A HIGH RESOLUTION HOLOCENE PALEOCLIMATE RECORD FROM WESTERN IRELAND: EVIDENCE FROM POPULATION, BIOMETRIC, AND STABLE ISOTOPE VALUES OF FRESHWATER MOLLUSKS

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INTRODUCTION

The Headford blanket bog in County Galway, western Ireland, caps several meters of marl which precipitated in an ancient freshwater lake. This marl has abundant shells of freshwater gastropods and bivalves. A 4.5 m core was recovered from the bog to determine changes in gastropod and bivalve abundance at 5 cm intervals throughout the marl sequence. Ecophenotypic variability was also assessed throughout the core at selected 5 cm intervals to determine any changes in gastropod or bivalve shell morphology. Both the changes in mollusk population abundance and the ecophenotypic variability observed in freshwater gastropod species *Lymnaea peregra* reveal changes in the paleoecology and paleohydrology of the lake throughout the Holocene. Stable isotope values were retrieved from accretionary aragonitic opercula of the freshwater gastropod species *Bithynia tentaculata* using computer-assisted micromilling to determine past climatic variability. _^{18}O and _^{13}C isotope values from opercula growth bands provide supporting evidence for variation in precipitation and temperature during the Holocene.

METHODS

A 4.5 m core was retrieved from the Headford blanket bog in the summer of 2002 using a Livingstone piston corer. Mollusks were sampled from a quartered portion of the core separated into 5 cm intervals. Each 5 cm interval was heated in a solution of ~10% KOH and then wet-sieved using a 42 μm mesh. Samples were picked under a dissecting microscope. Mollusks were identified using Ellis (1978) for the bivalve species and Macan (1977) for the gastropod species.
One modern operculum of *B. tentaculata* taken from the shore of Lough Corrib and eight *B. tentaculata* opercula selected from different intervals of Hed Core 1 were sampled for δ^{18}O and δ^{13}C stable isotope values using a computer-assisted Micromiller ESP 2.0. Computer-assisted micromilling permits sampling of accretionary growth bands in biogenic carbonate with high resolution (Wurster et al., 1999). Samples were taken within the opercula by digitizing paths along growth bands using an X-Y-Z

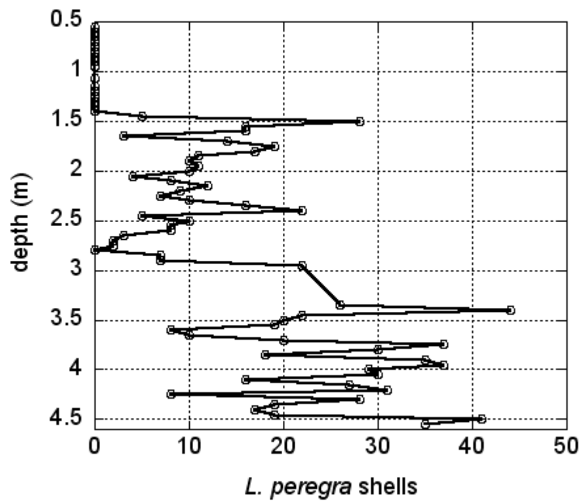

Figure 1: ***L. peregra*** **abundance through Hed Core 1.**

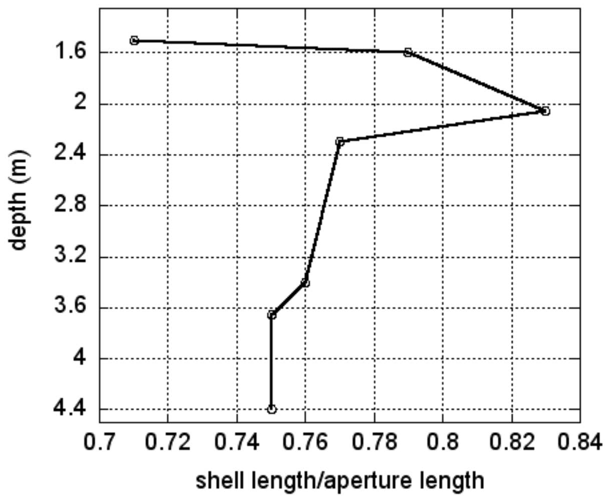

Figure 2: Average shell length/aperture length of *L. peregra* through Hed Core 1.

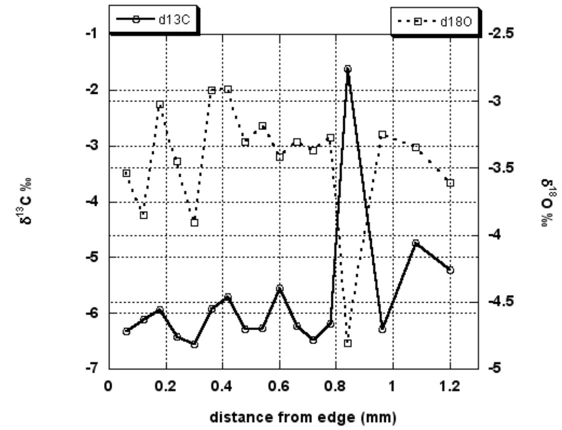

Figure 3: Stable isotope values through an operculum from 3.45-3.40 m.

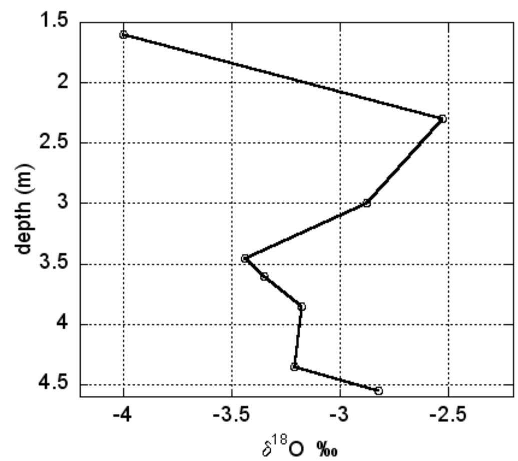

Figure 4: Average operculum $\delta^{18}O$ values through Hed Core 1.

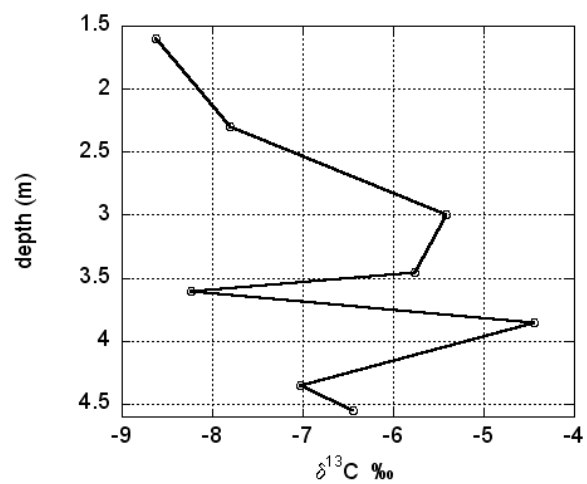

Figure 5: Average operculum $\delta^{13}C$ values through Hed Core 1.

coordinate system. A best-fit cubic spline was then interpolated along the digitized points to create overlying drill paths that simulated the contour of growth bands. Paths were then drilled by a small dental drill. Path widths average 40 μm to 90 μm, with average drill depths of 80 μm. One operculum tended to produce around 15 samples for stable isotope analysis. Carbonate samples were first roasted *in vacuo* at 200°C to burn off any organic volatiles and then placed in a Kiel automatic carbonate preparation system connected to a Finnigan 253 mass spectrometer. Stable isotope values are recorded in per mil relative to the PDB mean.

CHRONOLOGY

Two radiocarbon dates were obtained with funding provided by The College of Wooster. Seed pods from interval 4.55-4.50 m gave an average calibrated age of 8580± 320 BP, calculated using INTCAL98 (Stuiver et al., 1998). Plant material from interval 2.80-2.75 m gave an average calibrated age of 5530 ±40 BP. The average sedimentation rate for Hed Core 1, calculated from these values, is 0.57 mm/yr.

MOLLUSK ABUNDANCE

Mollusk abundance exhibits frequent, high amplitude variation that suggests large-scale changes in lake levels, depositional conditions, and/or water chemistry. Although most freshwater mollusks are tolerant of a wide range of conditions and thus alone are not good indicators of changing environmental or climatic conditions, variability in growth and reproduction rate of one particular freshwater gastropod, *Lymnaea peregra*, is concomitant with changes in lake temperature and/or productivity. With higher water temperatures and/or a more eutrophic habitat, shell growth rate increases in *L. peregra* (Byrne, 1989). With lower temperatures and/or an oligotrophic habitat, shell growth rate is slower. A faster shell growth rate may lead to faster maturity and faster reproduction, creating overlapping generations (*L. peregra* tends to be annual) and more individuals. Boycott (1936) noticed that in hotter summers and under hotter laboratory conditions, *L. peregra* produced two generations instead of the usual one. As is easily observed from the core population data, *L. peregra* is nearly continually vacillating throughout the marl sequence, from high abundance to low abundance (Figure 1). These oscillations may be due to this environmentally-induced variability.

ECOPHENOTYPIC CHANGES

L. peregra is well known at times to have many different shell shapes due to environmentally-induced phenotypic plasticity (Boycott et al., 1932; Byrne et al., 1989; Evans, 1989). The average of aperture length to overall shell length for *L. peregra* increases upward through Hed Core 1 as the marl grades from fine, clay-like marl to coarse marl. Then, closer to the peat/marl interface (around 1.6 m), the average aperture to shell length ratio decreases (Figure 2). *L. peregra* individuals living in water with a current have a greater aperture length to overall shell length than *L. peregra* individuals that live in still water. This variability in aperture length to shell length is due to the necessity of a larger foot in moving waters in order for the gastropod to sufficiently attach to substrate and not be washed away (Hubendink, 1951; Lam and Calow, 1988). A larger aperture length to shell length ratio indicates a wider aperture, which in turn houses a larger foot. A narrower aperture and a smaller foot are indicated by a low aperture length to shell length. This ratio can also be influenced by the degree of stagnation in aquatic habitats (Hubendink, 1951; Wullschleger and Ward, 1998). A narrower aperture guards against desiccation of the body in dry periods (Eckblad, 1973; Wullschleger and Ward, 1998).

STABLE ISOTOPE RESULTS

Short $\delta^{13}C$ and $\delta^{18}O$ excursions within a single operculum may be related to storminess (Wurster and Patterson, 2001): a large storm could contribute enough precipitation to change the isotopic composition of the lake water, as in the operculum from interval 3.45-3.40 m (Figure 3). The internal variability in this interval is recorded as a single spike from -6.18‰ to -1.6‰ for $\delta^{13}C$ and from -3.27‰ to -4.81‰ for $\delta^{18}O$. Extended periods of low $\delta^{13}C$ within individual opercula reveal seasonality; with warmer summer temperatures, the metabolic rate of *B. tentaculata* may have increased, causing an increase in the amount of metabolic, 12-enriched C incorporated into its shell (Tanaka et al., 1986).

Average operculum $\delta^{18}O$ values fluctuate throughout the core, with trends toward lower values indicating warmer conditions, and with trends toward heavier values indicating cooler conditions. $\delta^{18}O$ values are not covariant with $\delta^{13}C$ values (Figure 4). Using the calculated average sedimentation rate, the warm Boreal period, from ~4.5 m to ~3.8 m, coincides with lower $\delta^{18}O$ values, while the cooler Atlantic period, from ~3.6 m to ~2.8 m, shows a trend toward heavier $\delta^{18}O$ values. The warm Sub-Boreal, calculated to commence at ~2.0 m, shows a return to lighter $\delta^{18}O$ values.

Low average $\delta^{13}C$ values from opercula throughout Hed Core 1 may reveal warmer summer periods when *B. tentaculata* was incorporating more metabolic carbon into its shell, or periods of decreased lake productivity (Figure 5). With increased lake productivity, shallow lake water should become enriched in ^{13}C unless there is a great deal of vegetative decay close to shore (Fritz and Poplawski, 1974). Intervals with opercula which have high average $\delta^{13}C$ values coincide with intervals with a high abundance of *L. peregra*. This indicates *L. peregra* responded to increased lake productivity (rather than an increase in lake temperature) by producing more than a single generation per year.

CONCLUSIONS

- *L. peregra* responded to an increase in lake productivity by producing more generations during one growth season. $\delta^{13}C$ values from *B. tentaculata* opercula support this hypothesis

- The morphological variability of *L. peregra* throughout the core reflects the evolution of the lake into a bog; as the shoreline approached, energy and the size of the aperture increased. As the lake began to dry out, the size of the aperture dramatically decreased to guard against desiccation.
- Stable isotope values show variability within individual opercula throughout the core, which indicate fluctuating hydrologic and/or temperature conditions on a sub-weekly to monthly scale. On a larger time scale, $\delta^{18}O$ values correspond with shifts from warmer to cooler conditions.

REFERENCES CITED

Boycott, A.E. 1936. The habitats of freshwater mollusca in Britain. Journal of Animal Ecology 5:116-186.

Boycott, A.E., Oldham, C., and A.R. Waterson. 1932. Notes on the lake *Lymnaea* of south-west Ireland. Proceedings of the Royal Malacological Society of London 20:105-127.

Byrne, R.A., Reynolds, J.D., and R.F. McMahon. 1989. Shell growth, reproduction and life cycles of *Lymnaea peregra* and *L. palustris* (Pulmonata: Basomatophora) in oligotrophic turloughs (temporary lakes) in Ireland. Journal of Zoology, London 217:321-339.

Dussart, G.B.J. 1979. Life cycles and distribution of the aquatic gastropod mollusks *Bithynia tentaculata* (L.), *Gyraulus albus* (Muller), *Planorbis planorbis* (L.) and *Lymnaea peregra* (Muller) in relation to water chemistry. Hydrobiologia 67(3):223-239.

Eckblad, J.W. 1973. Population study of three aquatic gastropods in an intermittent backwater. Hydrobiologia 41:199-219.

Ellis, A.E. 1978. *British Freshwater Bivalve Mollusca*. The Linnean Society of London, London, 109 pgs.

Evans, N.J. 1989. Biochemical variation and shell shape in populations of the fresh-water snail *Lymnaea peregra* (Mollusca, Gastropoda, Pulmonata)from south-west Ireland. Biological Journal of the Linnean Society 36:65-78.

Fritz, P., and S. Poplawski. 1974. ^{18}O and ^{13}C in the shells of freshwater molluscs and their environments. Earth and Planetary Science Letters 24:91-98.

Hubdendink, B. 1951. Recent *Lymnaeidae*, their variation, morphology, taxonomy, nomenclature, and distribution. Kungliga Svenska Vetenskapsakademiens handlingar 3(4):1-223.

Lam, P.K.S., and P. Calow. 1988. Differences in the shell shape of *Lymnaea peregra* (Muller) (Gastropoda: Pulmonata) from lotic and lentic habitats; environmental or genetic variance? Journal of Molluscan Studies 54:197-207.

Macan, T.T. 1977. *A Key to the British Fresh and Brackish-water Gastropods, with Notes on Their Ecology*. Kendal, Freshwater Biological Association, Titus and Wilson & Son Limited, 46 pgs.392 pgs.

Stuiver, M., P.J. Reimer, E. Bard, J.W. Beck, G.S. Burr, K.A. Hughen, B. Kromer, G. McCormac, J. van der Plicht and M. Spurk. 1998. INTCAL98 Radiocarbon Age Calibration, 24000-0 cal BP Radiocarbon 40(3):1041-1083.

Tanaka, N., Monaghan, M.C., and D.M. Rye. 1986. Contribution of metabolic carbon to mollusc and barnacle shell carbonate. Nature (London) 320:520-523.

Wullschleger, E.B., and P.I. Ward. 1998. Shell form and habitat choice in *Lymnaea*. Journal of Mollucan Studies 64:402-404.

Wurster, C.M., and W.P. Patterson. 2001. Seasonal variation in stable oxygen and carbon isotope values recovered from modern lacustrine freshwater molluscs: Paleoclimatological implications for sub-weekly temperature records: Journal of Paleolimnology 26:205-218.

Wurster, C..M., Patterson, W.P., and M..M. Cheatham.1999, Advances in micromilling techniques: a new apparatus for acquiring high-resolution oxygen and carbon stable isotope values and major/minor elemental ratios from accretionary carbonate. Computers and Geosciences 25:1159-1166.