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PAST GLOBAL CHANGES
MAGAZINE

SUSTAINING EARTH'S BIODIVERSITY

EDITORS
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MINI SECTION
PAGES' Young Scientists Meeting 2017

PAGES futurearth

News

PAGES 5th OSM and 3rd YSM
PAGES' flagship events - the Open Science Meeting and Young Scientists Meeting, held in Spain in May - were a huge success.
More than 900 scientists attended the OSM, with eight plenary sessions and 33 parallel sessions. In total, the OSM featured almost 1000 communications - ca. 650 posters and 340 orals. Eighty early-career researchers were chosen to attend the YSM. Access both programs and abstract books, and the post-meeting material, here: http://pages-osm.org

Two new PAGES working groups
In February 2017, SISAL (Speleothem Isotopes Synthesis and AnaLysis) launched to bring together speleothem scientists, speleothem-process modelers, statisticians and climate modelers to develop a global synthesis of speleothem isotopes that can be used both to explore past climate changes and in model evaluation.
http://pastglobalchanges.org/ini/wg/sisal/intro

In August 2017, PalEOclimate and the PeopLing of the Earth (PEOPLE 3000) formed to integrate archaeological data, paleoecological data and dynamic modeling to explain long-term patterns of growth in the consumption of energy in social-ecological systems, and the tipping points of these systems within the contexts of changing climates and environments, over the last 3000 years.
http://pastglobalchanges.org/ini/wg/people-3000/intro

PAGES 2k Network Phase 3
At the OSM, PAGES 2k Network launched its next phase and the call is open for projects. New projects include CoralHydro2k and Iso2k. All details: www.pastglobalchanges.org/ini/wg/2k-network/projects

New PAGES' co-chair
PAGES welcomed Willy Tinner as the new co-chair of the Scientific Steering Committee (SSC) starting 1 January 2017. Tinner is a Professor at the Oeschger Centre for Climate Change Research (OCCR) and the Head of Paleoecology at the Institute of Plant Sciences at the University of Bern, Switzerland. He is a leading ecologist and environmental scientist, specializing in terrestrial paleoecology, with a focus on fire history and past climate-change impacts on vegetation and land use. Tinner replaced outgoing co-chair Hubertus Fischer.

Guest scientist at PAGES IPO
Alan Mix, Fellow of the AGU and AAAS and president of The Oceanography Society, was a guest scientist in March to further develop PAGES' Warmer Worlds Integrative Activity.
http://pastglobalchanges.org/ini/int-act/warm-worlds

Podcasts
Several active PAGES members have been interviewed on the Forecast podcast by *Nature*'s editor for climate science Michael White. Nerilie Abram and Julien Emile-Geay (2k Network) and Kevin Anchukaitis (VICS) discuss their work and careers.
http://pastglobalchanges.org/products/multimedia/7426-podcasts

PAGES at AGU Fall Meeting 2017
Thomas Stocker, a former PAGES co-chair, will give the Cesare Emiliani Lecture at the AGU Fall Meeting in New Orleans in December 2017. Hubertus Fischer, who finished on the SSC last year, will receive the Willi Dansgaard Award.

Several PAGES working groups - PAGES 2k Network, DICE and PALSEA2 – have organized sessions.
http://pastglobalchanges.org/calendar/upcoming/127-pages/1724-agu-fall-meeting-17

Suggest a new working group or apply for meeting support by 20 October*
Propose a new working group http://pastglobalchanges.org/ini/wg/new-wg-proposal or apply for workshop support by 20 October 2017 http://pastglobalchanges.org/my-pages/meeting-support *This round of meeting support is only open to current PAGES working groups. The next open call for workshop support will be in the first half of 2018.

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Have you changed institutions or are you about to move? Please check if your details are current. http://pastglobalchanges.org/people/people-database/edit-your-profile If you have problems updating your details, we can help. Please contact pages@pages.unibe.ch

Upcoming issue of Past Global Changes Magazine
The next PAGES Magazine will be on centennial to millennial climate change. Contact the CVAS working group or the PAGES office if you are interested in contributing.
www.pastglobalchanges.org/ini/wg/cvas/

Calendar

CVAS: Space-time Holocene climate variability
25-27 October 2017 - Potsdam, Germany

PALSEA2: Phasing of ice sheet and sea-level
6-11 November 2017 - Playa del Carmen, Mexico

DICE: The role of dust in climate change
8-10 January 2018 - Las Cruces, Chile

EcoRe3: Functional paleoecology
9-10 January 2018 - Salt Lake City, USA

VICS: Progress in volcanic impacts
12-17 January 2018 - Tucson, USA

GPWG2: African fire history and fire ecology
April 2018 - Nairobi, Kenya

www.pastglobalchanges.org/calendar

Featured products

2k Network
Climate scientists will now be able to more accurately study global surface temperature changes than was previously possible, thanks to the 2k Consortium (2017, Scientific Data 4)

Aquatic Transitions
Keely Mills et. al, in "Deciphering long-term records of natural variability and human impact as recorded in lake sediments: a palaeolimnological puzzle" explain how a paleolimnological approach is a powerful tool for better understanding and managing global aquatic resources. (2017, WIREs Water 4).

Ocean Circulation and Carbon Cycling
Andreas Schmittner et al. compiled and compared more than 1700 $\delta^{13}C$ observations of the benthic foraminifera genus Cibicides from late Holocene sediments in the first paper by the OC3 working group (2017, Paleoceanography 32)

PALSEA2
Andrew Kemp et al. use foraminifera preserved in new and existing cores of dated salt-marsh sediment (2017, Quaternary Science Reviews 160).

QUIGS
Members of QUIGS published their findings on how astronomical forces lead to interglacials (2017, Nature 542).

VICS
Results emphasize the need for interdisciplinary approaches to climate change adaptation considering not only biophysical, but also social, economic and political aspects (2017, Environmental Research Letters 12).

Cover

The Gran Sabana, part of a huge savanna island within the Amazon-Orinoco rainforests (SE Venezuela), is mostly covered by treeless savannas, with forest-savanna mosaics at the edges and gallery forests along rivers.
At present, forests are receding due to recurrent burning events depicted by patches of green and brown tones. Paleoecological evidence suggests that the vegetation structure is as much a consequence of the management by humans during the last millennia as the influence of climate change since the Younger Dryas". Photo: Valentí Rull.

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Sustaining Earth's biodiversity

Peter Gell[1] and Lindsey Gillson[2]

The decline in the biodiversity of the Earth is a critical global issue with potential impacts on essential ecosystem services. The rate of biodiversity loss has already far exceeded safe planetary boundaries (Rockström et al. 2009) and measures to arrest species extinction have been found wanting, with conservation reserves too small, too few and too subject to change. So, society has called for a significant increase in investment in biodiversity conservation, particularly given the additive impacts of accelerated climate change (Pecl et al. 2017). In concert, understanding of ecological function and process is needed if ecosystem services are to be managed sustainably.

Conservation biology has long been identified as the "crisis science" (Soulé 1985). However, preventing species extinction is not enough to maintain ecological function, socio-ecological resilience and evolutionary potential (Sgrò et al. 2011). The links with society and the sustainable use of landscapes are increasingly part of the broader conservation remit (Wu 2011). The magnitude of the issues encountered greatly exceeds the foundational ecological knowledge available, and counting species and population declines is not enough. Historically, conservation biologists have grappled with the design of protected area networks, and preventing deforestation and desertification. Today, the portfolio of challenges has expanded to include ecological isolation, fragmentation and degradation of terrestrial and aquatic systems, and accommodating species whose habitats are at risk from changing climate patterns, as well as the sustainable use of natural resources. Furthermore, maintaining and restoring appropriate disturbance regimes has become increasingly important as land use has pushed disturbance regimes beyond their historical limits (North and Keeton 2008).

In fact, the rate of biodiversity loss tempts conservation biologists to focus predominantly on the recent, and even just the now. Here, however, they run the risk of misunderstanding the landscape elements that influenced system function, the factors that drove the declines and the historical role of people as ecological architects (Fig. 1). Further, they may overlook the existence of cultural ecosystems and the past, and future, role of people in them (Wu 2011). Yet even the value of these lessons may be challenged, as "novel ecosystems" emerge due to anthropogenic climate change, land use and alien species (Williams and Jackson 2007).

We maintain that the study of long-term ecosystem change can provide critical insights into the resilience of ecosystems, the restoration of disturbance regimes and the prediction of future responses to changing climate and disturbance – even when conditions are novel. This collection of papers is an illustration of this view.

Figure 1: The Gamo Highlands of Ethiopia – a landscape shaped by multiple interacting drivers (Photo: Rob Marchant).

The role of disturbance in ecosystems is widely recognized but rarely is the legacy of historical disturbance, particularly by humans, acknowledged in conservation planning. The neo-tropical Gran Sabana is a mosaic of vegetation that reflects the influence of climate change but also human burning as an agency of vegetation dynamics (Rull et al., p.82). The management of the vegetation mosaics here, as well as in the North American pine communities, requires an appreciation of the influence of cultural practices, and the impact of their removal (Colombaroli et al., p.78). The east African landscapes too, that have supported diverse megafaunas in close association with long human habitation (Marchant et al., p.80), attest to long interactions between people and biodiversity, but with this balance challenged in recent decades by the intensification of development.

The legacy of human occupation is often an increase in regional biodiversity, and cultural landscapes are themselves now considered valid conservation targets. The contemporary richness of some European communities evolved in association with human disturbance (Ekblom and Gillson, p.88). Similarly, the legacy of horticulture is the augmentation of botanical diversity in long-reforested Central and South American regions (Whitney and Cárdenas, p.84).

These vignettes of human-ecosystem interactions attest to the importance of long-term evidence to inform appropriate landscape management. Rarely has this occurred, however UN programs such as the Ramsar Convention are recognizing long-term variability to better ascribe natural ecological character and limits of acceptable change (Gell, p.86). Understanding ecological responses to external, including human, stressors is critical if management efforts are to be well targeted (Seddon, p.94). The scaling up of paleoecological records represents a means by which long-term data (Harrison, p.96) could be brought to biodiversity management decision making.

This issue of *Past Global Changes Magazine* focuses on the perspectives that can be brought to the crisis science from paleoecological evidence. It draws on lessons from the Americas, Africa and Europe, while also providing new insights into the long-term geological (Fritz and Baker, p.90) and climatic (Ledru et al., p.92) forces of biodiversity evolution, critical transitions in ecosystem change (Seddon, p.94) and utility of ecosystem change evidence for global conservation programs to enable them to better address the challenges imposed by intensive development. Lastly, it advocates for big data as a means of scaling up our knowledge to contribute best to informing programs that address biodiversity management (Harrison, p.96).

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Paleo records as a guide for ecosystem management and biodiversity conservation

Daniele Colombaroli[1,2,3], C. Whitlock[4], W. Tinner[1] and M. Conedera[5]

Projected climate and land-use changes challenge ecosystem management and conservation strategies to maintain biodiversity. Information on past vegetation and fire responses to human activity and climate variability helps identify which conservation targets (natural or cultural) best meet landscape management goals.

Ecological mitigation and restoration efforts aimed at reducing the effects of excessive land use are currently under revision in light of climate projections that suggest significant changes in vegetation structure and composition in the coming decades (Diffenbaugh and Field 2013). Given the magnitude of projected change, future ecosystem dynamics are often difficult to infer on the basis of short-term observations alone (Willis and Birks 2006) and limited time perspectives may result in poor conservation decisions with unexpected consequences under new climate conditions (Gillson et al. 2013; Williams and Jackson 2007). The information offered by historical ecology and paleoecology, spanning centuries to millennia, reveals a range of ecosystem processes occurring at different spatial and temporal scales, as well as the extent to which present vegetation has been altered by past human activities. Understanding past ecosystem dynamics, and particularly the role of climate and humans, offers a baseline for interpreting current landscape conditions and helps set goals for conservation and restoration. Conservation actions will vary depending on (1) where the current landscape falls along a land-use gradient from pristine to intensely altered; (2) the motivation (or cultural values) to achieve more natural, or maintain, cultural landscapes; and (3) a cost-benefit analysis of pursuing particular strategies. We provide two examples of how paleoecology can help identify appropriate restoration targets and discuss the role of past environmental reconstructions for restoration, forest management and biodiversity conservation.

Maintaining nearly pristine landscapes

Protected areas, like some of the large US national parks, are good examples of nearly pristine ecosystems, in that they support most of the species and ecological processes that existed prior to Euro-American settlement. In such settings, paleoecology provides critical insights about past ecosystem responses to a range of climate conditions and disturbance regimes in the absence of significant human interference (Millspaugh et al. 2000). Pollen records from across the Greater Yellowstone Ecosystem, for example, show that whitebark pine (*Pinus albicaulis*) was once more abundant and widely distributed than at present (Iglesias et al. 2015). During the early Holocene, when summers were warmer and drier and fires were more frequent than at present, this species grew at all elevations; its present restriction to high elevations is partly a result of the Holocene expansion of lodgepole pine (*Pinus contorta*; Fig. 1, top). Assessing whitebark pine's future based only on its present climate distribution underestimates its tolerance to warm summers and fire, and its intolerance of competitors. Today, the species is also under threat from the introduction of a non-native blister rust and warmer-than-previous winters. These novel conditions justify the need for careful monitoring of whitebark pine and the evaluation of any change against its response range to past climate and disturbance.

Preserving biodiversity in cultural landscapes

Alpine landscapes have experienced a long history of human activity, ranging from intensive agriculture in the lowlands to pastoralism at high elevations. Many of these landscapes are culturally and economically significant and some are "iconic" examples of traditional land use (Fig. 1, bottom). Highly valued cultural landscapes in Europe include the heathlands of Western Europe, Mediterranean *dehesas* of Spain, sweet chestnut and cork oak forests of southern Europe, and high diversity pastures and dry meadows of Central Europe and the Alps. Defining a climate-based range of acceptable variability for these landscapes makes little sense, because fire regimes have long been altered by humans, who changed forest vegetation through introductions, cultivation or setting aside of species (Conedera et al. 2017).

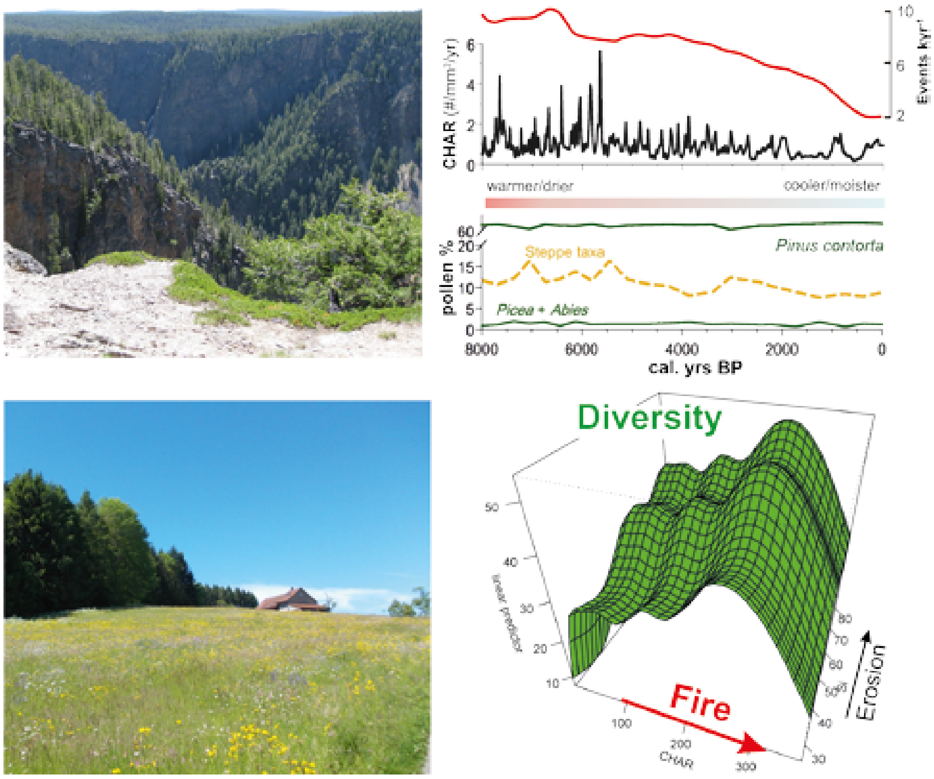

Figure 1: Top. Much of Yellowstone National Park is underlain by infertile rhyolite substrates that support lodgepole pine (*Pinus contorta*), a species that is also highly adapted to fire. Pollen and charcoal data suggest that lodgepole pine has maintained dominance in these geologic settings throughout the Holocene despite dramatic climate-driven changes in fire activity (Millspaugh et al. 2000; right panel, photo by CW). **Bottom.** Highly diverse meadows in mountain ecosystems offer important provisioning and cultural services (Broye Valley near Moudon, Switzerland, photo by DC). On the right: long-term records from the Valais (Central Alps) show variations in biodiversity (based on pollen data) as a function of fire (based on charcoal) and erosion (based on magnetic susceptibility). Plant diversity is maximized at intermediate levels of fire disturbances, in accordance with ecological theory. After Colombaroli et al. (2013). CHAR refers to charcoal accumulation rates, a measure of fire activity.

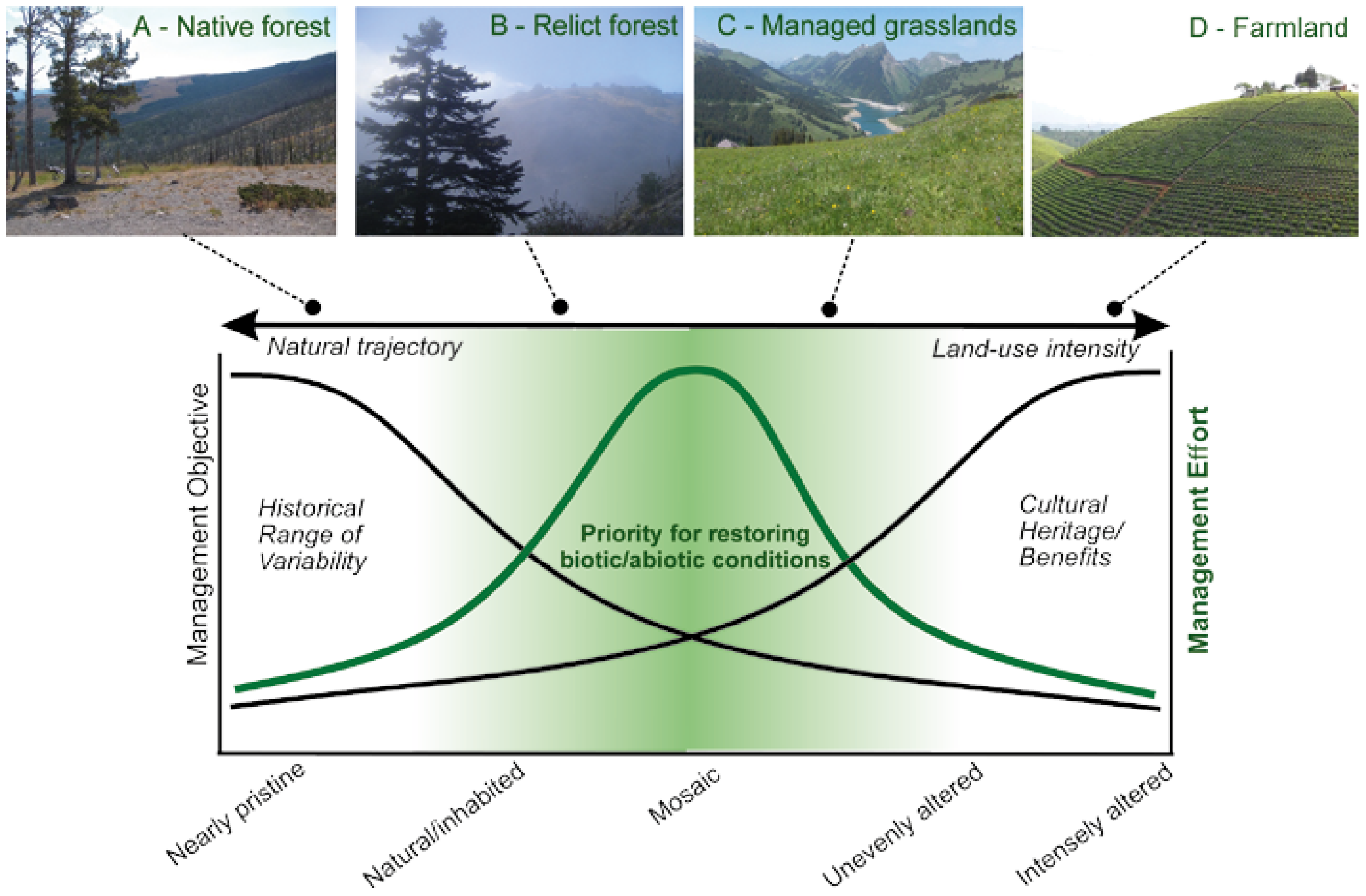

Figure 2: Top. Examples of landscapes with different levels of human alteration: **(A)** native *Pinus contorta* pine forest in Yellowstone National Park; **(B)** relict *Abies nebrodensis* forest in Sicily; **(C)** managed grasslands in the Alps; **(D)** tea crops in western Uganda (photos by DC). **Bottom.** Conceptual model showing management objectives across a gradient of landscape conditions, ranging from preserving historical range of variability in nearly pristine locations to promoting cultural benefits in intensely altered settings. The "landscape space" in the middle (green shading) highlights where pristine and humanized components co-exist and represent conservation opportunities for management objectives, for their potential to restore both historical range of variability and cultural values (based on Whitlock et al., in press).

For example, although the forests and grasslands in Switzerland are predominantly cultural landscapes, humans have and are altering their natural biodiversity differently. Alpine grasslands, prized for species richness, are now threatened by land abandonment and forest encroachment (Colombaroli and Tinner 2013). In contrast, forest diversity has been steadily depleted as a result of the deliberate reduction of some trees (e.g. *Tilia*, *Fraxinus* and *Abies*; Tinner et al. 2013) and the addition and promotion of others (*Castanea, Taxus, Juniperus, Fagus, Picea*; Conedera et al. 2017). The challenge for future conservation efforts in this region is to balance the legacies of past climate and land use against the conservation of cultural landscapes and ecosystems and their services.

Incorporating ecosystem history into conservation strategies

Recognizing the degree of past landscape alteration can help determine the appropriateness and feasibility of management objectives that seek to restore naturalness or protect cultural heritage. Between nearly pristine conditions at one end and highly altered conditions at the other, landscapes in the intermediate part of the gradient support both natural and cultural components (Fig. 2). These intermediate landscapes pose conservation challenges – to support natural structure and diversity and at the same time maintain cultural values – but they also represent conservation opportunities (Lindenmayer and Hunter 2010). For example, disturbance-sensitive species often grow as isolated, relict forests in a matrix of human-altered vegetation, facing high risks of extinction in some cases (e.g. *Abies nebrodensis* in Sicily; Fig. 2). Although the climate may be suitable for forest expansion, restoration requires fire suppression, grazing protection and removal of competing species to a level that may not be cost-effective or feasible (e.g. Henne et al. 2015). Deliberate intervention, careful management, and knowledge of landscape history can help guide realistic conservation planning.

Paleoecological information can play a key role in evaluating current ecosystem states, supporting (or disproving) the effectiveness of present conservation measures to balance specific targets (Fig. 2), and assessing future management strategies and vulnerability to climate change (e.g. Tinner et al. 2013). Capturing environmental and ecological variability requires knowledge of past climate legacies and human impacts, although such information is unevenly distributed and absent in some regions (e.g. tropical rainforests; Colombaroli et al. 2016). Research to better understand past fire activity, as it relates to climate, people and biodiversity, is the focus of the PAGES Global Paleofire Working Group (www.pastglobalchanges.org/ini/wg/gpwg2).

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Entangled ecosystem-people-animal interactions: perspectives from the East African savannas

Rob Marchant, C. Courtney-Mustaphi and E. Githumbi

Under current rapid environmental change there are numerous challenges for people and wildlife. Paleoecological records from southern Kenya are synthesized to provide understanding on how abiotic and biotic elements intertwine and can provide a foundation to inform decisions for environmental management.

Abiotic and biotic elements intertwine over multiple spatio-temporal scales to determine the present-day composition, structure and distribution of ecosystems. Rapid compositional and distributional changes, particularly during the past few hundred years, are attributed to anthropogenic modifications that are superimposed on long-term climatic and landscape changes (Dearing et al. 2010). It is crucial to have a paleo perspective to disentangle interactions of how the environment, ecosystems, animals and people have combined to influence current ecosystem states, and to learn how lessons from the past can be used to predict and constrain possible future trajectories (Marchant and Lane 2014).

The savanna ecosystems of East Africa are characterized by relatively rapid population growth, changing political, economic, social and cultural contexts, and an agricultural system that is increasingly focused on relatively recently adopted crops, such as maize and market gardening, for regional and international export. This expansion and intensification of agriculture across East African savannas induces particularly rapid land-use and land-cover change. East African savannas also support large human and herbivore populations and have become frontiers for water-intensive agricultural expansion on communal lands formerly dedicated to livestock grazing. Balancing economic development while maintaining ecosystem integrity and the globally important protected area creates policy challenges, which are further exacerbated by climate change. The traditionally reliable dry and rainy seasons have been increasingly disrupted and the unpredictability of the rainy season has become the norm for many savanna communities. Government policies that have encouraged formerly mobile herders to adopt more settled ways of life for both positive (health, education) and negative (land grab, containment) reasons, combined with land fragmentation and degradation, hamper the adaptive ability of communities to respond to inherent climatic variability, for example through transhumance pastoralism. Increasingly intensive land uses, often focused around Protected Area boundaries (Pfeifer et al. 2012), similarly pose threats and challenges for ecosystems, conservation and livelihoods. While there have been numerous calls to address such challenges, current intervention strategies have had limited success, as evidenced by continued encroachment, human-wildlife conflict and the rise of poaching and illegal hunting, along with unabated rapid agricultural development and associated pressure on water resources. These changes are leading to (wildlife) habitat degradation, increased fragmentation of populations, decreased resilience, and biodiversity loss across much of the East African savannas.

One area where these transformations have been acutely felt is within the Amboseli landscape, an area that is somewhat symptomatic of the wider Kenya Tanzanian borderland area (Fig. 1). The Amboseli landscape supports the highest wildlife densities in southern Kenya that migrates across the Kenyan and Tanzanian border. Within the Amboseli landscape there are several perennial wetlands distributed across the predominantly semi-arid landscape; these groundwater-fed wetlands, recharged from orographic precipitation falling on Mount Kilimanjaro (Fig. 2), provide an important source of water and wildlife refuge, and form a series of "stepping stones" for animal migrations between Amboseli National Park and the neighboring Tsavo and Chyulu Hills National Parks (Fig. 1). Unlike seasonally rain-fed wetlands, which are inundated during the wet season and dry out during the dry season, the Amboseli wetlands sustain perennially high local water-tables that enable peat accumulation through drought periods and hence form a paleoecological archive. Reconstruction of the vegetation, climatic and fire histories has been carried out on five of these swamps through pollen, non-pollen palynomorph and macroscopic charcoal analysis, which combine to produce a landscape scale understanding of ecosystem transitions and unpick the drivers behind these shifts. From the mid Holocene, East Africa shifted towards a drier environment characterized by reduced precipitation, increased evaporation, and/or an extension or intensification of the dry season. This period of regional aridity is clearly marked by a peak in aeolian dust deposition

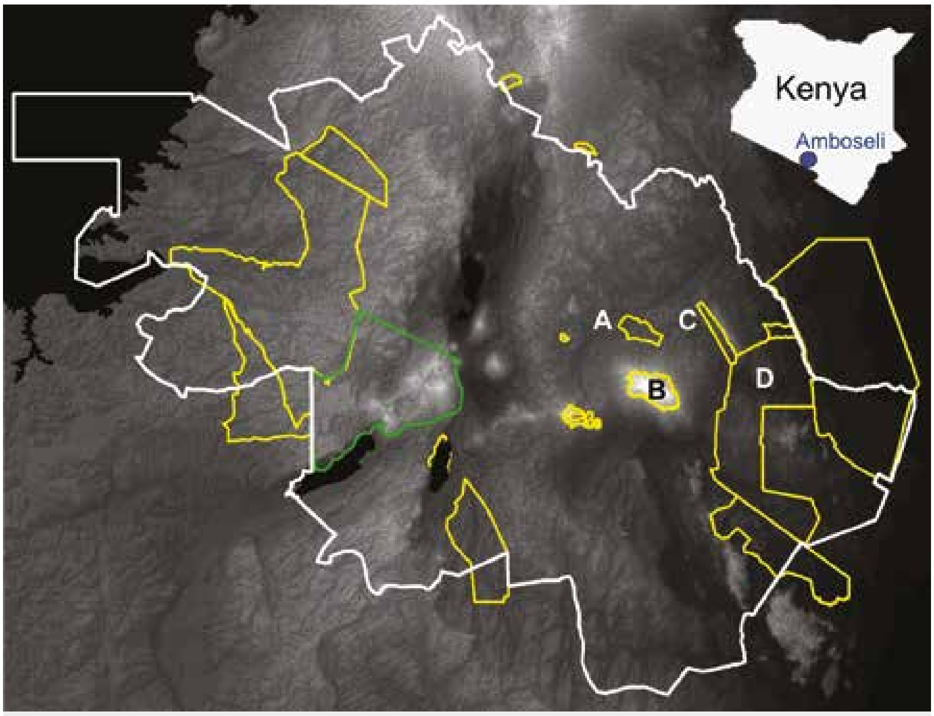

Figure 1: Map of the Kenya-Tanzania Borderlands within the white lines showing the outline locations of the National Parks (yellow) and the Ngorogoro Conservation Area (green). The protected areas (yellow) that surround the Amboseli National Park (A) are Kilimanjaro (B), the Chyulu Hills (C) and Tsavo National Parks (D).

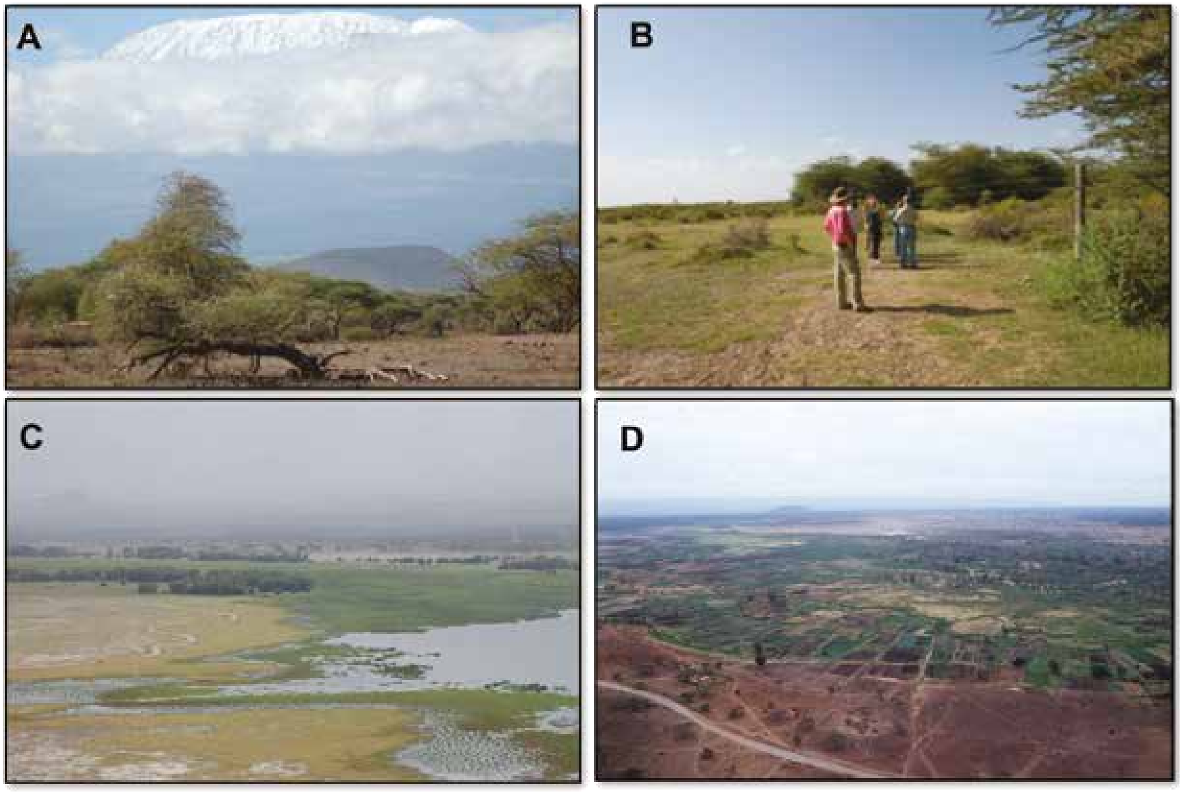

Figure 2: Different perspectives on Amboseli National Park. **(A)** The area is dominated by Mt Kilimanjaro; this is also the "water tower" that feeds the swamps with water to allow accumulation of sediments and the past ecosystem histories to be preserved. **(B)** Herbivores, particularly elephants, are crucially important ecosystem engineers across the landscape: the exclosure experiment clearly shows that with ca. seven years respite, a grazing lawn transitions into tree-dominated savanna (to the right of the fence). The wholescale removal of elephants from the East African landscape, particularly over the past four centuries, will have had a transformative impact on savanna structure and composition. **(C and D)** Current land-use transformations are similarly having a large impact on the swamps. Intact wetlands within the National Park boundaries (C) provide a grazing resource, particularly vital during dry seasons that are becoming increasingly severe and prolonged. They are a stark contrast to wetlands just outside the protected area that are drained and converted to agricultural production (D).

within the Kilimanjaro glacier dated to around 4000 cal yr BP (Thompson et al. 2002). Under these relatively arid conditions, the Amboseli ecosystems were dominated by semi-arid taxa (*Acacia*, *Aloe*, Amaranthaceae-Chenopodiaceae, Asteraceae and *Capparis*). Low charcoal concentrations due to low fuel availability show further evidence of the sparsely vegetated nature of the Amboseli landscape. Between ~2000 and 800 cal yr BP, there is an increase in pollen diversity as the savanna ecosystem became more dominated by woodland taxa (*Acalypha*, *Balanites*, *Commiphora*, *Cordia* and *Salvadora*), and aquatic taxa (Cyperaceae and *Nymphaea*) became locally more abundant. Increased abundance of wind-blown Afromontane forest taxa (*Celtis*, *Juniperus* and *Olea*), most likely derived from the adjacent slopes of Mount Kilimanjaro and the Chyulu Hills, further suggests a period of increased moisture that was concomitant with increased local biomass burning. After c. 800 cal yr BP, a drier environment returns with the increased presence of Amaranthaceae and Poaceae and decreased levels of mesic tree taxa such as *Syzygium* (Rucina et al. 2009), again with a regional expression of lower lake levels (Lamb et al. 2003; Westerberg et al. 2010).

Increased presence of *Acacia*, Amaranthaceae/Chenopdiaceae, *Balanites* and Poaceae in the uppermost samples dating to the last ca. 300 years could be indicative of a drier environment, but could also be a consequence of decreased elephant populations which have a major influence on vegetation composition, distribution and structure (Håkansson 2004; Fig. 2). Regional records, for example from Mt. Shengena located to the south of Amboseli in the Eastern Arc Mountains, reflect increased anthropogenic use of the landscape through the appearance and increased abundance of cultivated taxa such as Maize (*Zea mays*), Castor oil bean (*Ricinus*) and Pine (*Pinus*) to meet the needs of a growing and mobile population (Finch et al. 2016). Moreover, caravan trade resulted in the decimation of East African elephant populations (Håkansson 2004) that clearly would have been transformative for forest cover (Fig. 2). Anthropogenic modifications to the ecosystem have intensified dramatically in recent decades. Wetland areas were converted into agricultural production (*shambas* and commercial farming) as marked by the influx of crops and ruderal taxa (Fig. 2). Pastoralist populations with historical formal and informal land tenure have recently reorganized into more sedentary group ranches where some groups and individuals maintain pastoral livelihoods on an increasingly fragmented landscape. People have also migrated into the region and the increased population has placed additional demands on the Amboseli wetlands, clearly affecting socio-ecological resilience and wider ecosystem functioning of the landscape through the past ca. 4000 years.

It is clear from the Amboseli case study that long-term paleo perspectives provide understanding of the interactions between environment, ecosystems, animals and people, and as such provide a foundation to inform sustainable environmental management decisions (Gillson and Marchant 2014). Understanding how best to manage ecological systems, to protect biodiversity and benefit the human communities that rely on them, requires an interdisciplinary approach; this management is strengthened where paleo perspectives combine with social sciences and humanities to examine complex socio-ecological systems. To strengthen adaptive capacity, and promote resilience, it is crucial to understand how past and present socio-ecological systems are interlinked. Such insights are crucial to inform planning and practice, and inform longer-term planning frameworks such as the UN Sustainable Development Goals.

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Paleoecology as a guide to landscape conservation and restoration in the neotropical Gran Sabana

Valentí Rull[1], T. Vegas-Vilarrúbia[2] and E. Montoya[1]

Late Pleistocene and Holocene paleoecological reconstructions from the neotropical Gran Sabana provide objective criteria to assess realistic and feasible restoration targets, and to appraise the potential effects of global warming on the landscapes and ecosystems.

A significant contribution of paleoecology to conservation and restoration practices is its ability to provide evidence of past ecological conditions, thereby permitting the identification of baselines, to which it would be desirable to return. Choosing the most desirable target is the first step in restoration planning, and a frequent option is to choose to restore the ecological conditions that existed prior to human disturbance (Willis et al. 2010). Another relevant conservation output that may be derived from paleoecological records is the response of ecological communities to past climate change as a model for anticipating potential ecological responses to future climate change (Vegas-Vilarrúbia et al. 2011). Here, we use these approaches to analyze the case of the Gran Sabana region, located in northern South America.

The Gran Sabana is part of a huge savanna island within the Amazon-Orinoco rainforests (Fig. 1). Most of the Gran Sabana is covered by treeless savannas, with forest-savanna mosaics at the edges and gallery forests along rivers. A special type of gallery forest is the emblematic palm swamp of *Mauritia flexuosa*, locally known as "morichal" (Rull and Montoya 2014). The Gran Sabana is part of the Canaima National Park, in the headwaters of the Caroní River, a tributary of the Orinoco that is exploited for hydroelectric power. The savannas are nowadays in expansion to the detriment of forests, mainly due to burning by indigenous people, sparking a debate between defenders and detractors of these practices. Defenders argue that fire management is a fundamental part of indigenous traditions and should be preserved, while critics believe that fires have been responsible for the disappearance of the hypothetical ancient forests that covered the Gran Sabana before the onset of fire practices. This debate is relevant for conservation, as the detractors of indigenous practices argue that forest clearance should cease, whereas the indigenous defenders believe that fires are useful for land management and should be included in conservation planning (Sletto and Rodríguez 2013).

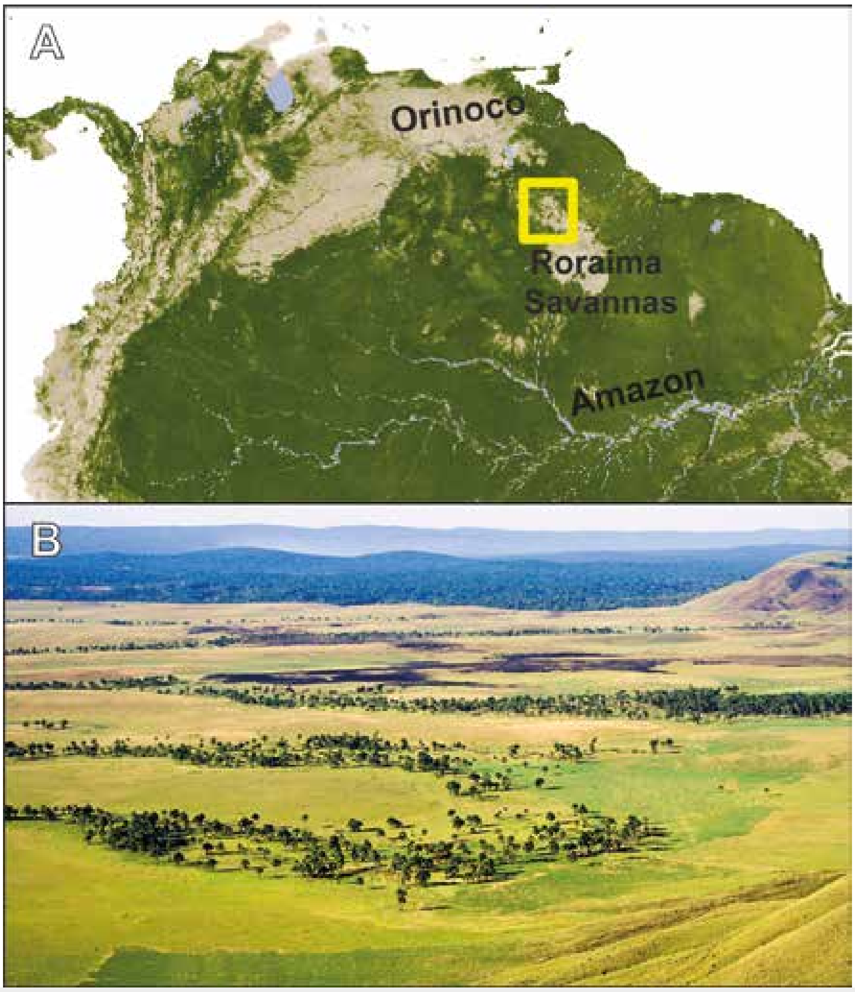

Figure 1: The Gran Sabana. **(A)** Map of northern South America showing the Roraima Savannas and the Gran Sabana (yellow box), between the Orinoco and Amazon basins. **(B)** Typical landscape of the Gran Sabana savannas and *Mauritia* palm swamps with dark patches corresponding to recent fires. The Orinoco-Amazon rainforests are in the background. Photo: V. Rull.

Paleoecology and restoration targets

The Gran Sabana paleoecological records extend back to the Younger Dryas, when it was covered by a mosaic of forests, shrublands and savanna patches. The vegetation cover was mostly ligneous but a continuous forest cover was not observed (Montoya et al. 2011a; Rull et al. 2013). The extensive savannization process started in the Younger Dryas-Holocene transition and culminated by ca. 10 cal ka BP (Fig. 2). Fires, possibly of anthropogenic origin, and the Early Holocene Warming seem to have been involved in this savannization trend, which was relatively rapid and hitherto irreversible (Rull et al. 2015a). During most of the Holocene, fires remained at low rates and the Gran Sabana was dominated by treeless savanna with gallery forests and without *Mauritia* palm swamps. Gallery forests experienced a significant increase during the middle Holocene (ca. 7 to 5 cal ka BP), likely due to a general increase in the available moisture (Montoya et al. 2011b; Rull et al. 2016). *Mauritia flexuosa* arrived to the Gran Sabana by 2 cal ka BP, coinciding with a significant exacerbation of fire, considered to be the onset of the present-like indigenous fire management practices, and the establishment of modern Gran Sabana landscapes (Montoya and Rull 2011; Montoya et al. 2011c; Fig. 2). During the last 2000 years, *Mauritia* swamps have experienced a remarkable expansion because they are not burnt by indigenous people, who use this palm for multiple purposes (Rull and Montoya 2014).

In summary, we have identified three general ecological states since the Late Glacial: (i) a forest-shrubland-savanna mosaic dominated by ligneous communities during the Younger Dryas, (ii) extended treeless savannas with gallery forests during most of the Holocene, and (iii) treeless savannas with gallery forests and *Mauritia* palm swamps during the last 2000 years. It is possible that the number of ecological states will increase as further studies on glacial and former times are conducted. Two other potential states not observed in the available past ecological records are: (iv) treeless savannas totally devoid of forests and (v) continuous forest cover without savannas. On the basis of paleoecological studies, both of these scenarios would be unrealistic as a conservation target.

Restoration proposals
Using the criterion of pre-human conditions (target i) would be problematic, because Younger Dryas climatic conditions differed from those of today, and because this would be in conflict with present-day indigenous practices. Restoring the prevalent Holocene conditions (target ii) would necessitate the removal of the emblematic *Mauritia* palm swamps, which would be a very unpopular proposal, involving the destruction of the present-day Gran Sabana landscape that is generally regarded as "natural". Moreover, it would be difficult to develop such actions in a national park created on the basis of current landscape features. In addition, *Mauritia flexuosa* is a key resource for indigenous people over the entire Neotropics (Rull and Montoya 2014), and its removal would be viewed as cultural aggression. The third option (target iii) - maintaining the Gran Sabana as it is at present - implicitly accepts the continued use of fire by the indigenous people, a condition that would not be acceptable to the defenders of the assumed continuity of former hypothetical rainforests. Because it does not require any special action, this option would be the least expensive in terms of budget and effort; however, its likely consequence will be the continued expansion of savannas to the detriment of rainforests. An alternative solution, at least in theory, would be the joint recreation of present and former ecological states (i, ii and iii) in different parts of the Gran Sabana. This option has been called conservation quasi in situ or inter situ (Burney and Burney 2007; Volis and Blecher 2010); its main drawbacks are that large investments are required to create and maintain such structures and that it would imply intervention into indigenous land-use practices, which is very problematic under the current socio-political circumstances (Rull et al. 2016).

Responses to global warming
The Younger Dryas-Early Holocene warming has been proposed as a past analogue of future global warming in the Neotropics (Rull et al. 2015b). According to the latest IPCC report, by 2100 the Gran Sabana region will experience an average temperature increase of 2-3°C, whereas precipitation will remain at similar-to-present values, with a range of variation of 20% (IPCC 2013). This scenario is

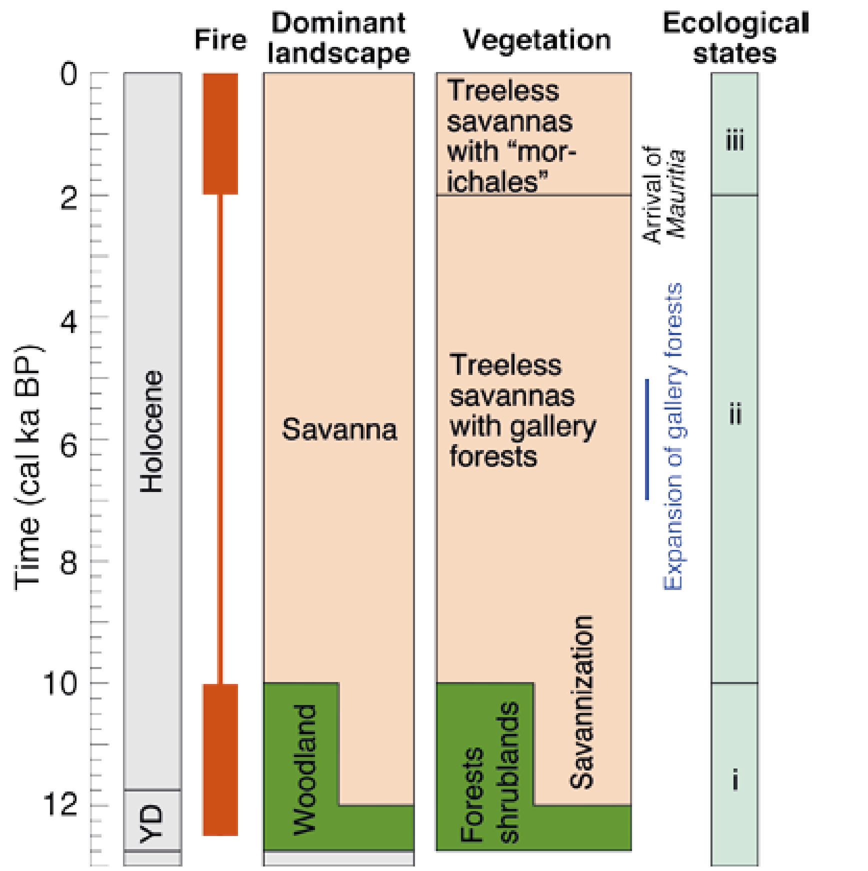

Figure 2: Synthesis of the main paleoecological trends during the last 13,000 years. The ecological states i, ii and iii are described in the text. Modified from Rull et al. (2016).

similar to the Younger Dryas-Early Holocene warming transition, when treeless savannas already dominated the Gran Sabana landscape and the incoming of wetter climates was not sufficient for forest recovery, likely due to fire continuity. As stated earlier, this savannization process was irreversible until today. Using this model, it can be predicted that continuation of present-day fire practices will likely result in the irreversible expansion of savannas and a concomitant reduction of forests, similar to that observed historically. Therefore, fire control measures should be agreed upon with indigenous people if the remaining Gran Sabana forests are to be preserved in their present state (target iii). If a landscape of treeless savanna devoid of forests and spiked with morichales is the desired conservation target (scenario iv), then no action is required. Again, the recovery of the pre-human Younger Dryas landscape (target i) seems unattainable under the IPCC predictions, using the past analogue scenario depicted here. For similar reasons, total reforestation of the Gran Sabana (scenario v) would be unworkable.

Conservation policy
All these considerations and others that have emerged from paleoecological studies should be evaluated by the stakeholders and policy-makers as a basis for developing the best conservation strategy. The role of paleoecologists is to provide the necessary information on aspects of temporal ecological dynamics that may be pertinent to conservation and possible restoration targets. Paleoecological information should be part of these deliberations; otherwise, conservation targets will be unrealistic and landscape development under the action of environmental drivers will be unpredictable.

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PAGES

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Legacies of Pre-Columbian land use on Latin American ecosystem composition and diversity: A case for paleoecology

Bronwen S. Whitney[1] and Macarena L. Cárdenas[2]

Impressive archaeological sites, often underlying dense forest, show evidence of past human impact within "pristine" ecosystems. Here we present four examples that highlight the challenges faced by paleoecologists in determining the potential legacies of human impact on these ecosystems.

Across Latin America, the uncovering of impressive archaeological sites, often underlying dense forest, shows evidence of past human impact within what are often viewed as pristine ecosystems (Bush and Silman 2007; Willis et al. 2004). Anthropogenic impacts were spatially heterogeneous and it is often argued that modern floristic composition in areas of past human occupation espouses a legacy effect in terms of an abundance of economically useful species. Many argue that we need to shift our perceptions of what is "natural" in modern tropical ecosystems and to consider indigenous knowledge and agencies in management and conservation strategies (Clement et al. 2015). This new perspective challenges us to take into account how vegetation diversity and composition in human-impacted areas have responded and changed according to different prehistoric land-use strategies. Most studies of legacy effects rely on modern floristic surveys (Ford and Nigh 2009) that compare composition in areas inferred to have experienced high and low impact in the past. A key limitation of the modern comparative approach is the lack of temporal dimension to the studies. Paleoecology can offer unique insights into legacy impacts on forest composition and biodiversity because it affords a longer temporal perspective than offered by comparative floristic studies and conventional ecology, and in most cases, the studies pre-date complex societies, so they can provide an ecological baseline. Here we review four case studies from the tropical and subtropical Americas (Fig. 1) that demonstrate how paleoecology is attempting to address the question of legacy effects on ecosystems that experienced varied prehistoric land-use strategies.

Ancient Maya palm cultivation

Questions over the persistence of past human impacts are no better illustrated than among studies of the seasonal forests of the ancient Maya lowlands. The issue of legacy impacts in Maya forest (Lambert and Arnason 1982) initially focused on Breadnut (*Brosimum alicastrum, Moraceae*), an economically important tree known locally as *ramón*, that occurs in high proportions in forests surrounding temple ruins, but their high abundance was linked to calcareous soils created by crumbling temple ruins, rather than direct human management. More recently, convincing evidence has emerged of higher abundance of economically important plant species, such as palms, in ancient forest gardens in Belize compared to high bush forest sites (Ross 2011). Few paleoecological studies have addressed legacy impacts on forest composition and biodiversity in the Maya lowlands, with most concerning forest clearance and agriculture at the height of the Classic Maya period. However, a detailed pollen study of Lamanai, Belize, showed clear evidence of palm monoculture (Fig. 2) at the height of the Classic period (Rushton et al. 2012). Palms are vitally important plants that have a multitude of uses, including thatch, nuts, oils, and dyes. The hyperdominant occurrence of several economically important palm species across the Neotropics have been presented as evidence of their wide spread use in prehistory. However, the high palm abundance in this pollen record did not persist into the modern era. As a consequence of the reduced human manipulation of the landscape, the palm plantation rapidly reverted to a more diverse seasonal broadleaf forest, suggesting that human intervention is required for monodominant palm stands to persist.

The legacy of human impact in *Araucaria* forest

Among the ridges of the subtropical southern Brazilian highlands, the living fossil *Araucaria angustifolia* tree dominates the landscapes that were once home to the complex Jê society that emerged at around 2,000 yr BP. *Araucaria* or the "monkey puzzle tree", provided to the Jê culture not only wood and shelter for their villages, but also one of their staple foods, the pinhão, a highly nutritious and calorie-dense nut used in their daily diet as well as in rituals and ceremonies (Iriarte et al. 2013). Paleoecological studies show that *Araucaria* trees arrived in the south of Brazil from about 6,000 yr BP, and expanded following the climatic trend of increased precipitation through the Holocene (Behling et al. 2004). Meanwhile, the paleoecological records within Jê archaeological

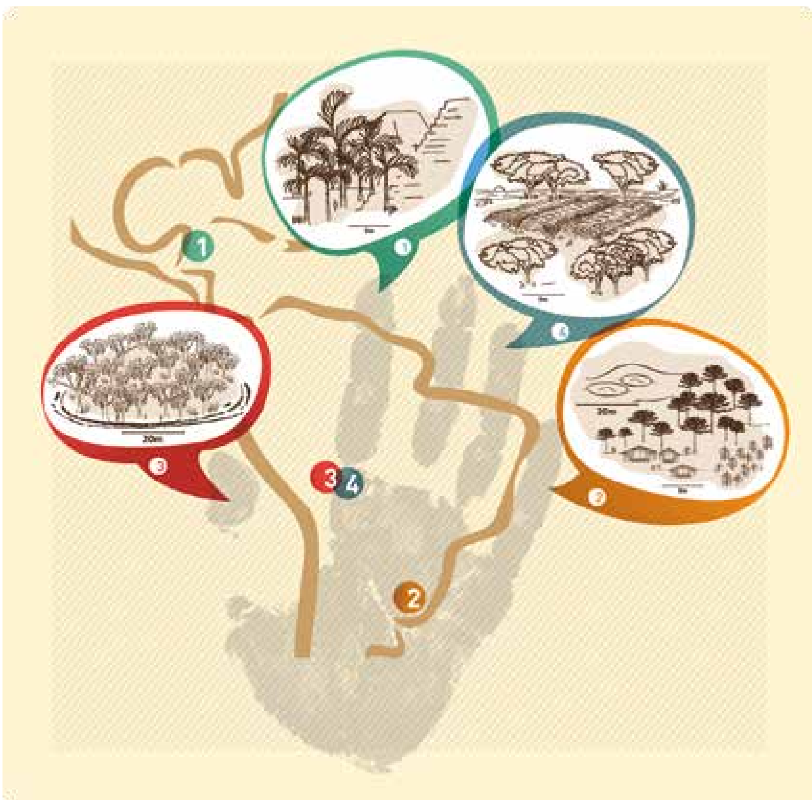

Figure 1: Locations of selected case studies in Latin America and illustrations of the land-use type and key plant species for each scenario.

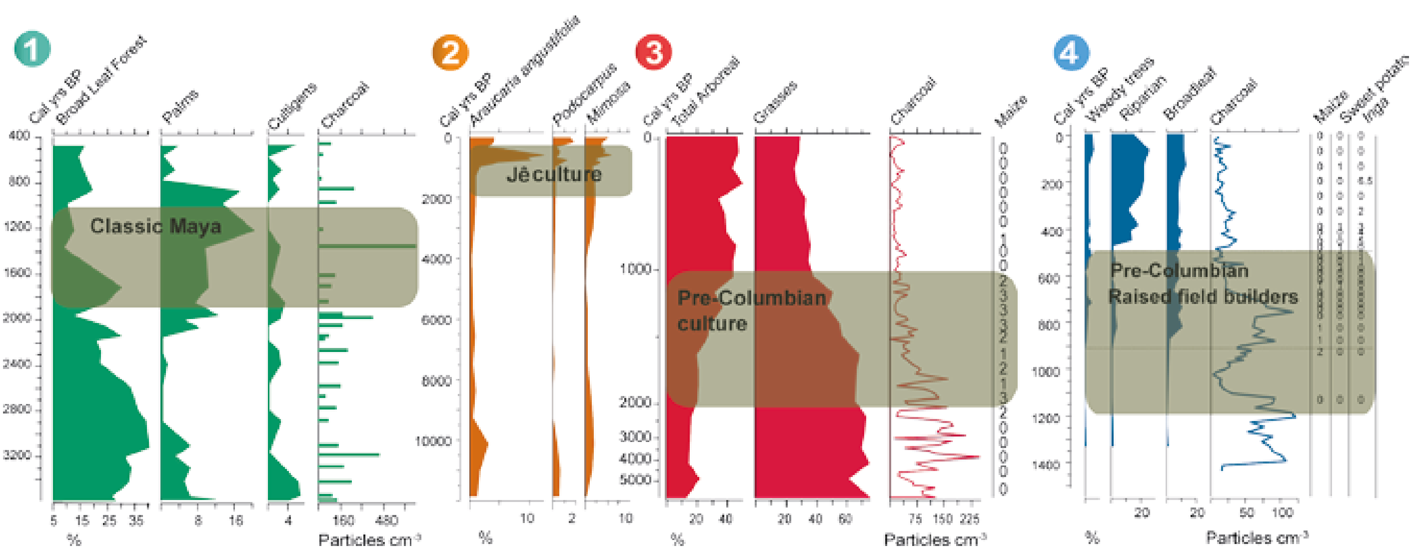

Figure 2: Selected data from the case studies showing the impact and legacy of Pre-Columbian land use on tropical ecosystems. Data are presented as percent abundance of all pollen, except in the case of large, rare pollen grains, such as *Inga* and maize, where individual counts are shown. (1) High palm abundance during the Classic Maya period in Lamanai (Rushton et al. 2012); (2) Very high *Araucaria* pollen coincides with the establishment of the Jê culture and increase in disturbance taxa (*Mimosa*), suggesting anthropogenic changes in the forest structure; (3) Forest expanded around the time of the establishment of "chocolate forest islands", but without evidence of *Theobroma* pollen in the record, we cannot determine if the high abundance of these trees occurred due to past cultivation; (4) Consistent *Inga* pollen after the shift from crop cultivation suggests this culture might have promoted the growth of *Inga* as a food source.

context shows unexpected patterns in the diversity of this forest and the abundance of *Araucaria* pollen if climate was the sole driving factor. The ongoing studies show that the more intense and permanent occupation of this region was associated with a regional expansion of the *Araucaria* forest at the same time that this culture modified the landscape at a local scale (Behling et al. 2004; Iriarte et al. 2013; Iriarte and Behling 2007). The varied proportion of *Araucaria* forest at human-impacted sites could reflect the legacy of pre-Columbians having facilitated the spread of this economically valuable tree species (Iriarte and Behling 2007). It is suspected that the heterogeneous local human land modification across the Jê landscape affected the diversity of "natural" vegetation (Iriarte and Behling 2007), suggesting past land-use legacies have influenced the modern vegetation.

Chocolate forest islands in SW Amazonia

Palm agroforestry by the ancient Maya may not be the only example of monodominant cultivation, as shown in the case of the "chocolate forest islands" in the *Llanos de Moxos* of southwestern Amazonia. The *Llanos de Moxos* is an Amazonian sub-basin that has been inhabited as early as 10,000 yr BP, with maize crop production beginning ca. 6,500 yr BP (Brugger et al. 2016). The basin contains impermeable seasonally-flooded soils overlain by savannas; although much of the region is not hospitable for forest growth, there are forest islands on well-drained soils of outcrops of the PreCambrian Shield located within savanna. One such forest island, where a ring-ditch traces the entire periphery of the forest island, shows clear evidence of past human manipulation of the landscape (Carson et al. 2016). Intriguingly, dense stands of cacao (*Theobroma cacao*) occupy a large proportion of the island, which are thought to originate from either 17th century Jesuit missionaries or Pre-Columbian agroforestry. Due to the highly-specialized pollination mechanism, however, *Theobroma* pollen was undetectable in the pollen record, even with counts of > 1000 grains, so the origin of the chocolate plantation could not be dated. What paleoecology could reveal, however, is that the dense broad-leaf forests of southwestern Amazonia became established in the late Holocene (3,000 yr BP) due to increasing monsoon strength, long after anthropogenic impacts had begun in this region. Given that the rainforest in this southwestern corner of Amazonia does not pre-date anthropogenic influence, composition of forest in areas adjacent to human habitation might have been influenced by people from its inception, thus the ecological baselines could be anthropogenic.

Cultivation of the ice-cream bean

Also among the lowland savannas of southwestern Amazonia, extensive Pre-Columbian raised fields show that people once cultivated these poor savanna soils where cattle ranching now predominates (Lombardo et al. 2011). Paleoecological analyses show that intensive land use began before 1700 yr BP, with burning and clearance of savannas and gallery forests, and raised fields were built for maize cultivation (Whitney et al. 2014). A shift towards less intensive land use incorporating sweet potato cultivation occurred around 700 yr BP, and accompanying this change, *Inga* species colonized the riparian zones. *Inga edulis* is a common food resource (the ice-cream bean) and also an ecological pioneer in the establishment of secondary tropical forest. Pioneer tree species tend to out-shade themselves in the first decades following forest regeneration (Guariguata and Ostertag 2001), so its centuries-long presence in the paleoecological record points to human management of the regenerating gallery forest that stopped forest succession towards a more diverse floristic composition. The mixed strategy of agriculture and agroforestry continued until 1800 AD, around the time land use switched to cattle ranching, suggesting that continued management was required for *Inga* species to persist.

This short review of Pre-Columbian impact on ecosystem composition and biodiversity shows variable evidence for legacies of past land use. The intensity and type of past management, combined with ecosystem type, might be key to controlling whether or not anthropogenic modifications create long-term changes to ecosystem composition and biodiversity. Despite having made significant inroads in redefining what is natural in tropical ecosystems, the complexity illustrated by these studies highlights the challenges ahead for paleoecology in disentangling the natural and human determinants of composition and biodiversity in tropical ecosystems.

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Using paleoecology to understand natural ecological character in Ramsar wetlands

Peter A. Gell

Long-term data from paleoecology can help identify the "natural ecological character" of wetlands and so inform "limits of acceptable change" and the design of appropriate restoration targets for management that consider the historical range of variability.

While the knowledge of the biodiversity of wetlands is poor, it is understood that, while they cover a small fraction (~6%) of the Earth's surface, they support a disproportionately rich assemblage of plants and animals. However, freshwater ecosystems are among the most threatened in the world and are suffering biodiversity declines as great, or greater, than terrestrial systems (Dudgeon et al. 2006). Global estimates suggest freshwater vertebrate populations have declined at ~2% per annum since the 1960s through a combination of overexploitation of water resources, pollution, hydrological change, degradation of habitat and invasive species. While these effects vary regionally, it is estimated that 30-90% of the world's wetlands have been destroyed or strongly modified (Junk et al. 2013). At an international level, the Ramsar Convention is an important framework to protect the world's remaining significant wetlands.

What is Ramsar?

The Ramsar Convention is a UN program that seeks to conserve the world's wetlands and their ecosystems. First ratified in Ramsar, Iran, in 1971, it is now represented by 169 countries which have at least one nominated site on the list. The main purpose of the Convention is to mitigate the worldwide loss and degradation of wetlands and this goal is now extended to the wise use of all wetlands within the signatory countries (www.ramsar.org). Today 2243 wetlands are protected under the Convention covering 216,320,717 ha of wetland habitat.

Listing involves the nomination of the site's boundaries and development of a case that the site satisfies one or more of nine criteria. Mostly the criteria relate to the site's role in hosting substantial populations of rare or vulnerable fish or bird species or communities. Signatory nations are required to produce a Site Information Sheet and are also encouraged to produce management plans within which they identify the "natural ecological character" of the site. Invariably this description is drawn from the character of the wetland at the time of, or through the period leading up to, listing.

All signatory nations are required to report to the Ramsar Secretariat if a wetland has changed, or is likely to change, from the identified condition. This invokes a pathway of committing to restore the site, offsetting it by nominating an equivalent site, or invoking "national economic interest". However, despite the Millennium Ecosystem Assessment reporting widespread loss and decline in the world's wetlands, few nations have reported change in site condition.

The mismatch between the observations of the declining extent and condition of the world's freshwater systems and the paucity of nation's reporting that their wetland has changed, or is likely to change in the future, could be interpreted as all declines occur outside the network of listed sites. This would confer considerable merit to the Ramsar Convention in mitigating the global decline in condition. However, what is more likely is that nations have been either unable to detect change, or have been reluctant to report because of the challenges of restoration, and how it may reflect their record of environmental management. In order to drive better reporting of the condition of a wetland relative to this baseline, the Convention has requested that nations identify the limits of acceptable change.

Means of determining the limits of acceptable change have been proposed based on the historical variability in a measured condition in the past (Fig. 1). However, the monitoring of wetland condition and populations of aquatic flora and fauna has a short history, even among developed nations with a strong tradition of aquatic-system research. Also, the influence of low frequency cycles of change question the representativeness of records of variability that may even span several decades. Paleoecological approaches can, and have, extended this knowledge of variability and so play an important role in the understanding of wetland change over time.

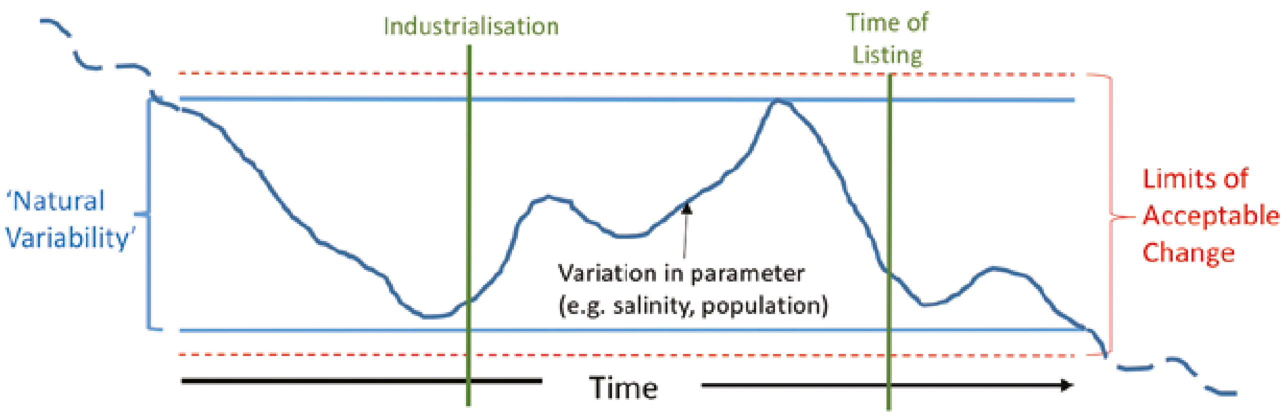

Figure 1: Theoretical approach to developing "Limits of Acceptable Change" within Ramsar wetlands (adapted from Phillips 2006). In principle, the limits of acceptable change are set just outside the margins of the range of condition as recorded from history. The dashed lines illustrate that longer cycles of change may challenge even this record of natural variability. More realistically, there is little continuous monitoring data that extends far beyond the time of listing to realistically assess variation in any parameter, and so paleoecological records are essential in defining limits.

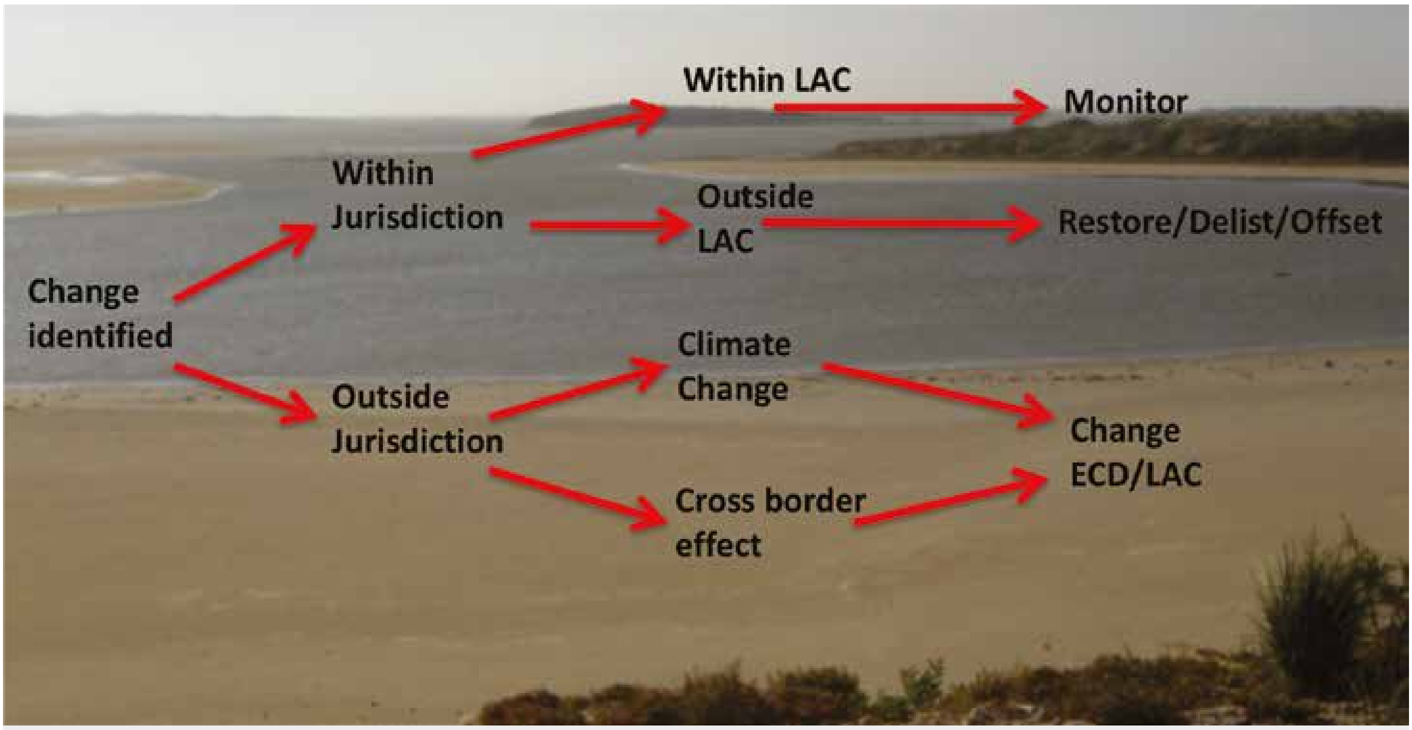

Figure 2: Proposed pathway to guide action following the identification of change to a Ramsar listed wetland. Paleoecological approaches can assist in assessing if the driver of change is within or outside the jurisdiction of the signatory party, whether it is within or outside limits of acceptable change (LAC) and whether it is in response to global climate change or a cross border effect. Nations are required to restore or offset when the change is outside long-term variability and if the driver of change is the responsibility of the signatory nation. ECD: Ecological character descriptions. Photo: The Coorong Ramsar site, Australia; Peter Gell.

Paleoecology and Ramsar wetlands

There have been many records of paleoecological research on Ramsar wetlands, although it is possible that not all researchers were aware of the status of the site at the time of listing, relative to its historical past. Evidence from the Coorong, Lower Lakes and Murray Mouth site in Australia revealed that the site description at the time of listing in 1985 reflected a condition that had changed in the 1950s (Reeves et al. 2015) and was unrepresentative of what would be considered the natural long-term baseline (Gell 2017). Ramsar sites along the Nile Delta have also been shown to have been substantially impacted in recent decades and that the present condition is a departure from the long-term baseline (Flower et al. 2001).

Paleoecological research can also provide direct evidence on the status and breeding success of significant waterbird populations. Loch Ruthven near Inverness in Scotland was listed as a Ramsar site in 1996 mainly by way of the important population of breeding Slavonian Grebe it hosts. Brooks et al. (2012) used a sediment record to relate the annual recruitment success of Slavonian Grebe, based on historical surveys, to the availability of chironomid prey for the hatchlings, as recorded in the lake sediments. The increased nutrient load is linked to larger populations of this key food item for the Grebe chicks leading to enhanced recruitment and securing one of the main criteria of the loch's listing.

PAGES has a long history of documenting the impact of people and climate on wetlands through themes, projects and working groups e.g. LIMPACS and Aquatic Transitions. Many records attest to considerable condition change both before and since the Convention began. So, from a paleoecological perspective, it is clear that long-term records have the capacity to provide better understanding of present condition in the context of variability, including the impacts of low-frequency climate cycles, as well as providing records of shifting baselines due to human impact. Acknowledging this, PAGES and the Ramsar Secretariat hosted a workshop in Queenscliff, Australia, in late 2013 to examine the opportunities that may exist, for the Convention and for paleoecological researchers, to bring a long-term perspective to the identification of character and the setting of acceptable limits to change based on knowledge of long-term variability. The proceedings of this workshop are published in a special issue of *Marine and Freshwater Research* (Gell and Finlayson 2016), including an editorial from the previous Ramsar Convention Secretary General (Davidson 2016) declaring the benefits that paleoecology can bring to more realistic assessments of the world's wetlands of international significance.

Shifting baselines and limits of acceptable change

While it remains challenging for nations to identify how current wetland conditions have deviated from long-term trends, if only a recent state is used as a baseline the failure to consider pre-listing state allows for all of the previous human impact to be excused, potentially perpetuating mismanagement in a degraded state (Finlayson et al. 2016). The Millennium Ecosystem Assessment documented widespread reduction in the extent and condition of freshwater wetlands worldwide, so it is implicit that time-of-listing condition is unlikely to reflect the range of wetland conditions before impact by industrialized society. Without long-term data, nations might continue to manage for a derived, and perhaps less productive, wetland than previously existed.

Conversely, armed with a better understanding of variability and defined limits of acceptable change, a nation is better equipped to decide when and how to act, and when to report change as being outside, or within, past historical range. Further, it is unreasonable if a nation is held to account for the change in the state of a wetland if the driver of that change is due to the actions of a neighbor (e.g. upstream), or is global (e.g. climate change) in scale. By partitioning human impact from climate, and proximal and distal causes of change, paleoecology can assist with an appropriate pathway for the Ramsar Secretariat to assess the obligation of nations to act (Fig 2).

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The importance of paleoecology in the conservation and restoration of cultural landscapes

Anneli Ekblom[1] and Lindsey Gillson[2]

Cultural landscapes are enormously biodiverse. Presently, customary management of cultural landscapes is diminishing, resulting in loss of biodiversity and landscape heterogeneity. Here, we stress the role of paleoecology and other forms of paleoscience in restoring productive and biodiverse landscapes.

Extinction rates today rival the five major previous extinction events in Earth's history. The biggest loss of biodiversity is due to land-use change, for example the conversion of forests, grasslands and other habitats through cultivation and urbanization, as well as the degradation and fragmentation of habitats (MA 2005). Stressed and fragmented ecosystems and populations are also less resilient to changing climate and other impacts such as pollution and invasive species. Restoration of ecosystem function, resilience and adaptive capacity is equally as important as maintaining species richness; therefore, different land-management options need to be considered. Intensive agricultural systems provide little wildlife habitat, whereas many land areas under traditional management (e.g. small-scale, low-intensive agricultural practices, referred to hereafter as customary) are significant havens for biodiversity (Fischer et al. 2012; Gillson 2015). Many cultural landscapes are biodiverse and are considered as important conservation targets (Agnoletti 2014). For example, cultural landscapes are now part of the International Union for Conservation of Nature protected areas classification. However, many customary management techniques have been eroded due to socio-economic pressures, with a subsequent loss of biodiversity and landscape heterogeneity. There is therefore a need to review customary management practices and the landscapes they produce, and to revive and reinforce the adaptive management techniques that are embodied in traditional land-use systems.

A role for paleoecology in landscape management

There is a role for paleoecology and other forms of long-term science in restoring productive, biodiverse landscapes. In many areas of Europe, rural land abandonment has led to the degradation of semi-natural woodlands, meadows and heathlands due to the discontinuation of customary practices (Weissteiner et al. 2011). Many species of high conservation value are specifically associated with these cultural landscapes and require a continued and active management. In Europe, 55 of the 231 listed habitat types of European interest depend on, or benefit from, continued customary practices (EEA 2011).

Paleoecological and historical studies have consistently shown a decrease in biodiversity associated with the loss of customary land-management practices, and higher biodiversity associated with low-intensity land uses, which generate mosaics of wooded and grassy habitats. For example, Swedish semi-natural woodpastures and forest meadows are important examples of relict cultural landscapes in Europe. Paleoecological research has shown a decrease in the diversity of forest taxa within the last centuries as the result of the reduction in grazing and mowing practices and accompanying canopy closure, with detrimental effects on the mixed deciduous forests trees such as lime (linden) and beech. Paleoecological knowledge has been important in the management of these landscapes (Bradshaw and Lindbladh 2005). Similarly, remnants - a function of old grazing practices, such as oak meadows (oak savannas) - are now threatened through the lack of grazing and management (Fig. 1). Dahlström et al. (2008) show that the highest species richness in plants in central Sweden is found in what today is semi-natural grassland subjected to a long continuity of grazing. It is estimated that since 1870, 99.7% of the semi-natural hay meadows have been lost, the few remaining semi-natural hay meadows are now managed mainly for conservation purposes. In this case, long-term data may provide knowledge on management practices that have now been lost.

In Tuscany, Italy, there has been a 45% decrease of landscape mosaics between 1832-2004, due to the combination of EU regulations in the agricultural and forestry sectors (Agnoletti 2006; Fig. 2). Historical analyses show that meadows and chestnut orchards

Figure 1: Oakmeadow, central Sweden, is regularly grazed by cows to maintain the open meadow vegetation. Photo: Siri Pettersson.

Figure 2: Tuscany landscape. Photo: Martin Falbisoner, Wikimedia Commons.

are being replaced by forest expansion, with an overall loss in landscape heterogeneity, biodiversity and ecosystem services. Pastoral customary practices often combine grazing with fire management to maintain wood pastures, but since the 18th century many state authorities have actively used fire both in agriculture and forestry. Shakesby et al. (2011) showed an increase in wildfire and erosion following rural land abandonment in the Mediterranean region, associated with increased shrub cover and afforestation with flammable species. Paleoecological studies in the Pyrenees have shown that these pastoral landscapes have been systematically managed by fire over millennia (Mazier et al. 2006) and similar results have been shown for the Iberian Peninsula (Gil-Romera et al. 2010). In Scandinavia, the ecological role of fire in both semi-natural and old growth forests is now being realized (Bradshaw and Hannon 2006). In the Finnish boreal forests, dominated by the conifers Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), local slash-and-burn practices were common until the early 20th century. The mixed forests and grazing lands within the boreal forests are now experiencing a degradation and reduction in species diversity as slash-and-burn practices have been discontinued (Myllyntaus et al. 2002). In other parts of Scandinavia, the historical importance of fires in the boreal forests is shown by the presence of fire-adapted species (Bradshaw and Hannon 2006). In all cases listed above, paleoecological knowledge is essential in managing and restoring landscapes, and for the protection and management of rare species through sound management practices (Gillson 2015).

The importance of co-learning

With only 12% of land in protected areas globally, conservation strategies are needed that integrate food production and biodiversity conservation. Intensive agricultural systems provide little wildlife habitat, whereas many land areas under customary management are compatible with biodiversity conservation and provide a wider range of ecosystem services. Cultural landscapes are now an important conservation target, but many customary systems have been eroded due to socio-economic pressures.

Alongside historical studies and stakeholder participation, paleoecological data can help to identify periods of time in which biodiversity and food production co-existed, enabling realistic future scenarios to be envisioned (Gillson 2015). Landscape management needs targets for both the extent and configuration of habitats needed to maintain species, plus political arenas where stakeholders can resolve (the inevitable) conflicts arising from different land-use practices and goals (Angelstam 2006). Rural areas where customary practices are in use today are often either marginal or remote with poorly developed infrastructure, and areas that typically lie very far from the centers of political power where decisions are made. As most biodiversity protection will have to be provided by local initiative and through local practices, we need to better understand and encourage local interest in building and maintaining cultural landscapes. Most importantly, local practitioners, farmers and smallholders or herders must have a place at the negotiating table. Co-learning and co-production of landscape management plans can help to foster ecological and social resilience, as well as nurturing social cohesion and a sense of place, resulting in more effective landscape stewardship.

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Geogenomics – integrating geology and phylogenetics to unravel the evolutionary history of Earth and its biota

Sherilyn C. Fritz[1] and Paul A. Baker[2]

Phylogenetic data have great potential for testing hypotheses about the nature and timing of geological and climatic events. We provide examples of how phylogenies have been used to constrain environmental history and propose the broader use of this approach.

Phylogeography investigates the evolutionary history (phylogeny) and spatial structure of groups of organisms (Avise 2000), often linking the history of biological lineages to Earth history. In this approach, similarities and differences in the genetic composition of various contemporary species or taxonomic groups are used to establish evolutionary relationships (phylogenetics), and this evolutionary history is time calibrated using dated fossils and molecular clock calculations. In phylogeography, the time-calibrated history of descent is subsequently related to coincident geologic events, such as mountain uplift, river formation and migration, glaciation, or climate change. These events may have created barriers to dispersal and fragmented populations (vicariance) or alternatively generated corridors for migration that increased gene flow among populations. The explosive development of genetic sequencing technologies has resulted in a proliferation of recent phylogeographic studies that reconstruct the evolution of life and link the history of diversification and speciation to the evolution of the environment.

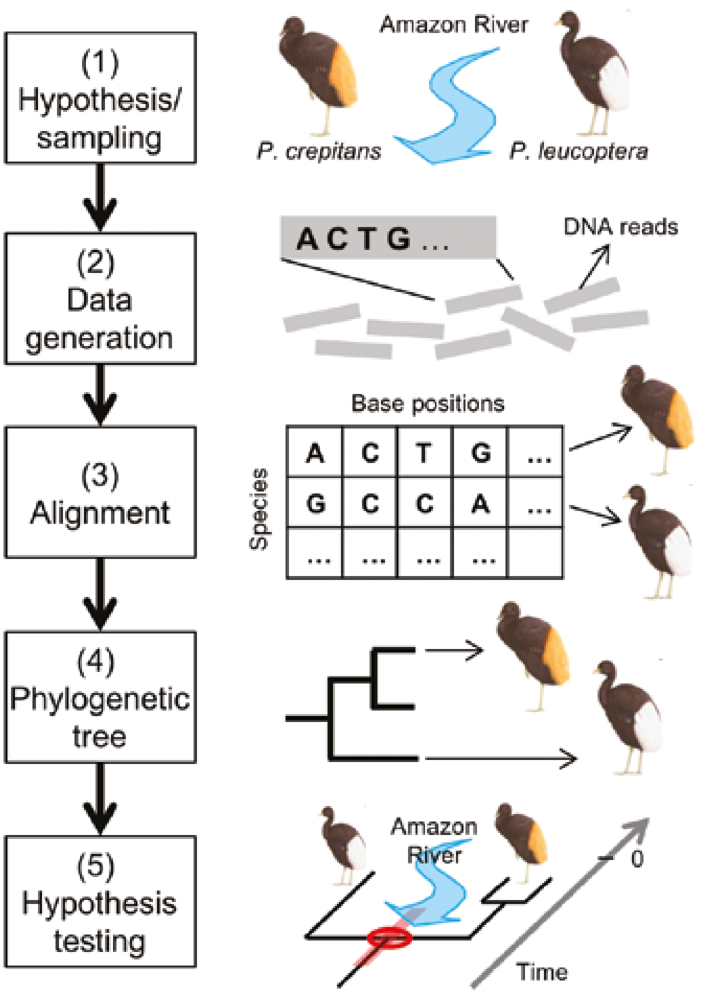

Figure 1: A schematic diagram showing how phylogenetic data on modern flightless bird populations has been used to test the timing of the formation of a river system. The phylogenetic tree defines the evolutionary relationship between bird species that occupy different river drainages in the Amazon, and the dated branching points in the phylogeny suggests events that split populations and led to genetic isolation and subsequent speciation. From Baker et al. 2014, reprinted with permission from Elsevier.

This process of studying the role of geological and climatic processes in the evolution of ancient lineages also has been called "phylogeology" (Acosta et al. 2014). Such studies rely on a well-constrained history of geological and climatic events.

Often, the nature and timing of geological events is not well constrained, and contrasting scenarios of various aspects of Earth history have been proposed in the literature. We suggest that, in some of these cases, the most common direction of study, relating phylogenetic divergences to geological events, can be inverted, such that time-calibrated phylogenetic trees can be used to inform environmental history. We call this new integrated discipline of testing geologic scenarios with genetic data "geogenomics" (Baker et al. 2014). Here, we summarize a few recent studies that use phylogenetic data to constrain geologic history. In presenting these examples, we hope to encourage additional geogenomic investigations and increased communication among evolutionary biologists and geologists.

The evolution of riverine barriers

A study by Ribas and colleagues (2013) of trumpeters, a group of flightless birds that exhibits a high degree of endemism, with different species occupying different drainage basins of the Amazon River system, first stimulated our interest in geogenomics and its potential for advancing understanding of Earth history (Baker et al. 2014). The timing of the development of the current trans-continental drainage pattern of the Amazon River is hotly debated, with estimates ranging from Miocene to Quaternary. Ribas and colleagues used a phylogenetic analysis of trumpeters to test different models of the geomorphic evolution of the river (Fig. 1). The analysis showed that diversification of trumpeters occurred relatively recently, between 3 and 0.5 Ma (millions of years ago), consistent with the more recent (Plio-Pleistocene) estimate for the establishment of trans-continental drainage. Moreover, the pattern of divergence between one clade (a group of organisms with a common ancestor) and another was used at finer resolution to constrain the ages of several major Amazon tributaries. Thus, the phylogenetic data were used to generate a testable hypothesis of geomorphic evolution.

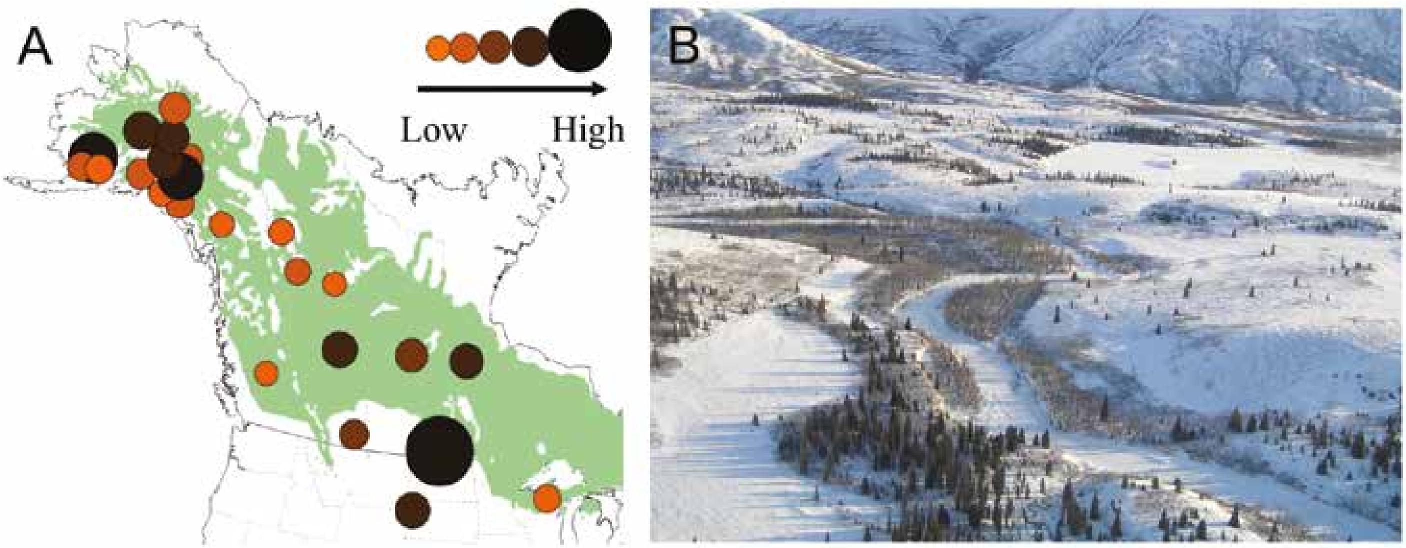

Figure 2: (A) The genetic diversity (chloroplast DNA haplotypes) of white spruce populations across northern North America. High genetic diversity suggests population persistence for long periods, spanning back through glacial times. **(B)** Isolated spruce populations, similar in density to the refugial populations envisaged during intervals of North American glaciation. From Hu et al. 2009, reprinted with permission from the Ecological Society of America.

The Great American Biotic Interchange

For many years, the Great American Biotic Interchange (GABI) between North and South America (Marshall 1988) was thought to be driven by the closure of the Isthmus of Panama and the generation of a continuous corridor of land between the two continents, dated at about 3 Ma. Yet recent geological studies (Montes et al. 2015) suggest a much earlier age for the closure (15-13 Ma), a hypothesis that is being contested in the geologic literature (O'Dea et al. 2016). Bacon and colleagues (2015) used molecular divergence dates, coupled with fossil data, to evaluate the timing of dispersal and vicariance in several different groups of organisms. Their analysis suggested a dramatic increase in the number of terrestrial taxa migrating between the continents about 3 Ma, but it also indicated increased migration during two earlier periods of the last 23 Ma, consistent with an earlier date for a land-based connection between North and South America. Similarly, marine organisms showed divergence in genetic structure consistent with an earlier separation of eastern and western populations by an emergent land bridge.

The hypothesis of an earlier (Miocene) closure of the Isthmus of Panama also has raised the question of whether the 3 Ma date for GABI derived from paleontological data is robust and also whether a different environmental event facilitated an increase in bi-directional exchange. One possibility is that faunal exchange was enabled by the expansion of savanna in the Central American corridor, caused by altered atmospheric circulation patterns associated with the onset of Northern Hemisphere glaciation. This hypothesis was proposed decades ago by several vertebrate paleontologists who first studied GABI, because many of the mammals involved in the exchange are adapted to savanna (Webb 1978). Bacon and colleagues (2016) conducted a subsequent phylogenetic analysis of mammals involved in GABI and calculated that the majority of changes in genetic structure between the continents occurred between 4 and 3 Ma. While this analysis does not address the nature of the environmental trigger, it does confirm paleontological estimates of the timing of major biotic exchange.

Glacial refugia

Molecular genetic studies have revolutionized our understanding of the dynamics of plant populations following the retreat of continental ice sheets and montane glaciers at the end of the Pleistocene. In the Northern Hemisphere, paleoecological studies have used transects of pollen data to establish rates of migration and range expansion of tree populations that were thought to have survived glacial intervals in regions to the south and then migrated northward as the ice sheet retreated and climate warmed (Davis and Shaw 2001). More recently, however, population genetic studies of northern tree populations (Hu et al. 2009) have suggested that some species, such as white spruce, survived in refugia as small populations in areas adjacent to the ice sheet and subsequently expanded from these local areas to establish their current biogeographic distribution (Fig. 2). These new data have significant implications for calculations of potential tree dispersal rates and evaluating biological resilience to climate change. Early pollen analyses from Patagonia (Markgraf 1993) proposed that southern beech, *Nothofagus*, survived during glacial times in refugia on the now submerged coastal lowlands, rather than migrating long distances from the mid-latitudes, but this conclusion was controversial when originally proposed. Yet recent population genetic data (Premoli et al. 2010) indicate that species of *Nothofagus* persisted during glacial intervals both in ice-free regions of Patagonia, as well as in periglacial areas. Thus, a growing body of phylogenetic data indicates that in many regions small refugial tree populations persisted on the landscape through intervals of unfavorable climate.

Prospects for the future

The examples provided above suggest the potential for phylogenetic reconstructions to be used in generating or testing hypotheses about geological and environmental history. Doing so necessitates a well-developed understanding of the assumptions and uncertainties involved in phylogenetic reconstruction, just as biogeographic calibration of phylogenies based on geological data requires explicit accommodation of dating errors and an understanding of the mode and rate of the geological processes involved (De Baets et al. 2016). This need for a bi-directional flow of information suggests the value of expanded collaboration between geologists and evolutionary biologists in exploring the linkages between the evolution of life and the physical environment, and in furthering our understanding of the vital linkages between the biosphere and geosphere.

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Integrating paleoecology and phylogeography reveals congruent bioclimatic regions in the Brazilian Atlantic forest

Marie-Pierre Ledru[1], A.C. Carnaval[2], C.Y. Miyaki[3] and "AF Biota" project participants[4]

The integration of paleoecological studies and genetic data from various Brazilian Atlantic forest organisms reveals three main regions of contemporary spatial distribution of genetic diversity related to late Quaternary shifts in monsoon activity.

The Atlantic forest is the second most biodiverse domain in Central and South America after the Amazonian rainforest. Its distribution today has been strongly reduced to less than 16% of its original cover because of intensive deforestation. The Atlantic forest covers a large region along Brazil's 4000 km coast, from the Equator to 30°S (Fig. 1), and consequently is subject to a wide range of climatic conditions. These geographical characteristics, combined with a wide altitudinal range, resulted in one of the highest degrees of species richness and rates of endemism on the planet (Joly et al. 2014).

Three paleoclimatic regions

Modern regional climatic behaviors and past forest expansion and regression phases revealed by fossil pollen records (Ledru et al. 2016) define three main areas within the Atlantic forest: North Atlantic Forest (NAF) between 5° and 15°S, Central Atlantic Forest (CAF) between 15° and 23°S and South Atlantic Forest (SAF) from 23° to 30°S. NAF has a moist, cool, semi-deciduous forest restricted to coastal zones, lowland gallery forest and mountaintops. An evergreen forest was well developed during the late glacial instead of a deciduous forest (Fig. 2). CAF is composed of coastal forest patches of mainly dense evergreen forest, whereas more inland areas are occupied by semi-deciduous forests. The evolution of the CAF shows several phases of expansion and regression during the past 17 ka, which are linked to the precession cycle of the insolation (Ledru et al. 2009). SAF hosts *Araucaria* or mixed evergreen forest characterized by the presence of species adapted to cooler and wetter climates. The SAF expanded into the central region replacing the semi-deciduous forest during the late glacial, and since 3 ka is progressively expanding to the south (Fig. 2). This observation is in agreement with model predictions (Salazar et al. 2007). Two fossil pollen records from an interior northern site (Caço Lake, currently not forested) and from the central region (Colônia, currently forested) indicate that the expansion of the Atlantic forest cover was out-of-phase between these two regions - the northern site witnessed forest expansion from 17 ka to the beginning of the Holocene, while the central forest cover retracted (Ledru et al. 2016). Additional paleoecological datasets likewise indicate considerable expansion of the (nowadays small-ranged) northern forests during the deglaciation (17 to 12 ka; Wang et al. 2004).

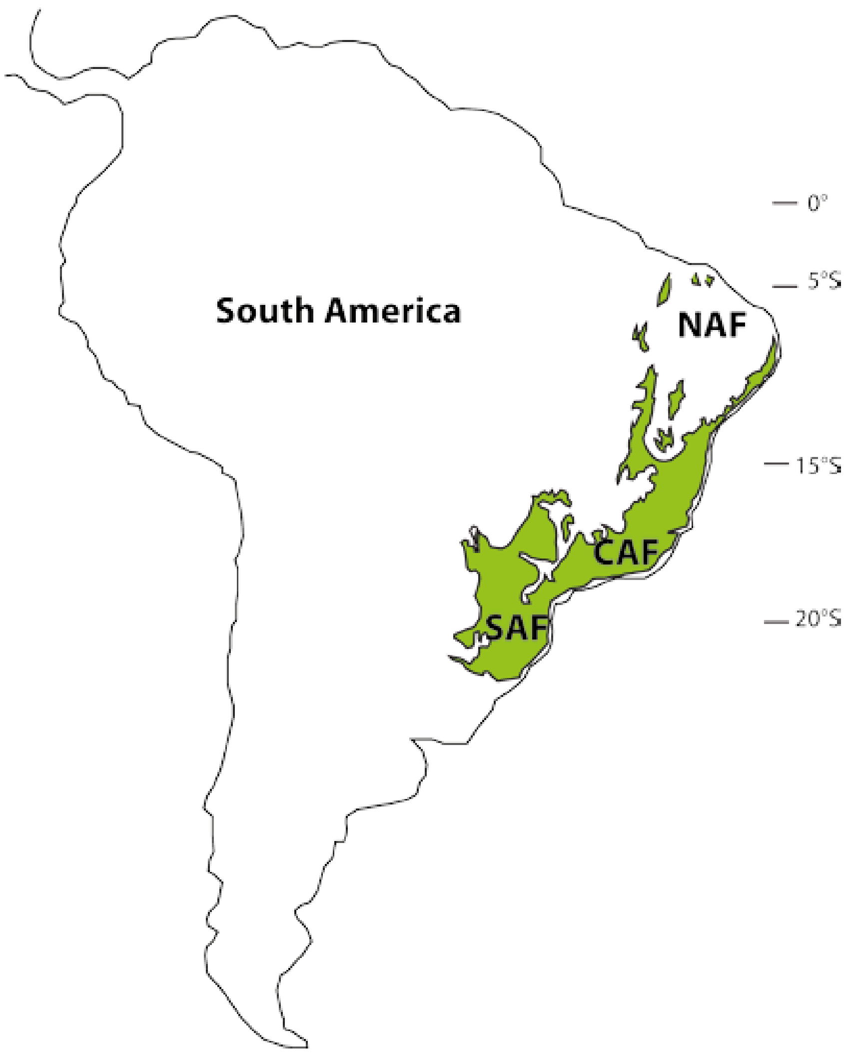

Figure 1: Map showing the modern distribution of the Brazilian Atlantic forest with three main regions. NAF: North Atlantic Forest; CAF: Central Atlantic Forest; SAF: South Atlantic Forest.

Genetic diversity

Comparative phylogeographic data from plants and animals provide a direct link between asynchronous Late Quaternary climatic shifts, the historical demography of forest-depended species, and genetic diversity patterns we observe today. If animal populations in the south have been tracking the Atlantic forest expansion in the late Holocene, then signatures of population expansion should be detected in DNA sequence data from multiple species. For instance, when a population becomes isolated, the succession of the generations within this population will generate new DNA imprints that will differ from the DNA imprints of the remote populations. On the other hand, populations restricted to northern, inland, highland sites must have been exposed to forest contraction over the same period and hence show genetic evidence of strong population bottlenecks that will reduce the diversity. NAF coastal populations, presumably exposed to permanently humid conditions throughout the last 21 ka (Carnaval and Moritz 2008; Carnaval et al. 2009), are expected to show high levels of genetic diversity due to climatic stability. Genetic data from coastal populations in the SAF confirm this hypothesis and show much lower levels of genetic diversity relative to NAF coastal populations, tied to genetic signatures of expansion and colonization that date post LGM. This pattern is detected in a vast array of forest taxa, including frogs, lizards, birds, bats, and plants (e.g. Cabanne et al. 2008; Carnaval et al. 2009; Fitzpatrick et al. 2009; Martins et al 2009; Ribeiro et al. 2010; Fig. 2). Post-3 ka colonization of the SAF is also seen in frogs and plants (Ramos et al. 2009; Carnaval et al. 2009). In turn, lineages restricted to mountaintop Holocene forest refugia in inland northeastern Brazil are narrowly endemic and show signatures of recent bottlenecks, presenting low levels of diversity (e.g. Ramos et al. 2009).

Climatic and diversity barriers

These asynchronous patterns of forest movements over the last 17 ka were tracked by various forest organisms, and largely determined contemporary spatial patterns of genetic diversity. Shift in monsoon activity, from north to south and south to north, driven by the precession cycles, led to significant differences in precipitation patterns (Cruz et al. 2005) and, thus, in the tempo and mode of rainforest contraction and expansion in lowland and mid-altitude tropical areas. This mechanism must have triggered strikingly different demographic trajectories between northern, central and southern species pools within forests distributed among this gradient. Such tracking of forested environments by whole tropical assemblages or species pools should largely explain contemporary patterns of genetic diversity in these tropical regions. In the Brazilian Atlantic forest, proposed forest refugia and areas of high genetic diversity and endemism match areas within the sea-saw monsoonal sector that were permanently moist over the last 17 ka. The three bioclimatic regions evidenced by phylogeography are located in the three paleoecological and paleoclimatic regions revealed by pollen records and related to past fluctuant monsoon activity at these latitudes.

The use of plant fossil information and genetic data from forest species to illustrate past climatic shifts and their associated responses from the fauna and flora of eastern South America question the timescale and pace of diversification, the role of refugia in

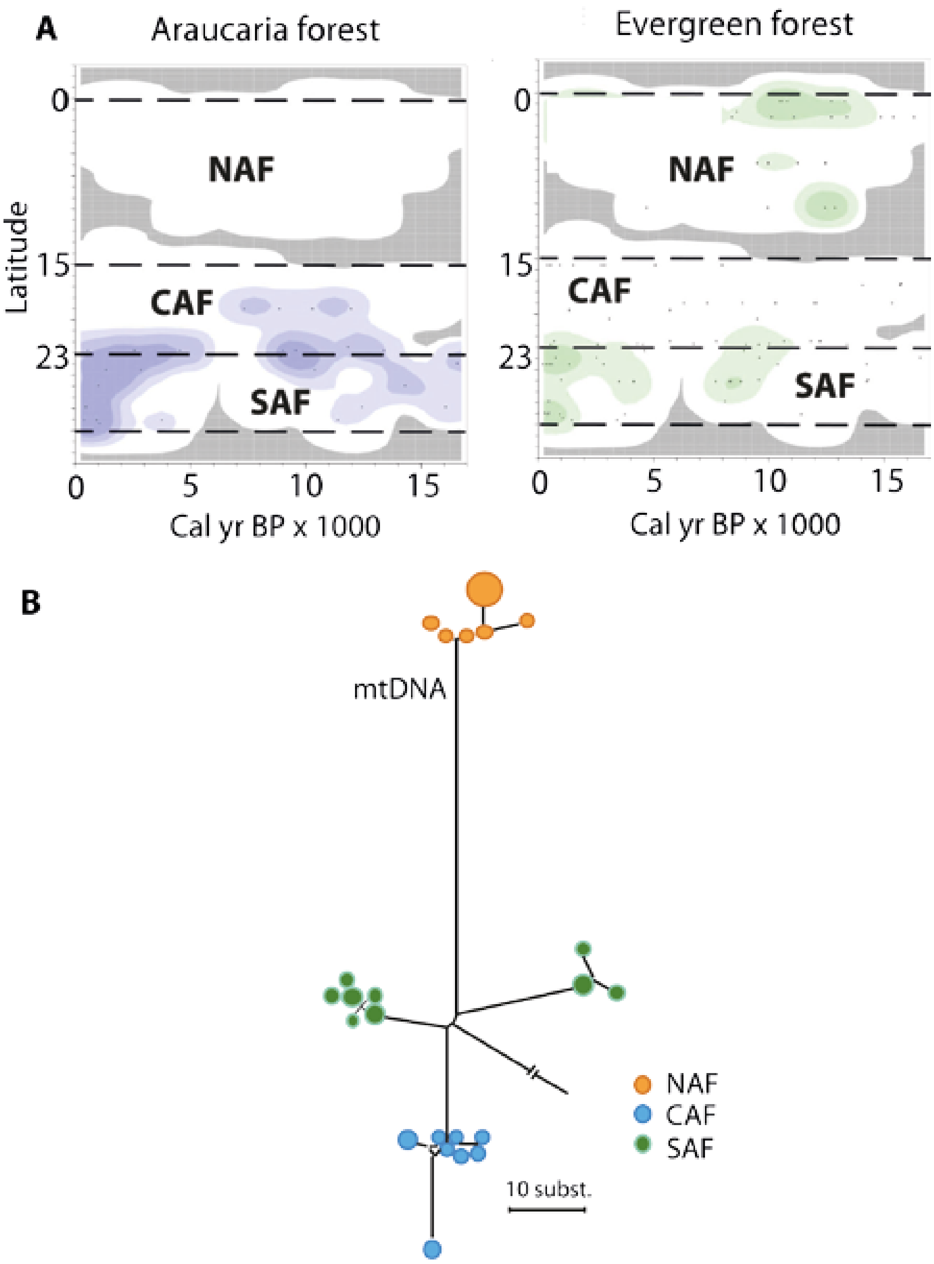

Figure 2: Paleoecology and biodiversity in the Brazilian Atlantic forest with: **(A)** Changes in the spatial distribution of groups of pollen taxa from Araucaria and evergreen forests as a function of time and latitude (modified from Ledru et al. 2016). Darker colors represent higher pollen concentrations. **(B)** Network showing relationships among mitochondrial DNA sequences of a bird species (modified from Cabanne et al. 2008). Each circle represents a sequence and their sizes are proportional to their frequency in the sample, the length of the lines represents the number of differences, and colors represent main areas (NAF, CAF and SAF). Note that two subgroups were distinguished within the SAF, but factors other than the monsoon shifts may have caused this separation.

tropical forest dynamics and the species-level tolerances to climate change.

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What do we mean by regime shift? Distinguishing between extrinsic and intrinsic forcing in paleoecological data

Alistair W.R. Seddon

"Regime shifts" are abrupt changes in ecosystem function and state commonly observed in paleoecological records. Understanding whether they represent a linear response to an abrupt external forcing, or are the product of intrinsically mediated dynamics, remains an important distinction.

Ecological theory indicates that ecosystems can experience "regime shifts" – abrupt changes between two or more ecological states, each characterized by their own dynamics, stochastic fluctuations, or cycles (Scheffer 2009). The paleoecological record provides numerous examples of potential regime shifts, but interpreting the dynamics underlying these changes remains a major challenge. On the one hand, ecological regime shifts may represent linear responses to an external forcing; alternatively, they may be the result of a series of intrinsic ecological mechanisms (Fig. 1). Here, I provide a summary of some of my own recent work that aims to distinguish between extrinsically forced and intrinsically mediated transitions, noting that care must be taken not to conflate these different types of regime shifts when interpreting abrupt changes in the paleoecological record.

Theoretical framework

A theoretical framework for understanding abrupt ecosystem change was proposed by Williams et al. (2011), contrasting extrinsically forced against intrinsically mediated ecosystem responses to an environmental forcing (Fig. 1). Abrupt biotic responses as a result of changes in climate during the cooling into, and subsequent warming out of, the Younger Dryas were used as examples of extrinsically forced ecosystem change. In contrast, intrinsically mediated responses result from a combination of site-specific abiotic factors (e.g. soil characteristics, groundwater regime and physiography), or from local-scale biotic processes (competition, facilitation and disturbance) (Williams et al. 2011). Under these conditions, abrupt ecological changes can occur following only a gradual external forcing (e.g. Holocene transitions at the prairie-forest boundary in the North American Midwest).

One type of intrinsic regime shift that has become of particular interest to paleoecologists are fold-bifurcation-type transitions (Fig. 1h), in which positive feedbacks lead to sudden and abrupt transitions in response to slow forcing mechanisms. For example, in shallow lake ecosystems, theory indicates that transitions from clear to turbid waters are the result of a loss of system resilience through gradual nutrient loading (Scheffer et al. 1993). The feedbacks associated with maintaining a system in the turbid state mean that managing a transition back to the original state can be difficult to achieve. Because such "critical transitions" can occur with little apparent warning, understanding their mechanisms has become a major focus for the ecological science community. Furthermore, critical transitions and their associated loss of resilience have been proposed to have been observed a number of times in the paleoecological record.

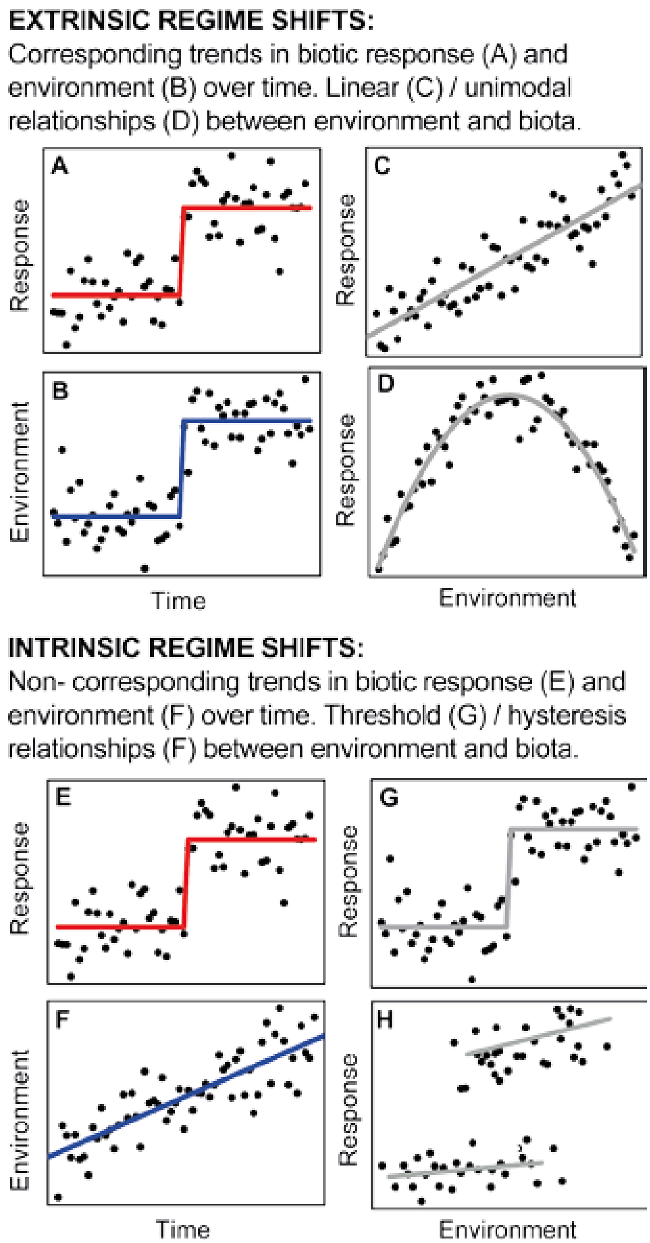

Figure 1: Framework used to identify intrinsic vs. extrinsic regime shifts (modified from Seddon et al. 2014). Equivalent trends in control and response variables, combined with linear or unimodal response functions represent extrinsic regime shifts **(A-D)**. Gradual changes in control variables, combined with an abrupt shift in the response variable are more likely to represent an intrinsically mediated response **(E-H)**.

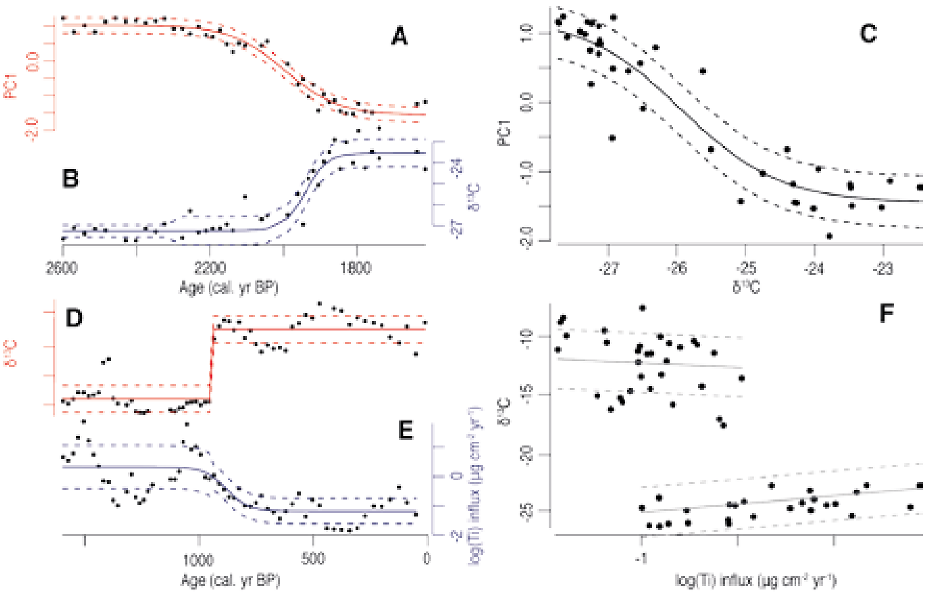

Figure 2: Evidence of extrinsic and intrinsic regime shifts at a coastal lagoon in the Galapagos Islands (modified from Seddon et al. 2014). **(A, B)** Example of an extrinsically forced regime shift. A change in habitat conditions (as detected by $\delta^{13}C$ analysis of the bulk sediment) result in an equivalent response in the diatom assemblage data in the lagoon (as described by the first principle component of a PCA on the diatoms) with a curvilinear response function **(C)**. **(D, E)** Potential evidence of an intrinsic regime shift. Minimal changes in the surrounding landscape (e.g. tidal disturbance events represented by geochemical data) result in an abrupt transition from mangrove (low sediment $\delta^{13}C$) to microbial mat (high sediment $\delta^{13}C$). Standard GNLS modeling was unable to adequately describe the relationship between the two variables, so the data were split at the major change in $\delta^{13}C$ and two separate models were fitted to demonstrate the dual relationship with the control variable **(F)**.

One of the key insights presented in the framework presented by Williams et al. (2011) is that abrupt ecological responses can occur as a result from both linear and non-linear dynamics. This is important to recognize, because not all abrupt changes observed in the paleoecological record might represent intrinsic regime shifts. The challenge for paleoecologists is to develop the tools and techniques that can be used to disentangle extrinsic and intrinsic responses.

Distinguishing extrinsic and intrinsic regime shifts

One key challenge for studying regime shifts in paleoecological data is the unevenly spaced samples resulting from variability in sedimentation rates. A generalized non-linear least squares (GNLS) regression model can be used to account for this issue, which enables detection of changes in mean and variance between two variables, whilst simultaneously accounting for temporal dependence of data points which are unevenly spaced in time (e.g. Randsalu-Wendrup et al. 2012; Seddon et al. 2014). An additional advantage of GNLS is that a variety of trends can be implemented (e.g. linear, quadratic, logistic), meaning that trends in time series (i.e. ecological variable regressed against sample age) and response functions (ecological variable regressed against environmental driver) can be determined.

Seddon et al. (2014) used GNLS to distinguish intrinsic and extrinsic dynamics in a late-Holocene coastal-lagoon sequence from the Galapagos Islands. Following the framework from Williams et al. (2011), they used independent proxy data to reconstruct a range of habitat and coastal disturbance changes in the lagoon, and statistical modeling to describe the trends in both diatom assemblage and environment across major biotic transitions, and the response functions between these variables. Linear or unimodal relationships between control and response variables, in addition to corresponding trends in the two-temporal series, were assumed to represent extrinsic regime shifts, whilst a slow or gradual change in the control variable, corresponding to an abrupt response, would provide statistical evidence of the importance of intrinsic mechanisms (Fig. 1).

The major diatom regime shifts observed in the lagoon showed the general characteristics of an extrinsic forcing (e.g. Fig. 2a-c). Given the fast generation times of the diatoms relative to the temporal resolution of the diatom record, perhaps this is not surprising (Hsieh and Ohman 2006), although critical transitions in diatom assemblages (i.e. intrinsic regime shifts) have been suggested elsewhere (Scheffer 2009; Wang et al. 2012). In contrast, the stable isotope data, representing transitions from a mangrove-dominated system to a microbial mat, appeared to occur at a time of limited salinity and other local environmental changes, hinting at evidence for intrinsic rather than extrinsic dynamics (Fig. 2d-f).

An alternative approach is investigating evidence for extrinsic responses from multiple paleoecological records. According to their framework, Williams et al. (2011) suggested that biotic responses to large extrinsic climatic drivers, such as those occurring during the last deglaciation, would be indicated by near synchronous responses across a large area. To investigate this, Seddon et al. (2015) applied a generalized additive mixed modeling approach to a series of ten high-resolution pollen records from Northern Europe. The modeling procedure tested whether a single smoother (i.e. pan-European, synchronous response), or multiple smoothers (i.e. individual site response) was the better explanation of the variance observed in the datasets. Results indicated that, during the early Holocene, vegetation changes provided evidence of similar behavior across sites, thus suggesting an extrinsic response.

Limitations and outlook

The studies outlined here represent just a few examples which have used quantitative approaches to identify and understand abrupt transitions. However, whilst these statistical methods are useful for identifying overall trends and associations within and between ecological and environmental temporal series, they do not fully characterize underlying mechanisms. Studies which can combine paleoecological data with process-based modeling are a challenge, but may be particularly useful for understanding the local-scale feedbacks, facilitation and competitive effects that mediate intrinsic responses in the paleoecological record (e.g. deMenocal et al. 2000; Jeffers et al. 2011).

A second limitation is that they are dependent on the availability of independent proxy data – using the framework outlined in Seddon et al. (2014) only works if all the key environmental forcing variables are available. Approaches such as early warning indicators, which use the underlying theory of critical slowing down to infer that fold bifurcations have occurred, have the potential to bypass this issue, but at present remain difficult to apply to paleoecological data on account of their sensitivity to unevenly spaced samples (Carstensen et al. 2013). Despite these limitations, statistical approaches can be used in conjunction with long-term ecological data in sediments to provide insights into the underlying dynamics of abrupt ecological transitions. Whether such transitions represent intrinsically mediated dynamics, or are the result of a linear response to an abrupt external forcing, remains an important distinction when interpreting abrupt changes in paleoecological records.

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The big data revolution and paleoecology

Sandy P. Harrison

Big data has revolutionized science. Cultural and practical issues have limited its impact on paleoecology, despite the field's long history of data synthesis. We need stakeholder interactions and outside-the-box thinking to maximize scientific benefits in the big data era.

Access to increasingly large quantities of data and enhanced data sharing through open-access databases have revolutionized many areas of science. The huge volume of astronomical observations generated by the Gaia mission have contributed to advances in fundamental physics. The explosion of human genomics data has led to better understanding of the causes of diseases and the development of personalized treatments. Multi-sensor Earth-observation data are being used to understand climate variability better and monitor environmental responses to changes in atmospheric composition, land use and climate. Connecting climate observations with economic data is enabling the implementation of sustainable agricultural practices; connecting climate information with energy-sector data is allowing projections of the response to climate variability to be factored into energy management practice. Thus, the big data revolution is not just about the amount of data or the use of high-powered statistics. It is about data being exploited to answer completely different types of questions from the ones for which they were originally collected.

Paleoenvironmental datasets have a long history, starting with the datasets created by CLIMAP (Climate: Long range Investigation, Mapping and Prediction) and COHMAP (Co-operative Holocene Mapping Project) in the 1970s and 80s. Several community databases originated in the 1980s, including the Global Lake Status Database (Street-Perrott et al. 1989), the International Tree Ring Database (https://data.noaa.gov/dataset/international-tree-ring-data-bank-itrdb) and the European (www.europeanpollendatabase.net) and North American (www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/pollen) Pollen Databases. Archives have subsequently been created for other kinds of paleoenvironmental records. These databases facilitate comparisons among records, regional paleoecological and paleoclimatic reconstructions, evaluation of paleoclimate modeling results and other applications.

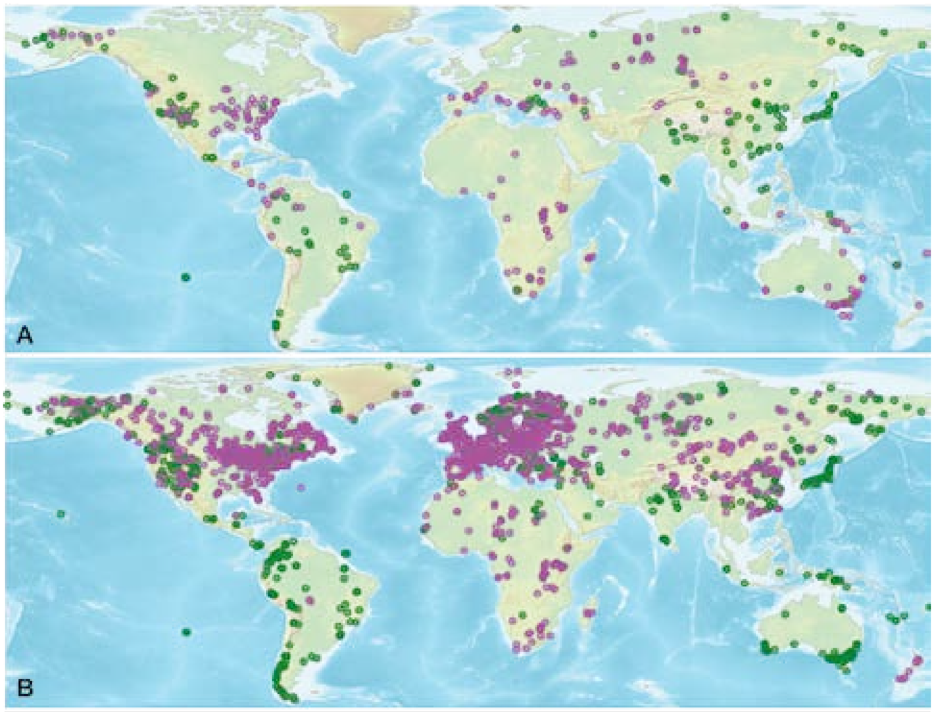

Figure 1: Pollen data are the most widely-distributed source of quantitative paleoclimate reconstructions used to evaluate model simulations of the mid-Holocene (MH) and Last Glacial Maximum (LGM). However, there are large gaps in the data coverage although many more pollen sequences are available from public-access databases that could be used for reconstructions. The maps show the distribution of sites for **(A)** LGM and **(B)** MH, where magenta dots represent sites with climate reconstructions (Bartlein et al. 2011; Prentice et al. 2017), and green dots represent pollen sites where it would be possible to make quantitative reconstructions (data from BIOME 6000 database; https://doi.org/10.17864/1947.99 and from the EMBSeCBIO database; Cordova et al. 2009).

Benefits of (big) data sharing

Data sharing is now firmly embedded in the scientific culture. Several factors have contributed to this development, including the activities of the research groups developing databases, national and international funding agency policies that mandate open-access publication and data archiving, journal rules that increasingly specify that original data must be available for scrutiny and replication of results, the increasing number of journals dedicated solely to publishing data sets, the increasing ease of obtaining persistent identifiers for data sets, and the recognition that openness about data increases research impact (Piwowar and Vision 2013). However, these advances have not led to a revolution in the approach to data in paleoecology. There are regional analyses (e.g. Huntley et al. 2013) and some global analyses of paleoecological data sets (e.g. Daniau et al. 2012). But the scientific focus is still largely on documenting changing vegetation patterns (e.g. Prentice et al. 2000) or reconstructing climate (e.g. Bartlein et al. 2011) – goals that date from the 1970s and provided the original motivation for the construction of paleoecological databases. Far more could be done using the data that now exist (Fig. 1).

As one example, a large community of ecologists focuses on plant functional traits and how community-mean trait values change along environmental gradients. At a fundamental level, this research seeks to explain aspects of the function of plants and ecosystems (Ali et al. 2015). Trait-based analyses are also being used to explore the controls on within- and between-site diversity (Ackerly and Cornwell 2007) and to develop vegetation models based on fundamental principles rather than empirical relationships (Fyllas et al. 2014). Ecologists are also exploring how species and ecosystems respond to climate change, on shorter (acclimation) and longer (adaptation, migration) timescales. There is growing literature on how the velocity of climate change affects species' potential for adaptation and migration (e.g. Loarie et al. 2009) and extinction risks for different groups of organisms (Settele et al. 2014). These are all important questions, with implications for conservation policy; paleoecological data should have a great deal to say about all of them.

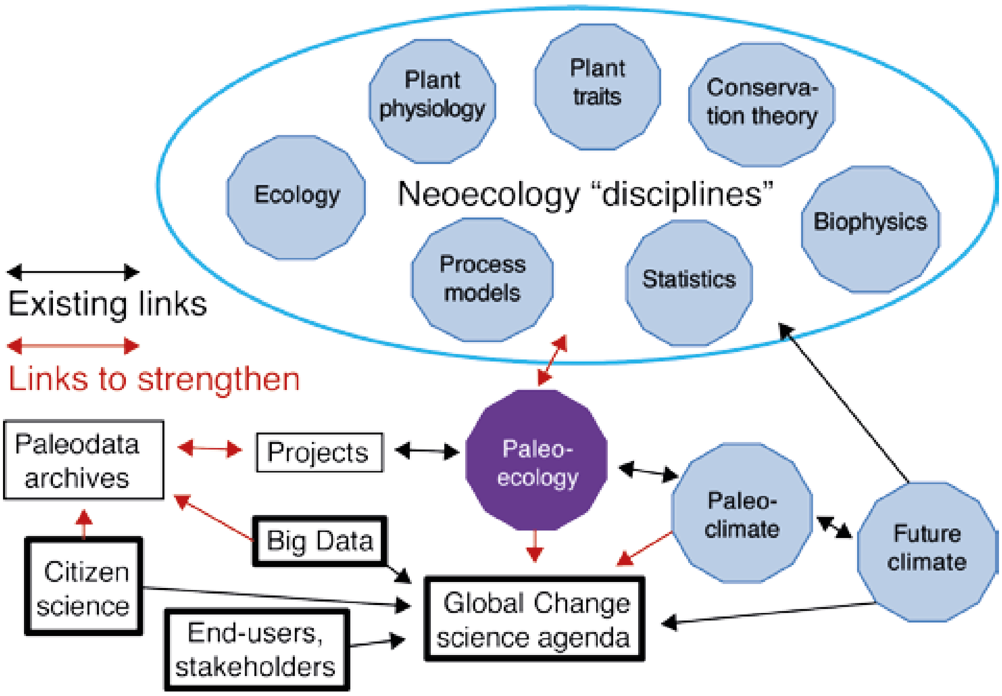

Figure 2: Conceptual diagram of the current and potential position of paleoecology (purple polygon) in the global change scientific framework, showing areas where relationships to other sciences (blue polygons), data sources and stakeholders could be strengthened to optimize the value of paleoecology to address real-world issues.

What stops us embracing big data?

Why has paleoecology missed out on the big data revolution? Contributory factors include the labor-intensive nature of data generation, lack of specialized training in data analysis and modeling techniques, and a persistent lack of cross-fertilization with contemporary ecology. Paleoecology has a strong site-based focus, and a tendency for practitioners to specialize in a particular group of organisms and a particular study region. This is understandable to some extent: the faunas and floras of each continent are different; hard-won expertise in the identification of one group of subfossil organisms does not help with other groups. However, in ecology generally, theoretical data-analysis and modeling approaches are well-established fields of endeavor. Paleoecology, by contrast, is still largely a field- and laboratory-based science; scientists are expected to serve an apprenticeship that involves primary data collection but generally does not provide training in the quantitative and data-analytical skills necessary to make sense of large data sets.

Data-generating techniques in paleoecology are notoriously time-consuming and this reinforces the site-based focus as well as limiting the amount of data that exists. Contemporary ecology and ecosystem science are benefiting from massive new data sources involving automated retrieval – from drones to satellites. Automation in paleoecology, for example in pollen counting, has been discussed repeatedly but there has been little concrete progress. Ecologists have also harnessed the power of citizen science to generate large data sets with high temporal resolution. Activities such as Climateprediction.net (www.climateprediction.net) and Zooniverse (www.zooniverse.org) show it is possible to involve non-specialists in scientific projects and generate valuable data on a scale otherwise impossible. We need to think creatively about harnessing people's enthusiasm for science.

The analysis of large data sets requires skills including working with database software, advanced statistical methods and multivariate analysis. Training in these skills at undergraduate and postgraduate level is patchy. Furthermore, the growing importance of quantitative models as a means to embody and test hypotheses puts a premium on mathematical and programing competencies that are increasingly prioritized in the training of ecologists and evolutionary biologists, but generally not in the training of paleoecologists.

A future for paleoecology

"The present is the key to the past; the past is the key to the future". Everyone says it, but how often does this crossover occur? There is very little interaction between paleoecology and developments in contemporary ecology, ecophysiology and biophysics. The Future Earth program (http://futureearth.org) could provide opportunities to embed paleoecology more firmly in a multidisciplinary Earth system science context (Fig. 2). Future Earth's stated commitment to "involving stakeholders throughout the entire research process from co-design to dissemination" should provide opportunities for scientists with different backgrounds, including the unique temporal perspective on species and ecosystems which paleoecologists provide, to work together towards the solution of real-world problems arising from global environmental change. But the realization of these aspirations will require paleoecologists, and others, to think "outside the box" and pay attention to other disciplines.

If paleoecology is to survive, we need a revolution in our definition of the legitimate sphere of investigation and our approaches to training the next generation of paleoecologists. We need to think creatively about generating paleoecological data efficiently and also about the questions that can be addressed with paleoecological data. We need to talk to scientists and practitioners from related fields to co-design research that will realize the unique contribution that paleoecological observations could make to Earth system science and management.

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MINI SECTION:
PAGES' YOUNG SCIENTISTS MEETING 2017

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Reports from PAGES' Young Scientists Meeting 2017

PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future:
a paleoscience perspective

Marie-France Loutre

The Young Scientists Meeting (YSM) Scientific Program Committee (SPC) worked for more than a year to prepare an exciting program for the three-day meeting. Four participants from the 2nd PAGES YSM were members of the SPC, in addition to members of PAGES' Scientific Steering Committee (SSC). We based this program on previous YSMs (Corvallis, USA, 2009 and Goa, India, 2013) and tried to keep their highlights and improve on any weaknesses. We exchanged a lot of emails, shared many documents and held several online meetings in order to finalize the program.

At the YSM, attendees presented their ongoing research and heard from two keynote speakers – SSC members Sheri Fritz (University of Nebraska, USA) and Mike Evans (University of Maryland, USA). Time was also allocated for discussion and networking – we organized social activities, panel discussions and breakout groups.

The committee received more than 200 applications to attend the YSM. It was a heartbreaking task to select the participants from all the excellent applications. The venue could only accommodate a limited number and we wanted to keep the meeting small to favor networking. Thus, 80 participants (38 from Europe, 24 from North America and nine from Africa, South America or Asia) disembarked the buses in Morillo de Tou on Sunday 7 May 2017.

Everything was ready! We (the YSM SPC) were just hoping that everything would run as planned, and that the early-career researchers would be delighted with the program.

The mini section hereafter provides an account of the participants' experiences during the YSM. They report on what they learned from the many activities and on what they discussed during the meeting. All views are their own and we hope you enjoy their insights.

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YSM 2017 participants

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Early-career paleoscientists meet in the mountains of Aragon

Evan J. Gowan[1], E.P. Dassié[2], Y. Ait Brahim[3], M.D. Holloway[4], X. Benito[5] and N. Kuosmanen[6]

3rd PAGES Young Scientists Meeting (YSM), Morillo de Tou, Spain, 7-9 May, 2017

PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

Three days prior to the 5th PAGES Open Science Meeting (OSM), 80 ambitious early-career scientists (PhD students and postdoctoral researchers) met in the restored village of Morillo de Tou, Spain. The remote setting in the Pyrenees, the old style buildings constructed of turbidites, and the clear and sunny weather made this place an inspiring location to discuss past climate, environment and human interactions. Despite some grumblings about cold coffee served in small cups, the conference was a high-energy affair that promoted connections.

The YSM meeting featured a tightly packed schedule, including two poster sessions, three oral sessions, workshops, and breakout group discussions. Poster and oral sessions displayed a great variety of topics including geology, oceanography, paleoclimate reconstructions, vegetation dynamics, human-climate interaction, and modeling. The quality of both the research and the presentations were excellent. Several workshops, led by more experienced/senior scientists and experts in the field, provided valuable insights to the topics that are near and dear to early-career researchers, including funding, scientific communication, and data sharing. Breakout groups split off for discussions on seven different topics, including how to advocate for the relevance of paleo-research, career opportunities outside academia, and our perspective of future challenges in our discipline.

Within the PAGES framework, working groups are sustained by a bottom-up approach. One of the key outcomes of this meeting is the desire to create an early-career scientists' working group within the framework of PAGES. The main idea of this group will be to assist early-career scientists to develop multi-disciplinary approaches to research and build collaborations and skills needed for career enhancement. This working group could provide training in soft skills, such as science communication, as well as technical skills, such as data-handling and the use of specific software. It could also provide a platform to gather, share and discuss information on a variety of subjects. Additional benefits of creating an early-career scientists group will also be to facilitate connections and networking with other international scientific organizations that already have early-career researcher sections established, such as the Future Earth Early Career Researchers Network of Networks or the Young Earth System Scientists (YESS) community.

Although the meeting was full of science, there was also time to relax and enjoy what Morillo de Tou and the surrounding area had to offer. On the first night, clear skies allowed stargazing with guidance and high-powered telescopes provided by the Huesca Astronomical Association. The event on the second night included traditional Aragonese music and dancing, which showed that we were not only skilled at science, but also at polka! Before heading back to Zaragoza for the OSM, we stopped at the nearby town of Ainsa to learn about the local geology (Fig. 1). The town was built upon a Marine Isotope Stage 4 (MIS4) river terrace, which formed during the peak extent of Quaternary glaciers in the region, overlying Paleogene turbidites.

Finally, attending the YSM provided a valuable opportunity for people at a similar career stage to meet and share their experiences, and also concerns, about being an early-career researcher. Furthermore, the participation of senior scientists at the YSM provided valuable insight into the different possibilities available within a research career. This networking opportunity – with researchers from different fields, institutions, and countries – built important links within a welcoming community immediately prior to the OSM and offered a foundation for long-lasting collaborations.

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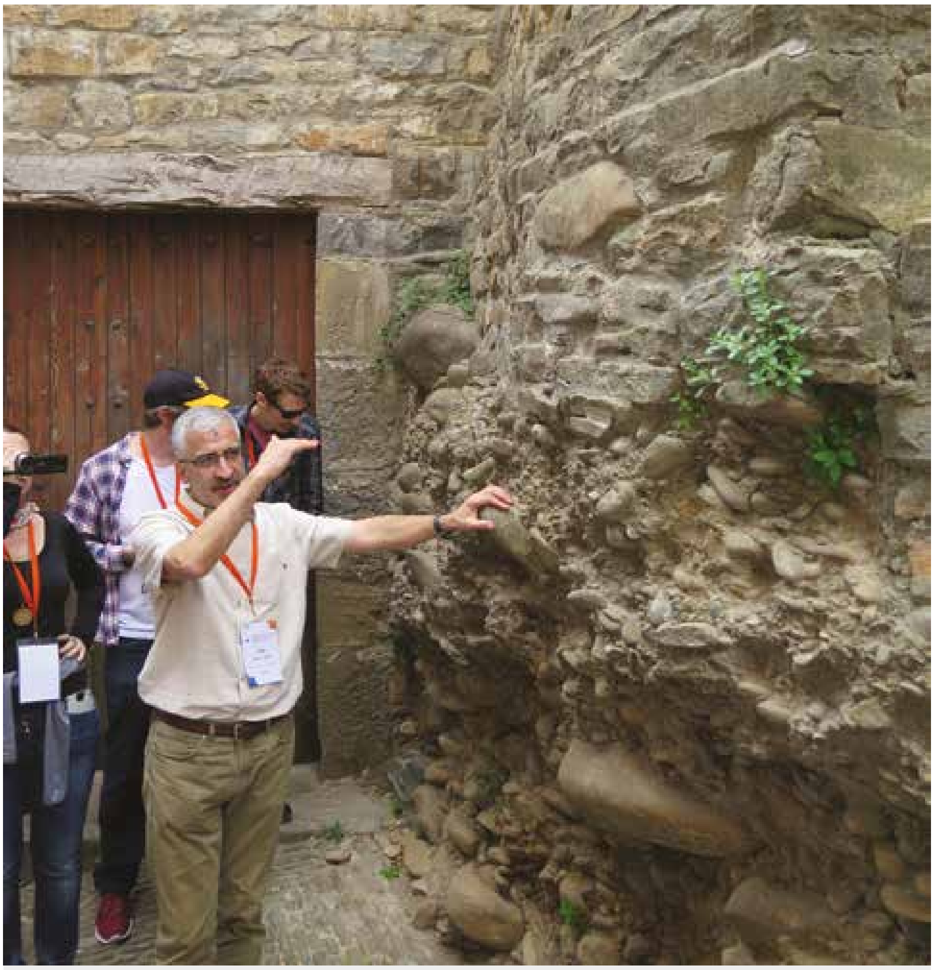

Figure 1: Blas L. Valero Garcés explains the geological setting of Ainsa, a small town near Morillo de Tou. It was built upon a MIS4 aged river terrace, which formed during the local maximum glacial extent. Image: Niina Kuosmanen.

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Science communication methods and strategies for paleoscientists

Heather Plumpton[1], Y. Ait Brahim[2], E.J. Gowan[3] and E.P. Dassié[4]

PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

Why communicate our science? Aside from our duty to let taxpayers, who largely fund our research, know what their money has been spent on, our motivation to communicate stems mainly from a desire to make a contribution towards a more sustainable world. Given the scale of the environmental challenges facing the planet and human societies today, doing only research is not enough. There is a clear need for us, as scientists, and even more as early-career scientists, to communicate to a wider audience than just our direct peers.

But how do we go about doing that? We can write press releases and hope that journalists will pick up the story. This can be an effective way to reach a wide audience, but control of the story is lost once you put the press release out. Additionally, we can utilize social media by writing blog posts, promoting ourselves and our work through Twitter, or even making YouTube science documentaries. Video media can be an excellent way of making science more accessible to the public, as demonstrated by initiatives such as TED Talks (ted.com).

Engaging with younger generations in science is also very important. For example, going to primary schools and running workshops can be hugely rewarding. However, it is also extremely time consuming to design these activities. Sadly, this time commitment is currently barely recognized or rewarded in terms of career progression. This puts up a significant barrier to early-career scientists doing outreach, as they cannot justify the time commitment in a hyper-competitive job market. Wider recognition of the value of committing time to communicating science to young people is necessary to encourage these activities.

To communicate better to scientific as well as non-scientific audiences, the following suggestions should be considered. Firstly, the art of communication is telling a story. As scientists, we get too easily bogged down in the data, but people need to have an emotional connection to really engage. One way for paleoscientists to do this is to include people in the story, perhaps by talking about and showing images of fieldwork. Secondly, know the audience and keep them in mind throughout. Use the appropriate amount of detail and avoid all jargon. The language barrier must be overcome: it should be adapted to the audience if you don't want to confuse them. Thirdly, know exactly what you're trying to communicate - be clear about one or two take-home messages. And finally, respond quickly to communications with journalists and do not pass them on to someone more senior. They will then be more likely to continue contacting you in the future.

Overall, despite the importance of communicating science to a broad range of audiences, there is little provision of formal training. This gap in our education could be filled by workshops or seminars organized by the newly proposed PAGES early-career scientists working group.

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Marie Eugenia de Porras a member of the Scientific Program Committee from Chile, spreads the YSM message on regional Aragonese television.

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Communicating the relevance of paleo research in the current societal environment

Heather Plumpton[1], E. Dearing Crampton-Flood[2], E.J. Gowan[3], E.P. Dassié[4]

PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

It is not an easy task for paleoscientists to communicate the relevance of their research to policy makers and funders. However, an increase in catastrophic environmental calamities related to climate change (e.g. landslide, droughts, flooding) demands a response both in terms of policy-making and future governmental decisions. Often, climate change in the recent past was linked to major shifts in human behavior, which masks the relative contribution of humans and nature. For example, the 4.2 ka BP aridification event was so severe that it may have triggered the collapse of several large civilizations (the Old Kingdom in Egypt and the Akkadian Empire in Mesopotamia; Gibbons 1993). Compilations of long-term records of past variability can help reduce the uncertainties on past, present and future climate changes, and thus support informed societal decisions. Therefore, policymakers should (and some may argue, must) consider the long-term perspective provided by paleoscience research.

Better interaction with funding bodies and policy makers may also glean further information on how scientists can advocate for the relevance of paleo research. If we want politicians to engage with our science, we have to spend time with them and open a dialogue. Of course, this does not necessarily mean joining political demonstrations. In the past, scientists were part of high society – teachers and peers of politicians who could directly influence policy. While that is not the case anymore, it can be discussed if it is possible, or desirable, to replicate this kind of influence today. Scientists still have a duty to shape a debate by interacting with and informing politicians.

Contacting local representation, by email or post, before a bill is passed with focused, short and specific information, can help politicians forge their final decisions, and could be a first step towards establishing a long-term connection. It is extremely important to know one's audience and frame the communication accordingly, for example by addressing societal concerns such as jobs or water quality. Furthermore, it may be helpful to engage optimistically by suggesting ways in which we can work with politicians to solve a problem.

An animated Guilaume Jouve, from France, explains the relevance of his research.

A lively discussion within the scientific community is about whether scientists should (try to) fit their research into an application-based narrative in line with funding agencies and stakeholder expectations, or whether there are still opportunities to do fundamental basic science, or "science for the sake of science". Many funding agencies request research proposals, prior to any grant allocation, which demonstrate how the work will benefit society. This approach of research and science completely disregards the fact that fundamental science underpins all application-based science. More generally, funding applications should tell a compelling story that sets the proposal in the broader picture.

The synthesis of important paleoclimate data will enable policy makers to make more informed decisions with respect to climate change mitigation. We stress the need to address societal concerns when communicating to funding bodies, stakeholders and policy makers, so the relevance of paleo research is appreciated by the wider community. We also highlight that advocating paleoclimate science is an exercise dependent on whoever is on the receiving end of the message.

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Is it important to create a PAGES early-career researchers working group? What should be its remit?

Xavier Benito[1] and Stella Alexandroff[2]

PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

Eighty international participants attended the YSM in Morillo de Tou, providing a great opportunity to network and discuss research.

What are the benefits for young paleoscientists in creating an early-career researchers working group within the framework of PAGES? This key question for the next generation of researchers was discussed during the breakout sessions at PAGES 3rd Young Scientists Meeting held in Morillo de Tou, Spain, in May 2017.

The goal of such a working group would be to favor cohesion among early-career researchers. This can be achieved through different tools and activities:

Platform
Building a platform for exchange on hard and soft researcher skills is viewed as extremely valuable. It would strengthen collaborations among early-career researchers, promote new science projects and enable early-career researchers to exchange and gain useful knowledge for their future careers. In this context, there is a strong desire to propose workshops and webinars to learn and expand skills, such as database management, specific software, new methodologies, and communication (e.g. practicing talks or how to present a poster). To start with, a skill database of the members' research backgrounds has been developed to enhance online networking within the early-career community.

Communication
Besides public outreach and science communication, sharing information was also identified as of paramount importance for early-career researchers. In a very competitive post-PhD world, it is essential for early-career scientists to keep themselves updated about research jobs and funding opportunities. PAGES is a bottom-up international organization consisting of numerous working groups. Although early-career researchers are already actively involved in many PAGES working groups, creating a dedicated early-career researchers working group would potentially increase their visibility and offer a new set of opportunities.

Collaborative projects
One of the objectives of PAGES working groups is to address big science questions that cannot be answered by single research teams. In this context, there is huge potential for early-career researchers to initiate collaborative projects, since they are usually deeply involved in their own research (e.g. dissertations). Therefore, they can provide new, fresh ideas and scientific hypotheses, although, being strongly focused, they need to develop collaboration to tackle major scientific questions.

Networking
Many early-career researchers leave the academic sphere for alternative career paths. A dedicated PAGES working group could develop a long-term network with them, to provide mentors outside academia, to identify valuable jobs other than professorships or to liaise with potential stakeholders.

An ECR working group may also act as a link between their own centers/universities and regional and global associations to organize conferences and meetings on PAGES-related topics.

Therefore, an early-career researchers working group is in development. The steering committee, with ten members (five PhD students and six postdocs) from six different countries, is currently working on a formal proposal to create a new working group that addresses all the remits mentioned above and investigates how it can contribute to filling research gaps in PAGES sub-disciplines in the long term.

Early-career researchers in past global changes are very welcome to join. Email us (pages.ecr@gmail.com) or join our online forum (https://groups.google.com/forum/#!forum/pages-early-career-scientists) for more details on how to be involved.

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No professorship: There is a normal, non-scary life outside academia

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PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

In today's scientific world, the definition of a successful career is often associated with professorship. This goal is unfortunately only achieved by roughly 0.5-16% of those who pursue a PhD (https://lifesciencenetwork11.connectedcommunity.org/blogs/leah-cannon/2016/09/15/how-many-phd-graduates-become-professors).

While the percentage varies between scientific domains and countries, this apparent "limited success rate" is an important source of stress for many early-career researchers (ECRs), as illustrated by the vivid discussions that took place during the breakout group sessions organized during PAGES 3rd Young Scientists Meeting (YSM). While most participants acknowledged feeling – or having felt – this pressure, we all agreed that alternative ways outside academia can, and should, lead to equally successful careers. Unfortunately, we also came to the conclusion that our ideas of what these alternative ways might actually be were rather limited.

A large part of this stress or pressure comes from our limited perception of the "outside world". During the PhD, most of us live in an academic bubble. We become so focused on our daily tasks that we forget about the non-academic world and sometimes even convince ourselves that academia is our only viable option (Fig. 1). This psychological barrier stems from not only a lack of knowledge about other worthwhile job opportunities, but also the stigmatism of choosing what feels like a "second-class" career. A perfect illustration of this came during a YSM discussion about children's education. Although all members of the breakout group agreed that engaging children in environmental issues early on is critical to educate the next generation, it was also strikingly evident that leaving academia to become a teacher was perceived as a failure for most participants.

Most of us enjoy working in science because it is a challenging job, with short- and long-term objectives that necessitate a large spectrum of competences, such as using/developing technical and analytical skills, collaborating and/or managing people, planning, writing papers, developing projects, etc. But it is important to remember that all these skills are transferable and valuable outside academia.

According to statistics, most ECRs will leave the galaxy of academia, but we can still rotate around it as satellites: data collection and management, logistics for expeditions, scientific journalism, teaching, and the list goes on and on. *Leaving academia does not automatically imply leaving science.* Opportunities exist in industry, government organizations, consultancy firms and areas like scientific management, communication and education. Possibilities are plentiful, but how do we approach them?

We all have mentors in academia who advise us about the right choices for an academic career. But we also need role models from outside academia. We have not received many insights from predecessors who have already left academia, but we now have the possibility to step in and provide assistance to the future generation. We, i.e. the current generation of ECRs, need to become the academic and non-academic mentors of the next generation of scientists. Those leaving academia within the next years – voluntarily or not – should leave a note about their future whereabouts and not "vanish" from the scene. This could be achieved by gathering a list of successful alternative career paths (e.g. on the PAGES website), by organizing seminars and webinars, structured mentoring programs at universities or even blogging.

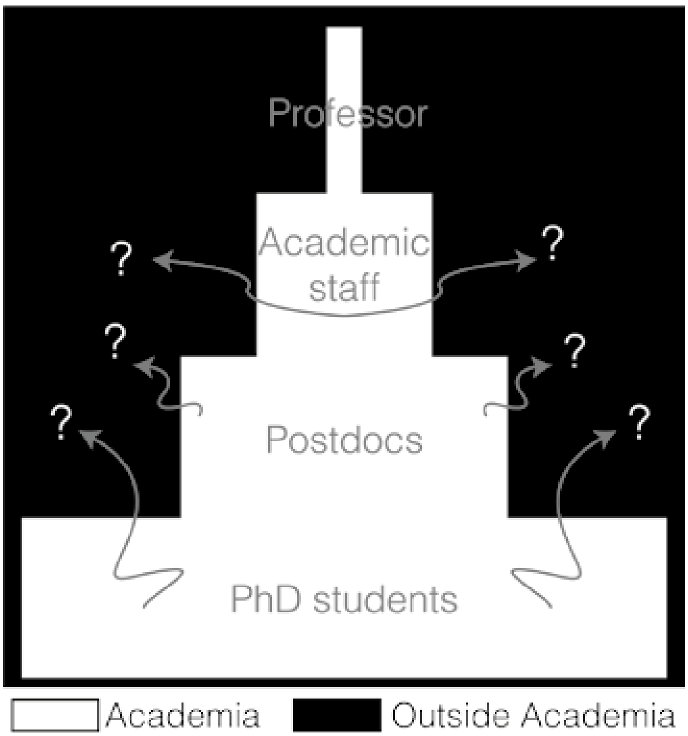

Figure 1: Sketch of the mental representation most ECRs have about their career path.

Light needs to be shed on the dark areas represented in Figure 1. Having access to this critical information should reduce some pressure from ECRs to aim for academic careers and assist them with finding their own way. This could and should be one of the aims of the planned ECR working group, and the next YSM in 2021 would provide the perfect opportunity to evaluate our progress.

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What should the research questions and priorities in paleoscience be for the next ten years?

PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

Michelle Chaput[1] and Manuel Chevalier[2]

The vision of the future of paleoscience shared by PhD students and postdocs who attended PAGES 3rd Young Scientists Meeting (YSM) in May 2017 centered on five key elements: interdisciplinarity, accessibility, creativity, innovation and progress. All of the top research questions identified could be traced back to these principles and reflected the group's desire for the field of paleoscience and its community to be barrier-free, engaging and strengthened by international partnerships.

Interdisciplinarity was mentioned frequently during group discussions. Many participants asked: how can I combine my research with someone's work from another field to solve a problem important to paleoscience? How can I build or strengthen collaborations with ecologists, social scientists or statisticians outside of the paleo community? Many participants expressed the need to avoid reinventing the wheel when it came to data analysis. Interdisciplinarity was of particular interest to participants struggling with data-model comparisons. The participants insisted on the importance of combining skills and academic disciplines.

Accessibility was often discussed, but in more ways than one. First, paleo research needs to be more accessible to the general public, and results communicated in a way that is inviting, easy to understand and consistent. The big question was: how best can we accomplish this? How do we get the public and policymakers more interested in our work? How do we highlight the importance of paleo research in the media? Put simply, we need to strengthen the link between science, policy, media, and the public. Second, paleo research needs to be more accessible to paleoscientists! We are all working towards a common goal and proper data sharing needs to be a priority. Initiatives like the PAGES Interactive Activity on Data Stewardship, the Coalition for Publishing Data in the Earth and Space Sciences (COPDESS), open-access journals like *Scientific Data* and *Open Quaternary*, and global databases like the Canadian Archaeological Radiocarbon Database (CARD) and the Global Charcoal Database (GCD) are helping to make this possible. Third, paleoscience needs to be integrated into high school curricula. High school graduates can no longer begin university without a basic knowledge of the evolution of the Earth system and the ways paleo data can inform predictions of the future.

Fortunately, participants where not afraid to express their *creative* side and admit that paleoscience is and should be portrayed as a fun endeavor! After all, curiosity is a feeling that connects all humans regardless of whether or not they are academics. Therefore, we owe it to ourselves and our peers to continuously ask ourselves: how can I pique the interest of someone not as excited about the topic as I am? Among the most popular suggestions were creating apps where paleo data could be viewed and 'played' with, and taking a friend or fellow scientist out for a "pint of knowledge" to discuss research in a general way. Creativity powers science, thus the group proposed that creative thinking should be both a personal and collective priority over the next ten years.

With creativity comes *innovation*. Many discussions focused on innovative research topics, including geogenomics, pollen sensitivity to ultraviolet light, ancient DNA, and multiproxy reconstructions, and their importance to the evolution of paleoscience over the next ten years. Participants agreed that the next suite of innovative projects would likely require state-of-the-art methods and multidimensional thinking. The most pressing questions seemed to be: are Bayesian methods preferable to the Frequentist approach for paleo data analysis? How do we address no-analogue climates and communities? How can we better incorporate sophisticated statistical and spatiotemporal models in the paleosciences and correct for factors like topography and altitude? How can we better integrate the Northern and Southern Hemispheres?

The discussion culminated in a unanimous desire to drive and maintain *progress* in the field of paleoscience. This progress should include increased high-resolution climate records from all hemispheres, improved climate sensitivity and time uncertainty studies, refined paleo data-model comparisons, linking marine and terrestrial datasets, identifying and amassing data from key regions currently lacking data, and an overall interdisciplinary approach. The next generation of researchers should combine their expertize, foster successful partnerships at home and abroad, and collectively work towards advancing the field of paleoscience.

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What issues will the paleoscience community be focusing on during the next ten years?

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Global Challenges for our Common Future: a paleoscience perspective

Strategies in highlighting paleo research

Estelle Razanatsoa[1], Y. Ait Brahim[2] and N. Schafstall[3]

Environmental change is being experienced worldwide; its extent and variation, however, are still poorly documented. In order to better understand the present-day environmental change and to predict the impact on ecosystems of climate and human social behavior, it is important to learn about the natural variability of Earth's ecosystems and the mechanisms behind these changes. Paleo research provides information on the causal factors and the succession of environmental and climatic events at annual to millennial time scales. However, many paleo studies are descriptive and provide little practical application from the socio-economic point of view. Several ideas might help highlighting paleo research as a useful tool to solve problems of socio-economic importance.

Paleoscientists need to understand the relevance of their research in solving specific present-day problems to enhance the public interest in the discipline. For example, paleoecological records describe how vegetation has changed and responded to various forms of disturbance such as fire or herbivores over time. By unraveling past vegetation patterns, baselines can be set to mark the development of a peatland, a nature reserve or a region. Such baselines are valuable to disentangle challenges of ecosystem degradation, species disappearance and species invasion. Relating those findings from the past with the current issues of ecosystem management would play an important role in positioning paleo research in the domain of conservation.

Communication of paleoscience to the general public and other stakeholders, like contributors of ecosystem services and governments, is also a key strategy to highlight its importance. Often, paleoscientists find it challenging to communicate their results to non-experts due to their complexity. In many cases, people have never met an actual researcher and do not understand the motivations behind paleo research. Therefore, it might be easier to engage with the general public by providing historical, human-related examples of environmental change such as drought or floods, and by showing how paleo research can evaluate their frequency and their probability of return on a longer time scale. However, this approach might not be applicable to socio-economic stakeholders as their interest is centered in tangible results like economic models or cost calculations.

Long-term environmental data could also be used to assess the economic value of ecosystem services. In fact, society is dependent on the services and goods offered by ecosystems and these services are explicitly expressed financially. Paleo research shows the long-term state of these services and goods that allow the assessment of the potential threats and the possibility to evaluate their sustainable use. When presenting their results, paleoscientists need to be aware of the quantifiable information they provided in terms of their monetary value. It is then crucial to associate the paleo data with the monetary assessment of modern analogues through collaboration with stakeholders. For instance, paleo research provides a long-term and large-scale view of the climate variability, as it explains its impact on socio-economic issues. In fact, continental or global data on a longer time scale would be more valuable to decision makers like NGO's, despite the fact that local case studies are relevant to local stakeholders for their own assessment. In addition, direct cooperation with socio-economical actors would enhance the ability of paleoscientists to interpret their data to solve present-day problems and might promote interdisciplinary projects that serve both research and its direct applications to the society. Since it can be difficult to show the prospective results of a paleo research project, it might even be worth collaborating with marketing or communication specialists to pitch the highlights and benefits of paleo research to all involved socio-economic stakeholders.

Despite current challenges, it is possible to highlight the importance of paleo research in solving present-day socio-economic problems. This could be achieved by understanding the different motivations of the various stakeholders and by adequately crafting the communication for the audience. The overall value of the services and goods should be measured against paleo research, and international and interdisciplinary collaborations should be favored.

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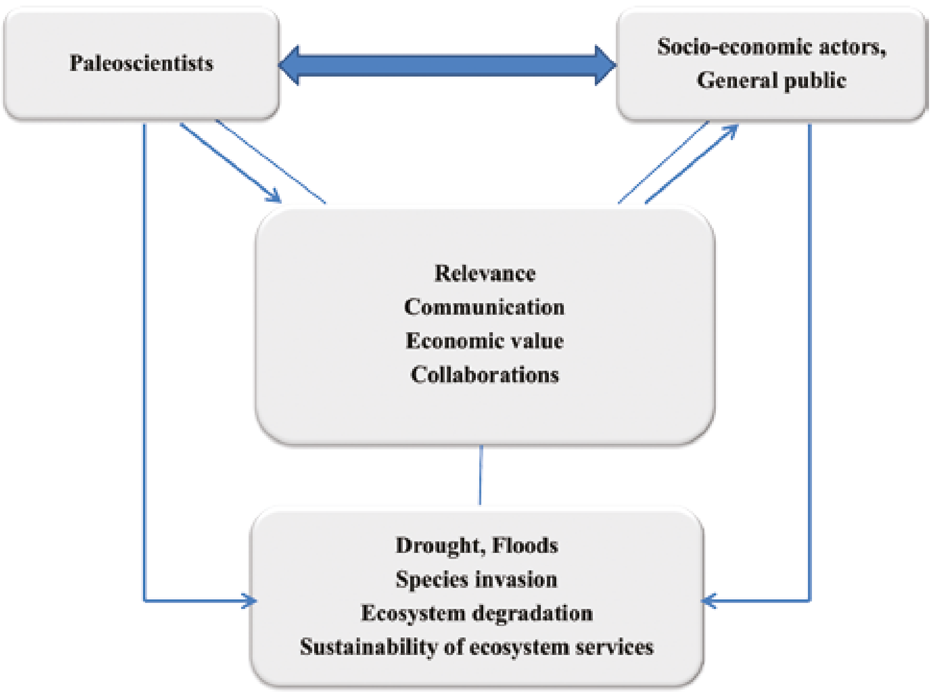

Graph of the interactions between the different actors for developing better strategies to highlight paleo research as a useful tool to solve present-day problems of socio-economic importance. This graph is an outcome of the breakout discussion during PAGES 3rd Young Scientists Meeting in Spain in May 2017.

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Insight about funding, communication and data sharing for early-career scientists

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PAGES Morillo de Tou 2017
3rd Young Scientists Meeting
Global Challenges for our Common Future: a paleoscience perspective

The YSM meeting in Morillo de Tou offered early-career scientists three valuable workshops, where experts in their respective fields gave guidance concerning funding, communication in science and data sharing.

Workshop 1: Funding

Finding your way through different funding bodies and producing a successful funding application can be challenging in the early stages of a scientific career. Hubertus Fischer (University of Bern) gave valuable advice on how to formulate a funding proposal. He highlighted the importance of having a great idea and being able to defend it. It is also essential to know the audience to whom you are writing and to adjust your text accordingly. For example, an expert panel in charge of funding decisions will expect a different level of detail than a staffer at the funding agency or a private foundation. The recipe for a successful proposal is three "C"s: be Clear, Concise and Consistent!

Valuable information about different possible funding bodies (such as Horizon 2020 and Marie Skłodowska-Curie Actions) was provided by Pilar Calatayud (European Projects Office at the University of Zaragoza). Jonas Bunikis (European Research Council Executive Agency) provided more detailed information about applying for European Research Council (ERC) funding. He stressed the importance of learning to write good grant applications and the necessity to show your independence as a researcher. He also pointed out that the promise of excellence means highlighting the potential of making a breakthrough in your field of research.

The same topic was then also discussed within breakout groups. The participants underlined the importance of time management between research and grant application. Indeed, you might have to write several proposals before one is selected. Don't lose patience! On the contrary, take advantage of any review received, and even ask for independent reviews to improve your proposal. Starting from a small proposal with well-defined goals and objectives and letting it evolve towards a broader research project was also a strategy that the breakout groups proposed.

Workshop 2: How to communicate science

Communicating science covers many aspects from writing a research proposal to making your research understood by people who are not familiar with your field. Alicia Newton (*Nature Geoscience*) stressed a few questions to successfully communicate research in a focused manner: Which specific question do you want to answer? What is the purpose of your research? Why should people believe you? Knowing your audience and adapting your message to it are also crucial to be understood.

Liz Kalaugher (*environmentalresearchweb*) spoke about promoting your research to the media. Making your research known and being involved in outreach outside of your own research community can raise your profile and may result in more citations. However, not every study makes it to the news. Studies directly affecting people's lives and controversial and unusual topics are most likely to get attention. Nevertheless, active promotion of your research in blogs, social media or at outreach events may increase your media exposure.

Angela Wade (PAGES) introduced the possibilities for early-career scientists to use publishing and other communication outlets within the PAGES network. One important conclusion from the discussion was the demand for more extensive workshops on science communication for early-career scientists.

Workshop 3: Data sharing

In the third workshop Darrell Kaufman (Northern Arizona University), Alicia Newton and Jonas Bunikis discussed the opportunities and challenges of sharing data. Making data freely and broadly accessible is important, because large data sets allow for questions to be tackled that cannot be answered by a single study. Data sets, even small ones, provide the means for assessing spatio-temporal patterns, conducting proxy-proxy comparisons and data-model comparisons, and identifying aberrant records. Challenges in data sharing include the often heterogeneous and multidimensional data and nuanced interpretation of different data types. Having a data management plan early in your career is essential, since both journals and funding agencies increasingly require documentation of data availability. Publication in data-oriented journals provides description for the data sets, favors the sharing and reuse of data and gives credit to those who share their data. Safe repository (for example with a certified organization) offers long-term archives for your data and easy citation.

Altogether, these three workshops provided valuable knowledge, topics for further thought and discussion, and guidance for our scientific careers.

Graciela Gil-Romera, a member of the YSM Local Organizing Committee, hands out a list of possible questions for discussion at the "Communication" round-table meeting

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The PAGES Football Cup 2017

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PAGES Zaragoza 2017
5th Open Science Meeting
Global Challenges for our Common Future: a paleoscience perspective

The PAGES Open Science Meeting 2017 was a great conference all around - an exciting scientific program, a labyrinth of rooms and talks, great meals, networking to Spanish rhythms with red wine and a full moon. It was easy to get carried away by science rushing from one talk to the next. But two things were cemented in every head: (1) Daily lunch from 13:00-15:00 and (2) the PAGES Football Cup on 10 May at 19:30. For two days, the OSM was buzzing with questions like "Are you playing?", "In which team?", "Free beer, really?"

Happy winners – team Modelers - of the PAGES Football Cup 2017, 10 May, Zaragoza, Spain.

If you believe the common paleoscientist stereotypes, you may be forgiven for thinking that the “Proxies” scientists could have a certain advantage over the “Modelers” when it comes to outdoor sports. After all, you may picture the Modelers as physics-savvy beings who shy away from the sun and tell each other jokes in binary code. The Proxies, on the other hand, will sleep strapped to a tree branch, take their daily shower in the mud and keep confusing the words projection and prediction.

But stereotypes are stereotypes, and not suitable to predict (or project) the outcome of a football game.

The match started off very even and both teams moved gracefully on the somewhat bumpy grass pitch. It was a majestic chain of pursuit: players chased the ball, biting insects chased the players, and everyone chased free beer. While the game stayed close and suspenseful for most of its duration, it eventually became evident that the Modelers were going to win. As spectacular as some of the Proxies’ goals were – one of them was a mere by-product of the attacker stumbling over the ball and falling flat on the face – the Modelers played their way to a deserved win. In one blow, stereotypes were shattered, the Proxies’ dreams were shattered, and everyone’s skin was shattered by insects. At this point, it might be worth mentioning that the Modelers team largely consisted of Proxies, as not enough Modelers had signed up to play sports in the first place.

All in all, the football cup was a great success; everybody left the pitch in a good mood after a fun evening and ready to tackle the talks and posters of the following day.

Please see some additional facts in graphic form (accuracy of information might have been affected by euphoria) ...

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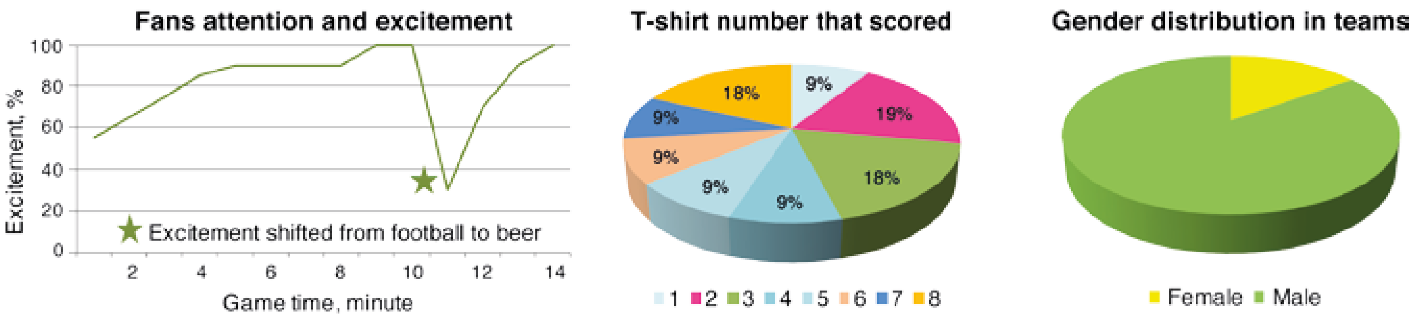

Egos and shins may have been bruised in the battle for the PAGES Cup, but ~~mosquitoes~~ ~~free beer~~ football was the winner of the day.

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Global Challenges for our Common Future: a Paleoscience Perspective

PAGES Zaragoza 2017
5th Open Science Meeting
Global Challenges for our Common Future: a paleoscience perspective

Blas Valero-Garcés[1], A. Moreno[1], P. González-Sampériz[1], G. Gil-Romera[1] and Local Organizing Committee[2]

PAGES Open Science Meeting, Zaragoza, Spain, 9-13 May 2017

The PAGES community met in Zaragoza, Spain, in May 2017 for the 5th Open Science Meeting (OSM). The meeting was organized by the Pyrenean Institute of Ecology, a research center of the Spanish National Research Council, with the collaboration of the University of Zaragoza. The city of Zaragoza is famous for the World Heritage *Mudejar* architecture, a syncretic art developed in the Christian kingdoms by Muslim artisans. The *Mudejar* star, the 2017 OSM logo, was chosen as a reminder of the positive outcomes when diverse minds and cultures meet.

Over 900 delegates (44% female) from 56 countries participated in 33 sessions (with up to six parallel sessions). In total, more than 980 communications were presented as posters (646) and talks (338). In addition, nine PAGES and affiliated working groups had meetings before, during and after the OSM. Lunch was served in the Auditorium to all participants in a wifi-free environment to promote interactions, sharing of new ideas, and some relaxation after the intense morning sessions. Science and Somontano wine helped to maintain lively discussions during the poster sessions.

Eight plenary speakers gave us the state-of-the-art in ocean warming (Nerilie Abram, Australia), geoinformatics (Julien Emile-Geay, USA), climate system variability (Gabriele Hegerl, UK), climate evolution of the Western Mediterranean (Isabel Cacho, Spain), interglacials (Erik Wolff, UK), greenhouse gases variability (Ed Brook, USA), human evolution and climate (Juan Luis Arsuaga, Spain) and the interactions of climate, vegetation and humans in the Iberian Peninsula (Penélope González-Sampériz, Spain).

The meeting structure, with its 33 sessions, was built around PAGES' scientific themes of climate, environment and humans. Also well represented were the strengthened connections between PAGES working groups and the increasing importance of interdisciplinary approaches in paleoscience. Particularly well attended were the sessions on the Southern Hemisphere, the Mediterranean, the climate of the last two millennia (2k) and Quaternary interglacials.

The Local Organizing Committee organized two outreach events: A film night with Leonardo DiCaprio's climate change documentary "Before the Flood"; and a Round Table, open to the public and led by politicians and scientists, on the topic "Climate change: from global to local challenges."

Social activities included the ice breaker with music by the O´Carolan Quintet, the conference dinner with subsequent disco, and a free visit to the Aljafería Palace. After the long scientific sessions, delegates strolled the city parks and the Ebro River, enjoyed light tapas dinners in bars and terraces downtown, and visited the museums and old buildings to get a taste of the city's rich culture. Four teams, representing modelers and proxies, played in the traditional PAGES Cup football (soccer) match, held in the José Antonio Labordeta Park. In spite of cloudy skies and mosquitoes, free beer and enthusiastic fans kept the sport spirit high (Ashastina and Alexandroff 2017).

For a few days, paleoscientists flooded Zaragoza and made the headlines in local and regional media coverage; see a selection of the many TV and print reports here: www.pages-osm.org/osm/post-meeting-material/pages17-media

Field trips were conducted to the Ordesa-Monte Perdido National Park to illustrate some of the glacial features; to the Segre River and its unique paleoflood record, and to the Huerva River to show the geoarchaeology of the region.

We thank all supporters, sponsors and volunteers who helped organize and finance the 5th PAGES OSM meeting. In these times of rapid change, the OSM showcased how our science is more useful than ever for society – from citizens to politicians. We thank all the attendants for presenting their science, participating in the discussions and field trips and creating links to strengthen PAGES as a global community. We wish you all a very productive, fruitful and inspiring period to face together the challenges ahead of us until the PAGES OSM convenes again in four years.

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Figure 1: Subset of the over 900 OSM participants in front of the venue in Zaragoza, Spain.

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Integrated initiative on extreme events and risk assessment

Hugues Goosse[1] and Blas Valero-Garcés[2]

Zaragoza, Spain, 10 May 2017

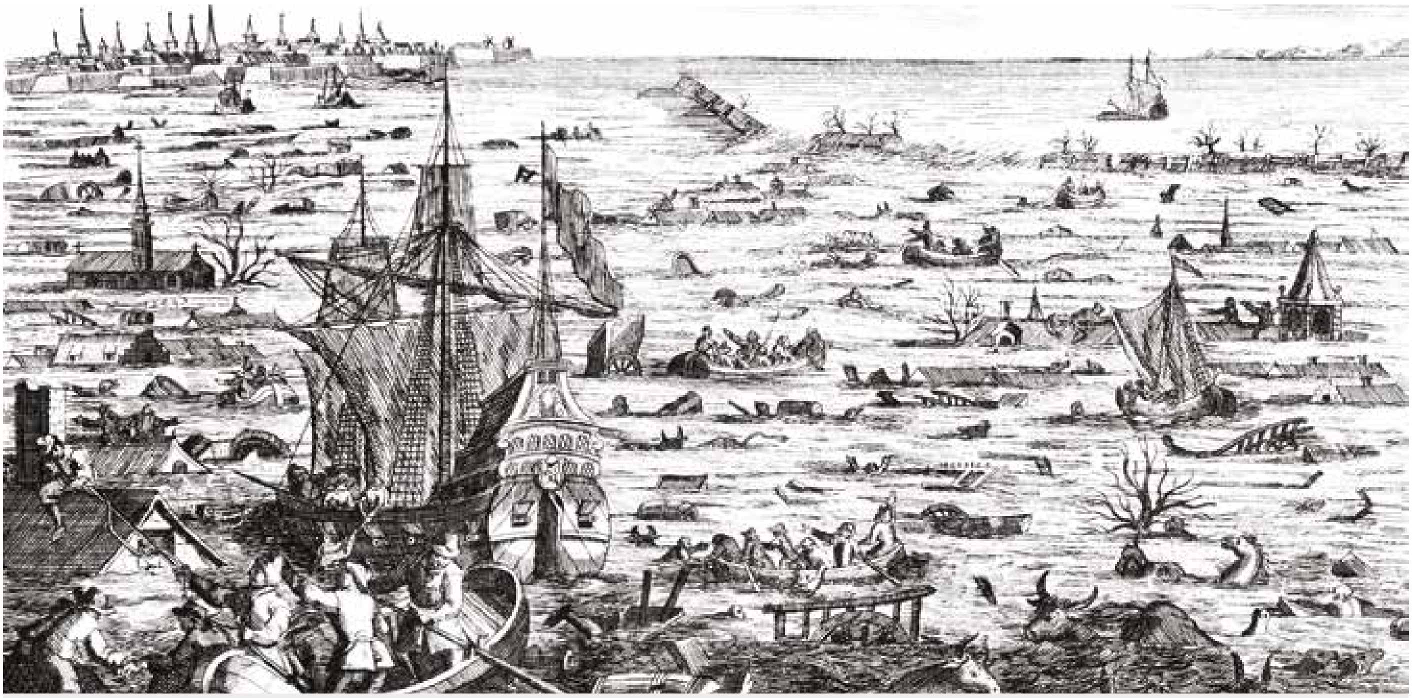

Figure 1: Example of a past extreme event: the Christmas flood, which killed approximatively 14,000 people in the Netherlands, Germany and Scandinavia, was the result of a major storm on Christmas night 1717. Author unknown, Wikipedia, public domain.

In 2016, PAGES launched a new integrated initiative with the goal to improve the coordination between different communities working on past extreme events such as hurricanes, storms, droughts and floods. The initiative wants to stimulate new lines of research and facilitate the transfer of relevant information, in particular to the users and stakeholders dealing, up to now, mainly with more recent events. A lunchtime session took place during the PAGES 5th Open Science Meeting in Zaragoza to receive the inputs of the community on the proposed activities, to suggest additional ones and discuss a timeline for the implementation of the first actions.

The group reiterated the large interest of studying past extreme events: they are important elements of the climate system whose dynamics need to be better understood; they have a large impact on environment and societies, and thus attract strong attention from many stakeholders, including the general public; and paleoscience offers the only possibility to analyze a wide range of observed realizations of those generally rare events.

Despite the larger number of activities on past extreme events, establishing links between them did not appear straightforward. As a first step, it was proposed to prepare a short glossary, giving a common definition of the main terms, such as what each of us mean by extremes, probability compared to possibility, etc., in order to facilitate the discussions. To gather input from the whole community, this will take the form of a Wiki page, on the web page of the Extremes Integrative Activity (http://pastglobalchanges.org/ini/int-act/extremes). A second action is to prepare a document on the PAGES website describing existing research on past extremes and presenting a few key results, with a specific link to the PAGES working groups active in the domain.

Another important point that was raised during the meeting and in subsequent discussions is that strong links need to be maintained and developed between communities working on past extremes and on more recent ones. In this framework, the World Climate Research Program (WCRP) Extremes Grand Challenge (https://www.wcrp-climate.org/grand-challenges/gc-extreme-events) and the Future Earth KAN on emergent risks and extreme events, the follow up to the Future Earth initiative on "Extreme events and environments – from climate to society (E3S)" (http://futureearth.org/extreme-events-and-environments-climate-society-e3s) are two clear opportunities of collaboration that will be actively pursued.

After those initial steps, a workshop will be organized in the first half of 2018, likely in collaboration with some WCRP and Future Earth partners, with the objective to determine the best way to synthesize the existing work on past extremes and, in particular, to contribute to assessments such as those proposed in the framework of the Intergovernmental Panel on Climate Change (IPCC).

The plans are still very open at this stage. If you are interested in this subject, you can join the mailing list of the Integrative Activity (https://listserv.unibe.ch/mailman/listinfo/extremes.pages), contribute to the Wiki page and send information to the activity coordinators, describing results that can be included on the web page or any suggestions that you consider useful to move the activity forward.

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Understanding the climate of the past 2000 years: Phase 3 of the PAGES 2k Network

PAGES 2k Network Coordinators*

Zaragoza, Spain, 11 May 2017

The PAGES 2k Network was created with the aim of reconstructing changes in regional and global surface climate over the past 2000 years. During Phases 1 (2008-2013) and 2 (2014-2016), regional and trans-regional groupings focused on building reconstructions for terrestrial regions and the oceans. The conclusion of Phase 2 coincided with the release of an open and transparent global database of temperature-sensitive proxies spanning the Common Era (Fig. 1; PAGES 2k Consortium 2017). This product will be followed up by a special issue of *Climate of the Past*, entitled "Climate of the past 2000 years: regional and trans-regional syntheses" (www.clim-past.net/special_issue841.html).

The third phase of the PAGES 2k Network was launched in May 2017 at the PAGES 5th Open Science Meeting (OSM). In this new phase, we aim to address major questions centered on past hydroclimate, climate processes and proxy uncertainties, with three distinct scientific themes:

- Theme 1 (Climate Variability, Modes and Mechanisms) aims to further understand the mechanisms driving regional climate variability and change on interannual to centennial time scales.
- Theme 2 (Methods and Uncertainties) aims to reduce uncertainties in the interpretation of observations imprinted in paleoclimatic archives by environmental sensors.
- Theme 3 (Proxy and Model Understanding) aims to identify and analyze the extent of agreement between reconstructions and climate model simulations.

At the OSM, anyone interested in the network was invited to a lunchtime meeting. The goals of this meeting were to present the framework for Phase 3, introduce the new coordination team, present proposals for new projects, and collect ideas for additional Phase 3 activities.

To stimulate new ideas for projects, a "Post-It" note exercise was held, where participants were asked to nominate scientific questions they would like PAGES 2k to address. This exercise led us to identify five themes that sparked widespread interest, and which could serve as foci for potential Phase 3 projects: (i) the combination of high- and low-resolution proxies; (ii) data stewardship and script availability; (iii) data-model comparison; (iv) the evolution of the mid- to high-latitude Southern Hemisphere climate; and (v) the hydrological cycle, temperature-hydroclimate co-variability and interannual to interdecadal variability. Participants split into groups to discuss potential projects in each of these fields.

The overall structure of PAGES 2k consists of a network of projects, each organized and led by members of the community. So far, nine projects have begun their activities. These are either trans-regional projects that have transitioned from Phase 2, or new projects that have been proposed and endorsed as part of Phase 3. Examples of Phase 3 projects include: Clivash2k, which will generate a community-based multi-proxy reconstruction of key modes of Southern Hemisphere variability over the past 2000 years; and Iso2k, which started its activities during Phase 2 and aims to create a global database of paleo-$\delta^{18}O$ and δD records. New projects can be proposed at any time.

Phase 3 of the PAGES 2k Network will run until 2020 and is open to anyone who is interested. There are a number of ways to participate: by contributing your data or expertise, by initiating a new project or by participating in an existing one. If you would like to participate in PAGES 2k, please contact us. To receive updates on our activities, sign up for the mailing list at https://listserv.unibe.ch/mailman/listinfo/pages2k.pages

For further information on the PAGES 2k Network, including details of existing projects and the procedure for proposing a new one, please see www.pastglobalchanges.org/ini/wg/2k-network

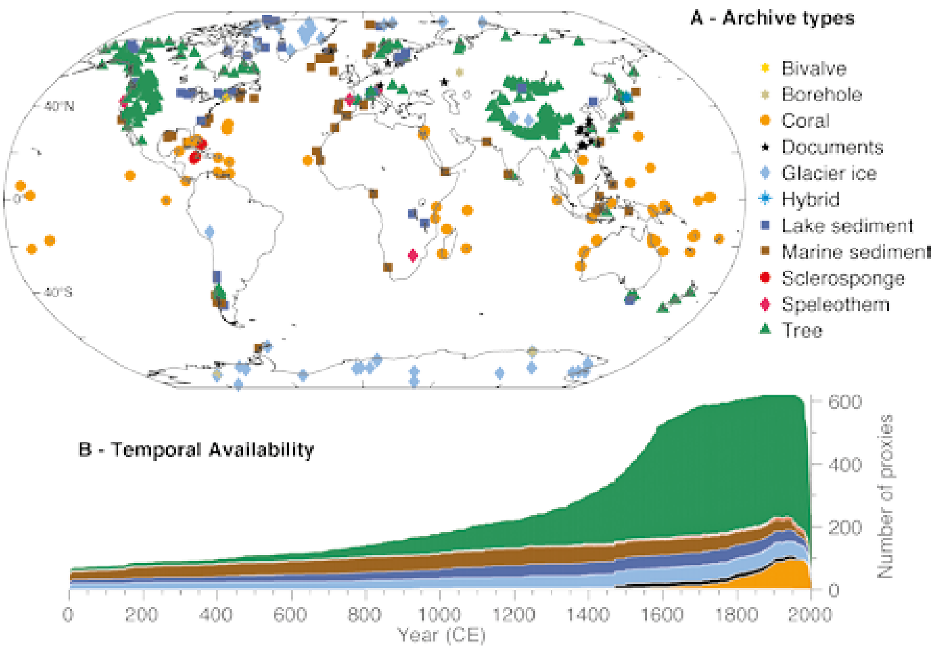

Figure 1: Location and length of the 692 records in the new PAGES 2k global temperature database v2.0.0. This resource will serve as a basis for many 2k projects. **(A)** Geographical distribution, by archive type, and **(B)** temporal availability. Modified from PAGES 2k Consortium (2017).

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Assessing hydroclimate patterns of the past 2000 years with paleo-$\delta^{18}O$ and δD records

Bronwen Konecky[1], L. Comas-Bru[2] and E. Dassié[3]

Iso2k Science Team Meeting, Zaragoza, Spain, 14-15 May 2017

Much of our understanding of Earth's hydro-climate history comes from proxies for the $\delta^{18}O$ and δD of environmental waters (e.g. precipitation, seawater, groundwater, lake water, permafrost, ice; Smerdon et al. 2017). The $\delta^{18}O$ and δD of environmental waters are recorded by sensors in a range of natural archives, such as glacier and ground ice, speleothems, corals, sclerosponges, lake and marine sediments, and tree rings. Despite this diversity, reconstructed $\delta^{18}O$ and δD can track common environmental signals such as moisture source and air mass transport history, precipitation characteristics, and temperature (Dansgaard 1964), and thus provide invaluable comparison targets for global climate models (Schmidt et al. 2014). However, no comprehensive synthesis of proxy $\delta^{18}O$ or δD yet exists in a format suitable for regional-scale climate reconstructions or for data-model comparisons.

The PAGES Iso2k project is creating a global database of paleo-$\delta^{18}O$ and δD records for the Common Era based on a range of archives, with resolutions from annual to centennial, and with extensive metadata fields to facilitate interpretation and uncertainty quantification of the emergent hydroclimate signal(s). The database is being used to identify regional- and global-scale features in hydroclimate and atmospheric circulation as well as their relationship with temperature reconstructions. As a formal project within the framework of PAGES 2k Network Phases 2 and 3, the Iso2k effort is currently the only global, multi-archive hydroclimate database being constructed for the Common Era, with strong ties to other archive and climate target-specific groups within PAGES. Iso2k comprises the first steps towards a broader "Hydro2k" synthesis.

Twenty-eight Iso2k members from ten countries, including 15 early-career scientists, met for the first in-person Iso2k Science Team Meeting. This meeting followed two years of productive, consensus-driven, tele-collaboration. The meeting took place at the CSIC (Consejo Superior de Investigaciones Científicas) Offices in Zaragoza, Spain, directly following the 5th PAGES Open Science Meeting. The main goals of the workshop were to evaluate climatic/isotopic patterns that are emerging from the "beta" version of the database (Fig. 1), which was created in early 2017, and to troubleshoot metadata and quality control issues.

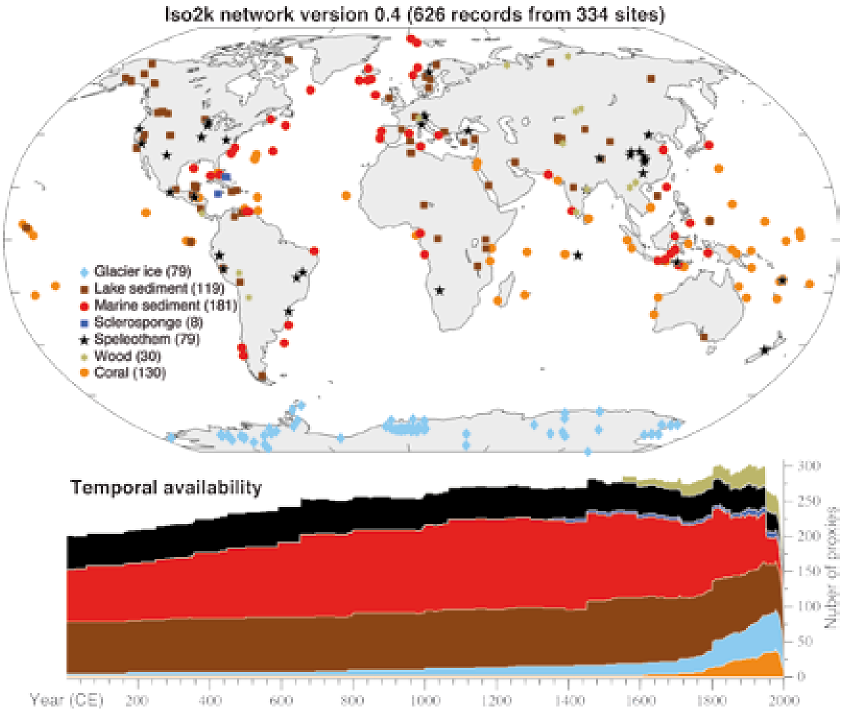

Figure 1: Status of the beta Iso2k database in June 2017. Symbols: records that have been both entered and quality-controlled. Figure courtesy of Nick McKay.

To stimulate the most productive discussion possible, prior to the workshop five small "buddy groups" were formed, each containing workshop participants and other Iso2k members who shared similar interests. These groups explored themes of broad interest for the Iso2k community: modes of variability in the high latitudes, the tropical Pacific, and the Atlantic; global comparisons with PAGES 2k temperature reconstructions; and isotope-enabled model-data comparisons. On Day 1, each group shared preliminary figures using the Iso2k database to evaluate climatic and isotopic patterns in space and time. These presentations formed the basis of the ensuing group discussion, in which participants identified the highest-priority scientific questions that will be addressed using the database. Participants also strategized about pressing metadata and data quality issues that needed to be resolved in order to address each scientific question.

Day 2 of the workshop was dedicated to the "nitty-gritty" of Iso2k: quality control, metadata, and future plans. Key points were drafted to serve as the structure for the group's first scientific papers. A mini "hackathon" allowed participants to revisit and expand on analyses presented on Day 1. Next, the group broke out into small metadata and data quality "task forces" to tackle pressing quality control issues that surfaced the previous day. After a final wrap-up discussion of next steps and a project timeline, the workshop adjourned.

For more information about Iso2k or to get involved, visit our website at www.pastglobalchanges.org/ini/wg/2k-network/projects/iso2k

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Summer temperature and drought co-variability

Fredrik Charpentier Ljungqvist[1,2], P.J. Krusic[3,4], J. Luterbacher[5], J.F. González-Rouco[6], E. García Bustamante[7], C.A. Melo Aguilar[6] and J.P. Werner[8]

Euro-Med2k workshop, Stockholm, Sweden, 1-2 December 2016

This workshop, hosted by the Bolin Centre for Climate Research and Department of Physical Geography at Stockholm University, marks the successful conclusion of Phase 2 of the PAGES Euro-Med2k working group. The objectives of the meeting were (1) to identify and document summer temperature and drought co-variability across Europe and the Mediterranean over the past millennium, and (2) to discuss opportunities for continuing the Euro-Med2k mandate after 2016.

Variations in the spatio-temporal distribution of droughts during past warm and cold periods arguably provide tentative information about future changes in European droughts associated with global warming. In light of recent progress in developing high-resolution European climate reconstructions, it is now, for the first time, possible to assess the co-variability between summer temperature and drought frequency and severity over the past millennium. To realize this goal, we use an updated version of the Old World Drought Atlas (OWDA; Cook et al. 2015), with its spatially resolved, tree-ring-based, summer drought index for the European-Mediterranean area extending back two millennia, and an updated version of the spatially resolved summer temperature reconstruction from tree-ring and historical documentary data by Luterbacher et al. (2016) extending back to 755 AD.

F. C. Ljungqvist opened the workshop by presenting the research background and a suggested outline for a proposed contribution to *Climate of the Past*. In this context, two recent studies by Hao et al. (2016) and Rehfeld and Laepple (2016) of East Asia were highlighted. Hao et al. (2016) found that hydroclimate patterns have varied considerably between different warm periods in eastern China over the past 2000 years. Rehfeld and Laepple (2016) found that the linkage between temperature and precipitation over Asia is timescale dependent, and that model simulations agree with proxy data on shorter timescales but disagree on longer timescales. These results, together with the Northern Hemispheric proxy-model comparison by Ljungqvist et al. (2016), indicate that the hydroclimate responses to low-frequency temperature changes are not yet sufficiently well known.

The Euro-Med2k group is committed to reduce this knowledge gap for the European-Mediterranean area by analyzing, in space and time, linkages between (1) 20th century instrumental temperature and drought data, (2) the gridded European temperature and drought reconstructions from 850 AD to the present, and (3) climate model simulations of summer temperature and soil moisture and precipitation from 850 AD to the present. It was decided to assess the co-variability from inter-annual to sub-centennial timescales, and to investigate potential changes in the dominant patterns of co-variability in relation to, or in tandem with, the timescales chosen. Preliminary results suggest that the co-variability between temperature and drought depends on the timescales chosen.

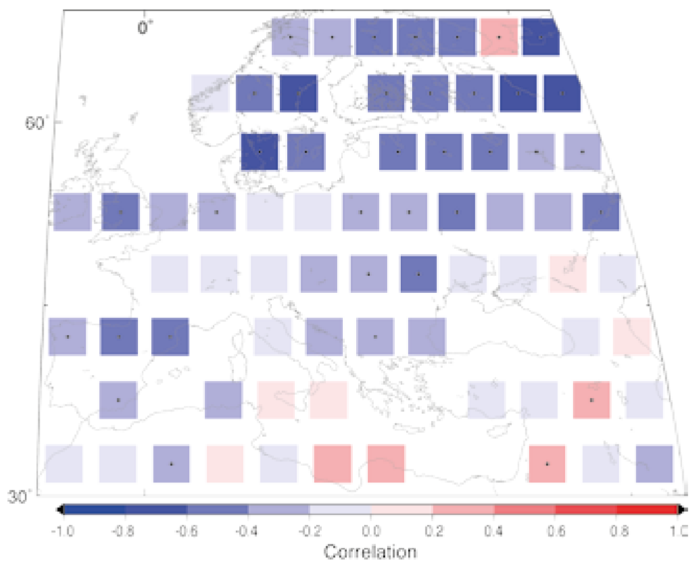

Figure 1: 21-year moving average, point-to-point correlations between simulated summer (JJA) temperature and soil moisture over the pre-industrial period AD 850 to 1850 on a 5°×5° grid using the CCSM4 model. Dotted squares indicate that the value in a grid-cell is significant at the 95% level, accounting for the loss in degrees of freedom of the filter (J.F. González-Rouco, E. García Bustamante and C.A.M. Aguilar, unpublished data).

Figure 1 shows an example of the correlations between simulated summer temperature and soil moisture over AD 850 to 1850 in Europe using the CCSM4 model.

The second part of the workshop was devoted to working in smaller groups with different tasks related to setting up experiments, discussing methods, and data–model intercomparisons. During the workshop, P. J. Krusic presented outlines for a new project regarding "European streamflow and drought: Continental scale outputs of the hydrological cycle". In a further presentation, J. Luterbacher talked about the Tambora eruption in April 1815 and the subsequent "year without a summer 1816", summarizing the current state of knowledge related to summer temperature and drought anomalies across different areas of the globe.

The last part of the workshop was devoted to discussions related to future collaborations within the Euro-Med2k working group after its official end in 2016. An agreement was reached to continue as an independent consortium, preferably in collaboration with PAGES, aiming for one meeting per year arranged by its members and their institutions. Over the past few years, Euro-Med2k has taken advantage of the spinoffs between the proxy and paleo-model communities and this was agreed to be an important aspect to continue pursuing.

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Overcoming reductionism when linking climate variability with human history

Ulf Büntgen[1,2,3], A. Kirdyanov[4,5], E. Vaganov[4,5] and workshop participants[6]

Krasnoyarsk, Russia, 10-14 April 2017

Attended by 45 scholars from seven nations, this first PAGES 2k Network workshop in the world's largest country took place at the Siberian Federal University in Krasnoyarsk, Russia. Timely aspects of archaeology, biogeochemistry, climatology, ecology, history, and epidemiology were catalyzed in 20 stimulating talks. Focusing on the available paleo-evidence from Inner Eurasia, the authors not only devoted critical discussion to data-inherent and methodological-induced limitations, but also prioritized future research avenues towards a better understanding of environmental and societal changes throughout much of the Holocene.

A cross-disciplinary mapping project was launched as a direct outcome of this meeting, with great enthusiasm from all participants expected to translate into a unique database. Considering the greater Altai region as a nucleus for sociocultural evolution, two geographical domains have been defined: A core region from 60-120°E and 40-60°N, as well as a wider expanse from 30-150°E and 40-60°N. Following on from the LALIA concept (Büntgen et al. 2016, 2017), the database will comprise information from archaeological findings, disease outbreaks, genetic structures, glacier dynamics, ice cores, lake sediments, pollen profiles, trade routes, tree rings, and written sources (Fig. 1). Output from externally forced, coupled climate-model simulations of the last 2000 years is anticipated to provide mechanistic understanding of the underlying processes of past climate dynamics and their potential direct and indirect influences on environmental conditions, as well as trends and extremes in the socio-political and economic behavior of ancient societies (Büntgen and Di Cosmo 2016). Operating across different spatiotemporal scales, our interdisciplinary approach aims to answer the question: *"How did climate change affect the rise and demise of Eurasia's nomadic steppe empires?"*.

In addition to its long-term goal, the consortium-driven workshop appeared particularly timely, because the ongoing and predicted rate of environmental and climatic change not only implies urgent research needs, but also offers a wide arena for (re)activating collaborations between Russia and the international scientific community (Büntgen 2014). Despite a variety of economic and logistic challenges, as well as political and administrative caveats, the workshop will hopefully contribute to mitigate deterioration of Russia's academic landscape, and to facilitate access to, and exploring of, a wealth of unique paleo-archives (Büntgen et al. 2014). Scholars from all disciplines and countries are kindly invited to strengthen the momentum and join any follow-up action.

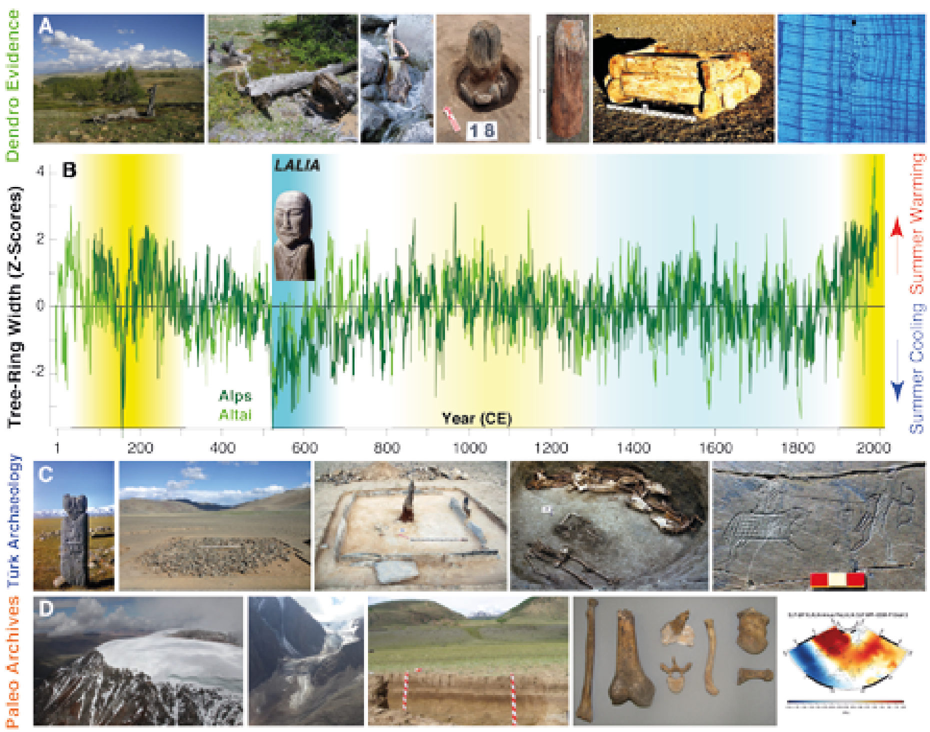

Figure 1: (**A**; left-right) Living and relict *Larix sibirica* (larch) ~2330 m asl in the Mongun-Tayga mountains of the Russian Altai, subfossil larch wood at the treeline (both A. Kirdyanov), and within a glacier (A. Nazarov). Archaeological larch wood from a Türk memorial in Kyzyl-Shin and from a Scythian burial in the Ulandryk valley (I. Slyusarenko), radiocarbon dated to ~1500 and ~2300 cal BP, respectively. Stained tree rings of a relict larch sample from the treeline (V. Myglan), with black dot referring to a cooling-induced growth depression after a large volcanic eruption in 536 CE (Churakova (Sidorova) et al. 2014). (**B**) Tree-ring width chronologies from the European Alps and the Russian Altai (Büntgen et al. 2016). (**C**; left-right) Türk sculpture from the Turu-Altai mountain steppe, Türk kurgan in the valley of Char-Jamaatyn-Gol in the Mongolian Altai (both G. Kubarev), Türk memorial (no 5) with its stone and wooden remains in Kyzyl-Shin, Russian Altai (I. Slyusarenko), Türk burial (kurgan 11) at Balyk-Sook I cemetery in the Russian Altai, as well as engraved worries at Zhalgyz-Tobe in the Russian Altai (both G. Kubarev). (**D**; left-right) Tsambagarav glacier in the Mongolian Altay (H. Machguth) where a 72 m long (and 6000-year old) ice core was drilled (M. Schwikowski), and Ak-Tru glacier in the northern Chuya mountain range of the Russian Altay (A. Kirdyanov). Soil profile within the Chuya river valley (A. Agatova). Material for DNA extraction (A. Pilipenko), and climate model simulation for the LALIA (E. Xoplaki).

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Central and Eastern Europe paleoscience symposium: From local to global

Marcel Mîndrescu[1,2] and Ionela Grădinaru[1,2]

Cluj-Napoca, Romania, 23-24 May 2016

The projected climatic changes and increasing anthropogenic pressure by the end of this century are generating global concerns about the potential impacts on environment and society. Most environments are currently shaped by the interactions between the changing climate and human disturbances, therefore understanding environmental dynamics cannot be achieved without considering both climatic and anthropogenic drivers (Dearing et al. 2015).

An increasing number and diversity of paleoclimatic studies spanning the Holocene have indicated that climate underwent complex developments that rarely followed larger spatial scale patterns (e.g. Wenniger et al. 2009). However, at continental levels the cohesion of climatic shifts was documented to increase, as more and more archives, unevenly distributed across Europe, contributed to the state of knowledge.

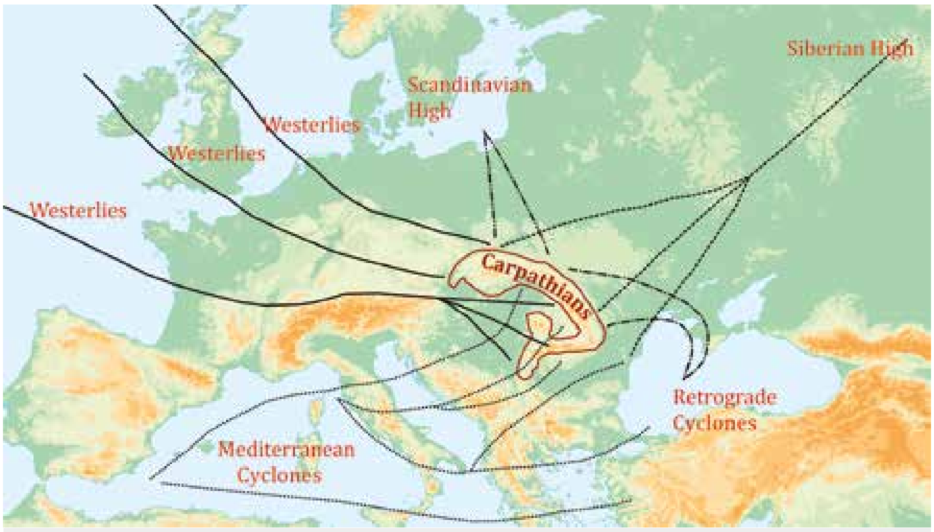

Figure 1: Relief map of Europe with the location of the Carpathian range (dark red contour line) and schematic representation of the main atmospheric circulation patterns in the region.

As part of the continental scale, Central and Eastern (CE) Europe has only recently entered the continental ensemble of paleoclimatic reconstructions, despite its significant potential given by the geographic location, at the junction of major air masses (i.e. Atlantic, Mediterranean and Siberian) which shaped a landscape with strong climatic regimes, and landform heterogeneity. Moreover, in this region lies the last orographic barrier of Europe, the Carpathians, beyond which Eastern climatic influences are most strongly felt, thus converting the Carpathian range into an area of climatic transition (Fig. 1).

The location and layout of the Carpathians, which interfere to a significant degree with the latitudinal advection of air masses (Baltic to Mediterranean and vice versa: *from sea to sea*), and, more prominently, with the longitudinal circulation (Atlantic to Ural and vice versa), have been a key factor for understanding past and current climate changes in the region (Fig. 1). The *Carpathian influences* include both long-ranging effects (decreasing air humidity and precipitation eastward, detaining drier, more continental Eastern air masses) and local effects (the Carpathians breezes, thermal inversions, foehn winds, etc.), which factor into the climatic heterogeneity of the region.

Although the climate of the past, especially for the last millennium, and its relationship to human activities has been extensively studied, there remains a paucity of paleoenvironmental information over significant geographical areas, including CE Europe (Florescu et al. 2017). Therefore, in order to support paleoenvironmental research conducted in the region by local and foreign scientists, a PAGES-supported conference was organized in 2016, focusing on climate changes in CE Europe and their implications at various scales: *Central and Eastern Europe Paleoscience Symposium: From Local to Global - CEEP 2016*. The event, attended by local and foreign researchers, senior and young scientists, stakeholders, policy makers and natural parks officers, addressed paleoclimatological and paleoenvironmental research and coincided with PAGES' annual Scientific Steering Committee (SSC) meeting.

The symposium comprised six sessions focused on: Coordinated global change research; The climate system from a paleo perspective; Landscapes, biota and biosphere interactions; Interactions between humans and the environment; Outreach - communicating past global change research to stakeholders; and Thresholds and extremes as examples of PAGES' integrative activities. The event was attended by 120 participants, of which 70 presented their contributions (39 oral presentations and 31 posters), from 22 countries. The abstracts for all the contributions were published in a special volume of Georeview Journal (http://georeview.ro/ojs/index.php/revista/issue/view/24). Some of the contributions presented at the symposium will also be published in a special issue "European Paleoscience" of *Quaternary International* (in prep.).

The meeting was held between May 20 and 26, which included PAGES' SSC meeting and a field trip which took participants to the Apuseni Mountains. The main site of interest there was the Scărişoara Ice Cave (700 m long, 105 m deep, 1165 m asl), famous for the world's largest (100000 m³, 22.5 m thick) and one of the oldest (ca. 10.500 BP) cave ice deposits (Racoviţă and Onac 2000). The duration and tone of the meeting were favorable for scientific interaction and the exchange of ideas, as well as acquainting participants with Romania's natural environment and traditions, which could perhaps be listed among the greatest achievements of this conference.

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Natural and human-driven fire regime and land-cover changes in Central and Eastern Europe

Angelica Feurdean[1] and Boris Vannière[2]

GPWG2 workshop, Frankfurt am Main, Germany, 5-8 December 2016

This workshop sought to expand the scope of the Global Paleofire Working Group (GPWG2), both by introducing the Global Charcoal Database (GCD; www.paleofire.org) to potential new contributors and users from Central and Eastern Europe, and to encourage them to present their datasets and initiate collaborative research using the GCD database. Twenty-six attendees, almost half early-career researchers, with expertise in past fire, vegetation, anthropogenic impact, land-cover changes, and climate participated in this workshop.

Although the continually increasing number of charcoal records in GCD has enabled a number of regional-to-global syntheses of trends in biomass burning (e.g. Marlon et al. 2016), the paucity of charcoal records from Central and Eastern Europe in the global databases has hampered a coherent synthesis of temporal pattern in biomass burning and associated fire-stakes in this region. Focusing on Central and Eastern Europe, this workshop aimed to fill the gaps in our understanding of fire-regime dynamics, under a range of past environmental conditions and anthropogenic land uses, in a region that contains fire-prone ecosystems of high conservation value on the one hand, yet lacks the knowledge of the optimal fire regimes to preserve their functioning on the other (Feurdean et al. 2017). The first session introduced the attendees and facilitated familiarization with the datasets available for the reconstruction of past fire activity in Central and Eastern Europe. The second session combined both instruction and hands-on statistical tool use with the GCD and "paleofire" R-package (Blarquez et al. 2014), to develop regional syntheses of patterns in past fire activity. To achieve this, all attendees brought and compiled almost 50 new charcoal datasets from Central and Eastern Europe to produce the very first sub-regional-to-regional paleofire synthesis for this part of Europe (Fig. 1). The third session was dedicated to sub-group and plenary discussions covering three key topics: (i) the interpretation of the preliminary regional and sub-regional cumulative curves; (ii) plenary lectures on proxy-based and modeled Holocene variation in climate conditions, land cover and population density changes; offering a background on the past environmental conditions and level of anthropogenic impact; and (iii) discussions related to statistical approaches to charcoal time series analyses and charcoal counting methodologies. A common theme in discussions was the importance of disentangling natural from human-driven fires, the role of anthropogenic fire on landscape dynamics, and the effects of fire on vegetation.

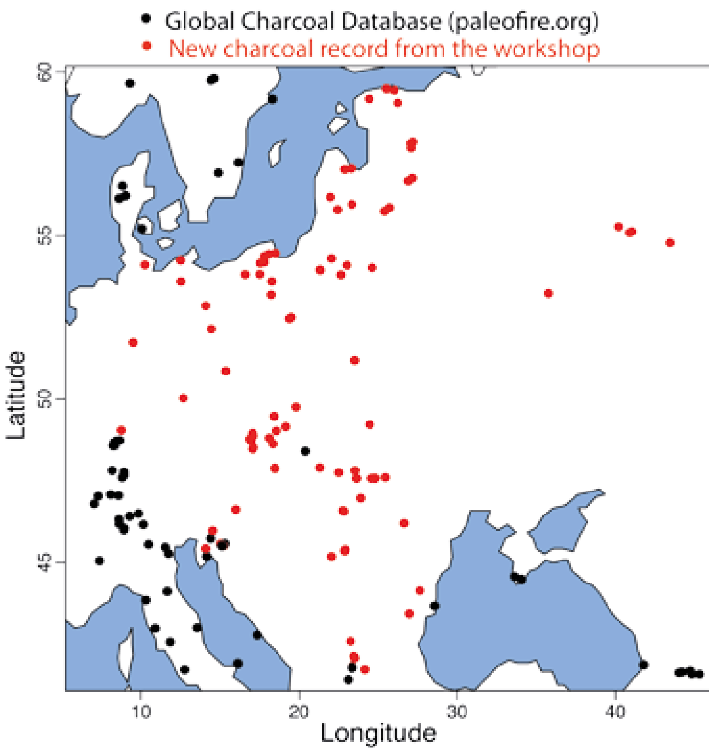

Figure 1: Distribution of our new charcoal records from Central and Eastern Europe in the Global Charcoal Database (www.paleofire.org).

Our preliminary results over the entire region indicate the following major phases in the trajectory of fire activity over the Holocene: the highest fire activity between 10-8 ka; a low activity between 8-3 ka; a re-increase in fire activity from 3 ka towards the modern times before a final decrease over the last century. Interestingly, separated in two regions, Central and Eastern Europe show a distinctly different pattern in fire activity during the late Holocene; a decline in Central Europe as opposed to an increase in Eastern Europe. Following the workshop, we augmented this new Central and Eastern Europe dataset with ca. 70 additional records and metadata information, and are in the process of evaluating the sub-regional composite records against other proxy-based and modeled datasets of past climate, vegetation, and land-cover changes. In the coming months, our group will focus on examining the following key research questions: How has biomass burning varied along ecological and climatic gradients? What is the link between biomass burning and land-cover changes in this region? How has anthropogenic use of fire changed over time, for example with shifts in land-use strategies and landscape fragmentation?

We conclude that this workshop provided an excellent opportunity to introduce the GCD both to potential new contributors and users, and to address a geographical "data gap" leading to important new collaborative research. We also invite other scientists and data contributors from this part of Europe to join our research initiative.

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Lessons learnt from paleoscience on a possible 1.5–2°C warmer world in the future

Hubertus Fischer[1], A.C. Mix[2] and K.J. Meissner[3]

Bern, Switzerland, 5-7 April 2017

"Understanding past climate variations plays a critical role in improving predictions for the future."

"The short time interval of direct observations hampers our understanding of climate variability and planetary boundaries but paleoscience can overcome this limitation."

"The study of warmer time periods in the past will improve our understanding of climate/ greenhouse gas feedbacks."

or "The past is the key to the future."

Statements like these are used in many paleoscience publications and often found in funding proposals. But what knowledge can we really gain on the changes our planet will experience in a 1.5-2°C warmer world, the challenging target of the Paris Agreement (http://unfccc.int/paris_agreement/items/9485.php), by looking at the paleorecord? Will a 1.5-2°C warmer world be a safe harbor and provide sustainable climate conditions for future societies? Will it avoid long-term tipping points that might have been crossed for a less-controlled future anthropogenic warming scenario?

These questions are at the very heart of PAGES. Accordingly, PAGES recently initiated an integrative activity on "Warmer Worlds" with the goal to bring together the expertise in PAGES working groups and the entire community, and to distill the relevant information on these questions. The Warmer Worlds integrative activity members met for their first workshop, jointly co-sponsored by PAGES and the Oeschger Centre for Climate Change Research of the University of Bern. The expertise of the 50 international scientists in the room covered the whole range of paleoscience, including a large spectrum of paleoarchives and climate models to reconstruct changes in the Earth system. Time scales covered ranged from warmer periods in the more recent Holocene (Wanner et al. 2008; PAGES 2k consortium 2013), past warmer interglacials in the Quaternary (Past Interglacials Working Group of 2016) and all the way back to the Mid Pliocene Warm Period (Haywood et al. 2016), the time period where CO_2 concentrations similar to the ones expected for a 2°C warmer world were encountered for the last time (Martinez-Boti et al. 2015).

The state of our paleo knowledge on different aspects of Earth system changes in a warmer world was summarized during plenary talks and three parallel sessions. This included (i) latest results on past changes in biogeochemical cycles with a focus on potential rapid greenhouse gas releases during warmer periods and feedbacks involved during these transitions, (ii) ice sheet and sea-level changes illustrating equilibrium sea-level increases of more than 6 m in a 2°C warmer world (Dutton et al. 2015), (iii) sea-ice and ocean circulation changes in response to warmer boundary conditions, (iv) the response of vegetation and ecosystems, (v) the risk of fire, storm and flood events in warmer worlds, and (vi) the change in climate variability accompanying generally warmer climate conditions.

Figure 1: Skiing in a warmer world - Former PAGES co-chair, and Warmer Worlds Integrative Activity leader, Hubertus Fischer gets trapped by a sudden lack of snow in the Bernese Alps after the workshop. Although paleo evidence on skiing is severely limited, documentations of snowline changes exist.

Furthermore, the workshop facilitated a unique community writing effort to create an authoritative assessment of paleo evidence that will inform us on different aspects of a warmer future. Five chapters for a review paper have been prepared in parallel using web-based editing tools by five sub-groups of participants. These chapters are currently being collated by the authors of this report into a coherent paper, addressing the following overarching topics:

- Can past climate states provide suitable analogues for future warming and its impacts?
- Impacts and feedbacks connected to past warmer climate.
- Changes in climate variability and extreme events.
- Rates of change and tipping points.
- Constraining climate sensitivity from past warm periods.

This paper is scheduled to be submitted later this year and will serve as the base for the paleoscience contribution to a special IPCC report (http://www.ipcc.ch/report/sr15/) currently in preparation.

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Towards a marine synthesis of late Pliocene climate variability

Erin L. McClymont[1], A.M. Haywood[2] and A. Rosell-Melé[3]

PlioVAR meeting, Durham, UK, 19-21 April 2017

The aim of the PlioVAR working group is to develop a synthesis of our understanding of late Pliocene climate variability over glacial-interglacial timescales. Twenty-four researchers met to discuss progress in the synthesis of existing multi-proxy data sets from marine sediment archives, and to finalize agreement on common protocols for the reporting and compilation of data.

The Durham meeting started with presentations outlining PlioVAR aims and objectives, reporting progress towards regional data assimilation, and discussing appropriate data management. A white paper on potential stratigraphic protocols by Marci Robinson and Tim Herbert was outlined and discussed. An update on ongoing efforts by the inter-linked Pliocene Model Intercomparison Project (PlioMIP) was provided.

The remainder of the workshop focused on identifying the following three priorities:

- Continued data collection from marine sediment cores for late Pliocene climate (ca. 2.4-3.6 Ma)

During the northern summer, the regional synthesis leaders will continue to collate multi-proxy datasets. It was agreed that this information should not be restricted to sea-surface temperatures, but span a range of climate variables where information is available. There was discussion around how to compare single-proxy and multi-proxy sites, how to handle potentially conflicting signals in multi-proxy sites, and how to represent uncertainties which are not always quantifiable. The two PlioVAR target intervals focus on (i) 2.4-2.8 Ma, to represent the intensification of northern hemisphere glaciation, and (ii) the marine isotope stages M2-KM3 interval (ca. 3.30-3.15 Ma), which marks a glacial-interglacial transition and had an orbital configuration similar to modern (Fig. 1). Between 20 and 30 key marine sites have been identified which will contribute to the PlioVAR synthesis. However, the heterogeneity of data availability across regions was highlighted. The highest number of sites are found in the North Atlantic (Fig. 1), whereas other regions have fewer sites represented. It was noted that recent International Ocean Discovery Program (IODP) expeditions will address some of these gaps (e.g. Expedition 353 Indian Monsoon, Expedition 354 Bengal Fan, Expedition 355 Arabian Sea Monsoon, Expedition 356 Indonesian Throughflow, Expedition 361 Southern African Climates).

- Evaluation of stratigraphic controls

A set of minimum standards was developed for the acceptance of datasets into the PlioVAR synthesis. Existing age models will be reviewed, and revised if required. It was recognized that there could be differences in the resolution of temporal control and the resolution of the proxy data, and the procedures for handling this were discussed.

- Continued population of the PlioVAR database

An interactive database which displays PlioVAR sites was shown, and will soon be launched. This resource will allow working group members to identify whether their own published or emerging datasets are missing from the current synthesis. For the data synthesis effort, a dataset template was agreed upon, which the leaders for each region will use, facilitating the statistical analysis required to investigate climate variability.

PlioVAR will continue to work on synthesis efforts over the next few months, and we welcome new participants to those activities. We are interested to learn of emerging data which might contribute to our planned assessment of glacial-interglacial variability within the two intervals detailed above. More information will be transmitted through the PAGES website and via the working group mailing list (www.pastglobalchanges.org/ini/wg/pliovar/intro). The Steering Committee chair can also be contacted directly (erin.mcclymont@durham.ac.uk).

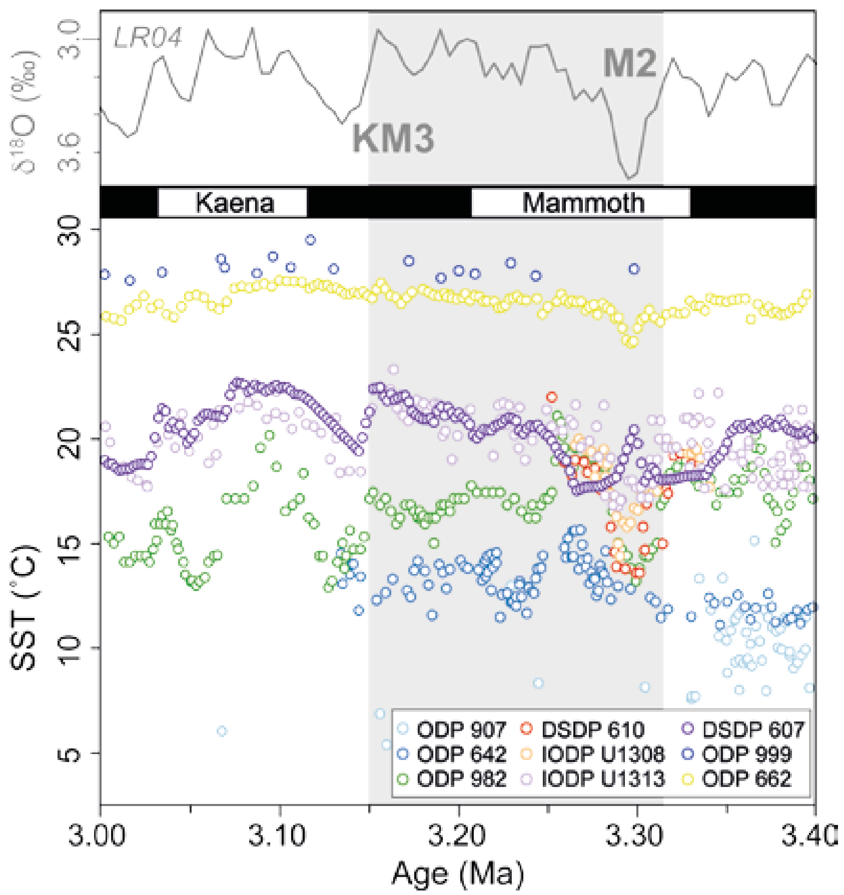

Figure 1: Ongoing data synthesis of late Pliocene climate variability, from the North Atlantic and Nordic Seas. Top, LR04 global benthic stack with the targeted Marine Isotope Stage M2 to KM3 interval (grey shading) and paleomagnetic timescale. Bottom, compilation of sea surface temperature records between 3.40 and 3.00 Ma. PlioVAR will characterize the glacial-interglacial variability in these records across multiple proxies, and compare it to the intensification of northern hemisphere glaciation around 2.4-2.8 Ma. Source: De Schepper S, Ho SL and Risebrobakken B (unpublished).

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Spatial pattern and temporal evolution of glacial terminations of the last 800 ka

Emilie Capron[1,2], N. Vázquez Riveiros[3], F. He[4,5], A. Jacobel[6] and X. Zhang[7]

Montreal, Canada, 18-20 October 2016

The second QUIGS workshop brought together 28 delegates to assess current knowledge and research needs on the spatio-temporal patterns of climate forcing, responses and feedbacks that characterize glacial terminations, i.e. transitions between glacial and interglacial periods.

Presentations and discussions outlined common features and differences between terminations. Similarities include nonlinear, multi-millennial scale changes in key climatic indicators, e.g. decreased global ice volume, atmospheric greenhouse gas concentration rise, surface temperature increases and Asian monsoon intensification. However, amplitude and duration of terminations are variable. Transitions initiate at various glacial ice sheet states and progress under a variety of orbital forcing scenarios (Fig. 1).

Numerous presentations evidenced increased record availability and understanding for Terminations I (TI) and II (TII). However, results from the low latitudes (Africa, South America) and outside the North Atlantic basin (Pacific, Southern Ocean) highlighted regional variability, emphasizing the need for further constraints and careful interpretation in less-explored regions.

Millennial-scale events are a crucial part of the dynamics of terminations. Terminations include periods characterized by Ice-Rafted Debris (IRD) deposition in the North Atlantic under Heinrich Stadial-like conditions (Fig. 1), likely associated with substantial Atlantic Meridional Overturning Circulation (AMOC) weakening. Each termination seems to feature a sharp increase in CH_4 and in Asian monsoon strength, coinciding with the end of the main CO_2 and Antarctic temperature increases. Evidences indicating sub-millennial-scale changes occurring at high and low latitudes in association with Heinrich Stadials (HS) 1 and 11 are increasing. Although millennial-scale investigations across older terminations are emerging, records are still scarce, and many have insufficient resolution to allow identification of abrupt climate changes.

Establishing the deglacial sequence, its regional fingerprint and the phasing with respect to orbital forcing beyond TI and TII requires paleoclimatic records of higher temporal resolution and improved chronologies, especially since the fingerprint of the Younger Dryas cooling and Bølling warming across TI does not appear as a consistent feature of older terminations. New ice core absolut age markers and precise radiometric dates on Asian speleothems (Cheng et al. 2016), now available for the last 700 ka, will represent useful anchors to improve paleoclimate record chronologies.

Modeling results were also a key part of the discussions. Initiatives by several climate modeling groups provide a dynamic framework to explain TI millennial-scale events (Fig. 1) and exploratory simulations for TII are in progress. A QUIGS paper in preparation will provide a framework and recommendations for the upcoming TII transient simulations. This effort will complement the TI deglaciation experiments of PMIP4, allowing an evaluation of the similarities and differences in the climate system response during TI and TII in concert with paleoclimate records.

Constraining the size and spatial distribution of ice sheets during the penultimate glacial maximum remains a challenge. New data will complement recent modeling efforts to describe the interaction between insolation and ice sheets and its role in pacing terminations. The proposed statistical models of orbitally driven terminations raised questions on the role of insolation during "failed" terminations. Further constraints are also required on the glacial carbon reservoir, and the mechanisms responsible for its modification across T1 remain debated.

The next QUIGS workshop focussed on interglacials of the 41 ka-world and the Middle Pleistocene Transition. It took place 28-30 August 2017 on the Greek island of Lesvos.

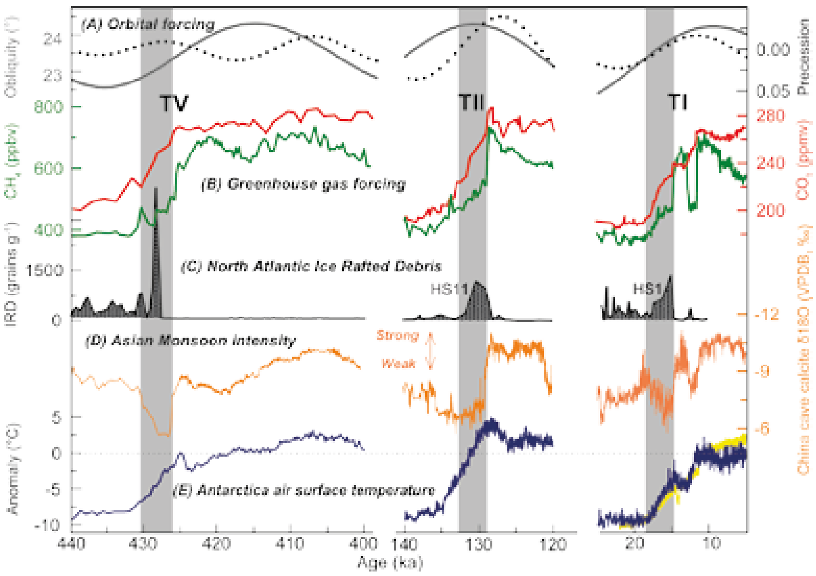

Figure 1: Terminations I (TI), II (TII) and V (TV) forcing and climatic parameters. **(A)** Orbital and **(B)** greenhouse gas forcing (Bereiter et al. 2015; Loulergue et al. 2008), together with records of **(C)** ice rafted debris, **(D)** Asian Monsoon intensity (Cheng et al. 2016), and **(E)** Antarctica air temperatures (Jouzel et al. 2007). TI: NA87-27 records (Waelbroeck et al. 2001), TII and TV: ODP-980 records (McManus et al. 1999); Transient surface temperature modeled with CCSM3 are shown in yellow (He et al. 2013). Temperature records represent anomalies relative to the last millennium. Grey bars indicate intervals characterized by substantial North Atlantic IRD deposition and weak Asian Monsoon.

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Proxy System modeling and data assimilation in paleosciences

Mike Evans[1], H. Goosse[2] and S. Khatiwala[3]

Louvain-la-Neuve, Belgium, 29 May - 1 June 2017

Data assimilation (DA) for paleoenvironmental reconstruction combines information from observations and models of the Earth system to develop mechanistically consistent estimates of environmental fields. There are four essential ingredients to paleoenvironmental DA: (1) Models of the Earth system describing possible system states; (2) Observations telling us what actually happened in the real world; (3) Proxy System Models (PSMs) describing how geological, biological or chemical archives are imprinted with environmental signals, and linking process models to observations; and (4) An algorithm that optimally combines model results, observations, and uncertainties in the various elements.

To review current activities in paleoenvironmental DA, a group of climate scientists recently met in Louvain-la-Neuve, Belgium. The group contained specialists of climate modeling and scientists more closely involved in the collection and analysis of paleoclimate observations. The goal was to consider challenges and potential for advances in DA and PSMs, and to stimulate new activities via practical training exercises.

Challenges and opportunities

Overview talks first reviewed the activities of a small but rapidly growing community. The parallels with modern DA were particularly inspiring. In addition to the product itself, reanalyzes are an opportunity to bring together scientists of different backgrounds, stimulate data recovery, and demonstrate skill improvement brought by additional data.

The talks and subsequent breakout groups identified many existing PSMs of varying structure and complexity for a number of major paleoenvironmental archives and observations. However, the uncertainty in PSMs – structural and/or systematic – is not well constrained. There are also multiple DA techniques that might be applied to paleoenvironmental reconstructions but no assessment of their relative advantages and limitations in settings corresponding to paleoclimate applications is currently available. Therefore, the choice of PSM for a particular DA problem is frequently unclear.

The workshop concluded with four classroom exercises introducing participants to proxy system modeling, adjoint methods and data assimilation.

Recommendations of the workshop

The participants proposed three activities to be launched in the coming months:

(1) Use case studies for particular replicated observations, proxy systems and archives to better describe the structural uncertainty and systematic error in PSMs and in observations as it seems important to first test the PSM independently of Earth system models.

(2) Create a testbed for the development and testing of paleo DA methods constrained by a realistic observing network corresponding to the past millennium, but using data for the last century with specific additional noise (Fig. 1), and compare the reconstructions to modern reanalysis products.

(3) Form a task force to explore uncertainty quantification procedures relevant to paleoclimate reconstructions, develop metrics to assess their relative merits, and to apply these to parameter estimation and data assimilation problems.

As a first step, the proposed activities are thus either devoted to the modeling of a specific type of record or to the comparison of DA methods in an idealized framework where observations are modeled variables with a precisely known uncertainty. First results of these activities are expected in early 2018 so that they can be presented at a planned DAPS session at EGU. As the ultimate goal of DAPS is to bridge the gap between modeling of a wide range of data and data assimilation, the next DAPS workshop in the second half of 2018 will be devoted to issues that limit a global approach and the means to tackle them. The path to solve those problems will be put forward in 2019.

DAPS is an open community of observationalists and modelers, and we invite you to bring your interests and expertise into the project. For more information, visit the DAPS website (http://pastglobalchanges.org/ini/wg/daps/intro) where the experimental design of the planned intercomparisons will be posted, join the working group mailing list (https://listserv.unibe.ch/mailman/listinfo/daps.pages) or email one of the coordinators.

A copy of the talks presented at the workshop is available here: http://pastglobalchanges.org/calendar/2017/127-pages/1657-daps-1st-wshop-2017

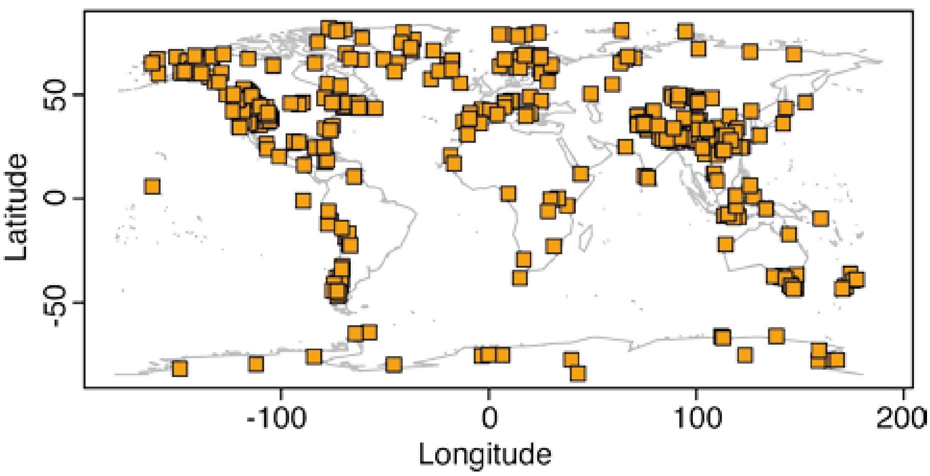

Figure 1: Example of the data distribution for the comparison of data assimilation methods, derived from the data distribution in 1500 CE in the PAGES 2k database (PAGES 2k Consortium 2017). Figure courtesy of J. Franke.

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Measuring resistance, recovery and resilience in long-term ecological datasets

Alistair Seddon[1], L. Cole[2,3], M. Fletcher[4], J. Morris[5], K. Willis[6,2] and EcoRe3 working group

EcoRe3 workshop, Finse, Norway, 27-31 March 2017

The aim of the first EcoRe3 working group workshop was to develop novel, quantitative approaches to measure components of ecosystem resilience (e.g. *resistance* - the amount of change following a disturbance; *recovery rates* - the speed of recovery following disturbance; and *latitude* - the distance to an ecological threshold) using proxy data from lake and bog sediments. It was attended by 23 participants from 11 countries, and was split into three main thematic sessions. The workshop also included a meeting to discuss working group organization over the next three years. It was co-funded by PAGES and the Research Council of Norway.

Session one built on preliminary work which used a variety of statistical approaches to measure resistance and recovery rates in pollen data. A key issue highlighted in discussions was that the timing and the impact of disturbance events are represented by a small number of data points in many Holocene sediment sequences. Numerical techniques which can identify signal from noise are therefore crucial for quantifying any disturbance-related ecological change in such records.

Two new projects were established which aim to address this issue using different approaches. First, a systematic review will be used to investigate current knowledge about the timing and magnitude of ecological disturbances in different systems. The result of this work will lead to a series of recommendations that highlight the appropriate analyses and ecological questions for any given paleo-dataset. Second, a series of model-based, statistical approaches were developed to enable robust detection and quantification of any disturbance-related response. Members of EcoRe3 are now working to implement these model-based approaches in a range of ecological settings (Fig. 1).

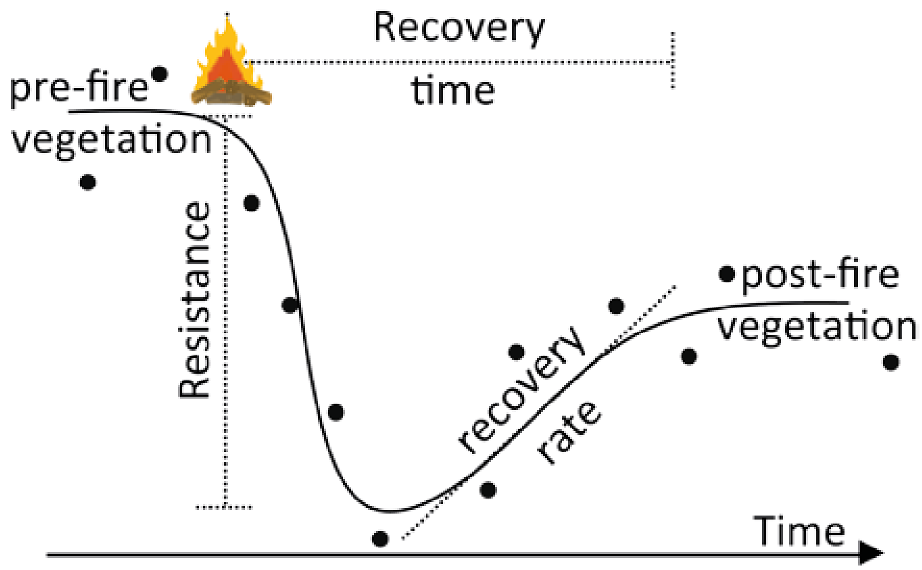

Figure 1: Example of resilience components estimated from pollen data (black dots).

Since a number of workshop participants were experts in measuring components of resilience using remote sensing data, a second session was dedicated to exploring methods of measuring biome stability, determining the number and presence of alternative states, and identifying distances to thresholds using a combination of both spatial and temporal datasets. A novel statistical approach was presented to address these aims using satellite data, and breakout discussion groups were held in which this method was subjected to rigorous critique and review. Discussions were then held to determine pathways for translating the approach, currently developed for univariate satellite data, to a large spatial network of paleoecological records.

Finally, a third session aimed to predict which functional traits (i.e. morphological, physiological or phenological characteristics that influence how organisms respond to the environment; Diaz et al. 2013) would be responsible for ecosystems with high resistance, and which traits would be related to fast recovery rates. From a paleoecological perspective, it was clear that the key challenge is to develop tools which enable one to move from pollen assemblages (with their known biases related to taxonomic resolution and representation) to species-based trait databases derived from present-day ecological understanding and sampling (e.g. the TRY database; Kattge et al. 2011). This would then allow predictions made by ecological trait theory to be tested using paleoecological data. A workshop which aims to tackle these issues is planned in Utah, USA, in 2018.

During the workshop, a number of participants gave talks on their own methods to identify alternative stable states and early warning indicators in long-term ecological data. A critical theme that ran throughout the discussions was the need to have an underlying model to support the assumptions of resilience theory, since abrupt changes are not necessarily always associated with fold bifurcations (e.g. Williams et al. 2011). During the EcoRe3 working group meeting, we distributed work tasks amongst members of the group, identified milestones for papers, and established the topics, timings and locations of future meetings. The spectacular Finse Alpine Research Station meant that many participants were able to try their hand at cross-country skiing as an antidote to the intense discussions over the course of the week. Further details of EcoRe3 activities will be published on the website (www.pastglobalchanges.org/ini/wg/ecore3) and on social media outlets (see below).

- EcoRe3 on Facebook (visit page and request to join): https://www.facebook.com/groups/286999515057710/
- EcoRe3 on Twitter: @Eco_Re3
- EcoRe3 on ResearchGate: https://www.researchgate.net/project/EcoRe3-Resistance-Recovery-and-Resilience-in-Long-term-Ecological-Systems-2

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Towards global land-cover and land-use reconstructions over the Holocene

Marie-José Gaillard[1], P. Gonzales[2], S. Harrison[3], K. Klein Goldewijk[4], F. Li[1] and M. Madella[5]

LandCover6k General Workshop, Zaragoza, Spain, 16-17 May 2017

The LandCover6K working group (Gaillard et al. 2015) met for its third yearly general workshop. The focus was on how the quantitative land-use and land-cover reconstructions achieved so far should be synthesized and formatted to be useful for (i) climate and dynamic vegetation modeling studies, and (ii) evaluation and improvement of scenarios of past anthropogenic land-cover change (ALCC). Introductory presentations by S. Harrison on CMIP6-PMIP4 (climate/paleoclimate modelling intercomparison programs); A. Dallmeyer on a new ensemble of transient model simulations of vegetation change performed in MPI-ESM1.2 using different forcings (e.g. land use); B. Stocker on recent modeling results of CO_2 emissions from ALCC estimated using global dynamic vegetation models forced by scenarios of the extent of past anthropogenic land use (Stocker et al. 2017); K. Klein Goldewijk on the latest version of HYDE 3.2 (Klein Goldewijk et al. 2016); E. Ellis on the concepts of anthrome, sociocultural niche construction and anthroecological change, and the GLOBE project; and M. J. Gaillard (global land cover), M. Madella (global land use), U. Lombardo and W. Gosling (Latin America), A. Kay and C. Courthey-Mustaphi (Africa), M. Chaput (Canada), S. Teng (China), and J. Bunting (pollen productivity estimates) on the major progress made in studies of pollen productivity estimates and land-cover/land-use reconstructions in the world provided the necessary background to formulate and plan LandCover6k products.

Pollen-based REVEALS reconstructions of plant cover exist for Europe (Trondman et al. 2015), temperate China (Li 2016; Fig. 1), and Siberia (X. Cao and U. Herzschuh, unpublished). Reconstructions for North America, Canada and Alaska are in progress, as well as studies on pollen productivities and REVEALS reconstructions in SE India and West Africa. Land-use maps are ready for Northern and Central America and the implications for the HYDE scenarios and effects on climate have been evaluated. The land-use maps for West Africa (A. Kay et al.) and a major synthesis of pollen data, archaeological and historical data for East Africa (R. Marchant et al.) were finalized. The process of gathering archaeologists and historians in Europe, Latin America, India and China has been successful. The LandUse6k community is now ready to achieve land-use mapping at the global scale in the coming few years.

Four LandCover6k products are currently in progress:

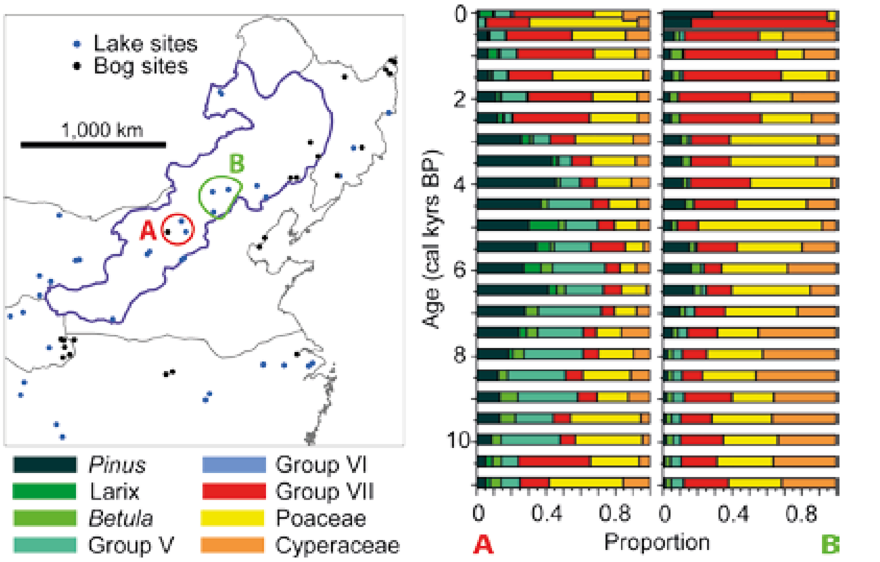

Figure 1: Examples of REVEALS estimates of plant cover (in proportion for an area >100x100 km) over the Holocene for five plant taxa and three taxa groups in the temperate steppes zone of China (purple on map). Each diagram represents the results from REVEALS runs using pollen records from several sites: **(A)** 1 bog (black) and 2 lakes (blue); **(B)** 3 lakes. V: Cool mixed forest, temperate broad-leaved forest, i.e. *Fraxinus*, *Quercus*, *Tilia*, *Ulmus*, and Rosaceae. VI: Warm temperate forest and tropical forest, i.e. in those reconstructions only Rubiaceae. VII: Cultivated land, temperate grassland, tundra, and desert taxa, i.e. *Artemisia*, Asteraceae, Brassicaceae, Caryophyllaceae, *Castanea*, Chenopodiaceae, Convolvulaceae, Fabaceae, *Cannabis/Humulus*, *Juglans*, Lamiaceae, Liliaceae, Polygonaceae, and Ranunculaceae. Data by Furong Li (pers. comm.; see also Li 2016).

1. Gridded (1°x 1°) pollen-based REVEALS estimates of plant cover in the northern hemisphere (>40°N) for five time windows of the Holocene based on the available REVEALS estimates in northern America, Canada, Alaska, Europe, Siberia and China.

2. A comparison at a 1°x 1° grid spatial resolution and 500 years' time resolution over the last 8 ka between (i) the plant cover obtained from the transient runs presented by A. Dallmeyer and (ii) the plant cover obtained from pollen data using the REVEALS model (Marquer et al. 2017).

3. A comparison at 1°x 1° resolution for Europe of the fraction of deforested land as estimated by the ALCC scenarios of HYDE 3.2 and the pollen-based REVEALS estimates of the cover of openland for five time windows of the Holocene (see 1. above).

4. A new set of multi-model land C cycle simulations covering the Holocene using LandCover6k-improved ALCC scenarios (Stocker, see above).

The "products" 1-2 above and a roadmap for the model-intercomparison study (product 4) will be presented at the 1st PMIP4 conference in Stockholm in September 2017 (www.pmip2017.se).

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Pollen-based reconstructions of past land-cover change in Latin America

Sonia L. Fontana[1], T. Giesecke[1], P. Kuneš[2] and M.-J. Gaillard[3]

Salvador de Bahia, Brazil, 29-31 October 2016

Latin America is an important region for the understanding of the global climate system as it extends from the northern hemisphere into the high southern latitudes. Few synoptic studies are available for this continental space. The purpose of this workshop was to bring together Latin American researchers working on past vegetation reconstruction to better integrate the local scientific community into the activities of the PAGES LandCover6k working group (Gaillard et al. 2015). Scientifically, a strong focus was to stimulate participants to attempt quantitative reconstructions and providing them with the tools to do so. The meeting attracted 22 scientists at all career stages, from Mexico, Colombia, Brazil, Bolivia, Argentina, Russia and Germany.

The workshop provided an overview of available methods for pollen-based reconstruction of land cover with emphasis on the Landscape Reconstruction Algorithm, including the REVEALS and LOVE models (Sugita 2007). Lectures also addressed the parameters required for these applications, including the need to estimate relative pollen productivity for selected plant taxa of interest, as well as the fall speed (settling velocity) of the respective pollen types. Validation and application of these models were illustrated through studies in Europe, North America and China. The modern analogue technique was discussed as an alternative way to obtain quantitative estimates of the cover of major vegetation units, such as woodland and open land, without the need of a detailed understanding of the pollen-vegetation relationship. However, modern analogue techniques need a large number of surface sediment samples representing good modern analogues of past vegetation, which is problematic in Latin America due to very recent and drastic land-cover change. The training course followed the path from vegetation surveys and estimating relative pollen productivities to their application in REVEALS-based reconstructions of past plant cover.

Discussions focused on the application of these approaches to the diverse ecosystems of Latin America that have their unique challenges for pollen-based quantitative vegetation reconstructions. Estimating the taxon-specific production and dispersal of pollen is crucial for a better understanding of the results portrayed in pollen diagrams and builds the basis for quantitative reconstructions. This type of investigation is scarce in Latin America and a challenging task, in particular in tropical and subtropical environments with high plant diversity. First attempts aiming to estimate pollen productivity and dispersal in southwest Amazonia and at the forest-steppe ecotone in Patagonia were presented and discussed.

Figure 1: Human land use at the forest-steppe ecotone in northern Patagonia. *Rumex acetossella* (red color in the grazed land) commonly known as sheep's sorrel or red sorrel, is a major anthropogenic indicator of animal-based disturbance activities occurring during the last few hundred years.

While LandCover6k aims to quantify human-induced changes in land cover, Latin America contains different environments where the proportion of woodland versus grassland has changed during the Holocene due to shifts in precipitation and temperature, namely the upper mountain forest versus páramo vegetation in the Andes mountains, the forest grasslands in the Llanos Orientales, the Mata Atlântica in Brazil, and the forest-steppe ecotone in Patagonia. However, these ecosystems were also preferred by humans that controlled the encroachment of forest with fire. Therefore, the effects of human action and climate change are often difficult to disentangle (Fig. 1).

Databases are an important prerequisite for larger synoptic studies. The Latin American Pollen Database and new tools available through the Neotoma Database were presented and discussed. Plans were made to develop a modern surface-sample pollen dataset and set up projects which aim to achieve pollen-based reconstructions of plant cover in the past.

This workshop was organized in collaboration with the XIV International Palynological Congress, the Federal University of Bahia and local colleagues, Francisco Hilder Magalhães e Silva, Paulino Pereira Oliveira, Vivian Jeske-Pieruschka, Kelly Regina Batista Leite, and Lázaro Benedito da Silva.

Further details about LandCover6k and this workshop can be found at www.pastglobalchanges.org/ini/wg/landcover6k/intro

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Past land-cover change for climate modeling: data from Eastern Asia

Xianyong Cao[1], U. Herzschuh[1], M.-J. Gaillard[2], K. Morrison[3] and Q. Xu[4]

Shijiazhuang, China, 6-11 March 2017

This workshop and related training course were held at Hebei Normal University in Shijiazhuang, China, and organized within the activities of PAGES' working group LandCover6k. The major aim was to gather the coordinators of the LandCover6k working sub-group Asia-Oceania, experts in the field of quantitative pollen-based vegetation reconstruction, and data contributors (pollen, archaeology, history). The purpose was to (i) explain and discuss the objectives and research strategies of LandCover6k, (ii) assess the availability of fossil pollen records and pollen data archives/databases, pollen productivity estimates (parameters needed for pollen-based quantitative estimates of plant cover), and archaeological and historical data, and (iii) plan the future activities necessary to achieve the objectives of LandCover6k in Asia-Oceania. Following a win-win collaborative approach during the workshop, an intensive training course was held on the methodological tools for pollen-vegetation modeling and calculation of pollen productivity estimates. The course also included instruction on upscaling of archaeological data to a global scale land-use scheme. Anthropogenic land-cover-change modeling was provided to the data contributors to facilitate the achievement of the LandCover6k objectives, and data contributors were encouraged to use those methodological tools for their own scientific questions. The workshop was attended by 83 participants including 63 Chinese and Indian young scientists and students.

The four major outcomes of the workshop are:

(i) An evaluation of spatial pollen-based reconstructions of vegetation cover and climate, and discussion on their interpretation and reliability issue.

(ii) Discussion on the status and availability of databases for pollen records in Eastern Asia. In particular, X Cao and U Herzschuh presented an extension of Eastern continental Asia pollen dataset (Cao et al. 2013; 2014) to Siberia (Fig. 1), and Jian Ni presented the development of a new version of the Chinese Quaternary Pollen Database.

(iii) The launch of the State Key Program of National Natural Science Foundation of China "Quantitative pollen-based land-cover reconstruction (1°×1°) for the purpose of climate modeling in China since 6 ka" coordinated by Q Xu, which includes studies of pollen productivity estimates in all major vegetation and climate zones of China and pollen-based reconstructions of past vegetation cover using REVEALS model (Sugita 2007).

(iv) Teaching and dissemination of methods, tools and strategies for pollen-data handling (e.g. the R program and packages for statistical computing), pollen-based climate and vegetation reconstructions (e.g. weighted averaging partial least squares WA-PLS, modern analogue technique MAT), calculation of pollen productivity estimates (ERV model), pollen-based reconstruction of vegetation cover (REVEALS and LOVE models), and land-use inference from historical and archaeological data.

By regularly following up on the four outcomes above, we expect that the workshop will result in a higher number of scientists in Eastern Asia who will (i) contribute new pollen productivity estimates for the major plant taxa characteristic for that region and (ii) submit fossil pollen records to international pollen archives and databases. This process will significantly improve the requirements for reliable reconstructions of past anthropogenic vegetation cover in Eastern Asia for the purpose of LandCover6k's goals.

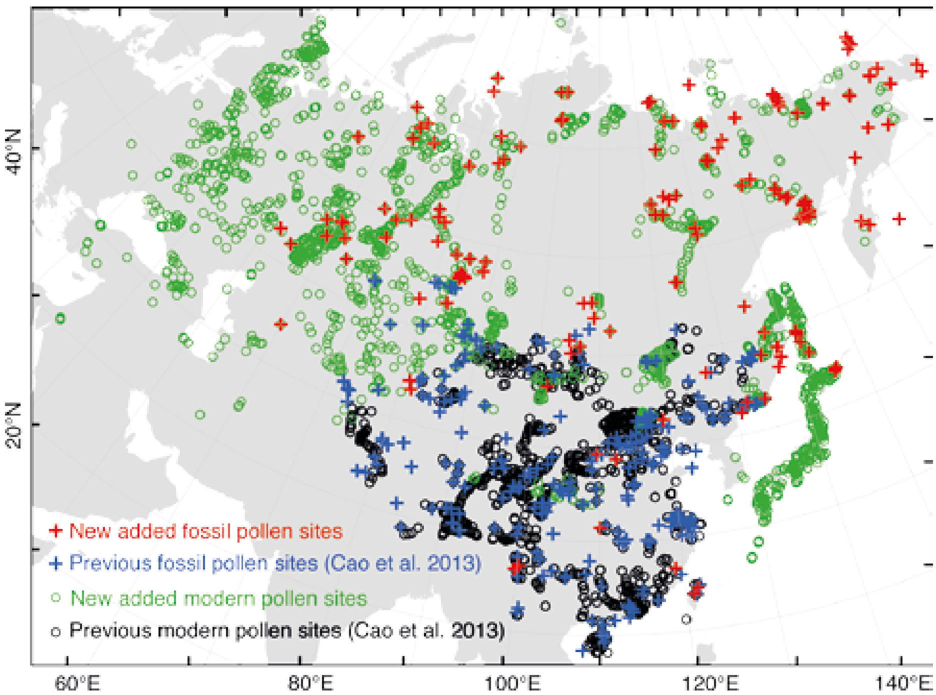

Figure 1: Extension of the Eastern continental Asia pollen dataset to North Asia, with 199 newly added fossil pollen records and 3943 modern pollen data. In total, the dataset now includes 470 fossil and 6569 modern pollen data.

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Paleolimnological puzzles, databases and aquatic transitions

Keely Mills[1], P. Gell[2] and J. Saros[3]

Bangor, USA, 26-28 April 2016

The second meeting of PAGES' Aquatic Transitions working group, held at the University of Maine, was attended by 23 members, including 16 new representatives from the UK, US, Canada, India, and Argentina. Given the number of new faces at the meeting, the workshop opened with short introductory presentations from the new participants, leading nicely into a recap on the outcomes and updates from the previous meeting in 2015 (Mills and Gell 2015).

Updates were also provided on a number of manuscripts currently in preparation. The manuscript "Modeling regime shifts in lake sediments" (led by Z. Taranu and M. Perga) stimulated much discussion among new members, and S. Juggins and G. Simpson provided fantastic statistical guidance with regards to the identification of "transitions" in paleolimnological archives. The review paper, by 24 members of the working group and led by N. Dubois, titled "Early human impacts of lakes and wetlands" is a large undertaking. The authors present at the meeting worked on the draft, the focus of the conclusions, and proposed additional sections to ensure a global perspective.

Prior to the workshop, K. Mills and P. Gell were invited by "Wiley Interdisciplinary Reviews (WIREs): Water" to write an overview paper on long-term changes in lake systems. We used this meeting as a sounding board for ideas and inputs, and outlined the now-published paper "Deciphering long-term records of natural variability and human impact as recorded in lake sediments: a palaeolimnological puzzle" which is co-authored by 15 members of the Aquatic Transitions community (Mills et al. 2017; Fig. 1).

J.-P. Jenny led a discussion on the content and nature of the data required to achieve the goals of Aquatic Transitions, and whether the overlap with other core working groups' databases (from PAGES 2k Network or the former Varves Working Group, for example) was an impetus for a joint effort, as opposed to "reinventing the wheel" for similar data collection.

Other key outputs from this meeting included the outline of a book proposal for the Springer series "Developments in Paleoenvironmental Research", in response to an invitation from the publisher. A session proposal was also written and submitted to the International Association for Ecology's (INTECOL) International Wetlands Conference (IWC) that was held in Changshu, China, in September 2016. This conference was a fantastic opportunity to broaden the membership of Aquatic Transitions in South East Asia, and the conference also opened up the opportunity to engage with key stakeholders (including Ramsar, catchment managers and other practitioners in water management). S. McGowan and K. Mills, who attended this meeting, wrote a report for the British Geological Survey's blogsite "Geoblogy" (McGowan and Mills 2016). The success of the INTECOL IWC session led to the next Aquatic Transitions meeting in Malaysia in February 2017, which focused on enhancing the understanding of freshwater systems in SE Asia.

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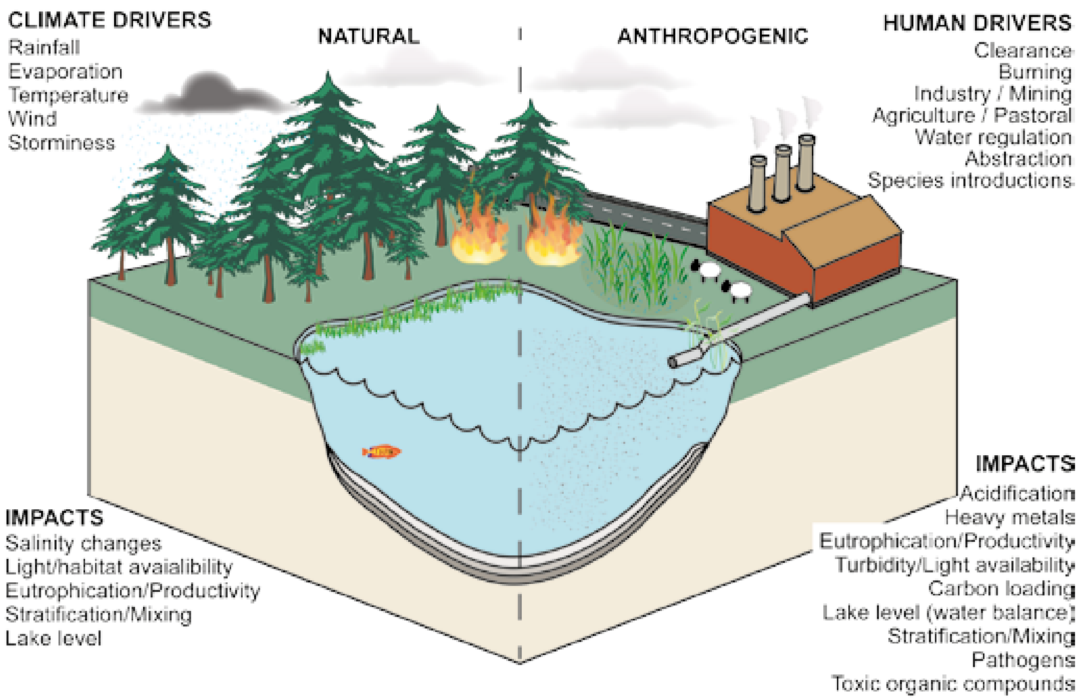

Figure 1: Identifying transitions in lake sediment sequences is complex, not least because both climate and humans can cause changes in lake systems that manifest in a similar fashion in the lake sediment archive. Reprinted from Mills et al. (2017) with authorization from BGS © NERC 2017.

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A global soil and sediment transfers database for the Anthropocene

Veerle Vanacker[1] and Thomas Hoffmann[2]

2nd GloSS Workshop, Louvain-la-Neuve, Belgium, 30 January - 1 February 2017

Anthropogenic soil erosion causes soil degradation, reduces soil productivity (Fig. 1), compromises freshwater ecosystem services and drives geomorphic and ecological change in rivers and their floodplains (Anthony et al. 2014; Wang et al. 2016). Despite our knowledge of the fundamental mechanistic processes of soil erosion, transport and deposition and the control of climate, soil erodibility, topography, and land use and management on soil and sediment transfers, the rich variety of past land use and human settlement patterns worldwide implies that global patterns of anthropogenic soil erosion and fluvial sediment transfer remain poorly understood (Vanacker et al. 2014).

We need better global assessments of anthropogenic soil erosion and the consequent transfer and storage of sediment to the coastal zones to reduce the societal impact of human-accelerated erosion. The PAGES Global Soil and Sediment transfers in the Anthropocene (GloSS) working group aims to build a comprehensive global database on soil and sediment transfers in the Anthropocene, to identify hotspots of soil erosion and sediment deposition in response to human impacts, and locate data-poor regions as strategic foci for future work. To achieve this aim, 39 participants from 15 countries with expertise in soil erosion assessments, erosion modeling, human-landscape interactions and global sediment fluxes attended the meeting.

Figure 1: Overgrazing reducing infiltration and accelerating runoff and soil erosion in the Northern Andes. Gully systems and landslides are the major contributors of sediment to the fluvial system. Credit: Veerle Vanacker, July 2013

The first part of the meeting was dedicated to oral and poster presentations, including 11 keynotes and smaller topical presentations on anthropogenic sediment fluxes, human-climate interaction on river systems and sediment fluxes, and temporal changes in sediment budgets for lakes and floodplains from various regions of the world. Major focus was given to the coverage of GloSS-related studies on each continent and regarding the various environments considered for the GloSS database (i.e. hillslope, river channels, floodplains, lakes and deltas). The second part of the workshop was entirely dedicated to breakout group discussions, where the workshop participants revised the GloSS database structure and discussed standard operating procedures for data-submission and internal procedures for server-side data cleaning and quality control. Participants agreed that the GloSS database should focus on a limited number of proxies/indices that are widely available: (1) sediment loads (e.g. Syvitski and Kettner 2011), (2) sedimentation rates (Yang and Lu 2014), (3) cosmogenic radionuclide denudation rates (e.g. Portenga and Bierman 2011), and (4) erosion rates (e.g. Maetens et al. 2012). For each of the four proxies/indices, a breakout group revised and improved the metadata structure, and defined parameters or variables that need to be included, their format, unit of measurement, quality control, and spatial and temporal integration. Group members reviewed the criteria, which have now been included in a comprehensive data dictionary.

The group also updated the GloSS roadmap for two primary products to be completed before the end of the project in 2017. Based on the GloSS database, we plan to produce a global overview map of the availability of proxies and indices to quantify soil and sediment transfers throughout the Holocene. The group also discussed how to take advantage of the expertise gained from highly detailed case studies worldwide, and proposed to work towards a review paper on erosion and sedimentation issues in the Anthropocene to increase awareness on the topic.

The GloSS working group held a brief gathering in May 2017, during the 5th PAGES OSM meeting in Zaragoza, Spain, to discuss progress. More information is available on the PAGES website.

The workshop was co-organized by the Université catholique de Louvain, University of Leuven and Université de Liège, Belgium. Funding was provided by PAGES and the Belgian Fonds de la Recherche Scientifique (FNRS).

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Effort to enhance paleoclimatic research in South Asia

APN
ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

Taniya J. Koswatta[1], X. Deng[1], A.V. Sijinkumar[2] and H.P. Borgaonkar[3]

APN-PAGES Proposal Development Training Workshop, Paro, Bhutan, 14-16 December 2016

The Asia-Pacific Network for Global Change Research (APN) organized a three-day Proposal Development Training Workshop to enhance the capacity of young scientists in South Asia to develop competitive project proposals. The workshop provided an opportunity for young scientists to identify peer scientists working in the area of paleoclimate and develop regional research proposals. The workshop aimed to build transdisciplinary collaborations among climate scientists including paleoclimatology. Twenty young scientists from South Asia attended the training workshop and developed five proposals, two of which were developed to address paleoclimate issues in the region. Of the two proposals, one focuses on the analysis of land-based tree-ring proxies, and the other focuses on lower-resolution proxies such as from marine sediment cores.

Environmental changes in the Himalaya during the last millennium

Understanding past climate in the Himalaya is especially important due to its prime role in maintaining and controlling the monsoon system over the Asian continent and serving as an orographic barrier to the cold winds blowing from the north into the subcontinent. In view of this, the group focused on reviewing the available meteorological data of the Himalayan regions. They pointed out that presently available data are not sufficient to provide a long-term trend analysis and realistic forecast of future trends. In this context, Himalayan trees offer an excellent dendroclimatic tool to reconstruct past climatic variations up to one thousand years. A few glacier and river run-off reconstructions were created, but these are limited to a specific location and do not capture climatic fluctuations in the heterogeneous terrain of the Himalaya. The group developed a regional proposal that aims to reconstruct regional, long-term glacier extent and river run-off of the higher Himalayan region. This project aims to fill the data gap and provide an empirical relationship between climate-change glacier and river runoff. Findings of the study will help to produce evidence-based water resource and disaster management, among others.

Asian monsoon system

The second group focused on Asian monsoon variability and subsequent erosional history of the Himalayan and Burman ranges. The group designed a research proposal with the objective to document the paleoclimate changes (monsoon and sea-level changes) at centennial to millennial timescales by using quantitative and qualitative analyses of microfossils and sedimentary geochemistry. The Bay of Bengal was selected as the study area considering its continuous and high sedimentation rate (Akter et al. 2016). It is also a core convective area of the South Asian monsoon. The sediments of the Bay of Bengal are a good repository of climate-change information, especially Asian monsoon and sea-level fluctuations (Rashid et al. 2011). However, the available paleoclimate records from the region are either single-core based or of low resolution (Marzin et al. 2013; Gebregiorgis et al. 2016).

The group will also investigate the linkages between South Asian and East Asian monsoon systems. The project is planning to use multi-proxy micropaleontological (planktonic foraminifera, benthic foraminifera, pteropods, pollens and ostracodes) and geochemical analyses (stable isotopes, major, minor and rare earth elements) to decipher past climate and environmental conditions; the aim being to examine linkages between global climate and regional environmental change with relation to physical and biological systems. A conceptual framework of the project is indicated in Figure 1.

Both paleoclimate groups plan to submit the developed proposals to APN in 2017 for funding. Group members are seeking to expand the studies in the region by engaging more South Asia scientists and institutions.

Figure 1: Project concept of Paleoclimate of South Asia: Causes, variations, biotic responses to environmental changes.

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Coevolution of climate, demography and food systems in North and South America

Jacob Freeman[1], A. Gil[2], M.L. Cárdenas[3], D.A. Byers[1], M.B. Cannon[1], J.M. Capriles[4] and C. Latorre[5]

Logan, USA, 8-11 November 2016

One of the less well-understood problems in paleoscience is the role of climate as a modulator of long-term changes in human demography, and, in turn, how changes in human demography influence climate because demography also determines how individuals choose to modify ecosystems. Our workshop compared the long-term interaction between climate, human population change and the organization of social systems to understand the coevolution of Social and Ecological Systems (SES). The feedbacks between climate, ecosystems and social systems may lead to threshold changes in the organization of SES (Anderies et al. 2013). Paleoscience is critical for understanding how and when interactions between climate, ecosystems, and human systems reach threshold-state changes. Such understanding is important because contemporary SES must adapt to population growth and climate change, and insights gained from past SES may inform sustainable development in the contemporary world.

Our workshop compared the past responses of SES to climatic and vegetation changes in case studies from North and South America. Our comparison revealed two patterns. First, after 3000 BP, human populations spiked in all case studies, though the timing of this spike varies. Why this occurred is an open question, and we discussed potential relationships between demography, climate change and local changes in vegetation. Understanding why this population growth occurred and how humans adapted to increasing demographic pressure is a critical area for future research. Second, among our case studies, populations declined, at a regional scale, after 800 BP. The timing of the decline is coincident with the transition to the Little Ice Age (700-100 BP). Declines in population and associated reorganizations of social practices take place in North America around 750 BP and not until 550 BP in our South American cases (Fig. 1). A major issue raised during our workshop is how the global transition to the Little Ice Age may have affected the ecosystems in each case study differently.

Two questions emerged from the comparison of our case studies: (1) Why does the increase in population vary from region-to-region? (2) Which factors best explain the threshold decline in population after 800 BP? We discussed the usefulness of the concept of robustness-fragility tradeoffs. Robustness-fragility tradeoffs occur when a set of strategies allow individuals to consistently achieve a goal, like biomass harvested per day, but these strategies set up a system for cascades of abrupt change and/or failure (Anderies 2015; Csete and Doyle 2002). Using the robustness-fragility concept, we proposed that investments in strategies that reduced variation in the production of food, in response to population growth, set up many SES for a major reorganization in response to the global climate shock of the Little Ice Age. The severity of the reorganization observed is a consequence, we speculate, of the ability of societies to maintain diverse social strategies and use diverse ecosystems to adapt to population growth. The role of variation in climate regimes, ecosystems and social systems in controlling the appearance of critical thresholds in SES is a major area for future research identified by our group.

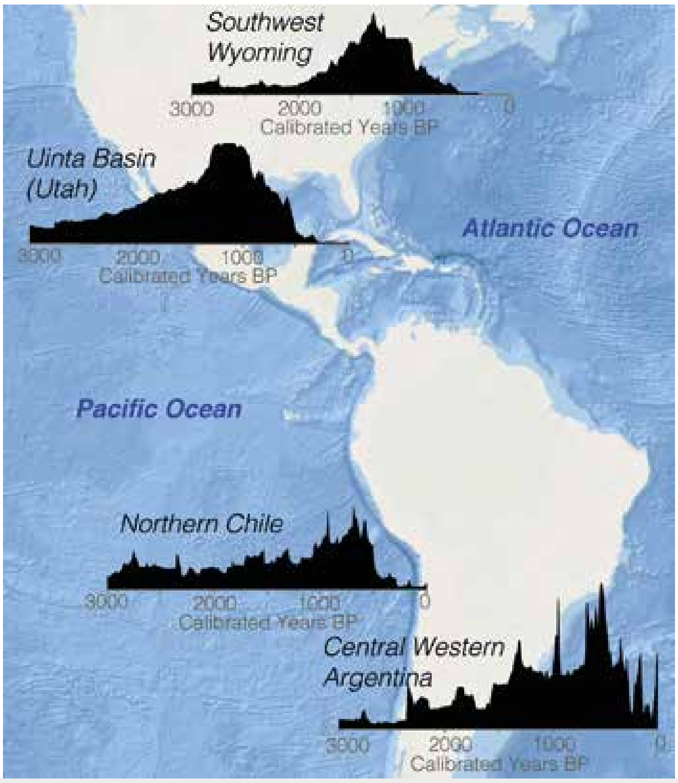

Figure 1: Summed probability distributions of radiocarbon dates from four regions in North and South America. The summed probability time-series is an estimate of population size over time. The proxy is for prehistoric societies only. The decline in dates after 250 BP is a function of the increasing prevalence of historical records. Northern Chile dates published in Gayo et al. (2015).

In the end, we developed a new working group called PEOPLE 3000 (PalEOclimate and the PeopLing of the Earth), composed of paleoecologists, archaeologists, ecologists and mathematicians. The goal of PEOPLE 3000 is to describe and explain the role of global climate change in the exponential increase of population between 3000 and 800 BP, and variation in the subsequent magnitudes of decline of population after 800 BP. This network will explore how climate impacts human socio-economic development over the long term and the tradeoffs associated with human adaption to climate change and population growth. Our work is specifically concerned with the potential for robustness-fragility tradeoffs associated with strategies for coping with climate change and population growth, and how such tradeoffs may set up human systems for failure in the face of global climate shocks.

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Scales and scaling in past climate data

Christian Franzke

1st CVAS workshop, Hamburg, Germany, 28-30 November 2016

The aim of the Climate Variability Across Scales (CVAS) working group is to quantify climate variability across space and time on centennial and millennial time scales which is relevant for better constraining future climate evolution. A second interesting aspect of climate variability on these time scales is that it is strong but cannot be explained by changes in orbital forcings. This suggests that internal, nonlinear, climatic processes dominate. Better understanding of these processes would allow a more accurate evaluation and to better constrain climate models. However, the description and understanding of centennial and millennial climate variability requires long-term climate datasets. Such datasets need to be based on proxy data and be developed by paleoclimatologists, climatologists and climate modelers, combined with nonlinear multi-scale and scaling analysis techniques developed by nonlinear geophysicists and statisticians.

In this workshop, we brought together leading scientists from these two community groups. In order to facilitate knowledge exchange, we had 11 tutorial-style, introductory talks together with shorter contributory talks and posters. About half of the introductory talks covered the themes of the physical processes leading to scaling, stochastic dynamical systems and linear response, and the spatial pattern of variability. Scaling is a geometric concept by which an object is enlarged or shrunk by a linear transformation and is described by a power law. The other half of the workshop focused more on scaling in proxy data. We also had presentations on the potential pitfalls and issues with proxy data sets and recording systems in general, and discussed these issues for ice cores in particular. Thom Laepple showed some intriguing results from recent measurements using snow trenches (Fig. 1) and how the proxy data vary across rather short distances. This suggests that the recording systems are intrinsically noisy and we should examine and perhaps even combine multiple measurements if possible. This highlights the need to be careful when interpreting the variability in proxy data, especially in a global context.

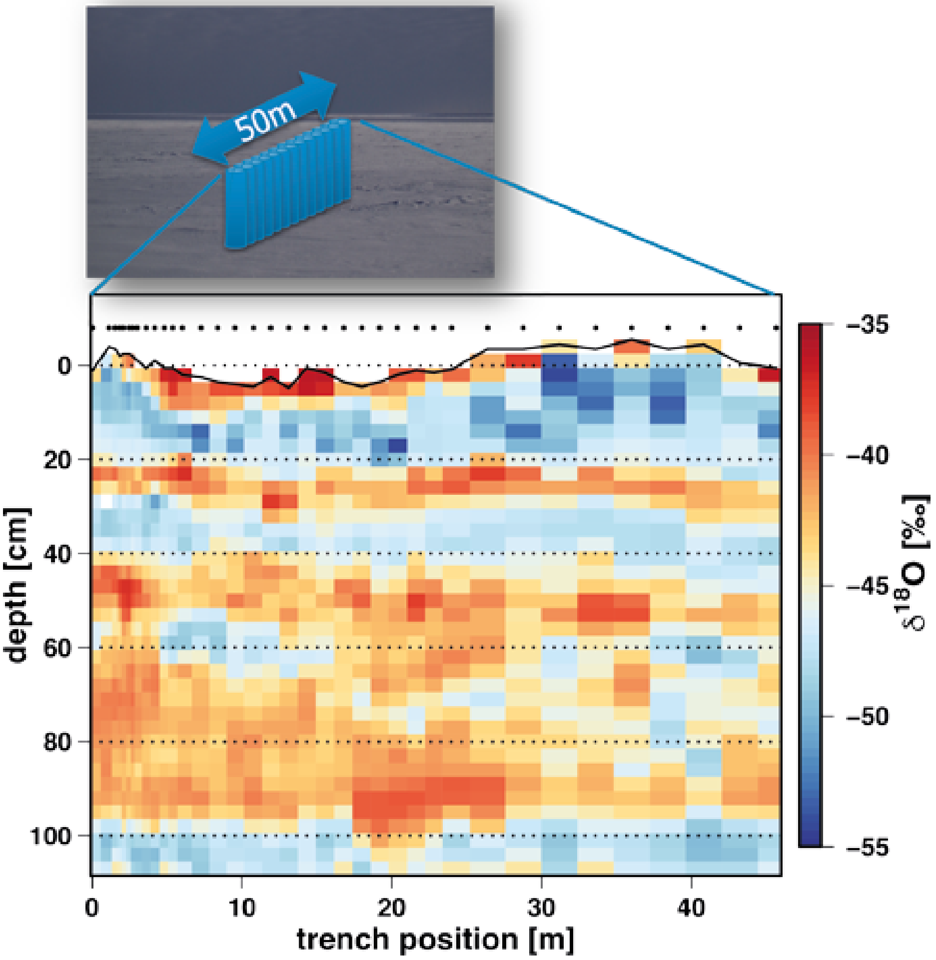

Figure 1: A two-dimensional view (horizontal x vertical) of oxygen isotopes ($\delta^{18}O$) in Antarctic snow near the EPICA deep ice-core drilling site (modified from Münch et al. 2016). Vertically alternating layers of enriched and depleted isotopic composition represent the climatic seasonal cycle. In addition to that, strong horizontal variability - stratigraphic noise - is visible. Such studies investigating the spatial structure of proxy data allow to quantify and correct for non-climatic variability in climate proxy records.

Part of the workshop was dedicated to discussions about the future directions of the working group. One identified outcome is the need for a data repository useful for centennial to millennial scale variability, together with case studies which describe the potential pitfalls of the respective data set and analysis tools, and readily available software allowing scientists to obtain reproducible results. Such a repository should also provide information such as the space-time resolutions of the data and all uncertainties.

As important research questions, we identified:

- What is the spatial pattern of centennial to millennial scale variability, especially in the Holocene? Do existing climate models reproduce these spatial patterns?
- What are the scaling regimes in the Holocene? Are there differences between the tropics, extratropics and the polar regions?
- Can we systematically separate or quantify internal from externally forced variability?

The CVAS working group had a session and conducted a short course at the EGU meeting in Vienna in April this year. The next workshop will take place in Potsdam 25-27 October 2017. The group also agreed on organizing a *Past Global Changes Magazine* special issue on scaling of climate variability.

The 1st CVAS workshop was supported by the German Research Foundation (DFG), through the cluster of excellence CliSAP (EXC177) at the University of Hamburg, and PAGES.

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Speleothem synthesis and analysis working group

Laia Comas-Bru[1], M. Deininger[1], S. Harrison[2,3], M. Bar-Matthews[4], A. Baker[5], W. Duan[6] and N. Stríkis[7]

Speleothems are secondary cave deposits formed mostly from inorganic calcium carbonate ($CaCO_3$). Deposits formed from dripping water are called stalagmites (growing up from the ground) or stalactites (growing down from the roof). Speleothems are useful paleoclimate archives as they preserve some aspects of the water chemical composition, providing information from the overlying climate, vegetation and soil. These climate archives are well distributed worldwide and are valuable sources for regional climate reconstructions and allow intra- and intercontinental comparisons of past climate changes. In addition, due to the high precision of uranium-series dating, speleothems provide opportunities to trace leads and lags of global climate events facilitating to uncover climate dynamics.

The different types of measurements made on speleothems, including the stable isotopes of oxygen and carbon ($\delta^{18}O$, $\delta^{13}C$), annual growth rate variations and various trace elements concentrations, give a wealth of information on past changes in the hydrological cycle, changes in atmospheric composition and the local environment. Significant past climate variations recorded in speleothems include shifts of the Intertropical Convergence Zone, variations of the North Atlantic Oscillation, glacial-interglacial transitions and millennial-scale variability of tropical atmospheric circulation in response to Dansgaard-Oeschger cycles, as well as climate-related migrations of the large Saharo-Arabian Desert and how they enabled migration of humans out of Africa. Speleothems, therefore, provide an opportunity to assess changes in mean climate and in climate variability on various spatial and temporal scales.

Although more than 400 speleothem records have been published over the last decades as a source of climate reconstruction (70% of which after the year 2007; Source: Web of Science), there have been only limited attempts to synthesize speleothem data. Such a synthesis could be useful not only for exploring past climate changes but also for evaluating state-of-the-art climate models that explicitly simulate water and carbon.

Since the understanding of past climate variability provides a crucial benchmark reference for current and predicted climate change, the recently launched SISAL (Speleothem Isotopes Synthesis and AnaLysis) working group will bring together speleothem scientists, speleothem-process modelers and climate modelers to develop a global-scale database of speleothem isotopic data. This synthesis must include an assessment of the quality of the records, including their reliability and interpretation, and this requires community-wide involvement.

SISAL's kick-off workshop took place in June 2017 at University College Dublin, Ireland, and served to discuss, amongst other things, the structure of the SISAL database and the key scientific questions that we would like to address with it. To feed into these discussions, our focus in the last few months has been on identifying the status of speleothem-based paleoclimate reconstructions globally and on creating a preliminary version of the database (Fig. 1).

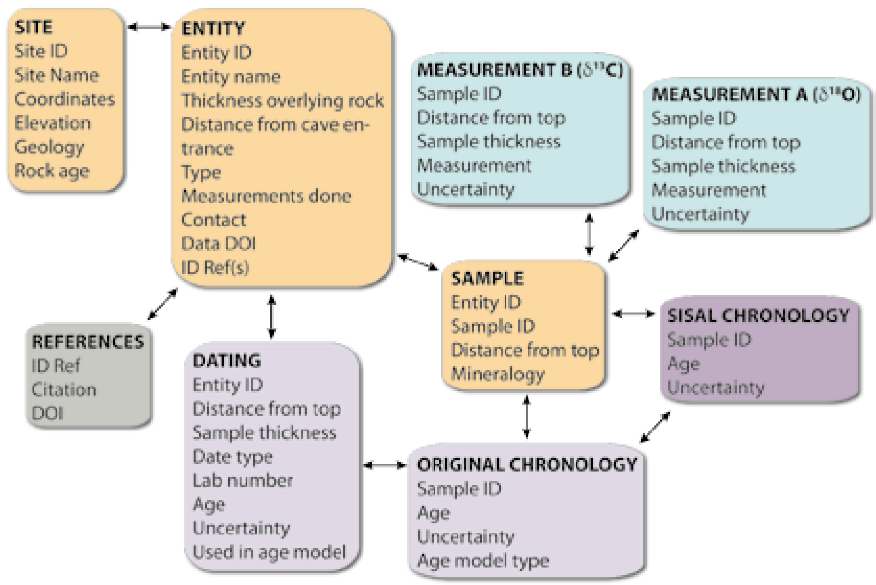

Figure 1: SISAL database structure that seeks to maximize the amount of information available for quality control and standardization of individual records.

Upcoming activities

Although much of the SISAL community interaction will be virtual, further workshops are already being planned for the next years. Each of these will focus on different analyses of the speleothem database.

Our 2nd workshop, aligned with the PMIP meeting, will be held in Stockholm, Sweden, in September 2017 and will focus on the design of data-model comparisons using the SISAL database (www.pastglobalchanges.org/calendar/upcoming/127-pages/1711-sisal-2nd-wshop-17).

Scientific goals

Paleoclimate records have a complex response to climatic and non-climatic factors (e.g. attenuation of the precipitation isotopic signal prior to the water reaching the speleothem) and, therefore, they need to be assessed for robustness and coherence between records and between different types of archives (e.g. $\delta^{18}O$ in ice cores, corals, and tree-ring cellulose) before using them to evaluate the output of climate models. This assessment will be the first concrete task for SISAL.

By encouraging interaction and exchange of information between the speleothem community and climate and speleothem-process modelers, SISAL aims to develop novel ways to compare speleothem records with the CMIP6-PMIP4 simulations of the Last Glacial Maximum (21 ka), mid-Holocene (6 ka) and Last Millennium (850-1850 CE).

Visit the SISAL website at: http://pastglobalchanges.org/ini/wg/sisal/intro and sign up to our mailing list, or follow us on Twitter (@SISAL_wg) to keep up to date with our activities.

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