HOLOCENE CLIMATE CHANGE IN WESTERN IRELAND BASED ON FAUNAL AND GEOCHEMICAL DATA

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INTRODUCTION

Lough Carra, a shallow, freshwater lake, 14.38 km.^{2} in area, is part of a series of interconnected lakes and rivers that empty into Galway Bay. Located in County Mayo (53º41'N/009º12'W), the lake's proximity to the coast and the isolation of Ireland from the European continent provide little opportunity for rain fractionation or continental weather effects (Figure 1). There is little or no annual snowfall accumulation in the area. Due to this, ground water is not likely to be tainted by the isotopic characteristics of older water that has been locked up in ice caps. The 104 km^2 catchment area of Lough Carra is composed entirely of Carboniferous limestone, and little to no siliciclastic material is provided to the lake (Champ and King, 2000).

Methods

Throughout the six days spent on Lough Carra during July 2003, five, two inch diameter cores were taken by a steel, 2.5 meter, hand operated push core device using a small fishing boat. Within the steel device, polycarbonate tubing segments with lengths of 50 and 100 cm and diameters of 5 cm were joined with tape in order to contain the sediment and to facilitate easy extrusion of the cores. Lengths of the cores range from 82 cm to 218 cm. It was estimated that the marl within each core was compacted by approximately 10% during the coring and extraction process. Each core was taken ashore and divided into one centimeter intervals. Bulk density measurements were taken at five centimeter intervals.

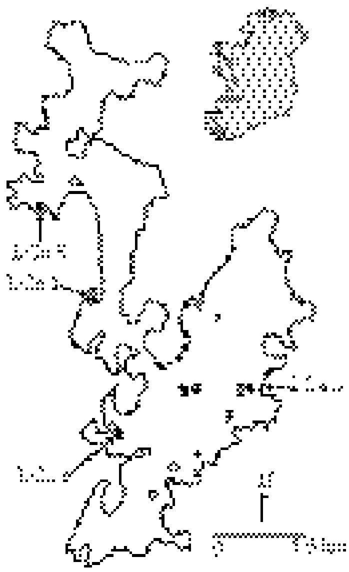

Figure 1: [illegible] Lough Carra [illegible]

The cores were transported to Amherst, MA, and the samples were sub-sampled for chemical analysis. The percentages of organic and inorganic carbon were determined through loss on ignition tests (LOI) that were run on the dried bulk density samples. The LOI tests were run at 500º C and 1000º C for one hour to determine the total organic carbon and total inorganic carbon contents, respectively.

At Trinity University, the five long cores taken from Lough Carra were examined for faunal analysis. Sediment from every fifth, one centimeter interval of the cores was soaked in 400 ml beakers with detergent and heated to allow complete disaggregation of the marl. The marl and its fauna were wet sieved using No. 30, 60 and 230 sieves. The residue from the No. 30 sieve was air dried and later picked for the mollusks. The bivalves and gastropods were then sorted, counted and taxonomically classified at a later time. One gastropod of the species *Lymnaea peregra* was taken from every fifth centimeter and sent to Dr. William Patterson at the University of Saskatchewan at Saskatoon for stable carbon and oxygen isotope analysis using a mass spectrometer

Discussion and Conclusions

When examining the trends in the isotopic data obtained from the three cores, LCa 1, LCa 2, and LCa 5, they all indicate trends toward lighter values (Figure 2). From bottom to top, the change is subtle, but all of the cores display this trend to one degree or another. This trend toward lighter values clearly shows a relative drop in temperature and decrease in lake productivity over time. General curvature around this trend is discussed in the section relating the stable isotope ratios to the faunal data. LCa 5 shows the greatest difference in average long term values with a drop of about 1.7 $^{o}/_{oo}$. Previous studies indicate that temperature shows a positive relationship with _^{18}O values with a coefficient of about .4 per mil / ºC (Mayer and Schwark, 1999). Because *L. peregra* grows primarily in the Fall, with little or no growth in the Winter or Spring, the isotope values reflect conditions at the end of the Autumn season (Byrne et al, 1989). With these facts in mind, analysis indicates that the average Autumn temperatures dropped approximately 4.25 ºC over the time span represented by the cores.

The loss on ignition (LOI) data is presented for 3 of the 4 cores examined in this study (Figure 3). LOI data for LCa 3 is incomplete and wrought with obvious error. However, LOI data is available for the three cores with stable isotope data. Trends in organic carbon contents of all 3 cores lend credibility to the interpretation that productivity throughout the lake has decreased over time. The organic carbon contents have decreased by about 2% for each core. Much like the carbon isotope ratios of the cores, LCa 5 and LCa 2 show the greatest change in productivity, while LCa 1 has a slightly steeper slope. LCa 5 appears to show that the greatest decrease in productivity for the site has occurred in the upper portion of the core. This is likely due to differences among the sites regarding water depth, microhabitats, and site energy.

Throughout many sections of the three cores sampled for stable carbon and oxygen isotopes, the _^{18}O and _^{13}C values exhibit weak to strong covariation. When a lake is hydrologically closed, it tends to exhibit the strongest degree of covariance and the isotopic ratios are more likely to reflect the temperature of the region and the biological processes within the lake (Talbot, 1990; Mayer and Schwark, 1999). Strong covariance and trends toward heavier isotopic values indicate a hydrologically closed system and the persistence of rising temperatures and greater lake productivity. If temperatures were to fall, both ratios would become more negative, yet the covariance would still be present. For hydrologically open systems, the residence time of the lake water is less and this often masks the isotopic effects of temperature and productivity (Mayer and Schwark, 1999). Lough Carra exhibits moderate to strong covariance throughout the cores, and the covariant fluctuations in carbon and oxygen isotope values indicate short term changes in temperature and productivity.

The covariance is punctuated by periods marked by inverse trends in the isotopic data in which the _^{18}O values decrease and _^{13}C values increase. This indicates episodes of dramatically increased precipitation. It has been shown that the amount of precipitation and its _^{18}O values have an inverse relationship (Rozanski et al, 1993). Therefore, during periods of substantially enhanced precipitation and storm intensity in the region surrounding Lough Carra, the oxygen isotope ratios of the precipitation became much lower. This water then traveled to the lake in streams and as groundwater, effectively lowering the _^{18}O values of the lake upon its arrival. The increased amount of stream water and ground water would also increase the amount of dissolved Carboniferous limestone that is contributed to the lake. The dissolution of Paleozoic carbonate contributes DIC values that range from -1 to 4 $^{o}/_{oo}$ (Dettman et al). This range is significantly higher than the typical _^{13}C values of -5 to -11 $^{o}/_{oo}$. Thus, a large increase in regional precipitation would cause a greater influx of relatively heavier DIC and raise the _^{13}C values recorded by the molluskan aragonite. The three cores with stable isotope ratios exhibit a period of increased precipitation and storm intensity near the top of each core. Similar events are recorded throughout the remainder of the cores.

Occurring at depths of 107 to 122 cm in LCa 2, we see a very prominent spike in the _^{13}C values from -10 to 1 $^{o}/_{oo}$. The rise in temperature indicated by the rise in _^{18}O values was accompanied by a very large increase in productivity at site 2. The carbon isotope data for sites 1 and 5 do not indicate an increase in productivity of the same magnitude, therefore the anomaly at site 2 is most likely due to local conditions within the microhabitat.

The four most abundant species found in the cores from Lough Carra, listed in order of descending abundance are: *Lymnaea peregra*, *Pisidium milium, Bithynia tentaculata,* and *Valvata piscinalis*. The most prominent ecological characteristic is that *Lymnaea peregra* is the most abundant and dominant species throughout the lake. Over relatively large time scales, the percentages of the next three most abundant species have inverse relationships with the percentage of *L. peregra*. When the quantity of each species rises, *L. peregra* rises at a greater rate, thereby increasing its presence during times of increased productivity. For each core, general trend lines are drawn in the graphs of depth versus _^{13}C values and depth versus the percent abundance of *L. peregra*. The trend lines clearly show a direct relationship between the productivity of the lake and the percent abundance of *L. peregra* (Figure 4). When productivity increases, _^{13}C values rise, and the quantity of *L. peregra* rises at a greater rate than the other common mollusks. The opposite relationship is also true. When lake-wide productivity declines, the percent abundance of *L. peregra* drops to levels roughly equivalent to the percent abundance of the other species. The percentage of *Pisidium milium* most consistently displays an inverse relation with the percentage of *L. peregra*. The graphs also indicate that for higher frequency fluctuations in productivity over short time periods, *L. peregra* generally has an inverse relationship with _^{13}C values. Thus, *Pisidium milium* would logically have a direct relationship with lake productivity during the short term. *P. milium* appears to take a greater advantage of short term rises in productivity, occasionally in unison with *B. tentaculata* or *V. piscinalis*; however, *B. tentaculata* and *V. piscinalis* exhibit less variation in percent abundance and quantity. This indicates that they are less affected by changes in lake productivity and provide ecological stability.

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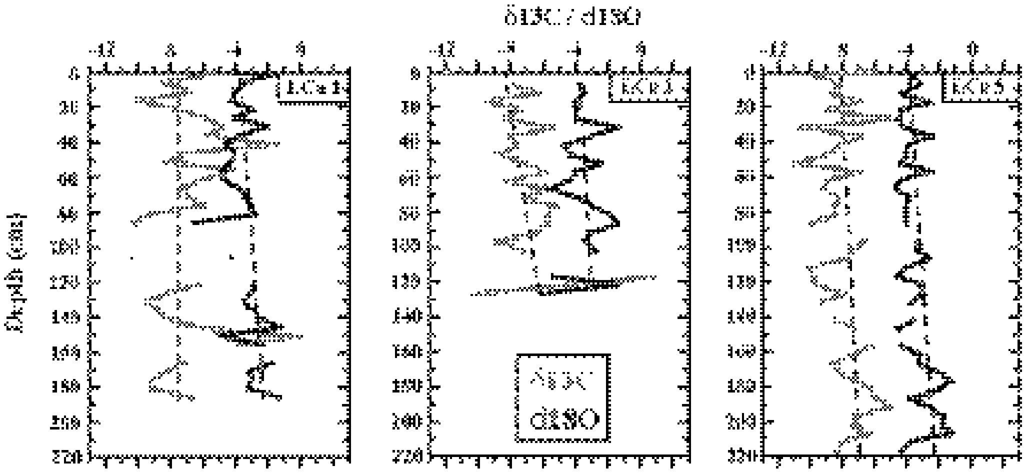

Figure 2: Carbon and Oxygen stable isotope data from Lough Carra. Dashed lines show general trends in the data, indicating a decrease in average Autumn temperature and a decrease in lake productivity. Covariance of the carbon and oxygen data sets indicates a closed hydrologic system. Inverse trends in the data sets indicate periods of increased regional precipitation.

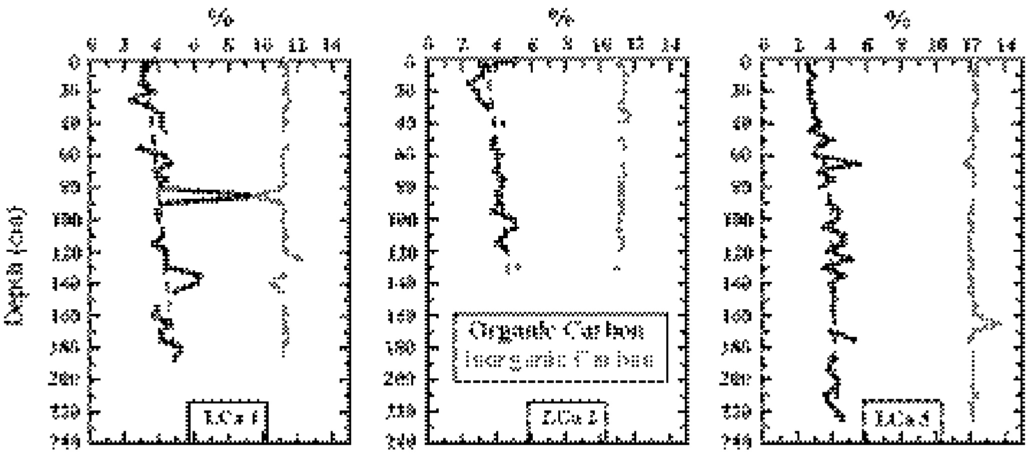

Figure 3: Loss on ignition data displaying the percent organic and inorganic carbon of each core. The dashed lines show trends toward lesser organic carbon values. This confirms the notion of a decrease in lakewide productivity suggested by the carbon isotope data.

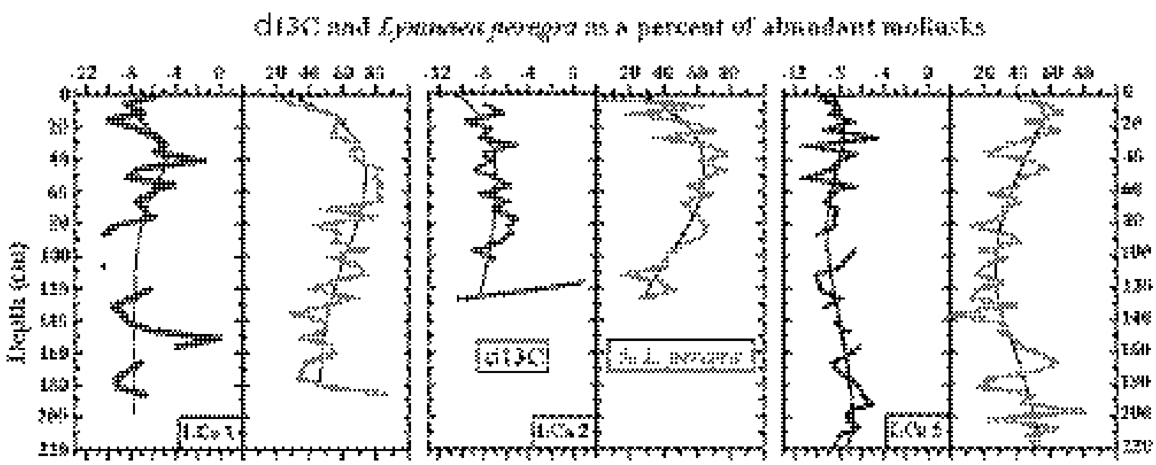

Figure 4: Graphs showing the carbon isotope values and the population of *Lymnaea peregra* as a percent of the total abundant mollusks. Note the long-term direct relationship in trend line curvature between the percent *L. peregra* and the d13C values. Over the short-term, the percent *L. peregra* has an inverse relationship with d13C values. This indicates that over longer time scales, *L. peregra* is more abundant during periods of high lake productivity while the species is less abundant during short-term productivity increases.