3]*INRA Rennes, France*

**presenting author: trueman@noc.soton.ac.uk*

Many marine animals return to coastal regions to breed or spawn. In these cases foraging behaviour prior to breeding or spawning may be difficult to study and consequently poorly understood. Sclerochronological approaches can offer valuable insights into these otherwise obscure life history behaviours and the corresponding relationships between location, environmental conditions and population dynamics.

Atlantic salmon are famed for their migration between open ocean foraging grounds and return to natal rivers to spawn. Despite more than 100 years of scientific study, the nature of ocean foraging within and among natal river populations has remained obscure, and this knowledge gap is particularly pressing in the context of large scale increases in marine mortality of Atlantic over the past 30 years.

Here we use the stable isotope composition of salmon scales recovered from c. 5000 salmon returning to 10 European rivers from Scotland to Iberia over a 40 year time period, combined with predictive models of the expected isotopic composition of salmon scales across the North Atlantic to infer and compare foraging locations and dynamics of foraging location at continental and decadal scales.

We find strong evidence for latitudinal effects in ocean foraging location, with fish returning to more southerly rivers (S England, France) consistently foraging in more distant, colder waters than fish returning to rivers in Northern Ireland and Scotland. Futhermore we find evidence for temporally coincident changes in population-scale foraging location, presumably driven by environmental conditions, and for plasticity in foraging location within a single river and cohort.

We argue that diversity in foraging location within populations provides some buffering against short-term ecological or environmental change, but salmon returning to rivers at the southern margin of the species range show less diversity in foraging location and may have less resilience to long term climatic change.

Spatial ecology is being revolutionised by smart tagging and genetic approaches, however sclerochronological methods on samples from museum and laboratory collections remain the only way to yield retrospective information on behaviour prior to return to coastal breeding areas in widely dispersed animals at the scale of individual populations.

Session: Fisheries Ecology and Management

Potential for developing multispecies chronologies in the Mediterranean Sea

Nicole Pavin[1], **Hana Uvanović[2*]**, Carlotta Mazzoldi[1], Ivica Vilibić[2], Hrvoje Mihanović[2], Krešimir Markulin[2], Tomislav Džoić[2], Melita Peharda[2]

[1]*Department of Biology, University of Padova, Via U. Bassi 58/B, 35131 Padova, Italy*
[2]*Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, 21000 Split, Croatia*

**presenting author: uvanovic@izor.hr*

Despite the increasing interest for developing multispecies chronologies using marine organisms, this approach remains mostly underutilized, in particular for climate studies. This study is the first attempt to develop bivalve multispecies chronology in the Mediterranean Sea. Samples of three long living bivalve species were collected by SCUBA from two shallow (3-5 m) coastal sites in the eastern Adriatic Sea – Pag Bay and Živogošće. Sampling was conducted on several occasions in the period from May 2014 to October 2016. Target species included commercially important Venerid clam *Callista chione* and two large Glycymerid species – *Glycymeris bimaculata* and *G. pilosa*. Although previous studies indicated that these species are common and locally abundant in the eastern Adriatic, a sufficient number of large sized individuals to enable chronology construction (older than 20 years) is obtained at both sampling sites only for *G. bimaculata*. For other two target species, *C. chione* and *G. pilosa*, sufficient number of older individuals were collected only at Pag and Živogišće sites, respectively. In laboratory, shell length, height, width and dry weight was measured prior to embedding the shells in epoxy resin. Samples were cut along the axis of maximum growth, ground, polished and etched in acid. Acetate peel replicas were prepared and photographed with Zeiss microscope and camera. Image Pro Primer program was used to stich composite images and to measure increment widths. Visual crossdating of images was done by list-year method and verified with program COFECHA. Dendrochronology software package ARSTAN was used to construct the chronologies. At Pag, estimated age of oldest *G. bimaculata* and *C. chione* were 23 and 29 years, respectively. Both species had synchronous growth within populations, but there was no statistically significant correlation between their chronologies. At Živogošće, estimated age of the oldest *G. bimaculata* and *G. pilosa* were 52 and 61 years, respectively, with intercorrelated chronologies. Bivalve chronologies were related to the mean monthly seawater temperature and salinity. Mean monthly precipitation and monthly values of absolute dynamic topography (ADT) of the northern Ionian Sea were also analysed, to quantify local vs. remote drivers of the bivalve growth. This study gives the basis for further investigation of bivalve multispecies chronologies in the Adriatic as well as other parts of Mediterranean Sea. Research has been conducted in a framework of the project SCOOL (IP-2014-09-5747) supported by the Croatian Science Foundation.

Session: Climate and Oceans: Past, Present and Future

Otolith chemistry of Greenland halibut – false hopes or an opportunity to learn about population boundaries?

Mikko Vihtakari[1*], Ole Thomas Albert[1], Elvar H. Hallfredsson[1], Alf Harbitz[1], Torild Johansen[1], Kirsteen MacKenzie[1], Erik Berg[1], Jane A. Godiksen[2]

[1]*Institute of Marine Research, Fram Centre, Tromsø, Norway*
[2]*Institute of Marine Research, Bergen, Norway*

**presenting author: mikko.vihtakari@gmail.com*

Greenland halibut (*Reinhardtius hippoglossoides*) is a large deep-water flatfish species with a circumpolar distribution. The fish supports an important Arctic fishery with a total landed catch of approximately 135 000 metric tons in 2017. Despite its importance, uncertainties remain regarding its distribution patterns, biology, and population structure. Currently, the North Atlantic fishery of Greenland halibut is managed as three separate stocks (i.e. regions). Results from mark-recapture studies and genetics show, however, that the species migrate among the regions at some point during their life cycle albeit the extent of these migrations is unknown. Ecologically inappropriate management routines increase the risk of local depletion with substantial implications for the coastal communities in Greenland, Iceland, Faroe Islands, Norway, Russia, and eastern Canada.

A project initiated by the Institute of Marine Research (Norway) attempts to determine the population boundaries of Greenland halibut in the Northeast Atlantic Ocean. The project contains four work packages: 1) genetics, 2) mark-recapture analysis, 3) spatial structure in the survey and assessment data, as well as, 4) otolith morphology and geochemistry. In this poster, we present the otolith morphology and geochemistry work package in a search for new collaborators, laboratory possibilities and fresh scientific ideas to carry out the project. We intend to run trace elements and stable isotope analyses on otoliths from fish that were marked in Svalbard and caught in Iceland. With this information, we hope to find the age when the fish migrated from one stock management region to another. Further, we search for a multi-proxy "fingerprint" to separate the geographic locations. The collected elemental information will be compared to genetics, mark-recapture data, and otolith morphology through shape analysis of the outer contour of otoliths.

Session: Fisheries Ecology and Management

Otolith geochemistry of *Diplodus puntazzo* and *Diplodus vulgaris* from marine waters and estuaries in the eastern Adriatic Sea

Dario Vrdoljak[1*], Hana Uvanović[1], Regina Mertz-Kraus[2], Sanja Matić-Skoko[1], Mišo Pavičić[1], Melita Peharda[1]

[1]Institute of Oceanography and Fisheries, Šetalište Ivana Meštrovića 63, Split, Croatia
[2]Institute for Geosciences, Johannes Gutenberg University, 55099 Mainz, Germany

**presenting author: vrdoljak@izor.hr*

Studies of fish otolith geochemistry have contributed to the understanding of the life history, segregation, connectivity and nursery identification of different fish species in many areas of the world. Otoliths are calcified structures located in the inner ear of fish that are composed of calcium carbonate. They represent archive of information on life histories in a chronological manner, making it possible to retrieve information on environmental conditions experienced by individual fish from hatching to capture. Otolith chemical signature in the core (young stage) may reflect nurseries areas, while the edge (adult stage) could indicate the presence of geographic management units. Differences in otolith geochemistry of sharpsnout seabream, *Diplodus puntazzo* and two-banded seabream, *Diplodus vulgaris*, which inhabited coastal waters and estuary, were determined to evaluate movement patterns. Juvenile fish of *D. puntazzo* and *D. vulgaris* were collected by beach seine net on two locations (estuary of river Pantan near Split and cove Sovlja near Šibenik) in the eastern Adriatic during June 2018. Upon collection fish were kept frozen and transported to the lab were the length and weight of each specimen were measured, the otoliths have been extracted, cleaned and prepared for transverse sections through the otolith core with a low-speed saw. On the predetermined sections of otoliths with visible cores and growth marks, laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to quantify concentrations of 12 chemical elements along maximum growth rates. Among them, Zn, Na, Mg, Sr, Ba, Mn, Li showed differences between the individuals and locations. Obtained concentrations and peaks could be related to the different habitats and certain part of the otoliths for each individual. The results represent the first geochemical study of *Diplodus puntazzo* and *Diplodus vulgaris* otoliths in the Adriatic and reveal the potentials of this method for the interpretation of ontogenetic movements. This work has been fully supported by Croatian Science Foundation (HRZZ) under the project IP-2016-06-9884 (NurseFish).

Session: Fisheries Ecology and Management

Were inoceramid chemosymbiotic bivalves?

Eric O. Walliser[1*], Bernd R. Schöne[2]

[1]*Institute of Geosciences, University of Mainz, Johann-Joachim-Becher-Weg 21, 55128 Mainz, Germany*

**presenting author: walliser@uni-mainz.de*

Inoceramids are a group of extinct bivalves that flourished during the Late Cretaceous. Their shells are often found in strata characterized by large amounts of pyrite and kerogen, weak/absent bioturbation, and low faunal diversity. This mode of occurrence prompted some authors to suggest a chemosymbiotic lifestyle for at least some inoceramid species. Yet, very little is still known on the metabolism of this bivalve taxon. Here, we present high-resolution sclerochronological data ($\delta^{13}C$, $\delta^{18}O$) obtained from shells of the USA, Japan, the Czech Republic, and Italy, which provide a new insight into the physiology of the inoceramids. Shells of *Platyceramus platinus* from the Santonian chalk deposits of the Western Interior Seaway (Kansas, USA) exhibited $\delta^{13}C$ values that resemble the typical ^{13}C-enriched signal of modern thioautotrophic bivalves. The ability to harbor sulfide-oxidizing bacteria also allowed inoceramids to colonize cold seeps as indicated by the $\delta^{13}C$ and $\delta^{18}O$ values of *Sphenoceramus* spp. shells from the Campanian deposits of Hokkaido (Japan). In this regard, these inoceramids did not host methanotrophic bacteria and could not survive direct exposure to methane. However, a chemosymbiotic lifestyle was not shared by all inoceramids as suggested by the near-equilibrium $\delta^{13}C$ and $\delta^{18}O$ values of *Inoceramus* spp. from the Teplice Formation of the Czech Republic and the Scaglia Rossa limestones of Northern Italy.

Session: Paleoecology and Evolution

Constructing sclerochronology networks in the northwestern Atlantic: A progress report

Alan Wanamaker[1*], Nina Whitney[1], Jared Ballew[1], Ian Searles[1], Caroline Ummenhofer[2], Bryan Black[3], David Reynolds[3]

[1]*Iowa State University, Department of Geological and Atmospheric Sciences, Ames, IA, USA*
[2]*Woods Hole Oceanographic Institution, Department of Physical Oceanography, Woods Hole, MA, USA*
[3]*University of Arizona, Laboratory of Tree-Ring Research, Tucson, AZ, USA*

**presenting author: adw@iastate.edu*

The Gulf of Maine is a highly important and productive ecosystem that has experienced increasing sea surface temperatures throughout the 20th century and it is considered highly susceptible to future warming. Recent warming in the Gulf of Maine is in part related to a decrease in the strength of Atlantic meridional overturning circulation, which has been noted by several recent studies. In the northwestern Atlantic, Labrador Sea derived water masses flow southward and mix with northerly flowing sub-tropical waters (Gulf Stream, Warm Slope Water) in the mid-latitudes and enter the Gulf of Maine system. Spatial and temporal heterogeneity is common in the marine environment, especially along dynamic boundaries like the Gulf of Maine. Because of the strong spatial variability along this oceanic transition zone and within the Gulf of Maine, it is unlikely that one specific site would capture the full variability of the ocean conditions in this region through time. Hence, the development of a sclerochronological network is appealing. In this study, we present multiple *Arctica islandica* master shell growth chronologies from the Gulf of Maine region and explore the extent of the common signal during the instrumental period. Various statistical techniques (composite analysis, principal components analysis, spectral properties) were used to explore extreme events, as well as the spatial and temporal coherence of these growth signals. Our findings suggest that sclerochronological networks offer several advantages over single chronologies such as reducing site-specific noise, better capturing the common signal over larger spatial scales, and improved detection of large-scale environmental drivers.

Session: Climate and Oceans: Past, Present and Future

Reconstruction of bomb ^{14}C in the North Sea derived from *Arctica islandica* using Laser Ablation AMS

Christiane Yeman[1*], **Rob Witbaard[2*]**, Marcus Christl[1], Bodo Hattendorf[3], Lukas Wacker[1], Hans-Arno Synal[1]

[1]*Laboratory of Ion Beam Physics, ETH Zurich, Otto-Stern-Weg 5, 8093 Zürich, Switzerland*
[2]*NIOZ, Netherlands Institute for Sea Research and Utrecht University, Department of Estuarine and Delta Systems, PO Box 140, 4400 AC Yerseke, The Netherlands*
[3]*Laboratory of Inorganic Chemistry, ETH Zurich, Vladimir-Prelog-Weg 1-5/10, 8093 Zürich, Switzerland*

**presenting author: rob.witbaard@nioz.nl*

Arctica islandica shells can be used to derive time histories of radiocarbon (^{14}C) across the north Atlantic. The annual resolution of the growth increments and the longevity makes the shell an ideal climate archive for the reconstruction of ^{14}C in the marine environment. Especially the identification of the bomb pulse can be used for indirect ^{14}C dating and as tracer of ocean circulation. These applications find their limits in the sample preparation for AMS measurements of carbonates which is time consuming, tedious and in need of a minimum amount of material. A much faster way of analyzing carbonate samples for their radiocarbon content requiring less material is using a novel LA (Laser Ablation)-AMS technique. By focusing a pulsed laser beam (ArF excimer laser 193 nm, 200 – 250 Hz) on the sample's surface, a mixture of CO/CO_2 is produced, which is directly and continuously introduced into the gas ion source of the AMS. A positioning system allows precise movement of the sample relative to the laser beam. Hence, scanning along the shell margin of a specimen results in a continuous ^{14}C profile. For the alignment of the LA radiocarbon data with the year of formation of the shell, an acetate peel is made of the analyzed section with the laser tracks, visualizing the growth layers of the shell.

Here, we present continuous ^{14}C records with 1-3 years resolution of individual specimens from six locations across the North Sea and northern Norway. All records comprise the marine radiocarbon bomb pulse. The magnitude ranges from 10% to 30% compared to the atmospheric bomb pulse. This variability correlates to the sampling depth and location of the respective shell. The data is in agreement with previously published ^{14}C data from *Arctica islandica* in the North Sea.

Session: Environmental Biomonitoring & Entrepreneurship

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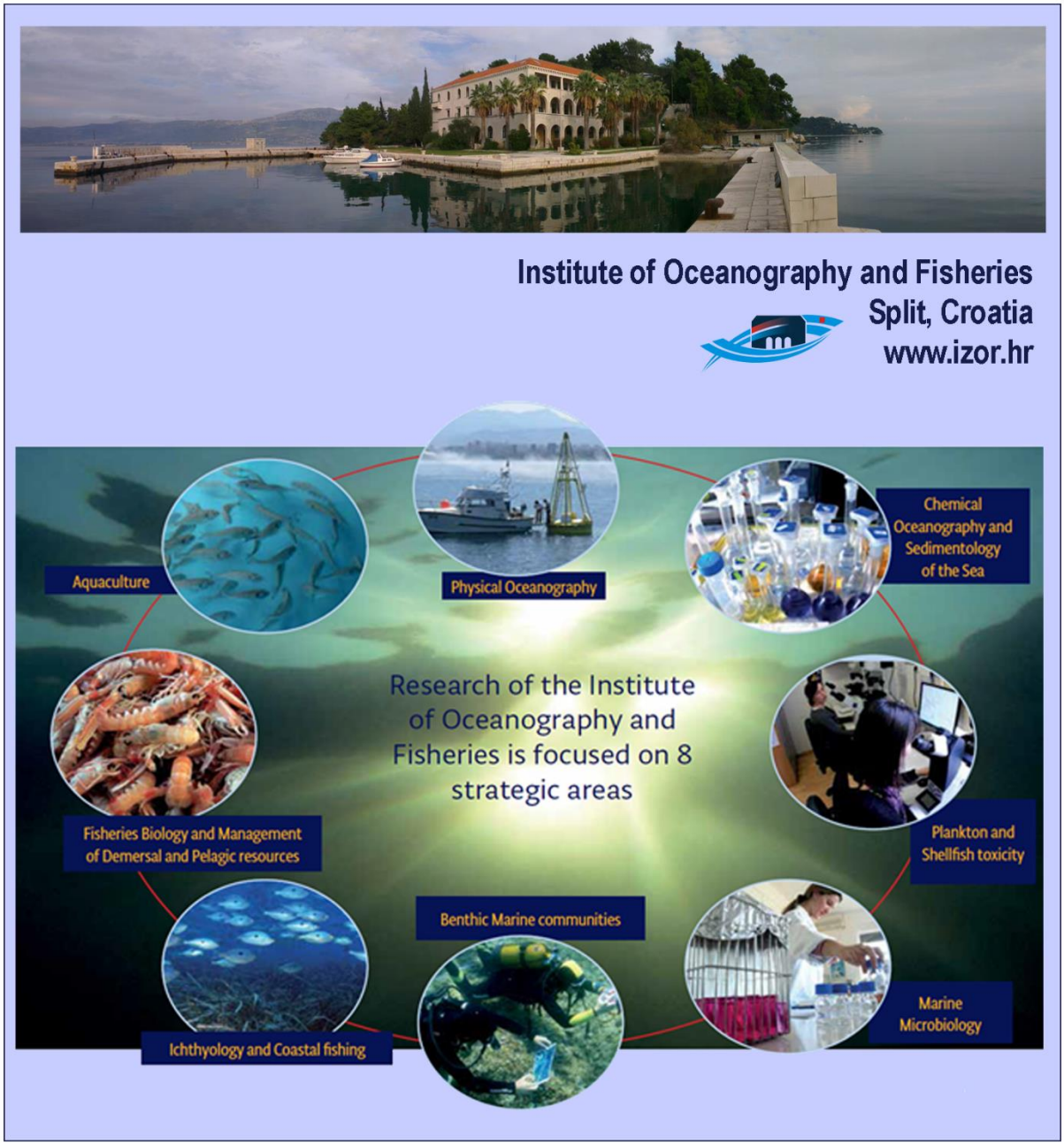

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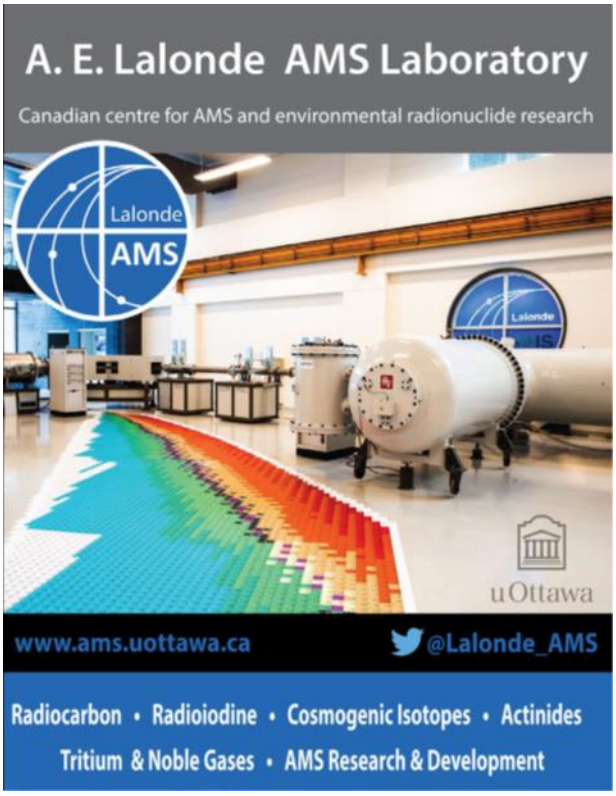

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