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Research paper

Pollen-based 17-kyr forest dynamics and climate change from the Western Cordillera of Colombia; no-analogue associations and temporarily lost biomes

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ABSTRACT

A 17 kyr long pollen record from the unexplored Western Cordillera of Colombia (Páramo de Frontino; 3460 m elevation) shows vegetation change and inferred climate dynamics at ~125 yr resolution. The cold and wet Lateglacial showed well-defined stadials and interstadials. At the transition to the Holocene the upper forest line (UFL) shifted within 200 years 700–800 m upslope reflecting a temperature increase of ~4.5 °C. Dead wood in the forests may have caused frequent fires. Individual taxa show clear and discrete successive expansion events, such as *Podocarpus* around 15 cal ka, *Quercus*, Melastomataceae, *Myrsine*, *Weinmannia*, and *Hesperomeles* around 11.5 cal ka, and *Alnus* around 9 cal ka showing the floristic composition of the montane forest changed during its upslope migration. After forest had reached around 9 cal ka a quasi-stable altitudinal interval forest taxa continued to change proportions showing that upslope forest migration caused significant internal forest dynamics. Forest stability is not found suggesting that an equilibrium between forest composition and environmental variables was not reached. We hypothesize trees migrated faster upslope than the shrubs causing a temporarily loss of this shrub biome. During most of the Holocene the UFL varied between 3500 and 3700 m indicating warmer temperatures than today. High upper limits of subandean forest suggest that the lowermost level of significant night frost was at higher elevations than today. Driest pulses were registered ~9170 and ~8200 cal ka since 620 cal ka deforestation of *Quercus*, *Podocarpus* and *Weinmannia* in particular shows anthropogenic impact. Comparisons with other Andean climate records show a climatic asymmetry mainly related to migrations of the ITCZ. An implication of the present benchmark records of vegetation and climate variability and modeling is that new records should be analyzed at better than century resolution.

1. Introduction

The impact of climate change on the environment is much discussed. The current projections for the end of this century (IPCC, 2007) anticipate significant impacts on natural ecosystems as well as on societies. In order to better understand how environments have been subject to climate change in the past, and to infer from such studies the operating mechanisms involved, fine resolution records of past environmental change are needed. Suites of proxies are available to reconstruct aspects of past environmental change. However, fossil pollen has the important advantage that climate change is seen in relation to the changing environments where people find their living. In the northern Andes evidence of human occupation goes as far back as the early Holocene (Van der Hammen and Correal-Urrego, 1978) but significant impact is registered since the last two millennia (Grosjean et al., 1997; Marchant et al., 2001; Bellwood, 2005). Mostly, human impact starts with deforestation, but such impact on the vegetation makes a pollen record invalid to infer climate change. Therefore, pollen records are needed from areas where human impact has started as recently as possible. Here, we present a palynological study of a 7 meter long sediment core from a little researched area of the northern Andes. The core comes from a basin at 3460 m elevation in the Western Cordillera of Colombia. Sediment accumulation started shortly after the landscape had lost its ice cover. This remote site in a well preserved and biodiverse area near the transition from South American and Central American biota offers an opportunity to study natural environmental change in much detail, and in the latest part of the record anthropogenic impact on the environment.

Climatic change has a perturbation on every single taxon (Shipley and Keddy, 1987; Feeley et al., 2011). However, elevational envelopes of suites of taxa are similar (Wille et al., 2001; Bach and Gradstein, 2011; Bogotá-A. et al., in review) and the abundant species interactions are leading to plant associations mainly altitudinally organized (Walther, 2010) and responding as quasi units. González-Carranza et al. (2012) showed that taxa with substantial pioneer qualities are responding first to climate change (e.g. *Hedyosmum* and *Podocarpus*)

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while late-successional taxa (e.g. *Weinmannia*) responded with a time lag. Such differential response is causing temporal variation in abundance and taxonomic composition of forest associations (Feeley et al., 2011) reflecting non-analog plant associations (Bush et al., 2004; Urrego et al., 2009; Cárdenas et al., 2011; Feeley et al., 2011; Punyasena et al., 2011; González-Carranza et al., 2012; this study). However, modern analog vegetation often includes impact of anthropogenic disturbance distracting from identifying non-analog vegetation of pre-anthropogenic age. There is little reason to assume that modern taxa in the setting of earlier Holocene or Pleistocene biomes have essentially different ecological and climatological constraints (Torres et al., 2013) making an interpretation of no-analog vegetation in terms of shifting altitudinal vegetation associations feasible.

Some sites in the northern Andes have provided robust records of vegetation and climate change reflecting the same period as reflected in this paper, e.g. core Guandera (Bakker et al., 2008) and core la Cocha-1 (González-Carranza et al., 2012). These records were used for comparisons. Several synthesis studies of north Andean Holocene climate change from sites between sea level and 4000 m elevation showed that along this altitudinal gradient climate changed uniformly in the same direction or in opposite directions depending on elevation (Behling and Hooghiemstra, 2001; Marchant et al., 2001, 2002a, 2009). In these syntheses studies the Western Cordillera was not included as pollen records from that area were lacking.

The objective of this paper is to reconstruct at sub-millennial time-scales vegetation development and inferred climate change. We address effects of rapid climate change at the Lateglacial–Holocene transition. Temporal changes in vegetation composition will be evaluated in terms of migration of individual taxa as well as interrelated complexes of plant taxa forming altitudinally constrained plant associations. We compare the new record to selected north Andean sites where records are located in the setting of an intraAndean valley or are located on the eastern flank of the Andes facing Amazonia to place our new results in a regional context and to explore possible mechanisms driving climate variability.

2. Environmental setting

2.1. Geography and geology

The sediment core studied in this paper comes from the Llano Grande basin which is part of the Páramo de Frontino, located at 6°29′N and 76°6′W. It reflects the largest tropical montane grassland area in the Western Cordillera of Colombia (Fig. 1). From a phytogeographical point of view this páramo area forms the link between the high mountain floras of Central America and the northern Andes (Luteyn, 1999). The low population density in the region explains this area is well preserved. The regional bedrock is made up of dioritic and monzonitic rocks with intruded Cretaceous turbidites (Parra, 1991). These igneous rocks are overlain by volcanic rocks (basalts, andesites, and conglomerates) and Tertiary tuffs. The acid soils are rich in organic matter (OM) and aluminum and have a low fertility (Jaramillo and Parra, 1993). The Páramo de Frontino includes steep slopes with long and deep canyons cut by rivers, and a flat zone with a variety of geomorphological landforms of glacial origin (Parra, 1991). Presence of rocky drumlines in the Llano Grande basin shows its glacial origin. The surrounding mountains reach up to elevations of 4100 m. During post-glacial time the basin was filled with almost 13 m of fluvial and lacustrine sediments finally giving rise to the present mire of 0.2 km^2 (Fig. 2).

The study area has a tropical alpine climate. The nearest weather station is located at the Macizo de Tatamá (Rangel-Ch., 2011). The diurnal temperature range is large and mean monthly temperatures vary little throughout the year. The mean annual temperature (MAT) is ca. 9.5 °C (Snow, 1976). Climate in the northern Andes is mainly determined by the position and strength of the Inter Tropical Convergence Zone (ITCZ) (Garcia, 1986; Groot et al., 2011). The westerly winds blowing from the Pacific Ocean cause orographic rains at the Pacific flank of the Western Cordillera (Lopez and Howell, 1967; Mesa et al., 1997) (Fig. 1). Precipitation is characterized by two annual rainy periods from April to May when the ITCZ moves northwards, and from September to October when the ITCZ moves southwards. Relatively dry periods occur in between. During the day air masses are ascending from the valleys; during the night, the opposite air movement occurs leading to daily night frost. Daily temperature contrast is largest during the dry periods (Trojer, 1958; Oster, 1979). With respect to temperature and humidity there is an asymmetry between the eastern and western slopes (Thouret and Pérez, 1983) reflected in the altitudinal position of the condensation belt: between 2800 and 3300 m at the western slope, and between 3000 and 3300 m at the eastern slope.

2.2. Modern vegetation

The elevation of the uppermost contour of closed forest, called the upper forest line (UFL) (Bakker et al., 2008) is at ca. 3450 m which equals to the elevation of the mire. The altitudinal vegetation distribution in the Western Cordillera follows Van der Hammen (1974) and Cleef and Hooghiemstra (1984). More detailed studies of the altitudinal vegetation distribution and main plant associations in the Western Cordillera were published by Cleef (1981), Rangel-Ch. et al. (1982), Van der Hammen and Ruiz (1984), Garcia and Londoño (1985), Rangel-Ch. and Lozano (1986), Salamanca-V (1991), Sanchez (1998, 1999) and Sanchez et al. (1999). Other studies have explored which pollen taxa are most important and how ecological envelopes do relate to temperature and precipitation (e.g. Wille et al., 2001; Marchant et al., 2002b; Bogotá-A. et al., in review). The regional pollen flora was studied by Velásquez (1999a,b).

Orographic precipitation at the Pacific flank of the Western Cordillera is very high explaining the vegetation in the 0–1000 m interval in Chocó shows a high floristic affinity with the montane forests between 700 and 2200 m. Both areas share 97.5% of the families, 90% of the genera, and 47% of the species (Muñoz and Cruz, 1993). The transition from subandean forest to Andean forest is mainly constrained by the occurrence of night frost which is most frequent during the dry season (Wille et al., 2001). The transition from Andean forest to subpáramo reflects the UFL and its altitudinal position is mainly driven by MAT. The UFL is also responsive to changing atmospheric pCO_2 (Boom et al., 2002; Groot et al., 2011; Hooghiemstra et al., 2012). Parameters constraining the transition from shrubby subpáramo to herbaceous grasspáramo are unclear but frost frequency and climatic humidity, partly interrelated, are considered important factors (Torres et al., 2013).

3. Materials and methods

A 760 cm long sediment core was recovered in Llano Grande mire using a hand operated Dachnovsky sampler. Sediment cores of 25 cm length and 2.5 cm diameter were sampled from 100 to 760 cm core depth; to collect the softer sediments in the uppermost 100 cm we used a Russian corer. Sediments were wrapped in plastic foil and protected by PVC-guttering. Samples were transported to the Palaeoecology Laboratory of the National University in Medellín and stored in a dark room at 4 °C.

The chronology of the sediments is based on conventional and accelerator mass spectroscopy (AMS) ^{14}C dating. In the absence of plant macrofossils we dated 18 bulk samples of 1 cm^3. We calibrated radiocarbon ages with CALIB Programme version 5.0.1 (Stuiver et al., 2012). For the development of the age model we applied a third degree polynomial interpolation of the calibrated ages.

Pollen samples of 1.5 cm^3 were taken at 5 cm increments along the core. Samples were treated with standard procedures for pollen preparation including sodium pyrophosphate, acetolysis, and heavy liquid