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Neotropical vegetation responses to Younger Dryas climates as analogs for future climate change scenarios and lessons for conservation

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ABSTRACT

The Younger Dryas (YD) climatic reversal (12.86–11.65 cal ky BP), especially the warming initiated at ~12.6 cal ky BP, and the associated vegetation changes have been proposed as past analogs to forecast the potential vegetation responses to future global warming. In this paper, we applied this model to highland and midland Neotropical localities. We used pollen analysis of lake sediments to record vegetation responses to YD climatic changes, which are reconstructed from independent paleoclimatic proxies such as the Mg/Ca ratio on foraminiferal tests and Equilibrium Line Altitude (ELA) for paleotemperature, and grayscale density and Titanium content for paleoprecipitation. Paleoclimatic reconstructions at both highlands and midlands showed a clear YD signal with a conspicuous warming extending into the early Holocene. A small percentage of taxa resulted to be sensitive to these YD climate changes. Response lags were negligible at the resolution of the study. However, changes in the sensitive taxa were relevant enough to determine changes in biodiversity and taxonomic composition. Highland vegetation experienced mainly intra-community reorganizations, whereas midland vegetation underwent major changes leading to community substitutions. This was explained in terms of threshold-crossing non-linear responses in which the coupling of climatic and other forcings (fire) was proposed as the main driving mechanism. Paleoecology provides meaningful insights on the responses of highland and midland Neotropical vegetation to the YD climatic reversal. Biotic responses at both individual (species) and collective (assemblage) levels showed patterns and processes of vegetation change useful to understand its ecological dynamics, as well as the mechanisms and external drivers involved. The use of paleoecological methods to document the biotic responses to the YD climate shifts can be useful to help forecasting the potential consequences of future global warming. Due to its quasi-global character, the YD reversal emerges as a well suited candidate for providing useful insights of global scope by analyzing the corresponding biotic responses virtually at any geographical and biological setting.

1. Introduction

This paper uses the "ecological paleoecology" approach and aims to show to the general paleoecological audience the usefulness of this approach in ecology and conservation using selected case studies. When analyzed from an ecological perspective, paleoecological records provide unique evidence not available from short-term ecological observations. In this way, ecological hypotheses involving long-term processes can be tested with empirical data instead of unwarranted assumptions and extrapolations (Rull and Vegas-Vilarrúbia, 2011; Rull, 2012). This paleoecological approach has been called ecological paleoecology, by contrast with other paleoecological approaches providing only descriptive paleoclimatic and paleoenvironmental reconstructions (Seddon, 2012; Rull, 2014). The usefulness of ecological paleoecology in the study of ecological patterns and processes such as latitudinal

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diversity gradients, climate-vegetation equilibrium, community assembly, ecological succession or biodiversity conservation, among others, has been recently highlighted (e.g. Willis and Birks, 2006; Willis et al., 2007, 2010; Birks, 2008, 2013; Vegas-Vilarrúbia et al., 2011; Rull, 2012; Rull et al., 2013). Ecological paleoecology may significantly increase the usefulness of paleoecology in the study of relevant global warming and biodiversity conservation issues thus enhancing the contribution of our discipline in the search for a better future.

Useful paleoecological information for ecological hypothesis testing is the empirical record of biotic responses to past climate changes, which can be used as analogs for improving predictions about the potential ecological responses to climatic change estimates for this century (Rull, 2012; Rull et al., 2013). Several potential past analogs for the ongoing and near-future global warming have been proposed (Willis and MacDonald, 2011). Most of these analogs are of the same magnitude, in terms of temperature change, as those predicted for the end of this century, but they usually involve much more time thus failing to reproduce current warming rates. However, faster warming occurred between the Younger Dryas (YD) cooling and the beginning of the Holocene, which seem to have occurred at similar rates and time scales to present warming, has been proposed as one of the best paleoanalogs available so far (Cole, 2009; Vegas-Vilarrúbia et al., 2011; Willis and MacDonald, 2011). The YD cold reversal has been dated between 12.86 and 11.65 cal ky BP in the Greenland ice cores (Rasmussen et al., 2006), and was preceded by the Bølling/Allerød (B/A) interstadial, and followed by the Early Holocene Warming (EHW) (Fig. 1). Both B/A-YD and YD-Holocene transitions occurred at centennial scales which in paleoclimatology, are usually considered as abrupt or rapid shifts (Alley et al., 2003).

This paper uses the YD model as a past analog in the study of two Neotropical Venezuelan localities situated in the Andean highlands, around 4000 m elevation, and the Gran Sabana (GS) midlands, around 1000 m elevation. The study is focused on relevant ecological questions about: 1) the species that are sensitive or insensitive to YD climatic changes, 2) their response types and lags in relation to the drivers and ecological mechanisms involved, 3) potential changes in taxonomic composition and biodiversity due to climatic forcing, 4) eventual differential responses according to elevation, environmental setting and vegetation types, 5) possible non-linear and threshold responses, and 6) the potential for future predictions and for the optimization of conservation strategies. These types of questions have been considered especially relevant when using paleoecological data in ecological hypothesis testing and model validation (e.g., Davies and Bunting, 2010; Seddon et al., 2014), an approach that is gaining support in northern temperate areas but is still in its infancy in other regions, including the Neotropics.

2. YD climates in northern South America

In northern South America, the YD climatic reversal has been documented, well dated and quantified in climatic terms, in lake sediments from the Andean highlands (Van der Hammen and Hooghiemstra, 1995; Van't Veer et al., 2000; Groot et al., 2011; Stansell et al., 2010) and in marine sediments from the Cariaco Basin (Fig. 3) (Hughen et al., 2000; Haug et al., 2001; Lea et al., 2003). At both sites, the YD was characterized by cold and dry climates (Fig. 2), which coincides with speleothem paleoclimatic reconstructions from the Amazon Basin (Cheng et al., 2013) suggesting trends of more regional amplitude.

However, a closer look at the climatic trends reveals some differences between the Andean and the Cariaco records. The Cariaco trends are a better match to the changes recorded in the Greenland ice cores. Indeed, in Cariaco, both B/A-YD cooling and YD-Holocene warming occurred in a few centuries, with an intermediate phase (~1000 years) of stable cold climates covering most of the YD. Contrastingly, the Andean records show a different pattern consisting of a rapid cooling (but slightly less abrupt than in Cariaco) attaining a thermal minimum (3 °C below than average present temperatures, as estimated by past ELA reconstructions by Stansell et al., 2010) around 12.65 ky BP, followed by a more gradual warming of approximately 1000 years until the beginning of the Holocene (Fig. 2). Regarding precipitation and the precipitation/evaporation (P/E) balance, the Cariaco records show patterns similar to temperature, the only difference is that the Ti curve shows a more gradual precipitation increase than the grayscale record in the YD-Holocene transition. In contrast, the Andean records indicate that drier climates did not extend over the whole YD but only during the so called Northern Tropical Climate Reversal (NTCR) (Stansell et al., 2010), extending from ~12.9 to ~12.1 ky BP. A

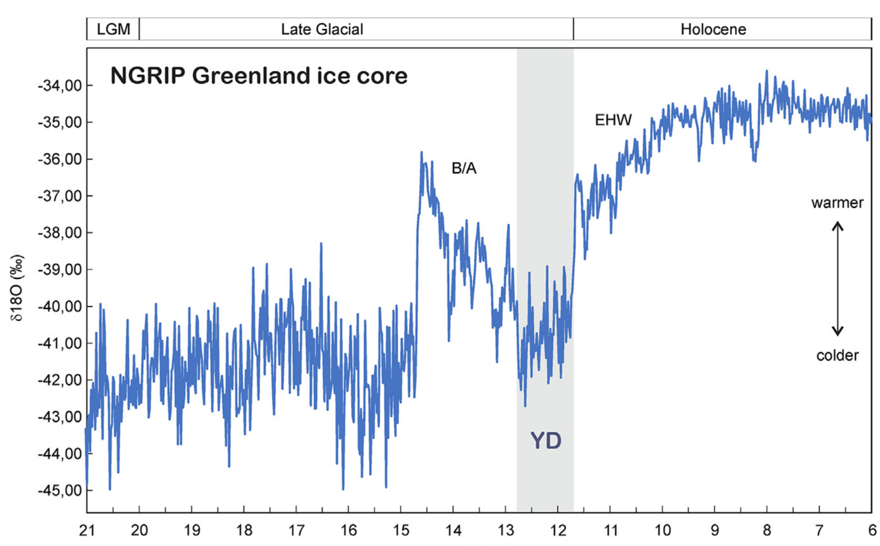

Fig. 1. Lateglacial climatic trends as recorded in the NGRIP Greenland ice core. LGM – Last Glacial Maximum, B/A – Bølling/Allerød interstadial, YD – Younger Dryas, EHW – Early Holocene Warming. Raw data from Rasmussen et al. (2006).