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ECOSYSTEM PROCESSES AND PAST HUMAN IMPACTS

Mono Lake, California. The hydrological systems of the western Great Basin, including relicts of Pleistocene great lakes, are key ecosystems in the semi-arid regions of western United States. Dams and diversions have diverted water to metropolitan and agricultural areas for over 70 years, with significant impacts to endemic species, critical habitats, and human health. The emerged tufa towers surrounding the lake are impressive monuments to the impact of water diversion for human use as this comes to over-ride the effects of natural variability (see article by Constance Millar in this issue).

EDITORIAL

As a result of human actions and their impact on the environment, we now live in a 'no-analogue' biosphere; but these human actions have a history which, in some areas, stretches back over thousands of years. Understanding present day and effectively anticipating future global changes calls for a thorough appraisal of this history, as several of the articles published here emphasize.

PAGES has paid little attention to this theme until recently and this is our first Newsletter to concentrate almost entirely on **Human Interactions in Past Environmental Changes**, the subject of 'Focus 3' in the PAGES Agenda. Our hope is that this will soon evolve into the broader theme of **Past Ecosystem Processes and Human-Environment Interactions** – a re-definition that recognizes the need to:

- integrate past human-environment interactions at sub-continental scale with research and modeling based on present day ecosystems and watersheds.
- expand PAGES concern with ecological *responses* to global change

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The challenge is enormous and meeting it will be a long-term endeavor. It will involve uniting methodologies from many areas of the environmental sciences, as well as creating true synergy between the perspectives on either side of the biophysical/socio-cultural divide. We have to take into consideration the fact that the diverse cultural basis of all human activities has led to impacts on the biosphere and on biodiversity through time that are strongly differentiated from place to place. We therefore need a regional/case-study based approach designed to improve our understanding of the processes of past global change in all their different manifestations. The present selection of articles illustrates the vigor and diversity of the field, as we begin to include it in PAGES. The contributions include information on the three interlocking strands of 'Focus 3', HITE (Human Impacts on Terrestrial Ecosystems), LUCIFS (Land Use and Climate Impacts on Fluvial Systems) and LIMPACS (Human Impact on Lake Ecosystems and the role of Paleolimnology), as well as articles with a strongly conceptual and methodological basis and a wide range of case studies including some which illustrate fruitful paleodata-model interaction in this field.

Out of this vigor and diversity, the challenge will be to develop the best possible unified frameworks for achieving effective research coordination, data assimilation, data-model comparisons, mutually reinforcing interactions between the 'paleo' and 'contemporary' modes of study, as well as regional-global spin-offs in both directions. Bearing in mind that natural resources in general, and food and water in particular, will become integral topics in future global change research programs, PAGES has a responsibility to analyse the dynamic interactions between past natural variability and human activities in the context of a growing world population and its rapidly increasing use of natural resources. We are not discouraged by the enormity of the challenge, for our personal perspective on the recent history of paleo-research convinces us that it is just a question of time, motivation and the urge to cross boundaries and collaborate. We see this newsletter as an early step.

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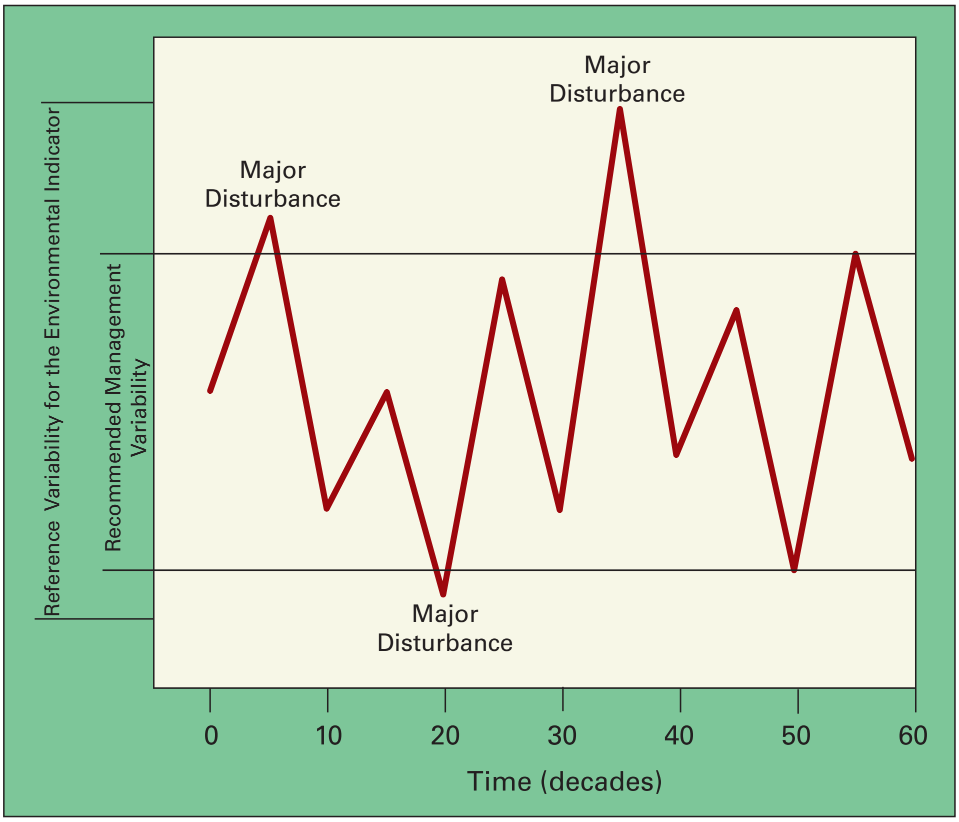

Historical Variability in Ecosystem Management

As frontiers closed in North America's wildlands during the late 20th Century, ecosystem management emerged as the guiding principle for many public land-managing agencies. Mandates shifted from emphasis on resource extraction (timber, water, minerals) to ecosystem protection, and the concept of ecological sustainability became central. The mission statements of the U.S. Forest Service, Bureau of Land Management, U.S. Fish and Wildlife Serivce, and U.S. National Park Service, for example, herald ecosystem sustainability – maintaining composition, structure, and process of a system – as key policy goals. Similarly, many conservation programs and non-governmental organizations such as The Nature Conservancy and The Wilderness Society embrace sustainability as a scientific foundation to conservation planning.

Although ecosystem sustainability caught on quickly as a policy goal, implementing it on-the-ground has proven difficult. The newly proposed land management planning rules of the US Forest Service (USDA FS, 1999) are among the first to prescribe operational steps to achieve ecosystem sustainability. The rules, based on a national committee of scientists' report (COS, 1999), codify what has become common thinking among conservation communities: "*Ecosystems whose current range of variability, through space and time, approximates the historical range are considered to have high integrity and be in a sustainable condition*" (USDA FS, 1999).

Historical variability has thus emerged as a surrogate for sustainable ecosystems. The logic behind this derives from recognizing that ecosystems were functioning adaptably (i.e., sustaining themselves) prior to arrival of modern humans. Thus, if managers

Figure 1: Hypothetical variability of an environmental indicator over 600 years, used as an example of historical, or reference, variability in a federal ecosystem-management guidebook. Such portrayals erroneously assume that background conditions remain unchanging (i.e., have a flat average) over time and that ecological dynamics are contained within a constant range of variation. (USDA FS 1995)

ensure the restoration of historic conditions, ecosystems will be sustainable. "Historical" in these contexts has been interpreted as meaning an unprescribed amount of time prior to Eurasian settlement, which in the western United States occurred in the mid-1800s. Inferences of pre-settlement conditions (e.g., USDA FS, 1993) are used as references for evaluating impacts of human activities in landscape analysis, targets for ecological restoration, baselines for monitoring, and descriptions of desired future landscape conditions.

Although we should applaud the incorporation of time and variability concepts in conservation planning, a deeper understanding of paleoscience is needed. Modern ecology has embraced concepts of ecological dynamism, yet often this has focused on short-term forces of succession and disturbance. An erroneous implicit assumption remains that there are insignificant background changes over time – i.e., that trendlines are flat (fig. 1). For western North American wildlands, for instance, this translates to using the Little Ice Age as the reference historical period. There is little recognition that conditions during that period might be significantly different from the present, and are likely inaccurate pictures of what adaptable "natural" systems would be now. Without understanding the nature and magnitudes of past climate and ecological changes, conservation scientists and managers are limited in the ability to first separate and then mitigate real human impacts from inherent environmental change. Further, using historical variability as a baseline for evaluating human impacts can lead to misdiagnosing the cause of changes and to a misprescription of management and restoration treatments (Millar and Woolfenden 1999).

Concerns such as these are at the heart of discussions emerging within the paleoscience community. The PAGES Focus 3 programs address past impacts of human activities on ecological and hydrological systems. Other efforts, to name only a few, have included special sessions and publications at annual meetings of the Ecological Society of America (Parsons and Swetnam, 1999; Hyeerdahl and Card, 2000), and at the fall 2000 meeting of the American Geophysical Union ("Past land cover, human activities, and climate variability: Future implications", December 2000).

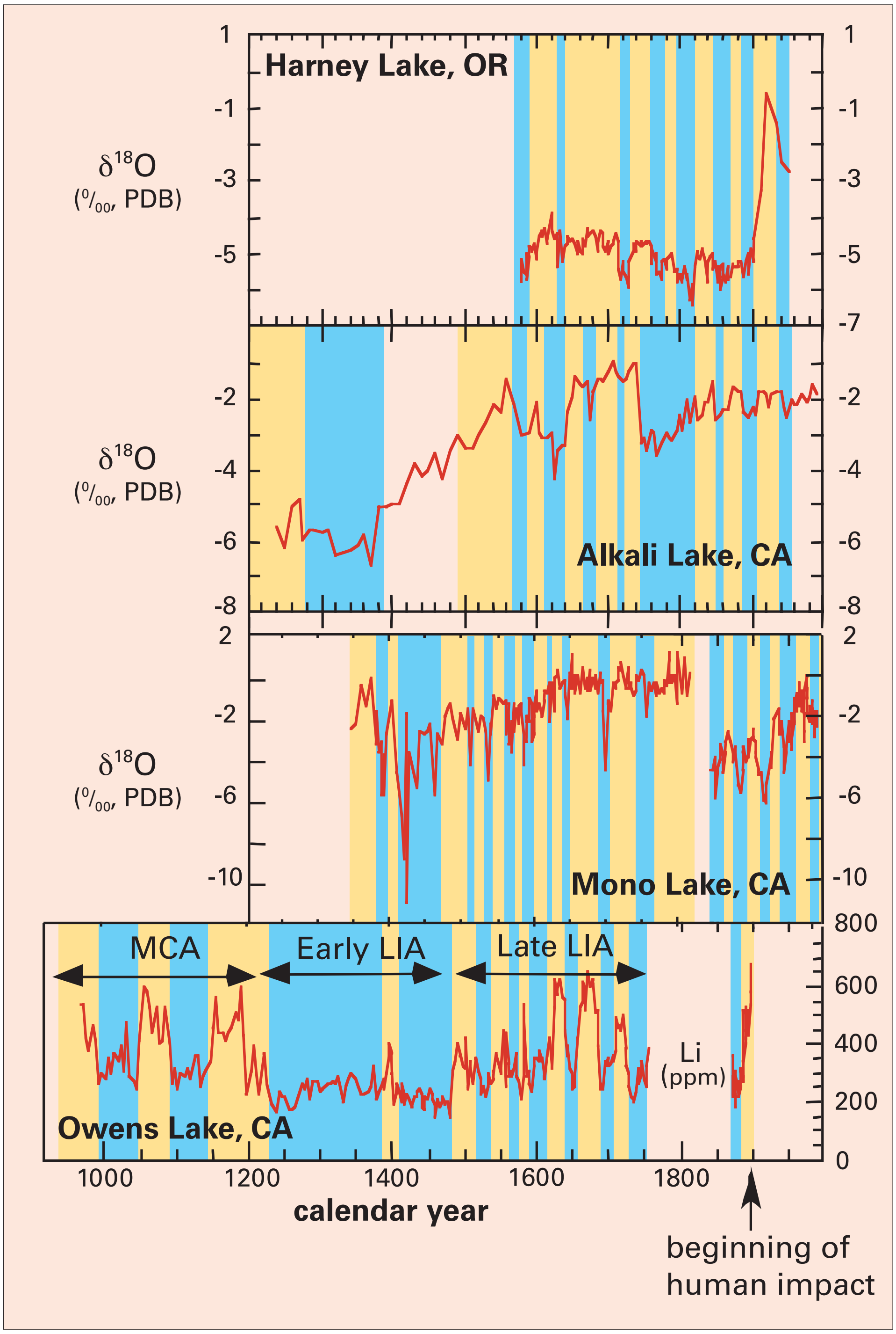

Figure 2: Variability at annual to century scales in lithology and δ18O for the last 1000 years at Owens, Mono, and Alkali Lakes, CA and Harney Lake, OR. In each panel, higher values of indicators indicate drier conditions. Colored bands highlight significant positive (yellow) and negative (blue) anomolies; patterns of correspondence among lakes show both similarities and discrepancies in lake histories. Impacts from water use began in the Owens Valley in the mid-1880s. Information on past variability such as this will help conservation scientists and policy-makers interpret potential future climate effects and guide development of restoration strategies within a context of high water demand (unpublished from Hungchun Li, Dept. of Earth Science, University of Southern California, Los Angeles, CA, USA).

A recent workshop in Bishop, CA, sponsored by the US Geological Survey, US Forest Service, and six other agencies on "Impacts of climate change on landscapes of the eastern Sierra Nevada and western Great Basin" brought 80 scientists and resource managers together for 3-days to discuss application of climate change science to resource management (see: *www.wmrs.edu/sw-greatbasin*). Some conclusions from the Bishop meeting exemplify common, if not surprising

Ecosystem Management, continued from page 3

to paleoscientists, lines of thought that run through these discussions: Climates have changed significantly over the past centuries, with large effects on ecosystems; climate trends can reverse or change abruptly — plant and animal communities track these; mechanisms for medium- to high-frequency climate changes are posited, but effects on local regions are poorly understood; useful historical analogs for the present do not exist; climate and ecosystem conditions for the next 50–100 years cannot be accurately predicted, yet likelihood of change is high; the best guess about near-future climates is toward greater extremes and more frequent shifts; human effects are now integral to ecosystems and must be incorporated in planning; social infrastructures for natural resources are built on assumptions of steady states and unchanging climates, and are unprepared for high variability and uncertainty.

Managing ecosystems for resilience becomes a major conclusion of such observations. Resilience will take different forms depending on scale, biomes, and regional histories. Resilient ecosystems may not look like historical or "natural" systems, and templates are not obvious. Much can be learned about resilience by studying responses of historic ecosystems to past climate and environmental change. Thus, understanding how systems vary (fig. 2) and what makes a particular system resilient under different climate change conditions are priority topics in the nexus between paleoscience research and resource management.

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The Human Factor in Paleoclimate

The suggestion that human activities are having a major influence on contemporary climatic patterns is being accepted by an ever-increasing number of scientists and citizens. Today, two-thirds of the terrestrial surface of the planet is covered by agricultural land, livestock grazing areas, and managed forests (Farina 2000). In addition humans use over half of the accessible fresh water on Earth and more atmospheric nitrogen is fixed by human activities than by all natural terrestrial sources combined (Vitousek *et al.* 1997:494). The more we study, the clearer it becomes that virtually all ecosystems throughout the world are strongly influenced by human activities. Anthropogenic forces are something that must be factored into any analysis of the condition of the atmosphere, land surface, or climate. Moreover, we expect these human drivers to become even more dominant in the future, leading to the much-feared impacts on our global systems.

The more difficult question is how far back into the past have humans been a significant force in environmental transformations and climatic change. Where past impacts have been siginificant a better understanding of them would significantly improve modeling of future climate change. After reviewing the growing archeological literature on this subject, I have argued elsewhere (1999) that substantial human impacts, especially through dramatic changes in land cover, are as old as the introduction of agriculture (2,000 to 10,000 years ago depending on region) and some forms may be much older. The introduction of agriculture is regarded by many to be the single most important transformation in human history. The shift from nomadic hunting and gathering to a settled agricultural village existence heralded changes in almost every facet of life and laid the necessary foundations for the growth of urban society and political hierarchies. Looking back from the perspective of today, the decisions and innovations that were associated with the introduction of agrarian village life must have been rational at the time, but we now know they had social consequences of debatable merit and long-term environmental impacts that were unquestionably negative and ultimately undermined the very subsistence base they had

Figure 1: Salinization has undermined the productive potential of this region in southern Iraq, as it did to many regions in the past.

worked so hard to establish. People settled into sedentary communities, population aggregated into denser settlements, and increasingly, communities relocated themselves to favor certain geographic locations over others. Initially this meant a preference for arable land that could be easily farmed with available rainfall, but even in prehistory the best land was soon filled. Further growth was only possible through the intensification of production, which meant a further aggregation to areas where irrigation was practical. This led to higher productivity per acre, as witnessed by the fact that 40% of modern crop production comes from only the 16% of agricultural land that is irrigated (Matson *et al.* 1997:506). The key point is that over the millennia, as world population has increased dramatically, it has not spread itself evenly over the landscape, but has increasingly favored select locations over vast stretches that remain lightly settled, if at all. Accompanying this concentration of human settlement and intensified agrarian strategies has come massive redirection of natural processes, such as the impoundment and redistribution of surface water through irrigation, the construction of flood control devices, or the spread of urban settlement itself.

Also relevant to our consideration of land cover change is that agriculture involves the substitution of a managed community of domesticated plants and animals for the species native to the region. Suppression of competition for light, water, and minerals usually has meant the removal of native trees and shrubs in favor of planted cereal grains, an overall reversal of the naturally occurring successional sequence. With more intensified efforts to increase productivity and to respond to the opportunities in a market

economy many farmers chose to specialize in fewer crops, leading to large areas with monocrop fields.

Although agriculture has in most cases led to short-term increases in productivity, the imbalances created through deforestation, soil erosion, and soil mineral depletion undermined the sustainability of the newly established food production system in many localities, leading to food shortages, and eventual abandonment. Case studies of early farming successes followed by local disasters have been documented in 7th millennium BC. Jordan (Rollefson and Kohler-Rollefson 1992), the prehistoric American Southwest (Kohler 1992), ancient Greece (Van Anadel *et al.* 1990), and many other areas (see Redman 1999). Over time, the cumulative effect of these types of episodes in a region would be widespread land cover transformed in support of agriculture as well as many landscapes that have reverted to a degraded forest condition after the demise of the agrarian system. This in turn may have been followed once again by new efforts at farming, leading to regions exhibiting mixed use landscapes with both cultivated fields and remnant patches of degraded natural vegetation (see Butzer 1996 for a discussion of the Eastern Mediterranean).
Despite local setbacks, the introduction of agriculture led to regional and even continental scale land cover transformation as long ago as 6000 BC. With the adoption of a food producing economy most communities became sedentary and increased in size. With the control of production, the ability to store annual food surpluses, and the advantages derived from investment in facilities and more sophisticated equipment the foundation was laid for regional and eventually for global population increase. Taken together this led to what I consider the second major transformation in the human career, the emergence of complex, hierarchical society. Cities and state political organization are their most obvious manifestations, but their growth is tied to a fundamental transformation in human perception of the natural world. With the ability to produce and store more goods than one could consume and a food production strategy in which some tracts of land were more valuable than other tracts, there emerged far more developed concepts of value and ownership. When one could use only what one could consume there would be less impetus to produce a surplus, but if that surplus could be transformed into objects that yielded special status or represented power over others, the drive to produce more would be strong. Prestige goods, especially those whose production could be controlled by being made of exotic raw materials or according to a guarded technology played a central role in the emergence of hierarchical urban society. The environmental implications of this transformation are dramatic: a multiplication in demand for food production, extraction of minerals, and construction of public works. With these changes came early mass production industries, regular long distance movement of goods, huge urban aggregations of population, and the initiation of large-scale military campaigns. Evidence of a human imprint on the landscape became even more pervasive than with farming villages alone. These cultural landscapes were characterized by vast fields of cereal grains, orchards, terracing of mountain slopes, canals and levees to redirect surface water flow, and cleared and often paved roadways to facilitate the movement of goods and people. Periods of deforestation (the Maya; Rice 1996), soil erosion (west Mexico; O'Hara, Steet-Perrott, and Burt 1993), or salinization of irrigated lands (Mesopotamia and American Southwest; Redman 1992) were sometimes the result of growing urban populations, while at other times these state level societies were able to stabilize the land surfaces and regenerate soil fertility to produce an agricultural regime that could be sustained for centuries (west Mexico; Fisher and Thurston 1999).

Figure 2: Goats consume both leaves and twigs on these oak trees. Note the goat foraging in the tree in the foreground.

Figure 3: Young villager gathering vegetation for her domestic hearth in the western Mediterranean region.

There is increasing archeological evidence documenting that for long periods of time people have had a widespread impact on land cover distributions and therefore on climate change. The far more difficult questions revolve around what that relationship was and how significant were these impacts. The answer to these questions will only come with continuing cooperation between archeologists and paleoclimatologists. Increasingly precise reconstructions of habitats and land cover changes and accurate correlations with changes in local societies are necessary if we are to move beyond hypotheses to a working science.

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

The Ystad Project – A Case Study for Multidisciplinary Research on Long-Term Human Impact

"The cultural landscape during 6000 years in southern Sweden" was the topic for a multidisciplinary study of an area bordering the town of Ystad in southermost Sweden during the 1980´s. The study area (30 000 ha), covering a coastal lowland and an inland upland involved a gradient from a "central" and early inhabited area to a "marginal" and late inhabited area. Such an ecological gradient is typical for many regions in Europe and this is also convenient for settlement and landscape historical studies, since it is then easier to detect signals of so-called expansions and regressions of settlement and agrarian activities. The main aim of the project was the documentation of such a pattern, which was earlier described by pollen analysts (Berglund 1969), but not compared with archeological data in a systematic way. Our project employed a coordinated strategy for paleoecologists, archeologists, historians, human geographers and plant ecologists in order to describe the landscape history from the introduction of agriculture until modern time, the interaction between humans and environment and the causes behind Late Holocene landscape changes. Inventories were made in the entire area, key sites (often lake catchments) were selected along the main gradient for paleoecological and settlement historical field studies. The paleoecological techniques involved were pollen and plant macrofossil analyses, diatom analysis, sediment geochemical and mineral-magnetic analyses. Combined paleoecological and archeological data made it possible to interpret the land use patterns and the openness of the landscape for ten selected time windows. These data resulted in ten landscape historical maps for the entire area, and some more detailed maps for selected village areas. The calibration procedure for paleodata was semiobjective; quantification methods are still under development (Sugita *et al.* 1999). A survey diagram demonstrates the general pattern of the cultural landscape development, comparing coast/inland and dry/wet ground (Fig. 1). This project resulted in one main interdisciplinary, monographic synthesis (Berglund 1991), two archeological monographs and numerous journal papers.

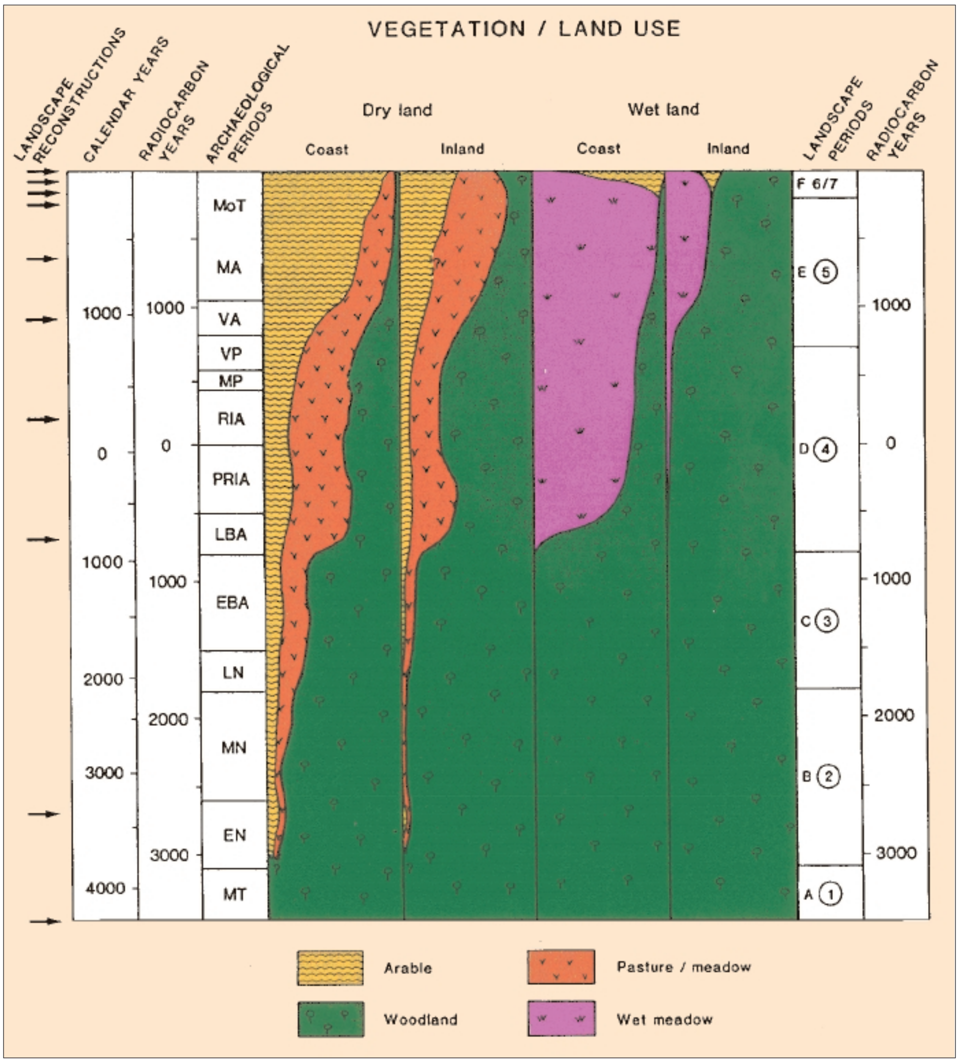

Figure 1: Synthesis diagram based on 10 pollen diagrams from the Ystad area, Southern Sweden, showing the deforestation and land-use pattern for the last 6000 years (Berglund 1991). Landscape reconstructions (maps) have been performed for the 10 time windows indicated by arrows.

The results from southern Sweden may be correlated with similar studies in a wider geographical area. Within Southern Scandinavia (Denmark and Southern Sweden) we can identify five obvious expansion periods during the last 6000 years. They correspond to the beginnings of the landscape periods 2 to 6 indicated in Fig. 1. A further correlation has been done by using numerous pollen diagrams along a NW European transect from Ireland to Estonia (Berglund *et al.* 1996), in fact showing great synchroneity of two main phases of human expansion, which lead to deforestation and some erosion in NW Europe: c. 1000–800 BC and AD 600–1000 (Fig. 2).

In the synthesis of the Ystad project the causes behind the landscape/land use changes were discussed. The background to the expansion phases were generally found in the changes of the society in Central Europe (population pressure, organization, economy, technology, etc), impacting on Southern Scandinavia. However, when compiling and comparing the most important human impact events of the agrarian society in NW Europe, expansions as well as regressions, it is striking that environmental changes caused by climate change occurred at the same time (Fig. 3). The timing even shows a pattern similar to the Bond cycles, with coolings at c. 5900, 4200, 2800 and 1400 BP (Bond *et al.* 1997). However, to quantify such correlations requres improved dating

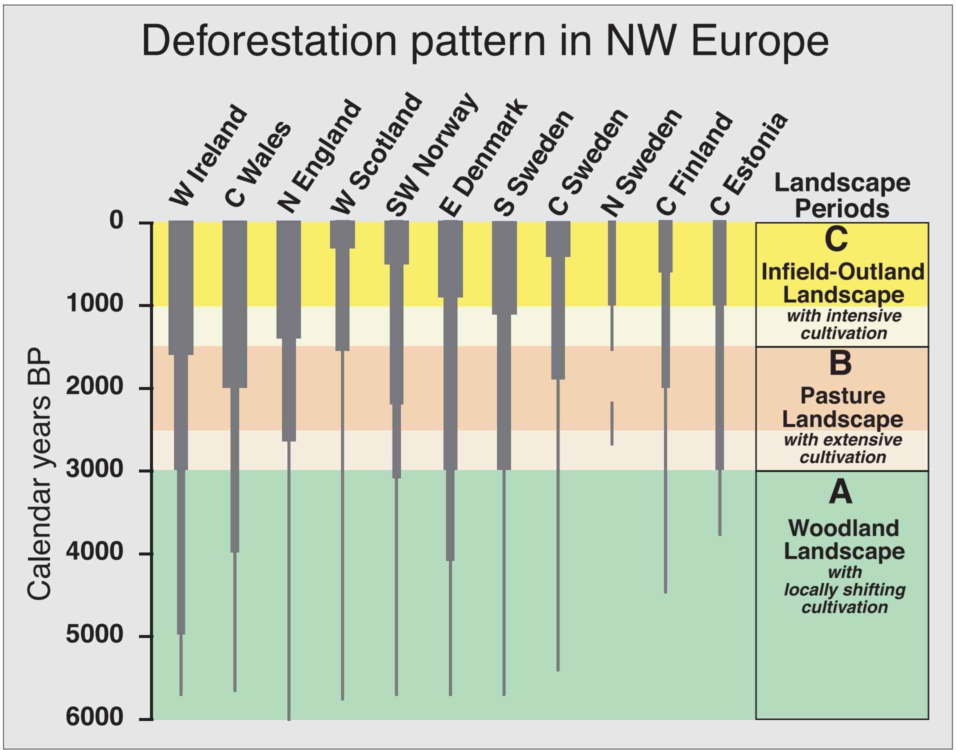

Figure 2: Deforestation pattern in NW Europe, which indicates the main changes of land-use and cultural landscape after 1000 BC and before AD 1000 (based on Berglund et al. 1996).

Human impact /climate change events in NW Europe

Event	Age cal BP	Human impact	Climate change	Geogr. area
1	5900 BP	+ agriculture: deforestation erosion?	+ tree limit - glaciers - lake level	NW Europe
2	5500 BP	- agriculture: forest regeneration	- tree limit + lake level	NW Europe
3	4500 BP	+ agriculture: deforestation heathexpansion	+ bogs + glaciers	Ireland Scandinavia
4	3800 BP	+ agriculture: deforestation	- tree limit + bogs + erosion	Scotland Scandinavia
5	3000–2800 BP	+ agriculture: deforestation erosion	- tree limit + glaciers + bogs + lake level	Ireland S Scandinavia Poland Holland
6	1500 BP	- agriculture:	- pine growth + bogs	NW Europe
7	1100 BP	+ agriculture: deforestation erosion	+ tree limit and pine growth - glaciers - bogs	NW Europe C Europe

Figure 3: Comparison of human impact and climate change in NW Europe for selected events (1-7). The direction of the ecological change patterns are described with + for expansion/rise, with - for regression/reduction/lowering. Selected references (besides Berglund 1991,1996): event 1 (Digerfeldt 1988, Karlén and Kuylenstierna 1996, Karlén and Larsson 1999, Sandweiss et al. 1999), event 2 (in addition to event 1: Molloy and O`Connell 1995, Schibler et al. 1997), event 3 (Aaby 1976, Karlén and Kuylenstierna 1996, Molloy and O`Connell 1995), event 4 (Aaby 1976, Anderson et al. 1998, Karlén and Kuylenstierna 1996, Snowball et al. 1999, 2000), event 5 (Aaby 1976, Digerfeldt 1988, Karlén and Kuylenstierna 1996, Kullman 1988, Snowball et al. 1999, 2000), van Geel et al. 1996), event 6 (Aaby 1976, Eronen et al. 1999, Karlén and Kuylenstierna 1996), event 7 (as event 6).

precision and a better understanding of the climate signals (cf. Sandweiss *et al.* 1999). Some of these events seem to involve complex climate dynamics of cool as well as warm phases, e. g. events 1 and 5.

Future research on long-term human impact, in Europe as well as worldwide, should preferably adopt the following strategy:

- apply multidisciplinary paleoecological research in a network of key areas
- combine paleoecology and archeology in order to obtain mutual calibration of data
- use high-resolution chronology, i.e. annually laminated sediments or wiggle matching radiocarbon dates (cf. Ralska-Jasiewiczowa *et al.* 1998, Segerström 1999, Snowball *et al.* 1999, Zolitschka 1998)
- calibrate paleovegetation data by using the modern analogue technique (cf. Sugita *et al.* 1999)
- develop methods and strategies for discriminating climate change from human impact

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Main reference

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

Bridging the Biophysical-Cultural Divide: The Role of Historical Ecology

Throughout the twentieth century, the need to reach scholarly consensus in characterizing the relationship between humans and the environment steadily grew more pressing. Assumptions at the beginning of the century favored a determining role for environment and biology; this was then countered by social scientists, who convincingly demonstrated the enormous role of culture in explaining behavior.

Contemporary research assumes both that humans have altered the environment and that environmental change has shaped the human species and revised human activity. The beginning of the twenty-first century finds humanity with greatly expanded powers to bring about both beneficial and detrimental changes in the global system, but also facing enormous dangers – many, although not all, the result of previous human activity. The quality and quantity of evidence documenting change in the global ecosystem have never been greater but, as understanding of a dynamic Earth system that includes humans increases, discipline-based research frameworks still treat only portions of the system.

The enormous complexity of the human/environment interaction poses an urgent new set of questions: Which human activities impact the global system? How are those impacts manifested? How do global changes threaten human activity? Where are the thresholds beyond which the harm done to human populations and to their environments cannot be repaired? Can human activity that is in accord with the global environment be identified and fostered? In the search for answers, a major challenge is how established scholarly disciplines can collaborate.

In the middle decades of the last century, the complexity involved in answering various aspects of these questions necessitated greater specialization in every field of study. Today, the resultant discipline-based structure of educational and funding institutions has made it immensely more difficult to foster research that untangles circumstances in which both human activity and the global system are in flux. If answers to the new questions are to be found, some basic changes must be made. Disciplines and institutions long accustomed to setting unitary research goals must learn to formulate and carry out collaborative projects, and individual researchers must be rewarded, not punished, when they expand their understanding (if not their expertise) beyond their own training.

What is needed is a flexible framework that integrates biological, physical, and social scientific information with insights from the humanities. Such a framework would focus on spatial and temporal scales that permit the dynamic effects of both human activity and environmental change to be monitored and their links tested. Because values and perceptions motivate human activity, an integrated framework must also include evidence that is difficult to quantify but critical to policy making (Dunlap 1992, 1993; Gore 1994; Kempton *et al.* 1995; Olsen *et al.* 1992).

Historical Ecology: Enabling Interdisciplinary Collaboration

Several key elements of an integrated framework are now in place. Scientific understanding of the interconnectivity of the atmosphere, hydrosphere, biosphere, and geosphere in the global system is growing (Broecker 1995; Gunn 1991; Lovelock 1989; Root and Schneider 1995; Turner *et al.* 1989); this parallels earlier research in ecosystematics (Holling 1986; Ellen 1982). Similar developments in social science theory and methods enable comparable evaluation of human activity at several temporal and spatial scales (Balee 1998; Crumley and Marquardt 1987, 1990; Crumley 1993, 1994; Gunn 1994a, 1994b; Gunn and Crumley 1991).

This new framework integrates diverse types of evidence, enabling researchers to investigate complex cause-and-effect linkages. Although particular disciplines and individual investigators can make important contributions, development of such an enterprise accelerates when collaborative research projects are made a priority (Chen *et al.* 1983; Rockwell 1990; Rotberg and Raab 1981). The elements that characterize a new collaborative activity, here termed historical ecology, are appropriately diverse and drawn from several disciplines and intellectual traditions. Important contributions are the overlapping temporal frameworks that guide both historically-informed social science (e.g., archeology) and the historical sciences such as geology and astronomy. Interpretation, both in history and the sciences, relies on evidence for events and processes that must be set in both immediate and broader temporal and spatial contexts.

By employing temporal and spatial analytic units (such as scale, disturbance, community, landscape, region, niche, boundary, ecotone, etc.) common to several disciplines, diverse fields of study can contribute to a shared language.

Rearchers seeking ways to address time and space simultaneously have found research at the 'landscape' scale particularly useful. Broadly defined as the spatial manifestation of the relations between humans and their environment (Marquardt and Crumley 1987:1), landscape offers a common unit of analysis in several fields (geography, archeology, ecology, geomorphology, architecture, art, regional planning). Landscapes help integrate diverse evidence and allow changes to be traced through time. In conjunction with work in cognition, the study of changes in landscapes (a primary focus in archeology, historical geography, and environmental history) offers practical means of integrating the natural and social sciences and the humanities.

Inasmuch as all research is subject to bias, the more varied the sources of evidence and style of interpretation the more likely we are to effectively characterize a subject. Varied sources of data enable hypotheses to be evaluated with greater independence. Historical ecology challenges all researchers to incorporate both qualitative and quantitative information. The interactive analysis of multiple temporal and spatial scales employs evidence from the prehistoric as well as the recent past, incorporates local and regional spatial data with global data, and serves as a check on assumptions and methods (Marquardt 1992).

Regional Historical Ecology and Global Change

The introduction of historically and culturally informed environmental analysis into regional studies offers an important physical basis upon which to practice these new collaborations. Regional studies allow researchers to use previously accumulated data in their models: geology and topography, climate and weather, hydrology, pedology, botany, zoology, and other data are available and, except for the costs of locating them, essentially free. In many regions, historic and contemporary demographic, economic, social, political, and other data are also abundant.

Certain regions of the world are particularly sensitive to environmental changes that affect both human and other living populations. As a laboratory in which previous and current environmental experiments (intentional and unintentional) may be closely analyzed, such regions foster creative thinking about contemporary issues of risk and sustainability. Since the success of mitigation is often determined by how well indigenous cultural practices have been understood, it is important to shape policy that can incorporate local and regional knowledge.

Particularly important to this effort are case studies, which capture both environmental change and human activity over decades, centuries, and even millennia. This broad temporal perspective combined with a manageable spatial unit allows researchers to apportion causation among several factors. Such analyses permit recognition of a "cascade effect" in which one event or circumstance or decision triggers several others in quite different realms that together cause major ecosystemic disruption. Another finding is that the length of time a group has occupied a region is a good rough measure of their ability to use the region's resources wisely.

A period of cultural florescence in one region is sometimes mirrored by eclipse in another. For example, the period AD 500–900 in the Maya lowlands is one of cultural expansion; the same period in Western Europe is characterized by unseasonal weather, famines, pestilence, invasions, and cultural decline, often termed the Dark Ages.

Figure 1: The environmental history of this agricultural landscape in Burgundy, France is being reconstructed by means of palynology, ethnobotany, dendrochronology, historical climatology, fluvial geomorphology, archeology, documentary research and ethnography.
It is just as important to understand the dynamics of a landscape that expresses resilience and adaptation as it is to document the dynamics of past landscape degradation.

This may not be so mysterious once the climatic and marine history of the Atlantic Basin and consequent effects on regions that lie at its margins are better understood. After AD 900 the rainy season was diminished in magnitude and its timing changed, with myriad effects on the Maya environment, economy, and society. In Western Europe a more favorable growing season after AD 900 increased harvests and helped usher in the economic and cultural attainments of the High Middle Ages. These and other examples demonstrate that while many factors can cause economic and social disruption, chief among them is a reduction in environmental diversity coupled with a major change in climate.

Why should all this matter to us today? Human populations' varied responses allow recognition of elements of particular landscapes that successfully maintain species diversity, soil quality and the like. The examination of historic changes in a region's landscape can thus pinpoint useful strategies for long term landscape maintenance. Historical ecology offers an integrated theoretical framework, draws on diverse studies of long- and shorter-term social and environmental change, and allows the construction and comparison of regional ecologial histories, thus joining human and planetary scales. This powerful explanatory framework requires committed interdisciplinary collaboration and a shared vision of linked scales of time and space from local to global. Through it, it can be seen that each of the world's regions and all its peoples can contribute to our understanding of the global system.

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

Non-Linear Responses and Surprises

We certainly live in a nonlinear world where rapid and unpredicted system responses can result from small changes in forcing conditions or gradual and continuous environmental change. Nonlinear behavior may emerge from complex interactions and feedbacks or from simple biochemical and structural threshold-like responses with cascade effects throughout the functioning of a system. Such a behavior can display from deterministic chaos to emergent complexity and self-organization that, for instances, can result in multiple steady states for a given system.

This type of behavior is very much part of the way ecological systems function, yet, tremendous efforts with numerical and experimental approaches have been geared to simplify complex nonlinear responses into a more easily tractable linear world. The linear thinking is also much entrenched in the way policy perceives environmental change and, in consequence, ways to manage it (e.g. the assumption that climate change will alter production of terrestrial ecosystems progressively).

A deeper understanding of the nonlinear nature of systems will contribute to increasing our capacity to predict future ecosystem behavior under novel combinations of resources and forcings that brought about global change, and to detect early in advance low-probability catastrophe events, such as the terrestrial biosphere's flip from C sink to C source or the collapse of production systems.

IGBP, building upon an early initiative from GCTE, has initiated a new research focus to study biospheric responses to global change that involve rapid nonlinear changes and thresholds. The initiative is very much in its early stages of development but some of the emerging objectives are:

- To identify processes and resource gradients more prone to generate nonlinear responses, and therefore, unexpected system's behavior under future global change.
- To understand when nonlinear responses are important as related to scaling issues in time and space.
- To quantify transfer functions between forcings and responses for verifying and parameterizing predictive process models.
- To develop new numerical tools and experiments to study nonlinear responses (e.g., thresholds).
- To formulate new hypotheses derived from mathematical treatment of model systems (e.g., spatial scale-dependent effects of perturbations) that may be tested using reconstruction methods.
- To use knowledge of nonlinear phenomena to better guide policy development for adaptation strategies and mitigation.

A scientific committee has been assembled to prepare a first workshop that will bring together relevant research on this field from various core projects of IGBP. The committee is made up of Ian Noble (GCTE), Jim Reynolds (GCTE), John Dearing (PAGES), John Schellnhuber (GAIM), Paul Crutzen (IGBP-SSC, IGAC), Roger Pielke (BAHC), TBA (JGOFS), and Pep Canadell (coordinator). Inquires about this new activity can be sent to Pep Canadell (pep.canadell@gcte.org). This Duke University meeting is a further stage in IGBP nonlinear initiatives, and, in PAGES terms, partly builds on an earlier article in the PAGES Newsletter 99–2. PAGES Newsletter readers wishing to have an input to this initiative should contact me – all views will be most welcome.

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Land Use and Climate Impacts on Fluvial Systems During the Period of Agriculture (LUCIFS)

LUCIFS aims to understand the variations in water and particulate fluxes through fluvial systems at various times since agriculture began on our planet. We wish to know how fluvial systems have responded to past changes in climate and/or land-use, what factors controlled fluxes of water and particulates (sediment, particulate nutrients and carbon), how sensitivity to these factors varies in space and time, and how present day changes are affected by long-term processes and trends. Finally, LUCIFS wishes to contribute to our understanding of the feedbacks to global environmental change from changes in fluvial systems. Such feedbacks occur principally through changes in the carbon cycle, modulated by sediments and nutrients delivered to the coastal zone by rivers.

There are currently 20 case studies in LUCIFS, from New Zealand, the Pacific, Europe, Asia, Australia, and the Americas. These case studies are being analyzed within conceptual frameworks that are general enough to cope with a wide range of system types. Material budgets are central to all LUCIFS case studies. In addition, one framework that is being used and further explored consists of input time series (eg. land use and climate change) and output series (eg. sedimentation and nutrient fluxes to sinks such as lakes and reservoirs), linked by transfer functions that modulate inputs to produce outputs. This system – level understanding is essential to meet the aims of LUCIFS.

Further information about LUCIFS can be found at: *http://www.fas.nus.edu.sg/geog/davidt.htm.*

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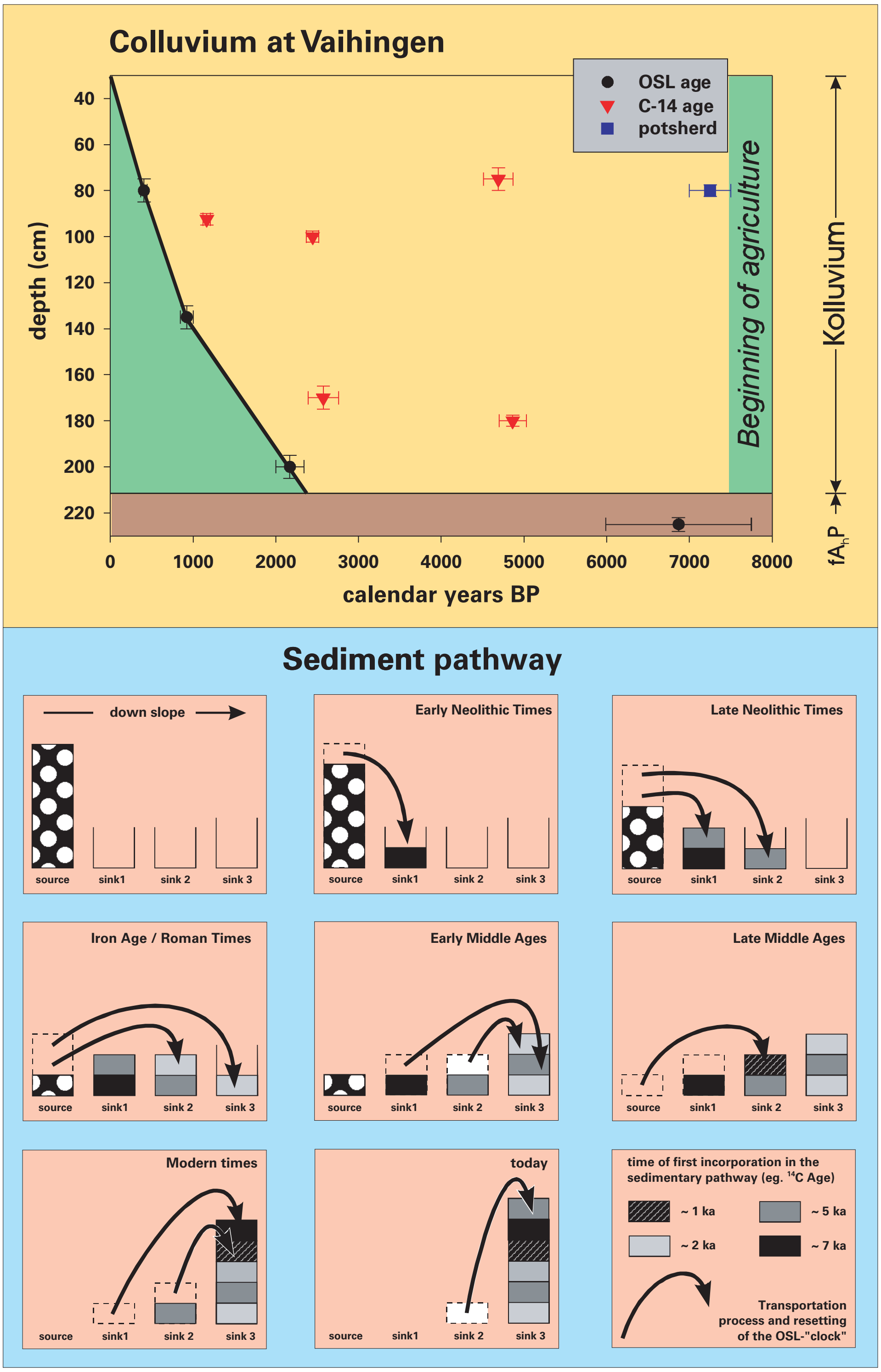

Figure 1: (adapted from Lang and Hönscheidt, 1999)
a) (upper part) Age versus depth plot for colluvium from Vaihingen/Enz. OSL ages and calibrated AMS ^{14}C ages (1 σ confidence level) of organic remains are plotted according to the depth of sampling. The archeological age of a ceramic fragment is also plotted. The ages of the strata imply that most of the material was brought to its present location not in a single event, but after several pulses of transportation with intervening periods of storage.
b) (lower part) Model of colluvium formation at Vaihingen/Enz: The first erosion occurred as early as Neolithic times (at about 7 kyr), partly filling sedimentary traps on the upper slope. As soil erosion proceeded, ca. 5 kyr-old material (Late Neolithic) became trapped in the sinks (represented by the 3030–2700 BC and 2870–2510 BC organic remnants). During the Iron Age/Roman period (around 2.5–2 kyr ago) up-slope sinks were filled up (represented by the 520–370 BC and 760–390 BC organic remnants). During this period for the first time eroded material was transported all the way down to the lower slope (represented by the 2170±170 a old colluvium). When erosion occurred on the crest and the upper slopes, the erosion of sediment trapped in the depressions (sinks 1 and 2) also started. Around 1.5 kyr ago sediment was incorporated in the colluvium which had entered the depositional pathway 0.5 kyr to 3 kyr earlier. About 0.5 kyr ago Neolithic material was deposited on the lower slope, covering sediments deposited here about 1 kyr ago.

Examples from the Rhine Catchment

The Rhine river drains large parts (189.700 km^2) of central Europe. The river channel stretches 1320 km and drains into the North Sea. On its course the hydrological regime of the Rhine changes from glacio-nival in the Alps and upland areas to pluvially dominated lowlands in the Netherlands. Here the mean discharge is 2500 m^{3s-1}, the mean flood discharge is 6000 m^{3s-1} and the mean discharge at low flow is 1000 m^{3s-1} (IHP/OHP, 1996).

Agricultural activities in the Rhine drainage basin date back to the Neolithic. The loess landscapes of northern Switzerland, southern Germany, and France were especially favourable for settlement due to fertile soils and the relatively mild climate. By medieval times the whole Rhine catchment had been settled, with only a few exceptions in remote mountain environments. Today the Rhine catchment can be characterised as 'advanced industrial' (LUCIFS - PAGES report, Series 96-2).

In this report we present results of two studies from the German part of the Rhine catchment related to the long-term development of the fluvial system under human impact. The first shows the sedimentary record of the entire period of agriculture. The second example is based on field evidences and historic records of the last 1350 years.

Loess Hill-Country

The first case study is located in a tributary catchment of the Rhine river. Large parts of the Rhine drainage basin are covered by loess deposits. Most of these regions can be described as rolling hill country, the so called 'Gäu' areas. In these areas anthropogenic soil erosion has led to extreme truncation of soil profiles and deposition of thick colluvial and alluvial sediments. Colluvial sediments accumulated on the lower slopes have proved to be valuable archives for studying man-landscape interactions over the period of agriculture. The sediments are deposited close to their source areas, so interpretation of results is generally straightforward. However, when looking in detail at such deposits, temporal changes in sediment delivery pathways are obvious. Results obtained at an Early Neolithic settlement near

Rhine, continued from page 11

Stuttgart serve as an example (Fig. 1a; Lang and Hönscheid, 1999). Dating is based on artefacts and ^{14}C dating of organic remains incorporated in the sediments, and on optical dating. Radiocarbon dates the death of an organism, so it determines the time when sediment particles first enter the erosion-transportation-deposition pathway. If deposition follows quickly after, the ^{14}C age provides a close approximation to the time of sediment deposition, but in many colluvial environments this is not the case because reworking of older colluvial sediments occurs. The time of reworking can, however, be estimated by optical dating techniques (Aitken, 1998; Lang *et al.* 1998). Chronological data allow reconstruction of the depositional history of the colluvium and also the identification of temporary sedimentary sinks along transportational pathways. A cascade-model of colluvium formation was developed (Figure 1 b). Colluvial sediments resulting from early soil erosion in the Neolithic to Iron Age periods were mainly deposited on the upper slopes. Significant deposition on the lower slope occurred for the first time during the Iron Age and Roman period. Since then deposition rates have increased because of more intensive land use.

A more general picture of colluvium formation is shown in Figure 2: Optical ages obtained from 54 colluvial sediments in southern Germany are plotted as frequency distributions. Periods of colluvium formation roughly coincide with periods of strong human impact on the environment. Climatic changes seem to play only a minor role.

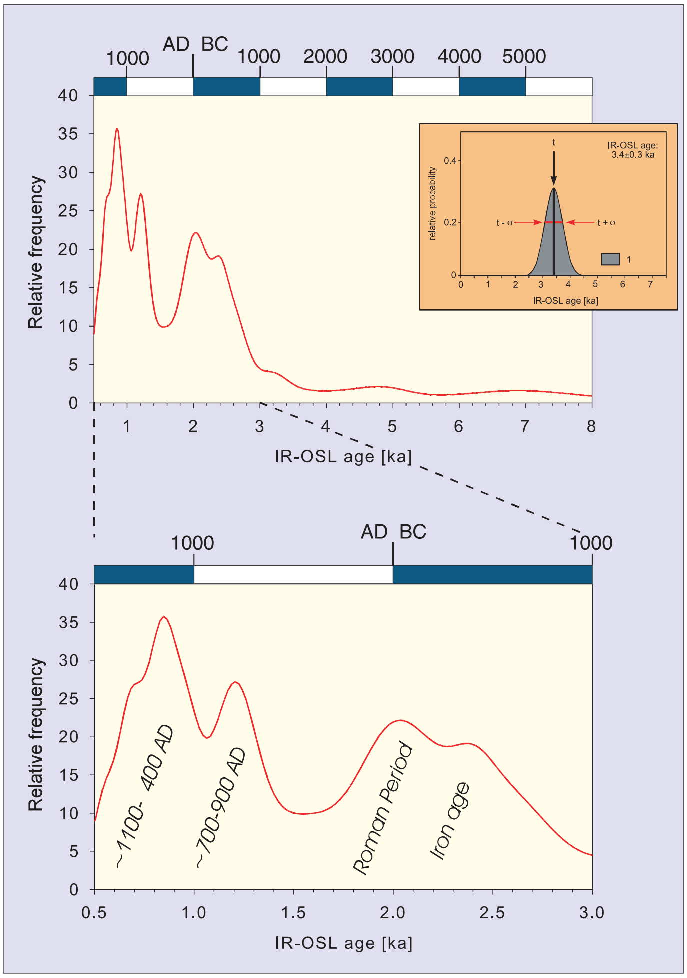

Figure 2: Frequency analysis of OSL-ages. OSL ages obtained on soil erosion derived sediments from several different sites in the loess hills of South Germany. OSL-ages are plotted as Gaussian-curves and the area below the curves set to one (see inset). The individual curves were then summed and the resulting distribution plotted. The lower plot gives an enlargement of the upper plot. Only the number of ages is used for analysis, and volumes of sediment deposited is not considered. Nevertheless, phases of colluviation clearly coincide with phases of strong human impact: First colluvial sediments were deposited during early Neolithic times. A second small maximum in the distribution occurs towards the end of the Neolithic period. Many colluvia originate in the Iron Age and Roman periods, while the maximum number of optical ages relate to Medieval times. (from: Lang 2000)

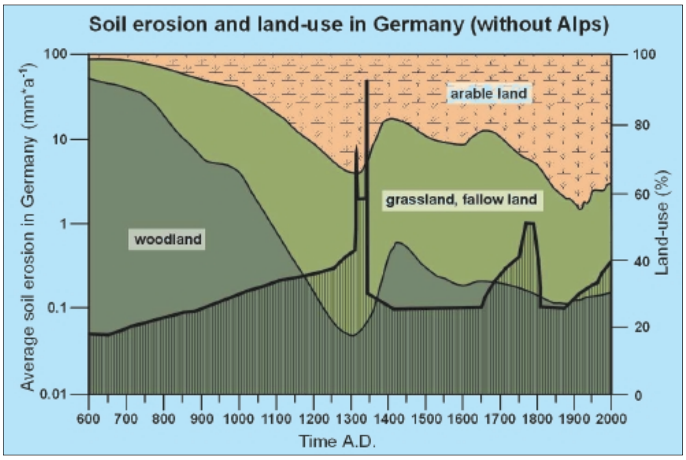

Figure 3: Soil erosion and land use in Germany during the last 1400 years (changed after Bork et al. 1998a). The average soil erosion in Germany (thick line, left axes, note: log scale!) and the percentages of woodland, fallow and arable land (right axes) are plotted on a calendar scale. Extreme rainfall events during the 14th century coincided with high percentages of arable land and fallow land and caused extreme soil loss.

Landscape Dynamics in Germany During the Past 1350 Years

The population density in Germany was reduced drastically during the Dark Ages as a result of diseases (e.g. the bubonic plague), cold and humid weather conditions resulting in crop failures, famines, ecological catastrophes and migrations from central to southern Europe. Most settlements of the Roman Ages were abandoned and forest returned to the former agricultural land. In the mid 6th century AD around 90% of Germany was again covered with nearly natural woodland (Bork *et al.* 1998a). In addition to historical documents, this is also evidenced by a period of rather intense soil formation. In early Medieval times areas with fertile soils and favourable climatic conditions for agriculture were again cleared. When population density increased the hilly regions in southern, western and central Germany as well as the lowlands of northern and northeastern Germany were also cleared and used for agriculture. By the early 14th century the area covered by woodland was reduced to only 15% (Figure 3).

In a modelling approach where climatic conditions were held constant during the past 1350 years the effects of land use change were investigated (Bork *et al.*, 1998a). The drastic decrease of the total biomass reduced evapotranspiration (-20%) and raised total runoff in Germany considerably (+60%). These effects are confirmed by field data. Soil profile analysis show a strong rise in the mean groundwater level from the Dark Ages until the late high Medieval Ages. Oxidation horizons of Gleysols from the early 14th century often lie 2

or 3 m above those of the 7th century AD. Soils at concave downslope sites were deeply decalcified during the Dark Ages, while higher groundwater levels since the high Medieval Ages have reversed this trend through imported calcium. Thus calcium enriched horizons developed in horizons that had earlier been leached.

Besides the changes in the average water balance, an increased number of extreme rainfall events characterised the first half of the 14th century as is clearly documented in sediment successions (Bork *et al.*, 1998a). During the first half of the 14th century widespread colluviation and fan development started. Fertile ploughing horizons of fields not densely covered with summer crops were frequently totally eroded. Half of the total hillsope erosion since 650 AD occurred during 1310 to 1350 AD. Where shallow fertile soils were completely eroded above stony layers the areas were abandoned and in many cases have been woodland since then. Where infertile sands were exposed by soil erosion (Bork *et al.* 1998b, Schatz, 2000) agricultural land use had to stop until soils enriched in organic matter were newly developed under woodland. In dells and furrows of sparsely vegetated fields (e.g. in ridge and furrow areas) deep U- or V-shaped gullies were formed. Some gully systems achieved depths of more than 8 m, widths of several decameters and lengths of several hundred meters to some kilometers. In some areas the development of extended badlands precluded further agriculture use. The formation of these extended gully systems based to only one or few catastrophic overland flow events which was shown by detailed analysis of erosional forms, their sedimentary fills and fan sediments (Bork, 1988, Bork *et al.*, 1998a). Where forests returned the gullies are still present today. In areas subsequently used for farming the gullies were quickly filled up over periods of some few decades.

Extreme weather events, famines, runoff, and floods during the second decade of the 14th century and in July 1342 are reported in contemporary written documents. In July 1342 a 1000-year rainfall event hit Central Europe (Alexandre, 1988, Flohn, 1949/50, 1958, 1967, Lamb, 1997, Pfister, 1980, 1985). Waterlevels for the period from the 19th to 25th of July 1342 are by far the highest ever recorded at several sites (Alexandre, 1988, Weikinn, 1958). Most stone bridges over the major rivers were destroyed. In July 1342 the overland flow rates in the catchments of the major central European rivers exceeded the 20th century maxima by factors of 50 to 200 (Bork *et al.* 1998a)! As a result of these catastrophes and of the Black Death during the years 1348/50 more than a third of Germany's population died. The area covered by woodland increased by three times from the mid 14th century until the late 15th century. Thus, also the average rates of transpiration increased and runoff decreased. Soil erosion again was of minor importance in most German landscapes until the mid 18th century.

Population density increased and woodland area decreased again during the 16th and 17th centuries. In the late 16th century a third of the landsurface of Germany was covered with woodland – most of it grazed. The size of the forest areas has not changed much since then, although the grazing intensity has been lowered in German forests since the 19th century.

Soil erosion rates increased again in many German landscapes during the fifth decade of the 18th century, in others a few decades later. Until the end of the 18th century, in some areas until the second or third decade of the 19th century, severe gullying was common. From soil and sediment analysis and from contemporary documents the occurrence of gullying can clearly be linked to an increased number of rainstorms. Of importance was the field size and the cropping sequence (namely the presence of fallow land). Hillslope erosion increased by an order of magnitude during the second half of the 18th century and was recognised as a severe problem. It was during this period that the first measures for soil erosion were proposed and used (cf. the publication of Heusinger, 1815, priced by the Royal Academy of Science at Goettingen).

After one and a half centuries of low hillslope erosion and an absence of gullying, soil erosion rates increased again significantly in the sixth and seventh decades of the 20th century. On average the rates tripled, due to changed crop sequences, increased field sizes and further mechanization. Today agricultural subsidies and the world market determine crop selection more than site characteristics. Crops with a low vegetation cover density in the erosive early summer months are common today (Dikau, 1986). Fields increased as a result of the reallocation of ground property. Soil conservation measures such as terraces and hedges that have been existing since the last period of intensive soil erosion (the late 18th century) were removed. The development of large and heavy agricultural equipment led to soil compaction and thus reduced infiltration capacities.

Summary

In the Rhine river catchment changes in the fluvial system seem to be dominated by changing human impact during the Holocene. Clearing of woodland and agricultural activities made the drainage basin susceptible to soil erosion by water. These changes influenced the water balance and runoff production. River dynamics changed dramatically due to the high supply of fine sediments that were produced by soil erosion. Today, smaller valleys are filled up several meters with flood loam – a sediment that has been developed mainly since Roman times.

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Synergistic Effects of Climate and Human Activities on Flooding and Soil Erosion: Lac D'Annecy, France

Projected climate change in the western French Alps anticipates increased mean temperatures and precipitation (Gyalistras *et al.*, 1998). This leads to a number of general questions about hydrological mechanisms in the densely populated sub-alpine landscape. How are soil erosion and flooding related to different combinations of land use and climate? Can land use be managed effectively in order to reduce the worst flooding effects? To what extent do past and present interactions between climate and human activities condition future impacts? These questions are at the heart of an ongoing research programme at Lac d'Annecy, eastern France designed to further our understanding of the synergies between climate and human activities through analyses of documentary and sedimentary archives.

Lac d'Annecy, Haute Savoie, France (Lat. 45°48'N; Long. 60 8'E; altitude 460 m) consists of two linked lake basins (Petit and Grand Lac) with a surface area of 26.5 km^2 draining a mountainous limestone catchment (251 km^2) that reaches an altitude of 2350 m. Early studies (Dearing 1979: Higgitt 1985; Higgitt *et al.*, 1991) of the Petit Lac lake sediments found substantial evidence for links between agricultural expansion and sedimentary evidence for enhanced flooding and soil erosion. Later, Thorndycraft *et al.* (1998) identified four sedimentary flood layers attributable to summer/autumn storms dating from the late 17th to early 19th centuries. The present study continues the use of geochemical, organic, physical and magnetic properties of lake and floodplain sediment sequences as proxy records of erosion and flooding over the past 5000 years, with documentary and palynological information providing the main evidence for land use and climate drivers of the hydrological system. However, the wealth of records from documentary sources and instrumental measurements has provided the opportunity to modify conventional paleomethodologies in three main ways. First, we have put great efforts into establishing independent records of forcings and hydrological responses from as many sources as possible (eg. Benedetti-Crouzet, 1972; Benedetti-Crouzet and Meybeck, 1971; French Ministry of the Environment SEMA). Sediment proxies for flooding and erosion are calibrated against modern discharge records, monthly sediment trap data and modern sediment source signatures for the whole catchment. Documentary and monitored records have been compiled from a very wide range of sources, and exhaustively evaluated in terms of accuracy and comparability. Debris flows and inactive gully systems have also been used as geomorphic evidence for past slope instability. Second, we have tried to consider the nature of hydrological change over a very wide range of time intervals and time-resolutions. A long lake sediment sequence allows environmental reconstruction over the past 5000 years with individual sediment increments equivalent to ~3–50 years. About 15 short cores allow spatial reconstruction of sedimentation patterns and hence estimates of sediment yield over the past 100–200 years at a time resolution of ~<1–10 years. Fine visible stratigraphy and analyses of thin sections in selected cores give historical information about discrete events and annual-seasonal changes. Third, we have used meteorological records, extending back to the late 19th century, and regional documentary climate indices back to the 16th century to develop simple climate-driven flood models and crop growth models. The former may be tested against 25 years of river discharge data, the documented record of major flood events at Annecy dating from 1570 and the lake sediment proxy record of flooding. Comparisons between reconstructed records of processes, land management, environmental conditions and modelled processes and conditions should help to discriminate between erosion/flood regimes that were driven by seasonal meteorological events, by specific combinations of land use and climate, or in response to major landscape disturbance. The ability to set each time period in the context of its history also allows us to examine the extent to which different regimes are, or were, conditioned by previous environmental changes.

Modern Calibrations

Establishing calibrations between flood events, suspended sediment sources and sediment deposition at the lake bed during the period of monitoring is the key to interpreting the long lake sediment records. River discharge records 1975–1998 show that 65% of maximum annual floods occur in the period November–March, often linked to snowmelt, while June–August are characteristically months with low flow, except during short duration and high intensity storms. Documentary records since 1570 show a similar pattern with 57% of floods recorded in the months November-May. This pattern is seen in the properties of sediment trapped at water depths of 20 and 46 m in the Grand Lac (May 1998–Oct. 1999) where seasonal differences in sediment magnetic characteristics are related to seasonal storms, river discharge and sediment delivery processes operating in different zones of the catchment. In particular, the total flux of detrital magnetisable minerals (χLF) rises by more than tenfold between September and Feb–Apr before declining rapidly in May (Fig. 1a). Comparing the full range of magnetic properties of the trapped sediment with the spatial patterns of soil magnetism in the Petit Lac catchment (Dearing *et al.* 2000) indicates some seasonal shift in sediment source. Topsoil from lowland and mid-altitude zones appears to make a greater contribution to the sediment load in late autumn following agricultural operations, while thin montane soils and river channel sources contribute most of the load in spring during snowmelt. High resolution analyses of millimetre thin sections from a zone of homogenous lake sediment dated to the early 19th century also show the same characteristic winter peak in susceptibility supported by evidence for seasonal fluctuations in absolute pollen. A preliminary comparison of near-inflow lake sediment susceptibility and smoothed records of daily river discharge since 1975 show a reasonable correlation (Fig. 1b), suggesting that the detrital-bound ferrimagnetic concentrations may be used as a first order proxy of annual discharge. Interestingly, the link to precipitation

is weaker, suggesting that modern discharge is strongly affected by seasonal changes in land use, groundwater storage and antecedent conditions. Other sediment properties appear to represent proxies for discrete discharge events linked to particular combinations of land use and storm types, supporting an earlier contention that high magnitude summer flood events are preserved in the lake sediments (Thorndycraft *et al.* 1998).

The Past 600 Years

Since AD 1400, documentary records show that the catchment has witnessed fluctuations in both land use and climate, and in the intensity and frequency of flooding. Matching the documentary records and sediment data is presently based on an assumed mean sedimentation rate in the long master core of 4 mm/yr, a figure derived from ^{210}Pb, ^{137}Cs, ^{14}C and pollen markers. A direct and positive link between the timing of peak values in a magnetic proxy (Fig. 1c) for annual discharge and the documentary flood frequency (back to AD 1600) is well within the errors for the sediment ages, and appear to be most strongly linked to negative anomalies in Pfister's (1992) precipitation index for the Swiss lowlands and shifts to greater continentality of the climate. A more rigorous hydrological model driven by meteorological data will be used to test these relationships further and to establish the mechanisms by which flooding has been directly linked to climate, but we can already make some tentative conclusions about the role of the agricultural communities. Since AD 1600 the human population in the high valley commune of Montmin has fallen from a peak at AD 1475–1561 to a low at AD 1750 before reaching the most recent maximum at AD 1800–1875. The rise during the period AD 1750–1850 is matched by decreases in the area under pasture and woodland, an increase in the area under cultivation, increases in the numbers of bovine and ovine animals, and is a period of increasing flood frequency (Fig. 1c). The pollen evidence for landscape 'openness' (NAP/AP) also follows the curves for the magnetic discharge proxies (χferri and χferri %). In contrast, a magnetic proxy ($SOFT_{20mT}$%) for summer floods (containing high proportions of lowland surface soil) shows

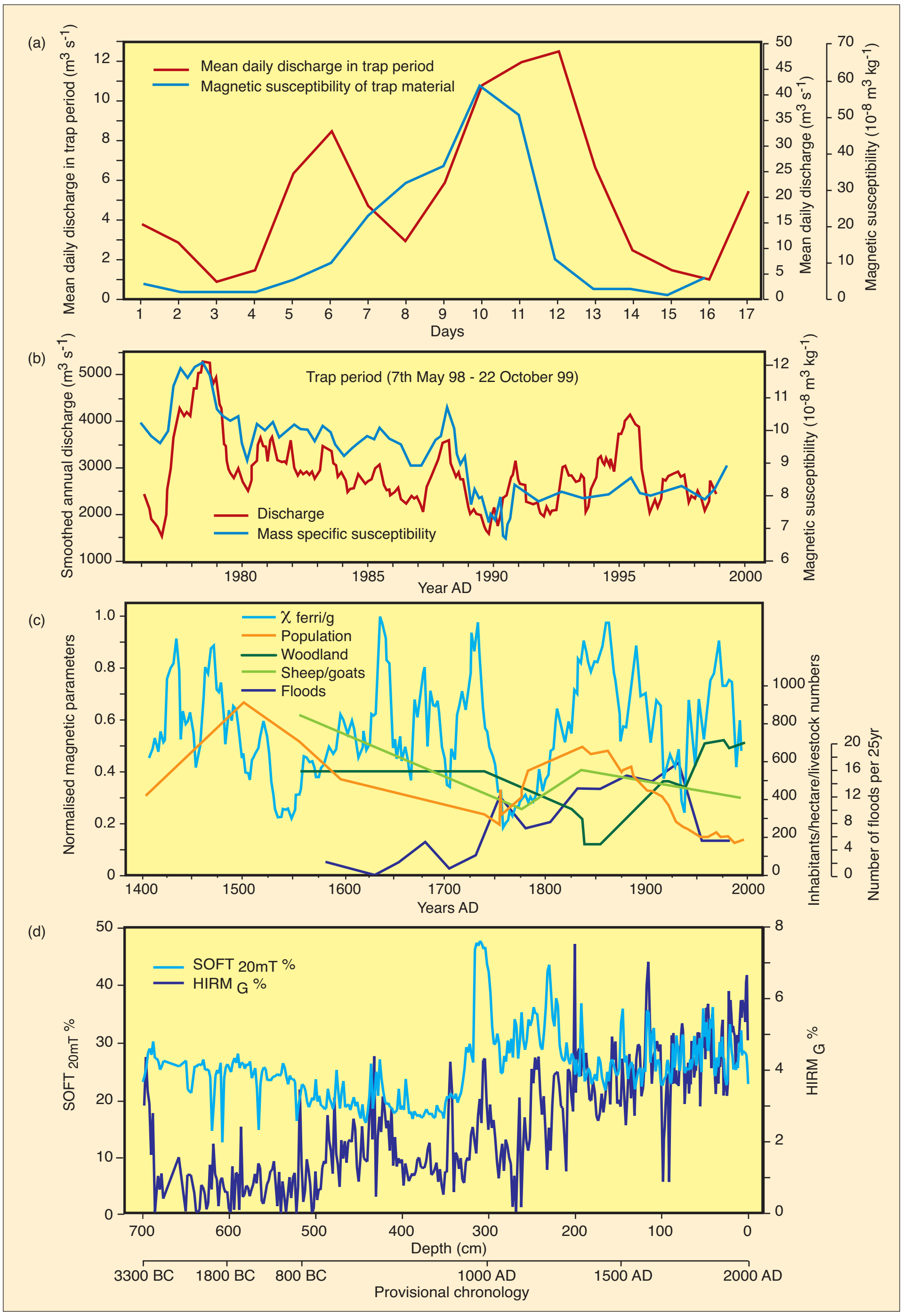

Figure 1: a) Magnetic susceptibility values of trapped sediment and monthly river discharge data May 1998–October 1999. b) Magnetic susceptibility values of lake sediment and smoothed annual river discharge 1975-1999. c) Lake sediment flood proxy record (χferri) AD 1400–2000; historically recorded changes at Montmin for human and livestock populations, and woodland cover; recorded flood frequency in catchment. d) Long term trajectories of erosion over the past ~5000 years using the magnetic parameters $SOFT_{20mT}$ % and $HIRM_G$ % as proxies for lowland surface soil and upland montane soil/unweathered substrates respectively.

high values ~AD1600 and ~1750 that do not appear to be strongly related to land use and cover. Taking the different records of land use and flooding together, there is strong evidence that annual discharge and erosion throughout the historical period may have been at least partially driven by the degree of vegetation cover determined by agricultural activities, while summer flooding may have been linked to specific timings and locations of individual storms. Preliminary assessments of the socio-agricultural economy for Montmin since AD 1561 based on crop yields, manuring levels and grazing pressures indicates an ill-sustained system where agriculture was potentially marginalised by both climatic and population forces. However a curve for modelled crop

Lac d'Annecy, continued from page 15

degree growing days for Montmin shows no significant climatic restrictions on summer crop yields since AD 1525. The weight of evidence gained so far suggests that fluctuations in the subsistence population and agricultural fortunes were determined by non-climatic factors, including outward migration and disease. There is the strong possibility that the most recent rise in human population during the late 18th century was coincidental with the timing of the shift towards more continental climatic conditions. The more open landscape at that time caused the natural climate-controlled processes of flooding to become accentuated in terms of higher magnitude and more frequent flood events that continued into the early 20th century even while the upland agricultural community declined.

The Record Back to 5000 BP

Sparse accounts of settlement before AD 1400, and pollen evidence, suggest that the structure of the present vegetation-agricultural landscape has its roots in Cistercian clearances around 1000 cal. yr. BP. Although the human impact on flooding and erosion probably started earlier, in Roman times, the long lake sediment records (Fig. 1d) show that high magnitude-low frequency flooding, which transported lowland and mid-altitude surface soil (Dearing *et al.* 2000; Noel *et al.*, 2000), reached a maximum at this time. Other evidence for major soil destabilisation comes from charcoal fragments dated to 960 cal. yr. BP found deep within a colluvial soil section in the Montmin valley, and from the Eau Morte floodplain stratigraphy where >2 m of silty overbank sediment has been deposited since ~2000 BP. Prior to 2000 BP, the evidence from floodplain sections and lake sediments is for a hydrological regime typical of stable wooded slopes, delivering clay-sized material from the montane zone except in extremely high energy events. Following the dramatic erosional response to forest clearance at ~1000 cal. yr. BP, the magnetic signatures for low-mid altitude surface soil and montane soil show divergent trends (Dearing *et al.* 2000) with the latter gradually increasing up to the present day (Fig. 1d). This may simply reflect the enhanced storage of surface soil in the floodplain after 2000–1000 BP. Alternatively, it may imply that while the lowland and mid-altitude soil-vegetation systems showed some sense of stabilisation over subsequent centuries, the montane zone progressively deteriorated. We may certainly hypothesise that early deterioration of the montane zone cultivation may have conditioned and, in the present situation, amplified the later hydrological responses to the agricultural changes documented since AD 1500.

Thus the findings are beginning to show that soil-vegetation-hydrological systems in diverse altitudinal zones, within the same catchment, appear to have significantly different degrees of resilience to climate and human activities. Some hydrological responses are clearly direct, broadly linear and exhibit negligible time-lags; other less obvious forcing-response relationships probably involve long term and threshold-dependent nonlinear change. Synergistic interactions between climate, human activities and hydrology in the Annecy catchment are therefore complex and require the present methodological framework in which all relevant spatial and temporal scales are included and integrated.

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

This article summarises the ongoing research output from many individuals involved with a Leverhulme Trust funded project (LEVAN), a Natural Environment Research Council studentship (GF) and the wider activities of the CLIMASILAC consortium, including: John Dearing, Peter Appleby, Fernand Berthier, Achim Brauer, Darren Crook, Jacques-Louis de Beaulieu, Gerald Foster, Emmanuel Garbolino, Peter James, Richard Jones, Jean-Luc Loizeau, Jim Nicholson, Hervé Noel, Frank Oldfield, David Siddle, Roy Thompson and Elisabeth Vergès. The Annecy project contributes to the Focus 3 Initiatives LUCIFS and HITE.

The Murrumbidgee River Catchment, Australia

European settlement in Australia, the USA, and New Zealand had dramatic impacts on the fluvial system, many of which are still working their way through river catchments. These trends, punctuated by episodic floods, produce a complex set of changes that have been documented in the SE Australian catchment of the Murrumbidgee River.

The history of the sedimentary system since 1820 AD, when European settlers arrived, has been reconstructed from a sediment budget for a 130km^2 subcatchment (Jerrabomberra Ck), from analysis of cores taken from Burrinjuck Reservoir (13,000km^2), from flood deposits in the mouth of Tuggeranong Ck (~5,000km^2), from documented large floods that have caused major channel changes and therefore sediment transport, and from major lateral migrations and sediment transport in the downstream river at Mundowey and Narranderra (~80,000km^2).

The Figure opposite shows a trend in sediment yield from Jerrabomberra Creek generated by the growth of gullies the yield from which dominates the budget. Declining yield since 1890 AD occurred as gullies stabilized, a trend reflected in Burrinjuck Reservoir. While erosion of subsoils, via gullies and channels, dominates the sediment transport, periods of high topsoil erosion (estimated from the tracers ^{210}Pb excess and ^{137}Cs) were produced by high runoff and floods.

Records of nutrient deposition and algal response in Burrinjuck Reservoir are also available, and are being compiled with the sediment records.

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

High Resolution Lake Sediments from New Zealand – a Record of Late Holocene Storm History, Vegetation Change and Landscape Response

New Zealand, isolated in the South Pacific Ocean ~2000 km southeast of Australia, was the last major land mass to be inhabited by humans. Polynesians are believed to have arrived less than 1000 years ago, while European settlement and extensive conversion of forest to pastoral land began only 150 years ago (Page and Trustrum 1999).

A maritime climate characterised by high intensity rainstorms, and strongly influenced by El Niño-Southern Oscillation, and a tectonically active, erodible landscape free of human impacts for much of the Holocene, makes New Zealand an ideal location to seek records of past climate variability and environmental change. The recent and dramatic human impact on the landscape also provides an opportunity to identify landscape response to land use/vegetation change.

A research programme is in progress to investigate the relative roles climatic, tectonic, and anthropogenic factors play in high rates of erosion and terrestrial and marine sedimentation, by providing late Quaternary paleoenvironmental histories of the East Coast region North Island, and by understanding the role of tectonism and long-term patterns of sediment fluxes on landscape evolution. Research by our team began in 1988 with a study of erosion and sedimentation responses to land use/vegetation change and climatic variability within a small catchment at Lake Tutira in northern Hawke's Bay (Fig. 1). This is essentially a closed system where sediment sources and sink are closely coupled. In 1992, the research transferred to the larger, more complex Waipaoa River basin, near Gisborne (Fig. 1). Here the depositional response to climatic, tectonic and anthropogenic forcing is buffered by transport lags, temporary storage, and the general diffusion of the magnitudes and frequencies of sediment contributions from the spatially variable distribution of erosion processes within the various tributaries (Trustrum *et al.* 1999, Gomez *et al.* 1999 and Hicks *et al.* 2000). More recently, the emphasis has shifted to examining sediment archives from coupled land and ocean environments in the Waipaoa sedimentary system. Key questions for sustainable land use and management of these landscapes are: at what rate, over what time scale, and to what level will the landscape respond and recover from naturally and anthropogenically induced changes? (Page *et al.* 2000).

Figure 1: Location of Lake Tutira and Waipaoa catchment.

Land Use and Climate Variability in the Tutira Catchment

Lake Tutira is one of a number of landslide-dammed lakes on the east coast of the North Island (Fig. 2). It is highly sensitive to environmental changes, both natural and human-induced, in the surrounding landslide-prone 32 km^2 catchment. The steep, dissected hills, underlain by soft siltstones and sandstones, have been mantled by a number of tephras that provide valuable time lines of landscape

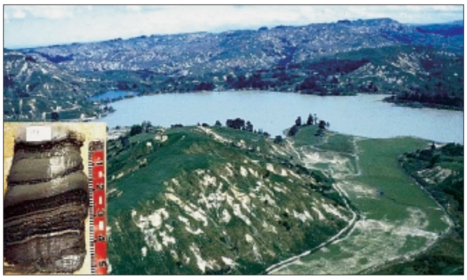
Figure 2: Lake Tutira and surrounding landslide-prone steeplands following Cyclone Bola. (Photo: N.A. Trustrum, September 1988). Inset shows laminated lake sediments – light grey layers are the products of individual storm events, dark layers are organic deposits produced by annual decomposition of weed and algae associated with eutrophication.

Murrumbidgee, continued from page 16

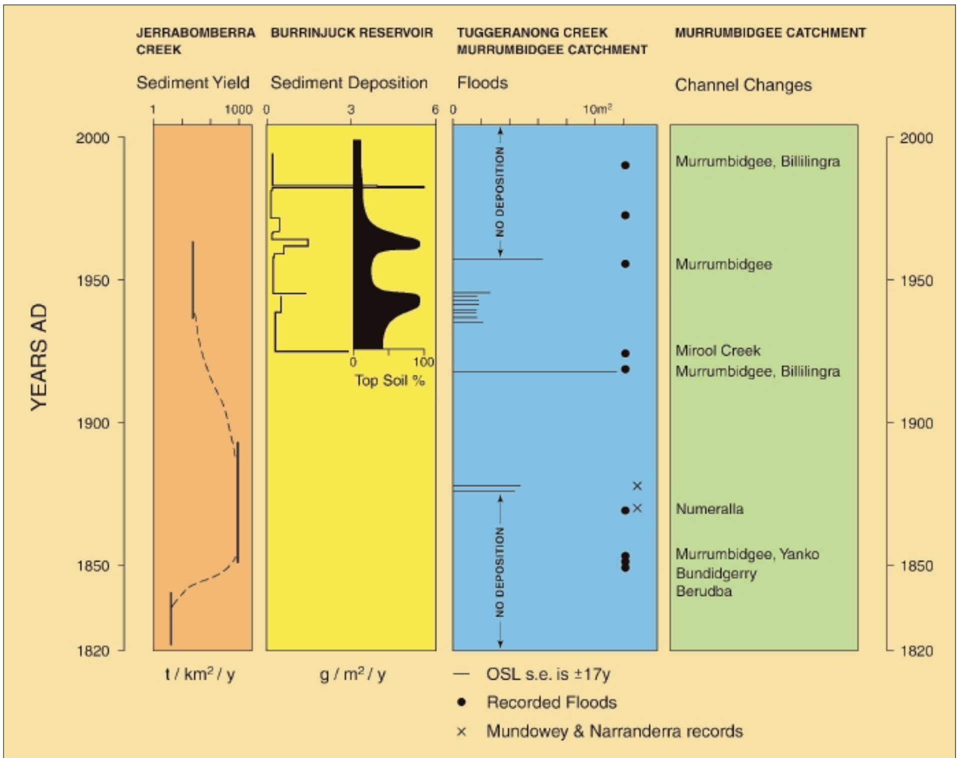

Figure 1: Evidence for sediment yield, sediment deposition, flood frequencies and channel changes at sites within the Murrumbidgee River catchment, Australia.

New Zealand, continued from page 17

change. These catchment characteristics, and the morphometry and thermal stratification of the lake, are conducive to the formation and preservation of laminated sediments, including the erosion products of individual storms (Fig. 2).

Our studies at Tutira began with the construction of a sediment budget for a major storm – Cyclone Bola. This storm, with a rainfall of 753 mm in 4 days, occurred in March 1988, and is the largest on record. Sediment was generated at a rate of 48720 t/km^2, 90% of which was derived from landslides. Fifty-six percent of this sediment then entered the lake (Page *et al.* 1994a). Analysis of the lake sediments show that high magnitude events produced disproportionately large amounts of sediment in comparison with low magnitude events, with Cyclone Bola and the next largest storms on record responsible for more than half the storm-generated sediment since European arrival.

Correlation of storm-generated sediment layers with storm history has identified the threshold for the generation of sediment, and the relationship between sediment thickness and storm rainfall. However, the relationship is not straightforward and is affected by changes in the threshold for landsliding or "event resistance", where the magnitude and/or frequency of earlier storms reduces the available sediment (Page *et al.* 1994b).

Human impacts in the catchment began only 500 years ago with Polynesian arrival, and consisted of repeated burning of the indigenous forest and replacement by fern and scrub (Wilmshurst 1997). European conversion to pasture began in the late 1870's. This recent but dramatic human impact is also recorded in the lake sediments. While the sedimentation rate increased by ~60% under fern/scrub, following conversion to pasture the sedimentation rate increased by an order of magnitude (Fig. 3) (Page and Trustrum 1997). These high erosion and sedimentation rates have led to concerns about the sustainability of pastoral farming on these landscapes.

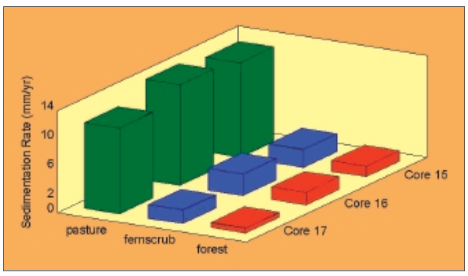

Figure 3: Sedimentation rates in Lake Tutira under forest, fern/scrub, and pasture (after Page and Trustrum 1997).

The lake sediments also contain a high resolution record of climate variability and landscape response for much of the Holocene that is free of human impacts. A 6500 year history of the magnitude and frequency of paleostorms is preserved in the sediment. To date, the chronology of storms for the last c.2250 years has been established from a c.6m core (Eden and Page 1998). In the pre-European record there are 340 storms layers, with an average storm return interval of ~6 years. However, the frequency of these storm varies. Clusters of sediment layers identify six major periods of increased erosion, five of which are related to increased storm frequency. During these periods the average return interval of storms is 1–3 years, whereas in the less stormy periods intervals are 7–13 years (Fig. 4).

The dates of the storm periods are 2175–2155, 2090–1855, 1455–1435, 1085–935, and 375–355 cal. yr B.P. Most of these periods correspond to warm climate intervals previously identified from New Zealand and other Southern Hemisphere paleoclimatic evidence. A majority of the storms recorded in the European derived sediment are associated with La Niña phases of ENSO, and we are currently investigating the relationship between the magnitude and frequency of storms and ENSO for the 2250 year period, and correlating this record with other proxy records of paleoclimate to identify long-term climate variability for this region of New Zealand.

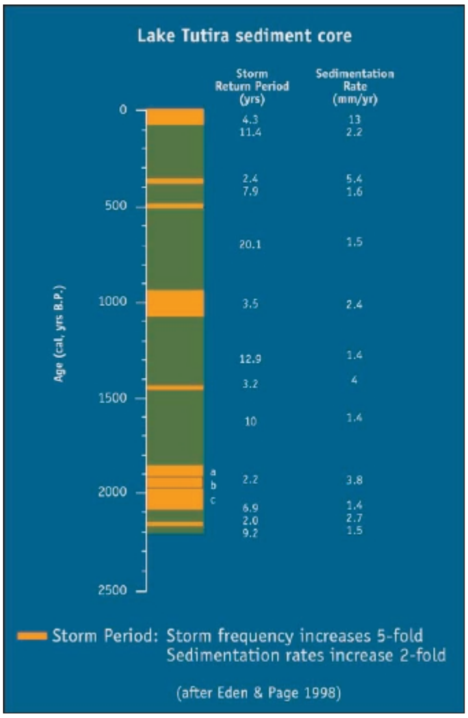

Figure 4: Variation in storm frequency derived from a c.2250 year long sediment record from Lake Tutira (after Eden and Page 1998).

Ongoing Research of Land–Marine Interactions in the Waipaoa Sedimentary System

Research in the ~ 2200 km^2 source and ~ 900 km^2 sink Waipaoa sedimentary system is focussed on using sediment budgets and high resolution sediment cores from floodplains, terraces and the marine depocentre to improve our ability to investigate how the magnitude and frequency of the erosional and nutrient response varies with land use/vegetation, climatic regime, and tectonic controls. Our intention is to improve understanding of significant global change issues, such as the influence of sea temperature changes on terrestrial rainfall, by determining the extent to which climate variability and tectonic forcing control land-marine sedimentary systems.

Key collaborators include scientists from Landcare Research, National Institute of Water and Atmospheric Research (NIWA–Oceanographic and Freshwater), Geological and Nuclear Sciences (GNS–Earth Deformation), Indiana State University and Gisborne District Council. The Waipaoa sedimentary system has been chosen as a focus site for the US NSF MARGINS Source-to-Sink programme. Paleoenvironmental studies here will primarily focus on Holocene shifts of climate, and anthropogenic disturbances since about 500 cal years BP, where accompanying changes in vegetation profoundly modified the pattern and rate of erosion and the sediment-nutrient fluxes. Research activities for the MARGINS programme will begin in July 2001.

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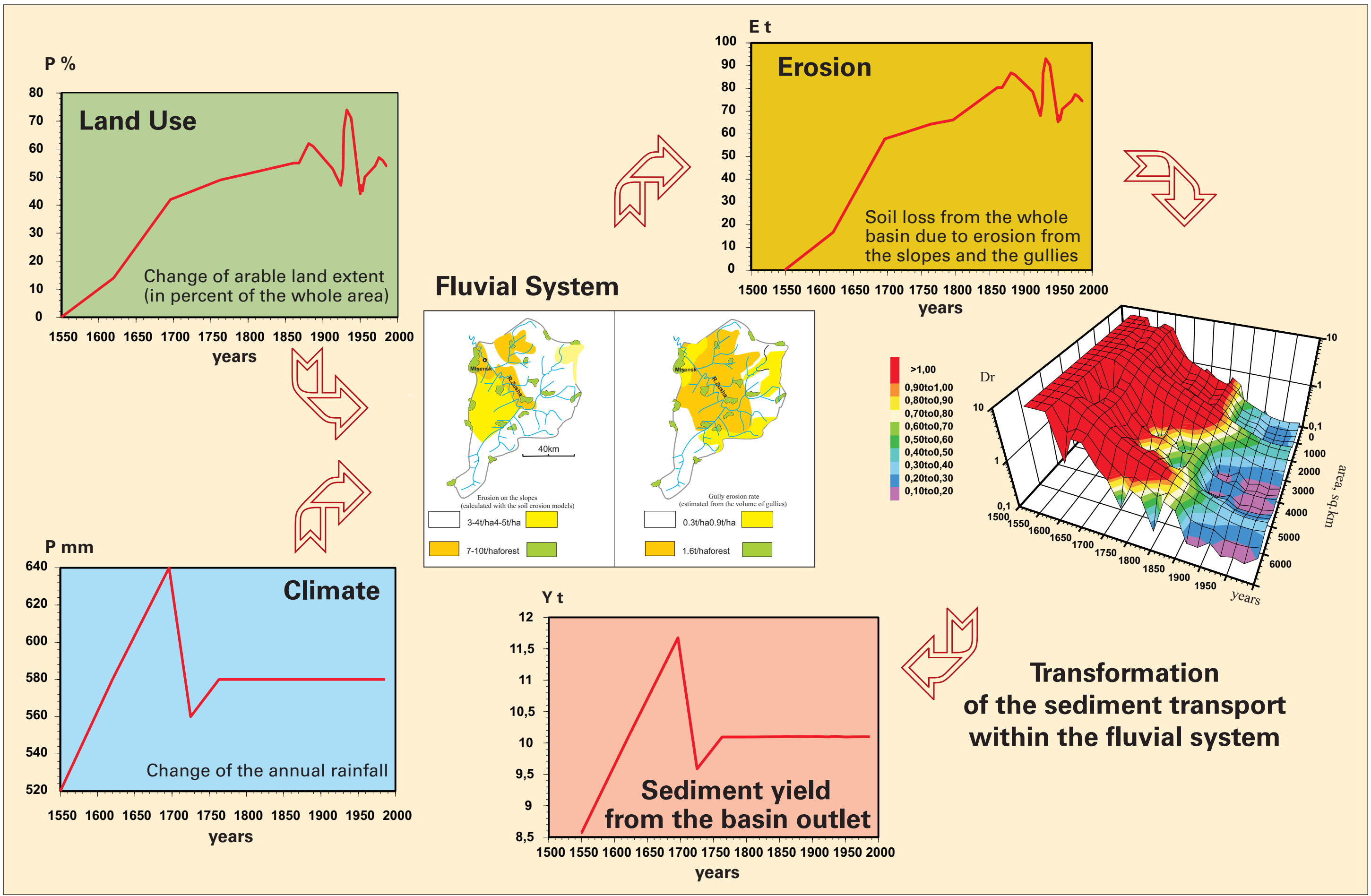

Figure 1: Land use and climate change cause erosion of the Zusha River channel net, altering sediment yield. Sediment delivery to rivers of the Zusha Basin is controlled by erosion of cultivated land. Sediment movement in the river is controlled by rainfall and runoff.

Past Erosion and Sedimentation within Drainage Basins on the Russian Plain

An aggregate sediment budget for the entire Russian plain has been estimated for the period of agriculture. A sediment budget equation for the river net has been derived (Sidorchuk, 1996) using coefficients which have been calibrated with contemporary and/or past erosion/sedimentation rate data. The equation is then used to reconstruct the sediment budget for climatic and land use conditions in the past, and for forecasting erosion and sedimentation for future scenarios of climate and land use.

In the Zusha River catchment, a tributary of the upper Oka River not far from Moscow, land use and climate have been estimated for the period since 1550 AD from statistical records (Krokhalev, 1960; Tsvetkov, 1957; Zlatokrilin *et al.*, 1986). Rates of sheet and rill erosion have been estimated by Belotserkovskiy *et al.* (1991) using two models tested under Russian conditions taking account of the time series of land use and climate. The volume of gully erosion was calculated by Kosov *et al.* (1989) and Sidorchuk (1995).

By applying the calibrated model, sediment yield from the Zusha basin and the sediment delivery ratio (ratio of basin yield to total basin erosion) have been calculated. The model results show that under natural conditions of dense forest-steppe vegetation during the 16th century, slope and gully erosion was very low and the delivery ratio (Dr) was greater than unity; that is, channel erosion dominated, sediment yield was equal to the transport capacity of the channel, and yield was greater than the input from hillslopes and gullies. Dr fell below unity once cultivation began in the 14th century because the transport capacity of the river was less than the input of sediments from slopes and gullies, despite river flow being at its highest for the last 500 years as a result of a peak in precipitation. Cultivation reached its maximum extent in the basin in the 1930's, and Dr was less than 0.2. During this time, erosion of slopes and gullies overwhelmed the transport capacity of the river and sediment storage was high.

The main factor controlling the slope and gully erosion rate during the last 500 years has been the area of arable land. Erosion variation has been large, from 0.2 kg/s under natural conditions to 70–90kg/s at the beginning of the 20th century, and 50–70kg/s at the end of the century. Precipitation varied by ± 10%, as did flow transport capacity and sediment yield, compared with a variation of ± 20% in the area of protective vegetation.

This case study suggests that the low relief, cold continental climate, grey forest soil landscape of the Russian Plain is very sensitive to the level of land use.

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

Human Impact on Lake Ecosystems (LIMPACS)

Although on a global scale lakes play only a minor role in hydrological and biogeochemical cycles, they have a special importance in many continental areas owing to their landscape value, their use as a natural resource (for water supply, recreation etc) and their value as natural ecosystems and centres of biodiversity. However, lakes are under increasing threat due to the separate, but often combined impact of:

- nutrient enrichment from domestic and agricultural pollution;
- acid deposition from fossil fuel combustion;
- salinisation from over extraction of freshwater;
- pollution from toxic metals, persistent organic pollutants and radionuclides;
- accelerated infill from catchment soil erosion;
- habitat disturbance from engineering projects;
- ecological disruption from species introductions and invasions.
- climate change from greenhouse gases;

In developing a global strategy for the protection or sustainable use of lakes it is crucial that we understand how lakes function on different time-scales in response to both natural forces and human impact and that we are able to predict how lake ecosystems will change in the future as stresses are altered.

The central theme of LIMPACS then is "understanding the past variability of lake ecosystems in order to predict better their future". It requires collaborative research between paleolimnologists and limnologists to bring together interdependent approaches for studying lake status, past, present and future. This interdependence involves modelling, measuring and reconstruction of lake attributes (Figure 1).

Modelling, especially process-based dynamic modelling, is needed to develop a system-level understanding of lake functioning and to make predictions of future status by scenario testing. Reconstruction, using paleolimnological techniques is needed to understand past variability on inter-annual and decadal time-scales and to provide model verification, whilst direct measurements from observation and experiment are needed to understand the nature of short-term variability and to paramaterise and calibrate models and transfer functions. Where direct observations of an individual water body have taken place over several years to provide longer-term records of seasonal to decadal variability, time-series are created that can be used to evaluate the performance of both dynamic models and paleolimnological transfer functions (e.g. Figure 2). For some lake types, e.g. mountain lakes, such time-series are comparatively rare but as monitoring networks expand the data available for this purpose are increasing. Sites with long-term records will consequently play a key role in LIMPACS and one task within the programme will be to develop an inventory of such sites suitable for model testing.

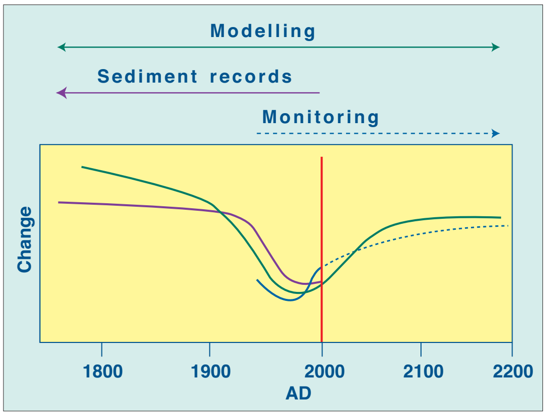

Figure 1: Limnological Change: The role of Sediment records, models and monitoring.

The Role of Paleolimnology

Few ecosystems contain inbuilt archives of their history to match those of lakes. Over recent decades paleolimnologists have begun to exploit this archive to provide unique insights into ecosystem change relevant to contemporary debates on lake functioning and human impact. LIMPACS will seek to develop this work further focussing especially on the need to:

- Disentangle natural forcing from human impact
- Identify the roles of different forcing variables
- Assess the response of lakes to known perturbation
- Define, where possible, lake naturalness
- Assess the current status of lakes in comparison to reference states

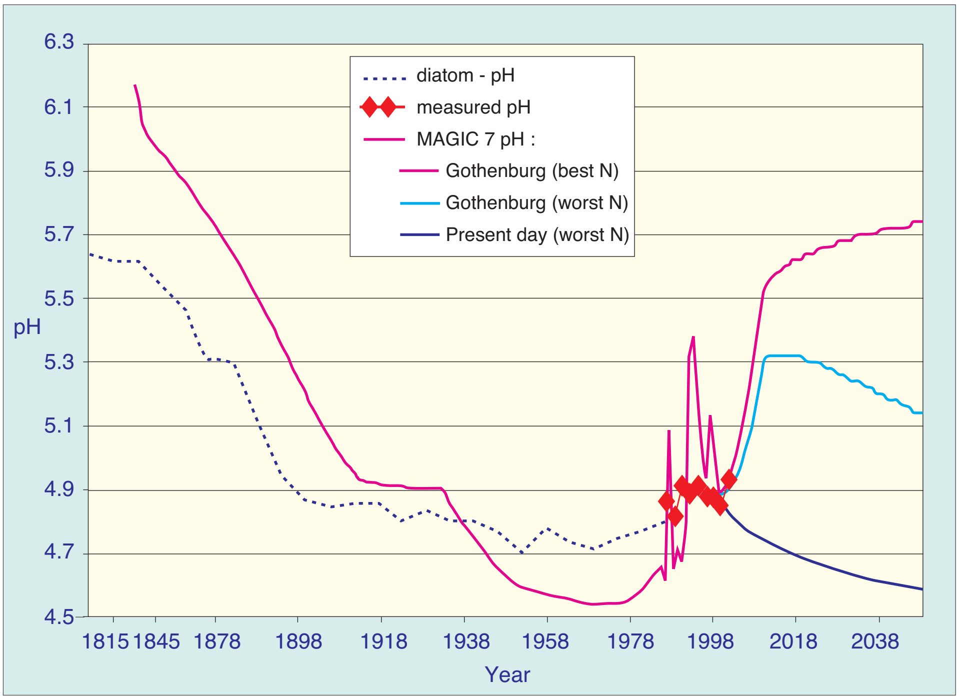

Figure 2: Combined plot of inferred, monitored and modelled pH for the Round Loch of Glenhead from 1800–2050. Inferred pH is based on a diatom-pH transfer function, monitored pH uses data from the UK Acid Waters Monitoring Network, and modelled pH is from MAGIC, a dynamic catchment acidification model. The model forecasts are based on UK sulphur emission targets set out in the UNECE Second Sulphur Protocal (Gothenburg) and assume current emissions of nitrogen into the future. Worst and best case scenarios relate to uncertainty over the timing of N saturation in catchment soils (Unpublished data from Jenkins, Monteith and Jones).

- Define, where possible, sustainable ecological targets for lake restoration
- Identify and provide early warning of new threats
- Generate cause-effect hypotheses for ecological change, especially in relation to the impact of multiple stresses
- Evaluate steady-state and dynamic model output

Whilst useful methods for reconstruction based on high resolution core sampling, relatively accurate chronologies, multi-proxy analyses and reasonably robust transfer functions already exist, LIMPACS hopes to identify where critical further methodological improvements are needed. It will also encourage a move towards a more holistic paleoecological approach within paleolimnology that is concerned with ecosystem responses and interactions as well as environmental reconstruction. Entirely new techniques for dating and analysis may also be needed and it will be essential to explore GIS and model-based approaches for upscaling to regional and global scales. It will also be necessary to work closely with the LUCIFS and HITE communities especially in exploring relationships between lake change and lake catchment change.

Progress so far

LIMPACS is still in its formative stages. A steering group* of paleolimnologists, limnologists and modellers has been set up and a science implementation plan is being developed. The next step is to set up a series of working groups. It is envisaged that each will be concerned with processes associated with specific threats or stresses as follows:

- acidity, sulphur and nitrogen
- uvb radiation, dissolved organic carbon
- nutrient enrichment, phosphorus and nitrogen
  (i) deep lakes, oxygen
  (ii) shallow lakes, trophic interactions
- salinity, ionic composition and hydrological change
- warming, stratification and mixing
- pollution, toxic metals and organics
- sediment infilling, catchment erosion
- introduced species

Further information is available on the LIMPACS web-page: *www://geog.ucl.ac.uk/ecrc/limpacs*. Anyone interested in taking part in LIMPACS should contact Rick Battarbee or Cathy Stickley (c.stickley@ucl.ac.uk).

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HITE

Ecosystem Processes and Human Dimensions – The Scope and Future Of HITE (Human Impacts on Terrestrial Ecosystems)

Introduction and Rationale

Ecologists are increasingly aware that a complete understanding of ecosystems may require the observation and analysis of ecosystem functioning over relatively long time-scales. This may be seen from three perspectives. First, information about the causes, rates of change and direction of long term ecological trajectories may show how modern terrestrial ecosystems are conditioned by past interactions between human activities and the natural environment. Second, analysis of past ecosystem processes and rates of change may provide at least partial analogues for present and projected responses to human impact and climate change. Third, long ecological time-series may allow calibration and evaluation of predictive ecological models.

For these purposes, information about past ecosystems gained through direct observations, monitoring and measurement will often be either of insufficient length or not available. This limits the value of such an approach both for documenting and understanding the processes involved in terrestrial ecosystem change, as well as for developing and validating relevant models. The over-riding goal of HITE is therefore to further the use of environmental archives for documenting and understanding terrestrial ecosystem change through time; thereby improving the scientific basis for ensuring the security and enhancing the value of terrestrial ecosystems for the future. The scope must embrace not only human impacts but also climate variability, since the two interact. It must also be firmly rooted in our understanding of ecological principles and processes derived from studies of contemporary systems.

The initiative seeks to define and to promote research on key issues relating to human impact and natural environmental change. Paleo-ecological research has a long tradition, but paleo-ecological findings have often been under-exploited in terms of their input to our understanding of terrestrial ecosystems. Within the context of PAGES, this reflects the extent to which research so far has laid stress on climate systems. In this type of formulation, paleo-ecological evidence is used almost exclusively as a basis for inferring climate by means of transfer functions of various kinds. This fails to accommodate paleo-ecology in its own right, that is to say, reconstructing the nature of past ecosystems through evidence independent of that used to infer climate change. Only by doing this will it be possible to understand, without recourse to circular argument, the complex of environmental factors and processes responsible for ecosystem development, modification, or demise. An additional impediment to a fuller development of paleo-ecology as we understand it has been the tendency for too many studies to use singly proxies (for example pollen analysis) as the sole basis for inferring past ecosystem change. Just as paleo-climate research has come to rely on a wide range of mutually constraining proxies, so must paleo-ecology learn to benefit from the

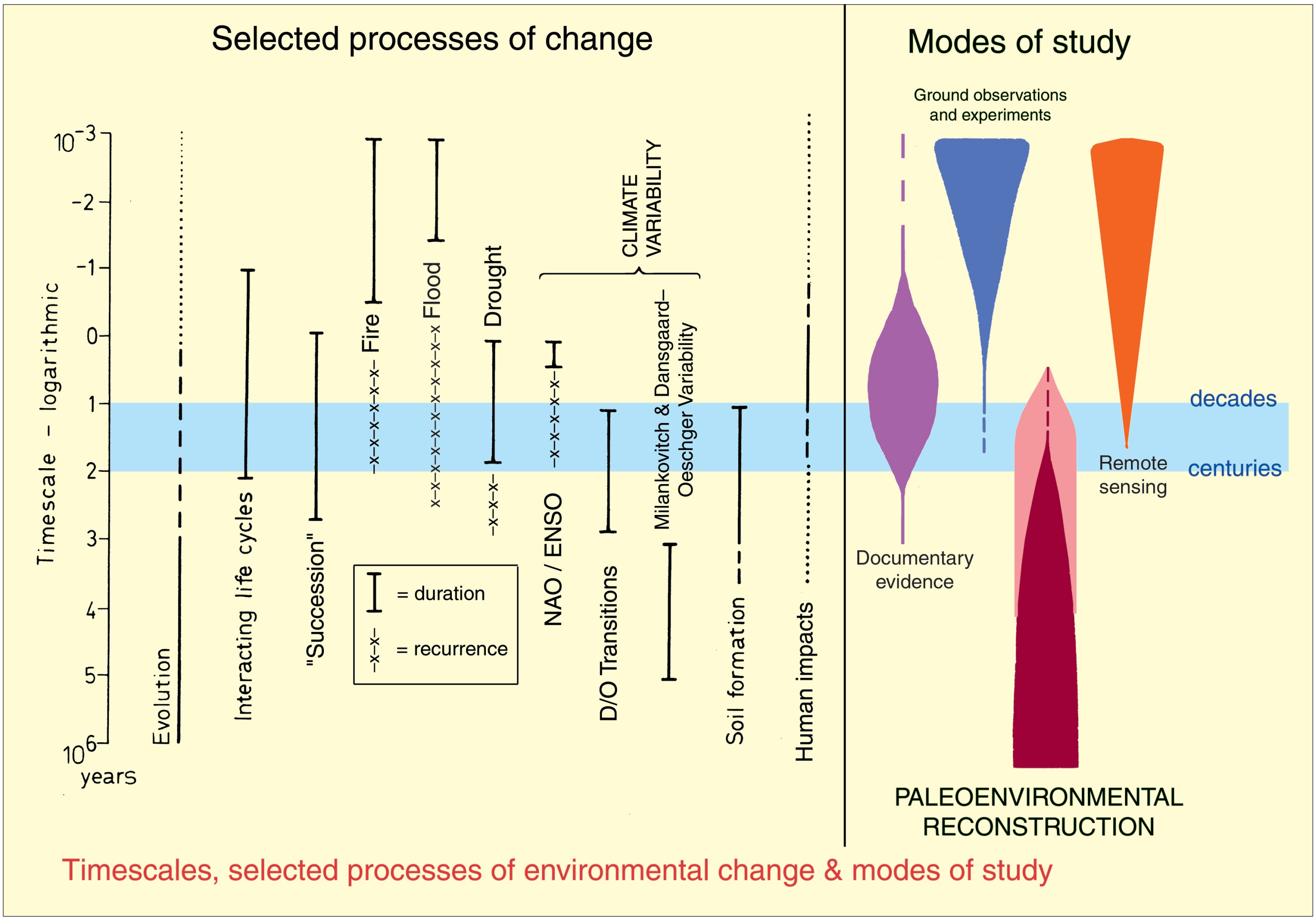

Figure 1 sets out the timespan over which a range of environmentally significant processes, both natural and anthropogenic, operate, against a sketch of the time frames with which different modes of study are mainly concerned. The vertical scale is logarithmic and refers to time frames, not to time elapsed before the present day. Thus processes with a short time frame may have operated in both the recent and the remote past. For fire, flood and drought, both duration and likely recurrence interval are indicated.

growing range of techniques, many of them sediment based, that complement pollen analysis and shed light on other aspects of past ecosystem structure and function.

Up until recently, within the broader context of IGBP, there has been a discontinuity between PAGES research and that on contemporary and future terrestrial ecosystems led mainly by GCTE. HITE aims to promote rigorous and integrated methodologies in which ecologists, modelers, environmental historians and paleo-ecologists may work profitably together. Figure 1 attempts to highlight the need for linking short- and long-term research as well as to capture the potential synergy inherent in the linkage.

The questions addressed by HITE focus explicitly on the responses of terrestrial ecosystems to the combined effects of human activities and natural environmental variability mainly during the second half of the Holocene, the period when human impact begins to interact with and eventually dominate the course of ecological changes in many of the long settled areas of the world. The goal is to produce output for the wider ecological and earth systems communities, conservation bodies, and land use managers and policy-makers.

At site, watershed and regional level, key questions include the following:

- What have been the major human impacts (driving forces) that have influenced the ecosystems that we see at the present day?
- How have these interacted with natural environmental variability?
- To what extent and in which ways are the changes brought about by the combination of human and natural influences threatening the future functioning of terrestrial ecosystems systems?
- What evidence does the past record provide as a guide to resilience, rates of recovery, irreversibility and future sensitivity?
- How realistic is it to retain any concept of 'natural' ecosystems?
- In the absence of such a concept, how may evidence about past conditions help to develop realistic policy and management targets?

Where major human impacts have been long-term and sustained, the concept of 'natural' ecosystems may be inadequate. Nevertheless, 'natural' processes are operating even in the most intensively managed ecosystems, and evidence about the past dynamics of processes in ecosystems are essential to increase our understanding of the dynamics of terrestrial ecosystems and, ultimately, to develop realistic policy and management targets.

In addition to the above questions that are applicable at the local to regional

level, there are more fundamental questions about ecosystem dynamics that paleo-data may help to address, for example:

- What can we learn about the dynamics of ecosystems which include, and in many cases are dominated by long-lived taxa?
- Is it possible to use the paleo-record to develop generalizations regarding the nature of ecological thresholds and non-linear changes?
- In so far as future climate scenarios for given ecosystems are sufficiently similar to past conditions, what does the paleo-record tell us with regard to survival and persistence at species, patch and landscape levels?
- In environments where long term succession is likely to influence future ecosystems, what does the paleo-record tell of successional processes, rates and trends?
- Where the periodicity / mean recurrence interval of extreme events or disturbance regimes is decadal or longer, what insights do paleo-data give on frequencies, impacts and interactions?
- What do studies with high temporal resolution during and after earlier periods of rapid environmental change tell us about rates of biotic response?
- In light of all the above, how can the paleo-record best interact with ecosystem modeling?

Scientific Contexts and Case-study Integration

The above questions cover a wide range of environmental contexts and research agendas and will be addressed mainly through site-specific case-studies leading where possible to generalizations about generic properties of particular sets of ecosystems

There is now an urgent need for us to select exemplary case-studies that have general significance for generating and testing hypotheses, that are likely to provide answers to important ecological questions and that represent extensive, valued or vulnerable ecosystems. In addition, there is an equally urgent need for a series of shared goals, priorities, criteria and research protocols that will provide an integrative framework for the case studies undertaken. HITE proposes to hold an initial Workshop in Spring 2001 to begin the process of articulating and developing the necessary research agenda. We envisage, at this stage, a group of around 20 colleagues representing key case studies which we propose to unite into a coherent research framework through the definition and adoption of common goals, priorities, criteria and protocols.

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Using History To Interpret Current Environmental Conditions and Future Trends: An Example from the US Long Term Ecological Research (LTER) Program

Acknowledgement of the value of a historical framework for modern studies has led major US agencies including the Forest Service and National Park Service to employ a wide range of retrospective approaches to define historical ranges of variability in landscape patterns and ecosystem structure and function as a basis for conservation and natural resource planning. Similarly, the 25 sites in the US National Science Foundation's Long Term Ecological Research (LTER) Program increasingly emphasize historical research involving scientists from diverse social and physical disciplines. Examples from the Harvard Forest LTER site in Massachusetts underscore the essential contribution of history to environmental research and planning. Importantly, historical studies figure into all aspects of this research program, from interpreting modern vegetation patterns and developing ecological restoration strategies to projecting the future role of temperate forests in the global carbon balance to anticipating forest response to atmospheric nitrogen deposition.

Like all of the New England states and much of the eastern US, Massachusetts has undergone a remarkable transformation over the past 300 years[11]. Following European settlement in the 17th–18th centuries, land was increasingly cleared for agriculture into the mid 19th C when 70% was open pasture and arable land and the remainder was largely coppice stands and woodlots. With industrialization and the development of mid-western agriculture in the 19th C, New England farmland was abandoned and the rural population joined a rapidly growing immigrant population in cities, industrial towns, and, more recently, the suburbs[23]. Neglected farmland reforested naturally, and with wood products increasingly supplied from elsewhere, tree size, forest age, and wood biomass are on an upward trajectory. New England is currently 50–90% forested[12].

Although ecosystem studies in the eastern US have generally proceeded with little consideration of historical factors, Harvard Forest research underscores the message that incorrect interpretations occur without a detailed knowledge of changing landscape conditions and environmental drivers over past centuries or millennia[14]. At a local scale, forest composition and structure in New England are strongly linked to prior use of sites as for example, pas-

ture, tilled land, or continuous woodland[21,22]. Site land-use histories are also clearly visible in the physical (e.g. horizonation) and biogeochemical (e.g. C:N ratios, N cycling) characteristics of the modern soil[7,8]. Such legacies of past land use persist despite more than a century of forest development and subsequent disturbances (e.g. intensive logging, hurricane, or fire)[22]. Interestingly, many aquatic parameters exhibit equivalent "memories" of past landscape conditions[15]. For example, sediment characteristics (e.g., organic content, C:N ratio) that changed dramatically as the catchments were deforested and farmed have remained largely unchanged over the past 150 years as the watersheds reforested. Paleoecological studies, which provide a unique ability to evaluate the entire sequence of changes from the pre-European period to the present, repeatedly show that for terrestrial and aquatic ecosystems alike the past continues to condition the present, modern conditions are unique, and there is little tendency to return to antecedent conditions[9,13].

At a broader scale (e.g., 5000 km^2) forest composition is relatively homogeneous across substantial physiographic and climatic gradients[12]. Historical and paleoecological investigations confirm that this homogeneity is only centuries old and is largely a product of the relatively homogeneous human disturbance regime. Indeed, at the time of European settlement (17th C) tree species distributions were closely related to growing season length. However, pollen studies from a network of sites indicate that land use is not the sole driver of this historical change[16]. Rather, over the past millennium high rates of vegetation change were initiated during the Little Ice Age (ca. 1450–1850 AD). In fact, the major compositional change previously attributed to historical land use – the decline of beech and hemlock – may have been largely a lagged response in populations already declining due to prior climate change. Clearly, the modern landscape is a complex product of past environments and multiple disturbances that can only be deciphered through many long views through time[19].

Lagging behind, but largely driven by the changing land cover and land use across the northeastern US has been a recent transformation in wildlife populations that poses major challenges for conservation, wildlife management, and public health and safety[10]. Notably, widespread and common plants and animals from the cultural agrarian landscape of the 19th century are becoming uncommon and are emerging as conservation priorities, whereas many larger mammals, birds, and fish, which were extirpated or reduced following European settlement, are spreading and thriving. With changes in land cover and species come threats to humans from: diseases facilitated by animal hosts or insects that thrive in the new environment (e.g., Lyme disease, giardia, equine encephalitis, West Nile Virus), vehicular or backyard encounters with wildlife (moose, bear, coyotes, deer), or the indirect activity of animals such as beaver. Understanding these wildlife and pathogen dynamics, educating the public, and managing the land and organisms require an understanding of centuries of landscape and human history. Whether and how to maintain species of cultural landscapes and how to manage the wide-ranging larger species are major policy issues rooted in history[4].

History also figures into emerging regional and global stories concerning nitrogen and carbon dynamics. High rates of atmospheric nitrogen inputs have resulted from fossil fuel combustion in industrialized regions of North America and Europe. Major questions loom regarding the ability of forest ecosystems to store this limiting resource, thereby mitigating its impact on aquatic systems and human health, and the effect of these inputs on forest ecosystem health[3]. Recently, major hypotheses regarding "nitrogen saturation" have been revised to incorporate historical effects and legacies as a consequence of unexpected results[2,3]. Field measurements and long-term experiments indicate that ecosystem history (e.g., past cutting, fire, agriculture) plays a critical role in determining initial site conditions regarding N availability and the potential for N uptake. In particular, land use over past centuries may be more important than modest regional differences in N deposition or forest type in determining current nitrogen

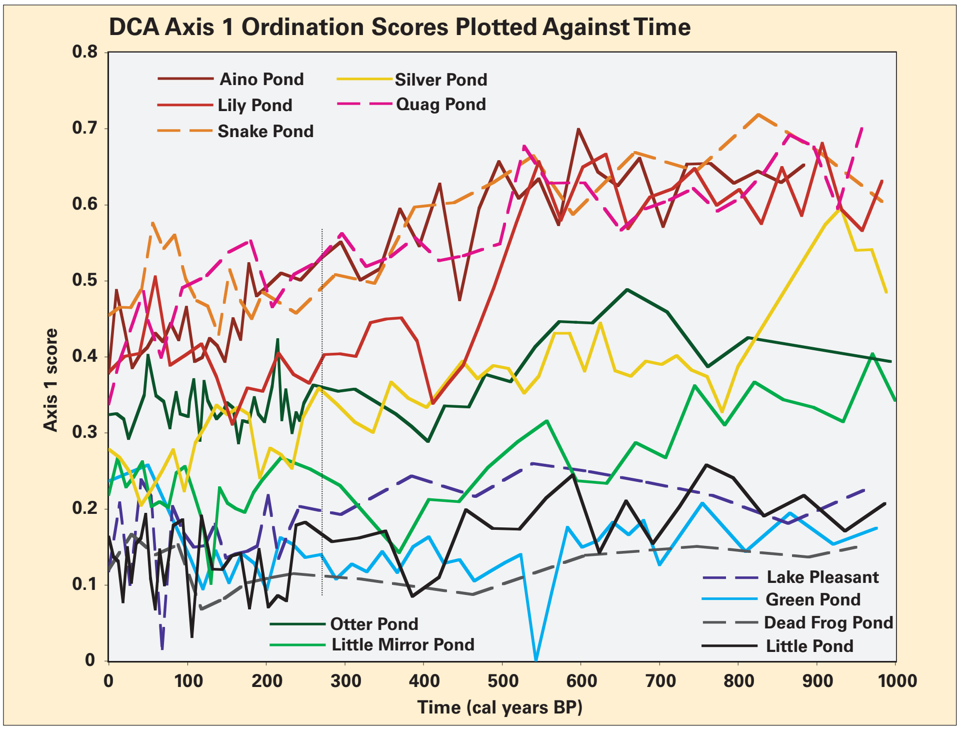

Figure 1: Long-term changes in forest composition in central New England USA, depicted through DCA (detrended correspondence analysis) scores for 11 pollen diagrams from small lakes. The lakes are distributed across a regional climate gradient of approximately 2°C in lowland (blue, green and black) and upland (red and yellow) areas. Major changes and regional homogenization in forest composition occurred after European settlement (vertical line, ca. 1725 AD). However, these historical changes were part of a longer-term trend driven by climate change coincident with the Little Ice Age. Separating human and environmental drivers of forest change requires a millennial perspective. From Fuller et al. 1998.

status and forest susceptibility to N saturation.

Finally, recent evidence suggests that the young (predominantly <100 years old) forests of eastern North American are an important global sink for atmospheric CO_2[17]. Long-term eddy flux measurements at the Harvard Forest document an average uptake of 2 tons C per hectare per year and lead to an estimate of a world-wide temperate forest storage of π to Π Gtons (0.25 to 0.50 billion metric tons) C per year[18,24]. Derivation and interpretation of this estimate and all predictions of future carbon dynamics for temperate forests must necessarily be grounded in a detailed understanding of the disturbance history of these landscapes.

Environmental studies and the agencies that support them and apply their results have demonstrated an increasing reliance on historical studies[19]. Although this interest is partly based on the fundamental insights that come from examining lengthy ecological processes and rare events unfolding through the past, it is ultimately grounded in a much more immediate consideration: an understanding of past conditions and historical legacies improves our interpretation of modern conditions and projections of future states and thereby places our policies on more solid footing[5,6,9]. In the absence of a detailed historical context our analyses will be incomplete and our management solutions often misguided.

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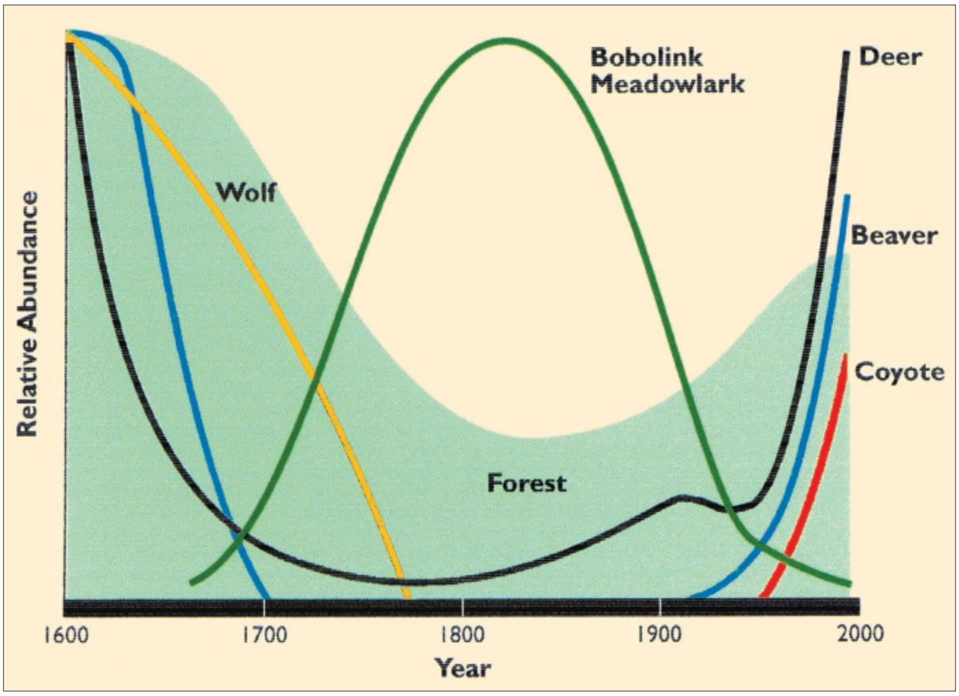

Figure 2: Changes in relative wildlife abundance in the northeastern USA linked to changes in forest cover since AD 1600.

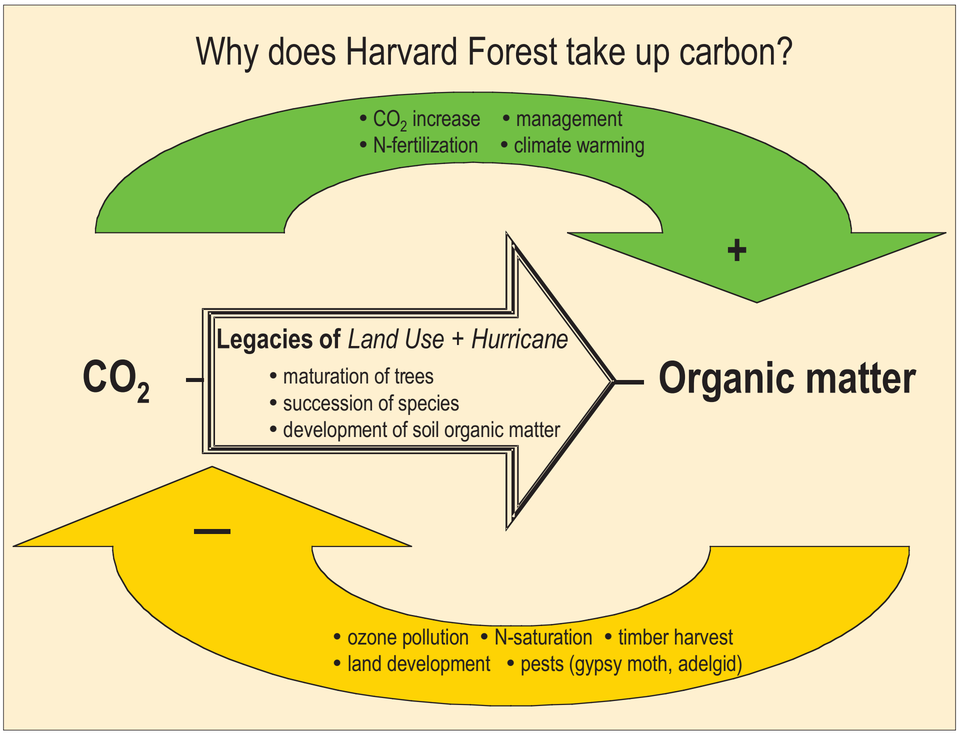

Figure 3: Controls on uptake and release of CO_2 at Harvard Forest. The major driving force is recovery from prior agricultural land use and disturbance by the hurricane of 1938. The rate of uptake is modulated by numerous environmental factors. Factors promoting sequestration or inhibiting decay of organic matter are placed in the upper arrow, others inhibiting sequestration or promoting oxidati on of organic matter are placed in the lower arrow (From S. Wofsy, in press).

The Role of Long Time Series of Ecological Data for the Calibration and Evaluation of Ecological Models

Mathematical models of ecological processes play an important role in the assessment of Global Change impacts on terrestrial ecosystems as well as for predicting the future of the Earth System as a whole. Over the coming decades to centuries, ecosystem function (e.g., biogeochemical cycling) will change directly as a consequence of drivers of Global Change, and indirectly as a consequence of changes in ecosystem structure (e.g., composition, life forms, etc.). The latter tend to be slow and lag behind environmental change, making difficult any experimental or observational approach to understanding these dynamics. Models are therefore required to project the longerterm consequences of environmental change on ecosystems and the entire Earth System.

Models may need to be calibrated, and their projections need to be evaluated against independent data. Calibration denotes the process of fitting model output to a set of observational data e.g. by manipulating those model parameters that cannot be estimated unequivocally from direct measurements. The failure to find a good fit between model predictions and observations may be indicative of a lack of understanding of the system, which often leads to changes in the model itself. Evaluation (often also termed "validation") refers to the process of testing model projections against data sets that were not used to estimate the model structure or the model's parameters. Failure to pass a model evaluation test usually leads to model reformulation, whereas successful model evaluations usually are followed by model applications, e.g. studies of Global Change impacts under scenarios of driving variables such as climate, atmospheric chemistry, or land use.

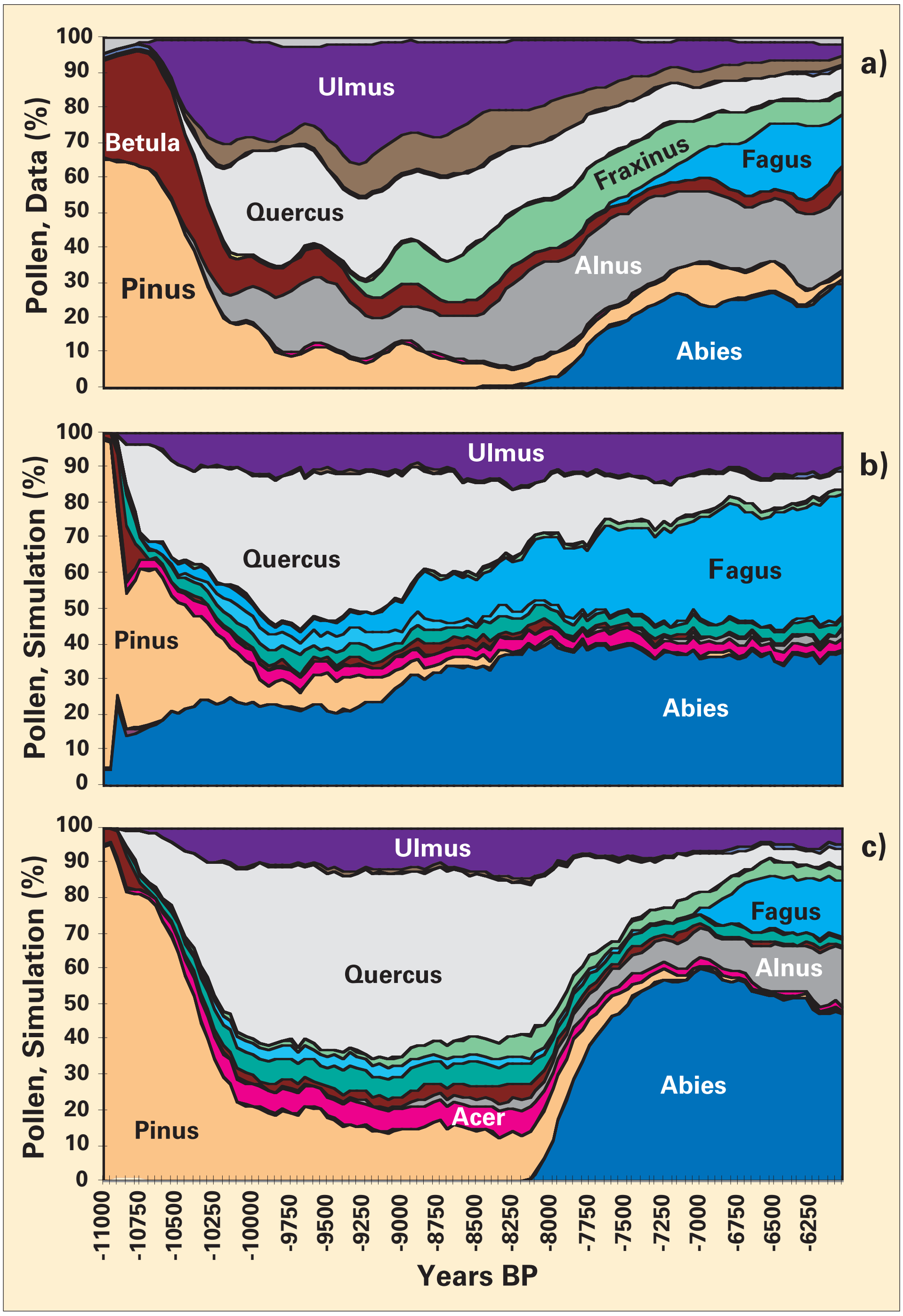

Figure 1: Pollen frequencies (ordinate, %) in the early Holocene (abscissa shows years BP) for Lake Soppensee, Switzerland (after Lotter 1989). a) Measurements from an annually laminated pollen profile. b) Simulation results of the FORCLIM forest gap model based on independently derived climatic input data (temperature and precipitation). c) as in b), but with postulated immigration dates for Abies and Fagus that were derived from the pollen record in a) (from Lischke1998).

Models of longterm ecosystem changes are best calibrated or evaluated based on long records of biotic changes. A key source of such records are environmental archives. Below, the current state of research is highlighted based on a few examples of model evaluation activities in one particular and widespread class of models, the "forest gap models" (Shugart 1984). These models simulate the establishment, growth and mortality of individual trees on small patches of land as a function of biotic (competition) and abiotic (climatic) factors. The mortality of a large, dominant tree produces a gap in the forest, which leads to the release of suppressed trees and enhanced recruitment, both of which drive succession; thus the term "gap" models (for a review, cf. Bugmann 2001). Gap models produce estimates of speciesspecific biomass, basal area, or leaf area index at the scale of a forest stand (i.e., 110 ha).

Although the first evaluations of gap models with paleo data were performed 20 years ago, we have not yet fully explored the potential of using paleo

data in a modeling framework, as will be shown below.

Pollen Records

Pollen data from mires and lakes have been used to evaluate the behavior of gap models on the time scale of millennia. This approach was pioneered by Solomon *et al.* (1980) and Solomon and Webb (1985). A distinct advantage is that it allows one to assess forest dynamics on very long time scales. However, pollen data usually have a low temporal resolution, making it impossible to determine rates of change that occur on time scales relevant for understanding Global Change in the 21st century. In addition, there are a number of methodological problems that have only partially been resolved in these modeling studies:

- The simulated data refer to a forest stand that is homogeneous with respect to climate and soil conditions, whereas pollen data most often represent a larger, typically heterogeneous area (catchment scale or larger). Detailed knowledge of soils and climate across the pollen source area as well as pathways of pollen transport would be required to set up simulation experiments that adequately reflect the pollen record; while such knowledge is available from paleo research, it has not been used by the modeling community yet.
- Measured records provide pollen frequencies, whereas the models simulate absolute values of speciesspecific biomass, basal area, leaf area index, etc., but not pollen production. To make a comparison of measured with simulated variables possible, Iversen factors (i.e., a simple linear model calibrated under current climatic and landuse conditions; Faegri and Iversen 1975) have often been used to estimate pollen production from simulated biomass. This procedure may introduce an error that is quite difficult to quantify, but likely to be significant.
- In most modeling studies, climate was either kept constant, which is not realistic across time spans of several millennia, or scenarios of climatic change were derived from the same data that were used for evaluating the behavior of the model, introducing a certain extent of circular reasoning. There are only a few examples of studies that were based on a reconstruction of climate that is entirely independent of the biotic record that was used for modeldata comparison.

For example, in a study that addressed the last of the above constraints, Lischke (1998) used an independent reconstruction of climate to drive a forest succession model at a site on the Swiss Plateau for which an annually laminated sediment record was available (Fig. 1). The simulation revealed broad agreement between simulated and measured pollen frequencies when immigration of two genera, *Abies* and *Fagus*, was delayed to the point where they appeared in the pollen record. While the simulation suggested that nonclimatic factors (such as the maximum migration rate) may be responsible for the late appearance of the two genera, the other differences between simulated and measured data are more difficult to interpret. They might derive from inadequacies in the pollen transfer functions, in the representation of the landscape by a single climatically and edaphically homogeneous site, or from inadequacies in the forest model itself. Clearly, a closer linkage between ecosystem modelers and palynologists is required to resolve these issues.

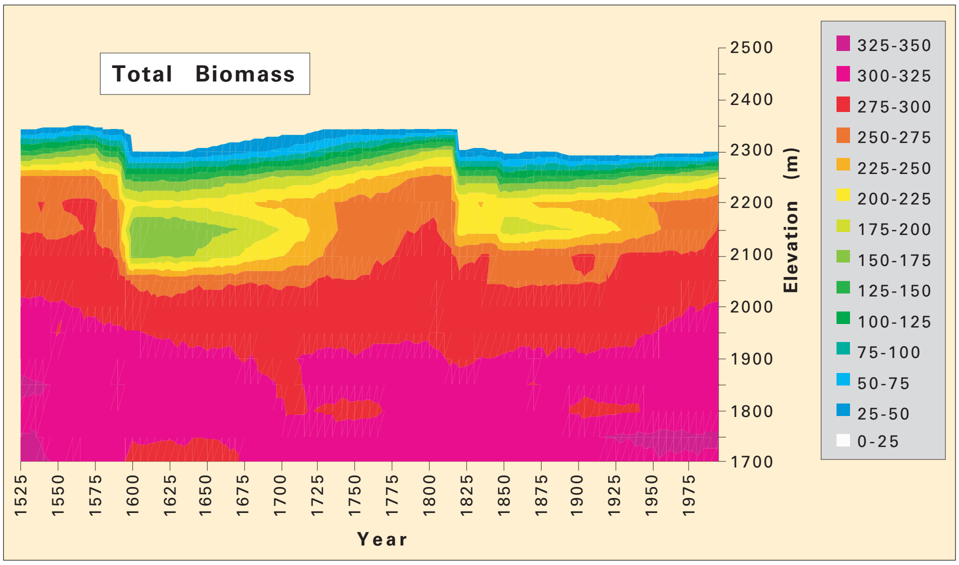

Figure 2: Contour plot of simulated total aboveground biomass (t/ha) along an elevational gradient near Davos (Switzerland) for the period 1525–1995 AD. From Bugmann and Pfister (2000).

Tree Rings

Tree rings represent another data source that is characterized by long records, but they have a higher temporal resolution (annual, seasonal, or even monthly). A distinct difference between pollen and treering data is that tree rings provide an individualbased measure from which standscale growth patterns can be reconstructed across time, whereas it is more difficult to assess longterm changes of plant abundances (i.e., population dynamics).

Ring width corresponds directly to diameter increment, which is the central state variable in many gap models. Treering data thus seem to be well suited for evaluating simulated growth patterns. Standardized treering chronologies could be derived from simulated tree growth using dendrochronological procedures (e.g., growth trend removal). However, there are only a few studies that attempted to use treering data for the evaluation of gap models (e.g., Keane *et al.* 1997, Bugmann and Pfister 2000), and there is a large potential for further exploration of this method. Because precise input data are required for driving a gap model in this mode of application, the comparison will not usually cover more than 100–150 years, but even such relatively short time series can be useful for evaluating simulated patterns with respect to the interannual or decadal variability of growth patterns.

In a larger effort to evaluate the sensitivity of a forest model to changes in climate variability, Bugmann and Pfister (2000) used the CLIMINDEX database of monthly thermic and hygric indices (Pfister 1999) to derive a climate reconstruction along a transect that crosses upper treeline in the European Alps (Fig. 2). The occurrence of the two tree-

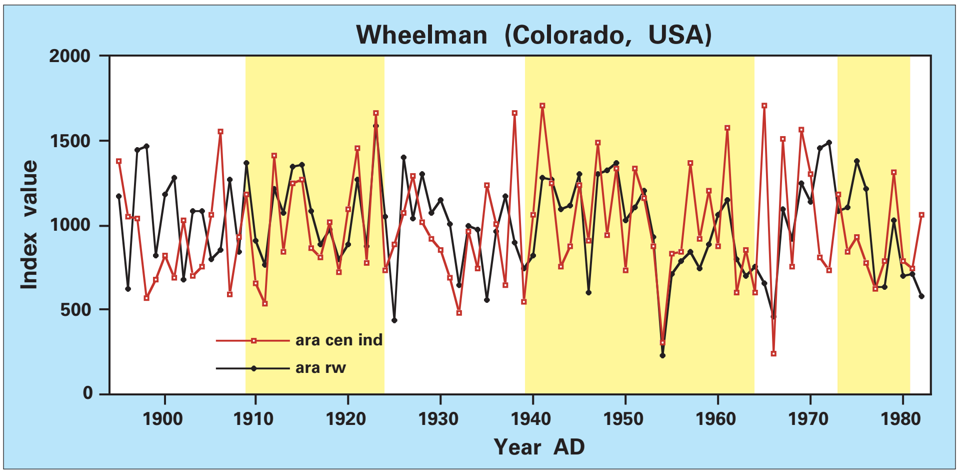

Figure 3: Comparison of tree-ring indices (rw) measured for Pinus ponderosa at Wheelman (Colorado, USA; cf. Kienast and Schweingruber 1986) with NPP indices (cen ind) simulated by the CENTURY model based on time series of weather data from the VEMAP database (Kittel et al. 1995) interpolated to the Wheelman site. Yellow areas denote periods with a good match between observations and simulation (H. Bugmann et al., unpublished data).

line dieback events and the growth patterns of *Picea abies* in the subalpine zone were evaluated against a number of qualitative and quantitative datasets, including several dozen treering chronologies from the Alps available from the International Tree Ring Data Bank. These tests indicated reasonable agreement between historical evidence and simulated behavior, but they were far from being conclusive, pointing to the need to conduct further tests to evaluate the usefulness of the model for studying the impacts of climate variability on tree population dynamics.

Finally, in an ongoing study treering data are being used to evaluate the interannual variability of ecosystem model responses across the 20th century in the context of VEMAP (Vegetation/Ecosystem Modeling and Analysis Project; Schimel *et al.* 1997). Bugmann *et al.* (unpublished) used the spatially and temporally explicit VEMAP climate database to provide sitespecific climatic input data for the CENTURY ecosystem model (Parton *et al.* 1994), and compared a simulated index of net primary productivity (NPP) against measured, sitespecific treering widths (Fig. 3). The results suggested that there is reasonable agreement between simulated and observed patterns across parts of the simulated time span, but the model had difficulty capturing some aspects of the measured time series. It is not clear at present whether the differences (Fig. 3) are due to methodological problems (such as comparing NPP to treering widths, the standardization procedures that were used, the derivation of climatic input data, etc.), or whether they point at model inadequacies. Again, further research is required to develop methodologies for these modeldata comparisons.

Conclusion

It is evident from the above considerations that there is a certain mismatch between the resolution and quantity of output variables provided by ecological impact models and the availability of long measured time series that could serve as a source of climatic input data for the models and to evaluate their predictions against truly independent data. Even with an improved collaboration between paleoecologists and modelers, it is unlikely that there will ever be a single data source that can be used to fully evaluate models of longterm ecological processes. Rather, we should strive to combine several data sources for evaluating both process formulations and the overall projections that result from any given model. Long time series of paleoecological data from palynological and dendroecological studies could play a very important role in this effort.

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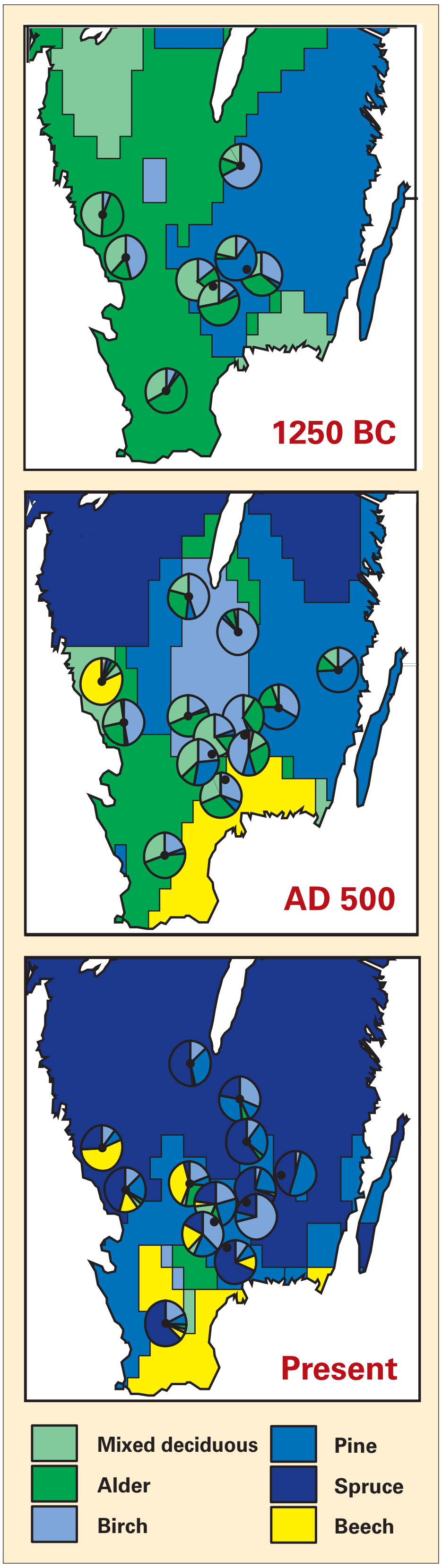

Figure 1: Forest maps of southern Sweden from 1250 BC, AD 500 and present based on regional pollen sites. The pie diagrams show data from stand-scale sites.

Shift From Deciduous to Coniferous Forest in Southern Scandinavia Driven by Climate Change and Land-Use Interactions

Large-scale changes in land-cover can have significant feed-backs to climate and we have documented a rapid shift from deciduous to primarily coniferous forest types in southern Scandinavia (Fig. 1). This shift began about 1500 years ago but analysis of rates of vegetational change, based on a suite of pollen analyses from small forest hollows in southern Sweden, showed that the most rapid changes occurred during the last 150 years (Lindbladh *et al.*, 2000).

We exploited the versatile nature of paleoecological data in order to work at both regional and stand scales within the boreo-nemoral zone of southern Sweden. Our major aim was to place recent vegetational change, sensed at two spatial scales, into a longer time perspective, breaking free from the normal constraints of neo-ecology. We had two unique paleoecological data sets at our disposal. Sixteen forest hollow sites yielded rather accurate but spatially restricted reconstructions of forest vegetation within maximum radii of a few hundred metres (Jackson and Kearsley, 1998). The regional data set covered a far larger proportion of the landscape but its value was limited by the inherent bias incurred when reconstructing vegetation using pollen that has dispersed long distances. The combination of these two data sets permitted more precise reconstructions of former tree distributions.

A detrended correspondence analysis (DCA) of the calibrated pollen data from the individual forest stands for 1250 BC, AD 500 and present, portrayed the similarities and differences between the sixteen individual stand histories. All stands moved away from the rich deciduous forest represented by *Alnus*, *Corylus*, *Quercus* and *Tilia* with some *Fraxinus* and *Ulmus*. The commonest successional pathway was via *Betula* and *Carpinus* to forest comprised of *Picea* and *Pinus*, although two stands became dominated by *Fagus*. The role of *Betula* as a prominent species in forests undergoing transition from deciduous to coniferous was emphasised in the DCA and many stands were at this intermediate stage at AD 500. The same tendency was observed at the regional scale especially in the central region of the study area. Only one stand showed a distinctly divergent pattern. Thus, although unique successional pathways can occur, the general pattern in southern Sweden during the last 3250 years has been along the pathways that lead to *Picea*- and to a lesser extent to *Fagus*-dominated stands.

A strong correlation between a decline in the percentages of pollen from deciduous trees and an increase in cereal pollen suggested that much of the vegetational development during the last 1000 years in southern Sweden could be largely explained by human impact through forest clearance and grazing management (Bradshaw and Mitchell, 1999). Direct climatic influence was of greater importance earlier in the Holocene (Cheddadi *et al.*, 1997). Jacobson *et al.* (1987) carried out a rate of change analysis on regional pollen data from eastern North America and they argued for a continuous underlying climatic control of the rate of vegetation change. The global climatic fluctuations during the last 1500 years that in Europe have included the Mediaeval Warm Period (MWP) and the Little Ice Age (LIA) have been regarded as among the most extreme experienced during the entire Holocene (Keigwin 1996), and a reaction of forest vegetation to these changes might be anticipated.

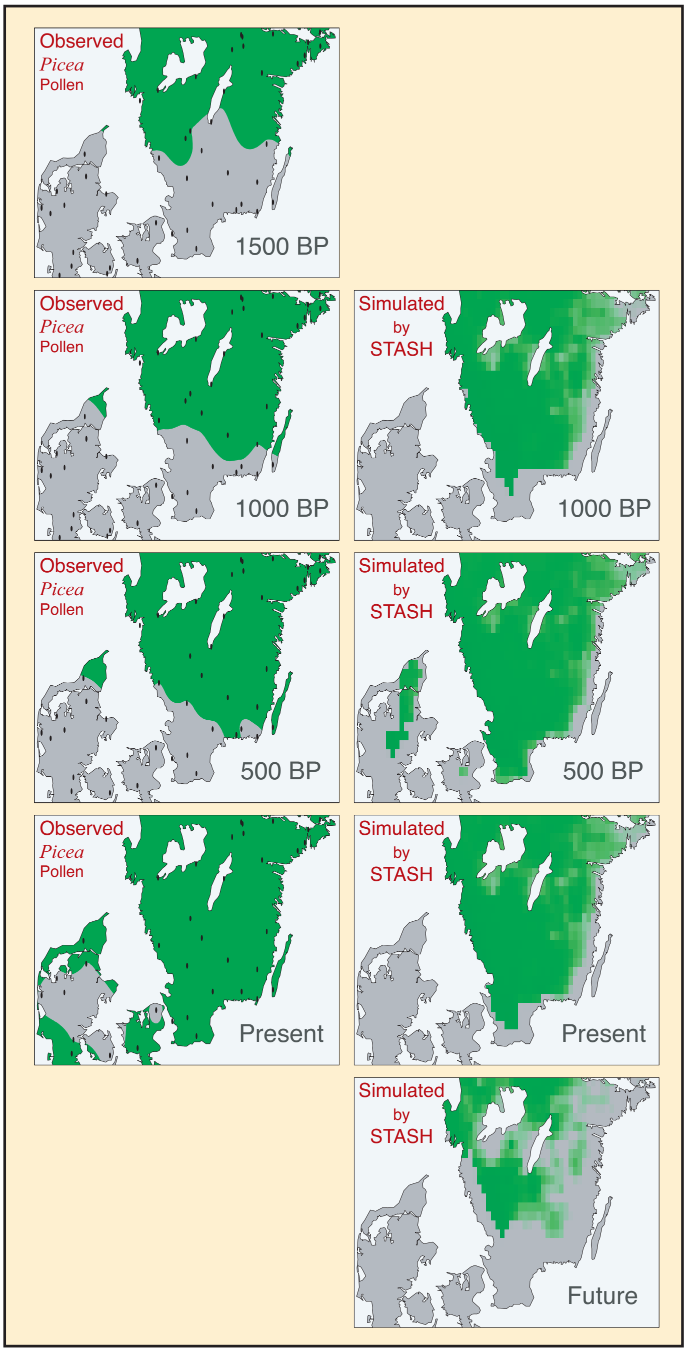

Figure 2: Observed and simulated Picea distributions during the last 1500 years. The observed distributions are reconstructed from fossil pollen data. The simulated distributions are generated by the bioclimatic model STASH. The predicted future distribution assumes an atmospheric CO_2 composition twice that of present.

In order to explore this possibility we compared the paleoecologically mapped distributional changes of Picea abies in southern Scandinavia during the last 1500 years with modelled limits generated by the bioclimatic model STASH (Sykes *et al.*, 1996; Bradshaw *et al.*, in press). STASH predicts the equilibrium range boundaries associated with particular climates. It takes into account

the response of species to winter cold, growing season warmth and soil moisture. The climate database used to run STASH comprised paleotemperature anomalies reconstructed from Fennoscandian tree-rings (Briffa *et al.*, 1992) and paleoprecipitation anomalies obtained from the semi-quantitative historical reconstruction by Lamb (1967) covering the last 1000 years. The application of northern data to southern Scandinavia is supported by the observation that major northern temperature anomalies are duplicated in shorter datasets from further south (Kalela-Brundin, 1999).

The comparisons of observed and modelled range limits for *Picea* in southern Scandinavia strongly suggested that the species distribution has tracked climate change during the last 1000 years, with only a small lag owing to the limits imposed by seed dispersal (Woods and Davis, 1989)(Fig. 2). The rate of change of the European *Picea* distributional limits has been rather slow during the last 1000 years compared to earlier in the Holocene, when very rapid rates of population expansion were recorded (Huntley and Birks, 1983). During the last 1000 years, the modelled, climatically imposed, potential range limits have been relatively stable, with some oscillations back and forth during the MWA and LIA. The realised range limit of *Picea* has approached the potential range limit and overshot during the last few centuries as a result of planting and establishment during climatically favourable years. Future predictions suggest that the range will retreat northwards, and outlying populations will be out of equilibrium with climate and under threat.

We conclude that the shift from deciduous to coniferous forest that we observed in southern Scandinavia was driven by anthropogenic land-use changes acting in conjunction with climate-driven shifts in distributional limits of a forest dominant – *Picea abies*. The climatic component is largely concealed by the anthropogenic, which comprises changes in grazing management and agricultural practices. Future research carried out as part of HITE will investigate the reversibility of this change and its possible feeedbacks to the global climate system.

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Long Term Land-Cover Changes on Regional to Global Scales Inferred From Fossil Pollen – How to Meet the Challenges of Climate Research?

Two major foci of global-change research are climate modelling and the use of paleoclimate reconstructions to test model outputs. In this respect, the effects of climate change on land-cover and the feed-back effects of land-cover change on climate belong to the numerous processes that we need to understand more fully over short and long time-scales.

A wealth of pollen data is presently available at more or less high-resolution over short to long time-scales, which represent an enormous potential for reconstructions of past land-cover at different temporal and spatial scales. However, setting up the approach and establishing the tools for translating pollen data into quantitative land-cover units are not an easy task.

Earlier Attempts to Quantify Landscape Openness in Europe

Within the frame of the European Science Foundation "Climate and Man" programme (1985-1995, leader: B. Frenzel), a major focus was the assessment of land-cover changes in terms of deforestation/afforestation in Europe during the last 6000 calendar years and their possible role in climate change (e.g. albedo effects). Archeological and palynological data were brought together for a series of time windows in order to get an estimate of the extent of deforestation or afforestation (e.g. Frenzel, 1992), especially during the Roman Iron Age (c. AD 200) and the time of migrating German tribes (c. AD 600). In this reconstruction, maps of non-arboreal pollen (NAP) percentages for more than 200 selected sites were drawn for the two time slices. These maps were then interpreted assuming that changes in NAP percentages could be compared directly between sites and interpreted in terms of differences in landscape openness between sites and through time.

The results provided a clearer qualitative picture of the history of landscape openness in Europe. Periods of extensive deforestation are recorded in many areas already during the Bronze Age (from c. 3500–3000 calendar years), when the landscape may have been as open or even more open than today (e.g. in Britain, Ireland, Denmark and southern Sweden). However, the first period of major deforestation in Europe as a whole occurs during the Late Iron Age (from c. AD 500–0). In most areas, landscape openness increased further through the Middle Ages. Modern Times are characterised by contrasting developments in different parts of Europe. Some areas were simply abandoned, or the management changed from an agricultural to a sylvicultural one, both resulting in afforestation; in other areas deforestation continued.

Case Study in Southern Sweden

In southern Sweden, since 1989, a series of research projects have been devoted to the study of pollen/land-use relationships, with the purpose of improving pollen-analysis as a basis for reconstructing past cultural landscapes. A database of over 125 pollen assemblages (from moss polsters) and related vegetation and soil properties from non-fer-

tilized hay meadows, pasturelands and cultivated fields, all managed in a traditional way, was used for qualitative and quantitative reconstruction of past land-use and soils (e.g. Gaillard *et al.*, 1992, 1994). Moreover, a first calibration of pollen data on landscape openness was attempted using pollen assemblages from lake surface sediments and vegetation mapping around 13 lakes in the same traditional cultural landscapes (Gaillard *et al.*, 1998). Predictive models were developed for a series of landscape units such as totally open land or dense forest, based on partial least squares (PLS) regression of the total modern pollen assemblages. PLS calibrations of these landscape units were then tested on a fossil data set. The results showed that the reconstructed percentage covers of total open-land were 10–20% higher than the NAP percentages, whereas the percentage covers of dense forest were 15–40% lower than the AP percentages. Comparison of the PLS reconstructions with historical maps demonstrated that the PLS reconstructions were reliable. This pilot study was performed in the southernmost province of Sweden, Scania.

The data set was extended to include sites north of Scania, up to the area of the large lakes Vänern and Vättern (Broström *et al.*, 1998). This study demonstrated that the relationship between landscape openness and NAP percentages from lake surface sediments is not straightforward. It was hypothesized that the complex relationship between landscape openness and NAP percentages could be explained by differences in regional vegetation composition and specific spatial patterns of vegetation patchiness between areas, resulting in different regional pollen productions and source areas of pollen. This assumption was further tested with a simulation model of pollen dispersal and deposition (e.g. Sugita, 1994) using landscapes simplified from the modern open agricultural and semi-open forested regions in southern Sweden (Sugita *et al.*, 1999). The simulated relationships between NAP percentages and percentage cover of open land within 1000 m around the lakes agreed with the empirical relationships (see figure). These simulations demonstrated that simple NAP percentages are insufficient to quantify the percentage cover of open land in open

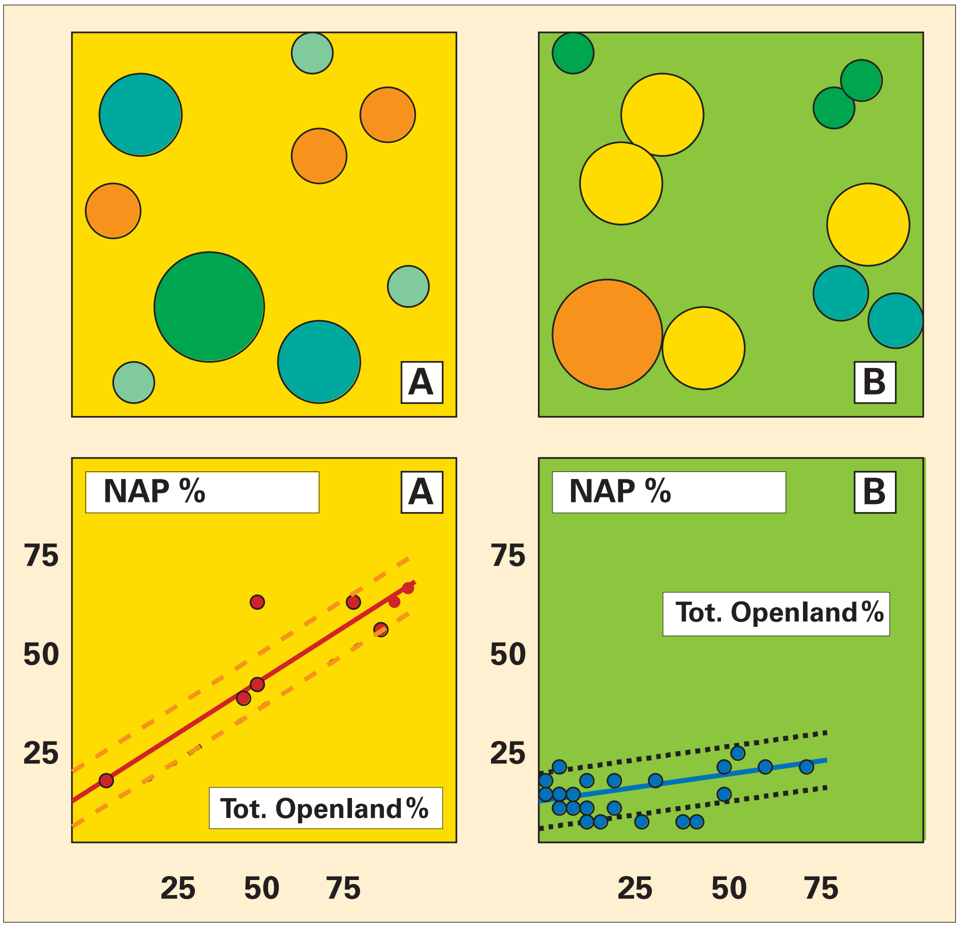

Figure 1: Hypothetical landscapes mimicking (A) the open, agricultural landscape in southern Skåne (southern Sweden), with a matrix of open land (yellow) and scattered patches of different woodland types (green and orange), and (B) the semi-open, forested landscape in northern Skåne and Småland with a matrix of spruce (green) and scattered patches of open land (yellow) and different woodland types (green and orange). The hypothetical landscapes are simplified from real landscapes, and species composition in each patch is simplified from existing vegetation inventories. In the scatter plots, the points and the plain lines represent the empirical relationships between NAP percentage versus percentage cover of open land within 1000 m of the lakes in southern Skåne (A, red) (Gaillard et al. 1998) and in northern Skåne and Småland (B, blue) (Gaillard et al. 1998, Broström et al. 1998). The dashed lines represent the area including the simulated relationships between NAP percentage versus percentage cover of open land within 1000 m of 3.14-ha lakes for landscape designs with 90 % openness (red, A) and 30% openness (blue, B) (the individual simulated values are not shown). Modified and simplified from Sugita et al. (1999).

to semi-open landscapes such as those characteristic of South Sweden.

Work in Progress

We are presently following a new research strategy to develop a more robust calibration tool than the ones attempted earlier for quantitative reconstruction of past land cover. We are using a two step procedure, i.e. the "Landscape Reconstruction Algorithm LAR" of Sugita (in press): (1) estimating the changes in background pollen through time and (2) reconstructing vegetation composition and landscape patterns using the background estimates. This strategy also implies that reliable estimates of pollen productivity for key taxa (trees, shrubs and herbs) are available. Such estimates have been published for all North-European tree species by Andersen (1970). These were, however, based on data collected in forest vegetation. Our approach requires pollen productivity estimates of trees growing in open to semi-open landscapes. Moreover, pollen productivity estimates are needed for herbs. This work is in progress and should result in quantitative reconstructions of past land-cover units such as various types of forests and open lands in southern Sweden for the past c. 2000–3000 years, i.e. the time for which the modern analogues used in our studies may be valid.

In parallel to these studies, the simulation program of Sugita (Sugita, 1994; Sugita *et al.*, 1999) is being modified in

order to be used in a GIS environment (Eklöf *et al.* in progress). Thanks to this technical improvement, it will be possible to simulate pollen assemblages in real modern landscapes, and therefore to test and improve the simulation approach. Moreover, it will open invaluable possibilities of comparing simulated pollen assemblages from past landscape scenarios against empirical pollen data, which should be the most effective tool for landscape reconstructions from fossil pollen data to date.

Prospects

The research strategy described above has as its ultimate goal, estimation of past openness at the global scale, which is a necessity if the effect of past vegetation changes on climate is to be modelled and understood. There are today several ongoing international research programmes tackling these questions. BIOME 300 was initiated this year by PAGES/LUCC/GAIM in order to generate global land-cover maps for a large number of time windows covering the past 300 years with the spatial resolution relevant to the needs of climate models. One of BIOME 300's priorities is to improve the accuracy of the maps with the help of all possible expertise within land-cover research, e.g. geographers, historians and paleoecologists (mainly palynologists). In order to achieve this enormous and challenging task, we believe that there are two possible complementary approaches if pollen data are to be used: (1) extrapolation of reconstructions from local to regional scale (areas of one to 500 kilometers diameter) using a robust calibration of pollen assemblages against landscape units, model simulations of past landscape scenarios, and model-data intercomparison ; (2) "biomization" based on the approach used in the reconstruction of past natural vegetation for the purpose of climate modelling (i.e. Prentice *et al.*1996), but introducing new "human-induced" biomes. We plan to test and combine both approaches. The former is currently tested in southern Sweden, and the latter approach is still in its very initial phase and proceeds independantly (Sugita *et al.* in progress).

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For full references please consult *www.pages-igbp.org/products/newsletters/ref2003.html*

WORKSHOP REPORTS

BIOME 300 – A Joint Initiative of LUCC and PAGES

An organizational workshop for BIOME 300 was held in Bern, Switzerland from the 5th through the 7th of March, 2000, under the auspices of PAGES, LUCC, and the Bern Geobotanical Institute, and funded largely by the Netherlands NWO. This meeting brought together over 40 researchers from nearly 20 countries in Europe, Asia, and the Americas to discuss which methods and data are most appropriate to the detailed reconstruction of past land-cover changes. More extended accounts of the meeting and subsequent progress may be found in current LUCC, IHDP and IGBP Newsletters.

Under the leadership of Frank Oldfield (PAGES), Emilio Moran (LUCC Focus Group 1), Rik Leemans (GAIM/LUCC), Andre Lotter (Switzerland), and Marie-Jose Gaillard (Sweden), this group had two primary objectives. The first is to devise a plan for the production of coordinated databases and revised land cover maps at 50 year intervals since AD 1700. The planned development path for this Fast Track BIOME 300 product will be approximately one year. Klein Goldewijk (Netherlands) and Navin Ramankutty (USA) will harmonize the results of their ongoing efforts to compile global data bases, consider the many constructive suggestions of the Bern workshop and prepare a new prototype database. This will be discussed at a meeting linked to a Symposium entitled "Past land cover, human activities and climate variability: future implications" to be held at the Fall meeting of the American Geophysical Union in San Francisco, December 15–19. Shortcomings will be reviewed and further improvements suggested. The months thereafter will be used to develop the final fast-track database, which will be released during the IGBP Open Science Meeting in July 2001 in Amsterdam.

The second objective is to begin the task of building a community for a longer-term effort to reconstruct and understand human impacts on the landscape over the past several millennia. This effort included discussions of the methods that should be included, the data sources available in the various regions, and the perceived gaps in data coverage and interpretive methods.

A steering group for this longer term research agenda, growing out of the BIOME 300 meeting, was established at the end of the workshop, that includes: Frank Oldfield (PAGES), Emilio Moran (LUCC), Carol Crumley (USA), Marie-Jose Gaillard (Sweden), Rik Leemans (the Netherlands), Charles Redman (USA), Shinya Sugita (Japan), and Bob Thompson (USA). Most of the members of this group will also hold a meeting at the Fall AGU (see above).

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The 5th ELDP Workshop: The Record of Human/ Climate Interactions in Lake Sediments

Pallanza, Italy, 7–12 October 2000

The European Lake Drilling Programme (ELDP) is an ESF (European Science Foundation) Scientific Programme aiming to achieve a better understanding of the regional dimension of past environment changes in Europe through high-resolution lake sediment studies (see PAGES newsletter Vol. 7, No.1, 1999). The theme of the 5th ELDP workshop, held in Pallanza, was the record of human/climate interactions in lake sediments. 39 participants from 12 European countries and from Israel and Japan presented their data in 28 contributions demonstrating the wide range of topics within this overall theme. Some presentations emphasized recent human impact on lake ecosystems through reconstructing the eutrophication history of both large circum-Alpine lakes and high altitude lakes in the Alps. Other contributions focused on the prehistoric period, discussing the relations between cultural and climate changes as well as on the causes and dates for the beginning of agriculture. Prehistoric human impact on the environment from Neolithic times onwards, most clearly reflected through forest clearance, has been documented right across Europe from the Atlantic fringes of Ireland to the areas of early agriculture in Turkey, Syria and Israel. The Pallanza workshop stimulated a lively discussion on the possible impact of climate change on past cultures and economies, a proposition currently discarded by most social scientists. It was shown that the major cultural changes in much of Europe at the beginning of the Iron Age probably followed a strong climatic deterioration at about 850 cal BC, a possible indication of the important influnce of climate on human societies. The discussion also revealed that disentangling climatic and human influences within any single sediment record is a difficult task because there are no proxies available which can be clearly interpreted in either one way or the other. Consequently, most studies mainly focus on evidence for either climatic or human impact on lake ecosystems. One approach to solving this problem was demonstrated by the example of the Mezzano crater lake in central Italy. There, a combination of high-resolution studies on a well-dated sediment record, combined with archeological investigations at the same site, showed that the impact of Bronze Age settlements started shortly after a dry climatic phase. The need to combine data from different scientific communities was recognised as the key to solving this type of question in the future.

An extended abstract volume has been published as Terra Nostra 2000/7 "The record of human/climate interactions in lake sediments" (ISSN 0946–8978) and can be ordered online from the Alfred-Wegener-Stiftung *http://www.aw-stiftung.de/publikationen.htm* More information about the Pallanza and previous ELDP workshops are available from the ELDP homepage at *http://www.gfz-potsdam.de/pb3/pb33/eldphome/*.

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INSIDE PAGES

New Office Manager
The PAGES office is pleased to announce that Ms. Elke Bergius has taken up the vacant position of Office Manager. Elke received her 'diplom' degree from the Botanical Institute at the University of Bern in 1999 and has scientific interests in numerical modeling of biological systems. Elke takes over office administrative and financial oversight duties from Niklaus Schranz, who has elected to continue to work at the PAGES office in a reduced capacity as technical editor and graphics coordinator.

Call for contributions to PAGES News
In the next issue of PAGES News, due to appear in March 2001, we plan to highlight and overview the role of numerical modeling in paleoclimate research, especially those aspects most relevant to the problem of future climate prediction. We encourage scientists from the PAGES community to submit material relevant to this theme. Types of contributions to PAGES News, include (1) research highlights of 1 or 2 pages based on recently published peer reviewed literature or (2) Program announcements which are meant to inform and engage the international community in national or regional research efforts.The deadline for the receipt of submissions is January 31, 2001. See *www.pages-igbp.org/products/newsletters.html* for details.

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Layout: Niklaus Schranz

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Improvements for Piston Coring Systems: Results of Technical Experiments

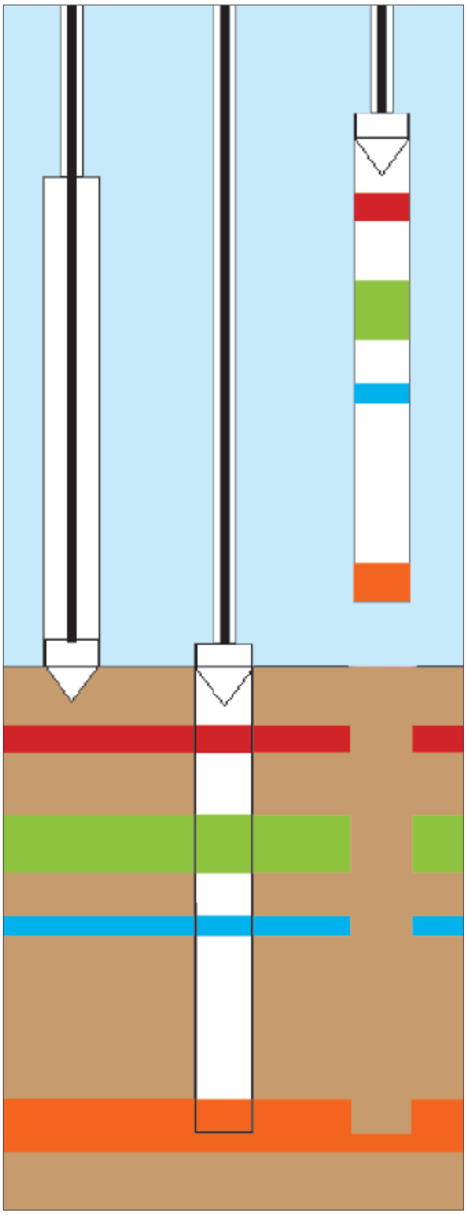

Fig. 1: Principle of piston corer operation in lake sediments

The GFZ Potsdam carries out crater lake coring for paleoclimate studies using a system (Fig. 1) based on the "Livingstone Piston Corer" which was modified according to Usinger with an inner rod to hold the piston at a fixed position and a 1 mm thin steel barrel without an inner tube to improve penetration into the sediment (Colman, 1996). Successful coring operations with the recovery of high-quality cores of up to 72 m total composite length at Lago Grande di Monticchio in southern Italy (Allen *et al.*, 1999; Brauer *et al.*, in press), demonstrate the capability of this low-tech hand-operated system. However, preliminary questions have been raised as to the limits and potential upgrading capabilities of this system to increase its capacity.

Systematic experimental investigations on technical or design requirements and parameters for successful continuous core recovery have seldom been published. Most such published data are based on individual experiences derived from field work mainly based on specific sediment types and pertaining to certain applications. These cannot be readily generalised and transferred to other technical systems or sediments.

This lack of basic technical background information in a currently rapidly developing research field inspired us to initiate a co-operation between drilling engineers and geoscientists to accumulate data on potential improvements of lake sediment coring devices.

We performed coring experiments in a 30 m deep testing shaft of the Institute of Oil and Gas Technology at the Technical University of Clausthal with the financial support of the Deutsche Forschungsgemeinschaft (DFG). These tests were performed on two geotechnically different end-member types of sediments: a medium-grained very homogeneous sand and a clay-rich fine-grained silt. For each experiment both sediment types were homogeneously and complexly packed into 3 m long steel test pipes (inner diameter: 30 cm) and then mounted into the testing shaft. The experiments included several variations in parameters such as core barrel coating, energy input and frequency. These were evaluated for core penetration as well as total core rod length and the length of individual rods.

The most noteworthy results of these tests are presented in the two diagrams of Fig. 2. The results demonstrate that the surface of the barrel is extremely important for the penetration rate especially in sand-rich sediments. An easy and rather inexpensive method is to carbo-nitrate coat and oxidize the barrels, with the result of doubling the penetration rate in comparison to an unmodified steel barrel surface.

Core barrel type	*Energy*	*Pipe Length*	*Sediment*
original	*hammer weight*	*2 m*	*sand*
with cutting shoe	*high-frequency vibrator*	*17 m*	*clayey silt*
chromium-plated	*Wacker-hammer*	*25 m*	
partly chromium-plated	*Cobra-hammer*		
nickel-plated	*Hydraulic-hammer*		
nitrated and oxidized			

Tab. 1: Test program and parameters investigated

Other important results of the study are:

- Frequency and impact force of common hand-held and motor-driven hammers such as the Wacker Hammer, yield high penetration rates. A high-frequency impact force did not result in increased total penetration or higher penetration per impact.
- The highest penetration per stroke is always achieved during the first beats. Pausing between impacts or stand-by time prior to retraction causes strong enhancement of sediment adhesion.
- Not the total length of the pipe but the number and type of connectors is critical for the energy yield at the tip of the piston. Each connector (tool joint) may cause a few percent dampening of each stroke. Therefore, connections must be very tightly closed and connector types with a high stroke energy throughput should be prioritised. Long pipes and/or a low number of connectors are of paramount importance for the transfer of energy downhole.

The GFZ piston corer has already been redesigned taking into account some of the results of this study. After modification it was applied on Lago Grande di Monticchio in late Summer 2000 with great success. In 12 m water depth 94 m of continuous high-quality core have been recovered with an overall operated system length of 110 m. In comparison to the previous operation on the same lake a depth increment of more than 30% was achieved.

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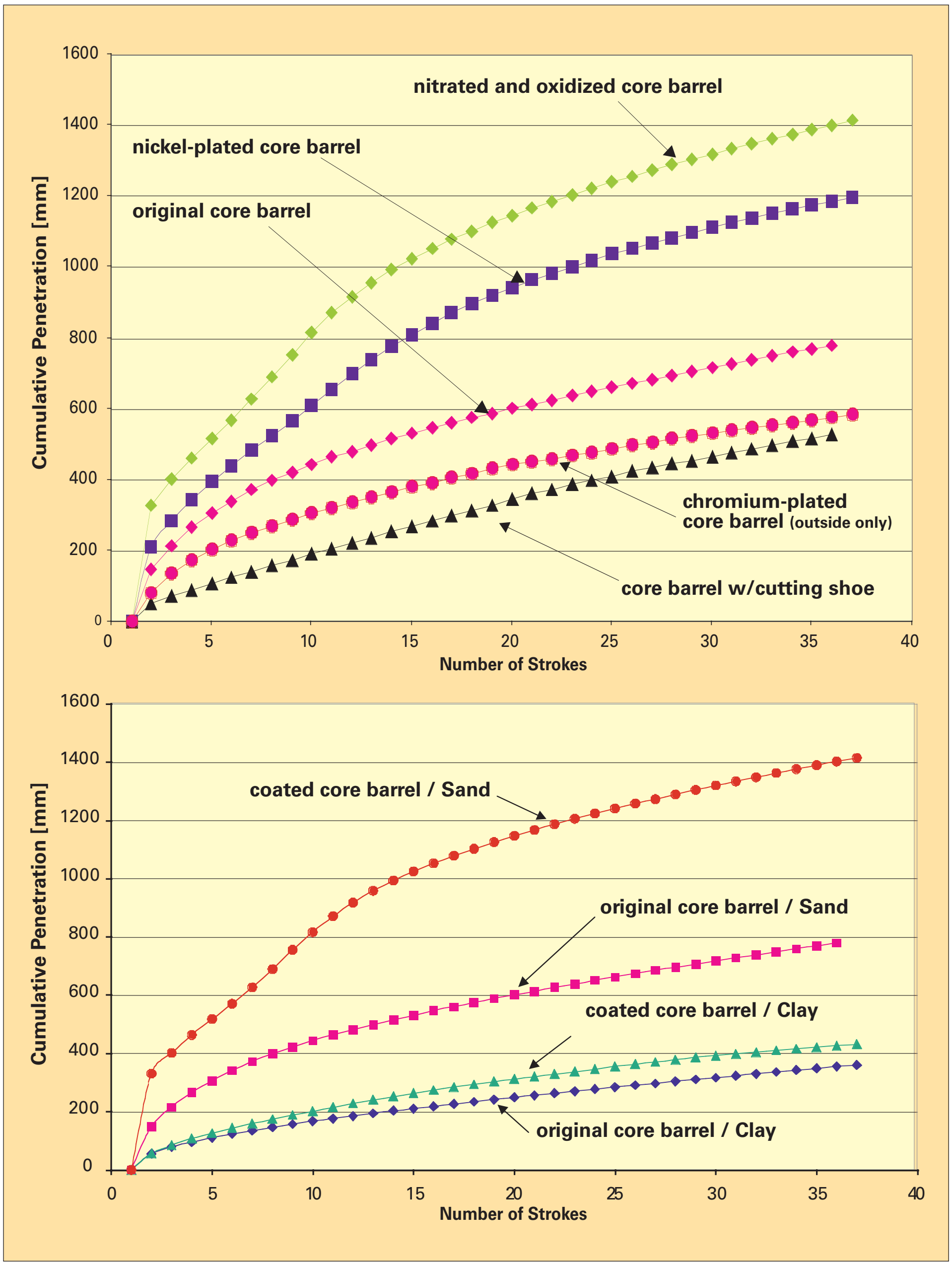

Fig. 2: Cumulative penetration rate against number of strokes with different barrel coatings in sand (top) and a comparison of piston coatings with highest and lowest penetration rates in sand and in clayey silt (bottom).

PAGES Website News

The PAGES website is now accessible using the url ***http://www.pages-igbp.org***, although the old url (*http://www.pages.unibe.ch*) will continue to work as well. Email addresses at the PAGES IPO remain unchanged. The new web URL has been chosen in order to provide a clear indication of our connection with IGBP, PAGES' parent body, and to indicate that pages is an independent non-profit organization, rather than a subsidiary of the University of Bern.

PAGES CALENDAR

(* indicates open meetings – all interested scientists are invited to attend)

- ***9–14 February, 2001 "CUBA 2001 – Symposium on Tropical and Subtropical Palynology (America - Africa)". La Habana, Cuba**
  Contact: Dr. Sonia Machado Rodriguez, Instituto de Ecologia y Sistematica, Carretera de Varona Km. 3 1/2. Capdevila, Boyeros, A.P. 8029, C.P. 10800 La Habana, Cuba
  ecologia@unepnet.inf.cu
  http://www.pages-igbp.org/calendar/calextras/cuba2001circ2.pdf

- **February 22–23, 2001 "WEPAMA (Western Pacific Margin) Working Group Meeting II: Western Pacific Paleoceanography: New Techniques and Directions". Taipei, Taiwan**
  Contact: Min-Te Chen, Institute of Applied Geophysics, National Taiwan Ocean University, Keelung 20224, Taiwan
  mtchen@mail.ntou.edu.tw
  Contact (US only): Joseph D. Ortiz, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964-8000.
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- ***22–24 March, 2001 "31st Arctic Workshop" Amherst USA**
  Contact: Julie Brigham Grette and Ray Bradley, Department of Geosciences & Climate System Research Center, University of Massachusetts, Amherst, USA
  brigham-grette@geo.umass.edu, rbradley@geo.umass.edu

- ***26–30 March, 2001 "EGS XXVI General Assembly" Nice, France**
  General Website: *http://www.copernicus.org/EGS/egs.html*
  Paleo-Sessions: *http://134.76.234.216/nice01pro/pcl.program.htm*

- **7–8 July, 2001 "PAGES SSC Meeting" Amsterdam, The Netherlands**
  Contact: Keith Alverson
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- **14 July, 2001 "PAGES–CLIVAR Working Group Meeting" The Netherlands**
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- ***18–22 September, 2001 "PAGES–PEP III Conference: Past Climate Variability in Europe and Africa" Aix-en-Provence, France**
  Contact: Catherine Stickley, ECRC, University College London, 26 Bedford Way, London WC1H 0AP, UK
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The full PAGES calendar is available on our website *(www.pages-igbp.org/calendar/calendar.html).* If you would like to have your meeting announced, please send us the conference details.