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Aquaculture-Based Calibration of the M.edulis Isotope Paleothermometer

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Principal Investigator: Kreutz, Karl J.
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Aquaculture-Based Calibration of the M.edulis Isotope Paleothermometer

Project Participants

Senior Personnel

Name: Kreutz, Karl
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Borns, Harold
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Introne, Douglas
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Barber, Bruce
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Funder, Sven
Worked for more than 160 Hours: No
Contribution to Project:

Post-doc

Graduate Student

Name: Hunt, James
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Wanamaker, Alan
Worked for more than 160 Hours: Yes
Contribution to Project:

Undergraduate Student

Name: VonHasseln, Zachary
Worked for more than 160 Hours: Yes
Contribution to Project:
Zach has participated in laboratory activites (aquaculture and isotope analysis), as well as going to Greenland to assist in fieldwork. He is using part of the isotope dataset in his Capstone experience project.

Technician, Programmer

Name: Fiendel, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

Scott set up and monitored the aqualculture system for the duration of the project

Name: Raymond, Nancy

Worked for more than 160 Hours: No

Contribution to Project:

Nancy assisted in the monitoring of the aquaculture system, and daily feedings

Other Participant

Research Experience for Undergraduates

Organizational Partners

University of Copenhagen

Dr. Funder is participating with us on the collection and culturing of M. edulis from Greenland, as well as collecting fossil M. edulis from coastal Maine.

Eckerd College

California Institute of Technology

Other Collaborators or Contacts

We have participated in the CORONA conference for the past four years, and established several contacts within that organization related to North Atlantic research.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

see attached file

Findings: (See PDF version submitted by PI at the end of the report)

see attached file

Training and Development:

This project has directly contributed to the education of two graduate students (Alan Wanamaker and James Hunt) and one undergraduate student (Zachary Von Hasseln). James Hunt began his MS thesis on this project, and completed one semester of classes and initial research before deciding to pursue a different thesis topic. Subsequently, Alan Wanamaker began his PhD dissertation supported by the project RA, and is scheduled to graduate in May 2005. Alan has been involved in all aspects of the project, including aquaculture, laboratory analysis, fieldwork, data interpretation, presentation on local, national, and international meetings, and publication. Alan has had several opportunities to form new collaborations as part of this project, namely with Dr. Bernd Schone of the Gothe University, Germany. Upon completion of his PhD., Alan will be poised to continue

on in academic research with a substantial set of skills and experiences, all due to the support of this project. Zachary Von Hasseln is a junior undergraduate Earth Sciences major at UMaine, and has worked the past two summers on the project, mainly as a laboratory assistant. Zach did have the opportunity to be involved in Greenland fieldwork during summer 2004, which was a new and unique opportunity for him. Zach is planning to use data collected on the Greenland trip as part of his Capstone Experience project at UMaine.

The PIs have had several opportunities to integrate the data and ideas generated from this project into graduate and undergraduate course curricula at UMaine. For example, PI Kreutz uses the M. edulis isotope data in ERS527:Isotope Geology to illustrate the concepts of equilibrium and non-equilibrium isotope fractionation. Also, Kreutz uses concepts from the project in a paleoclimate module as part of an undergraduate survey course (ERS200:Earth Systems). PI Borns uses environmental reconstructions from bivalves during the last glacial retreat in Maine in ERS543:Quaternary History of Northeastern North America.

Lastly, a K-12 teacher (Susan Wentworth) spending the summer at UMaine as part of an NSF GK-12 fellowship had the opportunity to work on the project during the summers of 2004 and 2005. Susan has mainly assisted with laboratory analysis and data entry, and has been able to take data from the project and integrate it into her 7th grade classroom science activities.

Outreach Activities:

The UMaine Climate Change Institute maintains a project website at http://climatechange.umaine.edu/Research/projects/aquaculture.html, as well as an expedition logbook from our work in Greenland during summer 2004 (http://climatechange.umaine.edu/Research/Expeditions/greenland.html). We have used these websites several times when visiting local classrooms (e.g., Asa Adams Elementary School, Orono; Indian Island School, Old Town) to give presentations of climate/paleoclimate research at UMaine. Over the past three years, we have hosted several (>20) tours in the Stable Isotope Lab from groups ranging from first grade to U.S. Congressmen. Our dedicated area for bivalve shell preparation and this project are always featured in these tours, and have given visitors a hands-on opportunity to see and understand paleoclimate proxy records and reconstructions. Likewise, several groups have visited the aquaculture system at the Darling Marine Center, providing another opportunity to disseminate project information to the public.

Perhaps the largest outreach effort as part of this project is the Ice Age Trail in Downeast Maine (http://iceagetrail.umaine.edu/content/intro.php). The Trail represents a unique opportunity to show and educate the public on the various glacial landforms that exist in Maine. This landscape is one of only a handful in the world where well-exposed ice-marginal glaciomarine deposits from a continental ice sheet exist. We are integrating data and results from this project, specifically coastal environmental reconstructions from M. edulis, into the tour stop information kiosks at several locations on the Trail.

Journal Publications

Alan D. Wanamaker Jr., Karl J. Kreutz, Harold W. Borns Jr., Douglas S. Introne, Scott Feindel, Bruce J. Barber, and Svend V. Funder, "An aquaculture-based method for calibrated bivalve isotope paleothermometry", Geochemistry, Geophysics, Geosystems, p. , vol. , ( ). near submission

Alan D. Wanamaker Jr., Karl J. Kreutz, Harold W. Borns Jr., Douglas S. Introne, Scott Feindel, Bruce J. Barber, and Svend V. Funder , "Comparison of location and environmental influences on M. edulis isotope fractionation using species-specific aquaculture techniques", Geochimica et Cosmochimica Acta, p. , vol. , ( ). near submission

Borns, H.W. Jr., Doner, L.A., Dorion, C.C., Jacobson, G.L. Jr., Kaplan, M.R., Kreutz, K.J., Lowell, T.V., Thompson, W.B., and Weddle, T., "The deglaciation of Maine, U.S.A.", in Ehlers, J. and Gibbard, P.L., eds., Quaternary Glaciations ? Extent

and Chronology Part II:
North America, Elsevier Publishers, New York, 89-109., p. 89, vol. , (2004). Published

Books or Other One-time Publications

Web/Internet Site

URL(s):

http://climatechange.umaine.edu/Research/projects/aquaculture.html; http://climatechange.umaine.edu/Research/Expeditions/greenland.html

Description:

These websites cover the project details, objectives, and chronicle the log of our fieldwork in Greenland during summer 2004

Other Specific Products

Contributions

Contributions within Discipline:

The techniques developed as part of this project represent a new approach to calibrating bivalve isotope paleothermometers. We specifically set up the experimental design to be species-independent, so that any bivalve species of interest could be calibrated using our published techniques. We believe this methodology will advance the use of bivalve geochemistry as a proxy for past oceanographic and environmental conditions.

Contributions to Other Disciplines:

We have already made several contributions to other fields (modern oceanography, geochemistry, species genetics and paleobiogeography) through our interaction with the CORONA organization. In particular, our work with M. edulis in both modern and paleoenvironments has led to new understandings about how the species migrated and re-populated coastal New England after the Last Glacial Maximum.

Contributions to Human Resource Development:

To date, two graduate students and one undergraduate student have been directly involved in the project. One student, Alan Wanamaker, is using the project data as part of his PhD dissertation. Project results have been used in several UMaine undergraduate and graduate courses, including ERS200:Earth Systems, ERS527:Isotope Geology, ERS442:Glacial Geology, and ERS530:Quaternary History of Eastern North America.

Contributions to Resources for Research and Education:

The aquaculture system developed as part of this project is now a permanent facility at the UMaine Darling Marine Center. We anticipate using it to culture other bivalve species in the future, but the system is also available for other researchers who have similar aquaculture needs (e.g., colleague Paul Rawson will use the system to test oyster growth conditions in the Gulf of Maine).

Contributions Beyond Science and Engineering:

None to report.

Categories for which nothing is reported:

Any Book

Any Product

Major Findings

Our major findings resulting from this project to date include:

***Aquaculture system*:** A closed aquaculture system was designed that allowed four temperature settings (8, 12, 16 and 20 °C) and three salinity settings (23, 28, and 32 ppt). This four by three factorial design allows 12 different growing conditions to be maintained simultaneously. Furthermore, a replicate growing environment is used for each temperature and salinity condition (i.e., 20 °C at 28 ppt bucket A, and 20 °C at 28 ppt bucket B). Each temperature regime is maintained by a recirculating freshwater system (Aquanetics Systems) capable of heating and cooling, which is controlled by a thermostat, with an alarm system if the system fails. Three large (500 liter) containers plumbed into each recirculating system hold four 20-liter containers. In each 20-liter container, for each temperature bath, specific salinity environments (23 ppt, 28 ppt, 32 ppt) are maintained.

The aquaculture system is continually monitored to ensure that it was operating within the design limits. The temperature of each bath is measured with a HOBO® H8 data logger every 30 minutes with an accuracy of +/- 0.5 °C (e.g., Fig. 1). The average water exchange in each recirculating bath is approximately 10 liters per minute. Complete water changes for each temperature/salinity environment are made weekly. The aquaculture design allows for one extra 20 liter bucket to be in place with identical water (isotopic composition and temperature), which makes for easy weekly water changes and transitions for the animals. Mussels are fed twice daily (total of 10 ml) a concentrated spat formula (Innovative Aquaculture Products, Ltd.) where 5ml of spat is diluted in 1 liter of appropriate salinity water. Water samples for each of the twenty-four

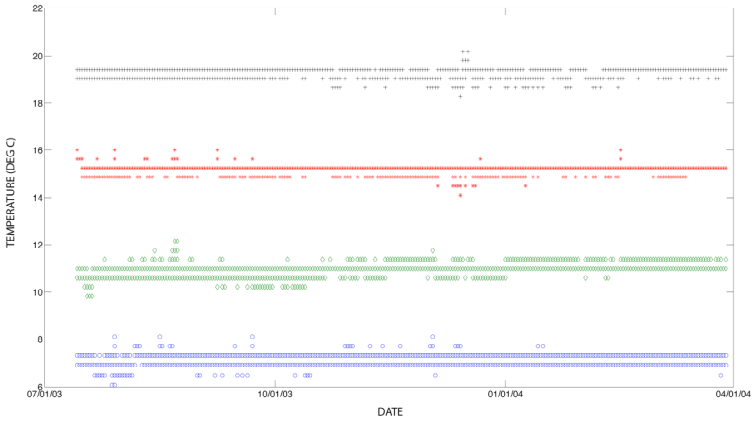

Figure 1. Aquaculture system temperature data for a 9 month period (30 mintue monitoring).

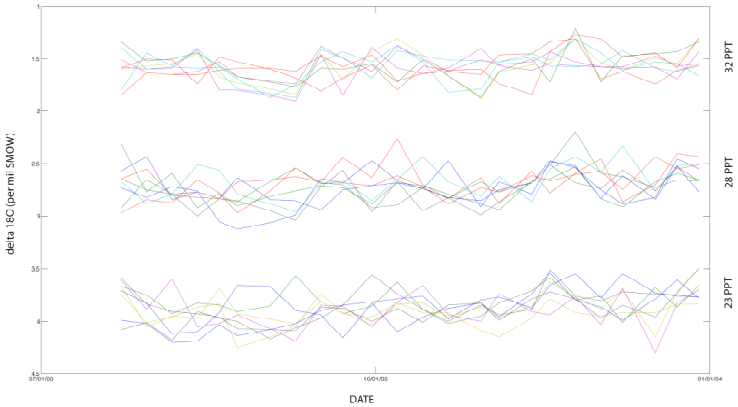

Figure 2. Aquaculture system water isotope data for a 5 month period (weekly monitoring).

buckets are collected weekly to monitor ! $^{18}O_w$ (e.g., Fig. 2). Throughout the experiment mortality was low (< 10%) for all temperature and salinity configurations for the first five months.

Calibration of Maine M. edulis paleotemperature equation: A specific paleotemperature relationship for *M. edulis* was developed during this study and compared to the Epstein et al. (1953) revised calcite paleotemperature equation and the O'Neil (1969) calcite equation (Fig. 3). This relationship, Temperature °C = 0.175 (Shell PDB – Water SMOW)^2 - 4.69 (Shell PDB – Water SMOW) + 16.19; r^2 = 0.986; N= 105; p < .0043) is nearly identical to the Epstein et al., (1953) revised calcite equation and the O'Neil (1969) calcite equation above 10 °C. Below 10 °C, the *M. edulis* paleotemperature equation deviates from the other two. There was similar isotopic variability (! $^{18}O_c$ - ! $^{18}O_w$) for the upper temperature ranges (standard deviations [‰] = +/- 0.12 at 20 °C; +/- 0.13 at 16 °C; +/- at 0.12 °C), and slightly less at the lowest temperature (+/- 0.09 at 8 °C) (Fig. 2). These variability were slightly higher or within the range of combined random analytical errors for water and carbonate analyses (+/- 0.11‰) using methods outlined by Miller and Miller (1993).

The *M. edulis* paleotemperature relationship developed supports that our methods are suitable for aquaculture paleothermometry. The animals grew in a natural temperature and salinity range. The growing conditions were controlled and monitored throughout the experiment. In addition, the benefit of this work is that it clearly establishes the range of variability in shell isotopic composition at various temperature and salinity conditions for an organism. Further, it increases confidence in developing empirical isotope calibrations, and hence environmental reconstructions, because there were multiple animals grown at each temperature and salinity setting compared to past studies (e.g., Epstein et al., 1953; Grossman and Ku, 1986), where limited animals were grown at one temperature and/or salinity range, thereby not fully assessing shell isotopic variability. Studies that developed empirical isotopic relationships from animals living *in situ* used only a small number of animals at a particular temperature range, and had to estimate key environmental parameters such as temperature and salinity (e.g., Epstein et al., 1953; Grossman and Ku, 1986), thus decreasing the confidence in using such calibrations. The

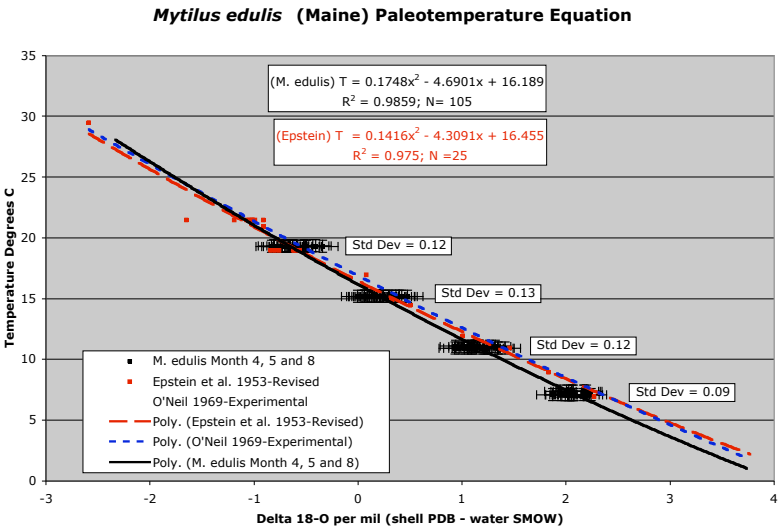

Figure 3. The M. edulis paleotemperature relationship (this study) is compared to the calcite equations of Epstein et al. (1953-revised) and O'Neil (1969). Standard deviations at each temperature range are shown.

ability to grow animals in controlled conditions to study the effects of temperature, salinity, age, growth rates, etc., on shell isotopic composition is key to better understanding if a particular bivalve is a suitable proxy for paleoclimate reconstructions. Furthermore, this experimental design allows for an in depth exploration to determine if a particular bivalve does or does not exhibit "vital effects", with possible insight to the reasons why if it does.

Potential Low-Temperature Disequilibrium for M. edulis: *M. edulis* deposited their shells in equilibrium with ambient water above 10 °C. The developed paleotemperature relationship for *M. edulis* is nearly identical to the Epstein et al. (1953) revised calcite paleotemperature relationship and the O'Neil (1969) calcite equation with the exception of a low-temperature deviation that is statistically significant (Fig. 2), possibly meaning *M. edulis* deposits its shell in disequilibrium at low-temperatures. In order to test this hypothesis, further experimentation is needed. It is unclear if the low-temperature deviation is because *M. edulis* exhibits some vital effect, or if it is an artifact of sampling. Current work is being conducted to address the potential low-temperature disequilibrium noted in this study.

***Age-related Isotope Effects*:** The size (shell length) distribution of mussels, based on 105 animals used in the experiment, ranged from 10.9 mm to 29.5 mm with a mean size of 19.8 mm. This variation in shell length allowed for quantification of potential vital effects based on age. A comparison of shell length (related to the age of the animal) and temperature deviation (measured temperature minus predicted temperature) is made (Fig. 4). There is a weak positive correlation ($r^2 = 0.05$) between the shell length of the animal and temperature deviation, but the relationship is not statistically significant. This result suggests that *M. edulis* does not exhibit age related disequilibrium during biomineralization. Because most of the animals used in this study were juveniles (less than 2 years-old), it is unknown if the paleotemperature relationship developed thus far will be suitable for adult animals.

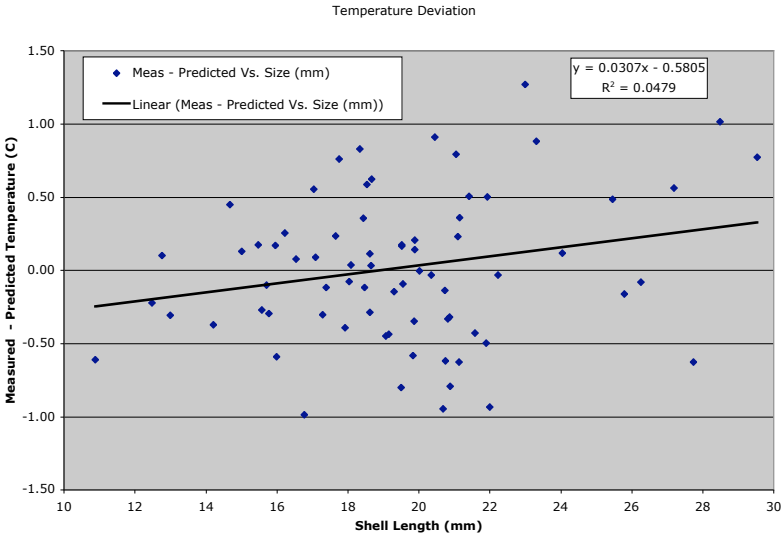

Figure 4. The relationship between shell length and temperature deviation (measured temperature – predicted temperature C) is illustrated.

***Greenland vs. Maine M. edulis*:** We have recently finished growing and analyzing juvenile and adult *M. edulis* from both Greenland and Maine. Initial results suggest that there is little geographic difference between the two datasets, however the low

temperature isotope disequilibrium noted in the Maine *M. edulis* is also apparent in the Greenland samples. This potential difference between our *M. edulis* paleotemperature equation and the original Epstein et al. (1953) equation had important implications for any reconstructions done for low temperature environments. In the next several months, we will be further investigating this problem with the data in hand, as well as analyzing additional Arctic bivalve species samples collected in Greenland and cultured with *M. edulis* (e.g., *Portlandia arctica, Hiatella arctica*).

Research and Education Activities

Oxygen isotopic analysis of marine carbonate shells (! $^{18}O_c$) is a standard paleoceanographic technique used to document the chronology of seawater temperature change. Shell ! $^{18}O_c$ depends not only upon seawater temperature, but also upon the isotopic composition of the seawater (! $^{18}O_w$; related to salinity) and any species-specific fractionation that occurs during biomineralization. In the past, the interpretation of shell ! $^{18}O_c$ has been based upon theoretical studies of chemical equilibrium and kinetics, or laboratory experiments involving the inorganic precipitation of $CaCO_3$ from solution. Other methods have employed an empirical calibration done by measuring the ! $^{18}O_c$ of collected shells where only estimates of time-series variability of the key parameters in the isotope paleothermometry equation (water temperature and ! $^{18}O_w$) could be made. The actual environmental conditions during biomineralization, any species-dependent fractionation, any growth-dependent changes in ! $^{18}O_c$ including growth hiati, and any geographical/latitudinal influences that may be affecting ! $^{18}O_c$ cannot be quantified by these methods. Hence, the ability to quantitatively estimate paleotemperatures and salinities from any particular species of interest and any specific environment is limited.

This project sought to empirically calibrate ! $^{18}O_c$ in a cultured marine mollusc (*Mytilus edulis*) with controlled and monitored water temperatures, salinities, and ! $^{18}O_w$. The development of this technique enables better correlation of ! $^{18}O_w$ and ! $^{18}O_c$ by increasing the temperature and salinity ranges to be used in calibration. The method will contribute significantly to the field of isotope paleoceanography, as it can be used to culture a wide range of species under specific environmental parameters. For example, we are particularly interested in fossil molluscan assemblages from ice-proximal environments where reliable temperature and salinity proxies are unknown.

Project objectives were as follows:

Objective 1: Design and develop aquaculture-based techniques for monitoring *Mytilus edulis* growth in controlled water temperature, salinity, and ! $^{18}O_w$ conditions. This will involve a four by three factorial experiment to simultaneously determine the effects of water temperature, salinity, and ! $^{18}O_w$ on isotopic uptake in *M. edulis* carbonate (shells).

Objective 2: Determine empirical relationships between shell ! $^{18}O_c$, water temperature and water salinity (! $^{18}O_w$) for *M. edulis* from Maine.

Objective 3: Quantify any vital effects occurring under different environmental and/or age conditions that affect shell isotopic composition. Shells grown under each set of environmental conditions will be periodically sampled from early post-settlement to adult stages.

Objective 4: Culture *M. edulis* collected from western central Greenland under varying conditions of temperature and salinity, and investigate any location-specific effects on isotopic composition.

Objective 5: Develop species-specific transfer functions which may depend on differences in age or location for temperate and polar *M. edulis*, and apply the calibrated paleotemperature equation to *M. edulis* shells collected from emerged glaciomarine sediments (ca. 15,000 – 13,000 ^{14}C yrs. BP) in coastal Maine.

A full-time graduate research assistant was to be involved in all aspects of this project, and utilize hydrographic and isotopic data as part of his/her M.S. or Ph.D. research. At least one undergraduate student will also be involved in the project, mainly on sample preparation in the Stable Isotope Laboratory. Data and ideas generated in this project will be used in several undergraduate and graduate-level classes in the Department of Earth Science (ERS), Climate Change Institute (CCI), and School of Marine Sciences (SMS), including Principles of Stratigraphy and Sedimentology (ERS315), Isotope Geology (ERS527), Quaternary History of Northeastern North America (ERS543), Glacial Geology (ERS441), The Role of Continental Glaciation in Global Climate Change (ERS547), Seminar in Quaternary Studies (INT500), and Shellfish Aquaculture (SMS309, SMS409). One of the PIs (H. Borns) is actively involved in developing an interactive Ice Age Trail that focuses on climatic, environmental, and glaciomarine conditions resulting from the Laurentide glaciation in eastern coastal Maine. Results of this project will be used in public presentations, materials, and roadside information signs associated with the Ice Age Trail. Lastly, we have had excellent success using web-based outreach in other NSF projects, and intend to design and maintain a website highlighting project progress, results, and broader implications.