Editorial: A role for palaeoecology in anticipating future change in mountain regions?

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1. Introduction

The International Open Science Conference 'Global Change in Mountain Regions' which met in Perth, Scotland (United Kingdom), 2 to 6 October 2005, had two intended outcomes (Price, 2006):

1. communication of new results between scientists and researchers working in the mountains around the world,
2. to develop a framework for long-term research on global change that can be implemented in Mountain Biosphere reserves and other mountain localities.

We hope that this special issue will help to fulfil these objectives by: i) presenting five original articles stemming from the *Palaeoecological record from mountain regions* sessions and ii) using this editorial to explore what past environmental record can tell us about anticipated future climate change in mountain regions, with particular reference to work presented at the meeting.

2. Mountain regions

Mountains can be found at almost any latitude or longitude and altitudinal definitions range from >600 metres (m) up to 8,848 m (Everest) (Figure 1). The term 'mountain' therefore encompasses a vast range of climatic, environmental and ecological systems. Altitudinal range in mountain regions means strong environmental gradients occur over relatively short distances. This factor has long marked out mountains as natural laboratories for studying the relationship between climatic conditions and living organisms (e.g. von Humboldt, 1817). The close relationship between climate and environment and relatively short transitional zones/ecotones found in many mountain ecosystems makes them sensitive to any climatic changes that occur. This sensitivity has led to wide ranging concerns regarding the potential impact of any future change, including threats to natural resources (e.g. biodiversity), human resources (e.g. water, soils and agriculture), socio-economic activities (e.g. tourism, trade and transport) and health (e.g. spread of diseases and increased risk of hazards such as landslides) (Beniston, 2003). However, the sensitivity to change means mountain environments are excellent places for studying past climatic or environmental change and are likely to be the first places to exhibit a response to current/future change. Since the United Nations declared 2002 as the international year of the mountain many programmes (including the Global Change in Mountain Regions programme itself) support integrated studies of present mountain environments as a basis for predicting and managing future system responses (e.g. de Jong et al., 2005; Huber et al., 2005). Relatively little attention is given to integrating palaeoecological perspectives, which can contribute to this agenda by explaining the present, improving understanding of long-term processes and feedbacks, and contributing knowledge of how the system has responded to past climatic oscillations.

Comment [w1]: More programs

3. Projected future change in mountain regions

The International Panel on Climate Change (IPCC) predicts that the average global surface temperature will increase by between 2 and 4.5^{o}C and that there will be major changes in seasonal precipitation patterns by 2100 (IPCC, 2007). The impacts of this global change will not be spatially uniform; greater warming is expected to occur on land masses (IPCC, 2007). These predictions are generated from Atmosphere-Ocean General Circulation model outputs for numerous future scenarios of economic, population and social development; for full details see Special Report on Emission Scenarios (SRES) (IPCC, 2000).

The extent and magnitude of predicted changes for the major mountain regions varies spatially and temporally (IPCC, 2007). Here we discuss predicted changes for the three major mountain chains, the Andes, the Rocky Mountains and the Himalaya under the three model scenarios (presented in Figure SPM-6 and SPM-7 in IPCC, 2007): 'low' emissions (scenario B1), 'moderate' emissions (scenario A1B), and 'high' emissions (scenario A2); for full details see IPCC (2000, 2007).

The models predict that for the period 2020-2029:

1. the Andes will warm by 0.5-1^{o}C along their entire length with a possible higher increase in the central Andes (+1-1.5^{o}C),
2. the western flank of the Rocky Mountains will warm by 0.5-1^{o}C and the eastern flank by 1-1.5^{o}C,
3. the Himalaya will warm by 1-1.5^{o}C, although the southern flank may only warm by 0.5-1^{o}C.

Discrepancy between predictions becomes wider for the period 2090-2099 as the future world scenarios diverge, but all three mountain zones are predicted to continue warming to at least +2°C relative to present, with particularly strong increases in the central Andes, the eastern flanks of the Rocky Mountains and the Tibetan Plateau.

Changes to global climate are also predicted to alter seasonal patterns in precipitation by 2100 (IPCC, 2007). However, model agreement over the nature of precipitation change in the three major mountain chains is poor (IPCC, 2007). In the Andes precipitation seems likely to increase at the equator and decrease to the south.

The southern Rocky Mountains are also likely to get less precipitation. Predictions for the Himalaya vary widely, generally suggesting that the Tibetan Plateau will see increased seasonality in rainfall with a decrease in December-January-February and an increase in June-July-August.

4. Palaeoenvironmental perspective

The IPCC's projected patterns of future temperature and precipitation change set challenges for global conservation and development policy makers. However, to effectively manage any future change it is necessary to understand what the response of natural systems to these high magnitude changes is likely to be. Throughout the Quaternary (last 2 million years) orbital forcing has subjected the Earth to global climate change of similar magnitude to those predicted by the IPCC (e.g. Emilliani, 1955; McMannus et al., 1999). Reconstructing the effects of these cycles of change allows us to investigate the response of near modern ecosystems to high magnitude global change and human activity.

The IPCC report predicts that future global change will be spatially variable across the globe. Records of past climate change from the Tien Shen and Tibetan Plateau in central Asia reveal that the likely ecological response to global climate change will probably also be non-uniform (Raspopov et al., this issue). Raspopov et al. identified a quasi-200-year solar cycle in $\delta^{14}C$ variation in tree rings; this periodicity is consistent with similar variations found on all five continents in a variety of palaeoclimatic records. However, the timing of the growth response in the tree rings was found to lag the actual solar-driven temperature event regionally by up to 150 years. Raspopov et al. attribute this to differences in local climatic conditions; in this case thought to be related to the proximity of glaciers. In contrast, Koch and

Clague (2006) suggest that glacial systems may have responded in a relatively uniform manner to Holocene solar forcing. The differential response of ecological and physical systems revealed by these palaeoenvironmental records provide insight into the nature and timing of response that we are likely to see from any future climate change.

This non-uniform response of natural systems is further complicated by feedback loops and by human intervention. In the tropical Andes, the IPCC predicts warming by 2.5-3.5^{o}C and changes in precipitation seasonality by 2100 (under 'moderate' emission scenario (A1B)). This region encompasses the eastern Andean biodiversity hotspot and understanding the likely impacts to this region is critical in managing and conserving this unique ecosystem (Possingham and Wilson, 2005). Palaeoenvironmental approaches can reveal system sensitivity and response to past climate change (di Pasquale et al., this issue; Gosling et al., this issue). Di Pasquale et al. investigate the interaction between páramo (grassland) and woodland ecosystems in the Ecuadorian Andes during the Holocene through the study and dating of charcoal within soil profiles. They conclude that the upper tree line may never have been higher during the Holocene than it is today and that the natural fire regime of the páramo may be a critical factor in determining the interaction between these two ecosystems. Gosling et al. use pollen analysis and other indicators to examine changes in moisture balance and vegetation in the Lake Titicaca region, essentially occurring in the absence of any human activity, through the last glacial-interglacial cycle (>151,000 years). These data reveal a close linkage between the terrestrial vegetation and fluctuating moisture balance, particularly with regard to the highly biodiverse *Polylepis* woodlands (Fjeldsa, 2002). In addition, the vegetation community that dominated the landscape during the peak of the last interglacial is revealed to have no modern equivalent in the Andes and is thought to be indicative of a climatic conditions more arid than today (see also Hanselman et al., 2005). This perhaps gives an insight into the type of ecosystem change we should anticipate for the future given the IPCC predictions of a drier and warmer climate for the central Andes by 2100. Palaeoenvironmental records from across the globe have demonstrated sensitive and complex responses in mountain ecosystems to climatic changes of similar magnitude to that predicted by the IPCC by 2100, e.g. the Southwestern USA (Millar, 2006), the Guyanan Highlands (Rull, 2004; Rull and Vegas-Vilarrubia, 2006), the Altari mountains (Timoshok et al., 2006), and the North-West Highlands of Scotland (Kattel, 2006, this issue; Shaw, 2006). Human impact can also have marked and persistent effects in these habitats, e.g. Allen (2006, in press), Bal (2006a, b), Stephenson et al. (2006), and these effects have to be separated from purely climatological responses; pre-human occupation records such as those presented by Gosling et al. (this issue) do not require this precaution.

One challenge that has to be addressed before the integration of palaeoecological records into wider research programmes focused on contemporary process can take place is the translation of data into useful formats to enable effective communication between scientists and between research methods. This is a particular challenge for pollen analysis, where taxonomic resolution is often problematic and taxonomy complex. Bunting et al. (this issue) discuss recent developments in modelling the pollen-vegetation relationship, and show how they might be used to translate past pollen data into vegetation maps. Similar approaches can be used to simulate the pollen signal from possible past communities produced by bioclimatic approaches (e.g. Heiri et al., 2006a, b) thus allowing the bioclimatic model output to be validated against palaeoecological information and therefore be used more confidently to predict system response to future climate changes.

5. The future

The impact of the 0.5 to 1.5^{o}C rise in temperature predicted for mountain regions by 2030 is likely to lead to the upward movement of taxa ranges (both plant and animal). Indeed evidence of climate change impacts on mountain ecosystems have already been measured, e.g. biodiversity pattern change in the Alps (Pauli et al., 2007) and shrinking glaciers in the Andes (Ceballos et al., 2006). In many cases this will reduce the land area available for high mountain ecosystems and change the nature of the human exploitation possible, e.g. by expanding areas where agriculture is possible and reducing snow cover (Beniston, 2003). The global changes predicted for 2100 (+2 to 4.5^{o}C) will certainly induce further movement of taxa and have a significant impact on water resources (IPCC, 2007). The predicted rate of temperature rise is rapid, meaning that there will be lags in response time of organisms and ecosystems, especially for long-lived taxa such as trees, and a large 'extinction debt' will continue depleting biodiversity and altering ecosystem function long after 2100, even if climate change was stopped at that point. Global climate changes on this order of magnitude have occurred during the Quaternary period, and in mountain regions these changes impacted on ecosystems similar to those of today. Investigation of these changes can provide valuable insight into likely future responses of physical and ecological systems.

The spatial structure of change seen in the IPCC predictions can be used as a framework for palaeoenvironmental investigations. The models have identified the locations that are likely to be effected most/least by future changes in global climate.

Palaeoenvironmental studies can be used to determine the degree of sensitivity of the ecosystems within these regions to past changes in global climate. Within mountain regions particular interest might be focused on those areas that are predicted to diverge climatically, e.g. the predicted increased temperature gradient between the western and eastern Rocky Mountains. Improved understanding of the spatial variation in past climate change and assessment of the impact on ecosystems might provide useful information for policy makers as well as a degree of model validation.

The findings and predictions of the IPCC represent the current state of knowledge of a broad scientific community. The palaeoenvironmental research community must be mindful of the valuable contribution it can make to the debate on predictions and consequences of anticipated change on both Quaternary and longer timescales (e.g. Beniston, 2003; Whittaker et al., 2005; Kemp et al., 2005; Cohen et al., in press). This may mean that sometimes we have to focus on communicating what we already know to a very different (and sometimes sceptical) audience in other scientific fields and beyond, in addition to carrying out new research. One method of broadening communication of palaeoenvironmental science is through multi-disciplinary organisations such as the Mountains Research Initiative (MRI) (http://mri.scnatweb.ch). The MRI provides a framework allowing researchers in a number of disciplines to coordinate work on a global scale, current projects include: The American Cordillera Transect and Global Change in European Mountains. We need to seek such opportunities to communicate with and engage in joint research with the mountain research community, and we also need the mountain research community to become more aware of and open to palaeoenvironmental contributions. The GLOCHAMORE Open Science Conference, at the end of a two year contemporary process research programme, was willing to include sessions on palaeoenvironmental research when asked, and to incorporate some palaeo-agendas in the Research Framework produced by the group. We hope that this is a good omen for better integration of palaeoecological perspectives in future large-scale projects in mountain regions, and that this special issue and its glaciological companion (Solomina et al., 2007) will contribute to a developing dialogue between the communities. Life on a globe with a rapidly changing climate means that predicting and responding to potentially drastic environmental changes will be major research foci for the foreseeable future. As palaeoenvironmentalists, we argue that looking to the past is an essential element of the scientific tool kit needed to meet these challenges.

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Figure 1: Global mountain regions map (darker shading indicates greater elevation above sea level). Numbers indicate studies sites of papers presented in this special issue: 1 = Central Asian Mountains (Raspopov et al., this issue), 2 = Andes, Ecuador (di Pasquale et al., this issue), 3 = Andes, Bolivia/Peru (Gosling et al., this issue), 4 = Scotland (Kattel et al., this issue), 5 = (Bunting et al., this issue). Letters indicate study sites of other research presented at the 'Global Change in Mountain Regions' conference: a = Canadian Cordillera (Koch and Clague, 2006), b = Southwestern USA (Allen, 2006, in press; Millar, 2006; Stephenson et al., 2006), c = Guyana Highlands (Rull, 2004; Rull and Vegas-Vilarrubia, 2006), d = Western Pyrenees (Bal, 2006a, b), e = Swiss Alps (Heiri et al., 2006a, b), f = Scotland (Shaw, 2006), g = Altai Mountains (Timoshok et al., 2006). Base map source (UNEP, 2006).