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Landscape-scale drivers of glacial ecosystem change in the montane forests of the eastern Andean flank, Ecuador

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ABSTRACT

Understanding the impact of landscape-scale disturbance events during the last glacial period is vital in accurately reconstructing the ecosystem dynamics of montane environments. Here, a sedimentary succession from the tropical montane cloud forest of the eastern Andean flank of Ecuador provides evidence of the role of non-climate drivers of vegetation change (volcanic events, fire regime and herbivory) during the late-Pleistocene. Multiproxy analysis (pollen, non-pollen palynomorphs, charcoal, geochemistry and carbon content) of the sediments, radiocarbon dated to ca. 45–42 ka, provide a snap shot of the depositional environment, vegetation community and non-climate drivers of ecosystem dynamics. The geomorphology of the Vinillos study area, along with the organic-carbon content, and aquatic remains suggest deposition took place near a valley floor in a swamp or shallow water environment. The pollen assemblage initially composed primarily of herbaceous types (Poaceae-Asteraceae-Solanaceae) is replaced by assemblages characterised by Andean forest taxa, (first Melastomataceae-*Weinmannia*-*Ilex*, and later, *Alnus*-*Hedyosmum*-*Myrica*). The pollen assemblages have no modern analogues in the tropical montane cloud forest of Ecuador. High micro-charcoal and rare macro-charcoal abundances co-occur with volcanic tephra deposits suggesting transportation from extra-local regions and that volcanic eruptions were an important source of ignition in the wider glacial landscape. The presence of the coprophilous fungi *Sporormiella* reveals the occurrence of herbivores in the glacial montane forest landscape. Pollen analysis indicates a stable regional vegetation community, with changes in vegetation population co-varying with large volcanic tephra deposits suggesting that the structure of glacial vegetation at Vinillos was driven by volcanic activity.

1. Introduction

Mid-elevation tropical forests have been identified as some of the most biodiverse yet at risk terrestrial ecosystems in the world due to their high degree of endemism, sensitivity to climate change and anthropogenic impact (Bruijnzeel et al., 2011; Churchill et al., 1995; Hamilton et al., 1995). However, questions remain regarding their ecosystem processes and the role of environmental drivers as mechanisms of ecosystem change.

Tropical montane cloud forests (TMCF) are distinguished from other types of tropical forest by their association with montane environments immersed in frequent ground level cloud (Grubb, 1971, 1977). TMCF on the eastern Andean flank of northern Ecuador occur between ca. 1200–3600 m above sea level (m asl) and inhabit a dynamic and heterogeneous landscape (Harling, 1979; Sierra, 1999). Steep topographical changes produce environmental gradients that change abruptly with variation in precipitation, temperature and solar radiation (Sarmiento, 1986). Changes in climate associated with cloud cover play an important role in natural cloud forest structure and composition (Churchill et al., 1995; Fahey et al., 2016; Hamilton et al., 1995). However, modern anthropogenic pressures (e.g. land-use change, land-cover modification, pollution) arguably exceeded climate as the dominant control on vegetation structure through much of the TMCF of the eastern Andean flank (Sarmiento, 1995).

Non-climate drivers of ecosystem change in TMCF play a key role in increasing landscape and vegetation heterogeneity (Crausbay and

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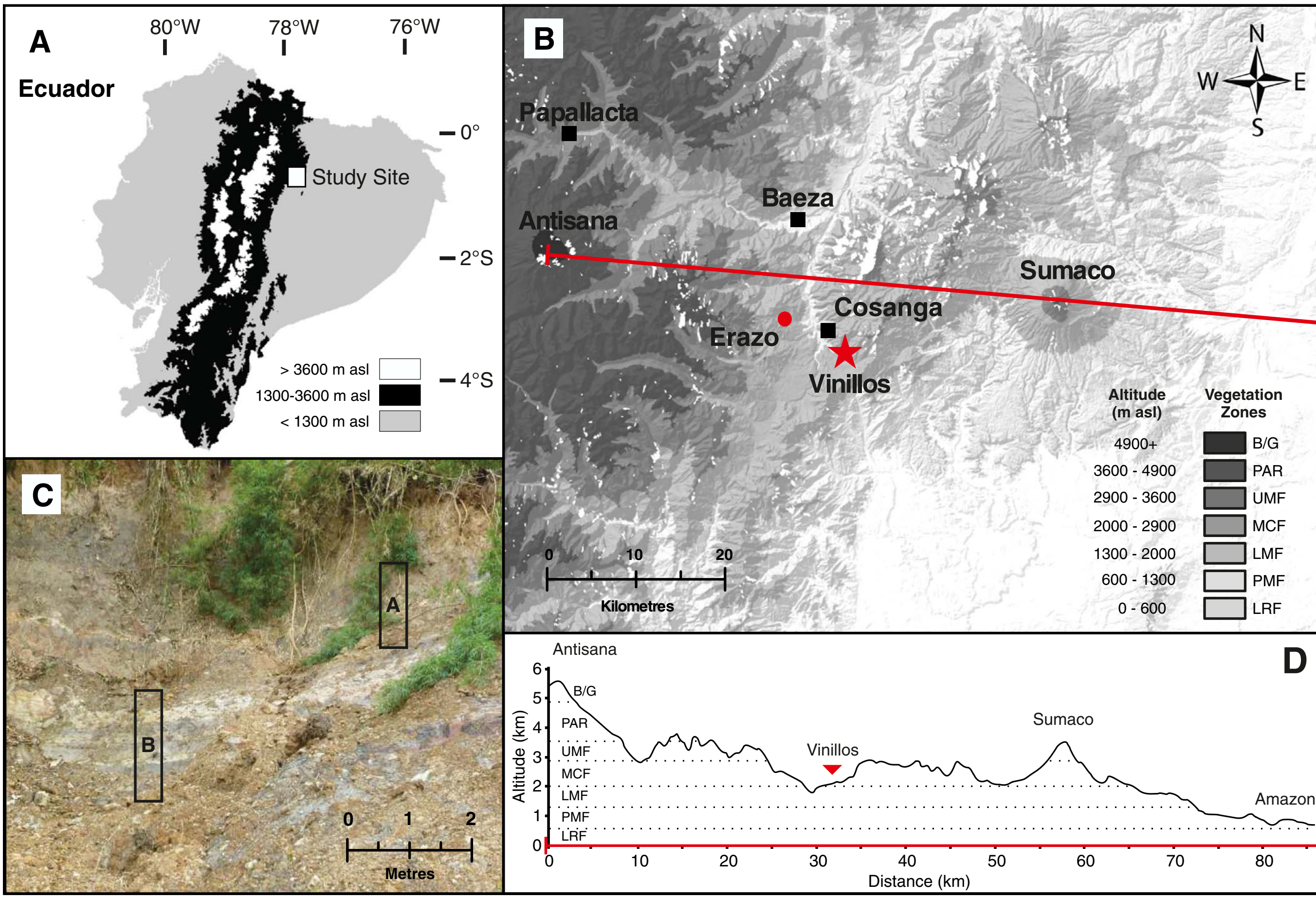

Fig. 1. Study sites. A. Location of study site in Ecuador, within montane forest vegetation zone (1300–3600 m asl), B. Topographic map of study region with generalized vegetation zone from Sierra (1999). LRF-lowland rainforest; PMF-pre-montane forest; LMF-lower montane forest; MCF-montane cloud forest; UMF-upper montane forest; PAR-páramo; B/G-barren/glaciers. Black squares indicate towns, red circle is Erazo section (Cárdenas et al., 2011), and red star is the location of the Vinillos exposure. Red line represents cross-section as seen in 'D', C. Photograph of Vinillos exposure prior to sampling and position of Section A and B, D. Cross-section across eastern Andean flank through Antisana and Sumaco volcanos, with generalized vegetation zones and position of Vinillos. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Martin, 2016). Modern natural (non-human) drivers of ecosystem change include abiotic processes such as volcanic eruptions, earthquakes, landslides and fire, while biotic processes such as plant-animal interactions, disease, forest die-back and a variety of edaphic factors, e.g. nutrient limitation, are all associated with landscape-scale modification of the environment. The stochastic nature of these abiotic and biotic drivers, coupled with high landscape heterogeneity can alter vegetation at a local to regional scale, over geologically short periods of time. In order to better understand ecosystem function in montane environments the role of non-climate drivers of vegetation change during different climate regimes (e.g. glacial periods), and in the absence of modern anthropogenic impact, needs to be ascertained.

Long sedimentary records from large lakes indicate climate is the primary driver of vegetation change over millennial scale time frames within the Andes (Hanselman et al., 2011; van der Hammen and Hooghiemstra, 2003). The only lake records from within the TMCF habitat of the eastern Andean flank that extend from prior to the last glacial maximum occur at Lake Consuelo in southern Peru (Bush et al., 2004; Urrego et al., 2005, 2010) and at Funza and Fúquene in central Colombia (Bogotá-A et al., 2011; Hooghiemstra, 1984; van der Hammen and Hooghiemstra, 2003). Analysis of past vegetation change in the TMCF of the eastern Andean flank of Ecuador is limited due to the paucity of suitably preserved sediments. Palynological analysis of discontinuous sediments from cliff sections at the Mera, Erazo and San Juan de Bosco sites indicate changing forest assemblages through the Quaternary are driven by long-term changes in climate (Bush et al., 1990; Cárdenas et al., 2011, 2014; Colinvaux et al., 1997; Keen, 2015; Liu and Colinvaux, 1985). However, the role of short-term non-climate drivers of vegetation change has yet to be investigated in this setting.

Here we use a multi-proxy approach (pollen, non-pollen palynomorphs, wood macro-remains, charcoal, geochemistry and carbon content) to reconstruct a snap shot of a glacial montane forest vegetation community. We assess the role of volcanic activity (volcanic tephra layers), fire regime (charcoal) and herbivory (*Sporormiella*) as ecosystem drivers of vegetation change in a glacial montane forest and discuss the importance of incorporating non-climate drivers of vegetation change into palaeoecological reconstructions of TMCF.

2. Study site

A new section was located at Vinillos (0°36′2.8″S, 77°50′48.8″W), near the town of Cosanga in the Napo Province, Ecuador. The Vinillos site is situated at 2090 m asl between the Cordillera Real and Napo Uplift on the eastern Andean flank of northern Ecuador (Fig. 1). The exposure is located on the eastern side of the Cosanga Valley, and was uncovered during construction of the Troncal Amazónica (E45); the highway adjacent to the Río Cosanga.

Modern climate data from the study region is sparse, however, 15 years of data from the nearby town of Baeza (Fig. 1) indicates an average of 2320 mm of precipitation per annum (Valencia et al., 1999). High levels of orographic rainfall and semi-permanent ground level cloud lead to persistent moist conditions (Harling, 1979). Mean annual