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Key words: biogeography, *fagus*, genetics, molecular markers, paleoecology, phylogeography, quaternary history.

Meetings

Quantifying ecological change using stable isotopes: digging deep into the past to predict the future

Isotopes as Tracers of Ecological Change Conference – a joint meeting of the Stable Isotopes in Biosphere-Atmosphere Exchange (SIBAE) program and the Biosphere-Atmosphere Stable Isotope Network (BASIN), Tomar, Portugal, March 2006

'The only constant is change' (Einstein, 1879–1955)

Isotopes as recorders

Since the beginning of the industrial revolution, ecological changes of unprecedented rate and magnitude have affected earth systems from oceans to forests to the atmosphere. Human population growth and ever-increasing resource consumption continue to drive major changes in atmospheric gas concentrations and climate (IPCC, 2001), biogeochemical cycles (Vitousek *et al.*, 1997; Klee & Graedel, 2004), land use and land cover (Brovkin *et al.*, 2004), and species distribution and abundance (Thuiller, 2003). Understanding how these factors have varied in the past is essential to predicting future ecological changes. Stable isotope recorders are allowing biogeochemists to reconstruct ecological history and, using historical data, forecast ecological trends. Researchers in the field of stable isotope biogeochemistry have developed ways to track dynamic ecological processes on temporal scales from days to millennia. Scientists from 26 countries recently converged at Tomar, Portugal, to discuss ecological changes recorded in materials as diverse as hair, wood, lake sediment, and ice cores.

> *'Trees are promiscuous integrators – they record so many interacting signals from their environment that interpreting their isotopic signatures is often difficult or impossible without adequate replication.'*

Isotope archives as windows into the past

Ice cores from high latitudes and altitudes have played a pivotal role in reconstructing the climate and atmospheric conditions of the past. James White (Colorado University, Boulder, CO, USA) and colleagues presented a 2000-year global methane budget estimated from Antarctic ice cores (Ferretti *et al.*, 2005). Methane is a very efficient greenhouse gas, and its atmospheric concentration has risen to historically unprecedented levels since the industrial revolution began. However, ice core $\delta^{13}C$-CH_4 values have fluctuated significantly over the past 2000 years, suggesting that source contributions to atmospheric methane have changed over time. Biogenic CH_4 emissions, originating from wetlands, are highly depleted in ^{13}C and are sensitive to climate. At the other end of the isotopic spectrum, biomass burning produces a less depleted $^{13}C\text{-}CH_4$ signal, approximating the $\delta^{13}C$ of the biomass being combusted. By linking CH_4 concentrations and isotope values from the ice archive with paleoclimatology and human population dynamics, White and colleagues found that the two principal controls on the 2000-year global CH_4 budget are climate effects on CH_4 biogenesis and a decline in North American biomass burning after *c.* 1500 AD (Ferretti *et al.*, 2005). The partitioning of CH_4 into sources is especially relevant in light of the current uncertainty in the global methane budget (Keppler *et al.*, 2006). White and colleagues hope that stable isotopes will help resolve critical questions concerning the current magnitude of CH_4 originating from terrestrial plants, as well as from shifts in land use and climate.

Temperate trees record climatic and biogeochemical signals in their growth rings with perfect annual resolution, making them excellent integrators of past conditions (McCarroll & Loader, 2004). Isotope records in temperate trees extending thousands of years into the past have been retrieved from ancient living trees and dead wood preserved in cold lakes. Ancient forest sites preserved in cold bodies of water are widespread in the northern hemisphere and are valuable sources of tree-ring isotope chronologies. By sampling individual trees as replicates, researchers can calculate confidence intervals around estimates of past climate conditions. Neil Loader (University of Wales, Swansea, UK) suggested in his presentation that replication is both a strength and a necessary evil in the realm of tree-ring isotope archives. Trees are promiscuous integrators – they record so many interacting signals from their environment that interpreting their isotopic signatures is often difficult or impossible without adequate replication. But, when sampled intensively, tree rings can provide precisely bounded estimates of past environmental conditions within stands and across regions. Such high spatial resolution could enhance our understanding of past regional-scale climate variability, which would be very useful to climate modelers today.

The future is in isotopes

Isotope recorders are not only used to reconstruct the past, but may also provide glimpses into the future. Claudia Mora and colleagues (University of Tennessee, Knoxville, TN, USA) are using isotopes to evaluate hurricane frequency over the past several centuries in the eastern USA, well before coastal weather events were routinely documented. Because ^{18}O is fractionated during evaporation, rain from hurricanes is heavily depleted relative to precipitation from even the most severe thunderstorms (Gedzelman & Arnold, 1994). Thus, hurricane precipitation carries a unique ^{18}O signal, providing a marker that is preserved in tree rings when taken up by shallow rooted species. Indeed, Mora and colleagues have identified highly depleted ^{18}O signals in tree rings that correspond with known hurricane events, and conversely they have found prolonged ^{18}O-enriched signals that are aligned with hurricane dry spells. So, what about linking the past to the future? Mora and colleagues hope that using this method to reconstruct hurricane patterns across the south-eastern USA over the past 500 years will inform us about what is controlling decadal variation in hurricane frequency, and ultimately improve models used to predict hurricane occurrence, severity, and distribution.

Isotopes also are becoming an increasingly popular tool for quantifying human influences on atmospheric gas composition and ecosystem function. Diane Pataki (University of California, Irvine, CA, USA) presented work on isotope tracers in urban environments, an area of research that is increasingly important as urban ecosystems expand (Grimm *et al.*, 2000). Pataki and colleagues used a dual isotope (^{18}O and ^{13}C) approach to partition CO_2 sources in urban environments, identifying the fraction of CO_2 emissions derived from respiration, and natural gas and gasoline combustion (Pataki *et al.*, 2003, 2006). In an effort to evaluate variability in CO_2 sources across the dynamic and mottled human land-use gradient surrounding cities, they are conducting research in suburbs and exurbs as well as in dense urban areas. Pataki works closely with land-use planners to translate results from isotope studies into tangible information for decision makers grappling with air pollution and energy consumption. Pataki envisions that this work will contribute to complex coupled human-environment models used to inform scientists, policy makers, and urban planners alike. Nina Buchmann (ETH Zurich, Zurich, Switzerland) expressed parallel sentiments, discussing the role stable isotopes play in assessing mechanisms of biodiversity and ecosystem function (Kahmen *et al.*, 2005).

A central objective of the isotope community is to synthesize empirical observations in models that predict global-scale trace gas composition and the distribution of anthropogenic source gases such as CO_2 and NO_2 (e.g. Cuntz *et al.*, 2003a, >b). Matthias Cuntz (Australian National University, Canberra, Australia) and Markus Leuenberger (University of Bern, Bern, Switzerland) discussed progress in the global modeling of trace gases and isotope fluxes. While improvements are being made in the predictive power of these models, the isotope community as a whole is unified in citing the need for a broadly distributed gas sampling network, analogous to and possibly in conjunction with the EuroFlux and AmeriFlux networks established to measure CO_2 and H_2O fluxes across a range of ecosystems in Europe and North America. Monitoring networks that emphasize real-time data collection will enhance our understanding of current global change trends and, when integrated into process models, could be used to make predictions about the future. As Keeling's atmospheric CO_2 data from Mona Loa did, long-term gas isotope measurements may reveal significant trends only after several years (e.g. Keeling *et al.*, 1995). With instruments such as the tunable diode laser providing instantaneous gas isotope ratios, widespread and long-term measurements of isotope fluxes may become much more common in the coming decade. Just as field measurements of H_2O and CO_2 fluxes have increased with portability of the infrared gas analyzer, expect the isotope community to grow with technology. And while the only constant may be change, as Einstein suggested, stable isotope recorders documenting past and present variability in climate, land use, and biogeochemistry undoubtedly will advance our capabilities to predict future change.

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