# The Role of Human Activities in Past Environmental Change

F. Oldfield
University of Liverpool, PO Box 147, Liverpool L69 3BX, United Kingdom

J.A. Dearing
Department of Geography, University of Liverpool, PO Box 147, Liverpool L69 3BX, United Kingdom

## 7.1 Introduction

A crucial task for modern environmental science is to document and understand the ways in which human impacts on the earth system interact with other processes of global change. Such understanding is an essential prerequisite for establishing the consequences of further population growth and increased economic activity, with all their implications in terms of higher demands on energy, water and a wide range of resources, both renewable and non-renewable. Most of the research in this field draws on a combination of methodologies, for example remote sensing, environmental monitoring, experiments, large scale observation programs and modeling, all of which rely on a relatively short time span of empirical knowledge - usually a few years or decades at most. The purpose of the present chapter is not simply to consider past human impacts on the environment on longer time-scales but to explore the extent to which the longer time perspective contributes to an enhanced view of potential future changes and impacts.

Writings that highlight the potentially damaging effects of human activities on the environment have grown exponentially during the last decades, but have only relatively recently gained both a quantitative dimension and a historical perspective. We now realise that the time-span of human impact on the environment, at least at the regional level, ranges over millennia and not merely the last two centuries of industrialisation. The story of past human impacts, their interactions with climate variability and the human consequences of these interactions thus forms part of the essential context within which to evaluate present day trends and likely future consequences.

Much of the history of human impact on environmental systems discussed here is concerned with those aspects of global change that are, in terms of the distinctions made by Turner et al. (1990) ‘cumulative’ rather than ‘systemic’ (Table 1). Although this distinction is not entirely unambiguous, it implies that, in contrast to elevated atmospheric concentrations of $CO_2$ and $CH_4$ (Chapter 2), and their potentially systemic effects on global climate, most of the impacts discussed in this chapter achieve global significance by either the widespread nature of their effects or their cumulative magnitude. A familiar example is the eutrophication of freshwater ecosystems.

**Table 1**. Types of global environmental changes. Modified from Turner et al. (1990).

| Type | Characteristic | Examples |
|---|---|---|
| **Systemic** | *Direct impact on global system* | a) Industrial and land use emissions of greenhouse gases<br>b) Stratospheric ozone-depleting gases<br>c) Land cover induced changes in surface albedo |
| **Cumulative** | *Impact through worlwide distribution of change* | a) Groundwater pollution and depletion<br>b) Species depletion/genetic alteration |
| | *Impact through magnitude of change* | a) Deforestation<br>b) Toxic pollutants<br>c) Soil depletion on agriculture lands |

## 7.2 Natural and human-induced processes of environmental change

For many ecosystems, hydrological regimes and biospheric processes, the problem of disentangling human from natural influences is dauntingly complex. There are still strongly divergent views regarding the extent to which human actions have influenced environmental systems in the past. The dilemma of interpretation arises largely from the inescapable fact that most of the environmental archives upon which reconstructions are based respond to both kinds of influence, especially in areas where human impacts have a long history. The most convincing insights have come from studies where deduction has been possible through retrospective research – as Deevey so neatly puts it: 'coaxing history to conduct experiments' (Deevey 1967).

Regional as well as global insights are important for understanding processes, for addressing contemporary problems at the human landscape scale and for contributing to future impact assessment. Global generalizations that overlook strong spatial diversity may be of only limited value. Among the most urgent regional needs are more high resolution records of climate variability and human impact from tropical regions where suitable environmental archives are scarce and much less critical research has been accomplished. The lack of such information often seriously compromises interpretation of contemporary ecological patterns, current trends and future implications (Fairhead and Leach 1998).

Seeking to establish the relative significance of natural and human drivers of past environmental changes is clearly important, but it is perhaps even more important to increase our understanding of the interactions between human and natural influences, especially in those situations where their effects are mutually reinforcing or where their combined impact is to drive systems over critical thresholds into modes of non-linear change. In this regard, the paleo-record is of considerable, though so far under-exploited, value. Even where such interactions can be modeled using data derived from experiments and observations, the validity of the models generated requires testing on timescales over which much of the essential evidence comes from paleoenvironmental research based on proxy records. Proxy evidence for past human-environmental interactions makes it possible to extend the record by providing reconstructions over longer time-spans. For quantitative interpretation however, proxies require rigorous calibration against independent data derived both from present day observations and short term instrumental and documentary timeseries.

An important issue is the potential vulnerability of human populations to human-climate interactions. Since, in reality, the effects of climate change on human societies are mediated by cultural factors, human activities may serve to amplify or moderate the impact of natural variability. The record of such interactions in the past contributes to our understanding of them and may well contain important information on, for example, the relationship between rates of change or persistence of stress on the one hand and human adaptability on the other. It is unrealistic to ignore the interactive nature of the relationship between environmental change and human societies just as it is inappropriate to conceptualize it as a simple one way causative linkage in either direction.

## 7.3 Past human impacts on the atmosphere

### 7.3.1 Greenhouse gases

Doubts no longer surround the conclusion that fossil fuel combustion over the last 200 years, and especially during the last decades of the twentieth century, is the main process responsible for elevating atmospheric $CO_2$ concentrations to levels that greatly exceed any recorded during the last 420 kyr (Chapter 2, Section 2.3). Forest clearance and increased biomass burning have made a significant additional contribution to this process, though these have not yet been fully quantified and remain the focus of ongoing research (see e.g. Foley et al. 1996). Increases in atmospheric methane concentrations have also been rapid and dramatic over the last few decades (Chapter 2, Figure 2.6). There can be little doubt that human activities underlie this trend, through expanding agriculture, especially paddy cultivation (Neue and Sass 1994) and growing livestock populations (Prather et al. 1995). Indeed, ascription of increasing atmospheric methane concentrations in the polar ice cores from the second half of the Holocene to tropical rather than high latitude sources (Chapter 2, Section 2.5) opens up the possibility that the effects of paddy cultivation on atmospheric composition may considerably predate the last two centuries.

The nature of these trends in past greenhouse gas concentrations in the atmosphere and their consequences for the functioning of the earth system are major themes in chapters 2 and 4 and are not considered further here.

### 7.3.2 Trace metals, other industrial contaminants and radioisotopes

Discernible widespread impacts of human activities on atmospheric chemistry begin with the early days of extensive metal smelting (Nriagu 1996). Although there are indications of these impacts from the Bronze Age onwards, they become much stronger during the time of the Greek and Roman Empires for which there are clear signs of enhanced atmospheric concentrations of lead, copper and other trace metals in ice cores from Greenland (Hong et al. 1994) and in European lake sediments (Renberg et al. 1994) and peats (Shotyk et al. 1996, 1998, Martínez-Cortizas et al. 1999) (Figure 7.1). Elegant lead isotope studies even permit ascription to particular sources (Rosman et al. 1993, 2000, Renberg et al. 2001) and are able to show that atmospheric concentrations of 'pollution' lead peak in Greenland and throughout Europe between 100BC and AD200. From early Medieval times onwards, metal burdens increase. Enhanced loadings to remote areas prior to the mid-19th century are recorded, but it is generally only close to industrial or urban sources that evidence for strong contamination is apparent (Brimblecombe 1987).

Within the period of widespread industrial and urban development over the last century and a half, evidence for atmospheric contamination became ubiquitous. Spatial patterns have changed, mirroring not only the process of industrial expansion but also trends in resource use as well as in production, abatement and dispersal technologies. Evidence for these changes comes from both documentary sources (e.g. Brimblecombe 1987) and paleoarchives such as lake sediments (e.g. Edgington and Robbins 1976, Galloway and Likens 1979, Rippey et al. 1982, Kober et al. 1999), ice cores (Rosman et al. 2000) and ombrotrophic (precipitation-dependent) peatlands (Aaby et al. 1979, Norton 1985, Clymo et al. 1990) all of which contain historical records of contamination by a wide range of compounds. Deciphering the record depends both on analysis of the growing range of industrially generated products, including distinctive particulates (Wik and Renberg 1991, Rose 1994) and on the development of dating techniques applicable to the period of industrialisation (Appleby et al. 1991, Appleby and Oldfield 1992). In developed economies, recent turning points detectable in the paleorecord are the rapid increase in power generation beginning in the late 1950's, the increased generation of often environmentally persistent organic compounds, for example polyaromatic hydrocarbons (PAH's) (Hites 1981) and organochlorine products (Wania and Mackay 1993), and the post 1970s trend towards reduced discharge limits, greater control and improved treatment. Following the first clear evidence for damage to ecosystems (e.g. Odén 1968), many contaminant emissions peaked in the 1970s and '80s. The record in environmental archives has confirmed the trend towards an amelioration of air quality in many parts of the world (Nriagu 1990, Boutron et al. 1991, Candelone et al. 1995, Schwikowski et al. 1999). Nevertheless, even in the richer developed countries, air quality problems persist (e.g. Blais 1998). Elsewhere, factors such as the legacy of previous political regimes, continuing dependence on fossil fuel as the main energy source, proliferation of vehicles, population growth and ongoing industrial development often combine and lead to a continued build-up in atmospheric pollution to the level where concern is increasing at both regional and global levels.

Significant radioactive contamination of the atmosphere on a global scale began with the fall-out from post-war nuclear weapons testing from 1953 onwards. Once more, paleoarchives preserve a vital record of the spatial patterns and temporal changes in atmospheric deposition resulting from weapons testing, nuclear power accidents such as the Chernobyl incident and discharges from nuclear installations (Figure 7.2). Not only do paleorecords complement and extend direct measurements, especially where these have been sparse, poorly organized, inconsistent or completely absent, they also serve as indicators of the subsequent behaviour and long term fate of radioactive species in the environment. This is especially important in the case of relatively long lived radioisotopes such as $^{137}$Cs (30 year half-life) and several isotopes of plutonium and americium. These same radioisotopes serve both as dating markers and as process tracers in studies of recent human impact on ecosystems (Walling and Quine 1990, Oldfield et al. 1993).

## 7.4 Paleoperspectives on acidification, eutrophication and the ecological status of lakes, coastal waters and peatlands

Just as environmental archives contribute records of past atmospheric contamination, many also allow us to identify the impact of contamination on ecosystems Nowhere has this been more clearly demonstrated than in the documented effects of industrial

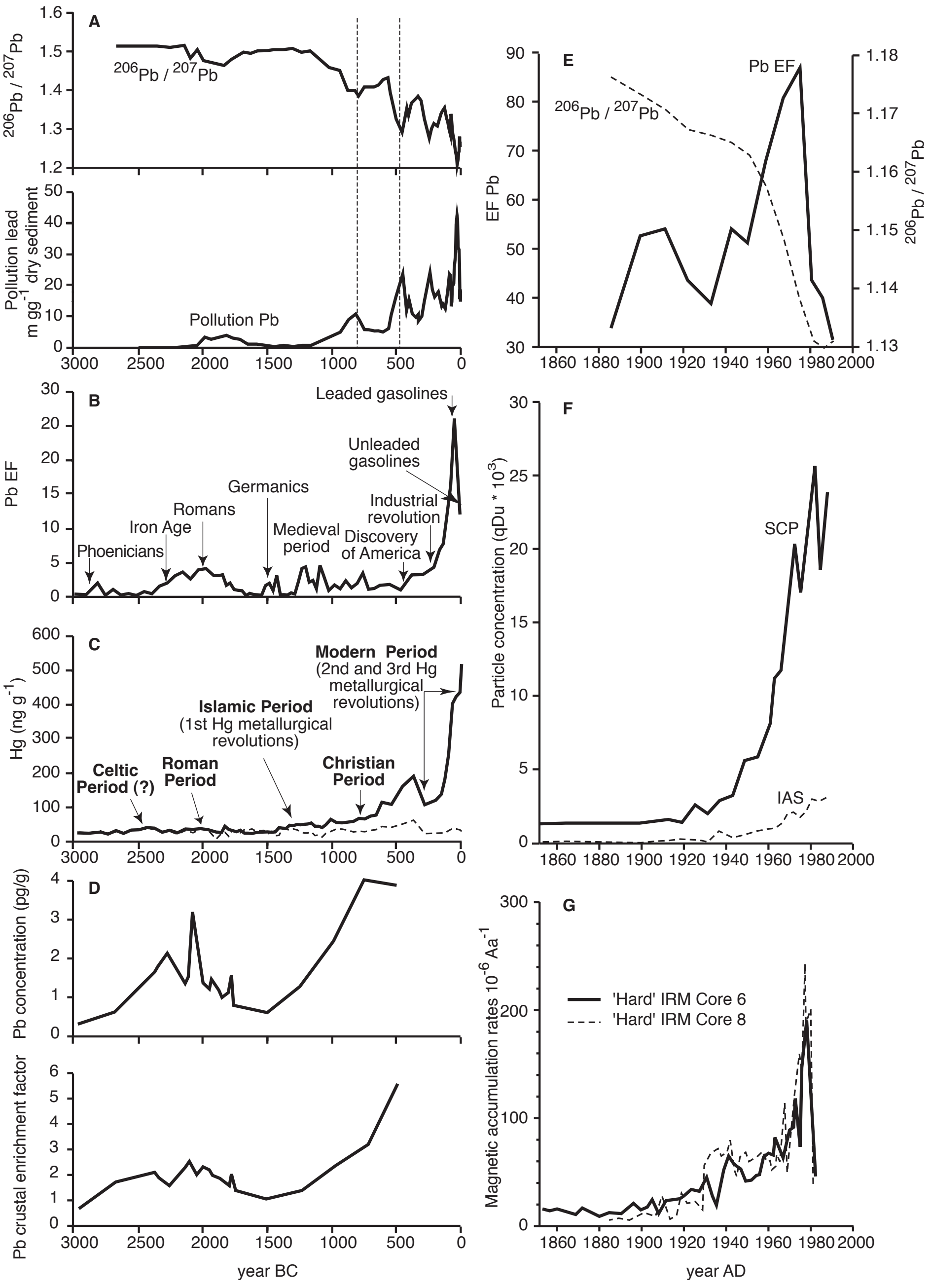


**Fig. 7.1**. Sedimentary histories of trace metal and industrially generated particulate deposition.

**A.** Pollution lead concentrations and $^{206}$Pb/$^{207}$Pb ratios as recorded in Koltjärn, a small lake in S Sweden (Renberg et al. 1994; 2000).

**B.** The total lead concentration record from Penido Vello, a peat profile in N Spain (Martinez-Cortizas et al. 1997) set against a series of historical events and cultural stages from 3000 BP onwards.

**C.** The total (solid line) and natural (dashed line) mercury (Hg) concentration record at the same site as **B** set against cultural and technological changes (Martinez-Cortizas et al. 1999).

**D.** Total lead concentrations and crustal enrichment values from Greenland ice for the period 3000 to 500BP.

**E.** A short-term record of total lead deposition and lead stable isotope ratios from La Tourbière des Genevez, an ombrotrophic (precipitation-dependent) peat bog in Switzerland (Weiss et al. 1999). EF = the Pb Enrichment Factor. The 20th century pattern is comparable to that at Koltjärn, Fig. **A**.

**F.** Indicators of industrially generated atmospheric particulate deposition as recorded in the sediments of a small lake in NW Scotland, very remote from industrial sources (Rose et al. 1994). The inorganic ash spheres (IAS) are mostly fly-ash derived from coal-fired power stations, the spherical carbonaceous particles (SCP) are derived from both coal-fired and oil-fired power plants, but mainly the latter.

**G.** Magnetic measurements used as a proxy for industrial particulate at Big Moose Lake in NE USA.

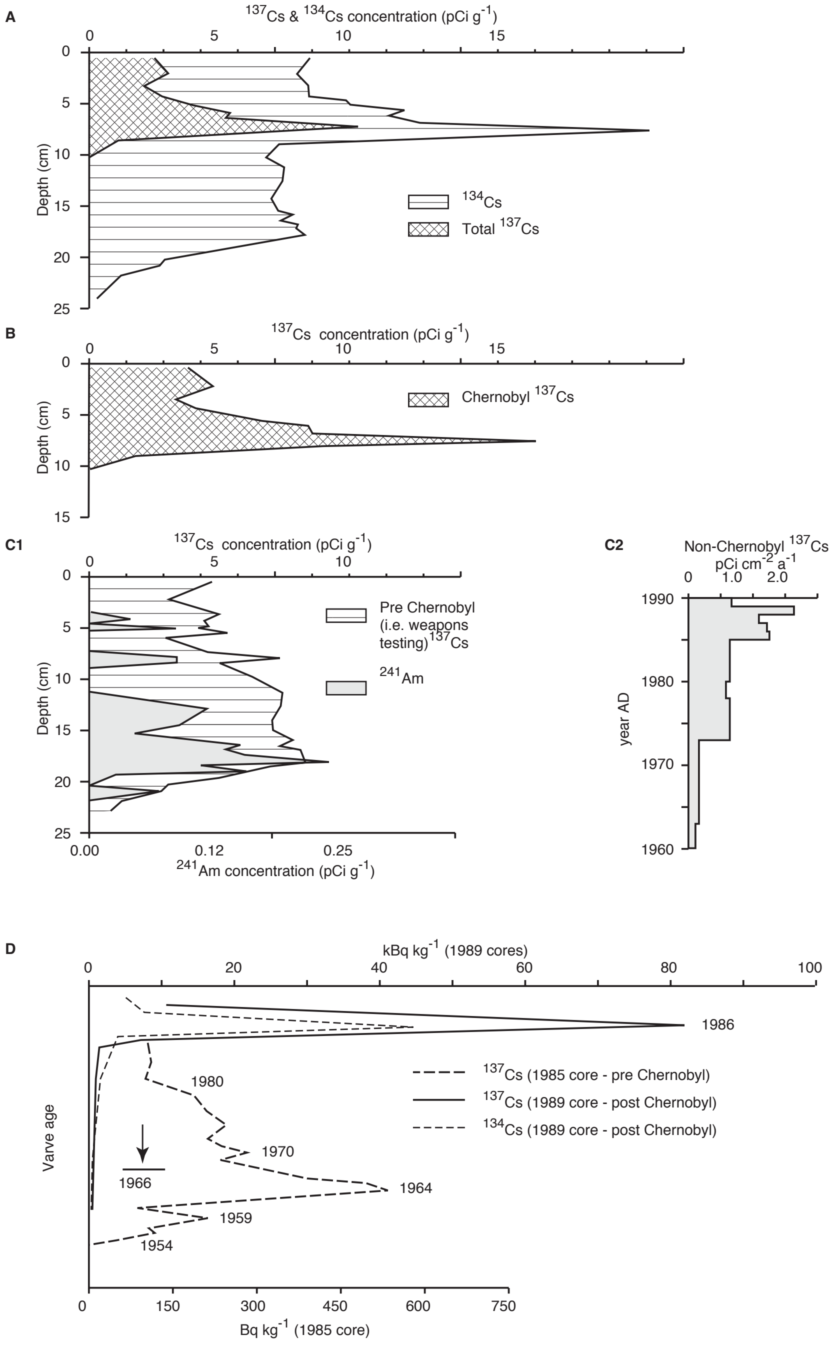


**Fig. 7.2.** Lake sediment records of direct and indirect atmospheric deposition of artificial radionuclides resulting from weapons testing and the Chernobyl accident. Plots **A** to **C** are from Blelham Tarn in the English Lake District (van der Post et al. 1997). Plot **D** is from Nylandssjön, Central Sweden (Crooks 1991). It is thus possible to confirm independently the integrity of the main features of the deposition record of $^{137}$Cs (derived from both weapons testing and Chernobyl), $^{134}$Cs (a marker for Chernobyl deposition) and $^{241}$Am, which was not dispersed by the Chernobyl accident. From the constant post-Chernobyl ratio of $^{134}$Cs to $^{137}$Cs (**A**) it is possible to calculate the Chernobyl-derived $^{137}$Cs (**B**) and subtract this from the total trace in A to give a record of pre-Chernobyl $^{137}$Cs (**C**). This is consistent with independent dating and with the $^{241}$Am deposition history - **C(i)**. The record of weapons testing $^{137}$Cs calculated in this way can then be converted into a depositional flux, using the independent dating evidence from both varves and algae – **C (ii)**. Plot **D** shows Caesium traces from both immediately pre-Chernobyl (Feb. 1986) and Post-Chernobyl (1989) cores taken from the varved lake sediments of Nylandssjön, Central Sweden (Crooks 1991).

on surface water quality. Early evidence for the acidification of rain around industrial cities dates back over 100 years (Smith 1872) and from the 1950's onwards, Gorham (1958, 1975) and Odén (1968) were pointing to the likely impact of acidification on soils, vegetation and lake biota. Much of the acid was derived from sulfur-bearing coal burnt by the power generating industry, and more locally from the smelting of sulfide ores. Not until the 1980's were such processes seriously considered as potential contributors to observed changes in both surface pH and forest health in wide areas of Europe and eastern North America.

Attribution of the observed acidification to industrial processes required elimination of alternative explanations. These included declining upland agriculture and consequent catchment recolonisation by soil-acidifying conifers or heathland vegetation; commercial afforestation; and natural long-term trends in soil development. By adopting a *post hoc* experimental strategy designed to test the validity of each of these, it was possible to eliminate all but industrial deposition as the *general* cause of acidification, though with two caveats. First, the added influence of the other factors was detectable in individual lakes. Second, the degree of chemical buffering in each lake-catchment system emerged as the most important single factor that determined vulnerability to acidification (Battarbee 1990). The following elements were crucial to the research strategy:

- paired lake-catchments were used to isolate and establish the role of each of the proposed causative mechanisms (e.g. Battarbee 1990, Whitehead et al. 1990, Birks et al. 1990a).
- robust, quantitative reconstructions of past lake water pH were developed using biological proxy records in the sediment that had been calibrated to measured values at the present day (Birks et al. 1990b)
- the capacity of sediment records to discern trends against the 'noise' of daily, seasonal and inter-annual variability was assessed; and
- detailed comparisons were made between recent trends and long term records (Figure 7.3).

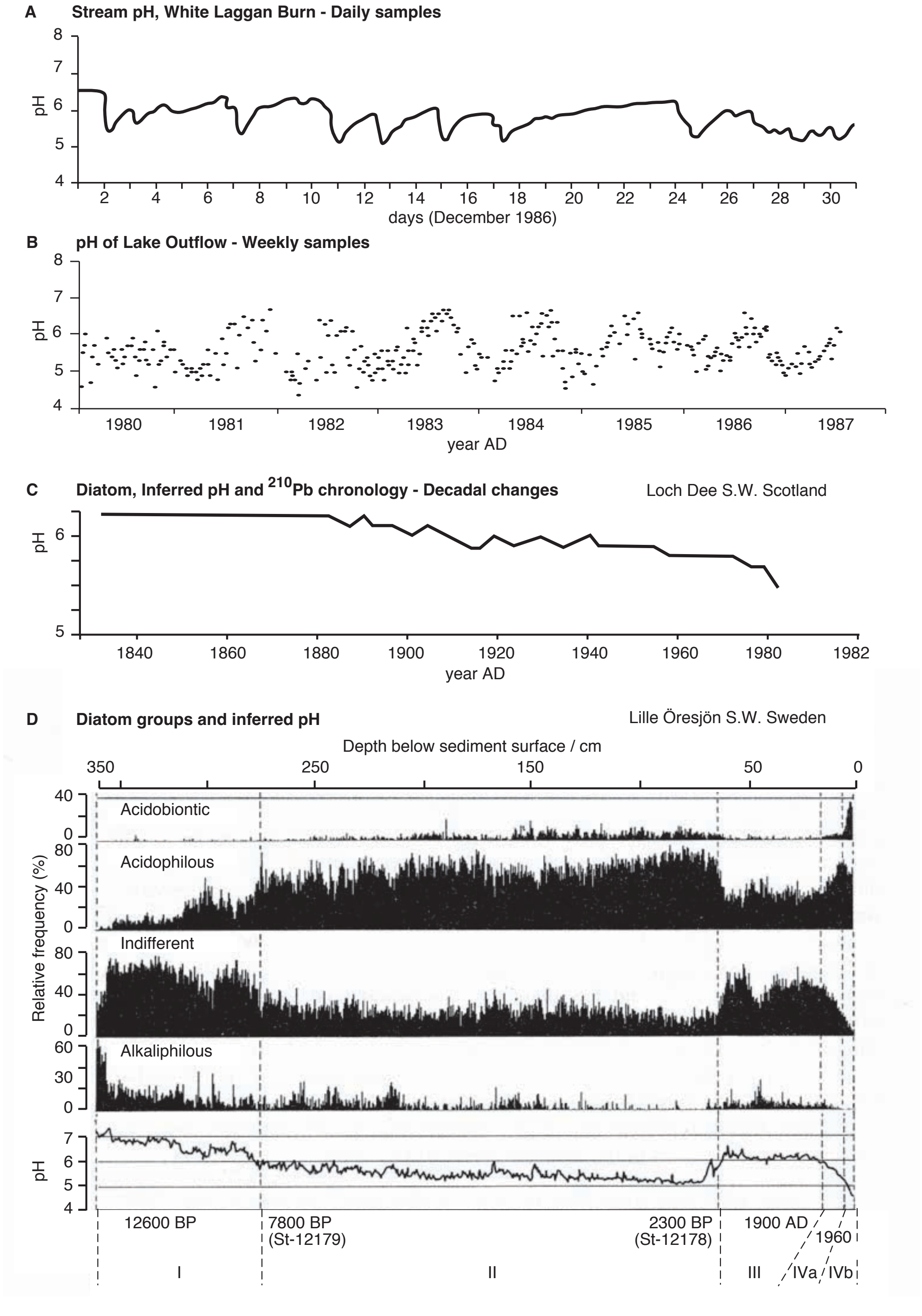
Such elements have important wider implications for paleo-research, the more so as paleolimnological research results are increasingly being integrated into predictive models (Jenkins et al. 1990, Anderson et al. 1995, Jenkins et al. 1997) (Figure 7.4), the identification of critical loads (Battarbee 1997) and the tracking of aquatic ecosystem recovery (Dixit et al. 1989, Allott et al. 1992, Anderson and Rippey 1994, Smol et al. 1998). Recent evidence from some impacted terrestrial catchments and the streams draining them suggests that recovery may be significantly delayed by the loss of calcium and magnesium from soils (Likens et al. 1996).

Parallel to research on the history of surface water acidification have been studies reconstructing the history of eutrophication. These too evolved from a need to establish the extent to which recent eutrophication was an expression of natural variability or a product of human interference with nutrient supplies to lake waters (e.g. Likens 1972, Battarbee 1978). There have now been many convincing demonstrations that accelerated eutrophication has been predominantly a consequence of human activities. These have included the routing of sewage effluents through integrated urban drainage systems from the late 19th century onwards, the discharge of industrial effluent to watercourses, the use of phosphate-rich detergents from the 1950's onwards and the application of artificial fertilisers to agricultural land (e.g. Lotter 1998). In many parts of the world, eutrophication is inexorably linked to population growth in regions where the treatment of effluent rich in human and animal waste is poor or non-existent. Recent research has begun to provide increasingly quantitative bases for estimating past biologically available phosphate loading from sedimentary evidence (e.g. Bennion et al. 1996), thus extending the value of paleolimnological studies by providing additional information on the historical background to recent eutrophication.

Most of the research summarised above relies on adaptations of classical paleoecological approaches to fine resolution studies of recent time intervals. Less common are long term studies of past lake water pH and trophic status. Exceptions include the reconstruction of trends and variability in lake pH throughout the Holocene by (Renberg 1990), (Figure 7.3), as well as of the impacts of early agricultural societies on water quality in Sweden (Anderson et al. 1995) and of the Maya in Guatemala (Deevey et al. 1979, Scarborough 1993, 1994).

Acidification and eutrophication are not the only anthropogenic changes affecting water bodies. Even more dramatic in terms of human consequences in prehistory are the inferred increases in salinization linked to cultural demise, notably in Mesopotamia (e.g. Jacobsen et al. 1958).

By now, paleolimnology is not merely a tool in paleoreconstruction, it has become increasingly


A Stream pH, White Laggan Burn - Daily samples

B pH of Lake Outflow - Weekly samples

C Diatom, Inferred pH and $^{210}$Pb chronology - Decadal changes Loch Dee S.W. Scotland

D Diatom groups and inferred pH Lille Öresjön S.W. Sweden

**Fig. 7.3**. Records of changing surface water pH over different timescales. Plots **A** and **B** show, respectively, daily and weekly direct measurements of pH at Loch Dee, SW Scotland. Plot **C** shows a diatom-based reconstruction of past pH from the analysis of recent sediments from Loch Dee dated by $^{210}$Pb (Battarbee 1998). The paleolimnological approach complements short term monitoring by allowing detection of the long-term decline in pH since the late 19th century, despite the fact that the diurnal and weekly variability exceeds the amplitude of change in the long term trend. In plot **D**, a similar century-long decline in pH at Lilla Oresjön (Sweden) is set in the context of a 12600 year long record at sub-decadal resolution. There are clear shifts in past lake water pH during the pre-industrial part of the Holocene, notable a slow, gradual decline in pH followed by a period during which settlement and farming around the lake led to enrichment and a reversal of the trend. The magnitude and pace of the 20th century decline resulting from acid deposition is seen to be unprecedented (Renberg et al. 1990). These examples show the value of the paleolimnological approach both in establishing trends against a background of short-term variability and in placing these trends in the context of long term natural changes.

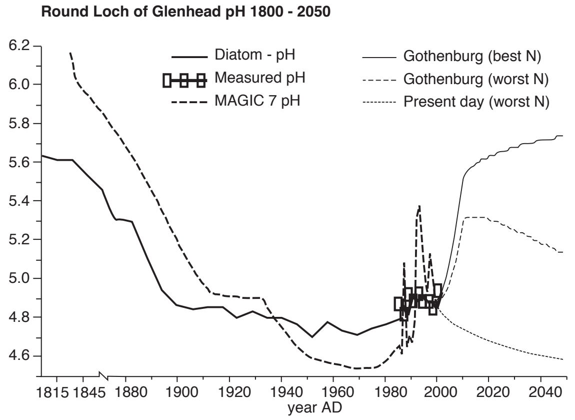


**Fig. 7.4.** The role of paleodata in substantiating models of trophic change in lake ecosystems. The left-hand side of the graph compares fossil diatom–inferred pH, modeled pH using MAGIC, and measured pH for the Round Loch of Glenhead, SW Scotland. The right-hand side of the graph shows alternative future scenarios developed from the MAGIC model under different atmospheric deposition scenarios (Battarbee 1998).

important as a diagnostic methodology for the assessment of ecological status and as a basis for setting remediation targets. Such targets are important in the design of management strategies (Dixit et al. 1996, Battarbee 1998).

An increasing number of recent studies have applied the types of 'paleolimnological' approaches outlined above to sediment records from near-shore marine environments. Andren et al. (1999, 2000) for example used silicieous microfossils (diatom frustules and chrysophyte cysts) to trace the impact of both climate change and human activities on marine ecosystems in the southern Baltic. They interpret a shift in the balance of diatom productivity from benthic to planktonic communities as a response to a thinning of the photic layer resulting from cultural eutrophication. At sites closest to the densely populated areas on the southern shores of the Baltic, the shift begins in the mid 19th century and parallels the evidence for cultural eutrophication in many North European lakes. Moving further north to the Gotland basin, the first clear evidence of an ecosystem response to increased nutrient supply takes place in the mid-20th century, coincident with lake sediment evidence also pointing to an increase in the rate of eutrophication as a result of use of artificial fertilizers and phosphate-rich detergents.

In the Adriatic (Figure 7.5A) from the Bronze Age onwards, changes in the benthic foraminiferal assemblage show a strong response to evidence for deforestation furnished by pollen data and, linked to this, accelerated delivery of terrigenous material to the sediments. Both the increase in *Valvulineria complanata* just before 4000 BP and its subsequent increase alongside *Bulimina marginata* coincide with the main periods of human impact on vegetation and soils (Oldfield et al. in press). These changes can best be interpreted as a response to a more stressed and oxygen-depleted benthic environment as a result of the increased deposition of terrigenous particulates, and, during the later period, organic matter resulting from higher autochthonous productivity (Asioli 1996).

Changes in organic carbon inputs, sedimentation rates, benthic foraminifer assemblages, diatom species distributions and sediment chemistry in Chesapeake Bay closely parallel the history of land clearance and erosion in the region that began on a broad scale in the 17th Century (Karlsen et al. in press). Anoxia in bottom waters of the Bay followed in the 20th Century as a consequence mainly of increased nutrient inputs (Cooper and Brush 1991, 1993, 1995). This response has been recorded by variations in the molybdenum concentration in the sediments (Adelson and Helz 2001).

The Baltic, Adriatic and Chesapeake Bay studies point to a strong link between human-induced changes in coastal regions and developments in marine ecosystems. In the case of the Adriatic, this linkage is evident from prehistoric times onwards. By contrast, the much wider scale development of anoxia recently observed in the northern Gulf of Mexico can be ascribed to increased nitrogen flux from the drainage basin of the Mississippi from the 1960's onwards (Goolsby 2000).

Comparable perspectives to those outlined above for lakes and near-shore marine environments are needed in order to assess the status of peatlands. Such systems are potentially highly sensitive to the combination of increased atmospheric deposition of anthropogenically linked contaminants and climate change, especially those that have developed to the stage where they are isolated from surface and ground water influences and are thus entirely dependent on atmospheric inputs (Clymo 1991). Although the stratigraphic evidence is not always easy to interpret, there are strong indications that sulphur deposition arising from past coal combustion, possibly in combination with climate variability, has led to changes in species composition, surface structure and erodibility (Lee 1998). When coupled with the role of peatlands in the global budget of atmospheric trace gases (Gorham 1990, 1991), such implied vulnerability makes the sustainability of such ecosystems a priority for future research.

In the text above, different processes and influences have largely been treated in isolation, but it is important to increase our understanding of combined and synergistic effects and how these may interact with climate change in the future. Research devoted to this end is increasing, as witness studies of lakes where future threats are likely to arise from the combination of increased deposition of nitrogen species, from impacts of ozone depletion and increasing UV flux, from continuing inputs of acid and, in remote, high altitude and high latitude areas, from cold distillation processes that enhance deposition of organic contaminants from distant sources (e.g. Schindler 2000).

The paleorecords described here strongly indicate that research dealing with recent changes in nutrient and ecological status should set contemporary process studies against the longer term context provided by well-dated and quantitatively calibrated proxy records from paleo-archives. Only in this way can the true scope of human impacts be compared with variability associated with natural processes.

## 7.5 Past human impacts as a result of land-use and land-cover changes

Many of the impacts on lake systems outlined above are mediated by processes taking place on the land surface. Thus our next focus is on the many ways in which human activity has modified terrestrial ecosystems. Evidence for human impact on vegetation, derived largely from pollen analysis, dates back thousands of years in many parts of the world (Edwards and MacDonald 1991, Walker and Singh 1993) and scientific awareness of its significance in prehistoric times dates back for at least 60 years (Iversen 1941). For some widespread non-agricultural ecosystems, there is still uncertainty as to the extent to which what we see today is a response to prevailing climate and soil conditions, or a product of human interference and management. For example, it is likely that the extensive lowland heaths of Western Europe owe their origin in part to anthropogenically induced changes in plant cover, soil status and nutrient cycling beginning as much as 6000 years ago on the sandy Breckland soils of East Anglia (Godwin 1944) and during later stages of prehistory elsewhere (Bartley and Morgan 1990). In the British Isles, even biomes as apparently 'natural' as upland blanket bog include areas where Mesolithic artifacts dating from an even earlier period of hunting and gathering are associated with evidence for burning at the base of the peat profiles. This has encouraged the view that human activity may have served as an important trigger to peat accumulation (e.g. Simmons 1969, Moore 1973, Casseldine and Hatton 1993). In each of these cases and others elsewhere in the world, the concept of decisive human intervention carries a range of connotations, from immediate environmental responses to longer term conditioning of the environment that may at some future time interact with climate in complex, non-linear and often unpredictable ways.

In many examples of ecosystem degradation through human activities, the key issue is a critical shift in the balance between the rate of depletion of key functional attributes and the rate of their renewal within a given system of production. Beyond a certain threshold in the shifting balance, a persistent state of lower productivity may develop that is difficult to reverse. In parts of the New Guinea Highlands for example, this type of transition has led to the conversion of a formerly productive forest-garden mosaic that reflected a cycle of forest clearance, subsistence horticulture and woody regeneration into a short grassland ecosystem. This *Themeda australis*-dominated grassland, with its low moisture retention, poor soil structure and low nutrient content yields a highly unproductive but persistent and quite extensive open landscape. Sediment-based evidence for changing catchment yields and erosion rates around small upland lakes in the highlands suggest that accelerated soil loss is associated with this process (Oldfield et al. 1980, 1985, Haberle 1994). Pollen evidence in the same region points to the spread of this type of ecosystem during at least the past 6000 years (Powell 1982, Haberle 1998), though too little is known to establish whether or not climate change also played a role in changing vegetation cover.

In areas where swidden (often termed 'slash and burn') agriculture is the main basis for food production and intensification of subsistence farming has led to a shortening of the regeneration cycle, the injudicious use of fire has often been cited as a crucial trigger in promoting rapid soil degradation that is difficult to reverse or repair (Pyne 1998, Redman 1999). Increasingly, it becomes apparent that in order to understand the present day status and future changes in contemporary systems that are undergoing this type of pressure it is necessary to study impact over relatively long time periods (Sandor and Gesper 1988, Sandor and Eash 1991).

Much uncertainty surrounds the degree of human impact on subtropical savannah landscapes in Africa (e.g. Mworia-Maitima 1997, Fairhead and Leach 1998), and on fire-adapted ecosystems in Australia (Bowman 1998), though there is growing evidence for human impact on the vegetation in African montane areas (Lamb et al. 1991, Taylor et al. 1999). Despite conflicting evidence, one conclusion becomes increasingly difficult to escape. Even in those countries where evidence for pre-colonial agriculture is sparse and where we tend to think of significant human impact as dating from 'recent' colonisation by Europeans, we should not minimise the impact of indigenous peoples on vegetation and soils (e.g. Bahn and Flenley 1992, Chepstow-Lusty et al. 1998, Dumont et al. 1998, Elliott et al. 1998, Behling 2000). Redman's summary of pre-conquest populations and likely environmental impacts in the Americas (Kohler 1992, Redman 1999, Chapter 1, Section 1.3) counsels strongly against either assuming negligible impact (cf. Fuller et al. 1998) or turning uncritically to reconstructions of pre-colonial conditions as templates for future management designed to reinstate 'natural' ecosystems. This last point is further reinforced once pre-Columbian impact is set alongside evidence for the ecological importance of past climate variability: pre-Columbian 'templates' used as goals in future management strategies may reflect climatic conditions that differed significantly from those experienced at present or predicted for the future (Millar and Woolfenden 1999, McIntosh et al. 2000). In those parts of the world with a long history of forest clearance and farming, the concept of a natural ecosystem has lost its meaning except insofar as modeling permits the postulation of some kind of potential vegetation or biome.

Of the long-settled areas of the world, the clearest evidence for the extended time span of strong human impact comes from Europe and the Middle East, largely because of the much greater attention devoted to these areas by Quaternary paleoecologists and archeologists. The degraded landscapes surrounding the Mediterranean have prompted numerous studies by archaeologists of the effects of human activity (e.g. Barker 1995). Geomorphologists (Vita-Finzi 1969), Quaternary stratigraphers (Van Andel et al. 1986, 1990) and palynologists (e.g. Atherden and Hall 1999, Ramrath et al. 2000) have contributed similar insights (Figure 7.5). In these cases, evidence for a dominant role for human intervention over millennia is overwhelming. Results from the Adriatic (Oldfield 1996, Oldfield et al. in press) also point to early human intervention but indicate that the first major phase of prehistoric clearance in the Bronze Age coincides with or quickly succeeds evidence for a change in sea surface temperatures as seen in the alkenone record (Figure 7.5). From this and other studies, the question of the relative role of climate change and human impact in the evolution of Mediterranean landscapes remains open to debate (cf. Jalut et al. 2000).

In other areas of the world with early records of agriculture, paleo-ecological evidence for prehistoric human impact from sediment records is virtually universal and takes the form of characteristic changes in pollen flora, often with associated increases in sediment yields and fire incidence. In East Africa, there is strong evidence for deforestation, increased fire incidence and accelerated erosion dating to 2.2 kyr BP (Taylor 1990). Signs of human impact have been confidently inferred from ca. 4 kyr BP onwards in Central Mexico (Bradbury in press) and for over 2000 years in the Peruvian Andes (Chepstow-Lusty et al. 1998). Archaeological evidence from India gives similar indications, (Misra and Wadia 1999) whilst in the other densely settled areas of south east Asia, dates for the earliest clear signs of human impact on ecosystems are never later than 2 kyr BP and often much earlier (Maloney 1980, Maloney 1981, Stuijts 1993, Van der Kaars and Dam 1995, Kealhofer and Penny 1998). Ren et al. (1998) find strong evidence for forest clearance in the middle and lower Yellow River Valley region from 5000 BP onwards, with the date for the earliest signs of human impact getting progressively later to the north and west. Even on the islands of the South Pacific, dates of first inferred impact range from around 3 kyr BP in Fiji and 2.4 kyr BP in the Cook Islands to 1.2 kyr on Easter Island and 0.7 – 1.4 kyr BP in New Zealand (Flenley, in press).

Taking a broader perspective, there is evidence that in some environments, the cumulative impact of human activities over long periods may gradually transform ecosystems and that in others, initial impacts can be critical in switching ecosystems into different functional modes. In yet other cases, the pattern of ecosystem response is one of repeated recovery and apparent resilience over millennia.

At local to regional scale, the importance of land cover feedbacks to the climate system has often been demonstrated (e.g. Couzin 1999). Thus changes in ecosystems, whether naturally or anthropogenically generated, can have feedbacks via local climate that may reinforce their persistence. In addition, inferences derived from models of intermediate complexity that include such feedbacks suggest that their effects may even be significant at continental to hemispheric scale (Brovkin et al. 1999, Kleidon et al. 2000, Ganopolski and Rahmstorf 2001, Kabat et al. 2001). There is therefore a growing likelihood that changes in land cover

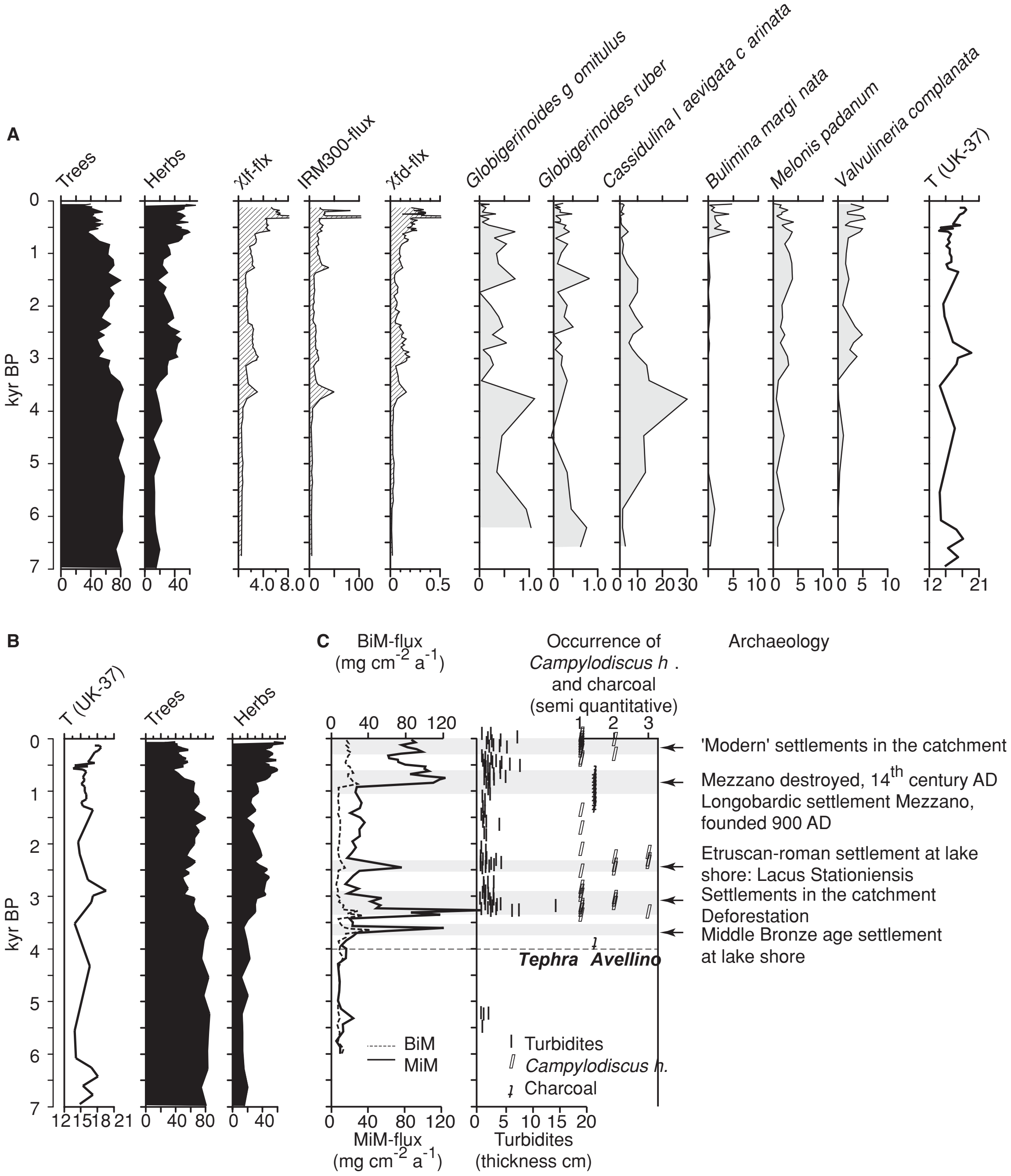


**Fig. 7.5.** Evidence for human impact and climate change in the Mediterranean region over the last 6000 to 7000 years. Part **A** shows pollen, rock-magnetic and benthic foraminifers records and Uk-37-based sea-surface temperature (SST) reconstructions from the mid-Adriatic (Core RF 93-30) plotted against a timescale derived from a wide range of chronological indicators (Oldfield 1996; Oldfield et al. in press). Pollen analytical evidence for forest clearance from ca. 3600 cal. BP onwards and from ca AD 1200 coincide with evidence for an acceleration in erosive input from the land surface (see especially the calculated fluxes of χlf χfd) as well as changes in the benthic foraminifers morpho-species assemblages indicative of increased stress as a result of higher sediment supply and organic enrichment. There are, simultaneously, major shifts in inferred SST and these, along with many other lines of evidence (eg. Jalut et al. 2000) point to climate changes taking place at roughly the same time. Parts B and C set the tree-herb pollen ratio and the Uk-37-based SST reconstructions from core RF 93-30 alongside several lines of evidence for human impact at the Lago di Mezzano site in C Italy (Ramrath et al. 1998). From the comparison, it can be seen that both of the main periods of forest clearance recorded in the Adriatic are strongly represented in the more site-specific record from Mezzano, which also correlates closely with the archaeological and historical record from the region. The data shown here are a small part of the large assemblage of data from the Mediterranean region that point to both climatic and human influences on late Holocene environmental change, but the nature of the balance and of the interactions between the two remains an open question.

may affect climate systemically. The possible contribution of land cover change to global warming in recent centuries is further considered in chapter 6.

It follows from the above that the climate-versus human antithesis represents not a simple dichotomy, but two complementary parts of a complex, interactive system. Distinguishing between directly climate-induced changes in vegetation and those reflecting feedbacks to anthropogenic impacts or delayed adjustments through long-term migration or succession is an area of palaeoecological research that has received little direct attention, but one that is vital to our understanding of natural ecosystem variability and the limitations of palaeoecological data as direct proxies of climate.

As the range of well dated climate reconstructions based on archives other than biotic response signatures increases, it should become possible to ascribe with greater confidence changes in extant ecosystems to dominantly climatic or anthropogenic forcing with greater confidence. This will increase our power both to generate models of past ecosystem transformation and to explore the nature of the interaction between natural and anthropogenic processes. The subtlety of such interactions is well demonstrated by the mystery of the dramatic and widespread European *Ulmus* (elm) decline some 6000 years ago. At least five hypotheses have been advanced to explain this feature that is common to virtually all Holocene pollen diagrams from W Europe. Peglar and Birks (1993) and Peglar (1993) use both high resolution pollen analysis and detailed charcoal counts to show that around Diss Mere in East Anglia, UK, the likeliest combination of causes is disease in forest stands that were already stressed by human impact**.** Their results suggest that multiple, including anthropogenic, threats to ecosystems are not new – they may date back thousands of years.

Fire plays a key role in ecosystem evolution, but like other variables, its frequency and impacts reflect both natural climate variability and ecosystem structure as well as human activities. Fire-scars on long-lived trees, sedimentary charcoal records (Patterson et al. 1987, Clark 1990, Lehtonen and Huttunen 1997), fire-related magnetic signatures (Gedye et al. 2000, and Figure 7.6) and geochemical markers provide a basis for reconstructing past fire frequencies. Quantitative reconstructions of the intensity and spatial extent of past fires are difficult to produce. However, recent studies (e.g. Whitlock and Millspaugh 1996, Clark et al. 1998, Tinner et al. 1998, Tinner et al. 1999) are improving the basis for interpretation through the analysis of sedimentary records of recent and well-documented fire events by combining charcoal counting with statistical and other techniques (e.g. Mworia-Maitima 1997). Paleoresearch should ultimately be able to provide bases for distinguishing between fire regimes of differing frequency and intensity. This will contribute to a better understanding of the role of fire in fire-stressed/fire-dependent ecosystems, of the impact on and ecological consequences of human modulation of fire regimes and of the likely long-term responses of present day ecosystems to different types of fire management. Failure of forest managers to understand until recently the vital role of fire in the regeneration and maintenance of widespread forest ecosystems in the western USA led to its injudicious suppression. The consequent build-up of combustible material has been one of the main factors exacerbating the incidence and effects of wildfires in recent times.

One of the most damaging impacts of human activity has been the destruction and degradation of wetlands as a result of reclamation drainage (Immirzi and Maltby 1992) and fire. Evidence for such activities date back to prehistoric times in established centres of civilisation. But, as discussed in the following section, and as Mitsch and Gosselink (1993) point out, it is only within the present century that the effects have attained global significance.

## 7.6 A paleo-perspective on human activity and biodiversity

One of the most controversial questions in Quaternary research is the possible role of prehistoric peoples in faunal extinction. Paul Martin's contention (Martin 1984) that human exploitation, through extensive hunting, was responsible for the extinction of the North American mega-fauna at the end of the last glacial period remains difficult either to prove or to refute, partly because the timing of the main prehistoric human expansion into the Americas coincides with incontrovertible evidence for major changes of climate. Nevertheless, a significant role for human exploitation pressure in changing ecosystems and faunal niches during the period of rapid natural environmental change remains a credible inference.

Many paleoecological studies lack the taxonomic resolution necessary for exploring questions of changing biodiversity at the level of species. Even where identification of higher plant remains can be made to the species level, it is rarely if ever possible to regard changing macrofossil assemblages as

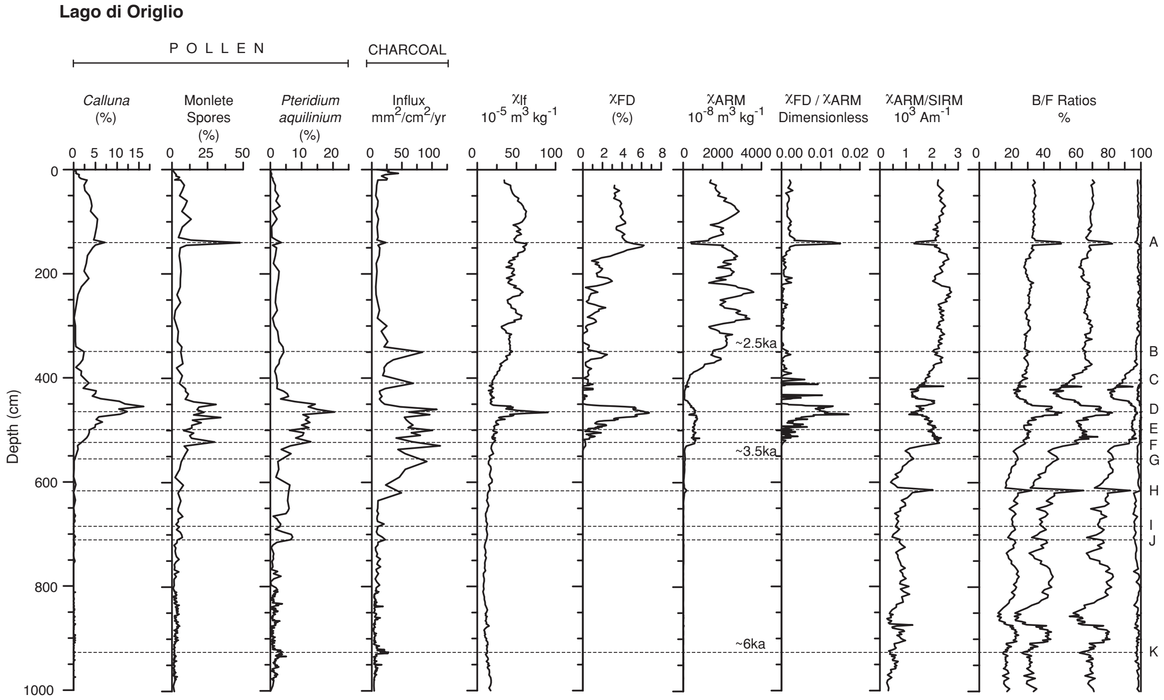


**Fig. 7.6**. A sediment-based reconstruction of fire history at the Lago di Origlio, S Switzerland (Tinner et al. 1998, 1999). The figure illustrates a multiproxy approach using pollen and spore analysis, charcoal counts and magnetic measurements. The dashed and lettered horizontal lines are drawn at or close to the depth of peaks in the depositional flux of charcoal. The pollen and spore types plotted represent taxa that often respond positively to fire. The magnetic measurements plotted may be used to discriminate for fine–grained burnt iron oxides (Gedye et al. in 2000). Below 400 cm any fire impact on the magnetic measurements is set against a background detrital, magnetic influx dominated by hard remanence minerals. Thus the charcoal peak 'H' is reflected in the magnetic measurements by a sudden, brief 'softening' of the reverse field (BF) ratios. Above 400 cm, the background magnetic signature appears to be dominated by bacterial magnetite which gives rise to high values of $\chi$ARM/SIRM. The fire 'spikes' from D upwards therefore also show up as peaks in the proportion and concentration of the finest grains which lead to high values for $\chi$FD and $\chi$FD%/$\chi$ARM. The high concentrations of fire-related magnetic minerals are produced mainly by temperatures in excess of 500 – 600ºC. Moreover, the minerals are much more likely to have originated within the catchment of the lake. The magnetic signature can thus give additional information on fire intensity and location. The pollen and spore record gives some indication of the impact, short- and long-term of individual fires and changing fire régimes. The fact that not all the indicators respond to each event and that, even when they do, the responses are not always in the same proportion, points the way toward a better understanding of the role of fire in the ecological history of the site.

being a reliable basis for tracing changes in biodiversity through time. Rarefaction indices derived from pollen or diatom records (for example Lotter 1998, Odgaard 1999), can, however, serve as proxies for biodiversity as noted below. Early paleobotanical literature is rich in studies that demonstrate the demise of plant taxa in Wurope with each successive glaciation. This serves as a reminder that what we see in many parts of the world are the remains of biota that survived many wrenching environmental shifts. This observation also applies on shorter timescales for many temperate mountain species now seen as threatened by future global warming. Evidence from temperate and sub-arctic environments points to a period in the early-to-mid Holocene when temperatures and tree lines were higher than they are now. What we currently see as threatened mountain biota survived this period. This does not constitute a reason for complacency in current thinking on the preservation of mountain biodiversity but it does provide a compelling reason to understand the survival strategies and microhabitats that allowed the persistence of the present day biota through earlier periods of environmental stress.

The foregoing observations highlight the important role paleoresearch can play in reconstructing the history of landscape elements and ecological niches crucial for the survival of biodiversity. Interestingly, in those cases (mostly from N.W. Europe) where past biodiversity has been reconstructed from pollen diagrams using rarefaction indices, human impact has had the effect of increasing taxonomic diversity at landscape scale through the creation of a greater variety of habitat types (Berglund 1991, Lotter 1999, Odgaard 1999). Thus, many areas of high biodiversity or conservation value are not, as was previously thought, pristine ecosystems where high value has resulted from lack of human impact. This can be seen on a wide range of spatial scales. At Blelham Bog in northwest England, the habitats responsible for the tiny nature reserve's conservation interest are not a reflection of natural processes, as was originally believed, but are the product of human interference in the form of peat cutting and drainage (Oldfield 1969). On the larger scale, we may cite the evidence from the Bwindi Impenetrable Forest area of Uganda, one of the most species-rich areas of montane forest in Africa. The belief that this is a pristine, undisturbed ecosystem is seriously challenged by paleo-ecological evidence that includes signs of disturbance over the last 2000 years (Marchant et al. 1997, Marchant and Taylor 1998). Thus, any strategies designed to preserve biodiversity that ignore site, ecosystem or habitat history, past climate variability and human activities – all of which contribute crucially to contemporary patterns - seriously limit their chances of success. This is especially the case where zones of high biodiversity span steep physiographic gradients or ecotones, as for example, in many mountain areas.

The situation is different in the case of many aquatic microorganisms, for example diatoms, where the problem of taxonomic resolution is overcome because fossil remains allow identification to the species or even sub-species level. This provides a promising context within which to explore questions of endemicity as well as human impact in watersheds. The latter possibility is well illustrated by recent research at Baldeggersee, Switzerland, (Lotter 1998) in which the close links between eutrophication and diversity are resolved on a near-annual basis (Figure 7.7B).

## 7.7. Past human impacts on erosion rates, sediment yields and fluvial systems

Transformations of terrestrial ecosystems are expressed through shifts in rates of erosion (Dearing et al. 1990, Duck and McManus 1990, Van Andel et al. 1990, Higgitt et al. 1991, Zangger 1992, Foster 1995, Van der Post et al. 1997), sediment yield (Douglas 1967, Davis 1976, Macklin et al. 2000) and river channel change (Hooke 1977, Wasson et al. 1998, Fanning 1999) and are recorded in sequences of lake sediment, alluvium and colluvium (Dearing 1994) stretching back over thousands of years. Paleo-records are now able to provide a long term perspective for many contemporary fluvial and sediment systems, as well as valuable short term perspectives where there is no other kind of record. The examples shown in Figure 7.8 illustrate the range of interactions between anthropogenic and climatic forcings and their impacts on river discharge and sediment transport during the Holocene. Where human activities have had significant and long-term impact, as in much of NW Europe, sediment records (Figure 7.9 c-e) often show linkages with the timing of settlement and agricultural changes (Dearing et al. 1990, Zolitschka 1998). Conversely, where human impact is considered to have been either recent or slight (Figure 7.9 a-b), the effects of climate variability may be seen, especially in alluvial sequences (e.g. Macklin 1999). The interaction between human impact and natural variability is particularly obvious in the incidence of extreme climatic-hydrological events such as floods or droughts (e.g. Eden and Page 1998, Thorndycraft et al. 1998, Foster et al. 2000). Not only land cover change but also modification of surface drainage through changes in soil structure, ditching and river channelization in combination modulate the expression of floods and accelerated sediment yield (Dearing and Jones in press, Foster et al. in press) and the human hazards to which they give rise. In many parts of the world, the short period of direct observation and monitoring is inadequate to capture the full interaction of these processes. This is clearly seen in the difficulties posed by effective

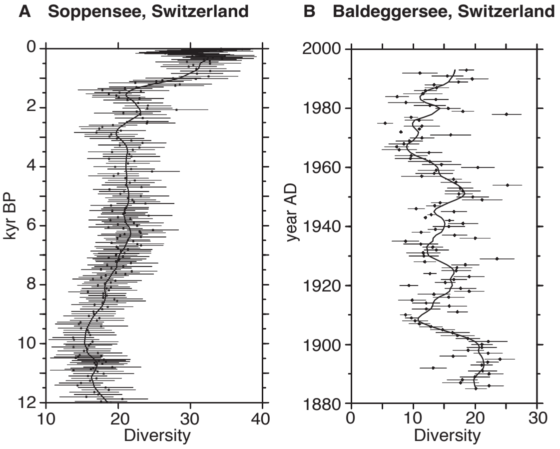


**Fig. 7.7**. Evidence for past changes in taxonomic diversity in both terrestrial and freshwater ecosystems. Both diagrams from lake sites in Switzerland use a rarefaction index (Birks et al. 1992) as a record of past changes in taxonomic diversity. Plot **A**, spanning the last 12000 years, illustrates the role of human activities in increasing diversity through the creation of a wider range of landscape and habitat types within the pollen source area of the site over the last 1500 years (Lotter 1999). Plot **B** spanning only the last 120 years of laminated lake sediment deposition shows how diatom species diversity declined with the onset of eutrophication around AD 1900 (Lotter 1998).

flood prediction within the framework of simple magnitude-frequency relationships as the boundary conditions of hydrological systems change through time (Knox 2000, Messerli et al. 2000).

New methods and techniques will improve our analysis of paleorecords. Adoption of a truly integrated lake-catchment framework where estimates of sediment yields based on lake deposits are compared with measurements of floodplain accretion, geomorphic evidence for slope instability and contemporary process monitoring (e.g. Dearing and Jones in press, Foster et al. in press) is allowing lake sediment properties to be directly calibrated to sediment sources and fluvial processes. Proxy records of sediment loads and flood intensities (eg. sedimentation rate, lamination thickness, particle-size) can be calibrated by comparison with monitored river discharges (e.g. Wohlfarth et al. 1998), rainfall records (e.g. Page et al. 1994) or documented records of flood events (e.g. Thorndycraft et al. 1998). Documented records of human and animal populations and land use provide independent evidence for the role of human activities (e.g. Higgitt et al. 1991) on fluvial and sediment processes (Figure 7.10). Such approaches when extended to paleorecords enable reconstruction and understanding of past sediment budgets and process-response mechanisms (e.g. Foster et al. 1988, Wasson et al. 1998, Fitzpatrick et al. 1999) that are comparable with contemporary studies of annual and seasonal changes, but over far longer timescales. As one example, long erosion records are already helping to define key properties of environmental change, such as resistance, resilience and lag-times between forcings and responses (Table 7.2). Contrasts in system trajectory, such as those shown in Figure 7.8, are providing a basis for defining the nature of human pressure, its interaction with natural variability and the sensitivity of the system under study.

**Table 7.2.** Lake sediment and model evidence for erosional responses to deforestation (Dearing and Jones, in press)

| Regions | Forcing | Response | yr |
|---|---|---|---|
| *Within $^{210}$Pb timescale* | | | |
| Papua New Guinea[1] | 19th C clearance | x10 | >150 |
| New Zealand[2] | 19th C farming | - | 30 |
| Michigan, USA[3] | 19th C settlement | x10-70 | 10 |
| Vermont, USA[4] | 18th C settlement | x4 | 100 |
| Tanzania[5] | 19th C clearance | x4 | 10 |
| *Holocene* | | | |
| Germany (1050 AD)[6] | Clearance | x10-17 | 250 |
| Sweden (800 BC)7 | Clearance | x4 | 200 |
| Pensylvania, USA[8] | Landscape evolution model | x40 | 50 |

[1]Oldfield et al. 1985, [2]Turner 1997, [3]Davis 1976, [4]Engström et al. 1985, [5]Eriksson and Sandgren 1999, [6]Zolitschka 1998, [7] Patterson et al. unpublished, [8]Tucker and Singerland 1997

Paleorecords, by improving our understanding of the fundamental dynamical behaviour of modern fluvial and sediment systems, will help form the basis for classifying their sensitivity to future impacts. Systems that have evolved into complex self-organized states under low levels of disturbance may be more susceptible to dramatic shifts in climate and land use than systems already conditioned by long histories of human impact (Dearing and Zolitschka 1999). Recent mathematical and cellular automaton models of long term erosion (Coulthard et al. 2000) suggest that sediment delivery over timescales of 10 to 100 years is a highly non-linear product of land cover change and high-magnitude rainfall events. Paleorecords can be used to test these models, thereby providing a framework of study across a very wide range of spatial (1-$10^6$ km$^2$) and temporal (1-$10^3$ yr) scales in many environments. In theory such approaches will overcome long-standing barriers to progress in hydro-geomorphological investigations and their application.

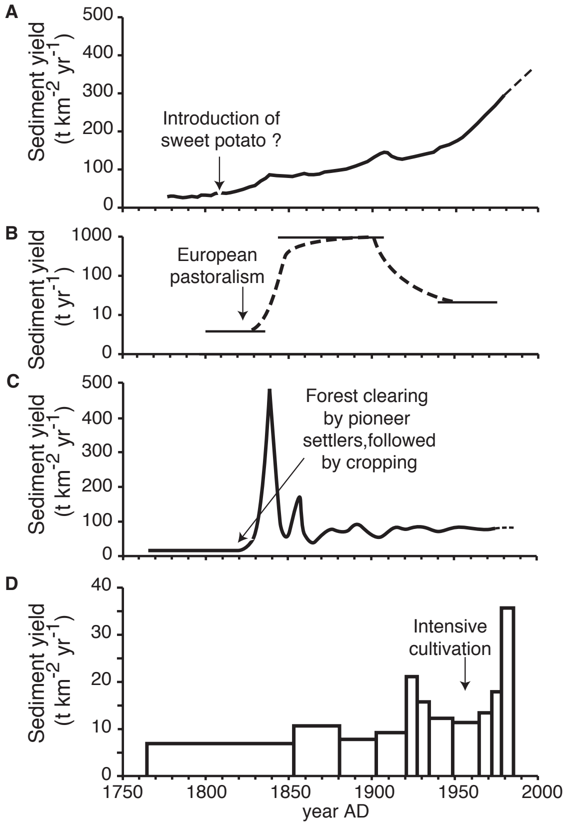


**Fig. 7.8**. Examples of sediment yield responses and subsequent trajectories of change associated with different kinds of major human impact over the past 250 years: **A**) Lake Egari, Papua New Guinea (Oldfield et al. 1980); **B**) southeastern Australia (Wasson et al. 1998); **C**) Frain's Lake, Michigan, USA (Davis 1976); **D**) Seeswood Pool, English Midlands (Dearing and Foster 1987).

## 7.8 Environmental sustainability and human vulnerability in the perspective of the paleorecord

The thrust of this chapter is towards demonstrating that in any evaluation of future sustainability or human vulnerability to environmental change, a deeper understanding of past interactions of environmental processes and human activities is essential. But there can be quite fundamental divergences in perspective across the divide between biological-physical and social sciences, and this divide must be bridged if the full potential of this area of research is to be realized.

The case of the demise of Anasazi in the semi-arid southwest USA provides a clear example. Dean et al. (1985) invoked persistent drought as a major causative agent in the decline of that society, while Kohler (1992) instead points to patterns of land use. These involved intensification and over-exploitation within a social context that favoured the continuation of such practices to the ultimate decimation of the resource base. The same contrast may be seen elsewhere, including the demise of Norse settlements in Greenland (Pringle 1997, Barlow et al. 1998), the collapse of classic pre-Columbian Mayan (Yucatán Peninsula) and Tiwanaku (Bolivian-Peruvian Altiplano) civilizations (Rice 1994, Hodell et al. 1995, Brenner et al. 2001, Nuñez et al. 2001), the evolution of food production in North Africa and the Middle East (Hassan 1994) and the collapse of Mesopotamian civilizations (Jacobsen et al. 1958, Weiss 1997, Redman 1999, Cullen et al. 2000). Even where the complexity of human-environment interactions is acknowledged, views on the nature of their interaction within the framework of multi-directional human-environment relationships differ widely. Most authors emphasize one or more of three components: damaging climate extremes such as droughts or cold (e.g. Hodell et al. 1995, Benedict 1999), human impact through non-sustainable resource use/environmental degradation (Redman 1999) and dysfunctional patterns of social organization not always directly related to resource use but nevertheless affecting it indirectly (Rappaport 1978, Crumley 1993). At one extreme, we have the view that maladaptive social systems are the proximal trigger, against a background of environmental degradation (Deleage and Hemery 1990) with no reference to the effects of climate variability. The opposing view is that climate extremes of exceptional magnitude or persistence are the triggers, particularly when they impact fragile environments and occur within the context of patterns of social organization that increase the vulnerability of a society (Messerli et al. 2000). A balanced view requires a collaborative effort by scholars with complementary training and frames of reference. It also calls for studies with the best possible chronological control on all the lines of evidence. The value of this approach is self evident in several recent studies. Nials et al. (1989) linked the demise of the Hohokam culture in S. Arizona (Redman 1999) to an annually resolved record of past stream flow (Figure 7.11). A tephra-based link between the marine sediment record and archaeological evidence is cited by (Cullen et al. 2000) as support for their view that climate change had a major role to play in the demise of the Akkadian Empire, while Macklin et al. (2000) used excellent chronological control to explore the relationship between environmental change and prehistoric settlement in Western Scotland. One of the most promising and indicative examples of synergy between environmental and cultural perspectives can be seen in the most recent study of the Anasazi by Dean et al. (1999), where a modeling approach was used within a context strongly constrained by both archaeological and palaeoenvironmental evidence, as well as tight chronological control. Transcending the biophysical-social divide is also well exemplified by Hassan's work on cultural and environmental change in Ancient Egypt (Hassan 1994).

Equally important, alongside case studies that embrace the complexity of human-environment interactions, are conceptual frameworks and models of change for uniting biophysical and cultural perspectives (Crumley 1994, Balee 1998). One of these is that of 'trajectories of vulnerability' developed by (Messerli et al. 2000), showing how detailed case studies of climate-human interactions in the past serve to highlight potential implications for the future.

Over the past century, technological responses to environmental variability have often succeeded in achieving protection against medium to high frequency, low to medium amplitude variations but, by both raising the thresholds of catastrophic impact and encouraging false confidence, they have increased vulnerability to high amplitude, low frequency events. If we view these trends in the context of past variability and human responses, sharp increases in vulnerability for many areas of human settlement appear unavoidable. Human responses to environmental stress and change that turn out to be inadequate or even destructive, in the long term run like a common theme through human history and prehistory right to the present day.

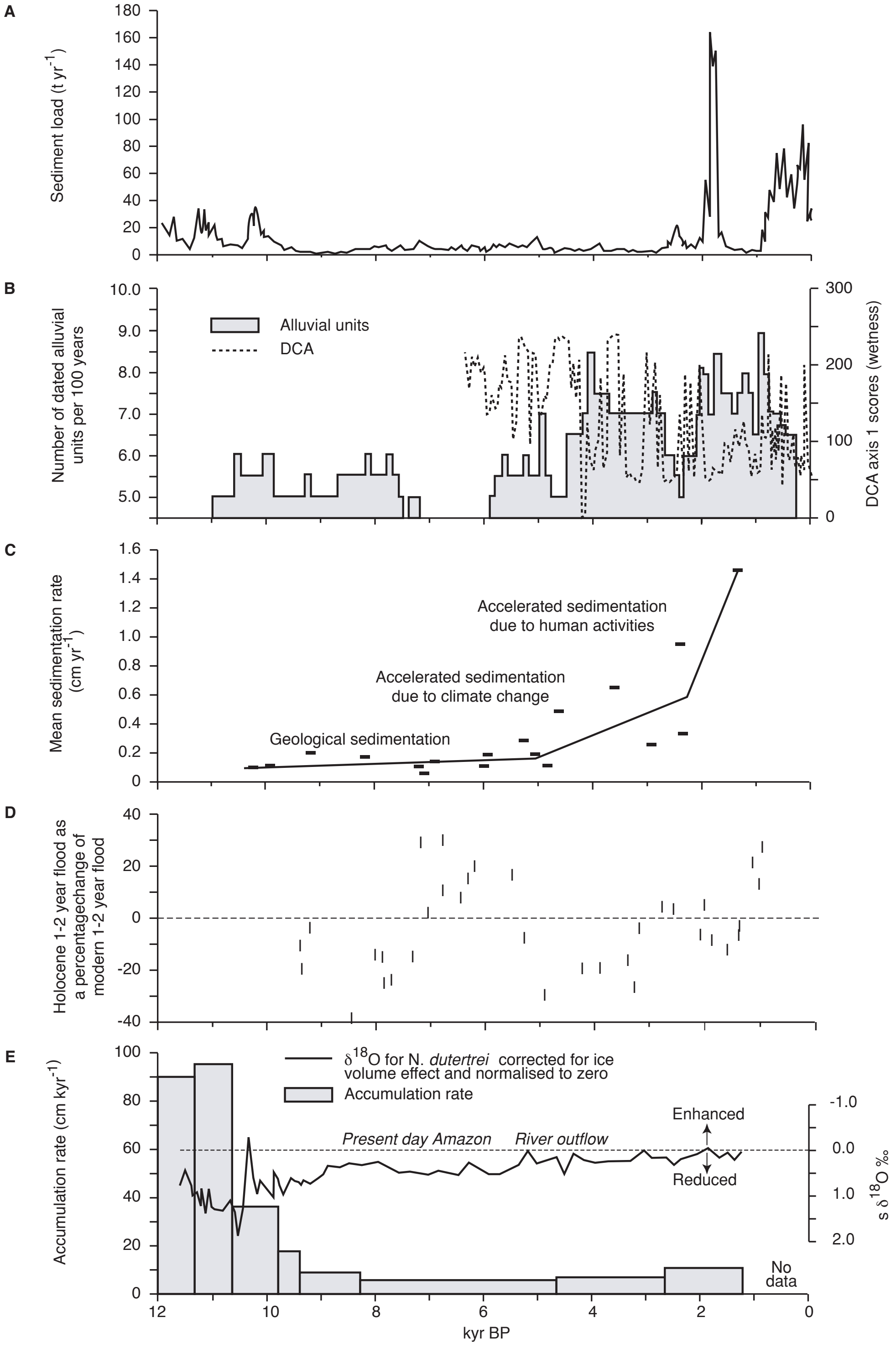


**Fig. 7.9.** Holocene proxy records of river discharge and sediment yield for landscapes where the forcings of change may range from solely climate to strongly anthropogenic: **A**) lake sediment accumulation rates at Holzmaar, Germany (Zolitschka 1998); **B**) frequency of dated alluvial units in Britain (Macklin 1999); **C**) alluvial accumulation rates in the Yellow River basin, China (Xu 1998); **D**) flood reconstructions derived from paleochannel cross-sections in southwestern Wisconsin, US (Knox, 2000); **E**) δ$^{18}$O measurements and accumulation rates from the Amazon Fan (from data in Maslin et al. 2000). All timescales are cal. $^{14}$C yr BP, except **C**) which is uncalibrated.

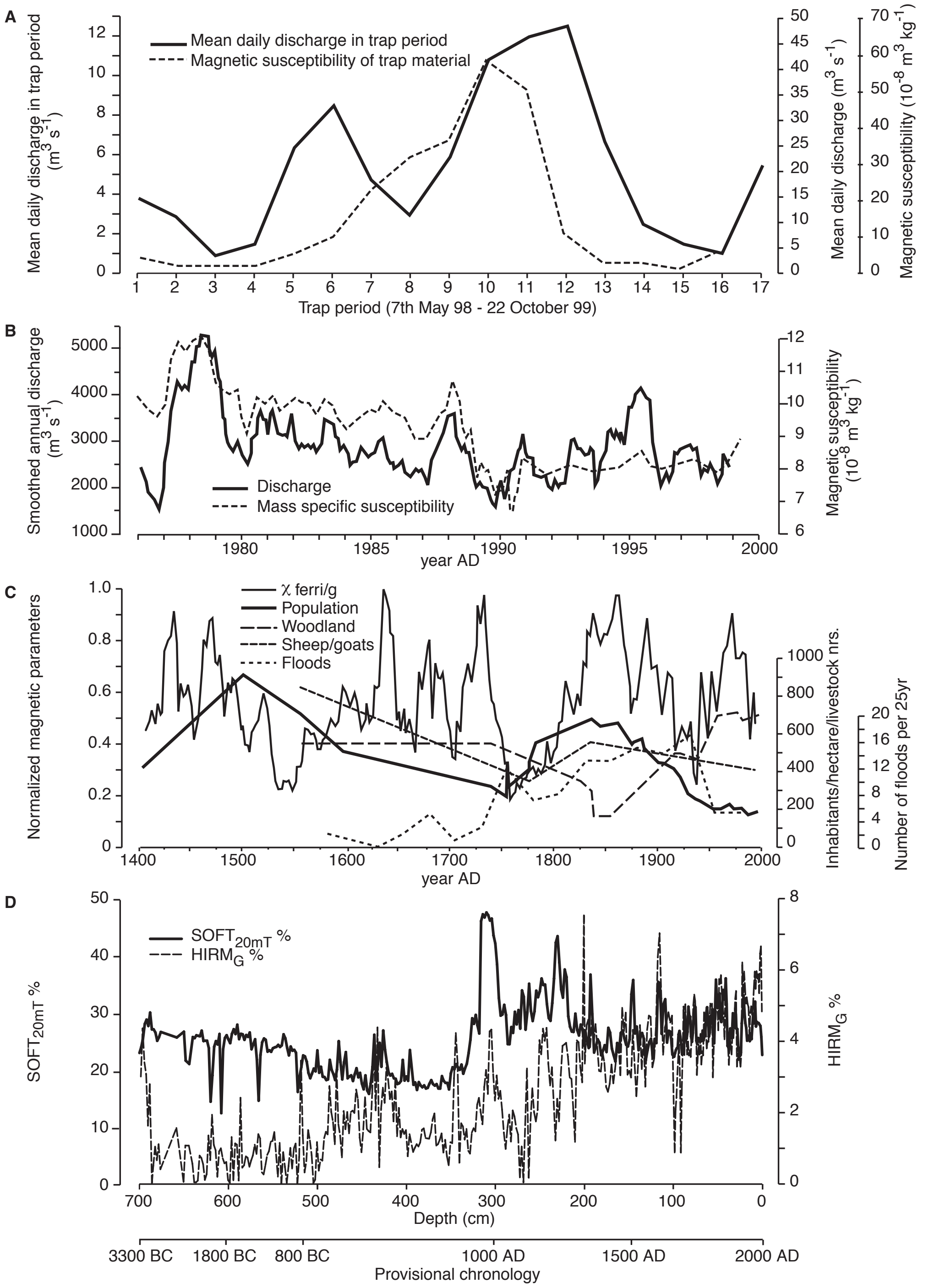


**Fig. 7.10.** Reconstruction of climate, human activities, river discharge and sediment transport at Lac d'Annecy based on calibrations and comparisons between sedimentary, instrumental and documentary archives over different timescales: **A)** magnetic susceptibility ($\chi_{LF}$) of monthly trapped sediment and monitored river discharge (1998-1999) showing winter peak in susceptibility; **B**) strong association between lake sediment $\chi_{LF}$ and river discharge record (1975-1999); **C**) proxy records of river discharge (normalised $\chi_{ferri}$ ) compared with documentary records of major floods, human population, animal stocking levels and land use in the upland Montmin commune (1400-1999); d) long records of lake sediment proxies for lowland surface soil (SOFT$_{20mT}$ %) and upland soil/unweathered substrates (HIRM$_G$ %) over the period 3300 BC – 1996 AD (Dearing et al. 2000; Dearing et al. 2001). Note the complex relationships between reconstructed discharge levels, historically recorded floods and land use changes (**C**), the major episodes of surface soil erosion following Cistercian clearances at ~1000 AD (**D**) and the trend of upland erosion, rising to the present day indicative of the long term conditioning of the montane zone by early clearance.

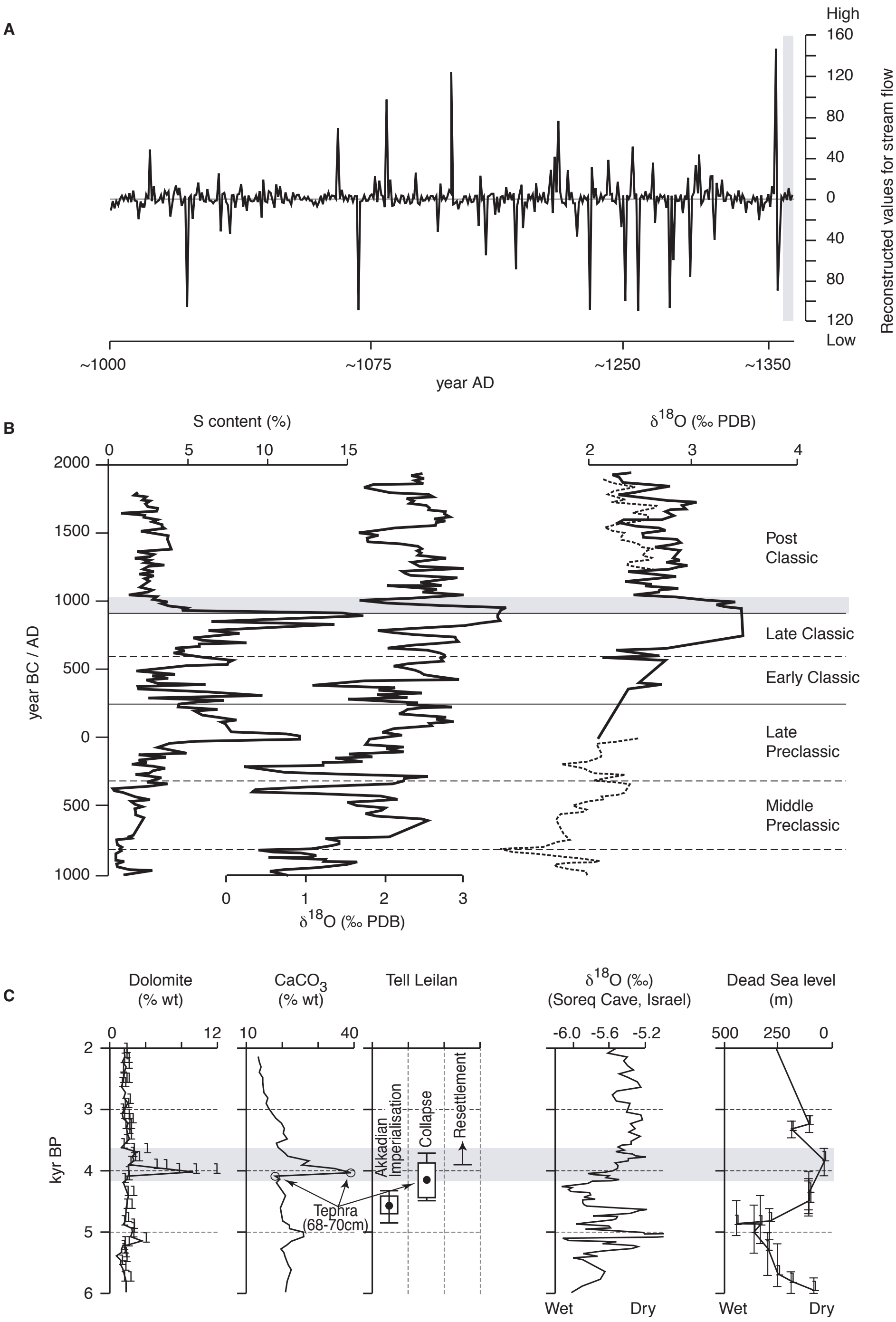


**Fig. 7. 11.** Evidence for the role of climate change in cultural collapse. Graph **A** shows Nials et al's (1989) annually resolved record of past stream flow linked to the demise of the Hohokam culture in S. Arizona (Redman, 1999). The major swings in stream flow after AD 1350 reflect alternating severe flood and drought conditions thought to have been major contributors to sudden cultural change. Graph **B** shows sedimentary evidence from the sediments of Lake Chichancanab, Yucatan, Mexico, for a major and prolonged drought culminating during the period when Classic Mayan civilization collapsed (Hodell et al. 1995). Graph **C**, from Cullen et al. (2000) shows the close temporal correspondence between peak eolian mineral concentrations in the Gulf of Oman sediments and evidence for cultural collapse of the Akkadian Empire at the Tell Leilan site: note that a tephra layer permits precise synchronization of the marine sedimentary sequence and the archaeological record. Other lines of evidence for drought at the same time from speleothem stable isotope analyses and lake level changes are plotted alongside.

Among these is the tendency for a combination of population pressure, optimistic assumptions, short temporal perspectives and escalating technological fixes to raise the stakes in the interaction between nature and human populations. Setting these in the future context of likely major climate change and rapid population growth in the next century poses a daunting challenge.

## 7.9 Some future research priorities

Palaeo-environmental research has begun to shed crucial light on many aspect of present day ecology and ecosystem management for the future. This is confirmed by its role in identifying the origins and growing impacts of freshwater acidification and eutrophication (Battarbee 1978, Battarbee et al. 1990), its contribution to the definition of management targets in both aquatic (Anderson et al. 1995, Battarbee 1997, 1998) and terrestrial ecosystems (Millar 2000), its crucial partnership with modellers testing the long term performance of their simulations against the record from the past (Bradshaw et al. 2000, Bugmann and Pfister 2000), the essential contribution it makes to interpreting the dynamics of ecosystems under long term observation and monitoring (Fuller et al. 1998, Foster et al. 2000) and its essential role in deepening our awareness of the complex of processes that have combined, through time, to create the environmental goods and services which we value and upon which human life depends (Messerli et al. 2000). Common to all these examples is the demonstration that the palaeoenvironmental perspective can make an essential contribution to developing strategies for sustainable development.

Looking to the future, the consequences, both practical and academic, of discounting either human impacts on past environmental processes or climate influences on past human activities (no matter how strong and valid the antipathy to simplistic, old-style determinism may be) are equally damaging; a shared enterprise crossing the classic two-cultures divide is now an urgent requirement.

Putting this into practice will require:

- establishment of close links between the concepts of ecological dynamics (e.g. Lindblagh et al. 2000) and ecological modeling (Bugmann 1997, Bugmann and Pfister 2000);
- a continuing search for unifying frameworks of study, whether primarily biophysical (e.g. Oldfield 1977) or more conceptual (Dearing and Zolitschka 1999);
- better understanding of the nature of environmental thresholds and nonlinear responses
- adoption of common research protocols and comparison of insights from diverse case studies (e.g. Wasson 1996) and from those with the range and depth exemplified by the cultural and environmental histories described for Southern Sweden (Berglund 1991);
- wider adoption of a *post-hoc* hypothesis testing approach (Deevey 1967) as illustrated in the acid-deposition section of the chapter, alongside model-data comparisons;
- greater reliance on quantitatively calibrated non-biological proxies of past climate change in order that biotic records may be interpreted as *responses* (Amman and Oldfield 2000)
- the use of all potential archives (e.g. Barber et al. 2000, Hughes et al. in press) and proxies (Oldfield and Alverson in press) for reconstructing climate change and human impact, including especially the work of environmental historians and historical ecologists who use documentary and archaeological sources (e.g. Egan and Howell 2001).
- The compilation of relevant global data bases (Klein-Goldewijk in press, Ramankutty and Foley in press) (Appendix B)
- Improvement of quantitative calibration of proxies in terms of environmental processes, conditions and patterns (e.g. Broström et al. 1998) and not only in terms of climate

The future research agenda that evolves from the above should promote a move beyond case-studies toward new theories, models and generalizations about future environmental responses linking together the full range of spatial and temporal dimensions (e.g. Dearing and Jones in press). The implications of such an endeavor for conservation (Birks 1996), landscape and ecosystem management (Heyerdahl and Card 2000) and environmental sustainability (Goodland 1995) are compelling.

## 7.10 Acknowledgements

We are particularly grateful to Rick Battarbee, John Dodson, John Flenley, Geoff Hope, Guoyu Ren, David Taylor, Peter Crooks, Sharon Gedye and Richard Jones for access to unpublished data and for the benefit of their help with sections of the text where our own experience was least adequate and to Keith Alverson, Ray Bradley, Carole Crumley, Vera Markgraf, Bruno Messerli, Tom Pedersen, Bob Wasson and Cathy Whitlock for essential constructive criticism. We also thank Sandra Mather for producing most of the figures.

# References

Aaby B, Jacobsen J, Jacobsen OS (1979) Pb-210 dating and lead deposition in the ombrotrophic peat bog, Draved Mose, Denmark. In: *Danmarks Geologisk Ungersoglse Arbog*. pp. 5-43

Adelson JM, Helz GR (2001) Reconstructing the rise of recent coastal anoxia: Molybdenum in Chesapeake Bay sediments. *Geochimica & Cosmochimica Acta* 65:237-252

Allott TEH, Harriman R, Battarbee RW (1992) Reversibility of acidification at the Round Loch of Glenhead, Galloway, Scotland. *Environmental Pollution* 77:219-225

Amman B, Oldfield F (2000) Biotic responses to rapid climatic changes around the Younger Dryas. *Palaeogeography Palaeoclimatology Palaeoecology* 159:175 pp.

Anderson NJ, Rippey B (1994) Monitoring lake recovery from point-source eutrophication: the use of diatom-inferred epilimnetic total phosphorus and sediment chemistry. *Freshwater Biology* 32:625-639

Anderson NJ, Renberg I, Segerstrom U (1995) Diatom production responses to the development of early agriculture in a boreal forest lake-catchment (Kassjön, N. Sweden). *Journal of Ecology* 83:802-822

Andren E, Shimmield G, Brand T (1999) Environmental changes of the last three centuries indicated by siliceous microfossil records from the Baltic Sea. *The Holocene* 9:25-38

Andren E, Andren T, Kunzendorf H (2000) Holocene history of the Baltic Sea as a background for assessing records of human impact in the sediments of the Gotland basin. *The Holocene* 10:687-702

Appleby PG, Oldfield F (1992) Application of $^{210}$Pb to sedimentation studies. In: Ivanovich M and Harmon R (eds.) *Uranium Series Disequilibrium: Applications to Earth, Marine and Environmental Studies*. Clarendon press, Oxford

Appleby PG, Richardson N, Nolan PJ (1991) $^{241}$Am dating of lake sediments. *Hydrobiologia* 214:35-42

Asioli A (1996) High resolution *Foraminifera* biostratigraphy in the Central Adriatic basin during the Last Deglaciation: a contribution to the PALICLAS project. In: Guilizzoni P and Oldfield F (eds.) *Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments (PALICLAS). Memorie del Istituto Italiano di Idrobiologia*. pp. 197 – 217

Atherden MA, Hall JA (1999) Human impact on vegetation in the White Mountains of Crete since AD 500. *The Holocene* 9:183-193

Bahn P, Flenley J (1992) *Easter Island – Earth Island. A message from our past for the future of our planet* Thames and Hudson Ltd, London

Balee W (1998) *Advances in Historical Ecology* Columbia University Press, Columbia

Barber KE, Maddy D, Rose N, Stevenson AC, Stoneman R, Thompson R (2000) Replicated proxy-climate signals over the last 2000 yr from two distant UK peat bogs: new evidence for regional palaeoclimate teleconnections. *Quaternary Science Reviews* 19:481-487

Barker G (1995) Land use and environmental degradation in Biferno Valley (Central Southern Italy) from prehistoric times to the Present Day. In: APCDA (ed.) *L'Homme et la Dégradation de l'Environnement. XVe Rencontres Internationales d'Archéologie d'Histoire d'Antibes.* Juan-les-Pins

Barlow LK, Sadler JP, Ogilvie AEJ, Buckland PC, Amorosi T, Ingimundarson T, Skidmore P, Dugmore AG, McGovern TH (1998) Interdisciplinary investigations of the end of the Norse western settlement in Greenland. *The Holocene* 7:489 - 500

Bartley D, Morgan H (1990) The palynological record of the King's Pool, Stafford, England. *New Phytologist* 116:177 – 194

Battarbee RW (1978) Observations on the recent history of Lough Neagh and its drainage basin. *Philosophical Transactions of the Royal Society* B 281:303-345

Battarbee RW (1990) The causes of lake acidification, with special reference to the role of acid deposition. *Philosophical Transactions of the Royal Society of London Series B* 327:339-347

Battarbee RW (1997) Freshwater quality, naturalness and palaeolimnology. In: Boon PJ and Howell DL (eds.) *Freshwater Quality: defining the Indefinable*. Scottish National Heritage, Edinburgh

Battarbee RW (1998) Lake management: the role of palaeolimnology. In: Harper DM (ed.) *The ecological basis for lake and reservoir management*. Wiley, London

Battarbee RW, Flower RJ, Stevenson AC, Rippey B (1990) Lake acidification in Galloway: a test of competing hypotheses. *Nature* 314:350 – 352

Behling H (2000) A 2860-year high-resolution pollen and charcoal record from the Cordillera de Talamanca in Panama: a history of human and volcanic forest disturbance. *The Holocene* 10:387-395

Benedict JB (1999) Effects of changing climate on game-animal and human use of the Colorado High Country (USA) since 1000 BC. *Arctic, Antarctic, and Alpine Research* 31:1-15

Bennion H, Juggins S, Anderson NJ (1996) Predicting epilimnetic phosphorus concentrations using an improved diatom-based transfer function and its application to lake eutrophication management. *Environmental Science & Technology* 30:2004-2007

Berglund BE (1991) The cultural landscape during 6000 years in southern Sweden – the Ystad Project. *Ecological Bulletins* 41:495 pp

Birks HJB (1996) Contributions of Quaternary palaeoecology to nature conservation. *Journal of Vegetation Science* 7:89-98

Birks HJB, Line JM (1992) The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data. *The Holocene* 2: 1-10

Birks HJB, Berge F, Boyle JF, Cumming B (1990a) A palaeoecological test of the land use-hypothesis for recent lake acidification in South-West Norway using hill-top lakes. *Journal of Paleolimnology* 4:69–85

Birks HJB, Line JM, Juggins S, Stevenson AC, terBraak CJF (1990b) Diatoms and pH reconstruction. *Philosophical Transactions of the Royal Society of London Series B* 327:263-278

Blais JM (1998) Accumulation of persistent organochlorine compounds in mountains of western Canada. *Nature* 395:585-588

Boutron CF, Görlach U, Candelone J-P, Bolshov MA, Delmas RJ (1991) Decrease in anthropogenic lead, cadmium and zinc in Greenland snows since the late 1960s. *Nature* 353:153-156

Bowman DMJS (1998) The impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* 140:385-410

Bradbury JP (in press) Limnological history of Lago de Patzcuaro, Michoacan, Mexico for the past 48,000 years: impacts of climate and man. *Palaeogeography Palaeoclimatology Palaeoecology*

Bradshaw R, Lindblagh M, Holmqvist BH, Cowling S (2000) Shift from deciduous to coniferous forests in Southern Scandinavia driven by climate change and land-use interactions. *PAGES Newsletter* 8:30-39

Brenner M, Hodell DA, Curtis JH, M. F. Rosenmeier, Binford MW, Abbott MB (2001) Abrupt climate change and pre-Columbian cultural collapse. In: Markgraf V (ed.) *Interhemispheric Paleoclimate of the Americas*. Academic Press

Brimblecombe P (1987) *The big smoke* Methuen, London

Brovkin V, Ganapolski A, Claussen M, Kubatski C, Petoukhov

V (1999) Modelling climate responses to historical land cover change. *Global Ecology and Biogeography* 8:509 – 517

Bugmann H, Pfister C (2000) Impacts of interannual climate variability on past and future forest composition. *Regional Environmental Change* 200:112-125

Bugmann HKM (1997) Gap models, forest dynamics and the response of vegetation to climate change. In: Huntley B, Cramer W, Morgan AV, Prentice HC and Allen JRM (eds.) *Past and Future Rapid Environmental Changes: The Spatial and Evolutionary Responses of Terrestrial Biota*. Springer Verlag NATO ASI Series, Berlin

Candelone J-P, Hong S, Pellone C, Boutron CF (1995) Post-industrial revolution changes in large-scale atmospheric pollution of the Northern Hemisphere for heavy metals as documented in central Greenland snow and ice. *Journal of Geophysical Research* 100:16605-16616

Casseldine C, Hatton J (1993) The development of high moorland on Dartmoor: fire and the influence of Mesolithic activity on vegetation change. In: Chambers FM (ed.) *Climate Change and Human Impact on the Landscape*. Chapman and Hall, London pp. 119-131

Chepstow-Lusty AJ, Bennett KD, Fjeldsa J, Kendall A, Galiano W, Herrera AT (1998) Tracing 4,000 years of environmental history in the Cuzco area, Peru, from the pollen record. *Mountain Research and Development* 18:159-172

Clark JS (1990) Fire and climate change during the last 750 years in northwestern Minnesota. *Ecological Monographs* 60:135 – 159

Clark JS, Lynch J, Stocks BJ, Goldammer JG (1998) Relationships between charcoal particles in air and sediments in west-central Siberia. *The Holocene* 8:19-31

Clymo RS (1991) Peat growth. In: Shane LCK and Cushing EJ (eds.) *Quaternary Research*. Bellhaven, London pp. 76-112

Clymo RS, Oldfield F, Appleby PG, Pearson GW, Ratnesar P, Richardson N (1990) The record of atmospheric deposition on a rainwater-dependent peatland. *Philosophical Transactions of the Royal Society of London Series B* 327:331-338

Cooper SR (1995) Chesapeake Bay watershed historical land use: Impact on water quality and diatom communities. *Ecological Applications* 5:703-723

Cooper SR, Brush GS (1991) Long-term history of Chesapeake Bay anoxia. *Science* 254:992-996

Cooper SR, Brush GS (1993) A 2,500 year history of anoxia and eutrophication in Chesapeake Bay. *Estuaries* 16:617-626

Coulthard TJ, Kirkby MJ, Macklin MG (2000) Modelling geomorphic response to environmental change in an upland catchment. *Hydrological Processes* 14:2031-2045

Couzin J (1999) Landscape changes make regional climate run hot and cold. *Science* 283:317 - 319

Crooks PRJ (I991) *The use of Chernobyl-derived radiocaesium for dating recent lake sediments* Unpublished PhD thesis, The University of Liverpool

Crumley CL (1993) Analyzing historic ecotone shifts. *Ecological Applications* 3:3

Crumley CL (1994) *Historical Ecology: Cultural Knowledge and Changing Landscapes* School of American Research Press, Santa Fe

Cullen HM, DeMenocal PB, Hemming S, Hemming G, Brown FH, Guilderson T, Sirocko F (2000) Climate change and the collapse of the Akkadian empire: Evidence from the deep sea. *Geology* 28:379-382

Davis MB (1976) Erosion rates and land use history in Southern Michigan. *Environmental Conservation* 3:139-148

Dean JS, Euler RC, Gumerman GJ, Plog F, Hevly RH, Kartstrom TNV (1985) Human behaviour, demography, and paleoenvironment on the Colorado Plateaus. *American Antiquity* 50:537 – 554

Dean JS, Gumerman GJ, Epstein JM, Axtell RL, Swedlund AC, Parker MT, McCaroll S (1999) Understanding Anasazi culture change through aged-based modeling. In: Kohler T and Gumerman G (eds.) *Dynamics in Human and Primate Societies*. Oxford University Press, pp. 179 – 205

Dearing JA (1994) Reconstructing the history of soil erosion. In: Roberts N (ed.) *The Changing Global Environment*. Blackwells, pp. 242-261

Dearing JA, Zolitschka B (1999) System dynamics and environmental change: an exploratory study of Holocene lake sediments at Holzmaar, Germany. *The Holocene* 9:531-540

Dearing JA, Jones RT (in press) Coupling temporal and spatial dimensions of global sediment flux through lake and marine sediment records. *Global and Planetary Change*

Dearing JA, Alström K, Bergman A, Regnell J, Sandgren P (1990) Recent and long-term records of soil erosion from southern Sweden. In: Boardman J, Foster IDL and Dearing JA (eds.) *Soil Erosion on Agricultural Land*. John Wiley & Sons Ltd, London pp. 173-191

Deevey ES (1967) Coaxing history to conduct experiments. *BioScience* 19:40 – 43

Deevey ES, Rice DS, Vaughan HH, Brenner M, Flannery MS (1979) Mayan urbanism: Impact on a tropical karst environment. *Science* 206:298 – 306

Deleage JP, Hemery D (1990) From ecological history to world ecology. In: Brimblecombe P and Pfister C (eds.) *The Silent Countdown. Essays in European Environmental History*. Springer-Verlag, Berlin/ Heidelberg/ New York pp. 21–36

Dixit SS, Dixit AS, Smol JP (1989) Lake acidification recovery can be monitored using chrysophycean microfossils. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1309-1312

Douglas I (1967) Man, vegetation and the sediment yields of rivers. *Nature* 215:25-28

Duck RW, McManus J (1990) Relationships between catchment characteristics, land use and sediment yield in the midland valley of Scotland. In: Boardman J, Foster IDL and Dearing JA (eds.) *Soil Erosion on Agricultural Land*. John Wiley & sons Ltd, London

Dumont HJ, Cocquyt C, Fontugne M, Arnold M, Reyss J-L, Bloemendal J, Oldfield F, Steenbergen CLM, Korthals HJ, Zeeb B (1998) The end of moai quarrying and its effect on lake Rano Raraku, Easter Island. *Journal of Paleolimnology* 20:409-422

Eden DN, Page MJ (1998) Palaeoclimatic implications of a storm erosion record from late Holocene lake sediments, North Island, New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology* 139:37-58

Edgington DN, Robbins JA (1976) Records of lead deposition in lake Michigan sediments since 1800. *Environmental Science and Technology* 10:266-274

Edwards KJ, MacDonald GM (1991) Holocene palynology: part 2, human influence and vegetation change. *Progress in Physical Geography* 15:364 – 391

Egan D, Howell E (2001) *Handbook of Historical Ecology* Island Press, Washington DC

Elliott MB, Flenley JR, Sutton DG (1998) A late Holocene pollen record of deforestation and environmental change from the Lake Tauanui catchment, Northland, New Zealand. *Journal of Paleolimnology* 19:23-32

Eriksson MG, Sandgren P (1999) Mineral magnetic analyses of sediment cores recording recent soil erosion history in central Tanzania, *Palaeogeography Palaeoclimatology Palaelecology* 152: 365-384

Fairhead J, Leach M (1998) *Reframing Deforestation. Global analysis and local realities: studies in West Africa* Routledge, London

Fanning PC (1999) Recent landscape history in arid western new South Wales, Australia: a model for regional change. *Geomorphology* 5:401-428

Fitzpatrick FA, Knox JC, Whitman HE (1999) Effects of historical land-cover changes on flooding and sedimentation, North Fish Creek, Wisconsin USGS Water-Resources Investigations pp. 3999-4083

Flenley J (in press) The history of human presence in islands of south-east Asia and the South Pacific

Foley JA, Prentice IC, Ramankutty N, Levis S, Pollard D, Stich S, Haxeltine A (1996) An integrated biosphere model of land surface processes, terrestrial carbon balance and vegetation dynamics. *Global Biogeochemical cycles* 10:603-628

Foster GC, Dearing JA, Jones RT, Crook DC, Siddle DS, Appleby PG, Thompson R, Nicholson J, Loizeaux J-L (in press) Meteorological and land use controls on geomorphic and fluvial processes in the pre-Alpine environment: an integrated lake-catchment study at the Petit Lac d'Annecy. *Hydrological Processes*

Foster IDL (1995) Lake and reservoir bottom sediments as a source of soil erosion and sediment transport data in the UK. In: Foster IDL, Gurnell AM and Webb BW (eds.) *Sediment and Water Quality in River Catchments*. Wiley, London

Foster IDL, Dearing JA, Grew R (1988) Lake-catchments: an evaluation of their contribution to studies of sediment yield and delivery processes. *Sediment Budgets, Proc. Porto Alegre Symp. I.A.H.S. Publn* 174:413-424

Foster IDL, Mighall TM, Wotton C, Owens PN, Walling DE (2000) Evidence for Medieval soil erosion in the South Hams region of Devon, UK. *The Holocene* 10:261-271

Fuller JL, Foster DR, McLachlan JS, Drake N (1998) Impact of human activity on regional forest composition and dynamics in central New England. *Ecosystems* 1:76-95

Galloway JN, Likens GE (1979) Atmospheric enhancement of metal deposition in Adirondack lake sediment. *Limnology and Oceanography* 24:427-433

Ganopolski A, Rahmstorf S (2001) Rapid changes of glacial climate simulated in a coupled climate model. *Nature* 409:153-158

Gedye SJ, Jones RT, Tinner W, Ammann A, Oldfield F (2000) The use of mineral magnetism in the reconstruction of fire history: a case study from Lago di Origlio, Swiss Alps. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:101 – 110

Godwin H (1944) Age and origin of the Breckland Heaths. *Nature* 154:6 – 8

Goodland R (1995) The concept of environmental sustainability. *Annual Review of Ecology and Systematics* 26:1-24

Goolsby DA (2000) Mississippi basin nitrogen flux believed to cause gulf hypoxia. *EOS* 29:321 – 327

Gorham E (1958) The influence and importance of daily weather conditions in the supply of chloride sulphate and other ions to freshwaters from atmospheric precipitation. *Philosohpical Transactions of the Royal Society, London* B, 241:147-178

Gorham E (1975) Acid precipitation and its influence upon aquatic ecosystems – an overview. In: Dockinger LS and Selinga TA (eds.) *First International Symposium on Acid Precipitation and the Forest Ecosystem*. Forest Service, USDA, Columbus, Ohio

Gorham E (1990) Biotic impoverishment in Northern Peatlands. In: Woodwell GM (ed.) *The Earth in Transition: Patterns and Processes of Biotic Impoverishment.* CUP, New York

Gorham E (1991) Northern peatlands; role in carbon cycle and probable responses to climate change. *Ecological Applications* 1:182-195

Haberle S (1994) Anthropogenic indicators in pollen diagrams: problems and prospects for late Quaternary palynology in New Guinea. In: Hather J (ed.) *Tropical Archaeobotany: Applications and New Developments*. Routledge, London pp. 172-201

Haberle SG (1998) Late Quaternary vegetation change in the Tari Basin, Papua New Guinea. *Palaeogeography Palaeoclimatology Palaeoecology* 137:1-24

Hassan FA (1994) Population ecology and civilization in ancient Egypt. In: Crumley CL (ed.) *Historical Ecology: Cultural Knowledge and Changing Landscapes.* School of American Research Press, Santa Fe

Heyerdahl EK, Card V (2000) Implications of paleorecords for ecosystem management. *Trends in Ecology and Evolution* 15:48-50

Higgitt SE, Oldfield F, Appleby PG (1991) The record of land use change and soil erosion in the late Holocene sediments of the Petit Lac d'Annecy, eastern France. *The Holocene* 1:14-28

Hites RA (1981) Sources and fates of polycyclic aromatic hydrocarbons. *American Chemical Society Symposium Series* 167:187-196

Hodell DA, Curtis JH, Brenner M (1995) Possible role of climate in the collapse of Classic Maya civilization. *Nature* 375:391-394

Hong S, Candelone J-P, Patterson CC, Boutron CF (1994) Greenland ice evidence of hemispheric lead pollution two millennia ago by Greek and Roman civilizations. *Science* 265: 1841-1843

Hooke JM (1977) The distribution and nature of changes in river channel patterns: the example of Devon. In: Gregory KJ (ed.) *River Channel Changes*. Wiley, Chichester

Hughes PDM, Mauquoy D, Barber KE, Langdon PG (in press) Mire development pathways and palaeoclimatic records from a full Holocene peat archive at Walton Moss, Cumbria, England. *The Holocene*

Immirzi CP, Maltby E (1992) *The global status of peatlands and their role in carbon cycling*. Friends of the Earth Trust Ltd., London

Iversen J (1941) Landnam i Danmark's stenalder (Land occupation in Denmark's Stone Age). *Danmarks Geologiske Undersöglse* Series II:1-68

Jacobsen T, Adams R (1958) Salt and silt in ancient Mesopotamian agriculture. *Science* 128:1251 – 1258

Jalut G, Amat AE, Bonnet L, Gauquelin T, Fontugne M (2000) Holocene climatic changes in the Western Mediterranean, from south-east France to south-east Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 160:255 – 290

Jenkins A, Whitehead PG, Cosby BJ, Birks HJB (1990) Modeling long-term acidification: a comparison with diatom reconstructions and the implications for reversibility. *Philosophical Transactions of the Royal Society* B 327:209-214

Jenkins A, Renshaw M, Helliwell R, Sefton C, Ferrier R, Swingewood P (1997) *Modelling surface water acidification in the UK: application of the MAGIC model to the Acid Waters Monitoring Network*

Kabat K, Claussen M, Dirmeyer PA, Gash JC, de Guenni LB, Meybeck M, Pielke RAS, Vörösmarty CJ, Hutjes RWA, Lütkemeier S (2001) *Vegetation, water, humans and the climate: a new perspective on an interactive system :A synthesis of the IGBP core project biospheric aspects of the hydrological cycle* Springer-Verlag, Berlin

Karlsen AW, Cronin TM, Ishman SE, Willard DA, Holmes CW, Marot M, Kerhin R (in press) Historical trends in Chesapeake Bay dissolved oxygen based on benthic *Foraminifera* from sediment Cores. *Estuaries*

Kealhofer L, Penny D (1998) A combined pollen and phytolith record for fourteen thousand years of vegetation change in northeastern Thailand. *Review of Palaeobotany and Palynology* 103:83-93

Kleidon A, Fraedrich K, Heimann M (2000) A green planet versus a desert world: estimating the maximum effect of vegetation on the land surface climate. *Climatic Change* 44:471-493

Klein-Goldewijk K (in press) Estimating global land use change over the past 300 years: the HYDE database. *Global Biogeochemical Cycles*

Knox JC (2000) Sensitivity of modern and Holocene floods to climate change. *Quaternary Science Reviews* 19:439-457

Kober B, Wessels M, Bollhöfer A, Mangini A (1999) Pb isotopes in sediments of Lake Constance, Central Europe constrain the heavy metal pathways and the pollution history of the catchment, the lake and the regional atmosphere. *Geochimica et Cosmochimica Acta* 63:1293-1303

Kohler TA (1992) Prehistoric human impact on the environment in upland North American Southwest. *Population and Environment: A Journal of Interdisciplinary Studies* 13:255 – 268

Lamb H, Damblon F, Maxted RW (1991) Human impact on the vegetation of the Middle Atlas, Morocco, during the last 5000 years. *Journal of Biogeography* 18:519-532

Lee JA (1998) Unintentional experiments with terrestrial ecosystems: ecological effects of sulphur and nitrogen pollutants. *Journal of Ecology* 86:1-12

Lehtonen H, Huttunen P (1997) History of forest fires in eastern Finland from the fifteenth century AD – the possible effects of slash-and-burn cultivation. *The Holocene* 7:223-228

Likens GE (1972) Eutrophication in aquatic ecosystems. In: Likens GE (ed.) *Nutrients and Eutrophication*. American Society of Limnology and Oceanography, pp. 3-14

Likens GE, Driscoll CT, Buso DC (1996) Long-term effects of acid rain: Response and recovery of a forest ecosystem. *Science* 272:244 – 246

Lindblagh M, Bradshaw R, Holmqvist BH (2000) Pattern and process in south Swedish forests during the last 3000 years, sensed at stand and regional scales. *Journal of Ecology* 88:113-128

Lotter AF (1998) The recent eutrophication of Baldeggersee (Switzerland) as assessed by fossil diatom assemblages. *The Holocene* 8:395-405

Lotter AF (1999) Late-glacial and Holocene vegetation history and dynamics as shown by pollen and plant macrofossil analyses in annually laminated sediments from Soppensee, central Switzerland. *Vegetation History and Archaebotany* 8:165-184

Macklin MG (1999) Holocene river environments in prehistoric Britain: human interaction and impact. *Quaternary Proceedings* 7:521-530

Macklin MG, Bonsall C, Davies FM, Robinson MR (2000) Human-environment interactions during the Holocene: new data and interpretations from the Oban area, Argyll, Scotland. *The Holocene* 10:109-121

Maloney BK (1980) Pollen analytical evidence for early forest clearance in North Sumatra. *Nature* 287:324-326

Maloney BK (1981) A pollen diagram from Tao Sipinggan, a lake site in the Batak Highlands of North Sumatra, Indonesia. *Modern Quaternary Research in South East Asia* 6:57-76

Marchant R, Taylor D, Hamilton AC (1997) Late glacial and Holocene history of Bwindi-Impenetrable Forest, southwest Uganda. *Quaternary Research* 47:216-228

Marchant RA, Taylor D (1998) Dynamics of montane forest in central Africa during the late Holocene: a pollen-based record from western Uganda. *The Holocene* 8:375-381

Martin PS (1984) Pre-prehistoric overkill: The global model. In: Martin PS and Klein RG (eds.) *Quaternary Extinctions: A Prehistoric Revolution*. University of Arizone press, Tucson pp. 354 – 403

Martínez-Cortizas A, Pontevedra-Pombal X, García-Rodeja E, Nóvoa-Muñoz JC, Shotyk W (1999) Mercury in a Spanish peat bog: Archive of climate change and atmospheric metal deposition. *Science* 284:939-942

Maslin MA, Burns SJ (2000) Reconstruction of the Amazon basin effective moisture available over the past 14000 years. *Science* 290:2285-2287

McIntosh RJ, Tainter JA, McIntosh SK (2000) *The Way the Wind Blows* Columbia University Press

Messerli B, Grosjean M, Hofer T, Nuñez L, Pfister C (2000) From nature-dominated to human-dominated environmental changes. *Quaternary Science Reviews* 19:459-479

Millar CI, Woolfenden WB (1999) The role of climate change in interpreting historical variability. *Ecological Applications* 9:1207-1216

Millar CL (2000) Historical variability in ecosystem management. *PAGES Newsletter* 8:2 – 4

Misra VN, Wadia S (1999) *Man and Environment*. Indian Society for prehistoric and Quaternary Studies, Pune

Mitsch WJ, Gosseelink JG (1993) *Wetlands*. Van Nostrand Reinhold, New York

Moore PD (1973) The influence of prehistoric cultures upon the initiation and spread of blanket bog in Upland Wales. *Nature* 241:350 – 353

Mworia-Maitima J (1997) Prehistoric fires and land-cover change in western Kenya: evidence from pollen, charcoal, grass cuticles and grass phytoliths. *The Holocene* 7:409-417

Neue HU, Sass RL (1994) Trace gas emissions from rice fields. In: Prinn RG (ed.) *Global Atmospheric-Biospheric Chemistry*. Plenum, New York

Nials FL, Gregory DA, Graybill DA (1989) Salt river stream flow and Hohokam irrigation systems. In: Graybill DA, Gregory DA, Nials FL, Gasser R, Miksicek C and Szuter C (eds.) *The 1982 – 1992 Excavations at Las Colinas: Environment and Subsistence 5*. Arizona State Museum Archaeological Series, pp. 59 – 78

Norton S (1985) Geochemistry of selected Maine peat deposits. *Bulletin of the Maine Geological Survey* 34:1-38

Nriagu JO (1990) The rise and fall of leaded gasoline. *Science of the total environment* 92:13-28

Nriagu JO (1996) A history of global metal pollution. *Science* 272:223-224

Nuñez L, Grosjean M, Cartajena I (2001) Human dimensions of late Pleistocene/Holocene arid events in southern South America. In: Markgraf V (ed.) *Interhemispheric Paleoclimate of the Americas*. Academic Press, London pp. 105-117

Odén S (1968) The acidification of air precipitation and its consequences in the natural environment. *Energy Commission Bulletin* 1:225

Odgaard B (1999) Fossil pollen as a record of past biodiversity. *Journal of Biogeography* 26:7 – 18

Oldfield F (1969) The ecological history of Blelham Bog National Nature Reserve. In: West RG and Walker D (eds.) *Studies in Vegetation History of the British Isles*. Cambridge University Press, pp. 141 – 157

Oldfield F (1977) Lakes and their drainage basins as units of sediment-based ecological study. *Progress in Physical Geography* 1:460-504

Oldfield F (1996) The PALICLAS project: synthesis and overview, International Journal of Limnology 55: 329-357

Oldfield F, Alverson K (in press) The human rationale for past global change research. In: Alverson K, Bradley R and Pedersen T (eds.) *Paleoclimate, Global Change and the Future*. Springer Verlag

Oldfield F, Appleby PG, Thompson R (1980) Paleo-ecological studies of three lakes in the Highlands of Papua New Guinea. I The chronology of sedimentation. *Journal of Ecology* 68:457 – 477

Oldfield F, Appleby PG, Worsley AT (1985) Evidence from lake sediments for recent erosion rates in the Highlands of Papua New Guinea. In: Douglas I and Spencer E (eds.) *Environmental Change and Tropical Geomorphology*. George Allen & Unwin, London pp. 185 – 195

Oldfield F, Richardson N, Appleby PG (1993) $^{241}$Am and $^{137}$Cs activity in fine grained sediments from parts of the N.E. Irish sea shoreline. *Journal of Environmental Radioactivity* 19:1-24

Oldfield F, Asioli A, Accorsi CA, Juggins S, Langone L, Rolph T, Trincardi F, Wolff G, Gibbs-Eggar Z, Vigliotti L, Frignani M (in prep) A high resolution Late-Holocene palaeo-environmental record from the Adriatic Sea: Core RF 93:30.

Page MJ, Trustrum NA, DeRose RC (1994) A high resolution record of storm-induced erosion from lake sediments, New Zealand. *Journal of Palaeolimnology* 11:333-348

Patterson WA, Edwards KJ, Macguire DJ (1987) Microsopic charcoal as a fossil indicator of fire. *Quaternary Science Reviews* 6:3 – 23

Peglar S, Birks HJB (1993) The mid-Holocene *Ulmus* fall at Diss Mere, South-east England – disease and human impact? *Vegetation history and Archaeobotany* 2:61 – 68

Peglar SM (1993) The mid-Holocene *Ulmus* decline at Diss Mere, Norfolk, UK: a year-by-year pollen stratigraphy from annual laminations. *The Holocene* 3:1 – 13

Powell JM (1982) The history of plant use and man's impact on the vegetation. In: Gressitt L (ed.) *Biogeography and Ecology in New Guinea*. Junk, The Hague pp. 207 – 277

Prather M, Derwent R, Erhlt D, Fraser P, Sanhueza E, Zhou X (1995) Other trace gases and atmospheric chemistry. In: Houghton JT, Filho LGM, Callander BA, Harris N, Kattenberg A and Maskell K (eds.) *Climate Change 1995: The Science of Climate Change*. CUP, Cambridge

Pringle H (1997) Death in Norse Greenland. *Science* 275:924 – 926

Pyne SJ (1998) Forged in Fire: History, Land and Anthropogenic Fire. In: Alén W (ed.) *Advances in Historical Ecology*. Columbia University Press, New York pp. 64 – 103

Ramankutty N, Foley JA (in press) Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles*

Ramrath A, Sadori L, Negendank JFW (2000) Sediments from Lago di Mezzano, central Italy: a record of Late glacial/Holocene climatic variations and anthropogenic impact. *The Holocene* 10:87-95

Rappaport RA (1978) Maladaptations in social systems. In: Friedman J and Rowlands MJ (eds.) *The Evolution of Social Systems*. University of Pittsburgh Press, Pittsburgh pp. 49 –87

Redman CL (1999) *Human Impact on Ancient Environments.* The University of Arizona Press

Ren G, Zhang L (1998) A preliminary mapped summary of Holocene pollen data for Northeast China. *Quaternary Science Reviews* 17:669 – 688

Renberg I (1990) A 12,6000 year perspective of the acidification of Lille Oresjon, southwest Sweden. *Philosophical Transactions of the Royal Society of London Series B* 327:357-361

Renberg I, Persson MW, Emteryd O (1994) Pre-industrial atmospheric lead contamination detected in Swedish lake sediments. *Nature* 368:323 - 326

Renberg I, Bindler R, Brännvall M-L (2001) Using the historical atmospheric lead-deposition record as a chronological marker in sediment deposits in Europe. *The Holocene* 11:511 – 516

Rice DS (1994) The human impact on lowland mesoamerican environments Society for American Archaeology 59th Annual Meeting Anaheim, California

Rippey B, Murphy RJ, Kyle SW (1982) Anthropogenically derived changes in the sedimentary flux of Mg, Ni, Cu, Zn, Hg, Pb and P in Louogh Neagh, Northern Ireland. *Environmental Science and Technology* 16:23-30

Rose NL (1994) Characterization of carbonaceous particles from lake sediments. *Hydrobiologia* 274:127-132

Rosman KJR, Ly C, Van de Velde K, Boutron CF (2000) A two century record of lead isotopes in high altitude Alpine snow and ice. *Earth And Planetary Science Letters* 176: 413-424

Rosman KJR, Chisholm W, Boutron CF, Candelone JP, Gorlach U (1993) Isotopic evidence for the source of lead in Greenland snows since the late 1960s. *Nature* 362:333-334

Sandor JA, Gesper PL (1988) Evaluation of soil fertility in some prehistoric agricultural terraces in New Mexico. *Agronomy Journal* 80: 846 – 850

Sandor JA, Eash NS (1991) Significance of ancient agricultural soils for long-term agronomic studies and sustainable agricultural research. *Agronomy Journal* 83: 29 – 37

Scarborough VL (1993) Water management systems in the Southern maya Lowlands: An accretive model for the engineered landscape. In: Scarborough VL and Isaacs BL (eds.) *Economic Aspects of Water management in the Prehispanic New World; Research in Economic Anthropology*. JAI Press, pp. 17 – 69

Scarborough VL (1994) Maya water management. *National Geographic Research and Exploration* 10:184 – 199

Schindler DW (2000) The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences* 58:18 – 29

Schwikowski M, Brutsch S, Gäggeler HW, Schotterer U (1999) A high-resolution air chemistry record from an Alpine ice-core; Fiescherhorn glacier, Swiss Alps. *Journal of Geophysical Research – Atmospheres* 104:13709-13719

Shotyk W, Cheburkin AK, Appleby PG, Frankhauser A, Kramers JD (1996) Two thousand years of atmospheric arsenic, antimony, and lead deposition recorded in an ombrotrophic peat bog profile, Jura Mountains, Switzerland. *Earth Planetary Science Letters* 145:E1-E7

Shotyk W, Weiss D, Appleby PG, Cheburkin AK, Frei R, Gloor M, Kramers JD, Reese S, Knaap WOVD (1998) History of Atmospheric Lead Deposition Since 12,370 $^{14}$C yr BP from a Peat Bog, Jura Mountains, Switzerland. *Science* 281:1635-1640

Simmons IG (1969) Evidence for vegetation change associated with mesolithic man in Britain. In: Ucko PJ and Dimbleby GW (eds.) *The Domestication and Exploitation of Plants and Animals*. Duckworth, London pp. 111-119

Smith (1872) *Air and Rain: The Beginning of a Chemical Climatology* Longman, London

Smol JP, Cumming BF, Dixit AS, Dixit SS (1998) Tracking recovery in acidified lakes: A paleolimnological perspective. *Restoration Ecology* 6:318 – 326

Stuijts I-LM (1993) Late Pleistocene and Holocene vegetation of west Java, Indonesia. *Modern Quaternary Research in Southeast Asia* 12:1-173

Taylor D (1990) Late Quaternary pollen diagrams from two Ugandan mires: evidence for environmental change in the Rukiga Highlands of southwest Uganda. *Palaeogeography, Palaeoclimatology, Palaeoecology* 80:283-300

Taylor D, Marchant RA, Robertshaw P (1999) A sediment-based history of medium altitude forest in central Africa: a record from Kabata Swamp, Ndale volcanic field, Uganda. *Journal of Ecology* 87:303-315

Thorndycraft V, Hu Y, Oldfield F, Crooks PRJ, Appleby PG (1998) Individual flood events detected in the recent sediments of the Petit Lac d'Annecy, eastern France. *The Holocene* 8:741-746

Tinner W, Hubschmid P, Wehrli M, Ammann B, Conedera M (1999) Long-term forest fire ecology and dynamics in southern Switzerland. *Journal of Ecology* 87:273-289

Tinner W, Conedera M, Ammann B, Gäggeler HW, Gedye S, Jones R, Sägesser B (1998) Pollen and charcoal in lake sediments compared with historically documented forest fires in southern Switzerland since AD 1920. *The Holocene* 8:43-53

Turner BL, Kasperson RE, Meyer WB, Dow KM, Golding D, Kasperson JX, Mitchell RC, Ratick SJ (1990) Two types of global environmental change. *Global Environmental Change* 15 – 22

Van Andel TH, Runnels CN, Pope KO (1986) Five thousand years of land use and abuse in the Southern Argolid, Greece. *Hesperia* 55:103 – 128

Van Andel TH, Zangger E, Demitrack A (1990) Land use and soil erosion in prehistoric and historical Greece. *Journal of Field Archaeology* 17:379 – 396

Van der Kaars WA, Dam MAC (1995) A 135,000-year record of vegetational and climatic change from the Bandung area, West-Java, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 117:55 – 72

Van der Post KD, Oldfield F, Haworth EY, Crooks PRJ, Appleby PJ (1997) A record of accelerated erosion in the recent sediments of Blelham Tarn in the English Lake District. *Journal of Paleolimnology* 18:103-120

Vita-Finzi C (1969) *The Mediterranean Valleys: Geological Changes in Historical Times* Cambridge University Press, Cambridge

Walker D, Singh G (1993) Earliest palynological records of human impact on the world's vegetation. In: Chambers FM (ed.) *Climate Change and Human Impact on the Landscape*. Chapman and Hall, London

Walling DE, Quine TA (1990) Use of Caesium-137 to investigate patterns and rates of soil erosion on arable fields. In: Boardman J, Foster IDL and Dearing JA (eds.) *Soil erosion on agricultural land.* Wiley, Chichester

Wania F, Mackay D (1993) Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions. *Ambio* 22:10-18

Wasson RJ (1996) *Land and Climate impacts on Fluvial Systems during the Period of Agriculture. Recommendations for a research project and its implementations*. PAGES report

Wasson RJ, Mazari RK, Starr B, Clifton G (1998) The recent history of erosion and sedimentation on the Southern tablelands of southeastern Australia: sediment flux dominated by channel incision. *Geomorphology* 24:291-308

Weiss H (1997) Late third millennium abrupt climate change and social collapse in West Asia and Egypt. In: Dalfes HN, Kukla G and Weiss H (eds.) *Third Millennium BC Climate Change and Old World Collapse*. NATO ASI Series, pp. 711-722

Weiss D, Shotyk W, Appleby PG, Kramers JG, Cherbukin AK (1999) Atmospheric Pb deposition since the industrial revolution recorded by five Swiss peat profiles: enrichment factors, fluxes, isotopic composition and sources. *Environmental Science and Technology* 33: 1340-1352

Whitehead DR, Charles DF, Goldstein RA (1990) The PIRLA project (Paleoecological Investigation of Recent lake Acidification): an introduction to the synthesis of the project. *Journal of Paleolimnology* 3:187 – 194

Whitlock C, Millspaugh SH (1996) Testing the assumptions of fire-history studies: an examination of modern charcoal accumulation in Yellowstone National Park, USA. *The Holocene* 6:7-15

Wik M, Renberg I (1991) Spheroidal carbonaceous particles as a marker for recent sediment distribution. *Hydrobiologia* 214:85-90

Wohlfarth B, Holmquist B, Cato I, Linderson H (1998) The climatic significance of clastic varves in the Angermanälven Estuary, northern Sweden, AD 1860 to 1950. *The Holocene* 8:521-534

Zangger E (1992) Neolithic to present soil erosion in Greece. In: Bell M and Boardman J (eds.) *Past and Present Soil Erosion. Archaeological and Geographical Perspectives*. Oxbow pp. 133-147

Zolitschka B (1998) A 14000 year sediment yield record from western Germany based on annually laminated sediments. Geomorphology 22:1-17