February 2011

PAGES - Past Global Changes Magazine formerly PAGES news

International Geosphere-Biosphere Programme

www.pages-igbp.org

PAGES news

Vol 19 • No 2 • July 2011

Integrative Paleoscience for Sustainable Management

Editors:

John Dearing, Markus Dotterweich, Thomas Foster, Louise Newman and Lucien von Gunten

The Murray-Darling River system (southeastern Australia) drains 1/7 of the Australian landmass and is known as the "food bowl" of the nation. Due to intense water and catchment use, much of the river system and associated water bodies are now significantly environmentally degraded. Psyche Bend Lagoon (River Murray floodplain) shown here, was first used for significant irrigation around AD 1890. Since this time, continued catchment change (stock grazing, land clearance, irrigation) has diminished ecosystem resiliance, which, in association with confounding effects of climate change, acidified this once pristine wetland. Paleodata demonstrates that the natural system is now outside its natural range of variability. This newsletter issue highlights research that aims to provide new integrations of historical information at regional scales towards developing sustainable management strategies (Photo: P. Gell).

Inside PAGES

Staff updates

Louise Newman will be relinquishing her position as PAGES Science Officer this August. She will return to her native Tasmania, where she has accepted the position of Executive Officer of the Southern Ocean Observing System (SOOS). We wish her all the best in her new role. We are grateful for her invaluable service, particularly with churning out the PAGES newsletter and coordinating the 2k Network. Louise will be replaced by Lucien von Gunten, who had served as her maternity cover earlier, and is thus familiar with the responsibilities of the PAGES Science Officer. We are pleased to welcome Lucien again, now as a more permanent member of the PAGES International Project Office team.

On the subject of new arrivals, we congratulate Michelle Kaufmann, the PAGES Finance and Officer Manager, on the birth of her daughter. Therese Jost will continue as her maternity cover until October this year.

Guest Scientist

Darrell Kaufman of the Northern Arizona University, USA, will join PAGES as resident Guest Scientist from July to November. Darrell's scientific interest is centered on the Arctic over the course of the Holocene. At PAGES he will contribute to the progress of the Arctic2k and SynTraCE-21 Working Groups.

If you're interested in becoming a PAGES Guest Scientist, please read the guidelines on the PAGES website (My PAGES > Get involved).

New National Contacts

PAGES appointed three new National Contacts who are responsible for promoting and strengthening engagement with PAGES science at the national level.

Daniel Veres (Romania) is a researcher at the Institute of Speleology of the Romanian Academy and Babes-Bolyai University in Cluj. He has specialized in Quaternary geology and paleoclimatology at the University of Stockholm, Sweden and University of Johannes Gutenberg, Germany. Daniel's main research interests include lake sediments and cave records as archives of climatic and human history, and tephras as chronological tools.

Min-Te Chen (Taiwan) is a Professor at the National Taiwan Ocean University. He received his PhD from Brown University in 1994 and has since then led paleoceanographic and paleoclimatological research of the western Pacific and East Asia in Taiwan. He has served as a scientific committee member for IMAGES.

Sri Yudawati Cahyarini (Indonesia) earned her PhD at IFM-GEOMAR, Kiel University, Germany in 2006 before returning to Indonesia. Her research interest is in high-resolution paleoclimate reconstruction from the geochemistry of fossil corals, particularly from Tahiti and Indonesia. "Yuda" has also served as a PAGES Guest Scientist.

To view the list of PAGES National Contacts or the nomination guidelines, please visit the PAGES website (About > National PAGES).

Busy second semester

The second half of 2011 is a busy time for PAGES, beginning with an abundance of meetings being held in Bern, the Project Office's host city. The biggest of them is the 18th INQUA Congress, featuring several sessions and breakout meetings from PAGES Working Groups. The annual PAGES Scientific Steering Committee meeting closely follows. Other PAGES Working Groups that hold meetings in July include Antarctica2k, LUCIFS and the PAGES 2k Network.

Workshops scheduled later in the year include the 3rd PALSEA workshop with a focus on ice sheet modeling, a Greenland Ice Sheet reconstruction workshop, the 2nd ADOM Working Group workshop on dust dynamics, and a workshop on future drilling activities in East African rift lakes. See PAGES calendar for details on these and other meetings.

Support for meetings

The next deadline for meeting proposals is 1 November 2011, for evaluation by the PAGES Executive Committee (EXCOM) in December. To apply for meeting support, visit the PAGES website (My PAGES > Meetings).

Photos for products

PAGES seeks high-resolution (min. 300 dpi) digital photographs for its website, brochures, newsletter and other products. Pictures of fieldwork activities and landscapes (including paleoscientists at work), archives and proxies are solicited to spice up our products. All contributions will be acknowledged if used. Please email your photographs to anand.chandrasekhar@pages.unibe.ch

Next newsletter issues

The next two forthcoming issues of *PAGES news* will highlight IGBP and Japanese paleoscience. The IGBP-focused newsletter will feature paired topical articles and will provide different temporal perspectives on global change questions. The Japan-focused newsletter will showcase the latest work of PAGES-relevant science in Japan.

You are invited to submit Science Highlights, Program News and Workshop Reports for the Open Section of *PAGES news*. The next deadline for such contributions is 31 Aug 2011. Guidelines for authors can be found on the PAGES website (My PAGES > Newsletter).

*** One-Stop-Shop ***

New to the PAGES website is the "My PAGES" webpage!

Offering a platform for the paleo-community to organize meetings, discuss data, browse publications and search for vacancies and events of interest. My PAGES is all about how you can contribute and make the most of the resources PAGES has to offer!

www.pages-igbp.org/my-pages/intro

Editorial: Integrative paleoscience for sustainable management

John Dearing[1], Markus Dotterweich[2] and Thomas Foster[3]

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New integrations of historical information at regional scales are needed in order to provide a stronger basis for developing strategies for sustainable management and adaptation to global environmental change.

Increasingly, international and national reports (e.g., Millennium Ecosystem Assessment, 2005; UK National Ecosystem Assessment, 2010) highlight the need to understand how interactions between society and the environment have evolved over multi-decadal timescales to create modern landscapes. Only with the perspective afforded by a relatively long timescale of observations can modern landscapes be effectively treated as complex interacting systems and analyzed for complex behavior, such as thresholds. Direct observations and measurements obtained from long-term survey or monitoring programs are usually too short or too limited in scope to provide a comprehensive record on their own (Fig. 1). As an alternative, reconstructing long and comprehensive records can potentially be achieved through integrating instrument, document, paleoenvironmental and archeology records within regions to produce "socio-environmental profiles". These profiles can provide the basis for assessing the relative degradation of different ecological services more effectively, identifying and modeling complex socio-environmental interactions, defining system behavior (e.g., trajectories and thresholds), identifying baselines, and providing the means to drive and validate local process-based simulation models (Dearing et al., 2006a, 2006b, 2010).

However, while there is a wealth of historical information available for many regions, much of it lies uncoordinated by virtue of disciplinary divisions or unidentified need. Thus the "Regional Integration" Theme, the newest to emerge from the PAGES Focus 4 "Past Human-Climate-Ecosystem Interactions" (www.pages-igbp.org/science/foci/focus-4), aims to promote interdisciplinary efforts for the compilation of recent multi-decadal historical data as an essential prerequisite for understanding contemporary system functioning at the regional scale.

The Theme also shares complementary approaches with the IGBP-IHDP-AIMES program "Integrated History and Future of People on Earth" (IHOPE; www.stockholmresilience.org/ihope).

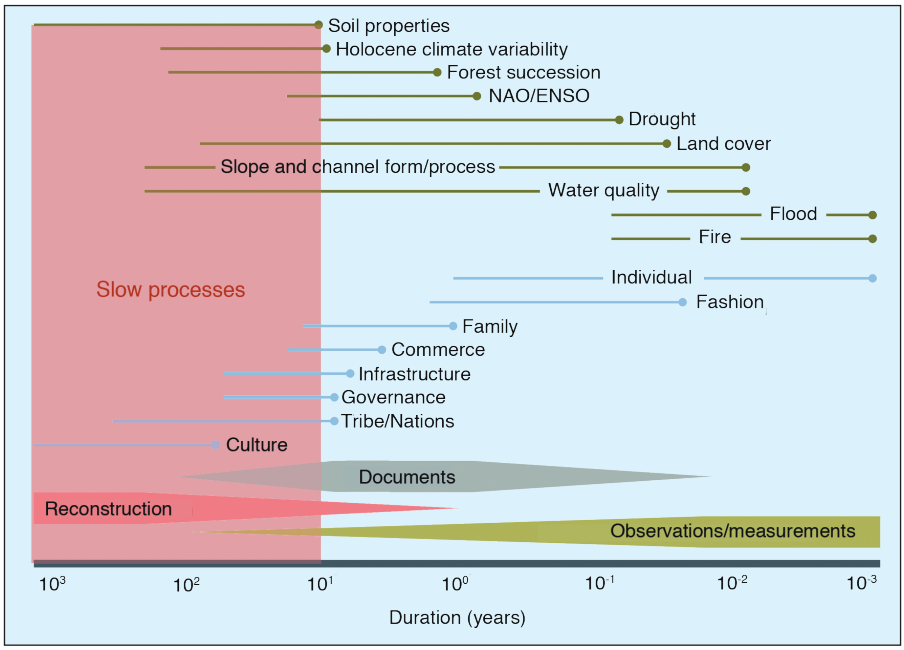

Figure 1: Slow and fast processes. Timescales for a range of biophysical and socio-economic phenomena range from "fast" subannual events (e.g., floods, fire) to "slow" multidecadal and centennial changes (e.g., culture). Understanding contemporary socioecological systems may require information from a similar range of timescales, but sources of information become more limited for longer timescales. The sources of information available for each segment of timescale with respect to the present are depicted by the horizontal lenses. Observations and measurements (e.g., instruments, remote sensing, censuses, economic statistics) and documents (e.g., diaries, gazetteers, land use descriptions) may only be available for relatively short timescales. Changes over longer timescales that are essential for assessing the role of "slow" processes (red shading) may need to be reconstructed. Reconstruction covers all the paleoenvironmental fields, including paleoecology, paleoclimatology, paleohydrology and archeology, which interpret artifacts and natural sediment archives (e.g., lake sediments, stalagmites, peat) in terms of past environment and society. Reproduced from Dearing et al. (2010), after Oldfield (1983) and Brand (1999).

An understanding of socio-environmental dynamics is important for the development of adaptive policies and strategies in all regions, especially where successful management of key environmental processes and their interaction with human activities is viewed as critical. For example, within natural wildernesses, biodiversity hotspots or regions projected to be particularly vulnerable to combinations of social and biophysical stressors. The priority over coming years is to provide socio-environmental profiles for "climate change hotspots", taking particular advantage of links to ongoing regional assessments of climate change being undertaken in PAGES Focus 2 "Regional Climate Dynamics".

In this issue of *PAGES news*, dedicated to the new Regional Integration Theme, we have selected a range of case studies that were either presented at the inaugural meeting in Southampton or have been compiled from recent peer-reviewed publications. They show a wide range of regions and contemporary issues that can be addressed through integrating paleo and other records. We would like to thank all the contributors for their speedy production and turnaround of manuscripts.

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For full references please consult:

http://www.pages-igbp.org/products/newsletters/ref2011_2.pdf

Regional integration of past records for management of modern resources and landscape

Southampton, UK, 22-24 September 2010

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The inaugural meeting of the PAGES Focus 4 Theme "Regional Integration" was held 22-24 September 2010 at University of Southampton, UK, supported by PAGES and the University of Southampton (USRG LWEC funds). Around 50 participants attended the meeting, representing all the major continental areas and with case study presentations in the form of talks and posters.

The goals of the meeting were: a) To develop methods and protocols for integrating multi-decadal biophysical and social records within sub-continental regions (data types, databases, visualization) using selected data sets from different world regions; b) To consider optimal means for reconstructing and analyzing complex, evolutionary interactions that have led to the contemporary socio-environmental system (narratives, complex behavior, resilience theory, information theory, systems modeling); and c) To outline a major multi-authored paper on the need and scope for regional integration of past records, with new protocols/methodologies using regional examples from the workshop.

On the first day, John Dearing opened the meeting with a talk that gave the background, aims and objectives to the Focus 4 Theme and the meeting. This was followed by four invited talks that described the scope and application of integrating archives in four regions.

Peter Gell (Ballarat) reported about the Lower Murray Darling Basin in south-eastern Australia, an area particularly sensitive to hydrological changes. Paleodata demonstrate that the natural system is now outside its natural range of variability and that resource management must adapt to the shifted limits in water availability (also see article of Reid and Gell on page 62).

Mohammed Umer (Addis Ababa) reported on East Africa, where human impact on the landscape was moderate for a long time. Cultural traditions and religious beliefs may have supported successful resource management. Around 2.5 ka BP human impact intensified due to climate drying, increased seasonality, the advent of agriculture and iron use.

Yang Xiangdong (Nanjing) and Zhang Weiguo (Shanghai) reported on the Lower Yangtze basin and effects on the Yangtse estuary. The estuary is sensitive to human activity both locally and upstream, which poses sustainability challenges for the city of Shanghai. Sediment records show that water purity has decreased over the last 3-5 decades and sediment discharge to the estuary dropped below the long-term background with the closure of the Three Gorge Dam in 2003.

Mary Edwards (Southampton) presented research on the New Forest National Park in southern England. She highlighted landscape evolution against the backgound of changing natural and anthropogenic influences and discussed management scenarios of successful long-term management and conservation of this landscape (also see article of Edwards and Grant on page 51).

The second day was devoted to break-out group discussions around Key Questions and Answers, and Data Sources, Databases and Dynamic Modeling. Richard Treves (Southampton) and Peter Gell (Ballarat) gave short talks on visualizations of regional data. The third day focused on strategic planning of the Working Group and outlining of workshop products, with several outcomes including the selection of a Theme Steering Group and a manuscript draft for a multi-authored position paper. Case studies presented at the workshop also provided the core of the articles of this issue of *PAGES news*, which is accordingly dedicated to the new Regional Integration theme.

The workshop organizers felt that this was a really energetic meeting with a high level of enthusiasm, which bodes well for future activities.

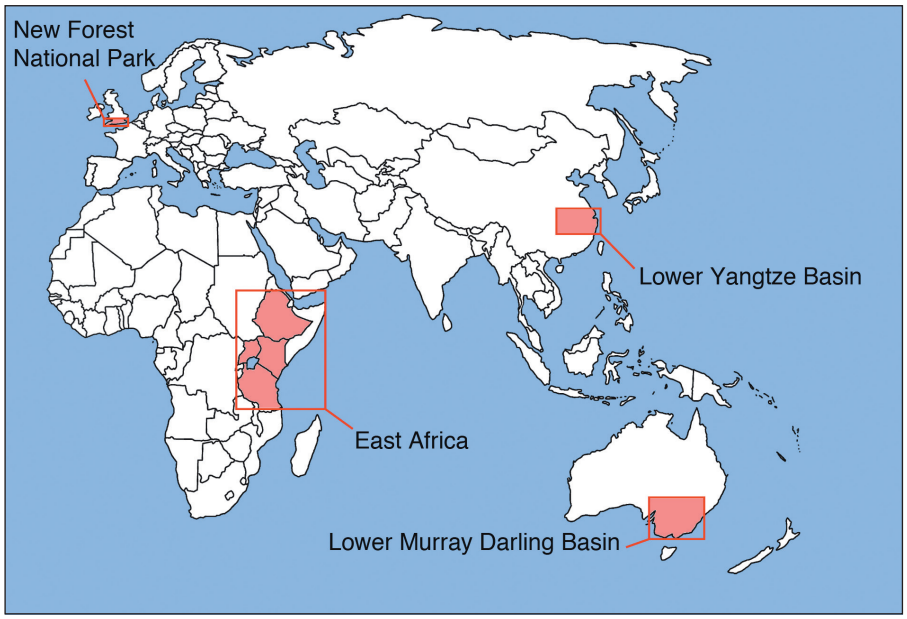

Figure 1: Map of the four regions that were the topics of four invited talks.

Conservation and habitat restoration of moorland and bog in the UK uplands: A regional, paleoecological perspective

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Regional paleoecological data can provide a wide range of possible restoration scenarios for degraded moorland and bog habitats.

Conservation practice in the United Kingdom (UK) uplands has been strongly influenced by policy responses to the Convention on Biological Diversity (1992). The UK was the first nation to produce a national Biodiversity Action Plan (BAP) (Department for Environment, Food and Rural Affairs, 2007a,b; UKBAP, 2008); policy is now enshrined in Habitat Action Plans (65 HAPs), Species Action Plans (1149 SAPs) and Local Biodiversity Action Plans (innumerable LBAPs), plus European designations of Special Areas of Conservation (SACs) and possible candidates (cSACs). This plethora of acronyms has emerged since Ratcliffe's (1977) Nature Conservation Review, which focused on Sites of Special Scientific Interest (SSSIs) and National Nature Reserves (NNRs). Habitat Action Plans focus on arresting decline of diminishing habitats, restoring habitats to satisfactory condition and expanding the habitat cover where feasible (Jones et al., 2003). Implementation is devolved separately to England, Wales, Scotland and Northern Ireland, but LBAPs provide for local decision-making. However, because local conservation practitioners frequently lack scientific capacity to address LBAP activity, BAP Scientific Services (2011) recommend expertise should be drawn upon regionally.

*Figure 1: **A**) Degraded mire and moorland landscape of Drygarn Fawr, Mid-Wales, dominated by* Molinia caerulea *(purple moor grass). **B**) Valley Bog, Moor House, Northern England. The Valley Bog core site (VB1: Fig. 2b) is located in the middle ground in heather moorland.*

Moorland and bog restoration

For some upland areas, it could be argued on grounds of biodiversity (following Bremer and Farley, 2010) that either economic coniferous forestry or amenity deciduous woodland would be legitimate objectives. However, if restoration of degraded moorland and blanket bog is the intention, this requires knowledge of the previous vegetation, specifically: how long it endured, which species are significantly reduced or extinct, which factors led to the claimed declines, whether those factors can be mitigated, and viable targets. Currently, restoration is predicated on decadal to sub-centennial survey data that show areal loss. For example, a 30% loss of or serious damage to blanket bog in Great Britain was estimated for the period from 1949 (when the Nature Conservancy Council was established) to the early 1980s (NCC, 1984; see also Usher and Thompson, 1988). This contrasts with thousands of years of cultural landscape history that preceded contemporary vegetation communities. Though emphasis is placed on restoration, few local conservation practitioners will be fully aware of past vegetation communities to which degraded habitats might be restored (see Hodder et al., 2009). Short-term targets and sub-decadal timescales dominate habitat restoration activity. Seldom is account taken of the millennial-scale development of upland ecosystems, shown by studies of long-term ecology (viz., paleoecology; Willis and Birks, 2006), which can be conducted on peat beneath moorland and bog vegetation (Chambers and Charman, 2004).

Favored vegetation types in the UK uplands, to which "restoration" is directed, include *Sphagnum*- (bog moss) dominat-

ed blanket bog and heather moorland, for which the UK has the largest expanse. The former is widespread in the Flow Country of northern Scotland (Lindsay et al., 1988), but is now relatively rare in England, Wales and Northern Ireland, owing to atmospheric pollution, drainage, burning, peat extraction, over-grazing, and afforestation with exotic conifers. Tallis (1998) calculated that in the British Isles only 18% of heather moorland remained in natural or near-natural condition.

In the open uplands of England and Wales, large expanses of mire and moorland are occupied by the plant community Molinietum (Fig. 1A). Its vegetation provides poor grazing for sheep, which are now the principal domestic grazers. The dominant plant, *Molinia caerulea* (purple moor grass), is deciduous. As it has no foliage in winter and grows coarse, long stems in summer, its palatability for sheep is limited to the "spring bite". In Northern England it provides only limited cover for the economic "game" bird, Red Grouse, which is better suited to Callunetum—heather moorland (Fig. 1B) dominated by *Calluna vulgaris* (ling, or common heather)—a cultural landscape maintained by grazing (Stevenson and Thompson, 1993) and controlled burning.

In contrast to blanket bog, which is mainly prized for its conservation importance, heather moorland has both economic and amenity value. However, it saw a calculated loss of 23% in Scotland within four decades (NCC, 1984), partly attributed by Robertson et al. (2001) to lack of management of some grouse moors. Heather moorland is favorably regarded for its attractive appearance in summer and early autumn, particularly for visitors to upland National Parks. These include Exmoor, in Southwest England, for which heather moorland has totemic significance, but where Red Grouse is extinct. There, "swaling" (controlled burning) is used to maintain heather, but some areas have been lost to *Molinia*. Landscapes dominated by Molinia are monotonous and unattractive for visitors, having low amenity value, and are regarded as degraded (Yeo, 1997).

*Figure 2: **A**) Dominant plant macrofossil abundances in a peat core from Drygarn Fawr, Mid-Wales (Chambers et al., 2007a). The rise in* Molinia *remains (red) occurs only after the Industrial Revolution (IR; estimated at c. AD 1900, gray shading). This rise was not caused by increased burning, as attested by no significant changes in the charcoal record at this time (black) but is likely the result of a change in grazing pressure and deposition of nitrogen following the IR. UOM: unidentified organic matter, which, in high abundance, may signify* Calluna*-dominated vegetation (e.g., Heather moorland). **B**) Dominant plant macrofossil abundances from Valley Bog, Moor House National Nature Reserve, Northern England. Heather moorland is present only in the most recent Zone (green shading, VB1–M6, characterized by abundant* Ericales *and* Calluna vulgaris *macrofossils), indicating that it has no longevity in this locality (unpublished data from Chambers et al., 2006). Timescales, calibrated to approximate calendar ages, compiled from record of spheroidal carbonaceous particles and radiometric dating (^{210}Pb; ^{14}C).*

Paleoecology informs restoration targets

Conservation agencies have targets for degraded moorland habitats, with restoration envisaged to heather moorland or conceivably to *Sphagnum*-dominated bog. Experimental data indicate the relative efficacy of pony grazing, use of herbicides, and burning as agents of control of *Molinia caerulea* (Marrs et al., 2004). However, the timing and cause of the overwhelming dominance of *Molinia* (variously attributed to overgrazing, lack of heather moorland management or uncontrolled burning) remained elusive until the initiation of paleoecological studies on a regional scale. Paleoecological data from Exmoor and Mid- and South Wales show the spread and expansion of Molinia only after the start of the Industrial Revolution. Importantly, the data also indicate multiple causes: not grazing pressure alone, but rather a change in the dominant grazer from cattle to sheep, nor burning alone, as *Molinia* has spread into areas without evidence of an increase in fire intensity or frequency (Fig. 2A; Chambers et al., 1999, 2007a, b). Additionally it has been hypothesized that nitrogen deposition post-Industrial Revolution provided *Molinia* with a competitive advantage in a pastoral regime of unprecedentedly high stocking density of sheep (Chambers et al., 2007b). Plant macrofossil data show that, before high density stocking of sheep, *Molinia* was only a minor component of the regional flora (Chambers et al., 2007a).

Regional significance of paleodata

In habitat conservation practice for moorland and bogs, the emphasis is on restoring the health of plant communities defined in the National Vegetation Classification (NVC; e.g., Rodwell et al., 1991, 2000). The NVC survey of British vegetation was conducted by expert ecologists

in the late 20th century. However, as a "snapshot" of the then current vegetation, it can be criticized for lacking a sufficiently long-term perspective. Paleodata from South Wales and Northern England show the former presence of plant species regionally extinct as a result of human activity, including *Sphagnum austinii* (syn. *S. imbricatum* ssp. *austinii*) (McClymont et al., 2008, 2009), which was also a major peat former in raised bogs in England and Wales for thousands of years in the mid-late Holocene (Hughes et al., 2007, 2008). Regional paleodata therefore imply that inter-regional translocation of key bog species could be justified as part of future habitat restoration. Moreover, paleoecological data of former plant communities show a wider range of possible restoration targets for Molinietum than is implied by the NVC, and so broaden the range of possible replacements. They also question the longevity of some Callunetum: its endurance in some parts of England and Wales has been shorter than generally thought (Fig. 2B; see also Chambers et al., 2007b).

Davies and Bunting (2010) argue there is an urgent need to "bridge the gap" between ecology and paleoecology. The latter has fundamental implications for the future practice of conservation and habitat management: regional paleoecological data question vegetation endurance, reveal regional declines, extinctions and their causes, and can help identify a range of viable restoration targets.

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For full references please consult:

http://www.pages-igbp.org/products/newsletters/ref2011_2.pdf

Spatial and temporal controls on hydro-geomorphic processes in the French Prealps

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Integration of paleoenvironmental reconstructions, environmental history and cellular modeling sheds light on the likely impacts of climate change on hydrological and geomorphological processes in the French Prealps.

By the end of the 21st century, IPCC reports (2007) suggest winter precipitation in European Alpine regions will increase by 10-20% compared with 1980–1999, while summer precipitation will decrease by approximately 20%. Here, we review findings from research undertaken in the French Prealps in order to shed light on the implications of climate change for hydro-geomorphic processes. Over the past 20 years, the Annecy lake-catchment (45°48'N, 6°8'E) has provided the focus for a number of studies, drawing on methods used in paleoecology, environmental history and process modeling, to investigate the links between human activities, climate and hydro-geomorphic processes. Lying at an altitude of 447 m asl in the prealps of Haute-Savoie, the lake comprises two basins, the Grand and Petit Lacs. Integration of data and models from mainly the Petit Lac and its catchment (Fig. 1) has generated significant insight into the spatio-temporal nature of human-environment interactions across the wider region.

Figure 1: The landscape of the Petit Lac d'Annecy catchment, Haute-Savoie, showing the southern end of the lake, the Eau Morte River delta, the intensively farmed lowlands, forested lower slopes and alpine pastures (Photo John Dearing).

Paleoenvironmental reconstruction

Foster et al. (2003) reconstructed the mechanisms of flooding and sediment transport within the Petit Lac catchment over timescales of months to centuries from lake and floodplain sediments that were representative of large catchment areas. Analysis of the results revealed that climate and land-use controls on the hydrological and sediment system were complex and varied according to the timescale of observation. In general, cycles of agricultural expansion and deforestation appeared to have been the major cause of shifts in the hydro-geomorphic system during the late Holocene. It was suggest-

ed that deforestation might have caused a number of high-magnitude flood and erosion events. The authors also argued that as the timescale of observation becomes shorter (annual rather than centennial), the impact of climate or meteorological events on hydro-geomorphic processes become progressively more important, The authors showed that since the mid-19th century, smoothed records of discharge roughly followed annual precipitation (Foster et al., 2003) whilst annual sediment load declined in parallel with the trend of declining land use pressure (Fig. 2). Episodic erosion events since the mid-19th century were linked to geomorphic evidence for slope instability in the montane and subalpine zones, triggered by intense summer rainfall (cf., Theler et al., 2010). At the annual scale, changes in seasonal rainfall become paramount in determining sediment movement to downstream locations. A recent rise in sediment yield, since the 1980s, points to a shift in seasonal rainfall patterns, which is also visible in the instrumental record (Fig. 2C).

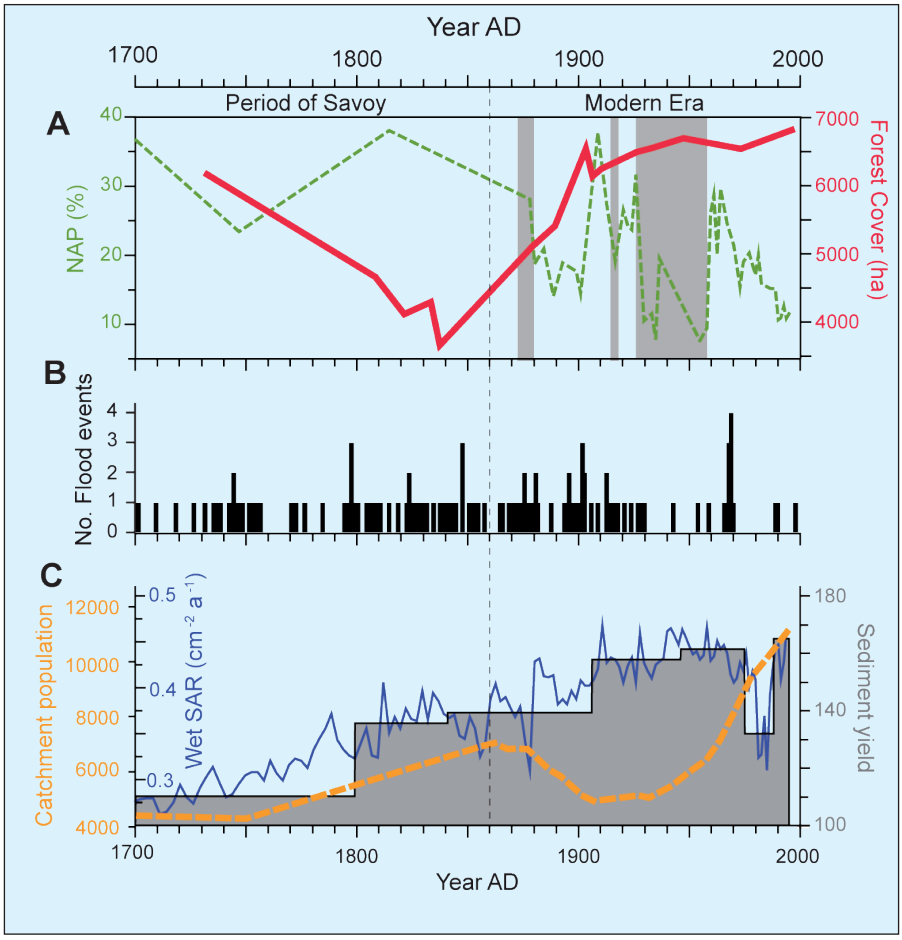

*Figure 2: Paleoenvironmental reconstruction and environmental history of the Petit Lac d'Annecy catchment since AD 1700. **A**) Changes in forested landscape based on non-arboreal pollen percentages (NAP%, green) and forest inventories (red) for the modern era and the period of Savoy from 1700 to 1860 (shaded areas show rapidly accumulating lake sediments with few pollen). **B**) Flood record based on documentary sources. **C**) Human population (yellow), accumulation rate of lake sediments (blue) and estimate of sediment yield (a composite proxy for flooding, slope instability and soil erosion) from the catchment (gray). Note the generally strong relationship between high catchment population and low forest cover, but progressively increasing levels of slope instability and soil erosion up to the mid-20th century. Rising sediment yields since the 1980s have now reached the maximum levels seen in the early 20th century.*

Environmental History

Crook et al. (2002, 2004) investigated the nature of human impact on forest cover in the Petit Lac catchment and its link to flooding using local documentary sources for land use, flooding and climate. In contrast to the sediment studies, they identified the main period of large-scale, uniform and rapid deforestation in the catchment as the early 19th century (Crook et al., 2002). It was a time of demographic expansion, industrial development, foreign occupation, war, caveats and laws, linked with local, endogenous pressures of land fragmentation, agricultural crisis, and the desire for new alpine pasture. However, coincident phases of deforestation and flooding (Fig. 2) were more evident in individual second order tributaries, such as the river Ire, than the whole catchment. Overall there were no obvious or simple causal links between forest cover change, climate anomalies and destructive flood events at the whole catchment scale in either the 18th or 19th century.

In a subsequent study, Crook et al., (2004), used archeological and documentary records to reconstruct land-use patterns and nutrient balance in Montmin, an upland commune, at even finer scales for specific periods in time between AD 1561 and 1892. Previous studies by Siddle (1986, 1997) and Jones (1987) gave insight into the social fabric of the commune and the land use practices. Together, the results demonstrated that during this period seven main phases of human activity had left their traces in the environmental record. The 1730-1770s and 1840-1860s stood out as two periods of heightened environmental pressures at higher altitudes that led to documented problems in the lowlands, such as flooding, increased erosion and declining soil fertility.

Modeling

These spatio-temporal interactions were tested through a modeling exercise (Welsh et al., 2009), using the spatially distributed (50 x 50 m grid) hydro-geomorphic process model, CAESAR (Coulthard and Macklin, 2001). Changes in the hydrological and sediment regime of the sub-catchments in the Petit Lac catchment were simulated at hourly time steps over the past 180 years, with forest cover and regional climate as drivers. The results suggested that while minor perturbations in forest cover had partially conditioned the response of the sediment system, the bulk of modeled sediment discharge and particularly the peaks in sediment discharge were controlled by flood duration and magnitude. These flood parameters were in turn driven by precipitation and snowmelt. Basin geometry and geomorphology of each sub-catchment (Ire and Tamie) were also important in producing differences in the modeled sediment discharge, largely in response to sediment accommodation space and the ability of each system to store and release sediments. The modeled suspended sediment discharge was shown to compare well with lake sediment proxies for detrital sediment accumulation. The results indicated that the model could be used as an exploratory and predictive tool in assessing the likely impact of future changes in climate, meteorology and land use on lake-catchment systems.

Implications for land management

These contrasting approaches reveal the importance of interactions across different temporal and spatial scales. Different archives of information are biased towards particular scales, and high-precision process models may be essential tools for

resolving apparent contradictions. For the modern French pre-alpine landscape, there are several significant lessons:

- Forest cover defines the boundary conditions for flood magnitude and slope instability over multi-decadal to centennial timescales, which has been mainly anthropogenically controlled for at least two millennia. In system dynamic terms, land cover represents the set of "slow" processes that control the system's resilience (Dearing, 2008).
- In contrast, the key drivers of short-term flooding and slope instability at commune and sub-catchment levels are linked to specific meteorological events (snowmelt and summer storms) rather than local land-use change, except where there is exceptional land degradation.
- If 21st century winter precipitation increases by 10–20%, the predicted increase in the frequency and magnitude of large flood events in winter and spring could be amplified further as water storage, in the form of snow, is reduced.
- Reducing forest cover and/or increasing frequency/magnitude of flood events render the fluvial system rich in sediment. This not only increases the rate of lateral channel migration, a hazard for farmland and buildings, but also shifts the rivers (mainly through bank erosion) to a more sediment-rich state.
- Anticipating the effects of climate change thus needs to focus on mitigation and adaptation strategies for the likelihood of more frequent extreme meteorological events causing local flooding. However, careful management of land cover across the region will also be needed to raise general levels of flood protection in the winter and spring, and reduce the risk of drought and forest fire in the summer.

Data

Some of the data discussed here can be found at http://www.liv.ac.uk/geography/research_projects/Levan/index.htm

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Past land use and soil erosion processes in central Europe

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7500 years of land use and soil erosion data provide an insight into modern links between human activities and the environment.

Agricultural development and geomorphology

The development of natural and socio-ecologically adapted agroecosystems, which have the capacity to ease demand on food and resources and mitigate climate change, is a major challenge. Looking at past land-use systems and their socio-economic history increases our understanding of slow processes and low-frequency events. These underlying processes appear to be key in assessing whether modern land-use systems will lead to sustainability or collapse.

In central Europe, phases of agricultural expansion and regression occurred with land clearance and reforestation back to the onset of agriculture, around 7500 years ago. Under natural conditions (except for short phases of severe climate deterioration in the early Holocene), the sheltering cover of vegetation and soil development largely mitigated geomorphic processes, resulting in a stable dynamic equilibrium (Dotterweich, 2008). With the clearing of forests, the natural water and matter fluxes changed into anthropogenically driven systems with greatly accelerated processes and higher vulnerability to soil erosion. Repeated or extreme events forced by climate change may have affected the fertility of the land to an extent that it could no longer be cultivated. On a local- to regional scale, this may occur surprisingly rapidly, especially in strong single events. As the system develops, two outcomes may occur: a) Driving forces may progress slowly, causing gradual and predictable degradation, or b) Exceptional

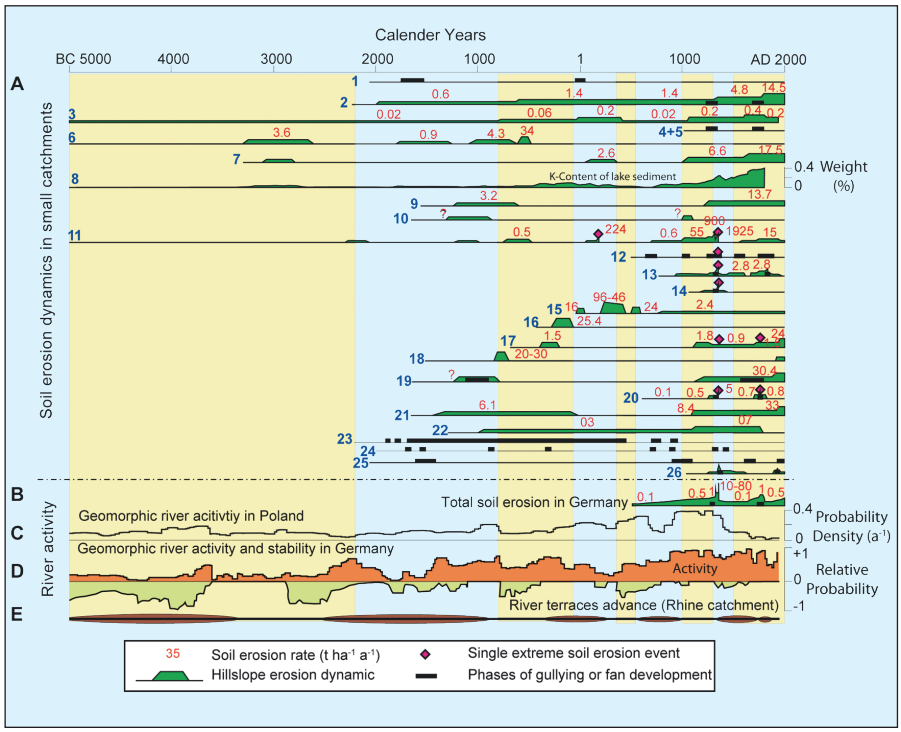

*Figure 1: Dynamics of soil erosion in small catchments (**A**) and river activity (**B**, **C**, **D**, **E**) in central Europe since the beginning of agriculture, based on studies by different authors. Blue numbers correlate to site names, type of geoarchive and references given in supplementary material (www.pages-igbp.org/products/newsletters/ref2011_2.pdf). Yellow shading represents cultural epochs (Figure modified from Dotterweich, 2008).*

events may trigger catastrophic changes, forcing premature abandonment of agricultural land. Regardless of the rate of degradation, the system will evolve through a reorganization phase and ultimately reach a new equilibrium, where either naturally or anthropogenically driven processes dominate the overall system.

As a result of these processes, erosion has changed soil conditions and patterns in many areas of Central Europe. Material has been washed downslope and gullies have incised, leading to the deposition of sediments at the slopes (colluvial layers), in floodplains (alluvial layers) or lakes (allochthonous input). These erosional landforms and depositional structures are geoarchives of past land use, human impact and climate change, at broad temporal (daily to millennia) and spatial (gully/slope to floodplains) scales. Efforts to retrieve these data have increased during the last few years (Fig. 1 and 2; Dotterweich, 2008; Dreibrodt et al., 2010; Notebaert and Verstraeten, 2010; Hoffmann et al., 2011). Based on many reconstructions of the history of soils, relief and river systems, we are now able to generalize about the fundamental effects of land use and climate on central European landscapes.

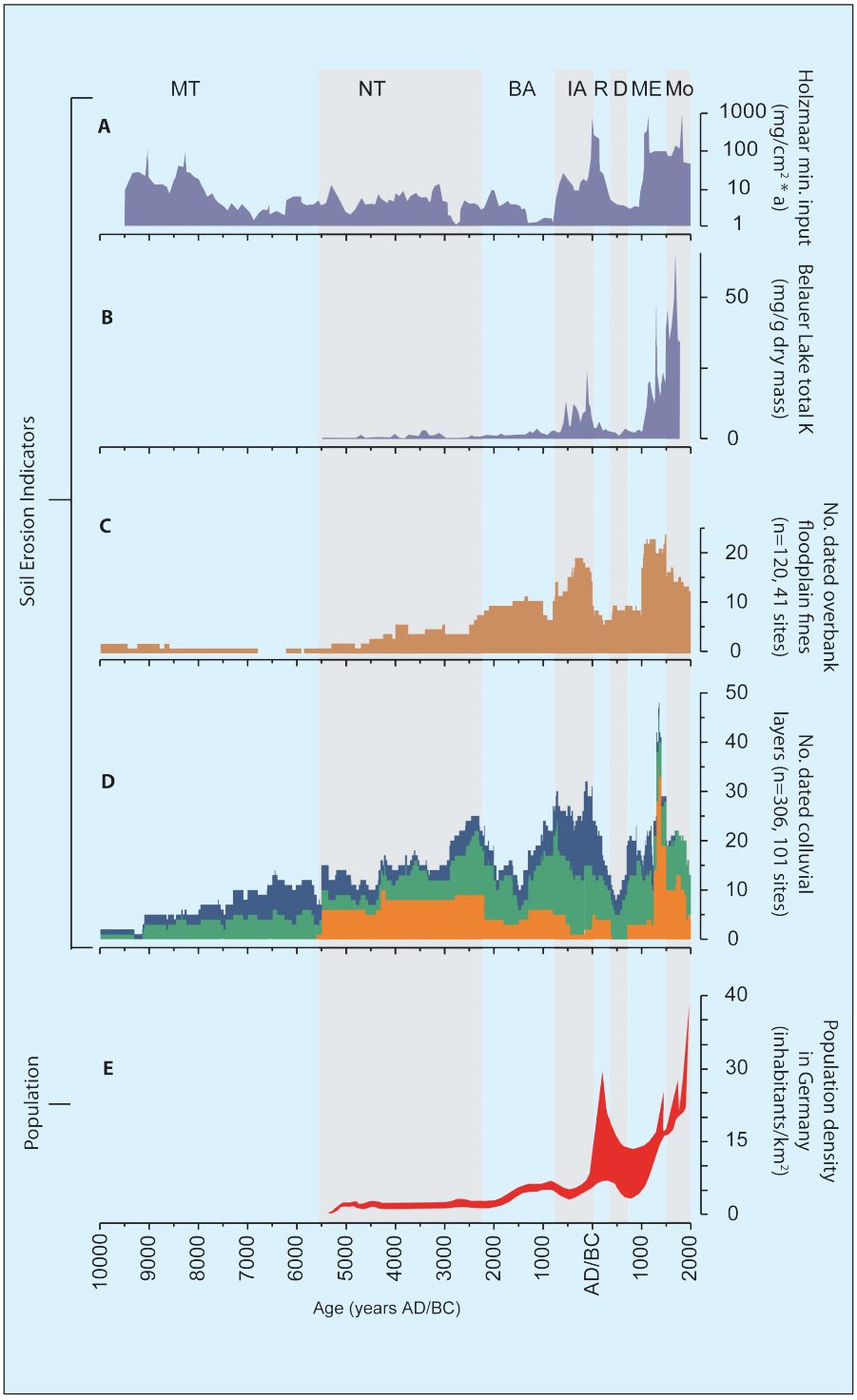

*Figure 2: Records of historical soil erosion in Germany from two lake sediment sequences (**A**, **B**), alluvial sediments (**C**) and slope deposits (**D**), compared to population density (**E**; Dreibrodt et al., 2010). Three methods were used for dating of slope deposits: Archeological dating (embedded finds; orange), radiocarbon dating (green), and IRSL-dating (blue). Shaded areas reflect cultural periods: MT- Mesolithic Times, NT- Neolithic Times, BA- Bronze Age, IA-Pre-Roman Iron Age, R- Roman Imperial Times, D- Dark Ages/ Migration Period, ME- Medieval Times, Mo- Modern Times. Note that the record of slope deposits and alluvial deposits for Modern Times underestimates soil erosion, as a lack of data exists for young deposits.*

Land use or climate?

The observed variability in erosion reflects, to a large extent, the varying intensity of population pressure and agricultural land use in Germany. This is illustrated by the pronounced increase in soil erosion, particularly at the onset of and during the Neolithic times (ca. 5500-2200 BC in southern and central Germany) and by the distinctive decrease in soil erosion during the migration period (ca. 300-700 AD) and the early Medieval times (ca. 700-1000 AD) (Fig. 2) (Dotterweich, 2008). It seems that centennial-scale climate change affected the observed variability by modifying the boundary conditions for erosion. For example, there are few erosion records from the early and middle Bronze Age (ca. 2000-1600 BC), a period known to have been a prominent dry period in central Europe (Dotterweich, 2008). The most remarkable phase of soil erosion occurred in the first half of 14th century, at the beginning of the Little Ice Age. The second well-known intense soil erosion phase occurred in the mid-18th to early 19th century—at the end of the Little Ice Age. Historical records document extreme precipitation events during these two phases, implying an influence of climatic extremes on geomorphological processes. However, certain phases of the record remain unexplained. For instance, during Roman Emperor times (27 BC-476 AD) there is little indication of soil erosion even though there is no evidence for particularly dry conditions and population density was high (Fig. 2). As a general finding, the majority of the studies on soil erosion in small catchments indicate that sediment fluxes are highly sensitive to changes in local land use, while climate change plays a secondary role.

Legacies of catastrophic events

Most of the gully systems in central Europe today are a result of catastrophic rainfall events. In the year 1342 AD, for example, extreme erosion events initiated many gully systems and hill slope erosion delivering over 50% of the total colluvial material that exists today in the investigated areas in central Europe (Dotterweich, 2008). A few extreme events were responsible for most of the currently deposited slope sediments, significantly modifying flood and erosion regimes of the landscape. This period in history marks the change from

natural- to human-dominated systems—a legacy that has ramifications for today's landscape. The ability of extreme events to cause steep changes in these landscapes, effectively changing the regional boundary conditions, should be seen as a warning for the potential impacts of extreme events in future climates. It also means that conventional modeling and assessment tools used for sustainable management strategies may be inadequate to accommodate legacies and complex interactions over decadal and centennial timescales because they generally don't integrate extreme events.

Human-environment feedback

In contrast to reconstructions of geomorphic and pedologic history, there are only a few studies concerning possible feedbacks from land use. These studies equate societal collapse to vulnerability to climate change, agricultural maladaptation or a mixture of both. For example, historical studies show that during the first half of the 14th century, many villages in Germany were abandoned as an ultimate consequence of a combination of socio-cultural processes, crop failures and soil degradation (Bork et al., 1998; Dotterweich, 2008). Food prices became very expensive in several consecutive years of the first half of the 14th century because of shortages as a consequence of soil degradation and economic mismanagement (Fraser, 2010). This unfavorable socio-economic, nutritional, and health situation might have prepared the ground for the European-wide pandemic, namely the Black Death, between 1347 and 1351 AD. In the 18th to early 19th centuries, soil erosion and crop failures led to major migration overseas. Soil erosion appears to have been one factor in a complex causality spiral leading to socio-economic instability and land-use changes.

Modern day environments

In light of historical and recent data (severe floods with high costs to our societies), we now have new insight into the interactions between societies and their environment. This type of research has the potential to help in the development of modern sustainable land-use strategies by providing evidence for the different timescales and complexity of interactions between human activities and geomorphic responses. However, many past studies combine and correlate different time series, assuming causality and neglecting the legacy of past forcings and responses. Future approaches must better distinguish proximate from ultimate causes to deliver a new understanding of complex system behavior. The research also has to extend the scope of analysis to the full spectrum of human–environment interactions including the demise of agriculturally marginal systems and the histories of more subtle, adaptive and cumulative changes and processes. This will extend our observation of background processes in modern human-dominated landscapes and their natural variability. Past records have an important role to play in the creation of adaption strategies for complex agricultural systems around the world.

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Long-term perspectives on an iconic landscape: Origins and future trajectories of the "Ancient and Ornamental Woodland", New Forest, UK

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Paleoecology, in combination with more recent ecological observations and future climate projections, can play a key role in providing a robust basis upon which to build ecological management strategies for important biodiversity areas.

The New Forest: Management dilemmas

National parks in Britain are managed for multiple uses: they are often scenic areas and attract numerous visitors, they support local economies beyond tourism, particularly agriculture and forestry, and they are foci of biodiversity. Climate change introduces uncertainty to this challenging and sometimes conflicting land use mixture, and will affect management strategies for the 21st Century. The New Forest (Fig. 1a), which lies just to the west of Southampton in central southern England, is one of the UK's newest parks, and was established in 2005. Its landscapes and ecosystems give rise to outstanding lowland scenery and there are well-established amenity uses (it is only two hours from London). High levels of biodiversity, compared with the agricultural regions and urban areas that surround it, have attracted numerous national and European directives on species and habitat conservation. The medieval wood-pasture system maintained via customary rights and administered by a local court, is recognized as a unique cultural attribute that is closely linked with the Forest's ecology and landscapes. The future of the New Forest will depend upon the management strategies of government agencies, landowners, and the local user groups who practice customary rights such as stock grazing. Increasingly, it will depend upon the interaction of climatic factors and the constituent species of its ecosystems. The Forest features a range of highly valued habitats; here we examine one habitat type of high biodiversity and amenity value, the so-called "Ancient and Ornamental Woodland" (A&O Woodland; Peterken et al., 1999; Tubbs, 2001; Fig. 1A).

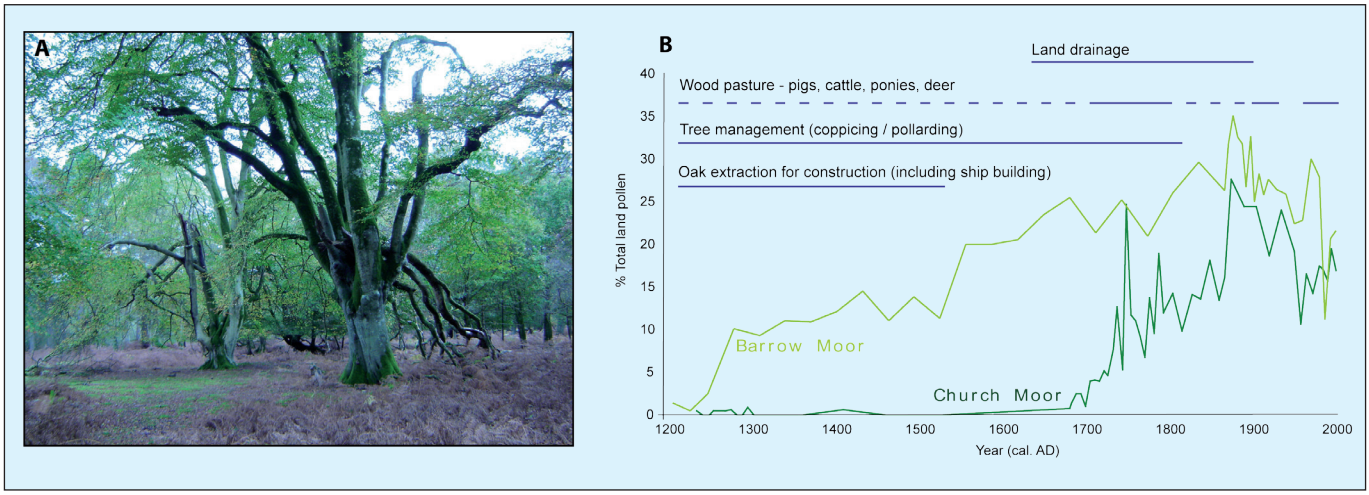

*Figure 1: **A**) Typical A&O Woodland featuring over-mature, previously pollarded beech trees (Photo M.J. Grant). **B**) Pollen percent curves for beech (*Fagus*) at two valley mire (peatland) sites, Barrow and Church Moor, located within Mark Ash Wood. Both curves are at their highest between ca. 1700 and 1900 AD and subsequently decline, however at Barrow Moor the initial increase in* Fagus *occurs several hundred years earlier than at Church Moor. The horizontal lines indicate past land use practices, dotted lines indicate less certain records.*

The A&O Woodlands form part of a mosaic that also contains open heath, grazed lawns and plantations, reflecting both traditional uses and more recent commercial forestry activities. The current dramatic appearance of many woodlands, typified by large, often over-mature, beech (*Fagus sylvatica*; Fig. 1A), is likely due to 100 years of abandonment that followed a period of intensive management. Formerly, beech was pollarded (cut above head height) in association with wood-pasturing, fuel and timber production (Rackham, 2003). A dilemma for managers is that many visitors appreciate the current appearance of the A&O woodland, but ecologically and structurally the system is gradually being transformed. To be maintained in the longer term, it must undergo a managed regeneration cycle that will inevitably alter current conditions over the decades to come. Knowledge of the past cultural and environmental conditions that have led to the development of the current system can inform current management choices and provide a temporal perspective on the key question of whether long-term sustainability of this landscape and ecosystem is truly achievable (see Grant and Edwards (2008) for more details).

Long-term record of beech

Two valley mire deposits lying within A&O Woodland were selected for pollen studies: Barrow Moor and Church Moor, located ~600 m apart from each other. The pollen record of Fagus (Fig. 1B) shows that it did not become a significant component of the woodland until a few hundred years ago and that its expansion was locally asynchronous. At both sites, expansion coincided with an increase in holly (*Ilex aquifolium*), the herbs *Plantago lanceolata* and *Rumex* spp., and bracken (*Pteridium aquilinum*), all indicative of increased grazing pressure, and a decline in hazel (*Corylus avellana*). This last development may relate to the deliberate removal of hazel, abandonment of coppicing (a traditional woodland management method where trees are cut at ground level) and a shift to wood-pasture, or increased grazing pressure. Selective removal of oak (*Quercus robur*), particularly for naval construction (Flower, 1980; Tubbs, 2001) and possibly enhanced drainage, also favored expansion of beech. The overall importance of beech appears to decline during the 20th century at both sites. Thus beech dominance within the A&O Woodlands is relatively recent, likely related to human intervention rather than natural processes alone, and is now decreasing.

Locally, ecological monitoring of New Forest A&O Woodlands for up to 50 years reveals a clear decrease in canopy and understory extent, particularly for beech, which can be related to several processes: high grazing pressure limiting regeneration, direct removal of holly from some areas, death or stress damage to trees following the severe drought of 1976 and the

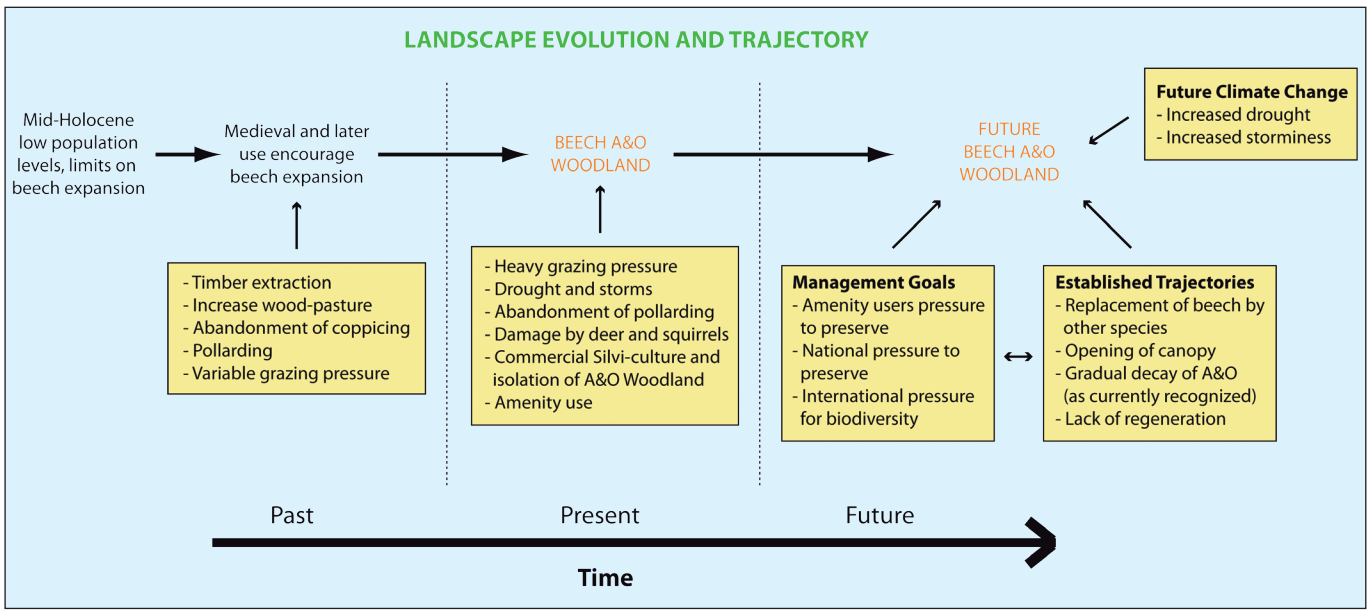

Figure 2: Past, present and future trajectories of A&O Woodland in relation to environmental pressures and management options (Modified from Grant and Edwards, 2008).

hurricane of 1987, and grey-squirrel damage (Mountford et al., 1999; Mountford and Peterken, 2003).

At broader spatial and temporal scales, the Holocene pollen sequence from Church Moor (Grant et al., 2009) and other localities in southern England indicate that beech was present as early as 6 cal ka BP, initially at extremely low abundance (1-2%). Its expansion typically appears to be associated with anthropogenic activity in the late Holocene. In the High Weald area of southern Britain, south of London, beech expansion is also related to a change in land use, particularly to the adoption of the wood-pasture system (Waller and Schofield, 2006). Pannage (feeding by domestic pigs on acorns) may have particularly favored beech, as its seeds are highly dependent upon ground disturbance for establishment (Björkman, 1999; Watt, 1923).

Future trends

A combination of natural and human-induced processes over the past several hundred years has led to the development of modern A&O Woodlands as a New Forest landscape element. Figure 2 summarizes the drivers of past change, contemporary pressures and possible future for A&O Woodland. Sustaining the culturally generated structure and composition may require revival of the traditional management practices that formed the current landscape (or substitutes that achieve the same effect). The balance (or imbalance) between openness and regeneration reflects levels of grazing and browsing by stock and wild deer, and thus there is a role for stock and deer management. The current age structure already contributes to any future trajectory, and further opening of old stands within the present woodlands is inevitable. It will now be some time before a new generation of trees matures, irrespective of which management strategy is adopted. Furthermore, any long-term management intervention now also requires anticipation of climate-change pressures. For example, beech is susceptible to wind-throw, which will increase with projected greater storminess. Revival of pollarding on younger trees would mitigate wind-throw while also continuing a traditional past practice that underlies the structure and composition of contemporary A&O Woodland. On the other hand, projected levels of summer drought in the south of England may stress beech to an extent that it cannot thrive, in which case the woodland will follow a different trajectory and A&O Woodlands as they are known today will eventually take on a new composition and appearance.

Data

More detailed accounts of the pollen data can be found in Grant and Edwards (2008) and Grant et al. (2009); the pollen data will be deposited with the European pollen database (www.europeanpollendatabase.net/) in due course and, until then, are available from M.J. Grant upon request.

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Grazing activities and biodiversity history in the Pyrenees: New insights on high altitude ecosystems in the framework of a Human-Environment Observatory

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Reconstruction of the relationship between pastoral activities and vegetation history in the central Pyrenees demonstrates the importance of grazing pressure in the maintenance of floristic diversity in highland regions that have been abandoned.

In the context of biodiversity management, as encouraged by the European Union Habitats Directives and by the implementation of national strategies, the preservation of traditional agro-pastoral farming activities (in particular extensive grazing), is a major issue acting to maintain or restore open land that is favorable to biodiversity. Here, we present a case from the Pyrenean Mountains, which is considered the most important mountainous massif in southern Europe due to its biodiversity and high levels of endemism. Since the mid 20th century, agricultural activities in these mountains have significantly declined, often accompanied by a change in grazing practices. From a pastoral point of view, the current situation in the Pyrenees is complex. In the Eastern Pyrenees, grazing areas are being abandoned, which is resulting in an expansion of heathland and forest. Conversely, in the Central and Western Pyrenees, an intensification of grazing is observed. This intensification creates problems that are characteristic of overgrazed areas; soil erosion and the fragmentation of animal habitats by fences. European and national policies are attempting to face this situation, where over-grazing and abandonment coexist, through support of conservation organizations, such as the Pyrenees national park, the regional natural parks, natural reserves, and nature charities, which participate in the local implementation of the networking program "Natura 2000" (Magda et al., 2001). The development of a co-management structure, with involvement of local and governmental environmental managers, is encouraged in order to set up strategies reconciling biodiversity conservation with restoration or maintenance of agro-pastoral activities. Pastoral activities are considered essential for maintaining open land, preventing the expansion of

invasive species, and forestalling secondary succession of forests following past anthropogenic activities. For the majority of cases, a return to extensive grazing activities is highly recommended. However, this suggestion is often based on present-day observations with a temporal record spanning no more than 10 years (Canals and Sebastià, 2000).

The potential of incorporating historical ecology and paleoecology in conservation biology is now recognized, including their applicability to biodiversity maintenance, conservation evaluation and changing disturbance regimes. Paleo-studies can provide guidelines for environmental managers (Swetnam et al., 1999; Valsecchi et al., 2010). The effects of long-term, human-induced disturbances (i.e., grazing pressure) on ecosystem dynamics and their biodiversity still need to be further investigated.

A Human-Environment Observatory: Insights on future dynamics

The Upper Vicdessos Valley (Ariège, eastern Pyrenees) is representative of a common scenario in the Pyrenean massif where agro-pastoral activities have reached an extremely low level, now characterized only by extensive grazing. Successional processes involving encroachment of open land and overgrowth by trees are now occurring rapidly at all altitudes. Hill slopes have all been subjected to an overwhelming encroachment of fallow land (*Betula, Fraxinus, Corylus*) whereas altitude zones used for summer grazing are progressively colonized by heathland (principally *Juniperus communis, Calluna vulgaris, Cytisus scoparius*). After thousands of years of intense agro-silvo-pastoral activities (going back to the late Neolithic period, Galop and Jalut, 1994), a rapid decline in human activities linked to rural depopulation took place during the first half of the 20th century.

The Vicdessos Valley is therefore a particularly interesting case study. Since 2009, a Human-Environment Observatory (http://w3.ohmpyr.univ-tlse2.fr/presentation_ohm_pyr.php) headed by the laboratory GEODE was set up by the Institute of Ecology and Environment of the French National Center for Scientific Research (INEE-CNRS). It aims to monitor past and present evolutions of human-environment interactions in order to anticipate future dynamics and consequently to provide a scientific basis for understanding the functioning of social-ecological systems. This implies a close collaboration with local and governmental planners in charge of management and conservation of landscapes and ecosystems. The observatory is a multidisciplinary consortium bringing together scientists to work on integrated micro-regional research (Pyrenean Valley scale). It involves observations and measures of present dynamics (e.g., meteorological and climatic observations, experimental approaches, monitoring of plant and animal communities) and studies of past human activities over long-term timescales. The latter uses instrumental and documentary data sources, tree demography (dendrology), old maps, agricultural statistics, aerial photographs, and long-term sedimentary proxy data (e.g., sedimentology, biogeochemistry, pollen and charcoal) from lakes and bogs in the valley.

From over-grazing to abandonment: 200 years of grazing activities

In the Vicdessos Valley, the hanging valley of Bassiès (altitude between 1400 and 2500 m asl) lies one of the study sites of

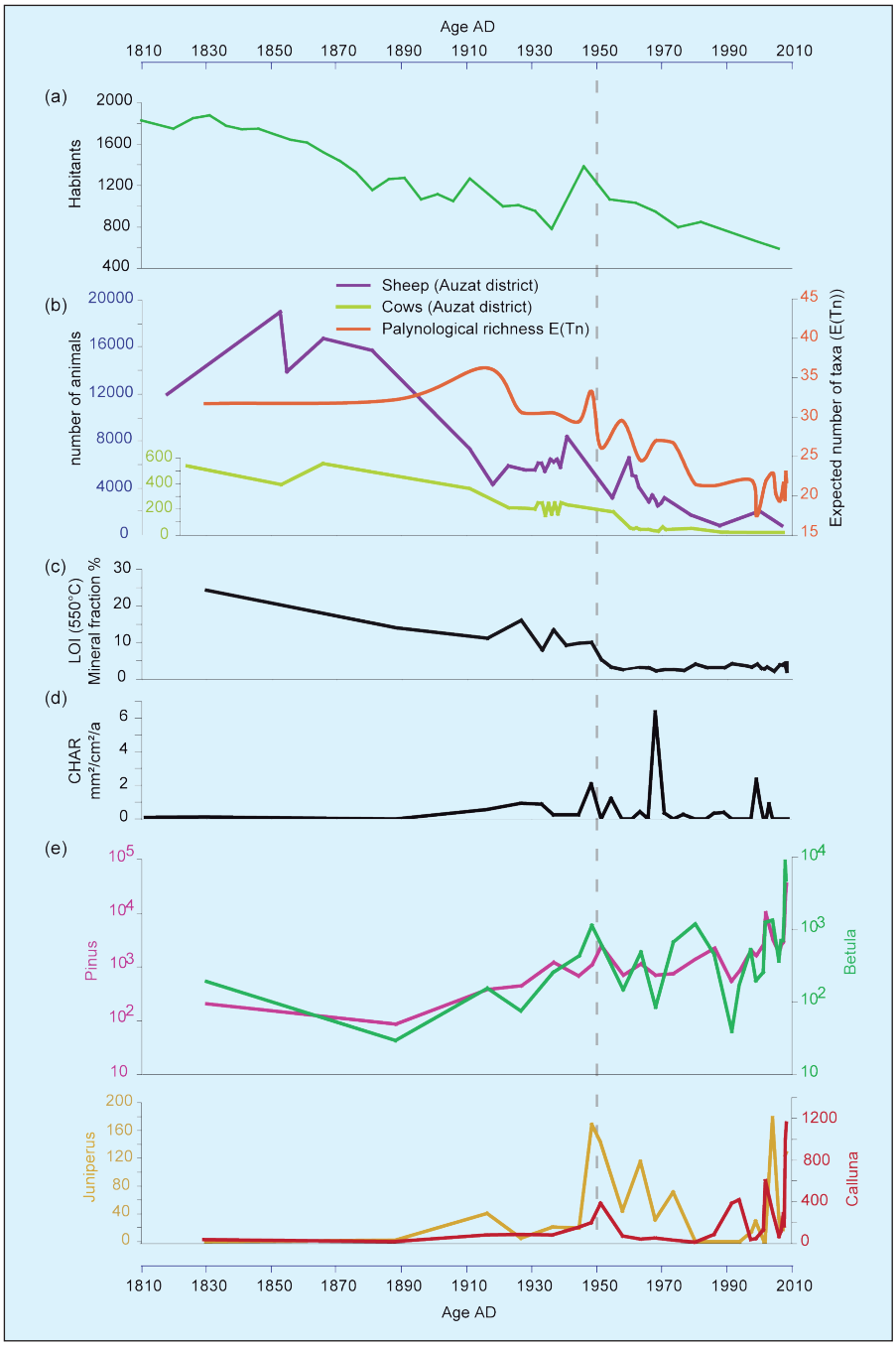

*Figure 1: Trajectories of changes observed since the beginning of the 19th century in the Bassiès Valley based on historical and paleodata. **a**) Evolution of the Auzat commune population; **b**) Comparison between the evolution of grazing pressure recorded in agricultural statistics of the Auzat commune and the estimated palynological richness (E(Tn)) inferred from pollen records from the Orry de Théo peat bog; **c**) Ash content (mineral fraction; LOI 550°C) recorded in the Orry de Théo peat bog; **d**) Charcoal (>150 µm) accumulation rate reconstructed in the Orry de Théo peat profile; **e**) Pollen accumulation rates (g cm^{-2} a^{-1}) of selected taxa recorded in the Orry de Théo peat bog. This reconstruction shows, at a local scale, the change from a scenario of over-grazing to a near-total abandonment of summer pastoral farming activities. In the 1950s, an important period of transition is noted during which grazing pressure can no longer curb the development of heathland species and tree recolonization (dashed gray line).*

the observatory. The research focuses on the impact of grazing activities on high-altitude ecosystems. Paleoecological data, including pollen and charcoal (>150 µm) accumulation rates and loss-on-ignition (LOI), have been retrieved from the small peat bog of Orry de Théo. This sequence illustrates the history of vegetation cover, soil erosion and fire in relation to grazing activities over the last 200 years (Fig. 1). Rarefaction analysis was undertaken on pollen data to estimate the variations of palynological richness assumed to reflect the floristic diversity, and vegetation and landscape dynamics over time (Berglund et al., 2008). The comparison of the palynological richness with documentary sources (demographic data and book records of number of cattle in the valley) provides valuable insights on the role of human-induced disturbances such as grazing activities on floristic and landscape diversity. Figure 1 shows a positive association between grazing pressure and floristic richness. This correlation remains high until around the 1920s despite a decrease in sheep numbers, whereas the presence of cattle leads to soil degradation. A threshold is reached in the 1950s: the decline of flocks associated with a modification of pastoral practices leads to under-grazing and limits the soil erosion. At the same time, the overgrowing of *Juniper* and *Calluna* heathlands and the expansion of trees (*Pinus* and *Betula*), no longer controlled by browsing, are favored. Fire signatures recorded between 1950 and 1970 may indicate the use of fire by the shepherds to restore and clear their pastures. From the beginning of the 1980s, a significant reduction in the number of farmers in the valley has progressively led to a near-total disappearance of grazing activity. In these previously grazed areas, an inevitable and probably irreversible (except through expensive restoration actions) return to forest has led to a decline in floristic diversity. Landscape dynamics are illustrated by reconstructions based on aerial photographs taken between 1962 and 2008 as well as repeat photographs showing the progression of pine-dominated forest between 1976 and 2009 (Fig. 2). The correspondence between paleoecological data and documentary sources confirms the complementarity of the approaches.

The local case study of the Bassiès Valley gives information on diversity baselines, thresholds, and the resilience of mountainous ecosystems to anthropogenic disturbances. This study is also rich in lessons on the loss of floristic diversity related to the variability or the decline in grazing activities and to pine-dominated secondary succession in a context of under-grazing. This kind of integration of data is already being used by managers to affirm the necessity or futility of restoration actions, and especially to avoid thresholds and to reverse the trajectories of key processes.

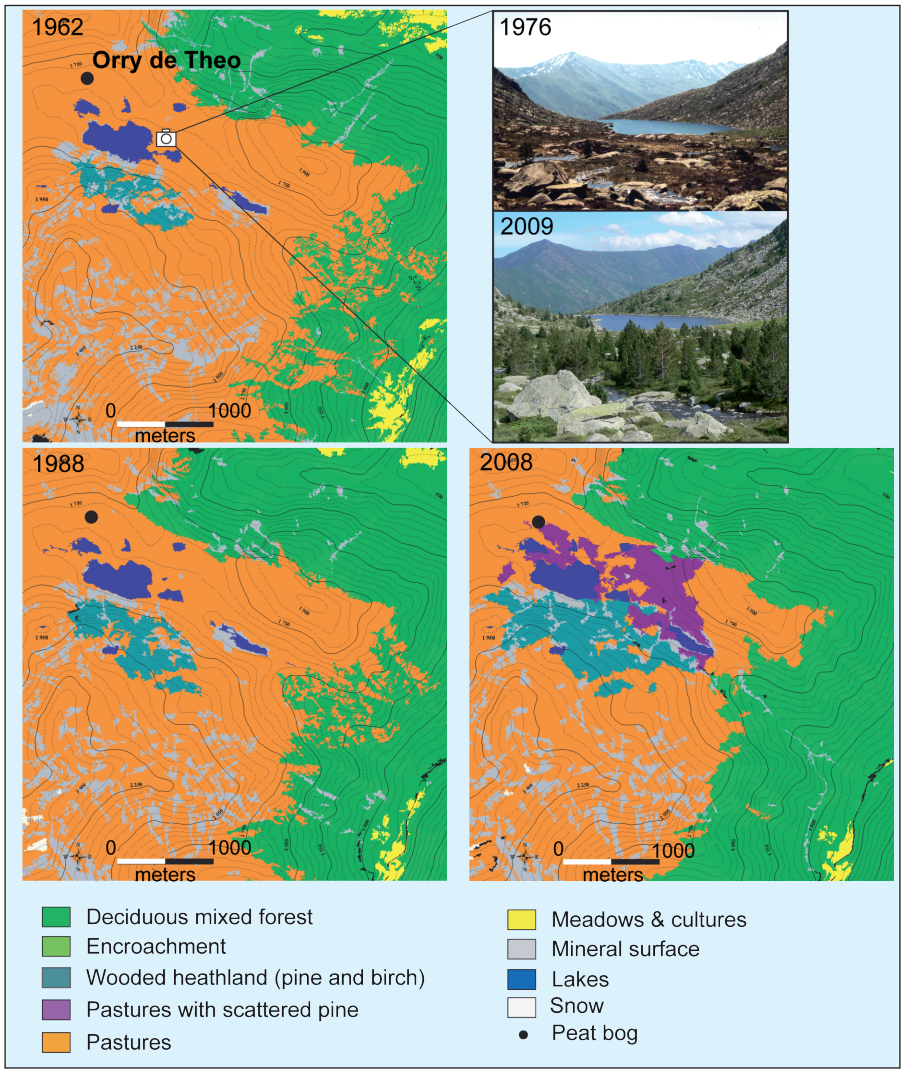

Figure 2: Maps based on aerial photographs (French National Geographic Institute) showing vegetation and land-use changes in the Bassiès Valley between 1962 and 2008. The grazing decline (orange area) is concomitant with increasing forest density, principally dominated by an expansion of Pinus uncinata *and birch (aqua and purple areas). This density increase has been particularly rapid during the last 20 years as shown by the repeat photographs taken in the valley's pastoral zones between 1976 and 2009.*

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Managing biodiversity using long-term regional data in the southeastern United States

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This article discusses how long-term regional data from historic documents, palynology and archeology are combined to inform decisions about biodiversity management in the southeastern United States.

The United States proactively manages federally owned lands with an objective to mitigate/limit the impacts of land-use activities on the long-term stability of the environment. For example, the United States Department of Defense (DoD) manages around 25 million acres of national military land. Impacts of military land use can include soil erosion, loss of endangered species, and degradation of habitats (Goran et al., 2002). Management involves planning and assessment that takes into consideration the types of environment to be managed and how they have changed over time, in order to maintain lands for training and operations. Fort Benning, founded in 1920, is a military base in Georgia and Alabama in the southeastern United States. It covers an area of 1052 km^2 and is situated near the fall line of the Coastal Plain where soils consist of clay beds and sandy alluvial deposits (Fenneman, 1938). The pre-European (before ca. AD 1825) forest was primarily a pine-blackjack oak forest (Black et al., 2002). This article summarizes some recent research on long-term environmental changes and how it is being used to manage current ecological problems.

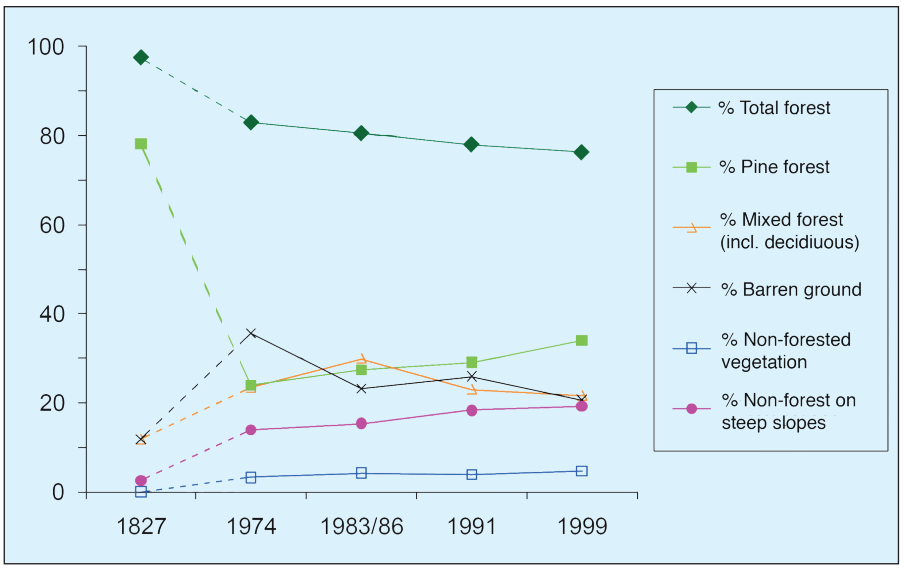

Figure 1: Graph showing the relative abundance of forest cover at Fort Benning, Georgia from 1827-1999 (adapted from Olsen et al., 2007). Data were collected from historic documents and satellite imagery.

Ecological Problems

At Fort Benning, management challenges include protection of federally endangered Red Cockaded Woodpecker (*Picoides borealis*) and habitats important to rare species, such as the Gopher Tortoise (*Gopherus polyphemus*) and relict *Trillium* (*Trillium reliquum*) (Addington, 2004), as well as combating erosion (Fehmi et al., 2004). Proscribed forest fires have to be scheduled so as to maximize ideal training environments (e.g., reduced undergrowth) and preserve a forest composition that is conducive to species diversity and protects endangered species. Environmental managers at Fort Benning not only need to understand the long-term dynamics of the landscape but must also have the management tools for planning.

Therefore, as higlighted in a series of recent publications (Dale et al., 2002; Dale et al., 2004; Dale and Polasky, 2007; Foster, 2007; Foster et al., 2004; Foster and Cohen, 2007; Foster et al., 2010; Goran et al., 2002; Olsen et al., 2007), the DoD has funded research at Fort Benning focused on identifying long-term ecological metrics, human population settlement, and human activities that may have altered the environment.

Data Sources

Environmental management at Fort Benning has included the use of archeology, historic documents, historic and modern satellite images, and pollen from sediment cores. For example, historical "witness tree" records reveal pre-European settlement forest composition. Witness trees are boundary markers recorded on land survey maps that were created when lands were acquired by the state and federal government in the late 18th to early 19th century in Georgia and Alabama. The corner trees and four "witness trees" were recorded at the corners of each survey lot (approximately 82 ha), and the species of the trees were noted on maps and field notes. These data provide a record of the forest composition at the time that the Native Americans were removed by state and federal agencies in the early 19th century and represent the pre-European forests and the forests under Native American management. These data were synthesized into a GIS and compared to historical satellite images (1974-1999; Fig. 1). Knowledge of human settlement and its intensity was revealed by systematic sampling of the military base with archeological investigation. The entire base was examined for human activity at 5 to 30 m intervals. The remains of human activity were analyzed for behavior type, intensity, population density, and economic activity. Lastly, long-term forest composition change was provided by analyzing pollen sequences from peat cores. Cores were dated with ^{137}Cs/^{210}Pb and ^{14}C (Foster and Cohen, 2007).

Findings

As revealed through archeological investigations, Native Americans had lived in the Fort Benning region for at least 10,000 years though their management of the forest had changed dramatically in the last 1000 years (Foster, 2007; Kane and Keeton, 2000). European settlement and military activities within the last 100-200 years further affected the modern environment. Comparisons of the Native American managed forest to satellite imagery during the 20th century indicates that the land cover at Fort Benning has changed significantly (Olsen et al., 2007). The prevailing trend is a decrease in pine and increase in deciduous forest (Fig. 1). Pine forest cover decreased from nearly 80% to below 40% from 1827 to 1999. The increase in deciduous forest is mostly associated with riparian areas, as the riparian areas became

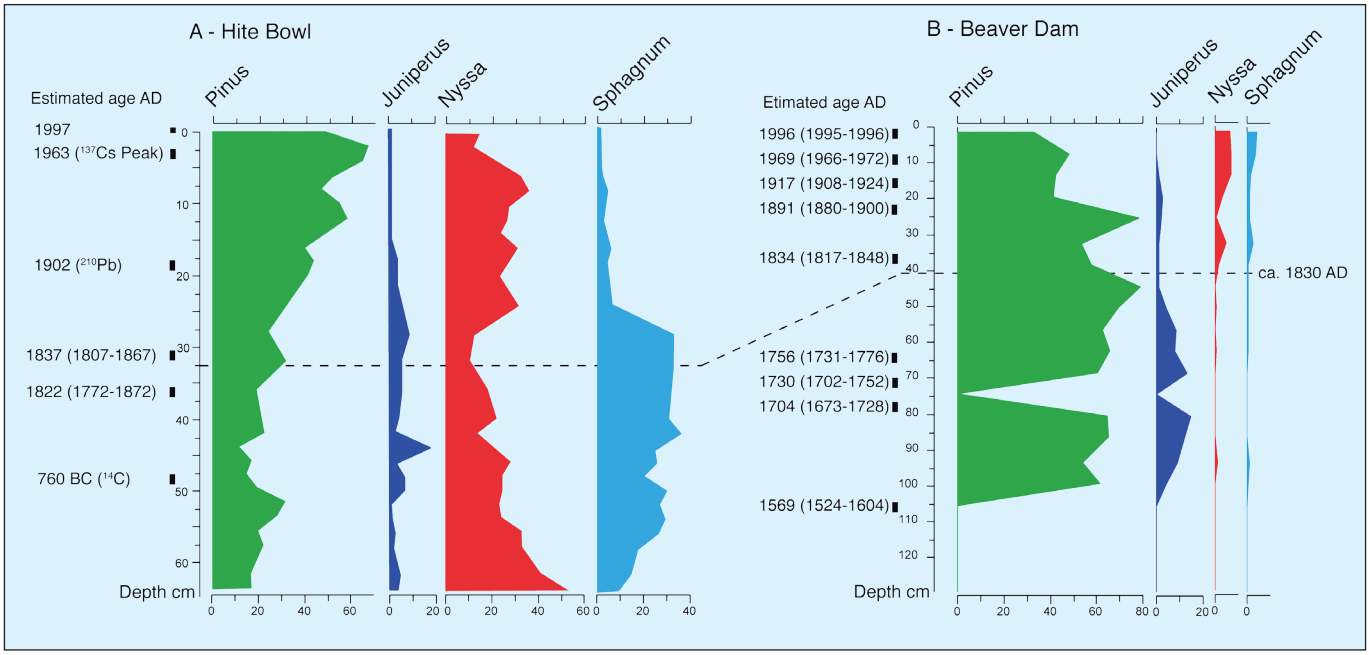

*Figure 2: **A**) Pollen abundance from the Hite Bowl site, Fort Benning, Georgia (adapted from Foster and Cohen 2007). **B**) Same as A) for the Beaver Dam site. These two plots illustrate the localized effect of human activity on vegetation cover.*

larger (Olsen et al., 2007). Forest cover was cut down soon after this area was settled by United States citizens, which resulted in increased soil erosion and habitat degradation (Foster and Cohen, 2007).

Analysis of pollen and charcoal from sediment cores revealed that change in forest composition was localized and affected by human activity. Figure 2 shows the significant changes in pollen composition since Native Americans were removed from the region around 1830. *Pinus* and *Nyssa* have increased in some localized areas whereas *Sphagnum* has decreased. The Native Americans had localized effects on pine and some hardwood species.

Lessons for management

Archeological data, in combination with analysis of pollen, charcoal and fungi from sediment cores (Foster and Cohen, 2007), indicate that the long term effects of human activity are highly localized. Sediment core data indicates that in areas where Native American settlement was dense, pine forest has increased dramatically since European and military settlement (Foster and Cohen, 2007). While in the areas where native people were less densely settled, pine forest has remained approximately the same (Fig. 2; Foster and Cohen, 2007).

Overall, the management plan at Fort Benning has prescribed intensive land use in some areas while preserving others. Based on comparisons of forest composition inside the base to that outside the base, this plan has increased the habitat for endangered species, such as the Red-Cockaded Woodpecker (*Picoides borealis*), to a level that is higher than the regions outside of the military boundary (Olsen et al., 2007). Long-term data have also revealed the localized effects of management policies and are being used to design better policies that are sensitive to the range of biological diversity at Fort Benning.

The combination of long-term data on human settlement and economic activity combined with long-term ecological data reveal that the modern management of forest ecosystems is complicated and regionally variable. Though these data were recovered using diverse methods and varying units of investigation, they can be combined for regional analysis of long-term environmental change. Management decisions that cross ecological regions will likely include variable human activities and ecological conditions. In the case of Fort Benning, modern management has increased pine density beyond that created by pre-European settlement in one region and decreased pine density in another region beyond that of the pre-European forests. An understanding of this process can only be gained through regional analysis of long-term environmental data combined with anthropological understanding of human activities. These data permit modern forest managers to understand the long-term effects of anthropogenic change and the interaction of those changes with the forest ecosystem. Such a long-term perspective is leading to better informed management practices.

Data

Data referenced in this article are available at http://semp.cecer.army.mil.

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Assessing environmental response and recovery of a Great Lakes watershed using a multiproxy paleolimnological approach

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Sediment geochemistry and diatom biostratigraphy can be used to identify stressor-response relationships in aquatic ecosystems for improved regional management strategies.

Aquatic ecosystems in the Great Lakes region of North America have been significantly altered since Euro-American settlement in the late 1700s. Human activities contributing to environmental degradation initially included population increase, land use change, and dramatic industrialization (Alexander, 2006). An understanding of the state of modern aquatic ecosystems can be gleaned from reconstructing the environmental history of the region. Integrating historical records with high-resolution paleolimnological data is an effective way to capture stressor-response relationships and evaluate human influence. These relationships facilitate an understanding of comprehensive aquatic ecosystem response, and are useful for developing predictive tools for future anthropogenic influences. Having such tools is critical for developing sustainable management strategies, and can be used directly by decision makers at the regional scale.

Impacts in the Laurentian Great Lakes Region

A sediment core from Muskegon Lake, Michigan, USA, was analyzed for multiple proxies to assess the system's response and recovery to human activity, with particular attention to ecosystem recovery since the introduction of environmental legislation in the United States (e.g., Clean Air and Clean Water Acts). Muskegon Lake is a 16.91 km^2 inland water body located in the Laurentian Great Lakes region (86°18' W, 43°14'N) (Parsons et al., 2004). Its mean depth is 7 m with a maximum depth of 23 m. Muskegon Lake itself is the end point of a drowned river mouth system that connects the Muskegon River Watershed to the coastal zone of Lake Michigan through a navigation channel (Steinman et al., 2008). This proximity to the Great Lakes and general ecological setting make it an important fishery, though invasive species, habitat loss and degradation continue to be factors of concern (Lake Michigan Lakewide Management Plan, 2004).

Muskegon Lake has a history of intense anthropogenic activity since the early 1800s (summarized in Fig. 1). During the lumber peak in the 1880s, the city of Muskegon had more than 47 sawmills. Following the depletion of lumber resources, Muskegon developed an industrial base, with oil and chemical industries being prominent (Alexander, 2006). In the mid-1900s, foundries, metal finishing plants, a paper mill and petrochemical storage facilities were built on the shore of Muskegon Lake (Steinman et al., 2008). Expansion of heavy industry and shipping in 1960s and 1970s contributed to over 100 000 m^3/day of wastewater discharged from industrial and municipal sources into the lake until a tertiary Waste Water Treatment Plant (WWTP) was installed in 1973 (Freedman et al., 1979; Steinman et al., 2008). Currently, there are eight abandoned hazardous waste sites (USEPA Superfund sites) in the region and fish consumption advisories have been issued due to significant levels of PCB (Polychlorinated biphenyls) and mercury.

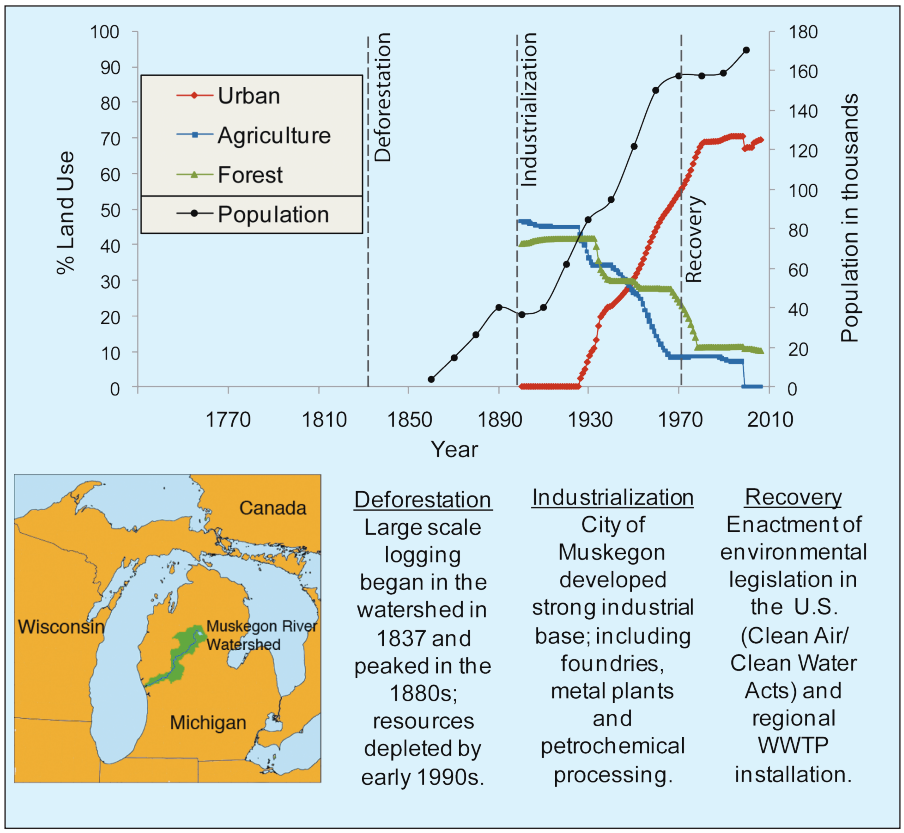

Figure 1: Trends of land use change since 1900 (Ray and Pijanowski, 2010) for the Muskegon River Watershed (location green on map inset), population data for Muskegon county since 1860 (US Census) and regional scale human impacts since Euro-American settlement. WWTP = Wastewater Treatment Plant.

Environmental response to regional impacts

Analyses of geochemical data from the sediment core showed suites of elements that corresponded to the source of the sediment, including terrestrial in wash, primary productivity, redox sensitive and anthropogenic related material (Long et al., 2010; Yohn et al., 2002). Elements influenced by terrestrial processes (e.g., Al, K, Ti and Mg) reflected drowned river mouth conditions of Muskegon Lake, and recorded deforestation-induced erosion in the late 1800s. Productivity related elements (e.g., P and Ca) indicated changes with nu-

trient inputs to the lake (presumably related land use change). Redox sensitive elements (e.g., Fe and Mn) were important for interpreting the redox state of the system. Elements associated with anthropogenic activity (e.g., Cr, Pb and Sn) had similar profiles, which closely track the history of human activity (see Fig. 2A), though concentration peaks for individual elements varied by specific industrial activity. For example, driven in part by policy mandates (e.g., discontinued use of leaded gasoline) Pb decreased to ~60 ppm in modern sediment from a peak of ~325 ppm, reflecting significant recovery from peak concentrations of anthropogenic elements. However, the Pb values did not return to the pre-disturbance Pb concentration of ~11 ppm. The geochemical reference condition was evaluated using sediment concentration profiles of the anthropogenic proxy group, which best indicates the pre-Euro/American settlement conditions. Results show that modern concentrations of anthropogenic elements have not decreased to the historical geochemical reference condition (e.g., Pb).

Biological change in Muskegon Lake, inferred from fossil diatoms, suggests that the pre-settlement community structure is markedly different from that of modern assemblages. Figure 2 includes specific diatom biostratigraphic changes that correspond to the timeline of various human stressors, including water chemistry changes resulting from agricultural development, industrialization and urbanization of the watershed. For example, taxa indicating high nutrient conditions (e.g., *Stephanodiscus* spp.) have peak abundances dated between 1930s and 1970s when nutrient inputs were increasing due to agriculture and urbanization. Moreover, productivity regimes in the lake, reconstructed from diatom habitat structure, identified a significant shift from planktonic- to benthic-dominated productivity in the top 25 cm of the core; this shift is dated to after the installation of the WWTP in 1973. Much of the water quality improvements in the past 30 years, reported by Freedman et al. (1979) and Steinman et al. (2008), and also noted in Figure 2, are presumably attributed to the WWTP installation. Decreases in lake-wide averages of total phosphorus and soluble reactive phosphorus at the water surface range from 68 to 27 µg/L and from 20 to 5 µg/L, respectively from 1972 to 2005. In addition, average chlorophyll-a concentrations have declined by 19 µg/L over this period, while Secchi disk depths (a measure for water transparency) have increased from 1.5 to 2.2 m (Freedman et al., 1979; Steinman et al., 2008). This partial recovery corresponds to the shift in dominant habitat of primary productivity, as the relative abundance of planktonic dominated taxa at the bottom of the core (i.e., in pre-settlement times) is between 56 and 77%, peaks at 88% in 24 cm depth (dated to 1970 at the peak of cultural eutrophication), and then quickly decreases to 26-37% in the top 8 cm of the core. The productivity shift in the top 8 cm (benthic taxa become 54-64% dominant) may also be influenced by the invasion of *Dreissena polymorpha* (zebra mussel).

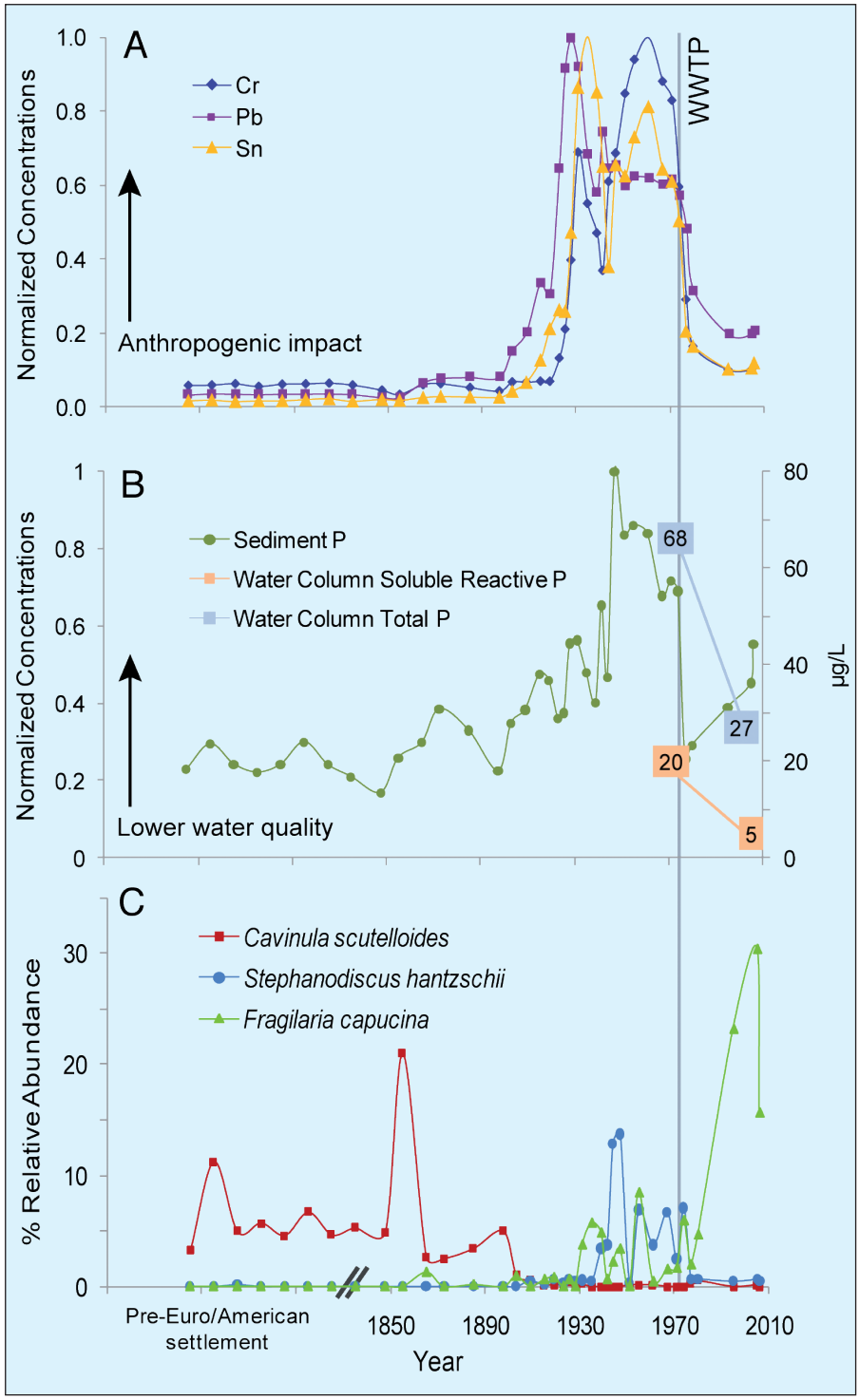

*Figure 2: **A**) Profiles of select anthropogenic elements with concentrations normalized to highest concentration of each element, **B**) Normalized sediment phosphorus (P) profile (as a measure of water quality) with measured concentrations of water column soluble reactive P and water column total P from 1972 and 2005 (Freedman et al., 1979; Steinman et al., 2008), and **C**) Relative abundances of select fossil diatoms indicative of water quality changes.*

This study identified causal agents at the regional scale directly linked to human activities such as deforestation, agriculture, industry and urbanization with an integration of geochemical and biological data inferred from fossil diatoms. Overall, the state of the lake system has dramatically improved as the result of environmental management efforts, and this study can be used as an indicator for the response of the larger Lake Michigan that it feeds into (Wolin and Stoermer, 2005). However, recent proxy trends (e.g., sediment P) do not indicate that the system has stabilized,

suggesting that modern stressors such as climate variability (Long et al., 2010; Magnuson et al., 1997), invasive species (Lougheed and Stevenson 2004; Steinman et al., 2008) and further land use alterations (Ray and Pijanowski 2010; Pijanowski et al., 2007; Tang et al., 2005) whose influence remain uncertain, are likely to influence system recovery.

Recovery challenges and recommendations

Efforts to manage the watershed have reduced the loading of metals and nutrients, improving the ecological health of Muskegon Lake as evidenced by geochemistry and diatom biostratigraphy. The current geochemical conditions demonstrate significant recovery from high concentrations of anthropogenic elements and the fossil diatom record from this core suggests that efforts to reduce nutrient loading have been successful. Despite improvements, these data indicate that the system is still changing in response to human impacts at the regional watershed scale, suggesting that management strategies also need to target non-point source inputs. As such, it is recommended that modern remediation targets consider the legacy and overprint of multiple stressors, as well as be aware of emerging stressors that could further alter ecological dynamics in the larger Great Lakes Region.

Acknowledgements

We thank the Great Lakes Fisheries Trust for funding this research, and the Aqueous and Environmental Geochemistry Laboratory at MSU for providing financial and technical support. Glen Schmitt and the Michigan Department of Environmental Quality are recognized for help in the field. Special thanks to Dr. Nadja Ognjanova-Rumenova for diatom taxonomical processing and identification.

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Landslides in São Paulo, Brazil: An integrated historical perspective

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The growing severity of floods and landslides in the state of São Paulo, Brazil, is related to rapid environmental changes, such as urbanization, deforestation and settlement in hazardous areas, rather than to natural events, and unless more sustainable land-use practices are adopted the impact of these (un)natural disasters might become more severe.

The Problem

The Emergency Events Database (EM-DAT, www.emdat.be/), an international database of disasters maintained by the Centre for Research on the Epidemiology of Disasters (CRED), states that during the period from 1948 to 2010 Brazil was hit by 146 disasters related to precipitation (storms, floods and mass movements) that caused 8627 deaths and affected nearly 3 million people. Approximately 75% of these calamitous episodes have occurred in the last three decades (1980 to 2010) (EM-DAT, 2010). These figures are probably underestimated (Marcelino et al., 2006; Nunes, 2009) but are consistent with other studies that have demonstrated an upward trend in the severity of disasters triggered by precipitation. It has drawn attention to the question of how strongly this dramatic trend is connected to societal changes, with an ever-growing vulnerability to weather and climate episodes (Kunkel et al., 1999; Changnon et al., 2000;

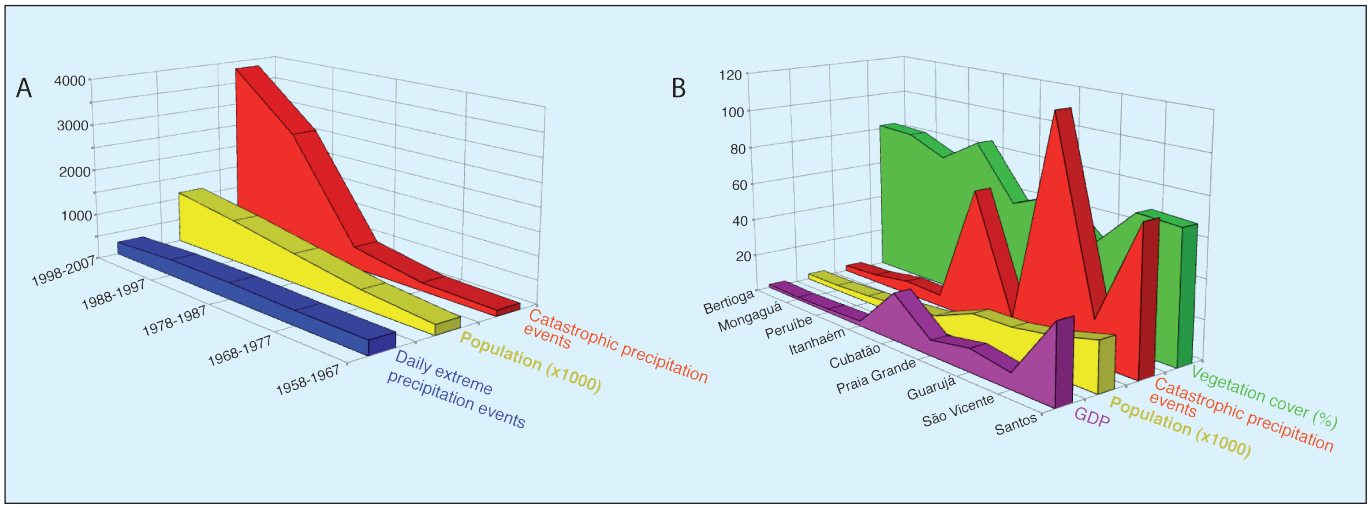

*Figure 1: **A**) Number of catastrophic events caused by precipitation (red) compared with population (yellow) and daily extreme precipitation episodes (blue) in Campinas, Brazil, for 5 decades (1958-1967 to 1998-2007). **B**) Comparison between Gross Domestic Product (GDP, purple, 2009), population (yellow, 2010), percentage of remaining vegetation (green, 2010) and survey (partially completed) of catastrophic events triggered by precipitation (red) from 1928 to 2009, for 9 municipalities of the Metropolitan Region of Baixada São Paulo, Brazil. Higher number of catastrophic events is related to higher deforestation, and lower GDP to lower rates of deforestation.*

Kesavan and Swaminathan, 2006; Araki and Nunes, 2008).

During the second half of the 20th century, urban population increased steadily in Brazil and according to the census of 2010 (IBGE, www.censo2010.ibge.gov.br/), 84.3% of Brazilians live in urban centers. The unplanned growth of cities has led to an increasing inability to house this growing population and to provide adequate infrastructure. Poor regulation has led to inappropriate land use transformation in hazard prone areas, higher pressure on natural resources, lack of appropriate waste treatment and sanitation, violence, and other environmental and societal problems. Rapid urban expansion has the potential to adversely affect ecological dynamics, biodiversity and local climate, as well as patterns of local energy and water consumption.

Land use pattern and natural disasters in the state of São Paulo

The impacts of extreme precipitation events are even more acute in the state of São Paulo, where 21.6% of the Brazilian population is concentrated (95.9% in urban centers) and which contributes 33.1% of the national GDP. Three recent assessments of the historical interactions between climate and social change are providing insight into the controls on landslides and flood:

1) Evaluating the consequences of extreme precipitation events between 1958 and 2007 in Campinas (1,080,999 inhabitants, census of 2010), Castellano (2010) observed a significant increase in the number of the impacts (e.g., damages to buildings and trees, power cut and traffic chaos) recorded from 129 impacts in the first decade to 3,837 in the last. During the same period, the population increased by 500%, but no changes in the frequency of extreme precipitation events were recorded (Fig. 1A).

2) The urbanization of Bauru (344,039 inhabitants, 2010) led to decreased soil infiltration with increased runoff released into the natural drainage network, further leading to gullies and more frequent floods. Comparing daily precipitation events above 10 mm/day and erosion and floods from 1967 to 1999, Almeida Filho and Coiado (2001) noticed that the rainfall pattern did not change significantly during the whole period. However, 66% of the episodes occurred between 1984 and 1999, the period of urban population expansion that was not accompanied by urban planning or adequate engineering.

3) The eastern portion of the state, a mountainous region with steep hills at the base of the coastal Serra do Mar Range, is particularly sensitive to natural disasters, with more than 16,000 people living in areas at risk of landslides, mudslides and floods. Some sectors register very intense precipitation episodes. In Cubatão (108,309 inhabitants, 2010), an industrial complex located in a valley surrounded by the unstable hill slopes of Serra do Mar, summer precipitation intensities reached 1021 mm in nine days (February 1929) and 712 mm in two days, (February 1934), as verified by Nunes (2008). In the past few decades Guarujá municipality, an upmarket resort area (290,607 inhabitants, 2010), has experienced an increase in tourism and related activities. This has attracted an influx of workers who largely occupy unstable slopes. As a result, the city has both the highest deforestation rate and highest number of catastrophes triggered by precipitation (floods and landslides) amongst the nine municipalities that are part of the Metropolitan Region of Baixada Santista (MRBS). For the entire area, the correlation between these two variables is -0.85, significant at 95%. Furthermore, the lowest deforestation rates are found in municipalities that also have the lowest GDP, suggesting that the economic development of the region is based on unsustainable practices (Fig. 1B). It is worth emphasizing that this pattern of occupation, with houses perched on steep slopes and next to rivers, is similar to the alpine district of Rio de Janeiro state, where the heavy rains of January 2011 have caused floods, landslides and mudslides resulting in hundreds of deaths and missing persons as well as major economic losses.

Historical information is also being used to highlight the rapid deforestation

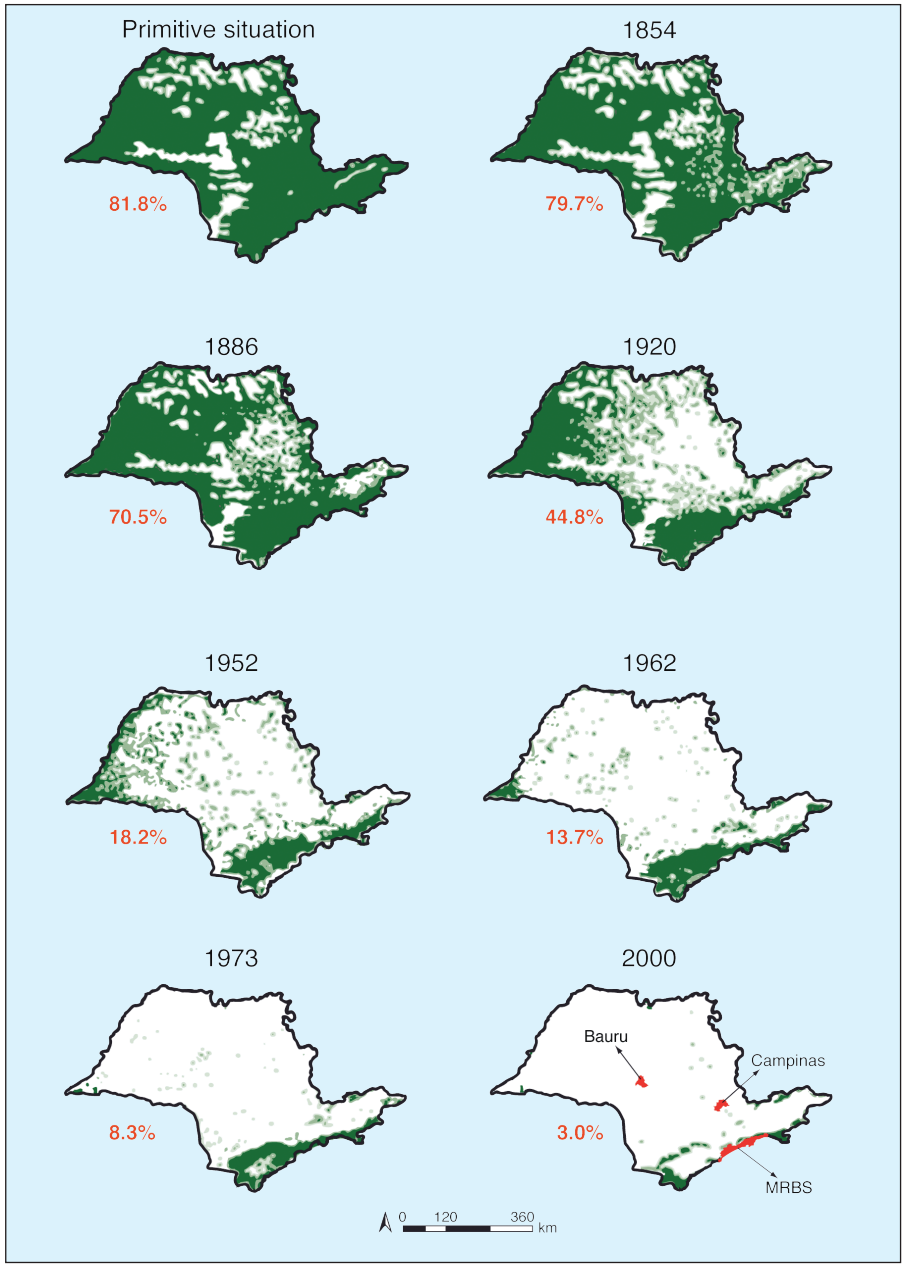

Figure 2: Deforestation of the Atlantic Rainforest in the state of São Paulo from 1854 to 2000. ***Red numbers*** *indicate the estimation of % forest cover for each period (from Victor, 1975).* ***Red shaded*** *areas indicate location of study areas discussed in the text. MRBS = Metropolitan Region of Baixada Santista.*

of the Atlantic Rainforest in recent decades, which is crucial to understanding the recent trends in environmental degradation in São Paulo state. An attempt to reconstruct the forest cover of the state was done by Victor (1975) and Victor et al. (2005) based on reports of pioneers and naturalists, the rise and mobility of population, agriculture expansion and more recently on aerial photo interpretation. It shows that the forest cover of the state was drastically reduced (Fig. 2) by the spread of agriculture and industrialization. The amount of forest cover remaining today corresponds to 2, 8 and 55% of the original area in Campinas, Bauru and Cubatão, respectively.

Future Directions

From the perspectives of both local sustainable development and global change, São Paulo is a "hot spot". There is a great need to break the cycle of destruction and reconstruction linked to catastrophic events. Knowledge of the extent of historical environmental degradation through depletion of resources, such as has occurred in the Atlantic Forest, and a comprehensive evaluation of the frequency and magnitude of floods and landslides are essential to understanding the evolution of natural disasters. Further studies that take into account the characteristics of the river channel network, the sediment yield from these catchments, the landslide scars, and the weathering and soil development must encompass at least decadal timescales in order to provide rates and nature of changes that take place over planning timescales. The evaluation of current economic development strategies, including policies, guidelines and laws, are vitally important to develop strategies that can lead the entire region towards a more sustainable development trajectory. Planning must be constrained by rules that are defined and rooted in long-term and regional to inter-regional analyses of the optimum and sustainable uses of space.

Acknowledgements

I thank Daniel Henrique Candido, PhD student at UNICAMP for the improvement of the figures, and MsD. Ciro Koiti Matsukuma and Valdir de Cicco, Instituto Florestal, for providing the information on deforestation. I also thank Dr. Francisco Sergio Bernardes Ladeira, UNICAMP and Professor John Dearing, University of Southampton, for valuable suggestions.

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Regional wetland response typology: Murray-Darling Basin, Australia

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Paleoecological records from billabongs (floodplain lakes) in southern Australia can be used to develop ecosystem response models that describe how the underlying hydrology and geomorphology of these aquatic ecosystems control their resilience to anthropogenic stressors.

Water demands

Lowland floodplain rivers are "hotspots" of biodiversity and productivity. The ecological importance of these environments is particularly substantial in Australian semi-arid and arid environments because of the moisture subsidy they provide to riverine ecosystems (Ogden et al., 2007). In Australia's dry climate, these environments have also become extremely important for agriculture, which in turn has led to deterioration in ecosystem function and reduced biodiversity. Competing demands for water by ecological and economic systems has led to an apparently intractable debate over how best to allocate water to support sustainable agriculture and ecosystems. The recent debate over the water allocation prescriptions within the Murray Darling Basin Plan (MDBA, 2010) reveal that the changing condition of floodplain wetlands (billabongs) across the region is not well understood. In order to meet this challenge it is vital that water is used efficiently for both agriculture and to support riverine ecosystems. The second half of this equation presents an immense challenge to scientists and managers because our understanding of riverine ecosystem function is limited by a lack of robust data on benchmark conditions, ecosystem variability, and the drivers and trajectories of change.

Ecosystem histories and complexity

Data and information needed to reconstruct ecosystem histories can be provided through paleoecological studies of wetlands. Furthermore, for a basin-wide appreciation, a regional integration of paleoecological studies can reveal the extent and timing of changes to provide broad insights into the ecological cost of the diversion of river flows to support irrigated agriculture.

While factors, such as invasive species and land use, can influence ecosystem structure and function (Roberts et al., 1995; Robertson and Rowling, 2000), floodplain aquatic ecosystems are principally driven by hydrology (Walker, 1985; Bunn et al., 2006). Thus, hydrological changes experienced by billabongs are likely to have a substantial influence on their ecology. However, while the hydrology of a river as a whole is primarily driven by extrinsic factors, the hydrology of individual billabongs is also strongly influenced by intrinsic factors, such as local adjustments in channel morphology, the deposition of sediments in secondary channels linking billabongs to the main channel, and the infilling of the billabongs themselves. Thus individual billabongs may reflect any number of environmental changes operating across a range of spatial and temporal scales. The distinction between local and regional drivers of change can

therefore only be revealed by the integration of a suite of studies over a range of hydrological contexts.

Understanding links between stressors and billabong responses is complicated by the fact that billabongs are ecosystems and therefore have system properties such as non-linear and threshold responses to drivers and system resilience. Clearly, billabongs are not passive receptacles that receive sediments and biological remains that reflect linear relationships to broad-scale environmental drivers. Instead, spatial and temporal variability in depositional processes should be anticipated and simple "dose-response", linear relationships between billabong ecosystems and environmental drivers cannot be assumed. Given this variability and complexity, our capacity to understand the nature, degree, and magnitude of ecological change in lowland river systems is greatly enhanced by robust study designs that incorporate replication of sampling units and a framework for interpreting sediment records that reflects system behavior.

Billabong typologies

The utility and value of this approach was demonstrated in early paleoecological research on billabongs in the southern Murray-Darling Basin systems (Ogden, 2000; Reid, 2002, 2008; Reid et al., 2007). Here, large, deep billabongs underwent apparently rapid transitions in state from macrophyte to phytoplankton-dominance at the time of European settlement, while smaller and shallower billabongs maintained substantial submerged macrophyte communities (Fig. 1). The switch from macrophyte- to phytoplankton-dominance was clearly the most significant ecosystem change in those habitats for centuries, and even millennia, and was attributed to reduced photic depth as a result of abiotic turbidity caused by the influx of eroded soils in the region in the mid 1800s. This interpretation is supported by numerous geomorphological studies, which have demonstrated that this period of early settlement was one of intense sheet and gully erosion in south east Australia, driven by the clearing of native vegetation and the introduction of ungulate grazers (Prosser et al., 2001). The patterns observed in these studies highlight the critical importance of photic depth as a driver of ecosystem structure in Australian shallow lakes, a feature demonstrated elsewhere (Scheffer and Carpenter, 2003). A critical aspect of the findings in the southern Murray-Darling Basin was the importance of the underlying morphometry in controlling the system's resilience to reduced photic depth.

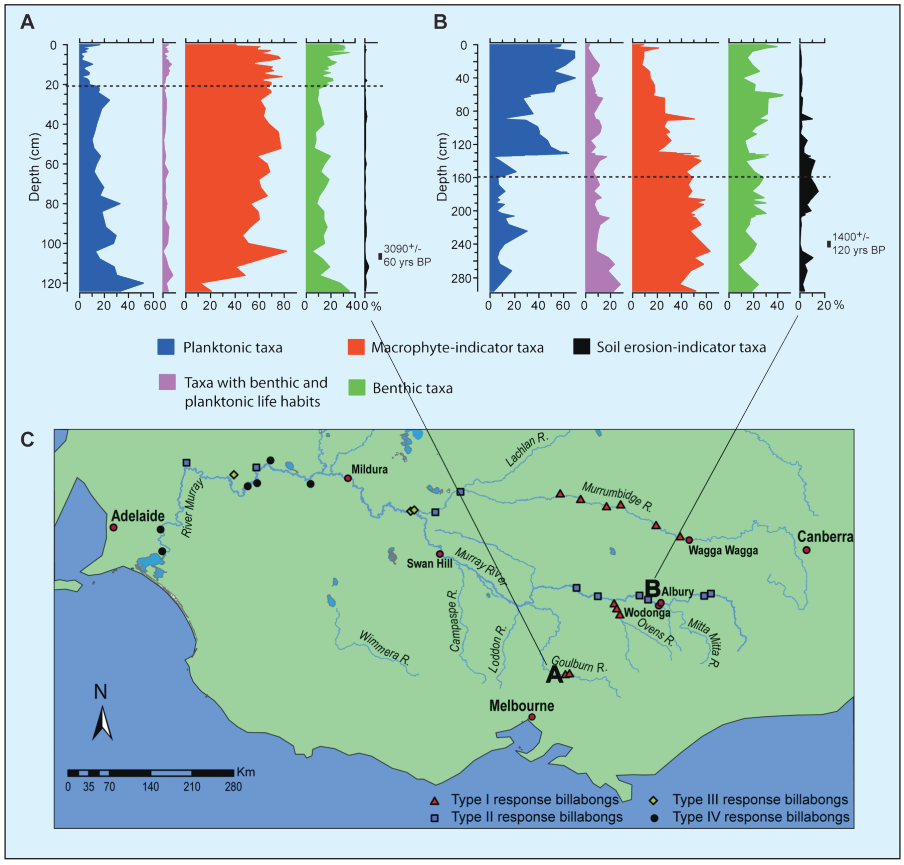

*Figure 1: Examples of Type I and Type II responses in billabongs: **A**) Persistence of macrophyte indicator diatoms (red curve) in a Type I billabong (Callemondah 1 Billabong on the Goulburn River; Reid, 2002) after settlement reflects retention of macrophyte cover, **B**) Diatom shifts to planktonic dominance (blue curve) in a Type II billabong (Hogan's Billabong on the Murray River; Reid et al., 2007) after European settlement. Dotted lines indicate onset of post-European settlement sediment deposition in each billabong based on appearance of exotic pollen and physical sediment character, **C**) Locations of billabongs subject to paleoecological study in the Murray Darling southern basin. Symbols indicate the response type inferred from the paleorecords.*

This simple two-response type framework does not appear to apply to billabongs further downstream in the Murray-Darling System. Numerous studies of billabongs and floodplain wetlands on the Murray below the confluence with the Goulburn River have been carried out, and the majority of the records derived from these studies do not conform to one of the types described above (Gell et al., 2005, 2007; Fluin et al., 2010).

Although there is site-to-site variation, analysis of the full suite of records suggests four broad response types exist (Fig. 2):

- Type I: where macrophyte-dominance persists throughout the record.
- Type II: where a switch from macrophyte to phytoplankton-dominance occurs, associated with European settlement.
- Type III: where periods of phytoplankton dominance occur before and after European settlement.
- Type IV: where there appears to be few periods of "stable" macrophyte or phytoplankton-dominance.

The nature of the changes varies across the southern basin and has a broad geographical pattern:

- Billabongs from Murray tributaries (Ovens, Goulburn and Murrumbidgee) tend to exhibit a Type I response.
- Billabongs from the middle Murray (between Hume Dam and the Murrumbidgee confluence) tend to exhibit a Type II response.
- Billabongs from between the Murrumbidgee and the Darling tend to exhibit a Type III response.
- Billabongs below the Darling tend to exhibit a Type IV response.

As the locations of sites in Figure 1 show, this pattern is not entirely consistent, particularly in the lower Murray. Nevertheless, the smaller channels of the Murray tributaries create smaller billabongs and hence a propensity for Type I responses. In contrast, the larger billabongs of the Murray are more susceptible to state changes in line with the model proposed by Ogden (2000). Further downstream, the drier climate and more variable hydrology introduces the potential for more frequent and extreme drying events. Thus, for billabongs exhibiting a Type III response, drying events may act to reset a new stable state once re-filling occurs. For billabongs exhibiting a Type IV response, drying phases may be too frequent for the establishment of strictly aquatic communities

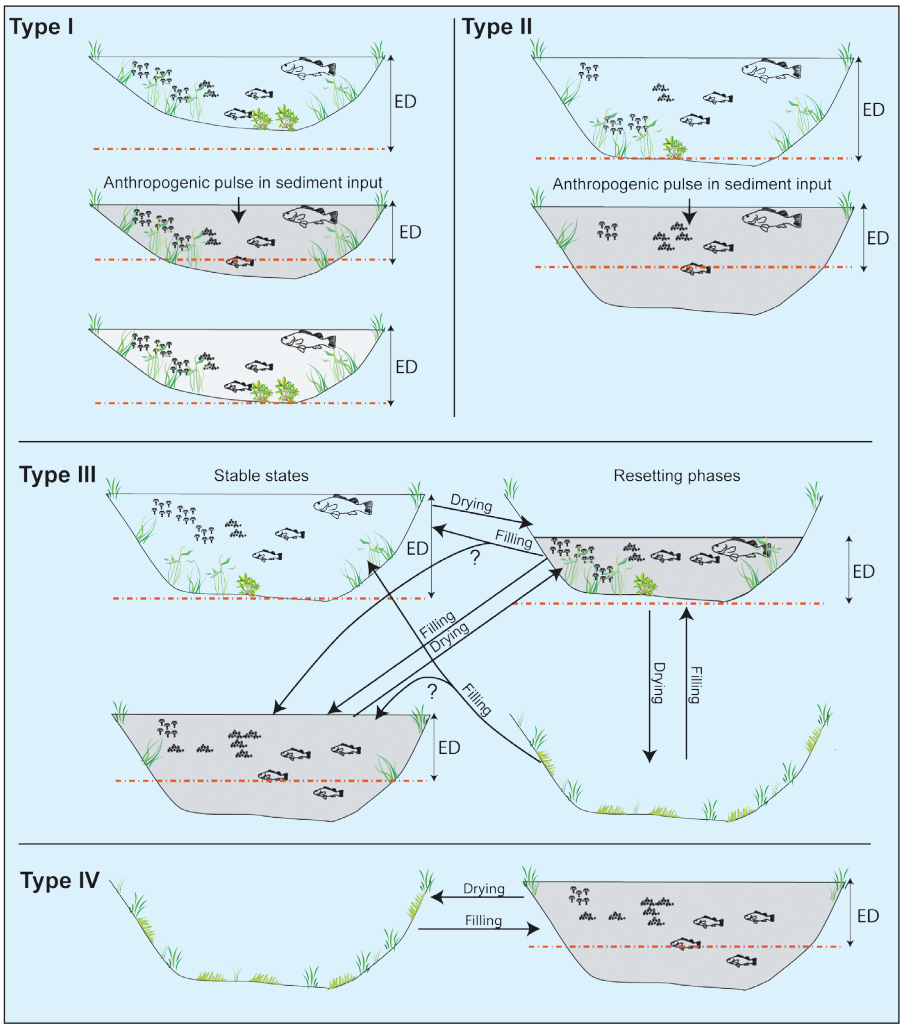

Figure 2: Conceptual models explaining the relationships between billabong geomorphology and hydrology and the proposed response types. In all types, dotted horizontal lines indicate the depth to which macrophytes could grow, ED = Euphotic Depth. ***Type I*** *billabongs are resilient to reduced photic depth because pulses in anthropogenic sediment input do not result in reductions in photic depth sufficient to remove the majority of the billabong bed from the photic zone.* ***Type II*** *billabongs are less resilient to reduced photic depth because pulses in anthropogenic sediment input result in the removal of the majority of the billabong bed from the photic zone. In both cases, feedback processes act to strengthen the original (Type I) or new (Type II) state once sediment influx is reduced.* ***Type III*** *billabongs behave as Type II billabongs, but can be reset to either of the stable states by drying events.* ***Type IV*** *billabongs undergo frequent drying events and thus develop no stable states.*

(planktonic or benthic) and hence these systems are dominated by opportunist taxa, such as amphibious or water tolerant terrestrial plants and algae, adapted to both benthic and pelagic habitats.

The broad geographical pattern suggests that the response types reflect the underlying geomorphology and hydrology of billabongs, because these features reflect the geomorphological and hydrological character of the parent river and reach. This understanding arises through the integration of a suite of site studies that enable the differentiation of site-specific change and regional drivers, and so provide evidence for management at a range of locations and management scales.

Implications

This regional synthesis allows for an assessment of the sensitivity of wetlands to catchment impacts and the status of groups of wetlands relative to their historical range of condition. For wetland managers, deep, large (Type II) wetlands are at risk yet smaller (Type I) wetlands reveal some resilience to catchment impacts. Lower down the system, armed with this evidence managers may better justify reinstating wetting-drying regimes to reset turbid wetlands provided sources of sediment are controlled. Lastly, for Type IV wetlands, this research shows that a "dry wetland" is an ecologically acceptable condition and regular artificial filling may not be justified. In all instances, this evidence reinforces notions that connectivity is key, but also that sediment flux remains a strong driver of wetland condition.

Data

Metadata on the data presented in this article is available in the OZPACS database (http://www.aqua.org.au/Archive/OZPACS/OZPACS.html). The raw data are available on request from the author.

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Evidence for bias in C/N, $\delta^{13}C$ and $\delta^{15}N$ values of aquatic and terrestrial organic materials due to acid pre-treatment methods

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Acid treatment of organic materials, necessary to remove inorganic carbon prior to isotopic analysis, adds an unpredictable and non-linear bias to measured C/N, $\delta^{13}C$ and $\delta^{15}N$ values questioning their reliability and interpretation.

C/N, $\delta^{13}C$ and $\delta^{15}N$ as paleoenvironmental proxies

The analysis of organic matter (OM) from modern and paleoenvironmental settings has contributed to the understanding of the carbon biogeochemical cycle at a variety of spatial and temporal scales. Specifically, the concentrations of carbon (C) and nitrogen (N), from which the C/N ratio is derived, and stable C and N isotopes ($^{12}C/^{13}C$, quoted as $\delta^{13}C$ relative to Vienna Pee Dee Belemnite (V-PDB) and; $^{14}N/^{15}N$, quoted as $\delta^{15}N$ relative to N_2-AIR) of OM have been used to understand processes from biological productivity through to paleoenvironmental interpretations. For example, C/N ratios are widely used as an indicator of OM origin (C/N < 10 interpreted as aquatic; C/N > 20 as terrestrial source) and $\delta^{13}C$ can be used to, among other things, understand broad-scale changes in vegetation type (e.g., photosynthetic pathways; C_3 and C_4 plant types; Smith and Epstein, 1971; Meyers, 1997; 2003; Sharpe, 2007). $\delta^{15}N$ has also been used to investigate OM origin (Thornton and McManus, 1994; Meyers, 1997; Hu et al., 2006), but is more commonly used to understand nitrate utilization, denitrification and N deposition in aquatic systems (e.g., Altabet et al., 1995). These interpretations are based on the assumption that we can reliably determine C/N, $\delta^{13}C$ and $\delta^{15}N$ values in OM.

Acid pre-treatment methods: The "free for all"

In the natural environment, carbon is commonly considered in two major forms—organic and inorganic (OC and IC). Both forms can act as a contaminant in the measurement of the other due to their distinctive isotopic signatures (e.g., IC is assumed to be enriched in ^{13}C relative to OC: Hoefs, 1977; Sharpe, 2007). Therefore, the accurate determination of C/N and $\delta^{13}C$ of OM necessarily involves the removal of IC from the sample material. This is commonly achieved by acid pre-treatment. A number of fundamentally different acid pre-treatment methods exist, within which a range of acid reagents and strengths, types of capsule and reaction temperatures are used. There is no consensus on "best practice". An inherent, and widely unrecognized, assumption of these acid pre-treatment methods is that their effect on sample OM is either negligible or at least systematic (and small), implying that, within instrument precision, all measured values should be indistinguishable from one another regardless of the method followed. The type and strength of the acid reagent, and type of capsule the sample is combusted in, are assumed to have no effect on measured values. However, these assumptions have hitherto never been systematically investigated, implying that the scientific approach remains to be validated.

We examined three common acid pre-treatment methods for the removal of IC in OM: (1) Rinse Method: Acidification followed by sequential water rinse, the treated samples from which are combusted in tin (Sn) capsules (e.g., Midwood and Boutton, 1998; Ostle et al., 1999; Schubert and Nielsen, 2000; Galy et al., 2007); (2)

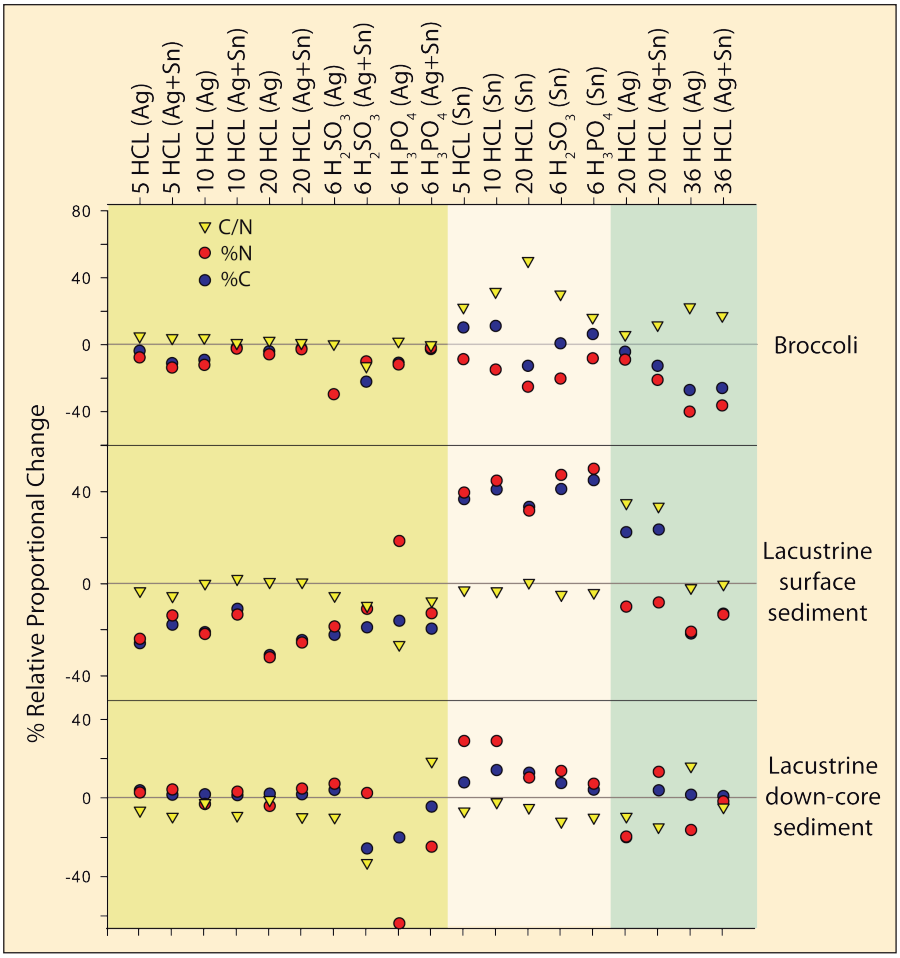

*Figure 1: Relative offset in %C (**blue circles**), %N (**red circles**) and C/N (**yellow triangles**) for a selection of materials sampled (Details of additional samples in Brodie et al., 2011a), and all combinations of acid pre-treatment methods (varying concentrations of HCl, H_2SO_3 and H_3PO_4). Broccoli was calculated relative to known values. Of note, broccoli C/N results suggest either aquatic (<10) or aquatic/terrestrial (>10) origin. The lacustrine surface sediment (Newstead Abbey Lake, Nottingham, UK) and lacustrine down core sediment (Lake Tianyang, South China) were calculated relative to their overall means from all measured acidified samples. Background shading represents pre-treatment method: Yellow = capsule, white = rinse, green = fumigation (figure modified from Brodie et al., 2011a).*

Capsule Method: In-situ acidification in silver (Ag) capsules (e.g., Verardo et al., 1990; Nieuwenhuize et al., 1994a, b; Lohse et al., 2000; Ingalls et al., 2004); and (3) Fumigation Method: Acidification by exposure of the sample to an acid vapor in silver (Ag) capsules (e.g., Harris et al., 2001; Komada et al., 2008). $\delta^{15}N$ is often measured from untreated sample aliquots weighed directly into Sn capsules, assuming negligible influence of inorganic nitrogen (e.g., Müller, 1977; Altabet et al., 1995; Schubert and Calvert, 2001; Sampei and Matsumoto, 2008). However, the application of "dual-mode" isotope analyses (the simultaneous measurement of C/N, $\delta^{13}C$ and $\delta^{15}N$ from the same pre-treated sample; e.g., Kennedy et al., 2005; Jinglu et al., 2007; Kolasinski et al., 2008; Bunting et al., 2010) is increasing. It was therefore also necessary to test whether acid pre-treatment had an effect on $\delta^{15}N$ results. Hydrochloric (HCl), sulfurous (H_2SO_3) and phosphoric (H_3PO_4) acid, at varying strengths have been compared (e.g., Kennedy et al., 2005; Brodie et al., 2011a).

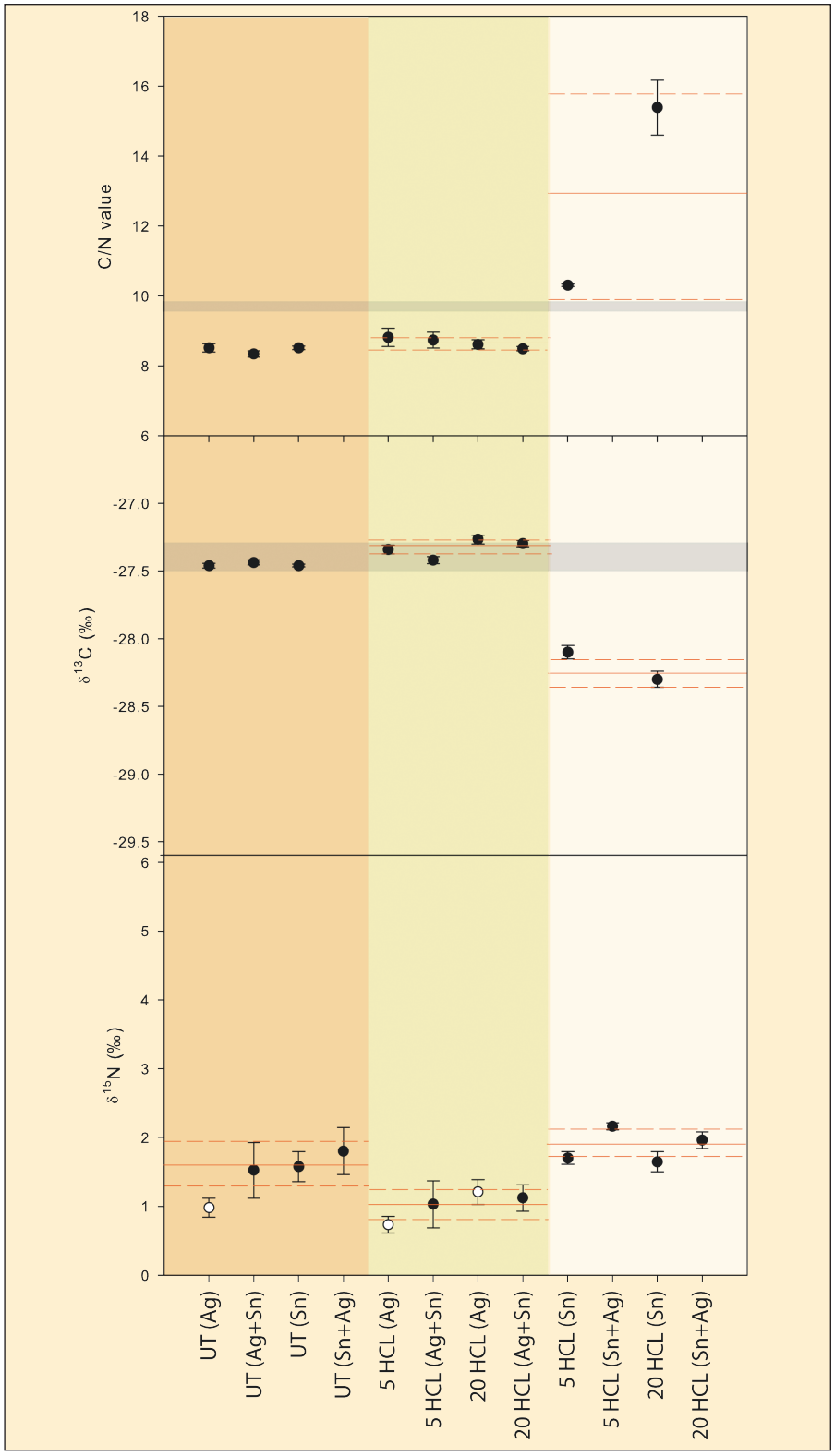

Figure 2: Broccoli C/N, $\delta^{13}C$ and $\delta^{15}N$ values for each pre-treatment method showing that measured C/N, $\delta^{13}C$ and $\delta^{15}N$ values vary in a non-linear, unpredictable manner within and between acid pre-treatment methods. Horizontal red lines indicate mean values for each method, and perforated red lines 1σ. Background shading represents pre-treatment method: Yellow = capsule, white = rinse, orange = untreated. Horizontal gray shaded bars represent known values. Error bars are calculated as standard deviation (1σ) of triplicate measurements. Unfilled circles represent samples analyzed in Ag capsules only (figure modified from Brodie et al., 2011b).

Non-linear, unpredictable bias to organic matter

Measured C/N, $\delta^{13}C$ and $\delta^{15}N$ values vary in a non-linear, unpredictable manner within (capsule type and acid reagent) and between ("capsule", "rinse" and "fumigation") acid pre-treatment methods (Fig. 1 and 2). In addition, the coherency of any one method or acid reagent is highly variable between the materials tested (i.e., high variability in accuracy and precision). This suggests that the measured C/N, $\delta^{13}C$ and $\delta^{15}N$ values of OM are not only dependent on environmental process, but also on analytical procedure, reducing the reliability of the data to the point of questioning the strength of the subsequent interpretation. Across all of the materials and pre-treatment methods tested, biases in C/N were in the range of 7 – 113; $\delta^{13}C$ in the range of 0.2 – 7.1 ‰; and $\delta^{15}N$ in the range of 0.2 – 1.5 ‰, resulting directly from bias to sample OM by acid treatment and in some instances residual IC (see Brodie et al., 2011a, b for a detailed discussion). The range and magnitude of these treatment-induced biases indicate that the assumption that there is negligible or systematic effect from acid pre-treatment is seriously flawed.

The range and magnitude of these biases are influenced by a number of factors. For example, %C and %N can be artificially concentrated by weight in the "rinse" method due to a loss a fine colloidal materials in the discarded supernatant; and C/N, $\delta^{13}C$ and $\delta^{15}N$ values can be biased due to loss of fine colloidal organic in the supernatant and solubilization of OC (Brodie et al., 2011a). These values can similarly be influenced in the "capsule" and "fumigation" methods due to volatilization of OC and residual IC. Furthermore, the type of acid reagent (e.g., HCl, H_2SO_3 or H_3PO_4) and strength of acid reagent (e.g., 5% HCl, 10% HCl or 20% HCl) within and between pre-treatment methods can affect the accuracy and precision of measured values. In addition, the capsule within which the sample is combusted can influence results due to the fundamental difference in combustion temperatures (Sn is 232°C and Ag is 962°C). Sample size, C and N homogeneity and the type, amount and nature of OM, can further influence the analysis. The underlying mechanisms causing these biases, however, remain unclear.

Implications for interpretation of C/N, $\delta^{13}C$ and $\delta^{15}N$ values

Bias by acid pre-treatment on OM can significantly undermine C/N values as indicators of OM provenance. For example, Figures 1 and 2 show that although broccoli (*Brassica oleracea*) is a terrestrial C_3 plant, an aquatic or aquatic/terrestrial combination could be concluded from the data, depending upon the method and/or acid reagent (see Brodie et al., 2011a). In addition, C/N values can also vary considerably depending on whether they are calculated with %N from treated or untreated sample aliquots (see Brodie et al., 2011a, b). For $\delta^{13}C$, biasing in the range of 0.2 – 7.1‰ can undermine C_3 vs. C_4 plant type interpretations, and together with C/N undermine bi-plot interpretations of C/N, $\delta^{13}C$ and $\delta^{15}N$ values. This clearly demonstrates that the data are inherently unreliable as a function of the analytical approach. Although the underlying mechanisms require further research, it is clear the biases represented here across a range of terrestrial and aquatic, modern and ancient organic materials has direct implications for paleo reconstructions: understanding and reducing the uncertainty on the data is an essential prerequisite for reliable interpretations and reconstructions.

Concluding Remarks

The systematic comparisons of Brodie et al. (2011a, b) clearly demonstrate non-linear and unpredictable biasing of OM due to acid pre-treatment, and concomitantly indicate that complete IC removal (the purpose of acid pre-treatment) is not guaranteed. It is concluded that these biases are inherently not correctable but inevitable, and have a direct consequence for the accuracy and precision of measured values (i.e., significantly greater than instrument precision). Moreover, environmental interpretations of the data in both modern and paleo systems could be highly questionable.

Acknowledgements

The author is grateful to J. Casford, J. Lloyd, Z. Yongqiang, T. Heaton, M. Bird and M. Leng for their support and discussions. Financial support came from the NERC through PhD studentship (NE/F007264/1), a NERC isotope Facility grant (IP/1165/0510), and the Dudley Stamp Memorial Fund.

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Extending glacier monitoring into the Little Ice Age and beyond

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Reconstructions of glacier front variations based on well-dated historical evidence from the Alps, Scandinavia, and the southern Andes, extend the observational record as far back as the 16th century. The standardized compilation of paleo-glacier length changes is now an integral part of the internationally coordinated glacier monitoring system.

Glaciers are sensitive indicators of climatic changes and, as such, key targets within the international Global Climate Observing System (GCOS, 2010). Glacier dynamics contribute significantly to global sea level variations, alter the regional hydrology, and determine the vulnerability to local natural hazards. The worldwide monitoring of glacier distribution and fluctuations has been well established for more than a century (World Glacier Monitoring Service, 2008). Direct measurements of seasonal and annual glacier mass balance, which are available for the past six decades, allow us to quantify the response of a glacier to climatic changes. The variations of a glacier front position represents an indirect, delayed, filtered and enhanced response to changes in climate over glacier-specific response times of up to several decades (Jóhannesson et al., 1989; Haeberli and Hoelzle, 1995; Oerlemans, 2007).

Regular observations of glacier front variations have been carried out in Europe and elsewhere since the late 19th century. Information on earlier glacier fluctuations can be reconstructed from moraines, early photographs, drawings, paintings, prints, maps, and written documents. Extensive research (mainly in Europe and the Americas) has been carried out to reconstruct glaciers fluctuations through the Little Ice Age (LIA) and Holocene (e.g., Zumbühl, 1980; Zumbühl et al., 1983; Karlén, 1988; Zumbühl and Holzhauser, 1988; Luckman, 1993; Tribolet, 1998; Nicolussi and Patzelt, 2000; Holzhauser et al., 2005; Nussbaumer et al., 2007; Zumbühl et al., 2008; Masiokas et al., 2009; Nesje, 2009; Holzhauser, 2010; Nussbaumer and Zumbühl, 2011). However, the majority of the data remains inaccessible to the scientific community, which limits the verification and direct comparison of the results. In this article, we document our first attempt towards standardizing reconstructed glacier front variations and integrating them with in situ measurement data of the World Glacier Monitoring Service (WGMS).

Standardization and database

The standardization of glacier front variations is designed to allow seamless comparison between reconstructions and in situ observations while still providing the most relevant information on methods and uncertainties of the individual data series. The standardized compilation of in situ observations is straightforward: the change in glacier front position is determined between two points in time and supplemented by information on survey dates, methods and data accuracies. The reconstruction of paleo-glacier front positions and their dating is usually more complex and based on multiple sources

of evidence. Spatial uncertainty can arise from ambiguous identification of the glacier terminus, while temporal uncertainty is associated with the dating technique used in each case. A good example is the use of oil paintings, where it is important to distinguish between the time of first draft (e.g., a landscape drawing in the field) and production of the painting itself, which could happen several years later.

The concept of integration of reconstructed front variations into the relational glacier database of the WGMS was jointly developed by natural and historical scientists. The glacier reconstruction data are stored in two data tables. The first table contains summary information of the entire reconstruction series including a figure of the cumulative length changes, investigator information, and references. The second table stores the individual glacier front variation data, minimum and maximum glacier elevation, and metadata related to the reconstruction methods and uncertainties. The metadata are stored in a combination of predefined choices of methods and open text fields. This ensures a standardized description of the data, but also provides space for individual remarks. Both data tables are linked by a unique numeric glacier identifier to the main table of the WGMS database with general information of the present-day glacier. This database relationship enables the direct comparison of reconstructed with observed front variations. Figure 1 shows an example for the Mer de Glace glacier with the sum of available meta-information stored within the database.

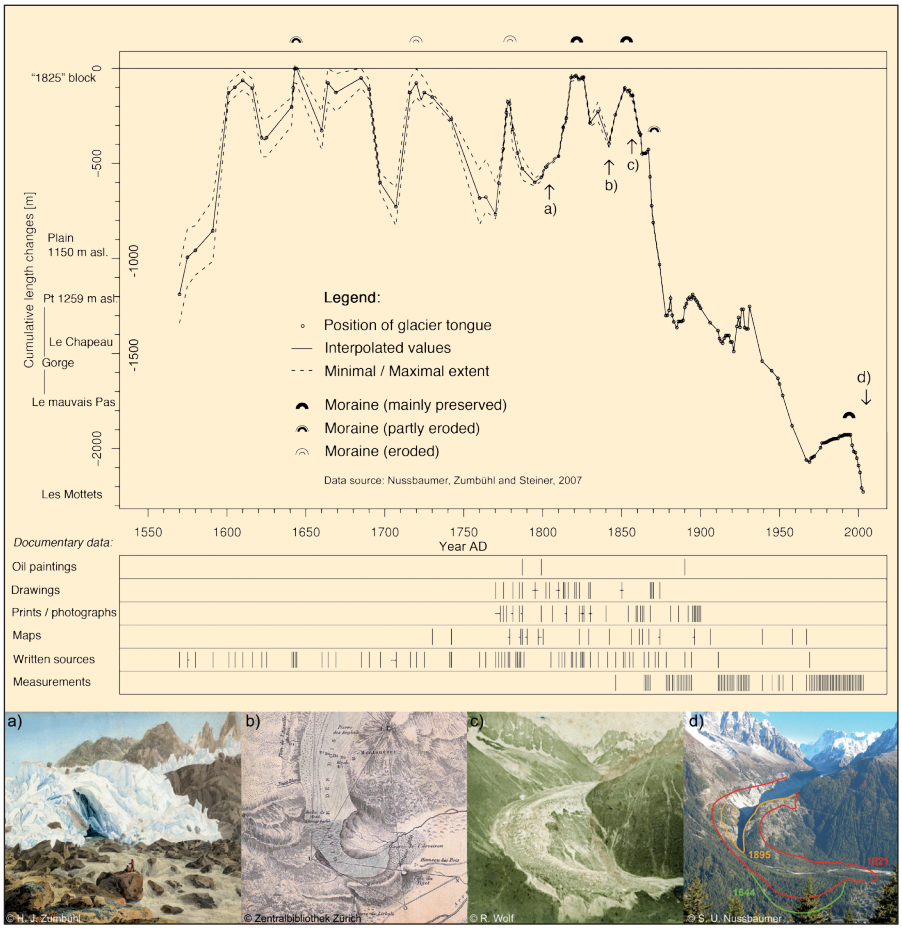

*Figure 1: Fluctuations of the Mer de Glace, France, during and following the LIA, reconstructed from a variety of sources (Nussbaumer et al., 2007). Length changes (relative to AD 1644 = maximum of LIA) were derived from documentary data as shown in the compilation below the x-axis, where small horizontal lines indicate uncertainties concerning the date of the document. Landmarks are indicated beside the y-axis. In situ measurements for the 1911–2003 period were obtained from the Laboratory of Glaciology and Geophysical Environment in Grenoble. Images a–d: The Mer de Glace (**a**) in 1804 drawn by Jean-Antoine Linck, (**b**) in 1842 mapped by James David Forbes, (**c**) in the 1850s photographed by Henri Plaut, and (**d**) in 2005 (Nussbaumer et al., 2007).*

Results and discussion

The WGMS database contains detailed inventory information of about 100,000 glaciers worldwide. In addition, in situ observations of frontal variations of 1,800 glaciers, mass balance data of 230 glaciers, and reconstructed frontal variations of the 26 glaciers mentioned below are now readily available in standardized and digital form. The reconstructed front variations extend the direct observations (mostly from the 20th century) by two centuries in Norway and by four centuries in the Alps and South America. Also available are moraines data back to the mid-Holocene. The direct comparison of long-term reconstructions with in situ observations reveals some striking features (Fig. 2).

The investigated glaciers in the western and central Alps show several periods of marked advances during the LIA, that are similar or even larger than LIA extent around AD 1850. Reconstructions reveal dramatic glacier advances that started in the late 16th century, overran cropland and hamlets, and reached maximum lengths at ca. AD 1600 and 1640 (Zumbühl, 1980; Nussbaumer et al., 2007; Steiner et al., 2008). Further maxima in glacier extent were reached around AD 1720, 1780, 1820 and 1850. After this last event, the direct measurement series show an impressive glacier retreat of 1-3 km, with intermittent minor re-advances in the 1890s, 1920s and between AD 1965 and 1985.

The historically based reconstructions for glaciers in southern Norway (Nussbaumer et al., 2011; Nesje, 2009) indicate that the maximum glacial extent of the LIA peaked around AD 1750 at Jostedalsbreen and in the late 1870s at Folgefonna. The reconstructed front variation series of Nigardsbreen (an outlet glacier of Jostedalsbreen) shows that the maximum LIA expansion occurred in AD 1748, and that it was preceded by a period of strong frontal advance that lasted (at least) 3-4 decades. Other sources report devastation of pastures by neighboring glaciers at that time (Nussbaumer et al., 2011). Direct observations at Nigardsbreen and other glaciers in southern Norway reveal a regional pattern of recent intermittent re-advances mainly during the 1990s. It is worthwhile to note that the extent of Nigardsbreen in the 17th century was similar to that of the present day (Nesje et al., 2008), and that the period of glacier re-advances in the 1990s is short (both in time and extension) considering the overall retreat of 1-4 km since the LIA maximum.

In southern South America, datable evidence for past glacier variations is most abundant in the Patagonian Andes. Despite recent efforts in this region and in other Andean sites to the north (Espizua, 2005; Espizua and Pitte, 2009; Jomelli et al., 2009; Masiokas et al., 2009), the number of chronologies of glacier fluctuations prior to the 20th century is still limited. In the southern Andes, most records indicate that glaciers were generally more extensive prior to the 20th century, with dates of maximum expansion ranging from the 16th to the 19th centuries. Based on the available evidence, Glaciar Frías (northern Patagonian Andes) probably contains the best-documented history of fluctuations since the LIA in southern South America, covering the period between AD 1639-2009.

Conclusions and outlook

Reconstructed LIA and Holocene glacier front variations are crucial for understanding past glacier dynamics and enable an objective assessment of the relative significance of recent glacier fluctuations (i.e., 20th and late 19th century changes) in a long-term context. The standardized compilation and free dissemination of reconstructed and in situ observed glacier fluctuation records offer several benefits for both data providers and users. Their incorporation within the international glacier databases guarantees the long-term availability of the data series and increases the visibility of the scientific results (which in historical glaciology are often the work of a lifetime). Furthermore, the database facilitates comparisons between glaciers and between different methods, and opens the field to numerous scientific studies and applications.

As the next steps of this new initiative, we aim to: (1) integrate a greater number of time series, (2) incorporate records that cover the entire Holocene, and (3) include data from other regions (e.g., the Himalayas, North America). Ideally, the growing new dataset will facilitate collaboration between the glacier monitoring and reconstruction communities and become an additional tool for the comparison of present-day to pre-industrial climate changes. This should eventually result in new scientific findings (e.g., related to the climatic interpretation of past and present glacier fluctuations).

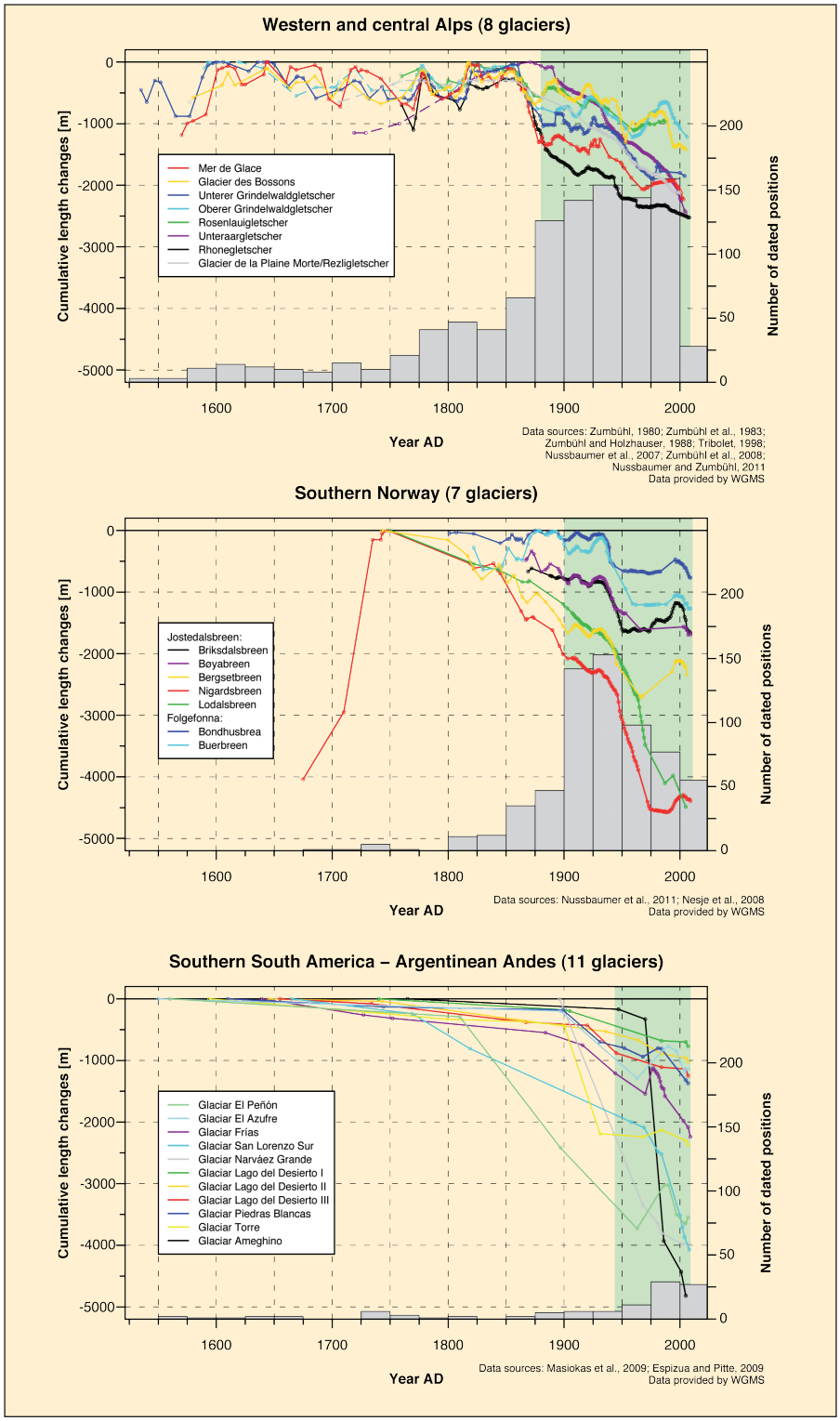

Figure 2: Reconstructed and measured cumulative glacier front variations in the Alps, Norway and southern South America since the Little Ice Age (LIA). The zero value on the y-axis corresponds to the most extensive front position of glaciers during the LIA. The period with direct front measurements is indicated by light green background. Gray vertical bars show the total number of available data for the selected glaciers. Note the significantly lower number of data points available from the Southern Andes.

International glacier databases: Requesting and submitting data

Worldwide collection of standardized data on the distribution and changes of glaciers has been internationally coordinated since 1894. Today, the World Glacier Monitoring Service (www.wgms.ch) is in charge of the compilation and dissemination of glacier datasets in close collaboration with the US National Snow and Ice Data Center (www.nsidc.org) and the Global Land Ice Measurement from Space initiative (www.glims.org) within the framework of the Global Terrestrial Network for Glaciers (www.gtn-g.org).

For available data or guidelines on data submission please check these websites and/or contact us directly: wgms@geo.uzh.ch

Acknowledgements

We are grateful to Wilfried Haeberli and Heinz Wanner for their valuable assistance. This work has been supported by the Swiss National Science Foundation (grant 200021-116354). The collection and processing of data from Argentinean glaciers was supported by Agencia Nacional de Promoción Científica y Tecnológica (grants PICT02-7-10033, PICT07-03093 and PICTR02-186), and the Projects CRN03 and CRN2047 from the Inter American Institute for Global Change Research (IAI).

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Proximal trigger for late glacial Antarctic circulation and CO_2 changes

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The Brazil Current may have played a key role in shunting heat towards the Antarctic during the meridional overturning shutdown at the end of the last ice age.

The remarkable relationship between late Pleistocene carbon dioxide variations and Antarctic temperatures has been as inscrutable as the faint smile of a stone Buddha. Recently, a string of papers provide promise of unlocking the secrets of that relationship by shedding light on ocean circulation/carbon dynamics involving the key first phase of carbon dioxide rise at the end of the last glacial period. During an interval that has long been termed the "Late Glacial", and is broadly correlative with Heinrich Event 1 (H1, ~17.8-14.6 cal ka), significant carbon reservoir changes at the time of the first major CO_2 rise have been related to Antarctic ocean circulation changes (Marchitto et al., 2007; Anderson et al., 2009; Rose et al., 2010). In turn, these changes link to variations in North Atlantic Deep Water (NADW) overturning rate (Anderson et al., 2009; Toggweiler and Lea, 2009), which cause a see-saw in sea surface temperature (SST) patterns between the North and South Atlantic (Crowley, 1992; Toggweiler and Lea, 2009).

In this note, I point out that an overlooked feature of the NADW see-saw provides additional insight into the nature of the "bolt of warmth" that characterized Antarctic temperature change at this time. As noted in Crowley (1992), shutdown of NADW production "banks" about 1 petawatt (PW) of heat in the South Atlantic, which would otherwise be exported north of the equator to compensate for southward outflow of NADW across the equator. An early modeling study indicates that adjustment of the South Atlantic to this shutdown involves an enormous 1 PW increase in heat transport (Maier-Reimer et al., 1990; Fig. 1A), which is shunted southward into higher latitudes via the Brazil Current, i.e., the western boundary surface current of the South Atlantic (Fig. 1B).

It is remarkable that the South Atlantic model heat transport for the perturbation run is greater than for the Gulf Stream in the control run (Fig. 1A). In a sense the deglacial Brazil Current vertical section and transport is dynamically similar to the Gulf Stream at present—the strong flow is required to compensate for both the increased northward transport of Antarctic Bottom Water and the decreased southward transport of both NADW and North Atlantic Intermediate Water. Enhanced Southern Ocean inflow into Atlantic Basins is supported by geochemical assays (Negre et al., 2010).

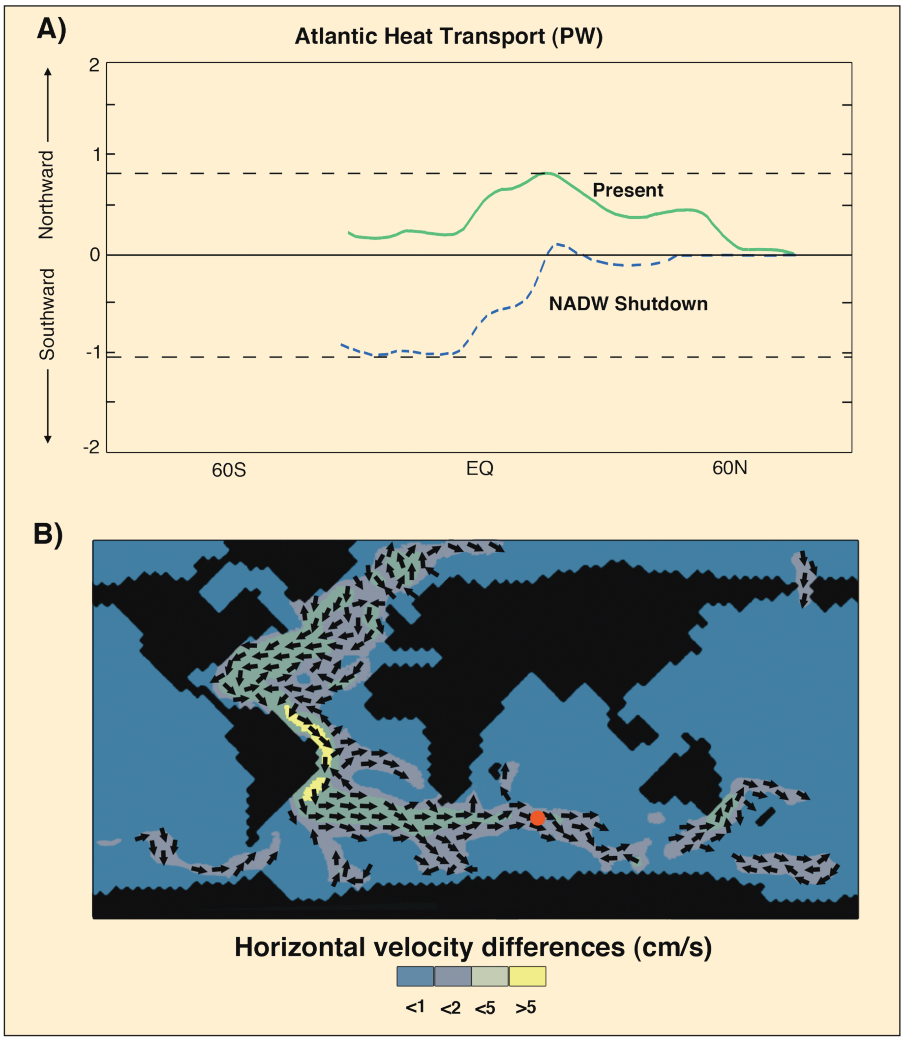

*Figure 1: **A**) Comparison of zonal poleward ocean heat transport (1 PW = 10^{15} Watts) in the Atlantic sector for the model runs illustrated in Figure 2. Figure from Maier-Reimer et al., 1996. **B**) Difference of surface current (25 m) between the control and perturbed run, illustrating the effects of an NADW shutdown (in this case due to an open central American isthmus) on global ocean circulation (Figure from Maier-Reimer et al., 1990). Red dot refers to location of sub-Antarctic core illustrated in Figure 2.*

In the illustrated model example, convergence of the stronger Brazil Current with sub-Antarctic waters leads to stronger currents (Fig. 1B) and presumably enhanced convergence in the frontal zone (cf., Marchitto et al., 2007), with changes extending zonally downstream at least as far as the eastern Indian Ocean. These changes are likely responsible for the observed zonal changes in the Antarctic Circumpolar Current (cf., Anderson et al., 2009). The heat injection, along with a sea-ice melt feedback, likely explains the long-known (Hays et al., 1976) rising temperatures in the sub-Antarctic at the time of H1 (e.g., Fig. 2), and the parallel rise recorded in Antarctic ice cores. Additional adjustments can be expected from the warming effects of surface warming on the Antarctic overturning circulation, with potential implications for possible tapping of the deeper ocean glacial carbon reservoir in the Southern Ocean (Toggweiler and Samuels, 1995; Rose et al., 2010). It is conceivable that warmer surface waters could have prevented recharge of very cold and saline deep Antarctic waters, leading to a transient enhanced vertical stratification (tidal mixing would probably break down

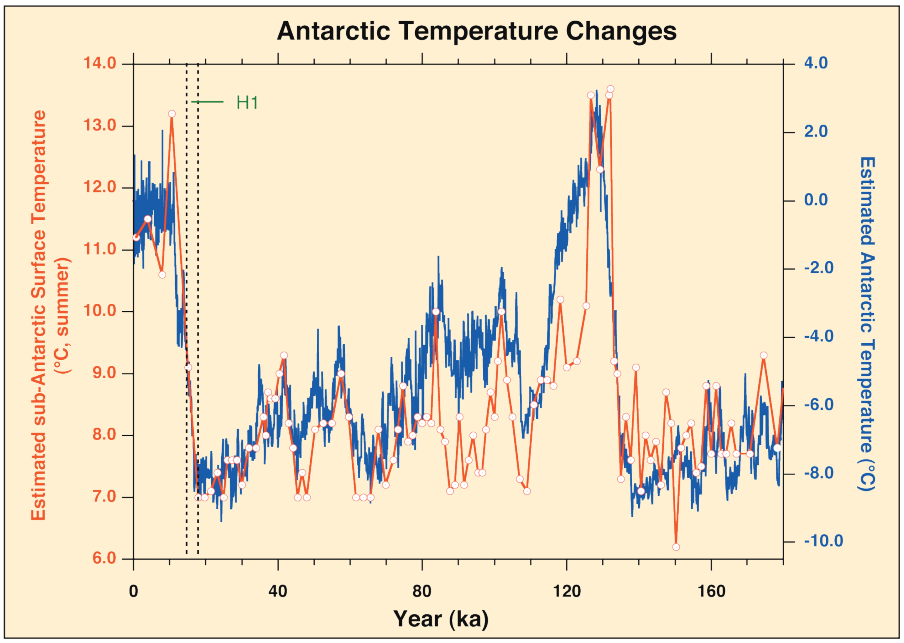

Figure 2: Comparison of the sub-Antarctic record (core RC11-120; Hays et al., 1976), using higher-resolution sampling from Martinson et al. (1987) and converted to an updated marine chronology (Lisiecki and Raymo, 2005), with the Vostok deuterium isotope record and ice core GT4 chronology (Petit et al., 1999). H1 interval is Heinrich Event 1.

this barrier after a few hundred years; R.-X. Huang, pers. comm.).

It therefore appears that the Brazil/Malvinas-Falkland Convergence (where the southerly vectors of the Brazil Current merge with the easterly flow of the Subantarctic in Figure 1B) may be the pressure point where the heat accumulated in response to stalled Atlantic overturning circulation is injected into southern high latitudes, thereby driving the planet into deglaciation through positive feedbacks from ocean-circulation releasing carbon stored in the deep ocean around Antarctica. Closer inspection of data from the Malvinas/Falkland region might provide enhanced insight into kinematics of this process. The postulated response should also be testable with the present generation of coupled climate/carbon models and would be much more realistic if started from a glacial base state. The transient model response would be especially intriguing to examine, for it could provide fascinating insight into the time-space evolution of the heat package injected into the sub-Antarctic region and the partitioning of the heat between the ocean and the atmosphere (Seager et al., 2002).

Even though the model results invoked herein represent an uncoupled run from twenty years ago, I suggest that the system response is so constrained by conservation of volume arguments—overturning shutdown in the north blocking heat export from the South Atlantic—that newer model simulations are likely to respond in the same manner. Elements of this argument can even be traced back to (or at least anticipated in) Henry Stommel's classic explanation for differences in strength of the Gulf Stream and Brazil Current (Stommel, 1965). His interpretation was certainly supported by the 1990 simulation (Maier-Reimer et al., 1990).

Data

Data for Fig. 2 from Martinson et al. (1986) and NOAA/NGDC Paleoclimatology website.

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Paleoclimate Reconstruction Challenge: Available for participation

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The last millennia Paleoclimate Reconstruction (PR) Challenge is a model-based venue for experimenting with climate reconstruction methods. The overall idea has been described before (Ammann, 2008) and a modified version of the Challenge is now "live" and available for participation. It is designed to engage the scientific paleoclimate community in examining its methods in a common framework for the purpose of evaluating their relative strengths and weaknesses. A key design element of the Challenge is to allow true "apples to apples" comparison of reconstruction methods across identical experimental platforms. The ultimate goal is to improve last two millennia PR methods so that paleoclimate science can offer the best possible information to help understand both natural and anthropogenic climate change.

The Challenge is organized around 4 themes. In each theme, a set of long (1,000+ yrs) forced global climate model (GCM) integrations is used to formulate simulated paleoclimate proxy data (pseudo-proxies) and to provide pseudo-instrumental climate data for calibration and examination of reconstruction fidelity. Several different GCM runs provide a range of simulated climate evolutions that present different reconstruction scenarios. In each Theme, the reconstruction method used is at the prerogative of the participants.

Theme 1: Reconstruction of Northern Hemisphere temperature with strongly limited proxy data set (implemented)

This theme focuses on the capacity of a very limited set of proxy data sites to enable reconstruction of hemispheric (20-90° N) mean annual temperature. The pseudo-proxy data-set consists of 14 extratropical tree-ring-chronology sites in the Northern Hemisphere (Fig. 1). It is designed to mimic the dataset used by Esper et al. (2002).

Theme 2: Reconstruction of Northern Hemisphere temperature and spatial patterns with a richer, but still somewhat limited proxy data set (in process of implementation)

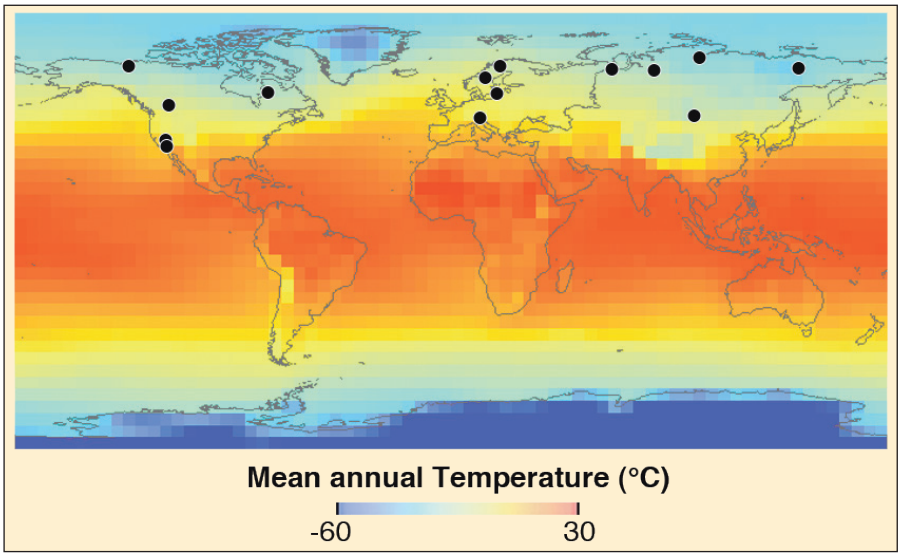

Figure 1: Map showing the location of the 14 simulated extratropical tree-ring-chronology sites (black dots) in the Northern Hemisphere that were used in Theme 1 for the reconstruction of Northern Hemisphere temperature with strongly limited proxy data set. Underlying colors represent average annual temperatures (1961-1990). Figure by W. Goss, NOAA-NCDC Paleoclimatology/WDC for Paleoclimatology).

This theme focuses on the capacity of a less limited set of proxy-data sites to enable reconstruction of hemispheric (again defined as 20-90°N) mean annual temperature and spatial temperature patterns. The pseudo-proxy data set consists of 66 tree-ring sites in the Northern Hemisphere at >40°N and is designed to mimic the dataset used by D'Arrigo et al. (2006).

Theme 3: Reconstruction of Northern Hemisphere temperature and global spatial patterns using a relatively rich proxy data set (to be implemented)

This theme focuses on the capacity of a richer and more spatially diverse set of proxy data sites to enable reconstruction of hemispheric (here defined as 0-90°N) mean annual temperature and global spatial temperature patterns. The pseudo-proxy data set contains 104 sites from different archives spread across the globe. It is designed to mimic the dataset used by Mann et al. (1998) and in numerous reconstruction simulation experiments (e.g., Mann et al., 2007; Smerdon et al., 2010).

The above three themes are designed to explore how proxy richness and spatial extent affect reconstruction fidelity of the Northern Hemisphere mean temperature (Themes 1-3), and of spatial temperature patterns in the Northern Hemisphere (Theme 2) and globally (Theme 3).

Theme 4: Reconstruction of spatial drought patterns (currently in development)

This theme is still under development; it will be based on a pseudo-proxy dataset designed to mimic that used in the North American Drought Atlas (NADA; cf., Cook et al., 2004). A timetable for implementation is being developed.

The Paleoclimatology Branch of NOAA's National Climatic Data Center/World Data Center for Paleoclimatology is providing the simulated proxy and instrumental data sets of the PR-Challenge and is also archiving the contributed reconstructions so that they can be cross-compared: www.ncdc.noaa.gov/paleo/pubs/pr-challenge/pr-challenge.html.

The PR-Challenge implementation team consists of Nicholas Graham, Rosanne D'Arrigo, Kevin Anchukaitis, Eugene Wahl, and David Anderson. We gratefully acknowledge Edward Cook for valuable ideas and encouragement, and Caspar Ammann for his inception of the PR Challenge project. Tree-ring pseudo-proxy formulation used the "VS-Lite" tree growth model developed by Suz Tolwinski-Ward and collaborators (Tolwinski-Ward et al., 2010).

The PR-Challenge is sponsored by NOAA's Office of Oceanic and Atmospheric Research/Climate Program Office (Climate Change Data and Detection Program, grant NA08OAR4310732) and the PAGES/CLIVAR Intersection.

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PAGES Calendar 2010/2011

4th PALSEA Workshop: Ice sheet modeling-consistency with RSL, ice-sheet extent and climate data, GIA and GCM modeling
24 - 26 Aug 2011 - Boston, USA
http://www.pages-igbp.org/calendar/upcoming

Developing new techniques and core locations to constrain the history of the Greenland Ice Sheet
20 Oct 2011 - Corvallis, USA
http://www.pages-igbp.org/calendar/upcoming

Processes and Quaternary history of dust dynamics: Low-latitude records and global implications
31 Oct - 03 Nov 2011 - Bremen, Germany
http://www.pages-igbp.org/calendar/upcoming

Continental drilling in the East African Rift: Strategic planning workshop
14 - 16 Nov 2011 - Providence, USA
http://www.pages-igbp.org/calendar/upcoming

3rd PAGES Varves Working Group workshop
21 - 23 Mar 2012 - Manderscheid, German
http://www.pages-igbp.org/workinggroups/varves-wg

4th PIGS workshop - Past Interglacials: Forcing and response
2 - 5 Jul 2012 - Cambridge, UK
http://www.pages-igbp.org/calendar/upcoming

Arctic2k: Synthesizing paleoclimate data to assess Arctic climate change

Meeting of the PAGES Arctic2k Working Group – San Francisco, USA, 11-12 December 2010

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The Arctic has witnessed increased warming in comparison to other parts of the globe. Due to this amplification, the Arctic is a key region for climate studies, and is potentially central in elucidating the processes that govern the 19th and 20th century global warming. The PAGES Arctic2k Working Group was initiated to research the climate of the Arctic region within the past 2000 years. The Working Group had its second meeting in San Francisco, which was attended by 10 participants.

To date, much of the Working Group's efforts have been focused on generating high quality, high-resolution proxy records from the Arctic region. At this meeting, a new Icelandic glacier proxy record was introduced in addition to a new type of ice cover proxy record. The group has also aspired to collect a comprehensive list of available records and information about their nature and quality. Figure 1 depicts the combined locations of proxy records used in recent multiproxy studies, as well as records available from the NOAA Paleoclimatology database.

The criteria for the inclusion of specific proxy records were thoroughly discussed and formulated to ensure selection of only high quality proxy records, to avoid swamping the collection and synthesis processes with low quality records. It was decided that the criteria and template for proxy metadata should be offered to other PAGES 2k Regional Groups, so that if adopted, the proxy lists of all 2k Regional Groups would be compatible and the collection efforts need not be replicated for a global synthesis.

The statistical problems of climate reconstructions were also discussed. The proxy records tend to be spatially clustered, which can cause overrepresentation of the clustered areas in the synthesis. Another problem discussed is that the proxy records do not directly record a certain climate parameter and transforming the proxy data to, for example, temperature is often not straightforward. Existing reconstruction methods were briefly listed and their assumptions were discussed.

The temporal uncertainty was identified as possibly the largest cause of uncertainty in proxy reconstructions. As annually resolved proxies do not have the necessary temporal and spatial coverage, proxies with uncertain dates are necessary for the inference of climate parameters, especially before 1000 AD. The temporal uncertainty has to be accounted for in the overall uncertainty of climate reconstructions, which poses methodological problems.

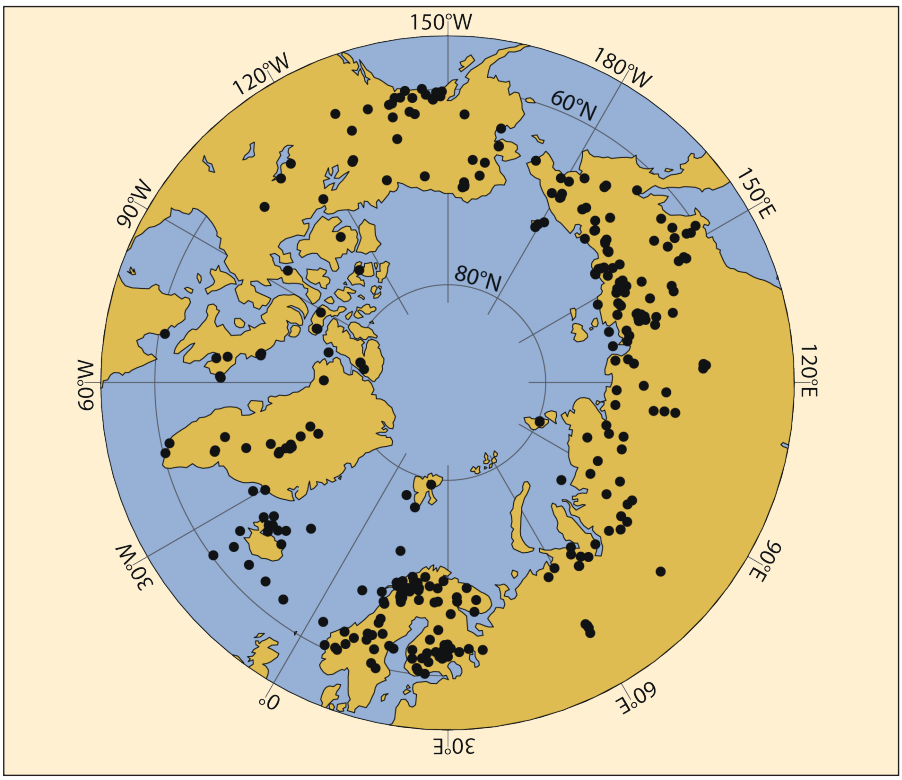

Figure 1: Spatial coverage of proxy records that extend back to 1500 AD in the Arctic. Proxy locations are a combination from Mann et al., 2008; Kaufman et al., 2009; Ljungqvist, 2010; Sundqvist et al., 2010; and from the NOAA Paleoclimatology database.

A number of scientific questions emerged during the workshop, ranging from the spatiotemporal patterns of the Arctic climate to the utilization of the future synthesis produced by the Working Group. The questions were subdivided into four milestones that form the outline of future research. The first milestone involves inferring the spatial and temporal variability of the Arctic climate, and how they relate to the instrumental records of the recent past. The second milestone tackles the abrupt events recorded in the history of the Arctic, with special focus on the frequency of such events and to the possible thresholds that were exceeded before these events. The third milestone combines the knowledge of the two previous ones and seeks to answer questions about the long-term modes of the Arctic climate variability, and how much of the variability can be explained by internal adjustment of the climate system versus the external forcings (such as changes in solar irradiance and volcanic activity). The final milestone aims at involving people from the climate modeling community to use the obtained results to improve and enhance the climate models and to increase the accuracy of future predictions.

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2nd Australasia2k Network workshop: Data synthesis and research planning

Meeting of the PAGES Aus2k Working Group - Perth, Australia, 27–29 April 2011

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The goals of the 2nd Australasia2k (Aus2k) workshop were to discuss the feasibility of producing an Australasian-wide temperature reconstruction, and identify a series of sub-regional studies to form a special Aus2k issue of *Journal of Climate*.

The Vice-Chancellor of the University of Western Australia, Professor Alan Robson, opened the workshop highlighting the importance of understanding natural climate variability. The two sessions on the first day were an open symposium devoted to showcasing state-of-the-art research developments in each of the main high-resolution Australasian paleoarchives.

Ed Cook provided an overview of the three multi-millennial tree ring chronologies from Australia and New Zealand. He was followed by Janice Lough who reviewed the suite of Great Barrier Reef coral records and promising new work from the North West Australian coast into the Indian Ocean. Tas van Ommen then outlined the utility of using the eastern Antarctic Law Dome ice core to infer changes in Southern Ocean circulation and precipitation anomalies in southwestern Australia.

Around 120 paleoclimatologists, hydrologists, ecologists, oceanographers, agricultural scientists and various natural resources managers attended the symposium resulting in energized discussions during the sessions and the deliciously-catered breaks.

The afternoon session was the start of the closed program for the core Aus2k group to discuss the issues associated with observational and proxy-climate data. Ed Cook reminded the group of the importance of replication wherever possible and the implications of using misdated series to infer high frequency climate variations.

Meteorologist Ailie Gallant then outlined the potential and limitations of using observational gridded datasets available in Australasia. We learned that the high spatial coherence of temperature over Australia (which takes up the majority of the Australasian domain) means that less than ten observational stations can capture over 80% of variance in mean temperature over the region, providing they are randomly and evenly distributed. This is perhaps unsurprising given that continental Australia is predominately a very flat, arid continent.

The rest of the day was spent discussing how we reassess the climate sensitivity of the existing Australian database, perhaps exploiting the clear co-variations observed between rainfall and temperature in many part of the region. This involved examining a series of spatial field correlation maps for the records identified through the compilation of the Aus2k metadatabase (see example in Fig. 1).

Day 2 of the workshop focused on a range of relevant multi proxy analyses that have been published for North America, Asia, South America, Europe (Cook et al., 2004; Cook et al., 2010; Neukom et al., 2010a; Neukom et al., 2010b) or are currently in development, to achieve the Regional 2k Network's objectives (Australia, New Zealand and the Southern Hemisphere).

The group was shown a preliminary 500-year annually resolved summer temperature reconstruction that has been developed by Joelle Gergis and others at the University of Melbourne. The group discussed the issue of proxy selection and the feasibility of developing a continuous, non-geographically biased temperature reconstruction spanning the past millennium. We will now move forward with refinements generated by the group to produce an Aus2k temperature paper to provide our regional contribution to a broader Regional 2k Consortium paper.

In recognition of the fact that most of Australasia's paleoclimate records is comprised of decadal to multi-decadal sedimentary records, Scott Mooney gave an overview of the availability of the Australian material that spans the last 2000 years.

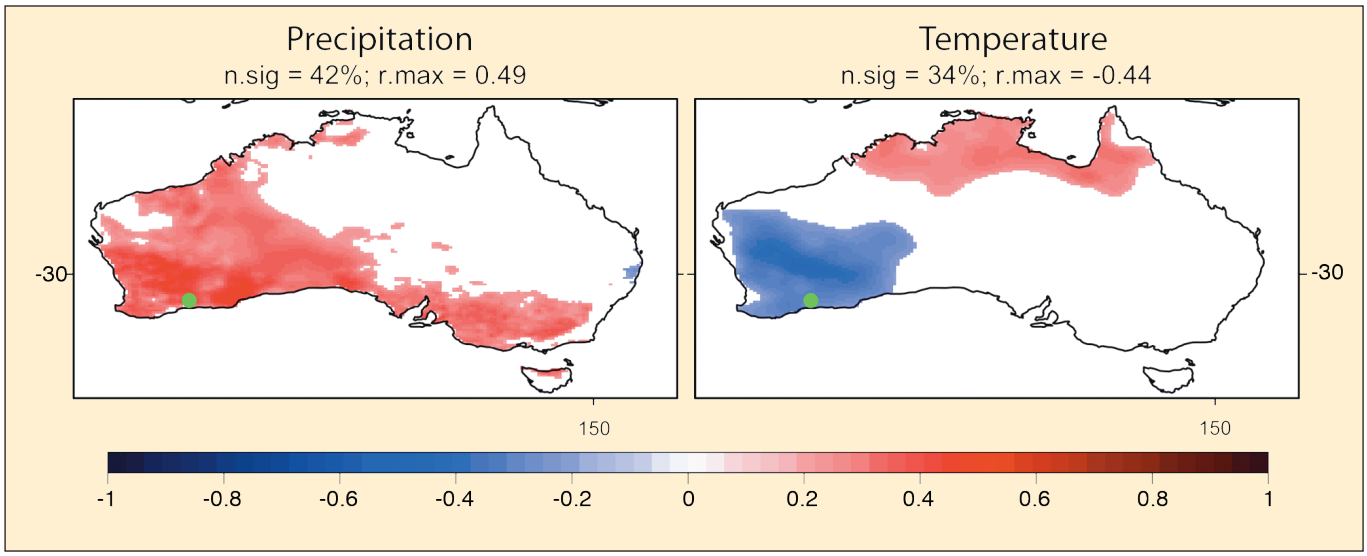

Figure 1: Spatial field correlation of the Cullen and Grierson (2009) Western Australian Callitris columellaris *tree-ring record with the Australian Bureau of Meteorology 0.05° x 0.05° (5 x 5 km) Australian Water Availability Project (AWAP) temperature grid for winter half year (June–November) temperature (right) and rainfall (left). Correlations calculated over the 1911–2005 period. Green circle indicates location of tree-ring record.*

Andrew Lorrey also illustrated a synoptic pressure reconstruction approach using speleothems and low resolution data. These reconstructions will form an important means of independently supporting low frequency trends and variability identified from the high-resolution material.

To round off the second day of presentations, Steven Phipps provided a thought-provoking discussion of the role of modeling in understanding the climate of the last 2000 years. He provided an example of evaluating the stability of regional teleconnections and influence of different climate forcings using simulations from the CSIRO Mk3L model.

The workshop wrapped up on a very productive note with the development of a proposed list of 15 papers for consideration in the *Journal of Climate* Aus2k special issue, and a clear direction forward to deliver Australasia's best available science for the Regional 2k global synthesis.

Acknowledgements

The meeting organizers would like to thank PAGES, Rio Tinto Iron Ore, the Australian Department of Climate Change and Energy Efficiency and the University of Western Australia.

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The first Euro-Med2k regional workshop: Review of current knowledge, available data and plans for multproxy integration

Alcalá de Henares, Spain, 22-24 November 2010

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Focus 2 (Regional Climate Dynamics) of PAGES places a strong emphasis on regional climate studies that consider past climate dynamics on seasonal to millennial timescales and (sub-) continental or ocean-basin spatial scales (PAGES, 2009). The first Europe/Mediterranean 2k (Euro-Med2k) regional meeting was held in Alcalá de Henares, close to Madrid, and brought together specialists working in different fields related to proxy data, statistical climate reconstructions and data modeling comparison. Discussions focused firstly on current knowledge and availability of documentary sources as well as on seasonally to multidecadally resolved terrestrial and marine archives (Fig. 1) covering the past 2000 years (2 ka) in

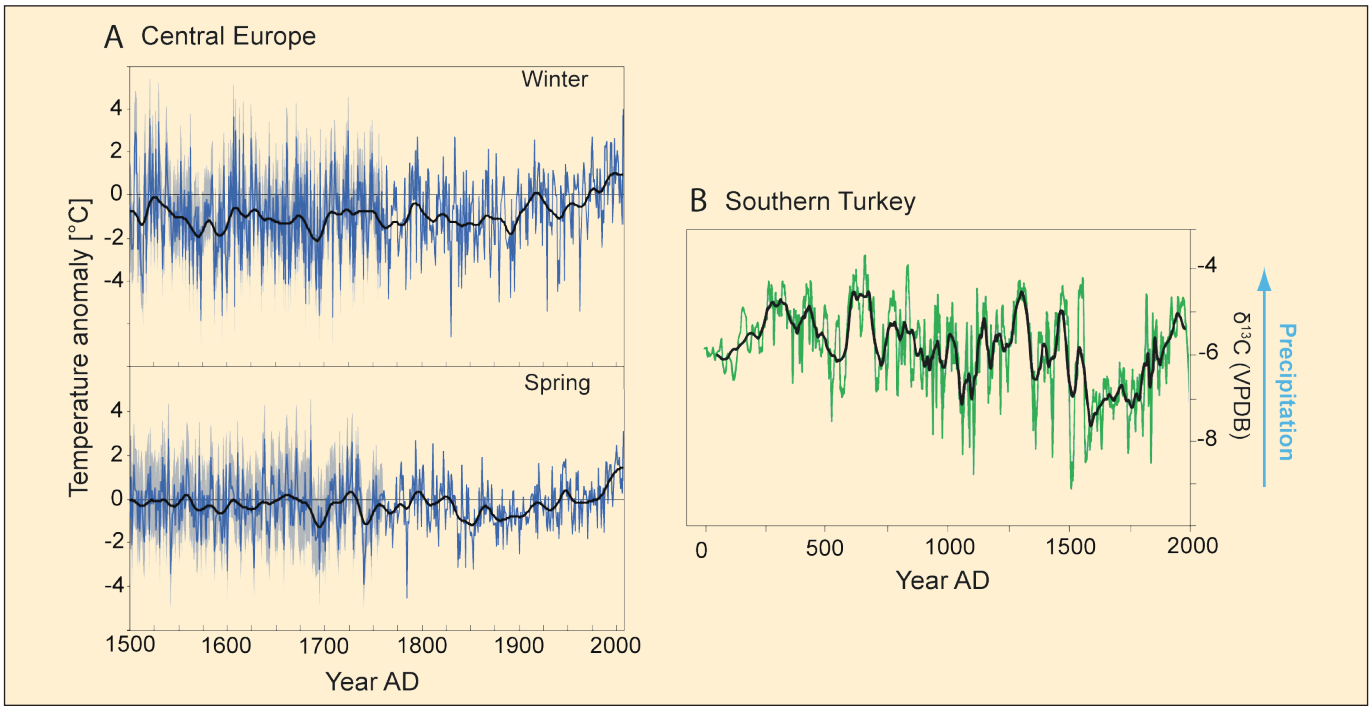

*Figure 1: **A**) Winter and Spring Central European temperature reconstructions AD 1500-2007 based on documentary indices 1500-1759 and instrumental measurements 1760-2007 (Dobrovolný et al., 2010). Temperatures are expressed as anomalies from the 1961-1990 average and completed with Gaussian low-pass filter (30 years window). The error bands are approximate 95% confidence intervals. **B**) Stalagmite $\delta^{13}C$ record of effective moisture from Kocain Cave in Southern Turkey (Göktürk et al., submitted).*

the European-Mediterranean region. The participants discussed proxy records with emphasis on their climatic interpretation and the suitability for their integration into the regional reconstruction. Particular issues that were addressed included the handling of differently resolved proxies, target variables, seasonality, preservation of low- and high-frequency variability, replication, "expert knowledge" and calibration/verification. An extended discussion took place on how proxy data should be most effectively collected. It was agreed that the community should collect only published data (using both raw and quantified analyses) from each of the different archives, with a full estimate of the uncertainties included. Importantly, objective criteria for the final selection of records must be developed prior to the generation of final statistically based reconstructions (in consultation with other regional 2k groups; criteria having been presented by two representatives of the Arctic2k group). Qualitative data will also be utilized to cross-check against the climate variability reconstructed from higher resolution records. As a starting point, the group was encouraged to develop a Euro-Med2k metadatabase on the project's website, to develop an inventory of the records that are currently available and/or being actively developed in the Euro-Med region. Discussions also focused on different statistical methods used in paleoclimatology that can integrate multiproxy data.

A better understanding of the strengths and weaknesses of established and new reconstruction methods and the behavior of different climate proxies was considered essential to reduce uncertainties and biases. A variety of available methods were presented including Bayesian hierarchical modeling and Neural Networks using pseudo-proxy data. These methods provide an estimate of the full covariance structure of the temperature and hydrological reconstructions, but need to be tested first using real proxy data from the Europe-Mediterranean region. A presentation provided new millennial-length coupled climate model results and ways to compare continental-scale multiproxy climate reconstructions with coupled paleoclimate model output.

The group agreed to write a peer reviewed paper including a comprehensive assessment of proxy data availability from the European-Mediterranean area, and a critical evaluation of their strengths, weaknesses, challenges and opportunities for climate reconstructions. To involve the wider community in sharing data and participating in the initiative, specialists on different archives will be approached. First results and a promotion of the initiative will be presented in the PAGES 2k session at the INQUA Congress in Bern in late July 2011. In parallel, data collected and published by the EU project MILLENNIUM (www.millenniumproject.net) and the ESF project MedClivar (http://www.medclivar.eu/) will be used to test different statistical methods. Preliminary reconstruction results from the European-Mediterranean area will feed a joint "2k Consortium" publication, (anticipated submission in late 2011). These results might contribute to the "regional assessment" of IPCC AR5. At a later stage, other initiatives of the group will include a data-model comparison paper using the new statistics-based reconstructions from Europe-Mediterranean covering the past 2 ka with new paleoclimate runs that will become available. The second Euro-Med2k workshop will be held in early 2012.

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Advancing North American climate field reconstructions: Data sources, methods development and comparisons

1st PAGES North America-2k Workshop, Flagstaff, USA, 8–10 May 2011

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The principal goal of the North America 2k (NAm2k) Working Group (WG) is to synthesize high-resolution, proxy-based climate reconstructions for North America for the past 2000 years. The motivation is to enhance our understanding of the patterns of natural variability of climate in North America and possible forcing mechanisms, and for comparison with high-resolution Earth System Models.

We assembled a group of climate and paleoclimate experts (see www.pages.unibe.ch/workinggroups/namerica2k for details of members) to provide an initial assessment of our capacity to carry out the task of producing a high-resolution reconstruction of key North American climate variables with at least a decadal resolution. The WG considered the following:

- Identification of the key paleoclimate time series available for analysis.
- Evaluation of available spatiotemporal reconstructions of the key regional climatic parameters (surface air temperature and precipitation) and reconstructions of large-scale circulation modes (e.g., AMO, PDO, ENSO).
- Validation of reconstructions through statistical methods and comparison with existing hemispheric- to global-scale multiproxy based reconstructions and climate model simulations.

The following are the major findings and action items from this workshop:

1) By far the most numerous climate proxy records for North America are tree-ring data (see e.g., Fig. 1), which are available at annual or better resolution over much of the continent. These records are sensitive to both temperature and precipitation variability. There is an extensive amount of peer-reviewed literature from more than 50 years of climatic reconstruction work that can be used for the NAm2k effort. The North America Drought Atlas (Cook et al. 2004) is currently the most extensive, high-temporal resolution paleoclimate record available for North America. It consists of gridded summer (JJA) Palmer Drought Severity Index values for the past 500–2000 years, with a trend towards

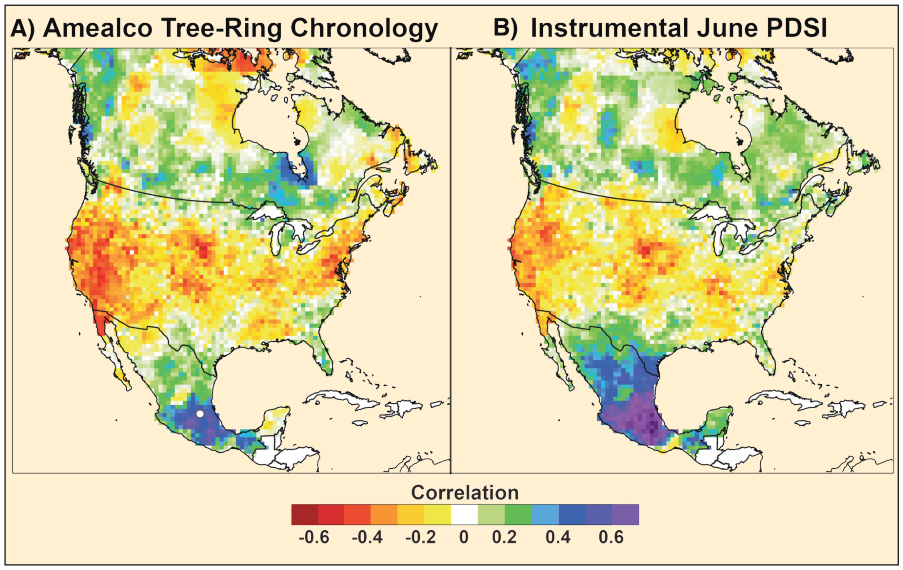

*Figure 1: Central Mexico June Palmer Drought Severity Index (PDSI) correlated across North America, 1950-2003 **A**) Reconstructed from tree rings, **B**) Observed. Figure from Stahle et al. (Climate Dynamics, in review), courtesy of Dave Stahle.*

longer records in western North America compared to eastern areas.

2) Other proxy records from lakes (e.g., isotopes, varves, chironomids, pollen, charcoal) are available for a number of sub-continental areas, and speleothem proxy records of precipitation are available for selected areas, such as the US Southwest. These records will generally reflect climate drivers for at least the last 2000 years, but with lower temporal resolution (generally) and with more limited spatial coverage than tree ring records. It was agreed that the temporal resolution of the proxy records needed for this activity would be on the order of at least 50 years, with minimum record lengths of 500 years.

3) A first step will be to develop an integrated inventory and archive of paleoclimate records for possible use in the NAm2k climate reconstruction. The goal is also to integrate the available data sets and reconstruction fields with those of the Arctic2k WG. A recommendation was made for the NOAA World Data Center for Paleoclimatology in Boulder, Colorado to become the central repository of data sets used in the NAm2k effort. The metadata could be mirrored with the PAGES 2k metadata archive on the PAGES website section for NAm2k.

4) A sub-working group composed of Scott Anderson, Henry Diaz, Darrell Kaufman, Brian Luckman, Dave Meko, Greg Pedersen, Dave Stahle, Valerie Trouet, Andre Viau and Gene Wahl will work toward the goal of assimilating (blending) the different input data sources and exploring mapping tools.

An analysis and synthesis workshop for the tree-ring chapter of the NAm2k Working Group is being organized, tentatively titled "North American Dendroclimatic Data: Compilation, Characterization, and Spatiotemporal Analysis" led by Valerie Trouet.

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2nd International Symposium "Reconstructing climate variations in South America and the Antarctic Peninsula over the last 2000 years"

Valdivia, Chile, 27-30 October 2010

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The 2nd International Symposium "Reconstructing Climate Variations in South America and the Antarctic Peninsula over the last 2000 years" was part of the PAGES research initiative LOTRED-SA (Long-Term climate REconstruction and Dynamics of South America). This symposium was organized by the Centro de Estudios Científicos (CECS) and the School of Forestry and Natural Resources (Universidad Austral de Chile). Nearly 200 scientists from 15 countries (mainly from Chile, Argentina, Brazil, Colombia, Switzerland and USA) came together for oral and poster presentations, mainly related to new high-resolution paleoclimate studies in South America and the Antarctic Peninsula. Prior to the Symposium, a graduate international course "South American Climatology and Quantitative High-Resolution Climate Reconstructions in Paleoecology" took place (see *PAGES news* 19(1) for a report). The 2nd International Symposium was the follow-up of the 2006 Malargüe-PAGES Meeting in Argentina, which had led to a special issue of *Palaeogeography, Palaeoclimatology, Palaeoecology* in 2009, titled Regional high-resolution multiproxy climate reconstruction for South America: state of the art and perspectives.

The goal of the 2010 meeting was to gather experts from different fields in climate dynamics, paleoclimatology (proxy data and models) and glaciology, in order to review recent discoveries, discuss new data sets, evaluate the interpretation of proxy data, and search for new calibration and quantification techniques of proxy data sets in South America and the Antarctic Peninsula. The long-term goal of this collaborative meeting was to produce a more comprehensive understanding of

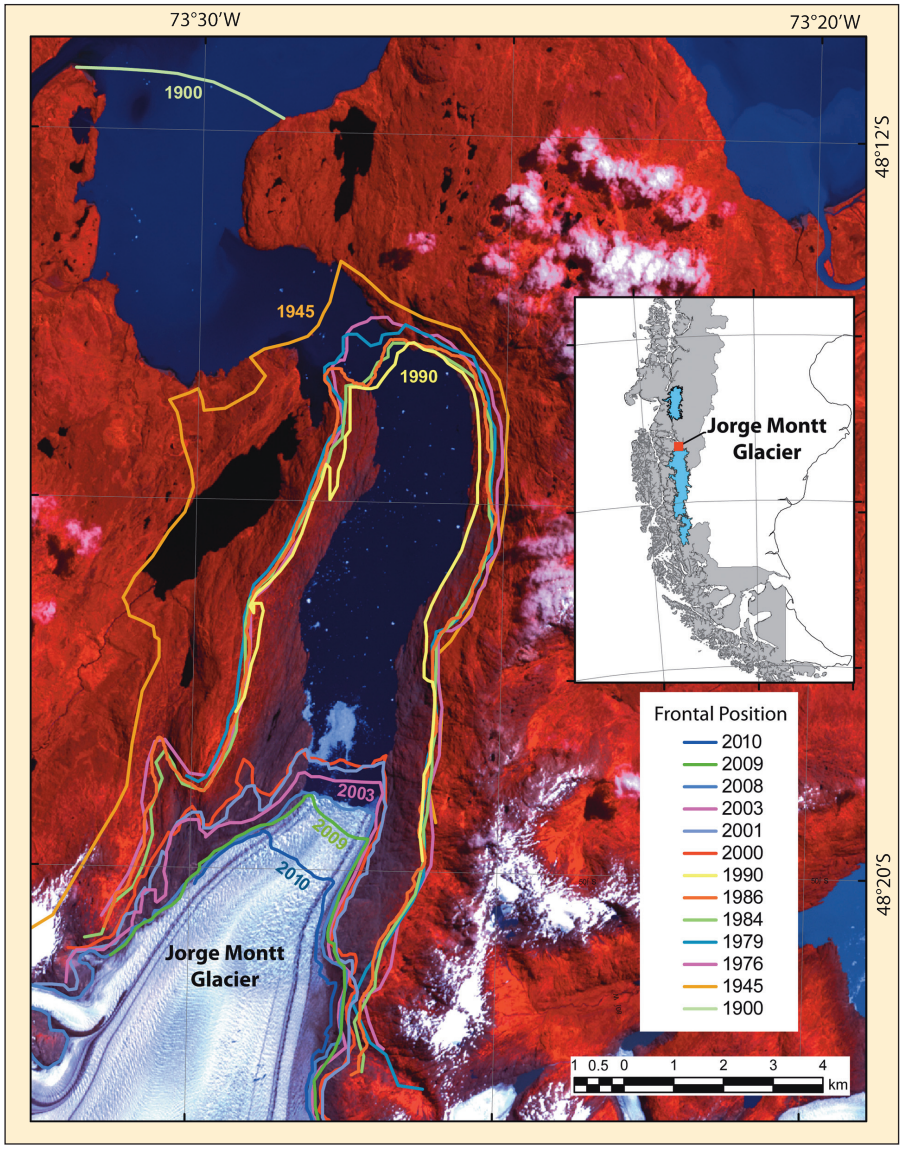

Figure 1: Frontal variations of Jorge Montt glacier as determined by historical records, satellite imagery and aerial photographs. This is one of the biggest tidewater calving glaciers of the South Patagonian Icefield where a maximum frontal retreat of 18 km between 1900 and 2010 was documented (Rivera et al., 2010).

regional forced and unforced climate variability, as well as environmental changes during the past millennia. The main idea is to improve the production of gridded data sets of climate variables from high-resolution multi-proxy time series.

This conference brought together senior and young scientists working on tree rings, glacier records, lake and marine sediments, geomorphology, ice cores, historical documents, speleothems and other paleoclimate archives. All these experts were interested in paleoclimatic reconstructions for different regions of tropical, extra-tropical and sub-Antarctic South America and the Antarctic Peninsula. The meeting also greatly benefited from the participation of climatologists working on modeling of the present climate of South America, providing a dynamically meaningful and physically plausible framework for the interpretation of past environmental records. One of the most exciting outcomes of this conference was the significant assistance it provided to young scientists and the great enthusiasm demonstrated by all in attendance.

At present we are working on a Special Issue of *Climate of the Past*, which will include the most outstanding contributions presented in the symposium. This special issue will provide an updated and comprehensive outline of ongoing research on this topic.

Guidelines for collaboration and contributions to LOTRED-SA are available at www.pages-igbp.org/workinggroups/lotred-sa or by contacting one of the coordinators: Ricardo Villalba (ricardo@lab.cricyt.edu.ar), Martin Grosjean (grosjean@giub.unibe.ch). For detailed information about this Symposium, and photos and videos of the conference presentations, please visit www.cecs.cl/pages2010/.

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Bayesian hierarchical models for climate field reconstruction

Lamont Doherty Earth Observatory of Columbia University, USA, 8-11 February 2011

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Bayesian Hierarchical Models (BHMs) have emerged as a powerful new method for inferring spatially complete climate fields from sparse and noisy proxy time series. BHMs have a potential theoretical advantage over "traditional" linear subspace-based (EOF) methods for inferring climate fields, because the Bayesian "posterior" distribution of the reconstructed climate, once estimated, can be directly sampled to yield complete uncertainty estimates of the reconstructions, along with a point estimate of the expected value. The Bayesian estimates of the climate field encapsulate the uncertainties involved in the estimation of all model parameters, which cannot readily be done using traditional linear subspace methods.

A primary goal of the workshop was to bring together reconstruction experts who currently employ reduced-space multivariate regression models for climate field reconstruction, and provide an in-depth exposure to the theory and applica-

tion of BHMs for climate reconstruction. Dr. Andrew Gelman of Columbia University gave the opening keynote address, and Drs. Martin Tingley of NCAR, Bo Li of Purdue University, Johannes Werner of the University of Giessen, Matthew Schofield of the University of Kentucky, and Naresh Devineni of Columbia University led the workshop with regard to the use and implementation of BHMs for spatially explicit climate reconstruction.

A second important purpose of the workshop was to explore how the more established multivariate regression based methods performed in comparison to BHMs, and to examine the extent to which the traditional methods could offer equally or near-equally valid ways to characterize reconstruction uncertainties in practice (see Fig. 1). This latter goal is important due to the additional complexity and computational expense of BHM approaches, and the more formal and complete treatment of uncertainties afforded by BHMs.

A strong focus was also put on separating model building, per se, from inference of model parameters. It was noted that climate scientists sometimes mix these two concepts, which can result in significant attention being paid to inference issues and comparisons of performance within a closely-related set of models (such as "flavors" of regression, cf., Bürger et al., 2006), rather than to the more general issue of developing conceptually appropriate yet computationally tractable models. In this regard, the key shift in thinking is not to Bayesian methods but to models—which would likely be hierarchical in nature. Inference can then be conducted using a range of tools, but as models become more involved, Bayesian inference strategies may be the (conceptually) simplest option.

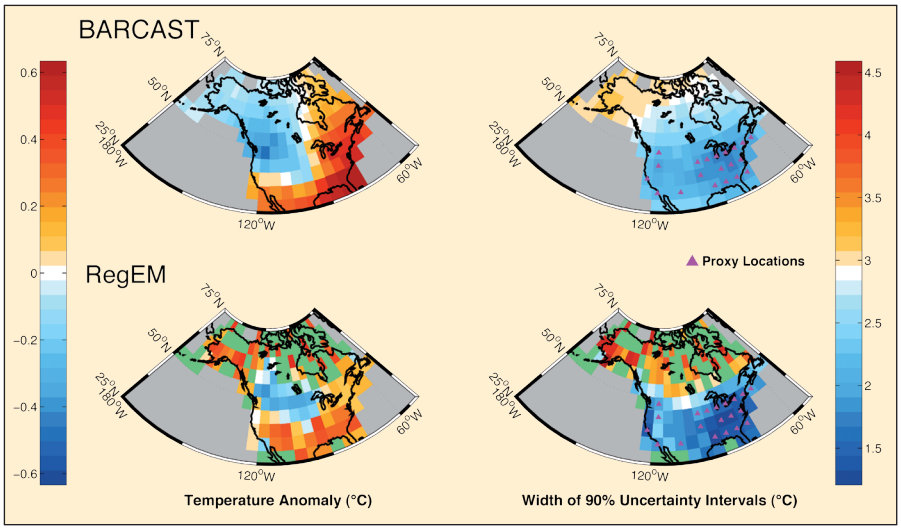

Figure 1: Results of a pseudo-proxy reconstruction experiment comparing Bayesian estimates from BARCAST (upper row; Tingley and Huybers, 2010) with frequentist estimates from RegEM (lower row; Schneider, 2001), an important "state-of-the-art" approach to climate field reconstruction. The left column shows point estimates of the temperature field, while the right column gives the width of 90% uncertainty estimates and indicates the locations of the pseudo-proxies. Results are for the year 1890 of the "medium" experiment described in Tingley and Huybers (2010). The additional assumptions made by BARCAST allow for spatially complete inference, while RegEM does not provide inference at locations where there are no instrumental observations during the calibration interval (indicated by the green shading)

Several presenters stressed that BHMs are not "one size fits all". A given model, such as BARCAST (Tingley and Huybers, 2010), may be appropriate for inferring a particular target process from a particular data set, in the sense that all diagnostics indicate the modeling assumptions are suitable, the Markov Chain Monte Carlo (MCMC) estimation process converges, and the resulting ensemble of draws has reasonable properties. However, the same model may produce results that are physically unreasonable or otherwise problematic if applied to a different data set, or used to infer a different target process examples of which were presented and discussed in the workshop. Such results can often be interpreted as an indication of model misspecification, and it was stressed that model building is an iterative process. Akin to the residual analysis that follows standard linear regression, BHMs allow for posterior checks of the suitability of the model assumptions for the data under analysis.

Bayesian Hierarchical Modeling is still in its infancy in the context of paleoclimate field reconstructions. A key goal of this workshop was to develop a common language, and to focus on formalizing scientific understanding through collaboration between paleoclimate scientists and statisticians. This first (and hopefully not last) workshop took significant steps towards enabling this necessary collaboration to proceed.

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Synthesis of transient climate evolution of the last 21 ka (SynTRaCE-21) workshop

Mount Hood, Oregon, 10-13 October 2010

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Climate reconstructions covering the last 21 ka provide critical observational data for testing state-of-the-art climate models for the simulation of climate evolution and abrupt climate changes. New proxy evidences and modeling activities have led to rapid advances in our understanding of climate change for this period. Therefore, a new PAGES Working Group, SynTraCE-21, was initiated in 2009 to synthesize the transient climate evolution of the last 21 ka. The overarching goals of the Working Group and the associated workshop series are (i) to facilitate an international synthesis effort of proxy climate records to better describe the major features of global climate during the last 21 ka, and (ii) to compare these data to transient

Figure 1: SynTraCE-21 meeting participants in the foreground, Mount Hood in the background.

model simulations. The first international SynTraCE-21k workshop was supported by PAGES, NOAA, and the US Department of Energy, and attracted more than 40 participants from around the world with expertise from terrestrial and marine paleoclimatology to climate modeling.

The first day began with a review of two previously held pilot workshops, which focused on marine and terrestrial records (held in Madison August 2008, and Boulder August 2009). Following this, the focus turned to an update of the meltwater history, which is the most uncertain component of climate forcing in the last deglaciation. The rest of the day was devoted to preliminary model-data comparisons in three models, two coupled general circulation models (CCSM3 and HadCM3) and a climate model of intermediate complexity (ECBilt). These transient simulations mark a new era beyond the "snapshot" studies on "time-slice" climate in paleoclimate model-data comparison because they allow for a direct comparison of time series between the model and data. The studies presented ranged from the evolution of monsoons and global surface climate to regional abyssal circulation variability, showing the great potential of these transient simulations for model-data comparison.

Transient simulations provide an unprecedented opportunity to the paleoclimatology community for model-data comparison and for improved understanding of climate evolution and abrupt climate change. As a result, it has become critical to develop a major data synthesis to better characterize the global climate variability and to compare with the new generation of transient model simulations.

The second day focused on the terrestrial proxies, with synthesis discussions of lake sediment records, including pollen and charcoal data, ice cores and speleothems. A special session was also arranged to discuss several model-data comparison strategies, including both forward and inverse modeling. The third day was devoted to marine proxies. Reconstructions of the character of the deep and intermediate waters with sedimentary isotopes studies were described. Finally, surface ocean proxies for sea surface temperature and salinity were discussed. Each day ended with an open discussion on the major topics of the day.

The presentations on each major proxy provided a great learning opportunity to all the participants, greatly promoting the interdisciplinary approach towards a multi-proxy data synthesis. To examine model robustness, the meeting participants also recommended coordinated modeling activities among the different research groups. To better assess model-model differences and climate sensitivities to external forcing, notably to meltwater forcing, while allowing for flexibility for such long simulations, one strategy proposed was to design common standard sensitivity experiments for different models. Finally, given the large amount of model data, a coordinated model data distribution was also discussed. The workshop participants agreed that the next meeting would be held in the summer of 2012. This workshop will focus on several key topics using an interdisciplinary synthesis approach. Notably, the topics will include the meltwater history and sea level reconstructions for the deglaciation, climate and terrestrial ecosystem in the North American region, and tropical hydrology.

The 3rd PAGES Past Interglacials workshop

Palisades, New York, USA, 20-22 October 2010

Jerry F. McManus[1], D. Raynaud[2] and P.C. Tzedakis[3]

[1]Lamont-Doherty Earth Observatory of Columbia University, New York, USA; [2]Laboratory of Glaciology and Geophysical Environment (LGGE), Grenoble, France; [3]Department of Geography, University College London, UK; p.c.tzedakis@ucl.ac.uk

Uncertainties related to climate variability in a warming world lend high priority to studies of warm periods in the past. The interglacial intervals of the last 800 ka serve as particularly appropriate targets for such investigations (Tzedakis et al., 2009), as they represent the culmination of warming over a range of partially ice-free global climates. In order to help focus and coordinate international efforts to study these intervals, the PAGES Working Group on Past Interglacials (PIGS) held the third in a series of workshops at the Lamont-Doherty Earth Observatory of Columbia University.

Previous workshops laid out the PIGS themes and addressed intra-interglacial variability and interglacial onset. The meeting in New York brought together 30 scientists representing the marine, terrestrial, ice core and modeling communities to focus on interglacial duration (Fig. 1) and glacial inception. Participants came

from 12 countries and included five post-doctoral investigators and five students.

The first day included a survey of interglacial duration based on different archives and climatic proxies. After an overview of insolation variations through time, a series of presentations reviewed the timing and duration of interglacials as viewed in climate records from ice cores, deep-sea sediments and terrestrial sequences. Presentations on ice cores focused on new chronologies, ultra-high resolution analyses, and the potential influence of atmospheric CO_2 concentrations on interglacial length. Several speakers then discussed the timing and duration of sea level highstands as seen in deep-sea sediment and absolutely dated coral records. After a presentation on the interglacial hydrological cycle recorded in speleothem records, the day concluded with a poster session and group discussion of the session themes.

The second day featured presentations of data and modeling studies of glacial inception. These included ice core results from Greenland and Antarctica, and data from different interglacials and glacial inceptions in deep-sea cores from around the globe. A session on climate modeling included presentations on the influence of atmospheric CO_2 concentrations and ocean circulation on the end of an interglacial, as well as attempts to incorporate the carbon cycle in climate modeling of the last interglacial and glacial inception. The day concluded with a discussion of the session themes and review of the Working Group progress.

The final day of the meeting centered on open discussions of issues related to the two primary topics. Although the participants noted that estimates and subsequent comparisons of interglacial durations are sensitive to the definition of interglacial conditions in each proxy and archive, and that the duration of any individual interglacial may vary in different proxies and different locations, they agreed that there are nevertheless valid and robust patterns that emerge among respective interglacials. Different intervals may be defined as short if they last no more than a few thousand years, intermediate if they last approximately ten thousand years, and long if their duration is tens of thousands of years. Similarly, the respective interglacials may be compared

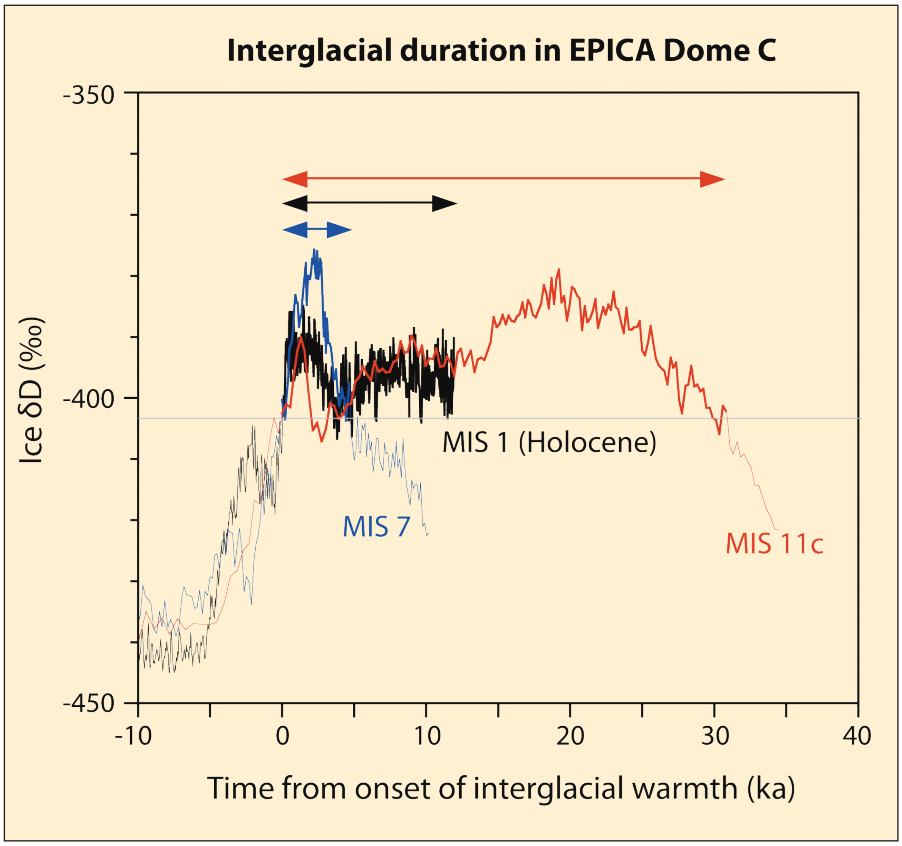

Figure 1: Examples of interglacial duration in an isotopic record from EPICA Dome C (Jouzel et al, 2007). For this illustration, the onset of interglacial warmth in Antarctica is defined by a threshold at -403 per mil in δD (Wolff et al., 2004). By this metric, past interglacial intervals lasted ~5,000 years and ~30,000 years, while the Holocene duration is now approaching 12,000 years.

using various climatic indicators referenced to the Holocene and defined as short or long depending on that relationship. A subset of the Working Group was therefore assigned to lead and compare differences in the duration of past interglacials in a joint publication. The physics and forcing of the climate system that lead to those differences can then be explored in a more targeted way.

In contrast to interglacial durations, which may be estimated for any number of interglacials in a single long record and may differ among locations and climate indicators, the sequence of events associated with glacial inception should be globally coherent, and is best determined using multiple climate records from different locations and archives for a single interval. In this case, Working Group members agreed that a useful approach would be to summarize the global sequence of events that accompanied the last glacial inception, and a smaller group was assigned to lead the task of preparing a joint publication on this topic. This will allow gaps to be identified and addressed, and would provide a target for comparison with subsequent compilations of previous glacial inceptions. Improved absolute and relative chronological constraints are crucial to the successful evaluation of both interglacial duration and glacial inception, and so chronology was taken up as a third focal point to emerge from the workshop.

A fourth workshop, to be hosted by Chronis Tzedakis, will be held in the UK in July 2012. This meeting will focus on efforts to explain the structure of interglacials from the forcing, and will attempt to synthesize the various aspects of past interglacials addressed by the PIGS Working Group.

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Reconstruction of Holocene environmental conditions along a W-E transect through northern Poland

NORPOLAR Workshop, Gdańsk, Poland, 3-8 September 2010

Wojciech Tylmann[1] and Bernd Zolitschka[2]

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[2]GEOPOLAR, University of Bremen, Germany

The project "Northern Polish Lake Research" (NORPOLAR) is a Polish-German joint research program based on a bilateral cooperation between the Department of Geomorphology and Quaternary Geology (Institute of Geography, University of Gdańsk) and GEOPOLAR (Institute of Geography, University of Bremen). In this framework, interdisciplinary research on annually laminated sediments at four lake sites in Northern Poland has been carried out, aiming at: (1) establishing absolute and multiple-dated chronologies for all four records, (2) linking paleodata with instrumental and monitoring data to improve our understanding of pathways from forcing factors via processes to proxy records, (3) providing high-resolution data sets of paleoredox conditions, paleoproductivity, lake water balance, lacustrine carbon cycling and soil erosion, and (4) providing regional data sets of reconstructed climate parameters to be used in combination with the output of downscaled or regional climate models.

Within NORPOLAR we also address one of the major aims of the former ESF-funded European Lake Drilling Programme (ELDP), i.e., to analyze past climate and environmental variability along transects throughout Europe. The NORPOLAR lakes are located along a W-E transect covering the entire latitudinal extension of Poland from 15 to 23°E (Fig. 1) with a distinct maritime to continental climatic trend, i.e., a decrease in mean annual temperature from 8.5 to 6.0°C from West to East.

The NORPOLAR Workshop was organized by Wojciech Tylmann and Małgorzata Kinder. It teamed 23 participants from Poland, Germany and Switzerland (Fig. 1). The aims of this workshop were twofold: (1) To familiarize all project participants with the up-to-date state of scientific results, and (2) To develop a strategy for future research activities. The workshop included invited lectures, oral presentations by all project members and a forum for discussion. Five oral sessions were organized during two days of intense work. The first day was devoted to a general introduction, the lithology of varved sediment records and dating issues, while the second day focused on biological proxies.

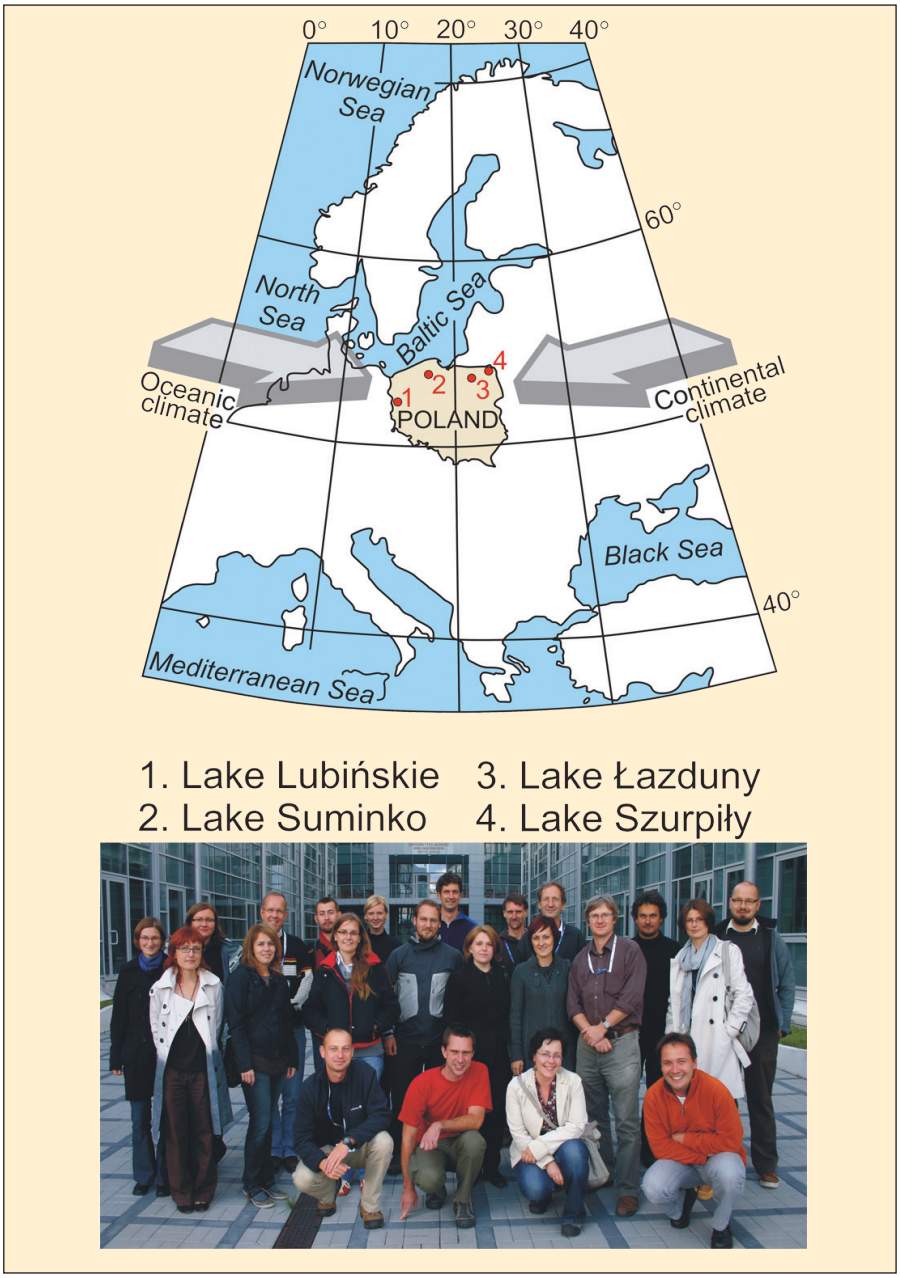

Figure 1. Locations of NORPOLAR lake sites and participants of the NORPOLAR Workshop in front of the Faculty of Social Sciences building at Gdańsk University

We started with excellent talks on the nature of varves and the current state of seasonal climate reconstruction from varved sediments presented by Achim Brauer (German Research Centre for Geosciences, Potsdam) and Christian Kamenik (University of Bern, Switzerland), respectively. The following talks explained the general idea of the project, reported on fieldwork, core correlation as well as on sub-sampling strategies, and shed some light on issues related to chronological and geochemical data interpretation. During the second day three sessions dealt with pollen, diatom and cladocera analyses of the varved sediment records from

four sites studied so far within NORPOLAR (Fig. 1).

The final discussion addressed future NORPOLAR research strategies. There was general consensus on the high potential of these sediment records, especially for high-resolution reconstructions of climatic and environmental variations during the last 3 ka but also back to the early Holocene. Based on personal links established during the 1st PAGES Varves Working Group Workshop (see: *PAGES news*, vol. 18(2)), NORPOLAR grew to become a trilateral research project, now also involving Swiss scientists from the University of Bern.

The workshop ended with two field trips taking workshop participants to the largest active dune field in Europe (Słowiński National Park), to the Gdańsk University Marine Station on Hel peninsula, and to the cliff at Jastrzębia Góra, one of the few outcrops in Northern Poland with exposed Miocene clays and silts covered by Quaternary glacial sediments. Here the observing eyes of the varvologists (Quaternary scientists working with varved sediments) recognized glacial varves in a small section that has most likely been relocated as a frozen block by the glacier. These two days filled with plenty of atmosphere were great for continuative and in-depth scientific discussions related to NORPOLAR.

NORPOLAR was jointly sponsored by the Polish Ministry of Science and Higher Education and the German Research Foundation (DFG). More information about NORPOLAR is available at www.norpolar.ug.edu.pl.

PMIP3 workshop

Kyoto, Japan, 6-10 December 2010

Andreas Schmittner[1], A. Abe-Ouchi[2], P. Braconnot[3], S.P. Harrison[4] and B.L. Otto-Bliesner[5]

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Past changes in Earth's climate, as evidenced by a myriad of paleo-environmental records, inform our understanding of the coupled climate system and can be used to evaluate models used for future projections. The Paleoclimate Modelling Intercomparison Project (PMIP; endorsed by WCRP, PAGES and INQUA/PALCOMM; Joussaume and Taylor, 1995) has taken on the important task of organizing and facilitating a systematic comparison of past climate simulations from different models and paleodata. This involves the definition of common experimental designs, running experiments for key time periods, and syntheses of data sets. Building on its successful work since the 1990s, PMIP, now in its third phase (PMIP3; Otto-Bliesner et al., 2009), remains close to future climate investigation, and has opened new research frontiers through investigation of additional time periods and transient simulations. More than 100 scientists from around the world contributed to this vibrant community effort at the recent workshop sponsored by the Japan Society of Promoting Science, the University of Tokyo and the Japan Agency for Marine-Earth Science and Technology.

PMIP3 continues work on the Last Glacial Maximum (LGM, 21 ka ago) and the mid-Holocene (6 ka ago), and has begun work on the Last Millennium. These key time periods are now recommended as high priority (Tier 1 and 2) simulations in the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2009) using the same models that will be used for projections of future climate for the upcoming 5th Assessment Report of the Intergovernmental Panel on Climate Change. This is a new and exciting development because paleoclimate simulations were previously done with different models—typically coarser resolution—from those used for future simulations, interrupting the direct link between past and future. PMIP will also be assessing carbon-cycle modeling, through its daughter project PCMIP (PalaeoCarbon Modelling Intercomparison Project; Abe-Ouchi and Harrison, 2009), focusing on simulations of the LGM and the Last Millennium.

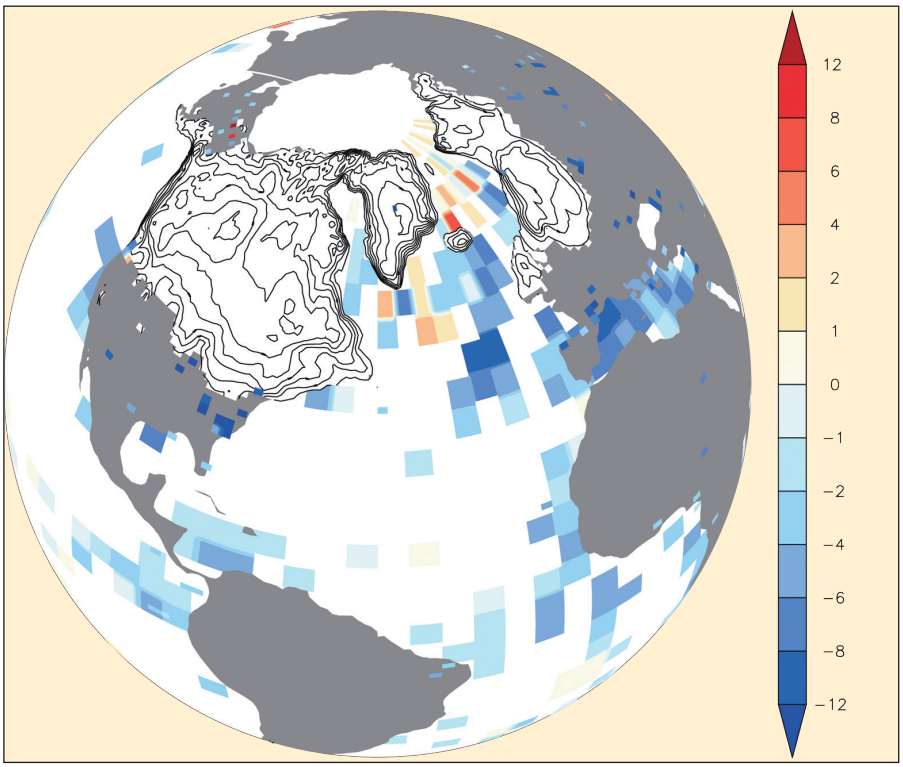

Figure 1: Reconstructions of northern hemisphere ice sheets (contour lines show 500 m elevation differences, available at http://pmip3.lsce.ipsl.fr) and surface temperature differences from modern (color scale in K) for the Last Glacial Maximum. Sea surface temperatures are from the Multiproxy Approach for the Reconstruction of the Glacial Ocean Surface project (MARGO; Waelbroeck et al., 2009), land surface air temperature reconstructions are based on pollen (Bartlein et al., 2010), with additional data from Shakun et al. (in preparation). These data, in combination with model simulations, provide unique constraints on climate sensitivity, confidently excluding high values (> 4.5 K per doubling of CO_2) (Hargreaves et al. 2011, Schmittner et al., Yoshimori et al., submitted).

A new ice sheet reconstruction (Fig. 1) is being used for the LGM simulations, which blends together several recent model-based reconstructions (Abe-Ouchi et al., unpublished). Recent syntheses of surface temperatures from oceans and land and other data (Fig. 1) are being used to provide important constraints on models' climate sensitivity, polar amplification, ocean versus land response, the hydrological cycle and interannual to multi-decadal variability. These and other data sets, such as vegetation distribution, fire regimes and peatland carbon accumulation, will be made available via the PMIP3 web site (http://pmip3.lsce.ipsl.fr). Missing data sets or ones that will require additional work in the coming year were identified at the Kyoto meeting, the most vital of these being a synthesis of short-term (interannual to interdecadal) climate variability during the LGM, the mid-Holocene and the last millennium. The PAGES 2k initiative (http://www.pages.unibe.ch/workinggroups/2k-network) is expected to take the lead on the last-millennium synthesis. Compilations of deep-sea data, such as carbon isotopes for the LGM, are also planned and will provide constraints on modeled ocean circulation and carbon cycle.

CMIP5 simulations are not the only focus in PMIP. New in the set of PMIP experiments are warm periods such as the Pliocene, the Eocene, the Last Interglacial and transient simulations of the Holocene and the Last Interglacial, which have obvious relevance to a future warmer world. Another new focus is on transient simulations of the last deglaciation and freshwater hosing experiments, such as the 8.2 ka event and Heinrich event H1. These experiments and model-data comparisons will provide new estimates of forcing thresholds that influence polar amplification, the low-latitude hydrologic cycle, and the relationship between ice sheets and sea level under different climate states. The transient experiments represent an important step towards a better understanding of the dynamics and temporal response of the different components of the climate system.

In the next two years, PMIP will be sponsoring a series of small workshops, including ones focusing on the compilation of new data sets, on the last-millennium carbon cycle (PCMIP), on benchmarking the CMIP5 simulations, and on data-model comparisons for the Pliocene (PlioMIP). In addition, PMIP will continue to hold annual meetings bringing the paleoclimate modeling community together to discuss progress on all of the PMIP foci.

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For full references please consult:
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The 3rd Eastern Africa Quaternary Research Association workshop

Zanzibar, Tanzania, 7-12 February 2011

Alfred Muzuka
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The workshop was hosted by the Institute of Marine Sciences of the University of Dar es Salaam. It was attended by 55 participants (Fig. 1) from 17 countries and received coverage in local media including Radio television Zanzibar and newspapers. The workshop was generously supported by the Directorate of Research of the University of Dar es Salaam, INQUA, Paleontological Scientific Trust (PAST), and Past Global Changes (PAGES).

The official opening was attended by the Permanent Secretary of the Ministry of State in the President's Office Public Services and Good Governance, Mr. Joseph Meza on behalf of the Minister Hon. Haji Omar Kheri. The workshop was officially concluded by the Director of Records and Archive Mr. Hamad Omar.

Mr. Meza underscored the importance of EAQUA as a regional body that fosters Quaternary Science research in East Africa. He pointed out that the treasures of the rich archeological and anthropological history of Eastern and Central Africa has not yet been fully unearthed owing to a lack of capacity and resources, thus requiring multidisciplinary cooperation and capacity development. Such treasures could help to fight poverty through promotion of ecotourism. He also reminded participants to reflect on how

Figure 1: EAQUA meeting participants

far EAQUA has achieved its mission of enhancing growth of the Quaternary science community in the region through training, collaborative research and information exchange. Participants were urged to come up with tangible results, such as student exchange programs and joint proposals. He challenged the Institute of Marine Sciences of the University of Dar es Salaam to develop a postgraduate program in maritime archeology, which could boost archeological studies in the entire Great Lakes Region.

The EAQUA workshop was preceded by a one day INQUA/EAQUA meeting with presentations from INQUA, Pan African START Secretariat (PASS) and EAQUA country representatives. INQUA presented objectives, activities and available opportunities for the EAQUA members to participate in the programs of the commissions. PASS presented opportunities to the members for training and research, for example, the African Climate Change Fellowship Program (ACCFP) and the Education Program on Climate Change and Biodiversity Conservation. Participants were urged to take a leading role in utilizing these opportunities. Country representatives reported on Quaternary research activities in the region and felt that more capacity building is required.

The general theme of the 3rd EAQUA workshop was "On- and off-shore: Eastern Africa during the last 100 ka". The workshop had 40 oral and 5 poster presentations. Talks were divided into six sessions namely (i) Marine and lacustrine records and reconstruction, (ii) Techniques and methodological development in Quaternary research, (iii) Paleoclimate reconstruction, (iv) Vegetation reconstruction (v) Recent trends in climate change-Impacts and vulnerability assessment for eastern Africa, and (vi) Trade, anthropology and archeological studies in Eastern Africa. Time was also allocated for a round-table discussion where several priority areas of research were identified: (i) Compilation of modern archives of climatic records for the last millennia, (ii) Reconnaissance program to establish caves hosting speleothems, (iii) Creation of a database of Quaternary scientists and projects working in eastern Africa; (iv) Archeology, environment and Humans focusing on issues such as hydrology, vegetation, fire, human-climatic influences, and others. Additionally, the need for several focused meetings with a progressive agenda was emphasized.

The EAQUA workshop concluded with a discussion of association matters, including the election of executive members. Elected for a period of 2 years are: Prof. Mohammed Umer (President), Prof. Alfred N.N. Muzuka (Vice President), Ms Christine Ogolla (Secretary General), Ms Jackline Nyiracyiza (Treasurer), Prof. Asfawossen Asrat (News Letter Editor), Dr. Immaculate Ssemmanda (National Representative (NR Uganda), Ms. Rahab Kinyanjui (NR Kenya), Elgidius Ichumbaki (NR Tanzania), Dr. Julius Lejju (Ex-Officio), Dr. Margareth Avery (INQUA).

Multidecadal and centennial ENSO variability

San Diego, USA, 3-4 September 2010

Jorge Sánchez-Sesma[1] and Arthur Miller[2]

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ENSO is the largest signal of sub-annual climate variability in the Pacific Ocean, affecting not only coastal but also inland locations. Its torrential rains and severe droughts result in economical losses of several hundred millions of dollars in affected countries, from the USA and Mexico to southern South America and as far as Australia. The increase of ENSO frequency and intensities during the second part of the 20th century has affected various sectors, from agriculture to health, from fisheries to the economy. Thus understanding, and ultimately forecasting ENSO variability, has an enormous potential societal benefit.

Although ENSO knowledge has been expanding enormously during last few years, scientists have not yet developed joint and interdisciplinary efforts to better reconstruct and model multidecadal and centennial climate variability (MCEV). The long-term trends that have been reconstructed through numerous proxy variables have neither been analyzed nor modeled well enough to understand the mechanisms required for long-term forecasts. The present trend towards more La Niña events, with more rainfall and tropical cyclones (as 2010 showed us) is highlighting the need to take into account different aspects of ENSO (such as multidecadal trends or ocean-atmosphere interactions) and merge the knowledge from proxy reconstructions, physical and mathematical simulations, non-linear climate analyses and socio-economical research to better understand, predict, and

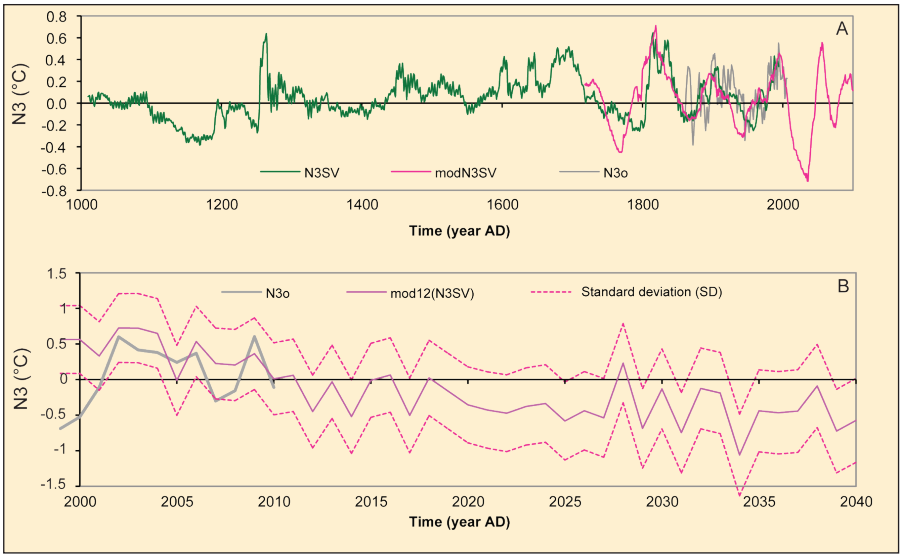

*Figure 1: Comparison of three ENSO (N3 annual average) models. **A**) 21-year moving average smoothed series. The green line (N3s) is the 1000-1999 AD Zebiak-Cane (ZC) model by Mann et al. (2005). The pink line (N3SV) was obtained from an ensemble's average of ZC simulation forced by volcanic and solar activity. The gray line (N3o) represents smoothed observation data for the last 150 years. **B**) Zoom of the annual (non-smoothed) N3SV same model, as A), over 2000-2040 AD and validation with independent observational data. Figure adapted from Sánchez-Sesma (2010).*

mitigate potential ENSO climate impacts in the future (see e.g., Fig. 1).

In order to discuss all these aspects, an international workshop on MCEV focusing on analysis, reconstruction and simulation of ENSO related climate oscillations was held in San Diego. The workshop drew more than 20 experts from Australia, Canada, Mexico, Spain, UK and the USA. The participants were mainly researchers from the fields of climate simulations and reconstructions or working on climate impacts and their related economical aspects. This workshop was a complementary meeting to the 10th International Conference on Paleoceanography (10th ICP) and was sponsored by the Institute for Mexico and the United States (UC-MEXUS) of the University of California.

Introductory presentations covered a wide range of topics including ENSO modeling, the linear and non-linear trends of climate variability, the differences between local and remote processes, the inherent noise behind the records and their biological feedbacks, GCM projections for the Pacific Decadal Oscillation in the 21st century, ENSO and PDO coincident contributions and trends, and new high-resolution geochemistry proxy records. Other aspects also discussed included: MCEV from simulations and proxies, non-linear decomposition of ENSO simulated records, and orbitally induced mean states of climate change in the Tropical Pacific during interglacials. Emphasis on ENSO climate reconstructions from geological records was provided through an overview of different aspects: (a) on the most adequate archives and the sensitivity of proxy variables linked to ENSO conditions, (b) on the influence of hemispheric climate processes on sea surface temperature (SST) during the Holocene, and (c) on isotopic and geochemical analyses from sedimentary records to determine the transmission of the ENSO signal from the western tropical Pacific and the relationship between ENSO and the California Current variability over the past millennium.

Another session focused on nonlinear mathematical analyses. For example, modeling the millennial synchronization between Greenland and Antarctic $\delta^{18}O$ records and the non-linear behavior of ENSO on different timescales were discussed.

The concluding session was centered around the regional impacts of ENSO: analysis of inter-annual variability of precipitation and temperatures over Mexico, the social value of climate predictions in terms of public investments, and the reliance on information provided by institutions and organizations.

The next workshops will focus on centennial scale climate forcings (volcanic and solar). Reconstructions, models and their centennial scale forecasts will be discussed taking into account the associated global and regional climate variability.

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Linking monsoon systems across timescales

2nd PAGES Global Monsoon Symposium, Shanghai, China, 13-15 September 2010

Pinxian Wang[1], B. Wang[2], and T. Kiefer[3]

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Monsoon systems have earned increasing attention from the climatology community over the past decades, yet remain a subject of regional, if not local studies. Following the first Global Monsoon (GM) meeting in 2008 (see report in *PAGES news* 17(2), 2009), a second meeting was held in an attempt to put regional monsoons into the context of a global system, and to analyze their variations across a range of timescales. A total of 95 participants from 12 countries presented 30 talks and 39 posters.

One focus was the hydrological cycle. In present-day climate, the GM was shown to be coordinated by internal feedback processes such as ENSO variability. An increasing trend in global monsoon precipitation over the last 30 years is attributed to both the effects of global warming and atmosphere-ocean interaction in the Pacific Ocean (B. Wang). However, the link between SST and precipitation is not straightforward (J. Fasullo). In his keynote,

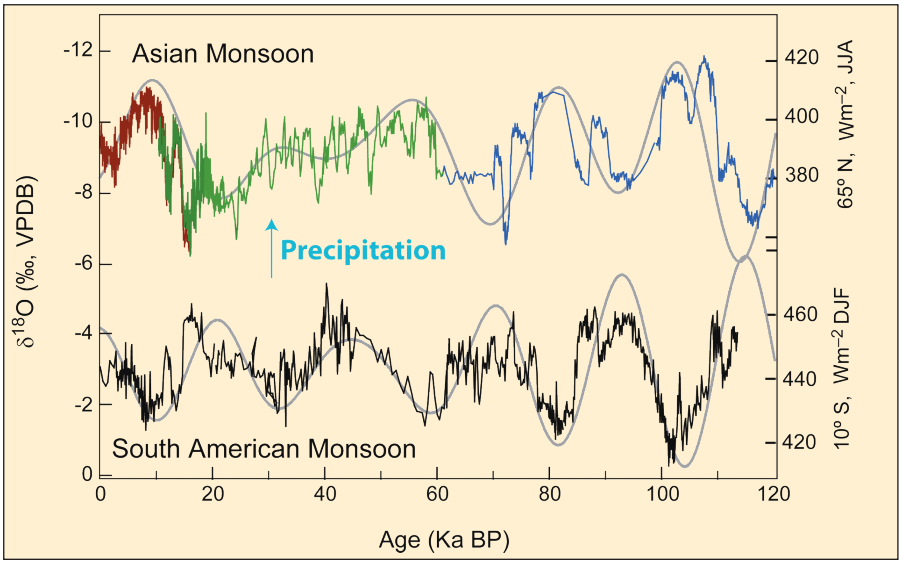

*Figure 1: Interhemispheric comparison of changes in monsoon precipitation and summer insolation between eastern Asia and South America. Precipitation changes are reflected in $\delta^{18}O$ records of speleothem calcite from Dongge cave (**brown**; Dykoski et al., 2005), Hulu cave (**green**; Wang et al., 2001), and Sanbao cave (**blue**; Wang et al., 2008) from eastern China, and from Botuverá cave in southern Brazil (**black**; Cruz et al., 2005). Insolation data are from (Berger, 1978). Figure courtesy of Hai Cheng.*

Peter Webster showed that the area of the SST-defined Tropical Ocean Warm Pool (using a fixed criterion of 28°C) increased by 70% since 1920 and is expected to oc-

cupy the entire tropical ocean in 2100. However, when related to the column integrated heating, the area of the "dynamic warm pool" remained almost unchanged as it is determined by the SST gradient.

Combined data and modeling were used to address monsoon-related hydrological processes, e.g., to demonstrate how monsoon and deserts coexist as twin features of multi-scale forcing (G. Wu). Vegetation feedback modeling simulated that afforestation in monsoon regions cools summers, warms winters and increases spring-summer precipitation locally, but can affect remote climate into an opposite direction (Z. Liu). The use of transient climate simulation in Africa successfully simulated the abrupt start of the African Humid Period in the Sahel and revealed its connection with North Atlantic climate (B. Otto-Bliesner).

The Symposium covered the full range of timescales. Solar cycles, for example, were suggested to have direct and indirect effects on monsoon variations at multi-decadal and centennial timescales (J. Nott; W. Soon), while on centennial timescales the GM strength seems to respond more to the effective solar forcing (J. Liu). Monsoon records from Asia, Africa, and South America could be correlated globally (R. Tada; R. Schneider; F. Cruz; L. Peterson) and compiled oxygen isotope sequences of stalagmites from Asia and South America reveal anti-phasing on orbital, millennial and centennial timescales (H. Cheng; Fig. 1). This provides strong evidence that the GM is connected across hemispheres by the seasonal migration of the ITCZ in response to asymmetrical heat budgets. Global correlation of monsoon records enables us to indentify specific regional features, as demonstrated by the distinct response of the African and Indian monsoons to fresh water flux and ice-sheet forcing during the last glacial (P. Braconnot). On tectonic timescales, steepening of tropical zonal and meridional SST gradients was called upon to explain the aridification of Africa from 2.8-1.6 Ma (P. deMenocal), coherent with the above-mentioned monsoon-desert coupling.

Interesting discussions unfolded over monsoon proxies. The hydrogen isotope ratio of fossilized plant wax lipids from marine sediments was presented as an indicator of monsoon precipitation (R. Schneider). Several proxies were proposed to reflect the global monsoon intensity on longer timescales, including inorganic marine carbon isotopes (eccentricity cycles in ocean carbon reservoir), atmospheric methane concentration (tropical wetland extent) and oxygen isotopes of ice-trapped air (Dole effect). The similarity between oxygen isotope records from stalagmites and marine planktonic carbonate in monsoon regions provoked the question whether the oxygen isotope composition of the rainwater had fluctuated together with the GM intensity (P. Wang).

Extreme hydrological events were the final topic of the symposium. A variety of approaches, including sedimentological, geomorphological and isotopic, were introduced to study floods, droughts, and cyclones over the last millennia in Australia and India. Increases in flood frequency were found over the last century, suggesting coherence in the long-term history of the Australia-Asia Monsoon (V. Kale; E. Valentine and B. Wasson).

In summary, the symposium provided not just a global view of regional monsoons, but also a new perspective of the regional monsoons as part of a global system. Just as the high-latitude processes are centered around the poles, so are the low-latitudes processes, represented by monsoon and ENSO, centered at the climatic equator, i.e., the ITCZ. The GM responds directly to external forcing and is modulated by high latitude processes through teleconnections. The next step of the PAGES Global Monsoon Working Group will be a Special Issue of *Climate Dynamics* followed by a synthesis paper.

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Relative sea level, ice sheets and isostasy past, present and future: Understanding the implications for human populations

PALSEA

3rd PALSEA Workshop, Bristol, UK, 20-24 September 2010

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The joint PAGES-IMAGES Working Group "PALSEA" (Paleo-constraints on sea-level rise; www.climate.unibe.ch/~siddall/working_group.html) aims to obtain information on climate and sea-level change during the Quaternary period with a multi-disciplinary approach. A better understanding of the relationship between climate, ice-sheet dynamics and sea level is critical for projections of future sea level rise expected from global warming and cannot be achieved using the instrumental record alone. The 3rd PALSEA workshop Relative sea level, ice sheets and isostasy past, present and future (understanding the implications for human populations) was held at University of Bristol.

The workshop was internationally attended by 80 participators from a wide range of sea-level related research areas including ice sheet and climate modelers, geophysicists with expertise in glacial-isostatic adjustment, field scientists engaged in reconstruction of ice-sheet extent and relative sea levels, and marine archeologists. Support was provided by PAGES, IMAGES, the Worldwide Universities Network, UK-Integrated Ocean Drilling Program and the University of Bristol. Scientific presentations and discussions were organized into broad themes of: (1) Predicting future sea-level and ice-sheet evolution (2) Sea level and ice sheets during Termination I (3) Ice sheets: observation and modeling (4) Sea level and ice sheets entering and during warm periods

Figure 1: Fossil coral reefs, here from Barbados, are an important archive for reconstructing paleo sea level. Using fossil corals at different localities to reconstruct the deglacial sea-level rise during Termination I are key for determining melt water pulse events and the fingerprinting of sources of the ice-sheet melting (e.g., Antarctica vs. Northern Hemisphere).

(5) Sea levels and ice sheets during the Holocene (6) panel discussions focused on deliverables and future funding strategies.

Among the variety of topics discussed was sea level and ice-sheet evolution following Termination I, including comparisons of records of the last deglacial sea-level rise (e.g., from Sunda shelf and Tahiti corals) and meltwater pulse events (MWP). Specific attention was given to the character of the MWP 1b event, which was suggested to have been very small (if it existed at all) to be consistent with near field data. Ideally, a combination of existing and new observable data on MWPs, with well-defined error estimates, coupled with glacio-isotstatic adjustment (GIA) modeling would help to quantify MWPs more accurately, which is key to the understanding of ice-sheet extent and dynamics. For example, for MWP 1a, there is a discrepancy between glaciological data and glacio-eustatic modeling on where the melt water was sourced (Antarctica, Northern Hemisphere or both). In order to address this problem, improved cross-disciplinary communication between data and model specialists is essential. Another important topic addressed was the stability of ice sheets during warm periods and in particular over the last 2000 years. Despite considerable attention, there remain many unanswered questions, particularly concerning sea level and ice-volume stability in relation to insolation forcing during warm periods. Research on ice-sheet stability during present and past warm climates will benefit our general understanding of ice-sheet dynamics of both the Antarctic and Greenland ice sheets. Improved sea level estimates for the Pliocene Warm Period (when ice sheets were greatly reduced), provides another way to address this issue and will be the focus of further research within the PLIOMAX project (Raymo et al., 2009).

1) We continue to work towards a global, open source and quality monitored database of RSL and ice-sheet extent

2) We support efforts to generate new RSL and ice-sheet extent records and improve techniques.

3) We support efforts in glacio-isostatic adjustment (GIA) and ice-sheet model intercomparison and aspire to the creation of community GIA models in line with other modeling communities.

4) We emphasize the critical importance of close working relationships between climate modelers, ice sheet modelers, GIA modelers and field scientists who study RSL and ice-sheet extent on a variety of timescales.

Table 1: 3rd PALSEA Workshop statements. These statements form the core framework for the continuing effort of the PALSEA workgroup.

Because the main focus points of the PALSEA Working Group is to tightly integrate the different communities working on research themes related to reconstruct past and predict future sea-level fluctuations, a set of key workshop statements was formulated (Table 1).

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Learning from other communities: Towards more robust varve chronologies

varves

2nd workshop of the PAGES Varves Working Group, Corpus Christi, USA, 17-19 March 2011

Mark Besonen[1], P. Francus[2], A.E.K. Ojala[3], R. Behl[4] and B. Zolitschka[5]

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Varved sediment records, i.e., sediment records that accumulate in discrete annual to sub-annual increments, archive an extremely rich variety of paleo information either via their simple physical sedimentology, or from the chemical, isotopic or biological proxies they may contain. Despite this richness, these records are only sparsely used in regional and global climate reconstructions, which tend to favor other annually resolved records such as tree rings. Against this backdrop, and a decade long gap without any large meeting of the varve community, the PAGES Varves Working Group (VWG) was established in 2010. The VWG held a productive first workshop in Tallinn, Estonia in April 2010 that focused on reviewing methodological advances in varved sediment studies over the last decade (Francus et al., 2010; Ojala and Kosonen, 2010). In order to expand the reach of the VWG, recognition by INQUA was recently petitioned, and the VWG was granted project status as "INQUA Project Number 1102—VWG Project".

A second workshop was held in March 2011 on the campus of Texas A&M University-Corpus Christi, USA. A scientific program and abstract volume is posted on the project's website www.pages-igbp.org/workinggroups/varves-wg/. This second workshop focused on the development of more robust varve chronologies based on what could be learned from the communities that work with other non-sedimentary annually resolved climate archives. It was attended by 31 scientists from institutions in 10 different countries. Early career scientists, such as graduate students, post-docs and new faculty, accounted for nearly half of the participants (14 of the 31); thus, the workshop provided a great opportunity for knowledge transfer from more experienced varve researchers to young academics.

The three-day workshop began with a review of sediment varve chronologies (a task that will form the basis of one of

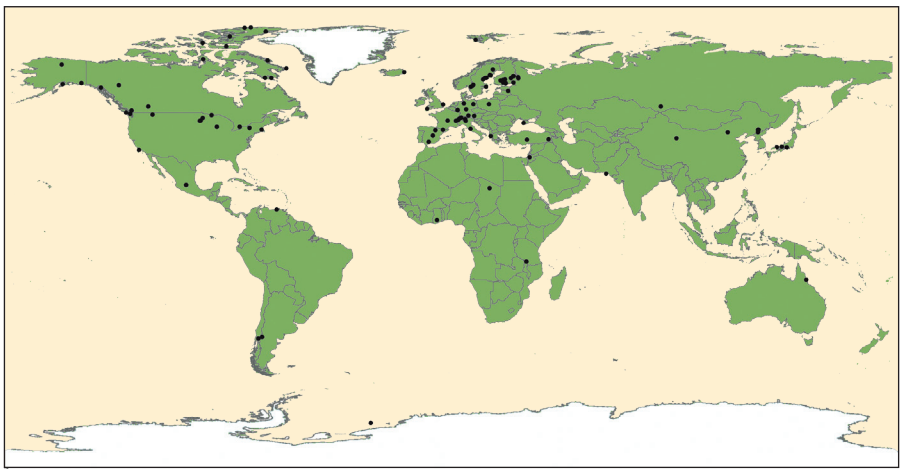

Figure 1: Distribution map of published varved sedimentary records with chronology lengths of at least 100 years. Figure from Ojala et al., in preparation.

the deliverables of the VWG), specifically, an up-to-date metadatabase and inventory of published varved records (Fig. 1). This exercise allowed the group to better identify gaps in reporting methodologies used to establish age-models for varved records, and thus, areas for improvement.

Keynote addresses were delivered by experts from the tree ring, ice core, coral and speleothem communities. By learning from other communities tools and methodologies, the goal was to address perceived or actual weaknesses in varve chronologies and dating (Jansen et al., 2007), that may, in part, be responsible for the sparse usage of varved records in climate reconstructions. Each of the keynote addresses was followed by an active group discussion about how "best-practice" techniques in these adjacent fields could be applied and adapted to varved sediment records. Presentations by the participants were organized thematically and interspersed with the four keynote addresses.

Several plenary discussion sessions were undertaken on the last day of the workshop to address practical issues, such as how to structure the metadatabase of known varved records, and to provide recommendations for the publication of varved records including the publication of raw data, a full set of images of the entire record, and error estimates. Moreover, it was decided to implement a database of papers dealing with varved sediments, and a metadatabase of varved records on the PAGES website. It was also agreed to produce two group publications, one on protocols and a review about the fidelity of sediment varve chronologies.

A third workshop of the VWG will be held in the Eifel region of Germany, 21-23 March, 2012, focusing mainly on the calibration of varved records for climate reconstructions.

Acknowledgements

The organizers wish to thank PAGES, INQUA, and the U.S. NSF (EAR-SGP and OCE-MGG Programs) for the generous financial support that made this workshop possible. Support by staff at Texas A&M University—Corpus Christi was also critical for the success of this workshop, and that support was greatly appreciated.

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Land-cover reconstructions in the monsoon affected tropical world: Pollen modeling approach and data synthesis

IGBP PAGES PHAROS Workshop, Puducherry, India, 27-29 January 2011

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This workshop, supported by PAGES and organized under the umbrella of the Golden Jubilee of the Laboratory of Palynology, French Institute of Pondicherry (IFP), was attended by over fifty participants from India and abroad (Sri Lanka, Australia, Sweden, Estonia and France). There was a good mix of participants from different fields (Earth science, ecology, paleoecology, history and archeology) with adequate representation of data producers and modelers. Compiled abstracts of talks, posters and presentations are available at the IFP website (see URL's in supplementary material www.pages-igbp.org/products/newlsetters/ref2011_2.html).

The need for quantifying land cover and land use, and reconstructing climate change in the tropics is well known. Very little has emerged so far in terms of a multidisciplinary synthesis, although much work has been done over the years in South Asia, specifically in the Indian subcontinent. To address this gap and initiate such synthesis, with India and Sri Lanka as a starting point, the workshop aimed to:

i) Bring together paleoecologists, archeologists, historians and ecologists in order to provide a multidisciplinary background
ii) Introduce the novel methodologies applied today to reconstruct past land cover from pollen data in Europe (the NordForsk POLLANDCAL and LANDCLIM networks, e.g., Gaillard et al., 2008, 2010) to the Indian scientific community
iii) Achieve a synthesis of relevant historical and archeological data.

After introductory talks on PAGES Focus 4 (Past Human-Climate-Ecosystem Interactions), the LANDCLIM project in Europe and Sugita's Landscape Reconstruction Algorithm (LRA) (Sugita, 2007 a, b), lectures focused on Holocene time chronologies and vegetation history, modern forest ecosystems and the history of human settlements, providing an overview of the Peninsular India background. This was followed by a session on models and methods in pollen-based Holocene vegetation and land-cover reconstruction. Both theoretical and practical aspects were explained, emphasizing the need for pollen productivity estimates. This session concluded

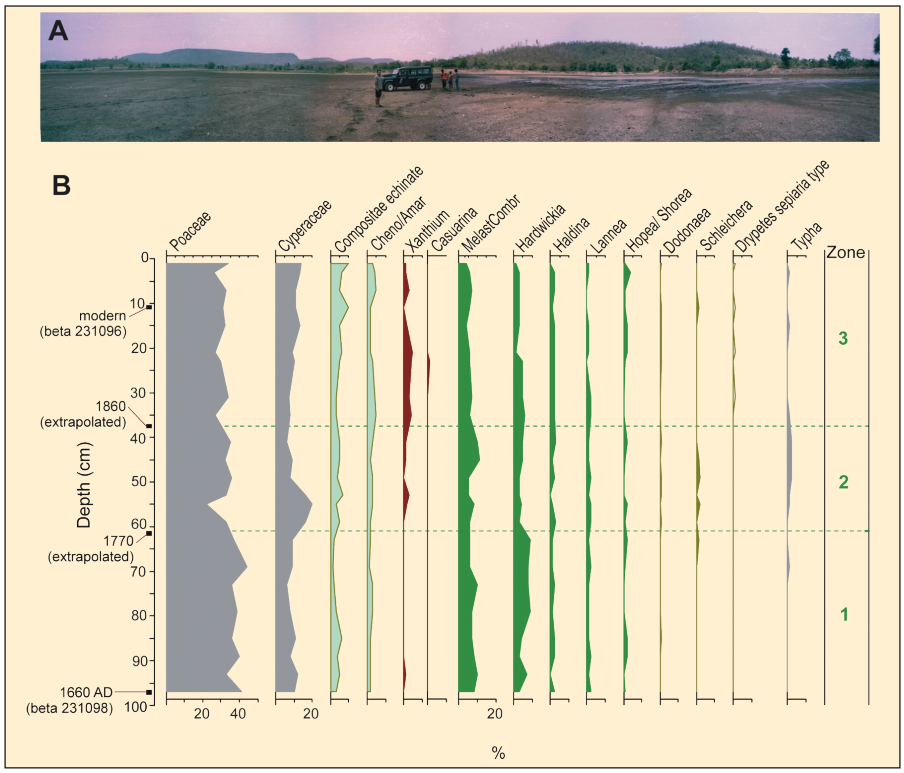

*Figure 1: Although there are very few natural lakes in peninsular India, there is an abundance of water reservoirs with artificial levees commonly referred to as "tanks", dotting the landscape of south India (Gunnell and Anupama, 2003). Several thousand tanks cover the south Indian landscape and offer the best potential for pollen-vegetation modeling in this region, of which Potapuram cheruvu (**A**) is an example. A late Holocene pollen diagram from a core in this tank (**B**; Anupama et al., 2008) illustrates human impact on the landscape (red) as interpreted from markers such as* Xanthium *(a weed) and* Casuarina *(common plantation tree) and other plantation trees occurring in tandem but in small proportions (*Eucalyptus, Cocos, Tamarindus *and* Tectona*). Significant among the deciduous forest catchment's markers (dark green) are Melastomataceae/Combretaceae,* Haldina, Hardwickia, *and* Lannea.

with a presentation on the first quantitative pollen-inferred Holocene land-cover in northwest Europe achieved within the Swedish LANDCLIM project (Gaillard et al., 2010). Lectures on the second day included an introduction to dynamic vegetation models, tools for spatial analyses, and studies in other regions (tropical Africa and Australasia). The third day comprised of invited talks on the dry evergreen forests of southern India and on the online Historical Atlas of south India (http://www.ifpindia.org/hatlas/). Palynological and multiple proxy studies in southern India, Sri Lanka and Borneo were presented during several lecture and poster sessions (Fig. 1).

As a concrete result of the workshop, three geographical regions of focus on the Indian subcontinent and their respective regional coordinators were identified, (1) Western Himalayas, (2) Eastern Himalayas, and (3) Peninsular India with Sri Lanka. These regions will each move forward in developing the following research themes (with their respective thematic coordinators):

A) Indian pollen database (to be housed at the IFP) and application of the biomization approach.

B) Pollen productivity estimates and landscape reconstruction algorithm application.

C) Archeology and paleoecology (syntheses and databases). Given the diversity of Indian archeology, an investigation into the long-term trends in the environmental context of human adaptation is essential. Starting with collecting all available, environmental proxies from archeological and historical contexts, the plan is to select sites/areas to carry out new case studies with standardized methods to answer specific questions through the establishment of multi-disciplinary research groups.

For the names of regional and thematic coordinators, please see the supplementary material (http://www.pages-igbp.org/products/newsletters/ref2011_2.pdf) or contact the first author of this report. The research stemming from the above mentioned aims will contribute to the PAGES Focus 4 PHAROS themes of Regional Integration and Land-cover and Use.

A post-workshop excursion to a 30 year afforestation effort of the Sri Aurobindo International Centre of Education, aptly illustrated land-cover changes and positive aspects of human intervention through restoration ecology.

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For full references please consult:
http://www.pages-igbp.org/products/newsletters/ref2011_2.pdf

2010 international workshop on XRF core scanning

Texel, The Netherlands, 8-10 September 2010

Rik Tjallingii[1], Y. Hamann[2], D. Garbe-Schönberg[3], G. Jan Weltje[4], U. Röhl[5] and workshop participants

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Over the last decade, X-ray fluorescence (XRF) core scanning has become an established method for non-destructive and fast acquisition of sediment compositions (i.e., element count rates) directly at the surface of split cores. State-of-the-art core scanners can measure element intensities at sub-millimeter resolution that allow detailed recording of compositional variations in finely laminated and even varved sediments. Core-scanning data are widely applied to paleoceanographic and paleoclimate reconstructions on timescales ranging from seasonal to millions of years. New developments in data processing and calibration techniques have increased the need to exchange experiences among users at various laboratories equipped

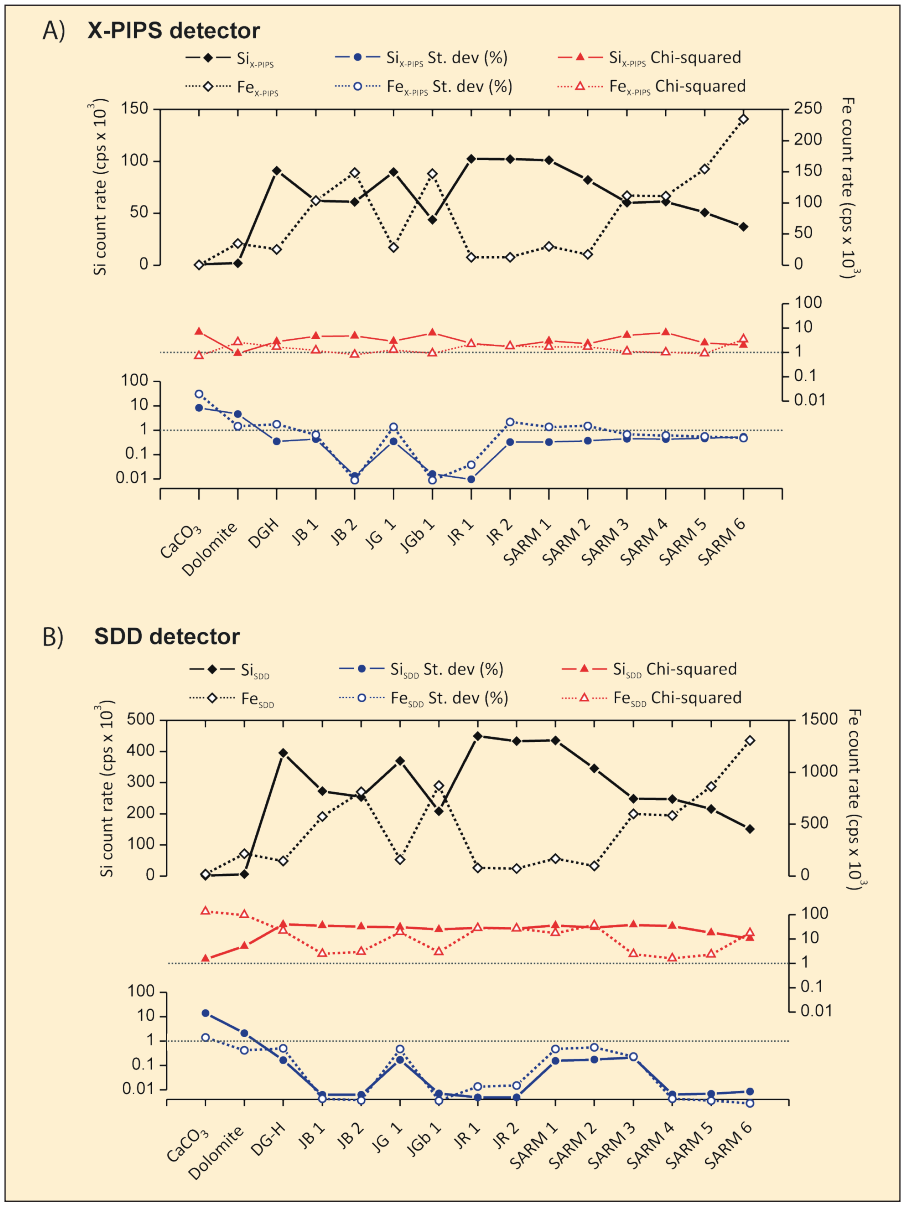

*Figure 1: Comparing count rates and goodness-of-fit statistics of element silicon (Si) and iron (Fe) measured on certified geochemical reference standards (x-axis; e.g., http://georem.mpch-mainz.gwdg.de/) with an Avaatech core scanner equipped with **A**) a pin-diode detector (X-PIPS) and **B**) a silicon-drift detector (SDD). The newly developed SDD detector increases the count rate (black) but also chi-square statistics (red) for Si and Fe due to higher sensitivity of this detector. The relative standard deviation (blue) decreases indicating better signal-to-noise conditions for measurements acquired with the SDD detector. The relative standard deviation is calculated as D-Area/Element-Area. For practical reasons the chi-square and relative standard deviation are plotted on a logarithmic scale.*

with an XRF core-scanner. Therefore, a three-day workshop was held at the Royal Netherlands Institute for Sea Research to discuss technical aspects and application challenges of XRF core scanning, in particular Avaatech scanners, in the wider field of paleoceanography.

On the first day of the workshop, leading researchers and laboratories gave an overview on applications of geochemistry to scientific problems and on the quality of geochemical data generated by XRF core scanning. The quality of XRF core-scanner data is commonly evaluated by comparing core-scanner records with destructive analyses of discrete samples (e.g., Inductively Coupled Plasma (ICP)-Optical Emission Spectroscopy or ICP-Mass Spectroscopy). Geochemical data are closed-sum data that are intrinsically correlated and cannot be directly quantified on an element-by-element basis. Geochemical data are therefore often represented as element ratios in order to interpret down-core composition variations in terms of changes in climate and environment, sediment transport mechanisms, or diagenetic conditions. Additionally, element intensities from XRF scanners are not solely related to element concentrations, but are also affected by down-core variations of physical sediment properties (size distribution, density, water content), as well as absorption and enhancement effects, and measurement geometry. It was shown that the log-ratio representation of XRF count rates and concentrations allows effective minimization of the noise caused by these down-core variations, and allows enhancement of the signal-to-noise ratio by means of appropriate multivariate filtering techniques. Log-ratio calibration permits rigorous quantification of the precision of XRF core-scanner data based on replicate measurements, which paves the way to fully quantitative applications of XRF core scanning.

The second day was dedicated to the discussion of the mathematical transformation of XRF spectra into elemental count rates by least-squares fitting of the characteristic X-ray peaks. Practical problems concerning data processing and goodness-of-fit parameters (e.g., chi-squared χ^2) were presented by members of the MARUM XRF core scanner laboratory of the University of Bremen, Germany. Many technical issues were discussed in a lively debate between XRF core-scanner users, specialists in XRF acquisition, and specialists in XRF spectrum evaluation. One of the key points in this discussion was that the increased efficiency of recently developed digital XRF detectors significantly reduces measurement times and increases the signal-to-noise ratio. However, this increased sensitivity of digital detectors also brings out the complexity of XRF spectra, which may result in strongly increased c2 statistics suggesting a poor spectrum fit. A suitable alternative approach to the use of c2 statistics is to express the goodness-of-fit in terms of relative errors (i.e., the standard deviation as a proportion of the element intensity; Fig. 1). As a rule of thumb, elements displaying negative count rates or relative errors in excess of 10% are considered to be below the detection limit.

The third day was devoted to complementary non-destructive scanning tools, which are optional for the latest scanners (e.g., visible-light and UV digital line-scan cameras, magnetic susceptibility sensors, radiograph imagery), and their applications to sediment and coral-core analysis. In addition, laser-ablation ICP-spectroscopy was presented as a complementary destructive chemical technique. In a final discussion, the workshop participants expressed the need for an electronic information platform to share practical experience on sample preparation, measurement techniques, data processing, technical solutions and preventive maintenance.

The next international workshop on XRF sediment core scanning will be held in two years time. More information about current developments concerning the electronic information platform and the workshop, including some of the presentations, is available at: www.nioz.nl/xrf-workshop

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Editors:
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Layout: Louise Newman
Editorial Support: Christoph Kull

Hardcopy circulation: 2400

ISSN 1811-1602

Printed on recycled paper by
Läderach AG - Bern, Switzerland

The PAGES International Project Office and its publications are supported by the Swiss and US National Science Foundations and NOAA.