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Geochronological database and classification system for age uncertainties in Neotropical pollen records

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Abstract. The newly updated inventory of palaeoecological research in Latin America offers an important overview of sites available for multi-proxy and multi-site purposes. From the collected literature supporting this inventory, we collected all available age model metadata to create a chronological database of 5116 control points (e.g. ^{14}C, tephra, fission track, OSL, ^{210}Pb) from 1097 pollen records. Based on this literature review, we present a summary of chronological dating and reporting in the Neotropics. Difficulties and recommendations for chronology reporting are discussed. Furthermore, for 234 pollen records in northwest South America, a classification system for age uncertainties is implemented based on chronologies generated with updated calibration curves. With these outcomes age models are produced for those sites without an existing chronology, alternative age models are provided for researchers interested in comparing the effects of different calibration curves and age–depth modelling software, and the importance of uncertainty assessments of chronologies is highlighted. Sample resolution and temporal uncertainty of ages are discussed for different time windows, focusing on events relevant for research on centennial- to millennial-scale climate variability. All age models and developed R scripts are publicly available through figshare, including a manual to use the scripts.

1 Introduction

Temporal uncertainty remains a challenge in databases of fossil pollen records (Blois et al., 2011). The demands for precise and accurate chronologies have increased and so have the questions needing higher resolution data with accurate chronologies (Brauer et al., 2014). The increasing number of studies testing for potential synchronous patterns in paleo-proxies (Jennerjahn et al., 2004; Gajewski et al., 2006; Blaauw et al., 2007, 2010; Chambers et al., 2007; Giesecke et al., 2011; Austin et al., 2012) rely heavily on precise comparison between different records. Hypotheses have been proposed as to whether abrupt climatic changes were regionally and altitudinally synchronous, or whether there were significant "leads" and "lags" between and/or within the atmospheric, marine, terrestrial, and cryospheric realms (Blockley et al., 2012). The popular "curve-matching" of proxy data has been a cornerstone for correlating potential synchronous events, but this method neglects time-transgressive climate change (Blaauw, 2012; Lane et al., 2013). Thus, accurate age–depth modelling has been identified as crucial to derive conclusions on climate change signals from different paleoarchives (Seddon et al., 2014).

It is important to identify those few (but growing numbers of) records which have relatively precise chronological information (Blois et al., 2011; Seddon et al., 2014; Sundqvist et al., 2014). The development of large-scale analyses is relatively recent, demanding occasionally a different approach to data handling of individual pollen records. The latter were most often developed to explore questions on a local or regional terrain, by researchers unacquainted with requirements for multi-site integration. Multi-site temporal assessments have recently been presented for the European Pollen Database (EPD; Fyfe et al., 2009; Giesecke et al., 2014), for the African Pollen database (Hélyet al., 2014), and for the

North American pollen database (Blois et al., 2011), but for Latin America this important assessment is still missing.

To support multi-site and multi-proxy comparison, collecting chronological information of pollen records and implementation of uncertainty assessments on their temporal spinal cords is an indispensable step. The recently updated inventory of palaeoecological studies in Latin America (Flantua et al., 2013, 2015; Grimm et al., 2013) shows the vast amount of available palynological sites with potential geochronological data throughout the continent. Therefore, we created a geochronological database originating from the updated Latin American Pollen Database (LAPD) and corresponding literature database (1956–2014). Here we summarize the collected metadata on chronological dating and reporting in Neotropical studies. We describe the most commonly used dating methods, age modelling, and calibration methods, and discuss fields of highest potential improvement in line with international recommendations. Furthermore, with the aim of enriching the discussion on uncertainty assessments of age models and exemplifying the use of geochronological data recollection, we produce age models from pollen records in northwest South America (NW-SA). Updated calibration curves are used and we evaluate the temporal uncertainty of age models by a conceptual framework proposed by Giesecke et al. (2014) for ranking the quality of the chronologies as well as the individual ^{14}C ages and depths with pollen counts. Based on the combined temporal quality and resolution assessment, the time windows best suitable for inter-site and inter-proxy comparison are highlighted. The resulting chronologies are not assumed to be the best age models, but serve as alternative or potential age models for studies lacking published chronologies, reinforced by a temporal uncertainty assessment. We postulate that this study serves as a guidance to open up the discussion in South America on temporal quality of pollen records by providing a method openly accessible for adjustments and improvements. To stimulate reuse for new analyses and capacity building on age modelling, all outcomes and R scripts are available from figshare at: https://figshare.com/s/0e9afb8fe758a0e6e8c8.

2 Methods

2.1 Geochronological database of the Neotropics

To obtain an overview of the control points and age modelling methods used in pollen records throughout the region, we performed a thorough review of the LAPD and corresponding literature database (Flantua et al., 2015). A total of 1245 publications were checked regarding their chronological information covering 1369 sites. For 270 sites only biostratigraphic dates were mentioned, no chronological details were provided, or the original publications with specifications were not found. These sites originate primarily from the 1970s and the 1980s, although even some recent publications lack details on the chronology. All other sites consisting of at least one chronological reference point enter the geochronological database at this stage (Fig. 1). The following chronology metadata were collected for each site: *Site Name, Year of Data Preparation, Age Model, Calibration Method, Software, Material Dated, Depth (min, max, mean), Thickness, Laboratory number, pMC (error),* ^{13}C *adjusted* (±*standard deviation*), ^{14}C *date (min, max, errors), Reservoir correction, Calibrated age (min, max, best age, errors), Additional relevant comments from authors.* Furthermore, all additional parameters needed to correctly reconstruct the chronologies, such as presence of hiatus, slumps, contaminated control points, and other outliers identified by authors, were included. As a result, the Neotropical Geochronological Database (Neotrop-ChronDB) currently contains a total of 5116 chronological dates from 1097 sites throughout the study area.

2.2 Age model generation

From the Neotrop-ChronDB, all sites present in Venezuela, Colombia, Ecuador, Peru, and Bolivia were extracted (Fig. 1, countries in grey). Over 300 publications were consulted to recalibrate control points and rebuild age models of 234 pollen records (Table 1). When more than one chronological date was available, new chronologies were generated with the updated calibration curves for the northern and the southern hemispheres, and maintained as closely as possible to the authors' interpretation of the age model. New chronologies were generated with updated calibration curves to (a) be able to implement the temporal uncertainty analysis (the "star classification system"); (b) to provide age models to studies without chronologies; (c) to provide alternative age models for records based on older calibration curves or Southern Hemisphere records using the northern hemispheric calibration curves; (d) to estimate the temporal resolution of pollen records in general and at specific time windows of interest in NW-SA.

Chronology control points

The most common control points are radiocarbon dates. For the age model generation we included the reported uncertainty of a date regardless of its origin (conventional or Accelerator Mass Spectrometry, AMS). Additional important control points in constructing chronologies are ages derived from tephra layers from volcanic material, radioactive lead isotopes (^{210}Pb) and fission track dates.

Biostratigraphic dates

For the generation of the recalibrated age models, stratigraphic dates were not used. Use of these layers would ignore the possibility that for example the palynologically detectable onset of the Holocene was asynchronous throughout

Table 1. List of sites for which age models were recalibrated.

LAPD ID	SITE NAME	COUNTRY	LATITUDE (decimal degrees)	LONGITUDE (decimal degrees)	TIME RANGE MINIMUM (cal yr BP)	TIME RANGE MAXIMUM (cal yr BP)	REFERENCES
0292	Cala Conto	Bolivia	−17.57	−65.93	10 000	36 000	Graf (1981, 1992)
0308	Cerro Calvario	Bolivia	−16.25	−68.50	4000	23 300	Graf (1992)
0309	Chacaltaya 1	Bolivia	−16.37	−68.15	0	7600	Graf (1981, 1992)
0310	Chacaltaya 2	Bolivia	−16.37	−68.15	0	9800	Graf (1981, 1992)
0311	Cotapampa	Bolivia	−15.22	−69.10	0	10 900	Graf (1981, 1992)
0312	Cumbre Unduavi	Bolivia	−16.35	−68.03	0	13 600	Graf (1981, 1992)
0333	Laguna Katantica	Bolivia	−14.80	−69.18	0	7500	Graf (1981, 1992)
0336	Laguna Bella Vista A	Bolivia	−13.62	−61.55	1530	51 000	Mayle et al. (2000); Burbridge et al. (2004)
0339	Laguna Chaplin A	Bolivia	−14.48	−61.07	0	50 000	Mayle et al. (2000); Burbridge et al. (2004); Mayle et al. (2007)
0344	Laguna Khomer Kocha Upper	Bolivia	−17.28	−65.98	0	18 100	Williams et al. (2011a)
0347	Laguna Yaguarú	Bolivia	−15.60	−63.22	0	5600	Taylor et al. (2010)
0348	Lake Chalalan	Bolivia	−14.43	−67.92	60	16 000	Urrego et al. (2012)
0349	Lake Santa Rosa	Bolivia	−14.48	−67.87	2500	16 000	Urrego et al. (2012)
0350	Lake Siberia 93-1	Bolivia	−17.83	−64.72	4500	40 000	Mourguiart and Ledru (2003)
0361	Monte Blanco 2	Bolivia	−17.03	−67.36	900	8300	Graf (1981); Graf (1992)
0378	Sajama 2	Bolivia	−18.12	−68.97	0	4400	Graf (1992)
0381	Sajama Ice Cap 2	Bolivia	−18.10	−68.88	0	15 000	Reese (2003); Thompson et al. (1998); Reese et al. (2013)
0383	Salar de Uyuni	Bolivia	−20.25	−67.51	14 900	108 300	Baker et al. (2001a); Fritz et al. (2004); Chepstow-Lusty et al. (2005); Gosling et al. (2009)
0394	Tiquimani	Bolivia	−16.20	−68.06	−35	6800	Ledru et al. (2013a)
0400	Titicaca LT01-3B 2	Bolivia	−16.23	−68.77	3500	151 000	Gosling et al. (2008); Gosling et al. (2009)
0401	Titicaca NE98-1PC 1	Bolivia	−16.13	−69.21	0	28 000	Paduano et al. (2003); Baker et al. (2001b)
0559	El Junco EJ-N-1	Ecuador	−0.90	−89.48	0	2690	Restrepo et al. (2012)
0736	Lake Challacaba-B	Bolivia	−17.55	−65.57	0	4000	Williams et al. (2011b)
0832	Agua Blanca PAB I	Colombia	5.00	−74.17	7490	47 000	Helmens and Kuhry (1986); Helmens (1990)
0833	Agua Blanca PAB II	Colombia	5.00	−74.17	0	8300	Kuhry (1988b)
0834	Agua Blanca PAB III	Colombia	5.00	−74.17	0	7150	Graf (1992); Kuhry et al. (1983); Kuhry (1988b)
0835	Alsacia	Colombia	4.00	−74.25	1110	21 500	Melief (1985); Melief and Cleef (2008)
0837	Andabobos	Colombia	4.08	−74.17	0	14 500	Melief (1985); Melief and Cleef (2008)
0839	Ciénaga El Ostional	Colombia	9.40	−75.88	0	3500	Palacios (2011); Palacios et al. (2012)
0840	La Zona − Bahía de Cispatá	Colombia	9.41	−75.80	0	364	Palacios et al. (2012)
0841	Bahía Honda	Colombia	12.56	−81.70	−50	2500	González et al. (2010)
0849	Cahuinari II	Colombia	−2.04	−70.75	40 000	51 000	Van der Hammen et al. (1992); Rangel-Ch et al. (2008)
0850	Caquetá V	Colombia	0.97	−71.54	1000	2800	Rangel-Ch et al. (2008)
0851	Carimagua Bosque	Colombia	4.07	−70.22	0	1200	Berrío et al. (2000b); Berrío (2002)
0852	Carimagua Laguna	Colombia	4.07	−70.23	1357	8270	Behling and Hooghiemstra (1999)
0855	Chenevo	Colombia	4.08	−70.35	0	7260	Berrío et al. (2002a); Berrío (2002)
0859	Castañuelo – Ciénaga de Córdoba	Colombia	9.14	−75.71	0	1350	García-M. and Rangel-Ch (2012)
0860	El Cigarro – Ciénaga de Córdoba	Colombia	9.02	−75.68	0	6410	García-M. and Rangel-Ch (2012)
0863	Ciénaga del Visitador	Colombia	6.13	−72.78	0	14 000	Van der Hammen and González (1965a)
0871	El Abra II−B1	Colombia	5.02	−73.95	22 200	50 720	Schreve-Brinkman (1978)
0873	El Billar I	Colombia	4.83	−75.85	0	6500	Melief (1985, 1989)
0874	El Billar II	Colombia	4.83	−75.85	0	13 350	Melief (1985, 1989)
0875	El Bosque EB I	Colombia	4.75	−75.45	2040	4790	Kuhry et al. (1983); Kuhry (1988a)
0877	El Caimito	Colombia	2.53	−77.60	0	3850	Velez et al. (2001); Urrego Giraldo and Berrío Mogollon (2011)
0878	El Camaleón	Colombia	−2.03	−70.58	50 000	55 000	Rangel et al. (2008)
0879	El Gobernador	Colombia	4.00	−75.00	0	10 500	Melief (1985); Melief and Cleef (2008)
0881	El Pinal	Colombia	4.13	−70.38	1065	18 290	Behling and Hooghiemstra (1999)
0892	Fuquene 2	Colombia	5.45	−73.77	0	42 000	Van Geel and Van der Hammen (1973); Mommersteeg (1998); Van't Veer et al. (2000); Hooghiemstra et al. (2006); Bogotá-Angel et al. (2011); Bogotá-Angel. (2011)
0893	Fuquene 3	Colombia	5.45	−74.27	0	124 000	Van der Hammen and Hooghiemstra (2003); Bogotá-Angel et al. (2011); Bogotá-Angel (2011)
0895	Fuquene 7	Colombia	5.45	−73.77	2000	85 500	Mommersteeg (1998); Vélez et al., 2003; Bogotá-Angel et al. (2011); Bogotá-Angel (2011)
0896	Fuquene 7C	Colombia	5.45	−73.77	2000	70 007	Mommersteeg (1998); Groot et al. (2011)
0899	Pantano de Genagra	Colombia	2.47	−76.62	−48	54 000	Behling et al. (1998); Wille (2001); Wille et al. (2001)
0901	Guandal	Colombia	2.22	−78.35	0	2100	Urrego Giraldo and Del Valle (2002); Urrego Giraldo and Berrío Mogollon (2011)
0907	Jotaordo	Colombia	5.80	−76.70	0	4300	Berrío et al. (2000a); Berrío (2002); Urrego Giraldo and Berrío Mogollon (2011)
0908	La Cachucha	Colombia	4.50	−75.50	0	9000	Bakker and Salomons (1989); Salomons (1986)
0910	La Cocha 1	Colombia	1.06	−77.15	0	14 000	González-Carranza et al. (2012)
0913	La Guitarra	Colombia	4.00	−74.30	0	15 650	Melief (1985); Melief and Cleef (2009)
0914	La Laguna	Colombia	4.92	−74.33	0	27 000	Helmens et al. (1996)
0915	La Primavera	Colombia	4.00	−74.17	20 00	12 000	Melief (1985); Melief and Cleef (2009); Van der Hammen and Hooghiemstra (1995b)
0917	La Teta 2	Colombia	3.08	−76.53	0	8850	Berrío et al. (2002b); Berrío (2002)
0920	Laguna de los Bobos	Colombia	6.17	−72.83	0	5000	Van der Hammen (1962)
0922	Laguna Ciega III	Colombia	6.50	−72.30	0	25 000	Van der Hammen et al. (1980/1981)
0923	Laguna de Agua Sucia	Colombia	3.58	−73.52	2000	4000	Van der Hammen (1974)
0927	Laguna de Pedro Palo 1	Colombia	4.50	−74.38	10 000	12 000	Van der Hammen (1974); Hooghiemstra and Van der Hammen (1993)

Table 1. Continued.

LAPD ID	SITE NAME	COUNTRY	LATITUDE (decimal degrees)	LONGITUDE (decimal degrees)	TIME RANGE MINIMUM (cal yr BP)	TIME RANGE MAXIMUM (cal yr BP)	REFERENCES
0929	Laguna de Pedro Palo 3	Colombia	4.50	−74.38	2000	13 000	Hooghiemstra and Van der Hammen (1993)
0930	Laguna de Pedro Palo 5	Colombia	4.50	−74.38	2000	12 000	Hooghiemstra and Van der Hammen (1993)
0933	Laguna Ángel	Colombia	4.47	−70.57	0	12 900	Behling and Hooghiemstra (1998)
0935	Laguna Piusbi	Colombia	1.90	−77.94	0	7700	Behling et al. (1998a); Urrego Giraldo and Berrío Mogollon (2011)
0936	Laguna Sardinas	Colombia	4.97	−69.47	80	11 570	Behling and Hooghiemstra (1998)
0937	Laguna Verde de Las Siete Cabezas	Colombia	4.83	−75.25	350	4330	Melief (1985, 1989)
0938	Las Margaritas	Colombia	3.38	−73.43	200	11 500	Wille et al. (2003)
0940	Llano Grande II	Colombia	6.46	−76.10	0	13 000	Velásquez et al. (1999); Velásquez (2004); Parra Sanchez (2005); Parra et al. (2010); Muñoz-Uribe (2012)
0941	Loma Linda	Colombia	3.30	−73.38	0	8700	Behling and Hooghiemstra (2000)
0943	Los Lagos	Colombia	5.17	−76.17	0	5600	Velásquez et al. (1999)
0945	Manacaro I	Colombia	−1.55	−70.13	11 600	12 500	Giraldo et al. (2008)
0946	Mariname I	Colombia	−0.73	−72.07	0	11 200	Urrego Giraldo (1994)
0947	Mariname-II	Colombia	−0.75	−72.05	0	10 800	Urrego Giraldo (1994)
0949	Mozambique	Colombia	3.97	−73.05	0	3500	Berrío et al. (2002a); Berrío (2002)
0951	ODP677	Colombia	1.20	−83.74	0	39 410	González et al. (2006)
0952	Otoño-Manizáles Enea	Colombia	5.00	−75.45	28 500	53 500	Cleef et al. (1995)
0954	Pantano de Mónica 1	Colombia	−0.70	−72.07	4730	11 150	Berrío (2002); Behling et al. (1999)
0955	Pantano de Vargas 1	Colombia	5.78	−73.10	2470	9450	Gómez et al. (2007)
0958	Páramo de Laguna Verde I	Colombia	5.25	−74.00	0	5600	Kuhry et al. (1983); Kuhry (1988b)
0959	Páramo de Peña Negra 1	Colombia	5.08	−74.08	0	14 000	Kuhry (1988b)
0963	Páramo Palacio PT 1	Colombia	4.77	−73.85	0	2720	Van der Hammen and González (1960)
0964	Páramo Palacio PT 2	Colombia	4.77	−73.85	0	5200	Van der Hammen and González (1960)
0965	Patía I	Colombia	2.03	−77.08	0	8500	Vélez et al. (2005)
0966	Patía II	Colombia	2.03	−77.08	0	8600	Vélez et al. (2005)
0967	Piagua	Colombia	2.50	−76.50	0	41 000	Wille et al. (2001)
0968	Pitalito PIT 11	Colombia	1.87	−76.03	17 500	67 700	Bakker (1990); Wille et al. (2001)
0969	Pitalito PIT2	Colombia	1.87	−76.03	0	7000	Bakker (1990); Wille et al. (2001)
0971	Potrerillo II	Colombia	2.03	−77.00	0	8500	González-Carranza et al. (2008)
0973	Puente Largo II	Colombia	6.48	−76.10	0	4500	Velásquez et al. (1999); Velásquez (2004)
0974	Quebrada África	Colombia	4.75	−75.25	0	12 000	Salomons and Noldus (1985); Grabandt (2008)
0975	Quebrada del Amor	Colombia	−0.58	−72.42	0	100	Berrío et al. (2003)
0976	Quilichao 1	Colombia	3.10	−76.52	0	13 150	Berrío et al. (2002b); Berrío (2002)
0979	Quinché I	Colombia	−0.88	−71.85	0	4050	Urrego Giraldo (1994)
0980	Quinché II	Colombia	−0.88	−71.83	0	1760	Urrego Giraldo (1994)
0981	Quinché III	Colombia	−0.93	−71.82	0	10 950	Urrego Giraldo (1994)
0986	Rio Timbio	Colombia	2.40	−76.60	0	27 000	Wille et al. (2000); Wille (2001); Wille et al. (2001)
0995	San Martin	Colombia	6.57	−76.57	0	3990	Urrego et al. (2006)
1001	Sierra Nevada VII	Colombia	10.78	−73.67	0	9000	Van der Hammen (1984)
1008	Totumo	Colombia	−2.03	−70.77	30 000	50 000	Rangel et al. (2008)
1013	TPN 21B	Colombia	4.50	−75.50	0	10 500	Salomons (1986)
1017	TPN 36C	Colombia	4.50	−75.50	0	14 000	Salomons (1986)
1027	Turbera de Calostros	Colombia	4.68	−73.80	100	8700	Bosman et al. (1994)
1029	Ubaque	Colombia	4.50	−73.92	0	4500	Berrío (1995)
1035	Laguna de la Herrera	Colombia	5.00	−73.91	0	5000	Van der Hammen and González (1965b)
1037	Valle de Lagunillas Core VL-VIII	Colombia	6.38	−72.30	6000	9800	González et al. (1966)
1038	Valle de Lagunillas Core VL-V	Colombia	6.50	−72.30	8000	12 500	González et al. (1966)
1040	Valle San Carlos	Colombia	4.70	−75.33	9100	12 500	Melief (1985, 1989)
1042	Villanueva	Colombia	6.57	−76.57	0	3420	Urrego et al. (2006)
1131	Anangucocha	Ecuador	−0.67	−76.42	0	3100	Frost (1988)
1133	Cayambe	Ecuador	−0.03	−78.03	0	7200	Graf (1989, 1992); Weng et al. (2004)
1134	Cerro Toledo CT	Ecuador	−4.38	−79.12	0	20 000	Brunschön and Behling (2009, 2010)
1135	Cocha Caranga Laguna	Ecuador	−4.04	−79.16	0	14 500	Niemann and Behling (2009); Brunschön and Behling (2010)
1136	Cocha Caranga Mire	Ecuador	−4.04	−79.16	0	1550	Niemann and Behling (2009)
1139	El Tiro	Ecuador	−3.84	−79.15	0	20 100	Niemann and Behling (2008a, b); Brunschön and Behling (2010); Behling (2008)
1141	G15-II	Ecuador	0.60	−77.70	0	6000	Bakker et al. (2008); Moscol Olivera (2010)
1144	El Junco EJ1	Ecuador	−0.50	−91.00	0	8800	Colinvaux and Schofield (1976)
1145	El Junco EJ5	Ecuador	−0.50	−91.00	2200	10 200	Colinvaux and Schofield (1976)
1146	El Junco EJ6	Ecuador	−0.50	−91.00	3400	8500	Colinvaux and Schofield (1976)
1147	Kumpack B	Ecuador	−3.03	−77.82	0	5200	Liu and Colinvaux (1988)
1149	Lago Ayauch	Ecuador	−2.08	−78.02	0	7000	Bush and Colinvaux (1988); Colinvaux et al. (1988a)
1155	Laguna Chorreras	Ecuador	−2.77	−79.16	0	17 500	Hansen et al. (2003); Rodbell et al. (2002)
1157	Laguna La Campana	Ecuador	−4.02	−79.17	−57	1500	Brunschön et al. (2010)
1158	Laguna Pallcacocha 1	Ecuador	−4.77	−79.23	0	15 000	Rodbell et al. (1999)
1160	Laguna Zurita	Ecuador	−3.97	−79.12	0	1300	Niemann and Behling (2010)
1161	Lagunas Natosas Forest	Ecuador	−4.73	−79.42	0	15 930	Rodríguez (2012); Rodríguez and Behling (2012)
1162	Lake Santa Cecilia	Ecuador	0.07	−77.02	600	800	Colinvaux et al. (1988b)
1163	Lake Surucucho (Llaviucu)	Ecuador	−3.06	−78.00	0	12 000	Colinvaux et al. (1997); Weng et al. (2004)

Table 1. Continued.

LAPD ID	SITE NAME	COUNTRY	LATITUDE (decimal degrees)	LONGITUDE (decimal degrees)	TIME RANGE MINIMUM (cal yr BP)	TIME RANGE MAXIMUM (cal yr BP)	REFERENCES
1164	Limoncocha	Ecuador	−0.40	−76.63	900	1200	Colinvaux et al. (1988b); Colinvaux et al. (1985)
1166	Maxus-1	Ecuador	−0.45	−76.62	0	2000	Weng et al. (2002)
1167	Maxus-4	Ecuador	−0.45	−76.62	0	9850	Weng et al. (2002)
1170	Mullumica	Ecuador	−0.25	−78.25	0	13 000	Van der Hammen et al. (2003)
1171	Pantano de Pecho	Ecuador	−0.33	−79.22	0	660	Wille et al. (2002)
1172	Laguna Natosas Bog	Ecuador	−4.73	−79.43	0	15 000	Villota et al. (2012)
1174	Rabadilla de Vaca	Ecuador	−4.26	−79.11	0	10 000	Niemann et al. (2009); Brunschön and Behling (2010)
1175	Rabadilla de Vaca Bog	Ecuador	−4.26	−79.12	0	2100	Rodríguez and Behling (2011); Rodríguez (2012)
1176	Reserve Guandera-G8	Ecuador	0.60	−77.70	0	2880	Moscol Olivera and Hooghiemstra (2010); Moscol Olivera (2010)
1178	San Juan Bosco	Ecuador	−3.06	−78.46	26 000	31 000	Bush et al. (1990)
1181	Tres Lagunas	Ecuador	−3.03	−79.23	−57	7800	Jantz and Behling (2012)
1183	Valle Pequeño	Ecuador	−4.12	−79.17	−60	1630	Rodríguez and Behling (2011); Rodríguez (2012)
1184	Yaguarcocha	Ecuador	0.38	−78.08	0	13 500	Colinvaux et al. (1988a)
1211	Quistococha QT-2010-1	Perú	−3.83	−73.32	0	2000	Roucoux et al. (2013)
1247	Eruoda	Venezuela	5.37	−62.08	0	12 700	Nogué et al. (2009)
1496	Chica-Soras Valley	Perú	−14.18	−73.53	0	3970	Branch et al. (2007)
1498	Gentry	Perú	−12.33	−68.87	0	6300	Bush et al. (2007a, b)
1502	Laguna Baja	Perú	−7.70	−77.53	0	13 300	Hansen and Rodbell (1995); Weng et al. (2004); Hansen (1995)
1503	Laguna de Chochos	Perú	−7.68	−77.60	0	17 150	Bush et al. (2005)
1504	Laguna Huatacocha	Perú	−10.77	−76.62	1100	10 050	Hansen et al. (1984); Weng et al. (2004)
1505	Laguna Jerónimo	Perú	−11.78	−75.22	0	11 300	Hansen et al. (1994); Hansen (1995)
1506	Laguna Junín	Perú	−11.00	−76.17	0	36 000	Hansen et al. (1984, 1994); Weng et al. (2004); Hansen (1995)
1507	Laguna La Compuerta	Perú	−7.30	−78.36	0	33 000	Weng et al. (2004); Weng et al. (2006)
1508	Laguna Milloc	Perú	−11.57	−76.35	10 000	11 000	Graf (1992); Hansen (1995)
1510	Laguna Pomacocha	Perú	−11.78	−75.50	0	11 000	Hansen et al. (1994)
1511	Laguna Salinas	Perú	−16.40	−71.15	0	15 000	Juvigné et al. (1997)
1512	Laguna Tuctua	Perú	−11.67	−75.00	0	15 600	Hansen et al. (1994); Hansen (1995)
1513	Lake Consuelo-CON1	Perú	−13.95	−68.99	0	48 000	Bush et al. (2004); Urrego et al. (2005, 2010);
1514	Lake Consuelo-CON2	Perú	−13.95	−69.00	0	12 000	Urrego et al. (2010)
1516	Lake Pacucha	Perú	−13.61	−73.50	0	24 700	Hillyer et al. (2009); Valencia et al. (2010)
1517	Lake Sauce	Perú	−6.71	−76.22	0	6500	Correa-Metrio et al. (2010)
1520	Marcacocha	Perú	−11.39	−76.12	0	4200	Chepstow-Lusty et al. (1998, 2003, 2009)
1546	Nevado Coropuna-COR300	Perú	−15.50	−72.67	800	9700	Kuentz et al. (2012)
1547	Nevado Sabancaya	Perú	−16.22	−71.08	0	9580	Graf (unknown year)
1549	Parker	Perú	−12.18	−69.10	0	7400	Bush et al. (2007a, b);
1552	Rio Blanco Pond	Perú	−10.83	−75.33	10 000	11 000	Hansen et al. (1984); Hansen (1995)
1555	Urpi Kocha Lagoon Core 2	Perú	−12.23	−76.88	1000	2350	Winsborough et al. (2012)
1557	Vargas	Perú	−12.33	−69.12	0	7900	Bush et al. (2007a, b)
1558	Werth	Perú	−12.18	−69.10	0	3400	Bush et al. (2007a, b)
1569	Lagunares de Santa Isabel	Colombia	4.82	75.37	0	2130	Salamanca and Noldus (2003)
1579	Acopan tepui ACO-1	Venezuela	5.20	−62.08	0	4100	Rull (1991, 2005b)
1580	Acopan tepui ACO-2	Venezuela	5.20	−62.08	0	5230	Rull (1991, 1996, 2005b)
1581	Amuri tepui AMU-1	Venezuela	5.17	−62.12	0	5500	Rull (1991, 1996, 2005b)
1582	Apakará tepui PATAM9-A07	Venezuela	5.32	−62.23	0	8000	Rull et al. (2011)
1585	Auyan−18	Venezuela	5.90	−62.62	0	4000	Rull (1991)
1593	Bosque El Oso	Venezuela	5.27	−61.12	0	3400	Leal Rodríguez (2010); Leal et al. (2013)
1606	Churi Chim-2	Venezuela	5.32	−62.17	0	6500	Rull (1991, 2004a, b)
1611	El Pauji – PATAM5 A07	Venezuela	4.47	−61.58	0	8250	Montoya and Rull (2011); Montoya et al. (2011c)
1613	Guaiquinima QUAIQ-1	Venezuela	5.83	−63.68	0	6600	Rull (1991, 2005a)
1614	Guaiquinima QUAIQ-2	Venezuela	5.83	−63.68	0	8610	Rull (1991, 2005a)
1615	Helechal Ariwe	Venezuela	5.72	−61.56	0	3400	Leal Rodríguez (2010); Leal et al. (2013)
1619	Helechal Colonia	Venezuela	4.56	−61.20	0	1400	Leal Rodríguez (2010); Leal et al. (2013)
1629	La Culata	Venezuela	8.75	−71.07	2550	7530	Salgado-Labouriau and Schubert (1976); Graf (1996); Rull (1999)
1631	Lake Valencia 1-14-77	Venezuela	10.27	−67.75	0	13 000	Bradbury et al. (1981); Leyden (1985); Rull (1999); Salgado-Labouriau (1980); Schubert (1980)
1633	Lake Valencia 76V 7-11	Venezuela	10.18	−67.01	0	13 000	Leyden (1985)
1636	Laguna de los Anteojos	Venezuela	8.54	−71.07	9350	14 680	Rull et al. (2010); Stansell et al. (2010)
1637	Laguna Divina Pastora	Venezuela	4.70	−61.07	0	5400	Rull (1991, 1992)
1638	Laguna Encantada	Venezuela	4.60	−61.11	0	7500	Montoya et al. (2011b, 2009); Montoya (2011)
1640	Mucubaji Core A	Venezuela	8.80	−70.83	2000	8300	Salgado-Labouriau et al. (1992)
1641	Santa Teresa	Venezuela	4.72	−61.08	0	5141	Rull (1991, 1992)
1642	Laguna Verde Alta	Venezuela	8.85	−70.87	0	15 500	Rull et al. (2005, 2008)
1644	Laguna Victoria	Venezuela	8.81	−70.79	0	13 000	Salgado-Labouriau and Schubert (1977); Graf (1996)
1646	Lake Chonita – PATAM1 BO7 – Part 1	Venezuela	4.65	−61.00	0	15 300	Montoya et al. (2011a, b)
1648	Lake Valencia 76V 1-5	Venezuela	10.18	−67.01	0	9000	Leyden (1985)
1655	Morichal Mapire A1	Venezuela	9.55	−63.67	0	2220	Leal and Bilbao (2011)
1657	Morichal Quebrada Pacheco	Venezuela	5.73	−61.11	0	1200	Leal Rodríguez (2010); Leal et al. (2013)

Table 1. Continued.

LAPD ID	SITE NAME	COUNTRY	LATITUDE (decimal degrees)	LONGITUDE (decimal degrees)	TIME RANGE MINIMUM (cal yr BP)	TIME RANGE MAXIMUM (cal yr BP)	REFERENCES
1663	Páramo de Miranda	Venezuela	8.92	−70.83	280	11 500	Salgado-Labouriau (1988); Salgado-Labouriau et al. (1988); Rull (1999)
1665	Piedras Blancas	Venezuela	9.17	−70.83	0	1300	Rull et al. (1987); Rull and Schubert (1989); Rull (1998)
1669	Quebrada de Mucubaji	Venezuela	8.75	−70.80	10 000	13 000	Salgado-Labouriau et al. (1977); Graf (1996); Rull (1998)
1679	Sabana Inundada Parupa	Venezuela	5.67	−61.63	0	7000	Leal Rodríguez (2010)
1682	Torono tepui TOR-1	Venezuela	5.23	−62.15	0	5000	Rull (1991, 2005b)
1705	Pantano de Mónica 2	Colombia	−0.70	−72.07	0	4000	Berrío (2002); Behling et al. (1999)
1706	Pantano de Mónica 3	Colombia	−0.70	−72.07	0	3260	Berrío (2002); Behling et al. (1999)
1715	El Abra III	Colombia	5.02	−73.95	0	9000	Schreve-Brinkman (1978)
1716	El Abra IV − 107N	Colombia	5.02	−73.95	20 000	25 000	Schreve-Brinkman (1978)
1717	El Abra II − 10E	Colombia	5.02	−73.95	9000	10 000	Schreve-Brinkman (1978)
1740	Cerro Toledo CTB	Ecuador	−4.38	−79.12	0	10 000	Brunschön and Behling (2009, 2010)
1744	Cocha Caranga Forest	Ecuador	−4.04	−79.16	0	200	Niemann and Behling (2009)
1748	ECSF Cerro de Consuelo	Ecuador	−4.00	−79.06	800	1300	Niemann and Behling (2008b, 2010)
1749	ECSF Refugio	Ecuador	−3.99	−79.07	700	1100	Niemann and Behling (2008b, 2010)
1751	Laguna Daniel Álvarez	Ecuador	−4.02	−79.21	0	1300	Matthias (2008); Niemann et al. (2013)
1767	Páramo de Laguna Verde II	Colombia	5.25	−74.00	0	5600	Kuhry (1988b)
1867	Reserve Guandera−G7	Ecuador	0.60	−77.70	0	3000	Moscol Olivera and Hooghiemstra (2010); Moscol Olivera (2010)
1922	Reposo	Colombia	5.17	−75.08	0	7000	Rangel-Ch et al. (2005)
1923	Mirlas 4	Colombia	5.17	−75.08	0	7000	Rangel-Ch et al. (2005)
1924	Tatama 225	Colombia	5.17	−75.08	0	5800	Rangel-Ch et al. (2005)
1936	Boquillas 2	Colombia	9.12	−74.56	1550	10 010	Berrío (2002); Berrío et al. (2001)
1996	Calancala	Colombia	11.58	−72.88	−52	1240	Urrego et al. (2013)
1997	Navío Quebrado	Colombia	11.41	−73.10	150	6280	Urrego et al. (2013)
2014	La Tolita 1	Ecuador	1.27	−79.02	0	5000	Lim et al. (2014)
2143	Papallacta PA 1-08	Ecuador	−0.36	−78.19	0	1600	Ledru et al. (2013b)
2222	El Cristal	Ecuador	−3.86	−79.06	0	19 750	Villota and Behling (2013)
2358	Porce PIIIOP-61	Colombia	6.89	−75.19	2900	4700	Cardona-Velásquez and Monsalve (2009)
2359	Porce PII-21	Colombia	6.76	−75.12	4500	9000	Castillo et al. (2002); Cardona-Velásquez and Monsalve (2009)
2360	Porce PII-45	Colombia	6.97	−75.09	5000	10 200	Castillo et al. (2002); Cardona-Velásquez and Monsalve (2009)
2361	Porce POIIIOI-40	Colombia	6.98	−75.10	1200	7300	Otero and Santos (2006); Cardona-Velásquez and Monsalve (2009)
2362	Porce POIIIOI-52	Colombia	6.98	−75.09	3500	10 300	Otero and Santos (2006); Cardona-Velásquez and Monsalve (2009)
2370	Quebrada La Caimana	Colombia	6.97	−75.13	0	7000	García Castro (2011)
2377	El Morro	Colombia	6.67	−75.67	0	30 360	Castañeda Riascos (2013); Velásquez Montoya (2013)
2379	Puente Largo I	Colombia	6.48	−76.10	0	8000	Velásquez et al. (1999)
2387	Llano Grande 1	Colombia	6.48	−76.10	0	17 000	Velásquez and Hooghiemstra (2013)
2388	La Cocha-3	Colombia	1.14	−77.16	0	3000	Epping (2009)
2518	Cerro Llamoca	Perú	−14.17	−74.73	0	8600	Schittek et al. (2015)

northern South America. Therefore any further inferences on spatial leads, lags, or synchroneity would become flawed. Only in very few cases were very recent time markers used like the introduction of *Pinus*.

Core tops and basal ages

The non-"decapitated" top of the sediment sequence can be assigned to the year of sampling, if explicitly mentioned by the authors as the result of being the youngest sample in an undisturbed way. Frequently, however, assigning depths to core tops adds a factor of uncertainty because the uppermost sediments have not been consolidated and can be lost during coring. We did not use most of the estimated core tops as additional ages, but as with the bottom ages, let the recalibrated age model produce the new ages of the core tops. In case of considerable extrapolation or heavy overshooting of the age model (very young top ages), we produced alternative age models including the estimated top age. We decided to use the uncertainty range of ±50 years considering that this standard deviation results in c. 300 years of total uncertainty. We consider this value an appropriate estimate of uncertainty of core top ages. As the R-code of the procedures here presented is made available, researchers may adjust this value accordingly. Extrapolations from the new chronologies that went beyond −50 cal yr BP (years before AD 1950) were not used for the estimates on resolution.

Calibration curves

The South American continent covers the Northern Hemisphere (NH) as well as the Southern Hemisphere (SH). The previous SH calibration curve (SHCal04) only extended to 11 thousand calibrated years before present (here abbreviated as kcal BP). In age model tools like CLAM (Blaauw, 2010), options were provided to "glue" the NH calibration curve to the SH curve to extend back to 50 kcal BP. However, recently the SH calibration curve was extended to 50 kcal BP (Hogg et al., 2013) and now obviates the need to use the NH curve for older dates in the SH. This provides new opportunities to recalibrate age models with updated calibration information and produce additional sample ages for reevaluation. Never-

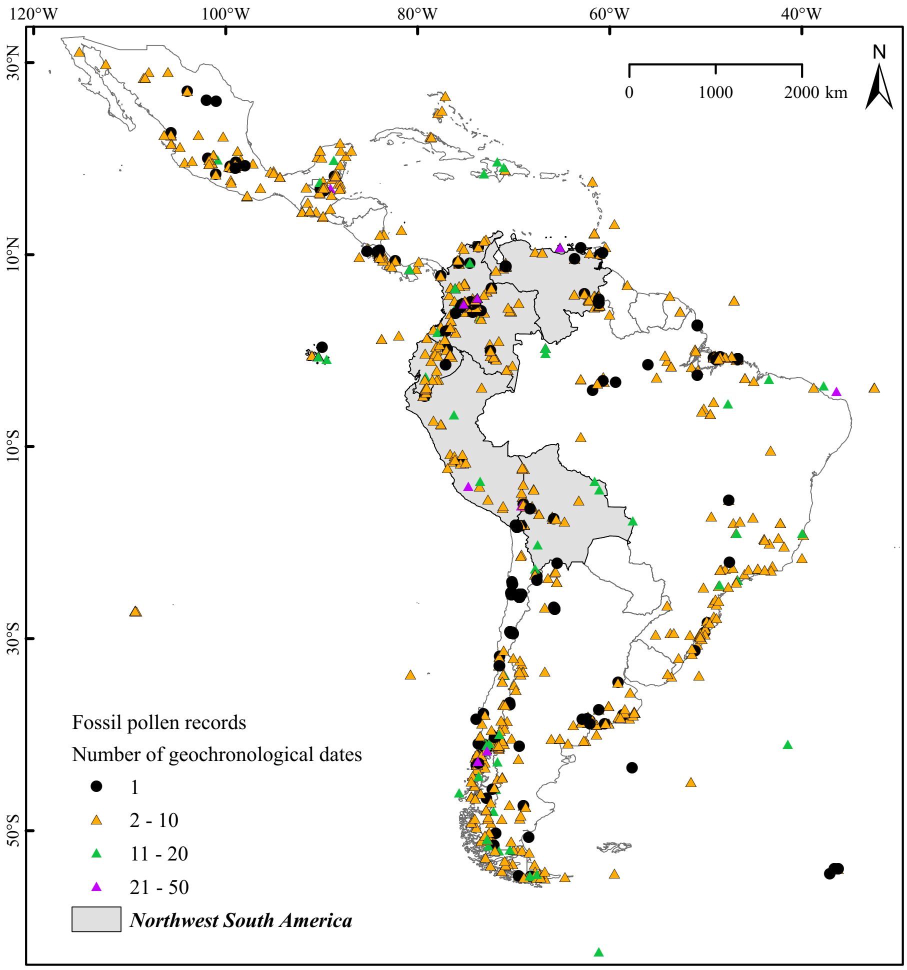

Figure 1. Pollen records currently present in the Neotropical Geochronological database. All records contain at least one geochronological date.

theless, tropical regions still face an uncertainty factor open to discussion, namely the southern limit of the Intertropical Convergence Zone (ITZC). McCormac et al. (2004) defined this limit to be the boundary between the NH and the SH, but models need additional data to better determine its exact location through time (McGee et al., 2014). For internal consistency we assigned the curve according to the general delimitation by Hogg et al. (2013) and Hua et al. (2013), or used the preferred calibration curve by the authors for the creation of the chronology. Mayle et al. (2000) for example, explicitly explain why their site in the Bolivian Amazonia experiences NH influences. Finally, a total of 22 sites include post-bomb dating for which five different regional curves options exist (Hua et al., 2013). Post-bomb calibration curves were as used by original authors or assigned according to Hua et al. (2013).

Age model methods

Depending on the number of available control points, two age–depth models were created per site. All age–depth relationships were reconstructed using the R-code CLAM version 2.2 (Blaauw, 2010; R Development Core Team, 2014), which is an R code for "classic age-modelling" (Blaauw and Heegaard, 2012). The simplest age model, namely the *linear interpolation* method, produces a straightforward interpolation. It connects individual control points with straight lines which is in most cases unrealistic as it assumes abrupt changes in sedimentation rates at, and only at, the dated depths in the sediment core. The second age model method we used is the *smoothing spline*, with a default smoothing factor of 0.3. This interpolation method produces a curve between points that is also influenced by more distant control points. This method provides a smoother outline of age model and is considered to produce a more realistic model of the sedimentation process compared to the linear interpolation method. However, smoothing splines can only be modelled at sites that present four or more control points. Furthermore, age models were not run on cores that were problematic from the start. Examples are: cores where a hiatus/slump disrupts the age model in a way that no linear interpolation is possible; cores with many age reversals (when an older date lies above a younger date with limited dates collected); and cores with many nearly identical radiocarbon dates regardless of depth. Studies using tuning methods to establish their age models were not included.

Sample depths and ages

The sample depths were derived from either the raw data set provided by the authors from the original paper or from the specifications and figures in the original publication. In a few cases, neither were available, so a 10 cm sample interval was assigned based on our assessments of the most likely depths for such dates. The sample age is obtained as the highest-probability age based on the distribution of estimated ages from 1000 Monte Carlo runs and the uncertainties are provided as 95 % confidence intervals.

Age model check

For each site, the newly produced models were evaluated and if necessary adjustments were made to deal with obvious outliers, "overshooting" of the age model towards the top, and degree of "smoothness" of the smooth spline model. Outliers were identified visually when control points deviated excessively from the general depth–age tendency. To solve over-extrapolation at the top (future dates), additional age models were created that included estimated surface dates. In some cases the default smoothing level of 0.3 was adjusted to "touch" more of the available dates or to avoid an age reversal in the model. The most appropriate age model was selected in accordance to the authors' description, with a general preference for the smoothing spline model. With this model, we calculated the multi-site summary values, such as overall resolution and star classification system.

Data accessibility

The original data, the R-codes and the recalibrated age models from this paper are available through: https://figshare.com/s/0e9afb8fe758a0e6e8c8. We provide a manual that explains step by step the setup of the data and the use of the codes. For each individual pollen record, the corresponding folder contains the description of the original age model (copyright prevented the inclusion of pictures/figures), details on the recalibrated age models and the outcomes of the star classification system at sample level.

Table 2. Classification of sample age uncertainty from the star classification system (Adapted from Giesecke et al., 2014).

Maximum distance to the nearest data (yr)	Stars	Colourbar Fig. 2
2000	1	Green
1000	2	Dark blue
500	3	Light blue
Straight segment	+1	Red

2.3 Temporal uncertainty estimates by the star classification system

We followed the age model evaluation proposed by Giesecke et al. (2014) to define the temporal quality and uncertainty of the chronologies and individual samples. An uncertainty classification based on assigning semi-quantitative "stars" focuses on the density of control point. The classification is additive and samples are assigned to the lowest class (a single star) where the estimated sample age is within 2000 years of the nearest control point. Additive stars are given at 1000-year and 500-year proximity to the nearest control point (Table 2). In addition to the three stars that characterize proximity to the nearest control point, an extra star is given to samples that are situated in a straight section of the sequence. The "straightness" star is given to a sample where, within the nearest four control points, the modelled sediment accumulation rate changes less than 20 %. Only sequences with at least four control points can obtain such an additional star. The evaluation is based on the position of the sample relative to the control points and is independent of the interpolation procedure. Therefore stars are assigned to the smooth spline output unless insufficient control points are available. The outcome of this classification produces a text file with the assigned number of stars for each sample along the core that is based on the depth file. The star classification is visualized along the vertical axis of the age model with coloured symbols (Fig. 2).

2.4 Time window assessment

Rapid events of climate change occurred during the Dansgaard–Oescher (D–O) cycles spanning the last glacial cycle and during the Holocene. Recently published pollen records, like at Lake Titicaca, Bolivia (Fritz et al., 2010) and Lake Fúquene, Colombia (Groot et al., 2011) show clear evidence of millennial climate variability of large amplitude during Marine Isotope Stage (MIS) 4 to 2. As an example of the implementation of the star classification system, we select a series of consecutive time windows relevant for paleoclimate reconstructions at millennial timescale. These time windows are: MIS 5 (c. 130–70 kcal BP), MIS 3 (c. 60–27 kcal BP; Van Meerbeeck et al., 2009), Heinrich event 1 (H1; c. 18–15 kcal BP; Álvarez-Solas et al., 2011),

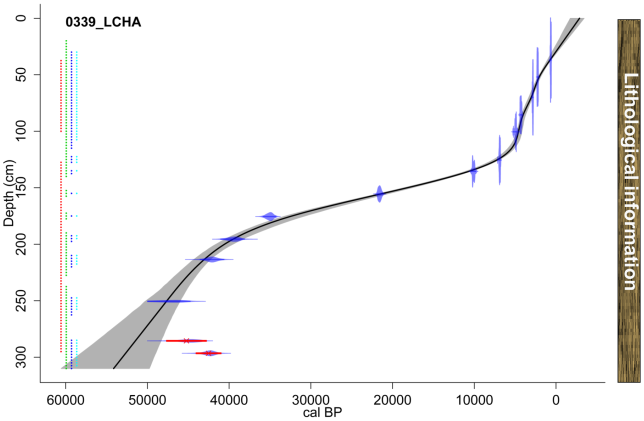

Figure 2. Recalibrated age depth relationship from Laguna Chaplin A (Mayle et al., 2007). The green, dark blue, light blue bars along the vertical axis reflect the proximity of a sample to the nearest control points, from "far", "good", "best" respectively. The red bar marks samples within a segment of the core supported by at least four control points within which the sediment accumulation changes less than 20 %. The addition of an additional upper age estimate would better constrain the extrapolation toward the top, which otherwise yield ages that are too young as shown in this example. The blue polygons at the control points represent the calibrated age range as a distribution, where the height of the polygon provides an indication of the probability of the age obtained from the control point. The dark bar alongside is shown as an example where the interpretation of the chronology can be supported by the lithological information alongside.

and the Younger Dryas (YD)/Holocene transition (c. 12.86–11.65 kcal BP; Rasmussen et al., 2006). For these time windows we summarize and discuss the temporal resolution and control-point density (the star classification system).

3 Results

3.1 Chronological data in the Neotropics

The number of available pollen records in this region has increased considerably in the last 20 years (Flantua et al., 2015). During recent years, the number of control points used for stratigraphic age models has trended upwards; since 2010, the mean and median number of control points per published pollen site has been five and three, respectively (Flantua et al., 2015). Here we provide more detail on the available chronologies, describing the most commonly used control points for dating, age modelling, and calibration methods.

Radiocarbon dates

The Neotrop-ChronDB stores a total of 5116 dates of which the most common control points are radiocarbon (^{14}C) dates. Radiocarbon dating has been used to date pollen records for more than five decades now. The first dated records in South America came from the Orinoco delta of Venezuela (Muller, 1959), and from Colombian sites such as Ciudad Universitaria, Laguna de la América, and Páramo de Palacio (Van der Hammen and González, 1960) and Laguna de Petenxil in Guatemala (Tsudaka, 1967). In the early stages of ^{14}C measurement, this technique required a minimal sample size of 0.5 g carbon (Povinec et al., 2009), while sample sizes differed greatly among materials (Bowman, 1990). In paleoecological research, this has always been a limiting factor as natural samples generally present a small ^{14}C / C ratio. As a consequence, material to obtain a ^{14}C date sometimes originated from a wide depth interval of the sediment core. Consequently, conventional radiocarbon dating based on bulk samples of lake sediments is often a high-risk undertaking as it can result in a substantial uncertainty and puzzling date estimates.

The great breakthrough came from the development of AMS dating in 1977 that consisted of direct counting of the ^{14}C atoms present in a sample (Bowman, 1990; Povinec et al., 2009). This technique reduced the requirements for sample size and therefore improved the accuracy of samples. Furthermore, the required time to obtain dates was reduced from months to minutes. It took some time for AMS dating to appear in the Neotropics. It was not until the early 1990s that AMS dating was used in sites as Lake Miragoane, Haiti (Brenner and Binford, 1988), Laguna de Genovesa, Ecuador (Steinitz-Kannan et al., 1998) and Lake Quexil, Guatemala (Leyden et al., 1993). Ever since, an increasing number of sites report AMS dates to support their chronologies with higher precision. Nevertheless, even in a recent record with AMS ages, authors have been struggling to compile a consistent age model due to low carbon content of the samples (Groot et al., 2014). The advantages of using ^{14}C as a dating method, having broad applicability on many different sample materials and covering the most prevalent time range (50 kcal BP), mean that it surpasses other methods and therefore remains to be the most commonly applied scientific dating method.

Currently c. 68% of the geochronological dates in the LAPD fall within the last 10 kcal BP, 20% within 20–10 kcal BP, and 4% within 30–20 kcal BP. A wide range of materials is used for dating: cellulose-containing materials (woods, seeds, achenes, plant remains, insect chitin; $n = 1732$); charcoal and charred material ($n = 191$); carbonates (shells and calcite; $n = 118$), collagen-containing materials (bones and coprolites; $n = 48$); and bulk sediments from different materials ($n = 1074$).

Tephrochronometry

The terminology *Tephrochronology* means "use of tephra layers as isochrons (time-parallel marker beds) to connect and synchronize sequences and to transfer relative or numerical ages to them using stratigraphy and other tools" (Lowe, 2011). The process of obtaining a numerical age or date for a tephra layer deposited after a volcanic eruption either directly or indirectly is called *Tephrochronometry* (Lowe, 2011). Primary minerals, such as zircon, K-feldspar, and quartz, can be used to date tephras directly. Indirect methods include different applications such as radiometric dating (radiocarbon dating, fission-track dating, argon isotopes K/Ar, Ar/Ar, luminescence dating, U-series, ^{238}U/^{238}Th zircon dating) and incremental dating (annually banded found in the layering of ice cores; Lowe, 2011). This field of advanced chronology is of essential importance in the search for precise dates for high-resolution paleoenvironmental records and research (Davies et al., 2012). Tephrochronology has become increasingly popular across a range of disciplines in the Quaternary field (Bronk Ramsey et al., 2015; Lowe, 2015), especially for linking and synchronizing paleorecords accurately along longer timescales. Several uncertainties in tephrochronology are similar to those known from radiocarbon dating such as methodological and dating errors, and reworking of dated layers. The specific challenges for this dating technique lay in that different tephras may display similar major element composition, or the same tephra may have a temporal and spatial compositional heterogeneity (for a review and examples see Lowe, 2008, 2011). International initiatives such as INTIMATE (http://intimate.nbi.ku.dk/) and INTREPID (Lowe, 2010) have aimed at improving uncertainties from tephrochronologies, supported by an expanding global database on tephra layers (http://www.tephrabase.org/). Although not extensive, we provide here an overview of studies that welcomed this technology to improve the chronologies of their pollen records.

From Mexico down to Patagonia, there are regions of elevated volcanic activities where frequent tephra layers can be found. Mexico's active seismic zones have numerous active volcanoes in the so-called "Mexico's Volcanic Axis" or "Trans-Mexican Volcanic Belt" (*Eje Volcánico Transversal*). Ortega-Guerrero and Newton (1998) collected tephra layers in southern Mexico specifically aimed to produce stratigraphic markers for palaeoenvironmental research. Tephra layers called Tlácuac, Tlapacoya, and Toluco can be found in different pollen records such as Lake Texcoco (Lozano-Garcìa and Ortega-Guerrero, 1998) and Lake Chalco (Lozano-Garcìa et al., 1993). Additional tephra layers played an important role in the chronology of Lake Peten-Itza PI6, Guatemala (Hodell et al., 2008) and Laguna Llano del Espino and Laguna Verde, El Salvador (Dull, 2004a, b).

The northern Andes forms part of the "Northern Volcanic Zone" (Stern, 2004; Rodríguez-Vargas et al., 2005) and is shared by Colombia and Ecuador. In the Ruiz-Tolima region (Central Cordillera of Colombia), Herd (1982) identified 28 eruptive events during the last 14 000 years. Sites like Puente Largo and Llano Grande (Velásquez et al., 1999) make use of these events in their chronologies. Even sites along the Eastern Cordillera capture these volcanic ashes, like Funza (Andriessen et al., 1994; Torres et al., 2005) and El Abra (Kuhry et al., 1993), while the ridge itself lacks volcanic activities (Rodríguez-Vargas et al., 2005). Otoño-Manizales Enea (Cleef et al., 1995) reports five events between 44 and 28.5 thousand calendar years (kyr) BP and Fúquene another six events between 30 kyr and 21 kyr BP (Van Geel and Van der Hammen, 1973). Fission-track ages on sparse zircons were obtained for the long cores from Funza 1, Funza 2, Rio Frío, and Facatativá (Andriessen et al., 1994; Wijninga, 1996).

Ecuador is also well known for its very active volcanic region. Two eruptions of the Guagua Pichincha and one of the Quilotoa were seen at pollen site Papallacta (Ledru et al., 2013b). Thanks to four radiometric ^{40}Ar–^{39}Ar dates from tephra deposits, the chronology of the Erazo pollen record was placed within the middle Pleistocene period (Cardenas et al., 2011). An important overview of tephrochronology in southern Ecuador was provided by Rodbell et al. (2002).

The central Andes forms part of the "Central Volcanic Zone" (Stern, 2004; Rodríguez-Vargas et al., 2005) and is shared by Peru and Bolivia. Several ice cores from the Sajama Ice Cap in Bolivia use ash layers from Volcán Huaynaputina in Peru as dating control (Reese, 2003). To support the chronology of the long core of Lake Titicaca, nine aragonite-rich layers for U/Th supported correlation with the last interglacial period (MIS5e; Fritz et al., 2007).

Finally, towards the south, the "Southern Volcanic Zone" covers Chile and Argentina (Stern, 2004). An overview of the Holocene tephrochronology of this volcanic zone is presented in Naranjo and Stern (2004). The Pleistocene–Holocene transition has shown similarity in timing with an increase in volcanic activity in southern Chile (Abarzúa and Moreno, 2008). Jara and Moreno (2014) assessed the potential of volcanic events as being a driver of vegetation changes at a (sub-) millennial timescale based on 30 tephra layers since 13.5 kcal BP. Other sites with tephras to support their chronology are at Puerto del Hambre in Chile (Clapperton et al., 1995) and Rio Rubens in Argentina (Markgraf and Huber, 2010), among others.

Biostratigraphic dates

Before dating by ^{14}C became available and more affordable, many records relied on the identification of biostratigraphic zones. Biostratigraphy is a branch of stratigraphy based on the study of fossils (Traverse, 1988; Bardossy and Fodor, 2013). Delimitated zones were interpreted as sequences of rocks that are characterized by a specific assemblage of fossil remains (Gladenkov, 2010). Each zone is a reflection of changing paleoecological settings different from the previous zone, identified by a set of characteristics such as taxon composition or abundance, or phylogenetic lines (Gladenkov, 2010). In general, stratigraphic schemes are still subject to constant adjustments, being updated by new records, improved dating, and taxonomic revision. Difficulties arise in the accurate delimitation of the boundaries of biostratigraphic zones. Furthermore, older records relied heavily on zonal matching without accurate chronological background and assuming synchronicity. Additionally, the zonation and biostratigraphy may depend on localized stratigraphic nomenclature and is sometimes not even directly applicable to adjacent areas. Finally, a biostratigraphic layer may have been defined using a sparse data set while depending heavily on correct taxonomy identification. Challenges of biostratigraphic correlation techniques are further explored in Punyasena et al. (2012) and Barossy and Fodor (2013).

Several biochronological schemes are used or under discussion in South America and describing their development (e.g. Van der Hammen, 1994; Van der Hammen and Hooghiemstra, 1995a) goes beyond the scope of this paper. Here we mention briefly some zones for NW-SA. Older records used presumably synchronous onsets of the Lateglacial as a reference point in time, such as numerous pollen records from the Valle de Lagunillas (González et al., 1966), Sierra Nevada (Van der Hammen, 1984), and Central Cordillera (Melief, 1985; Salomons, 1986). The transition of the Pleistocene/Holocene is often mentioned in diagrams, as is the YD. The onset of the Bølling/Allerød is less frequently used, whereas referring to and correlating regionally defined stadials and interstadials is more popular. For example, the “Guantiva interstadial” (Van der Hammen and González, 1965a; Van Geel and Van der Hammen, 1973) and “El Abra stadial” (Kuhry et al., 1993; Van der Hammen and Hooghiemstra, 1995b) are commonly used biostratigraphic dates within Colombia. These periods are considered to be an equivalent to the North Atlantic Allerød Interstadial and the Younger Dryas sequence, respectively (van der Hammen and Hooghiemstra, 1995b). Similarly in the tropical Venezuelan Andes, the “Anteojos” cold phase was proposed as equivalent to the cold reversal of the YD and as in some aspects comparable to El Abra (Rull et al., 2010).

Other dating techniques

An exceptional dating method was used at Ciama 2 in Brazil, through Optically Stimulated Luminescence (OSL) encompassing the period between the MIS3 (MIS5 ages were discarded) and the last millennium (de Oliveira et al., 2012). The same technique was used at the Potrok Aike lake in Patagonia. A 65 kyr long sediment core was recovered by the Potrok Aike Maar Lake Sediment Archive Drilling Project (PASADO; Recasens et al., 2012), where a combination of OSL, tephra, and ^{14}C was used to establish its chronology (Buylaert et al., 2013; Recasens et al., 2015). The pollen record from this multi-proxy study is to be published soon and will be an important comparison to other long cores from South America regarding late Quaternary climate variability.

There are two important records that serve in South America as a key reference for regional chronology testing, which are Fúquene-9C (Groot et al., 2014) and the MD03-2622 marine core from the Cariaco Basin (González et al., 2008). Both cores were analysed at high resolution (Fq-9C: 60 years; Cariaco: 350 years) and cover c. 284–27 and 68–28 kcal BP, respectively. Both sites, however, implement different kinds of age models, namely frequency analyses of arboreal pollen % and orbital tuning (Fq-9C) and tuning to reflectance curve of another marine core (Cariaco, which itself has been tuned to Hulu Cave in China). Long records, such as also from lake Titicaca (LT01-2B and LT01-3A; Hanselman et al., 2005, 2011; Fritz et al., 2007; Gosling et al., 2008, 2009), rely on advanced methods of orbital tuning for the older sections and are therefore not considered in this study for the recalibrated age model or star classification.

3.2 Reporting of ^{14}C measurements and corrections

Through the years the radiocarbon community has presented a series of papers indicating the proper way of reporting ^{14}C data (Stuiver and Polach, 1977; Mook and Van der Plicht, 1999; Reimer et al., 2004a). In the early days, the world’s laboratories reported all of their produced radiocarbon dates in the journal Radiocarbon, a journal then dedicated to compiling these overviews. Probably the earliest radiocarbon dates from the Neotropics can be found in Vogel and Lerman (1969), describing in detail dates produced from Cuba, Jamaica, Colombia, Guyana, Surinam, Peru, and Argentina. However, this system could not keep up with the increasing number of both laboratories and studies reporting radiocarbon dates. Since then the correct reporting of ^{14}C dates has relied completely on the experience and willingness of the researchers.

Measured radiocarbon concentrations require an additional correction due to mass fractionation of ^{14}C atoms during natural bio-geochemical processes (e.g. photosynthesis; Drake, 2014), and sample preparation and measurement (Wigley and Muller, 1981). This is a δ^{13}C-based correction which has a default value of -25 ‰ based on wood (Stuiver and Polach, 1977). In the Neotrop-ChronDB 1283 ^{14}C dates have reported fractionation corrections ranging from -42 to 30.2 ‰, but it is not always clear whether the authors implement any correction. This number represents a quarter of the total number of radiocarbon dates in the database, meaning that over 600 studies do not report this fractionation correction.

Studies specifying additional corrections such as the possible reservoir age are rare. Although organic material potentially presents this ^{14}C offset, it is rarely identified in terrestrial pollen records in the area of interest. For the marine reservoir correction, the marine calibration curves incorporate a global ocean reservoir correction of c. 400 years. Nevertheless, regional differences in reservoir values should be applied according to the Marine Calibration data set (http://www.calib.qub.ac.uk/marine). Some marine studies in the region implemented a fixed reservoir effect of 400 years (according to Bard, 1988) for marine dates, while others only mentioned the used version of the CALIB program. A handful of marine cores in Chile (MD07-3104; MD07-3107;

MD07-3088) estimate different local reservoir ages on calibrated ages from the IntCal calibration curve.

While Stuiver and Polach (1977) were the first to establish the conventions for reporting radiocarbon data, Reimer et al. (2004b) dealt with the growing use of postbomb ^{14}C and a corresponding new symbol in ^{14}C reporting. Correct postbomb ^{14}C reporting is problematic in the Neotropics. Negative ^{14}C ages are treated highly variably, from being totally discharged, titled "modern" or "too young" without specified ^{14}C value, or considered valid as the subtracted age from 1950 AD (resulting in any age estimate between 2014 and 1950). Also postbomb dates as percentage modern carbon values (% pMC, normalized to 100 %) or "fraction of modern" (F14C, normalized to 1) sometimes mislead uninformed authors to be acceptable ^{14}C ages. At this moment, only one pollen record is known to report the F14C value with the corresponding postbomb curve as proposed by Reimer et al. (2004b), namely Quistococha in Peru (Roucoux et al., 2013). Laboratory sample or identification numbers (ID), which are given to the samples by the radiocarbon dating laboratory, enable the laboratory to be identified and should always be published alongside the ^{14}C measurements (Grimm et al., 2014; See the long version of the workshop report published at http://www.pages-igbp.org/calendar/127-pages/826-age-models-chronologies-and-databases).

3.3 Current age models and calibration curves

The relatively recent development of freely available computing packages has as a consequence that there is a large bulk in the Neotrop-ChronDB without any age model ($n = 457$), where most radiocarbon dates are simply plotted along the pollen record without an explicit age-model. The most common age model ($n = 298$) is based on the simplest design, namely the linear interpolation between the dated levels, even though this is hardly a realistic reflection of the occurred sedimentation history (Bennett, 1994; Blaauw and Heegaard, 2012). Polynomial regression methods ($n = 31$) and the smooth spline ($n = 12$) are becoming increasingly popular but mostly in international peer-reviewed journals compared to national publications. In the latter linear interpolation is more persistent. In six cases, age models and calibrated ages were created by the authors without further explanation. In a significant number of cases, age–depth modelling was performed with uncalibrated ^{14}C ages, which does not produce valid results due to the non-linear relationship between radiocarbon years and calendar years.

The unclear geographical boundary between the NH and SH calibration curve has led to finding pollen records from the same region using curves from either side of the hemisphere. This is seen in the highland of Peru and Bolivia where the boundary between the IntCal13 (NH-curve) and SHCal13 (SH-curve) realms is still unclear and even causing the use of different calibration curves for the same lake. Several Bolivian lowland studies explain the influence of the southern range of the ITZC migration and therefore justify the use of the northern calibration curve (Mayle et al., 2000; Maezumi et al., 2015). The existence of a ^{14}C age difference of up to a few decades between the NH and SH has been discussed in the literature, e.g. McCormac et al. (1998), Turney and Palmer (2007), and Hogg et al. (2013). This temporal uncertainty should be taken into account and it would be useful if authors address the choice of calibration curve in the publications.

Statistical approaches to chronological modelling have expanded dramatically over the last two decades. Advances in computer processing power and methodology have now enabled Bayesian age models which require millions of data calculations – a method which would not have been possible before. The development of such freely available Bayesian age-modelling packages as "OxCal" (Bronk Ramsey, 1995), "BCal" (Buck et al., 1999), "Bchron" (Parnell et al., 2008), "BPeat" (Blaauw and Christen, 2005) and "Bacon" (Blaauw and Christen, 2011), has greatly advanced the science. To our knowledge, however, so far there has been only a single application of Bayesian methods for age modelling in South America, namely at Papallacta 1-08 (Ledru et al., 2013b). The authors included a priori information on sedimentation rates and tephra layers to construct the age model and consequently derive the best age for an uncertain tephra deposition. The use of the sedimentation conditions is a highly relevant component for age model development but rarely seen to be taken into account. Plotting the sediment record next to the age model would complement greatly the interpretation of the chronology (as shown as an example in Fig. 2).

Combining prior information from the sequences with the geochronological data is the basis of a Bayesian approach to construct an age–depth model (Blaauw and Heegaard, 2012). The current lack of Bayesian-based age models in the Neotropics could be due to classic age–depth models (based on linear interpolation, smooth splines or polynomial regressions) being regarded as the most realistic models, or to the usefulness of Bayesian methods not yet having been explored. Each model comes inherent with errors and uncertainties (Telford et al., 2004), and each method consists of different approaches to address them. Linear interpolation for example provides reasonable estimates for ages and the gradients between adjacent pairs of points, but only includes the errors at the individual age-determinations and does not consider uncertainties and additional measurements (Blaauw and Heegaard, 2012). A wider range of possible errors can be included in "mixed-effect models", while Bayesian age–depth modelling produces more realistic estimates of ages and uncertainties. Although we did not engage in Bayesian modelling in this study, even if researchers find themselves without much prior knowledge of regional accumulation rates, Bayesian methods could well provide more realistic estimates of chronological uncertainties than classical methods (Blaauw et al., 2016). Researchers are encouraged to make use of the freely available character of the

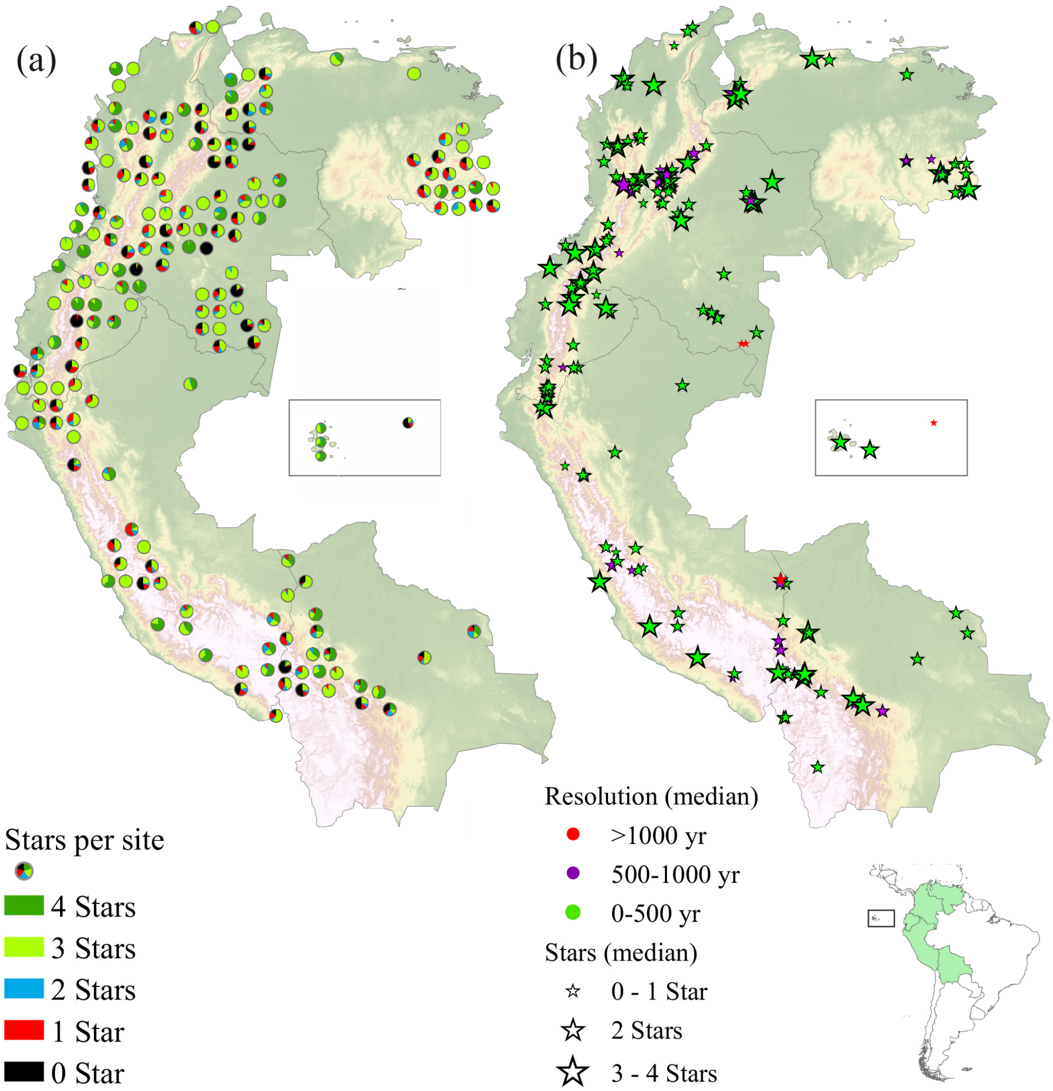

Figure 3. Temporal uncertainty assessment on recalibrated control points and age models in northwest South America. **(a)** Number of stars assigned to samples of recalibrated chronologies (normalized to 100 %). **(b)** Median value of stars and resolution of the recalibrated chronologies. The small window displays the region of the Galapagos Islands and the marine core ODP677.

Bayesian software packages to test multiple age–depth models, compare models that best approximate their knowledge of the sediment conditions, and address these comparisons in their studies.

3.4 Age model evaluation of northwest South America (NW-SA)

From a total of 292 pollen records revised, 242 preliminary age models were regenerated based on the provided dates. The other 50 pollen records either presented a lack of multiple geochronological dates or had too many chronological problems. During the process of adjustments of the age models for hiatus, outliers, and slumps, another nine pollen records were rejected as no reliable models could be produced. In 125 cases both linear interpolation and spline could be implemented, requiring at least four valid geochronological dates for the latter. The median number of stars for recalibrated chronologies of NW-SA is 3, which we consider surprisingly high.

Based on the 233 checked and recalibrated age models from NW-SA (Table 1), the sample resolution (maximum, minimum, median, and mean value) was estimated per pollen site and for the entire NW-SA. The resolution was calculated as the time between two consecutive depths with proxy information (sample depths). Minimum resolutions range from 10 years to 1 kyr, compared to the maximum value between 5 and 36 kyr (mostly due to extrapolations). The overall sample resolution estimates indicate that the average temporal resolution of this multi-site synthesis is c. 240 years, a res-

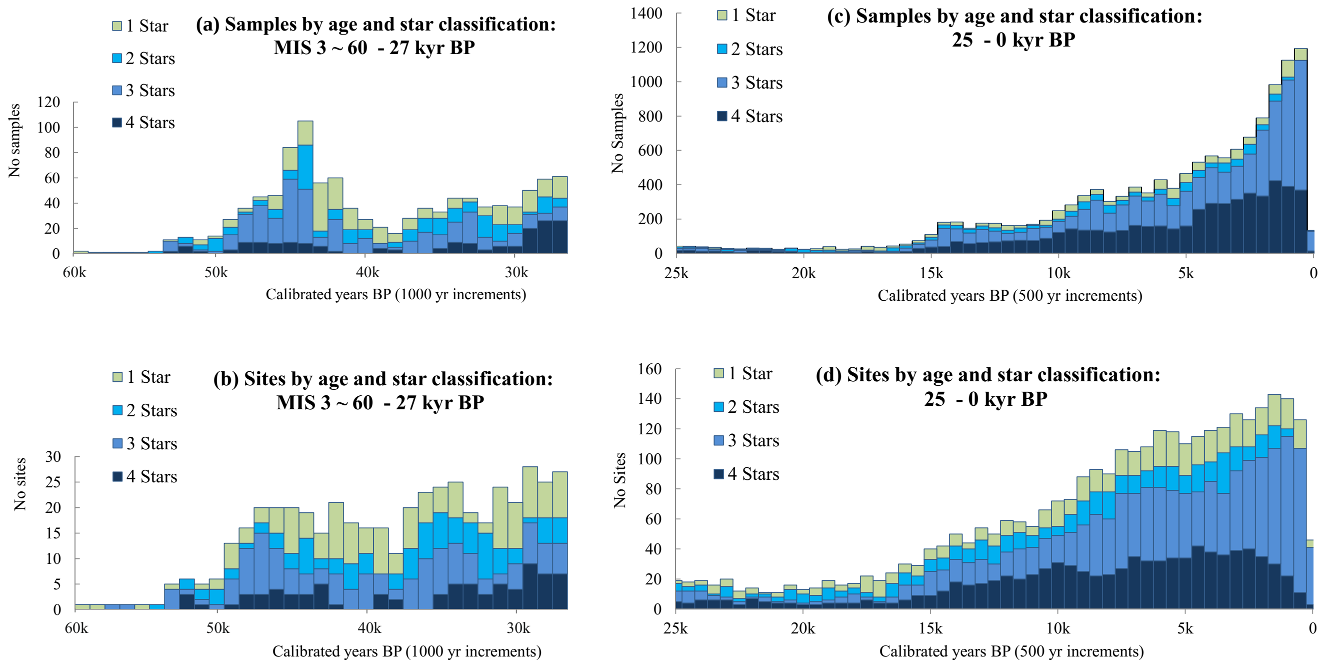

Figure 4. Histograms depicting the star classification outcome on sample level **(a, c)** and sites **(b, d)** for the last 60 kcal BP. Histograms **(a)** and **(b)** depict the MIS 3 (at 1000 year time bins) and histograms C and D the last 25 kcal (at 500 year bins). The height of the bar indicates the number of samples or sites with a certain number of stars. The different colours illustrate the number of stars assigned for that time bin. Samples and sites beyond 60 kcal BP were not presented due to the very low number of sites available (Fig. 5).

olution that allows analyses of ecological responses to sub-millennial-scale climate change. From a synoptic perspective, the NW-SA pollen records do not show spatial clustering based on the assigned stars (Fig. 3a). In other words, chronologies with good and poor control point density (number of control points per unit time) can be found along all the different elevational and latitudinal ranges. The best context to the star classification system can be given in conjunction with the sample resolution estimates as chronologies might present high sample resolution but poor chronological backup, and vice versa. What is evident as a result of the recalibrated age models is the high number of pollen records within the 0–500 years resolution with relatively high temporal quality (Fig. 3b).

3.5 Time window evaluation

MIS 5 (c. 130–70 kcal BP)

Within this study, this time window is represented by only 4 pollen records from two lakes, namely from Lake Titicaca LT01-2B and LT01-3A (Hanselman et al., 2005, 2011; Fritz et al., 2007; Gosling et al., 2008, 2009), and Fúquene 3 and 7 (Mommersteeg, 1998; Van der Hammen and Hooghiemstra, 2003; Vélez et al., 2003; Bogotá-Angel et al., 2011). Research into millennial-scale climate variability is difficult during this time window, as sample resolution varies greatly from a few centuries to several millennia. For periods older than 65 kcal BP, mean resolution shifts around 2000 years per sample with a star classification of mostly 0–1. Temporal uncertainty is high due to extrapolation of age models through a limited number of control points and additional hiatus difficulties.

MIS 3 (60–27 kcal BP)

MIS 3 is better represented in samples (Fig. 4a) and sites (Fig. 4b), and shows a wider variation in the star classification. The median number of 1 star still indicates a relatively poor control point density in the chronologies and therefore high temporal uncertainty. This time window is characterized by relatively older sites with reduced chronological quality even though overall resolution is at centennial timescale (430 years).

LGM, H1, and YD/Holocene transition

The vast majority of chronologies cover the Holocene and Lateglacial time intervals because they have been established from lakes formed after the last glaciation. Consistent with the large number of pollen records that reflect the Holocene (Flantua et al., 2015), the highest density of palynological sampling covers the last 10 kcal (Fig. 4c). Most samples fall within the category of presenting “good” control point density, namely either 3 or 4, just as the individual sites evaluated (Fig. 4d). There is an overall good point density in the

NW-SA sites that cover the YD/Holocene transition but the Last Glacial Maximum (LGM) and H1 are represented by far fewer records with varying temporal quality.

The integration of the recalibrated chronologies and the estimated sample resolutions indicate the essential value of the existing radiocarbon calibration curves: there is a clear threshold at c. 55 kcal BP (beyond the extent of the current ^{14}C calibration curves) from where the control point density and resolution currently do not support research on millennial timescales, as sample resolutions are on average 1300 years and temporal uncertainty high (Fig. 5).

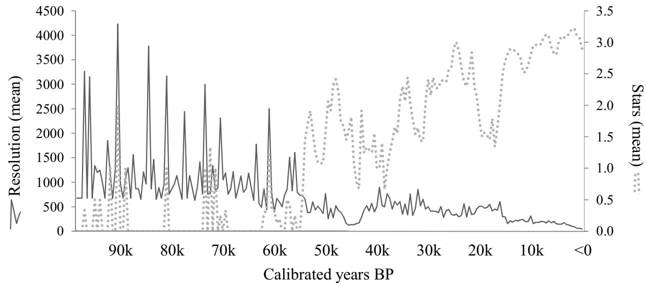

Figure 5. Changing mean sample resolution (left) and mean number of stars (right) of the pollen database of northwest South America during the period 100 kcal to −50 cal yr BP.

4 Discussion

4.1 Chronological data reporting

The relevance of publishing details on the sample, laboratory and reference numbers, provenance and reservoir correction details seems underestimated by authors in many cases. Studies with insufficient chronology reporting undermine the consistency and credibility of the results presented, and weaken the value of the radiocarbon dates. Furthermore, considering the expanding palynological research (Flantua et al., 2015), papers with deviations in chronology reporting will most likely not be used within the context of multi-proxy comparisons or more expanded regional synthesis efforts. Additionally, paleo-vegetation records with proper chronology details are frequently scanned by the archaeological community to correlate human and environmental dynamics (Aceituno et al., 2013; Delgado et al., 2015). Equally relevant are paleoecological records with solid chronologies for late Pleistocene understanding of megafaunal extinctions (Barnosky et al., 2004). Missing out on the chronology description is without doubt an unnecessary way to affect the credibility and citation rate of any study. A top-down approach to improve radiocarbon reporting initiates at the journals demanding complete and correct chronology information. Not less important are the reviewers in critically evaluating the presented age models. Sources to remain updated on the requirements of dating reporting are numerous (e.g. see Millard, 2014), but specific details can be online accessed through http://www.c14dating.com/publication.html. Additional recommendations can be found in Blaauw and Heegaard (2012) and from the "Neotoma Age models, chronologies, and databases workshop" in Grimm et al. (2014).

4.2 Temporal uncertainty assessment of chronologies

The importance of high-resolution records but especially temporal quality has been illustrated through the development of updated age models and control point density assessments. Compared to the implementation of the method in the EPD (Giesecke et al., 2014), there is a higher proportion of samples and sites in the last 5 kcal BP in NW-SA. The most common sample resolution in the EPD is between 50 and 250 years, while the NW-SA has a mean resolution of 235 years. This resolution is actually higher than we expected and this could be due to several reasons. First of all, during the age modelling procedure, chronologies with too many disturbing features were not used, implementing a first selection towards the best possible age models. Secondly, to assign 10 cm sample intervals for older pollen records to unknown sample depths could be an overestimation for sample resolution (many older records were sampled at > 20 cm). Thirdly, there are several very high-resolution sites that cover significant time periods overpassing greatly in sample numbers the sites with relatively low temporal resolution. Any calculation based on multi-site information should use a median value instead of the mean value (Fig. 3), which is less sensitive to extremes. Nonetheless, the general tendency is that pollen records in NW-SA are improving chronological settings with high sample resolution on centennial timescales.

Until now, differences in resolution and chronological quality between older and newer sites have hampered the ongoing discussion on the rapid climatic shifts such as the YD. A synchronous similar climate reversal at the YD is not evident throughout South America. Differences in magnitude have been observed between Venezuela and Colombia (Rull et al., 2010), while pollen records at relatively close distances in Peru/Bolivia are considered both different in timing and expression (Hansen, 1995; Paduano et al., 2003; Bush et al., 2005). This points again to the danger of using assumed synchronous events to align archives across a region – e.g. Israde-Alcántara et al. (2012a), who align several poorly dated sites in Latin America to circularly argue for a YD comet impact (Blaauw et al., 2012; Israde-Alcántara et al., 2012b). New studies on correlating biostratigraphic patterns with improved chronology are important as they can identify possible long-distance synchronicity of climate signals, but at the same time display their own local signature when supported by high-resolution data. Therefore, additional well-dated records have a high potential of contributing to this current discussion (e.g. Rull et al., 2010; Montoya et al., 2011a). However, advanced tools to assess leads, lags, and synchronicity in paleorecords are still urgently needed

(Blockley et al., 2012; Seddon et al., 2014) while only few case studies have yet explored the available tools (Blaauw et al., 2007, 2010; Parnell et al., 2008). As long as the discussion consists of correlating poorly dated events, new hypotheses based on assumed synchronous events fail to provide additional insights to current questions.

5 Conclusions and recommendations

This paper presents an overview on chronological dating and reporting in the Neotropics, based on a new Geochronological Database consisting of 5116 dates from 1097 pollen records. To support centennial- to millennial-scale climate research, the temporal resolution and quality of chronologies from 292 pollen records in the northwest South America were assessed based on the method proposed by Giesecke et al. (2014). This method includes associated evaluations of uncertainties for the inferred sample ages and age models, and is suitable for a wide range of proxies. Over 300 publications were evaluated and new age models were constructed based on new calibration curves implementing either linear interpolation or (preferentially) smoothing splines. Using the R-code CLAM these newly derived chronologies formed the basis to estimate the sample error from the uncertainties of control points density in the age model. These sample-age confidences are assigned so-called “stars” and this semi-quantitative star classification system is discussed for different time windows such as MIS5, MIS3, the LGM and the YD. Based on these classifications, uncertainties and age control requirement are discussed for research into millennium-scale climate variability. This provides a general-purpose chronology fit for most continental-scale questions and multi-proxy comparisons of temporal uncertainties.

Finally, we address specific fields of improvements for chronological reporting in pollen records. It is important for authors to report at the necessary detail the chronology of their sediment core because it is the spinal core of the interpretation. Furthermore, due to the spatial coverage of the LAPD, for the increasing number of questions requiring multi-proxy comparison, sites can be selected based on their considered usefulness for models. There is a lose–lose situation by not including potentially important sites just because the chronology is insufficiently presented in the paper. The number of recent sites that present incomplete descriptions of their presumed age model is striking, leaving out information such as depths, calibration method, and even only presenting calibrated dates without further explanation.

The discussion on detecting synchronicity of rapid climate change events should pass from correlating chronologies with incompatible resolution and temporal quality, to understanding the causes of leads and lags between geographically different localities with high chronological settings. Future studies on detecting rapid climate changes in a multi-site and multi-proxy context can be supported in their site selection procedure by the method presented in Giesecke et al. (2014). The method here implemented is fully suitable for other regions and proxies that deal with geochronological dating. As the Neotrop-ChronDB currently covers a much larger area, similar exercises can be done for other regions.

The vast number of sites reflecting the last 10 kyr BP with high samples densities and well-presented chronologies offer great opportunities for currently running working groups, like the International Biosphere Geosphere Programme/Past Global Change – 6k (IGBP-Pages 6k, www.pages-igbp.org/workinggroups/landcover6k/intro) and Long-Term climate REconstruction and Dynamics of South America – 2k (LOTRED-SA-2k; www.pages-igbp.org/workinggroups/lotred-sa/intro). Both multi-proxy working groups address human–environmental interactions in which pollen records in Central and South America are a vital source of information (Flantua et al., 2016).

The produced chronologies in this paper do not substitute the validity and interpretation of the authors’ original chronology, but serve the purpose to present an overview of the current potential temporal resolution and quality, and contribute to the discussion on age model assessments. Data control often varies throughout the record, therefore we emphasize the recommendation provided by Giesecke et al. (2014) that the star classification should be used in conjunction with the propagation of age uncertainty from the dates through the age model. The success of the use of Bayesian methods depends partly on the background knowledge of the researchers (e.g. knowledge of accumulation rates of comparable sites in the region) to adjust the age model accordingly. As we do not pretend to have this a priori information to make full use of the results obtained from Bayesian modelling, we think that it is more appropriate to motivate researchers to consider this method for future studies. Users should always check the original papers and address questions on the chronologies to the main authors. At the same time, calibration curves as well as age-modelling methods will continue to be updated, so age models should rather be considered as inherent to a dynamic process of continuous improvement, rather than a static side component of a paleoecological record. For that purpose, we would like to emphasize that there are increasingly more resources available for providing Digital Object Identifications (DOI) to stand-along data sets, figures and variable media to obtain the rights to be cited as any other literature reference (e.g. Fig Share: http://figshare.com; Data Dryad: http://datadryad.org/). Authors considering an updated version of an age model could evaluate these resources, as well as for unpublished pollen data sets

Supplementary information from this paper (all outcomes, R-scripts, and manual in English and Spanish) is available at figshare: https://figshare.com/s/0e9afb8fe758a0e6e8c8.

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References

Abarzúa, A. M. and Moreno, P. I.: Changing fire regimes in the temperate rainforest region of southern Chile over the last 16 000 yr, Quaternary Res., 69, 62–71, doi:10.1016/j.yqres.2007.09.004, 2008.

Aceituno, F. J., Loaiza, N., Delgado-Burbano, M. E., and Barrientos, G.: The initial human settlement of northwest South America during the Pleistocene/Holocene transition: synthesis and perspectives, Quat. Int., 301, 23–33, doi:10.1016/j.quaint.2012.05.017, 2013.

Álvarez-Solas, J., Montoya, M., Ritz, C., Ramstein, G., Charbit, S., Dumas, C., Nisancioglu, K., Dokken, T., and Ganopolski, A.: Heinrich event 1: an example of dynamical ice-sheet reaction to oceanic changes, Clim. Past, 7, 1297–1306, doi:10.5194/cp-7-1297-2011, 2011.

Andriessen, P. A. M., Helmens, K. F., Hooghiemstra, H., Riezebos, P. A., and Van der Hammen, T.: Pliocene-Quaternary chronology of the sediments of the high plain of Bogotá, Eastern Cordillera, Colombia, Quaternary Sci. Rev., 12, 483–501, 1994.

Austin, W. E. N., Hibbert, F. D., Rasmussen, S. O., Peters, C., Abbott, P. M., and Bryant, C. L.: The synchronization of palaeoclimatic events in the North Atlantic region during Greenland Stadial 3 (ca 27.5 to 23.3 kyr b2k), Quaternary Sci. Rev., 36, 154–163, doi:10.1016/j.quascirev.2010.12.014, 2012.

Baker, P. A., Rigsby, C. A., Seltzer, G. O., Fritz, S. C., Lowenstein, T. K., Bacher, N. P., and Veliz, C.: Tropical climate changes at millennial and orbital timescales on the Bolivian Altiplano, Nature, 409, 698–701, 2001a.

Baker, P. A., Seltzer, G. O., Fritz, S. C., Dunbar, R. B., Grove, M. J., Tapia, P. M., Cross, S. L., Rowe, H. D., and Broda, J. P.: The history of South American tropical precipitation for the past 25 000 years, Science, 291, 640–643, doi:10.1126/science.291.5504.640, 2001b.

Bakker, J.: Tectonic and climatic controls on Late Quaternary sedimentary processes in a neotectonic intramontane basin (the Pitalito Basin, South Colombia), Ph.D. dissertation, Agricultural University Wageningen, Wageningen, The Netherlands, 1990.

Bakker, J., Moscol Olivera, M., and Hooghiemstra, H.: Holocene environmental change at the upper forest line in northern Ecuador, Holocene, 18, 877–893, doi:10.1177/0959683608093525, 2008.

Bakker, J. G. and Salomons, J. B.: A palaeoecological record of a volcanic soil sequence in the Nevado del Ruiz area, Colombia, Rev. Palaeobot. Palynol., 60, 149–163, 1989.

Bard, E.: Correction of accelerator mass spectrometry ^{14}C ages measured in planktonic foraminifera: paleoceanographic implications, Paleoceanography, 3, 635–645, doi:10.1029/PA003i006p00635, 1988.

Bardossy, G. and Fodor, J. (Eds.): Evaluation of Uncertainties and Risks in Geology: New Mathematical Approaches for their Handling, Springer-Verlag, Berlin Heidelberg, Germany, 2013.

Barnosky, A. D., Koch, P. L., Feranec, R. S., Wing, S. L., and Shabel, A. B.: Assessing the causes of late Pleistocene extinctions on the continents, Science, 306, 70–75, doi:10.1126/science.1101476, 2004.

Behling, H.: Tropical mountain forest dynamics in Mata Atlantica and northern Andean biodiversity hotspots during the late Quaternary, in: The Tropical Mountain Forest – Patterns and Processes in a Biodiversity Hotspot, edited by: Gradstein, S. R., Homeier, J., and Gansert, D. Universitätsverlag Göttingen, Göttingen, Germany, 25–33, 2008.

Behling, H. and Hooghiemstra, H.: Late Quaternary palaeoecology and palaeoclimatology from pollen records of the savannas of the Llanos Orientales in Colombia, Palaeogeogr. Palaeoecol., 139, 251–267, 1998.

Behling, H. and Hooghiemstra, H.: Environmental history of the Colombian savannas of the Llanos Orientales since the Last Glacial Maximum from lake records El Pinal and Carimagua, J. Paleolim., 21, 461–476, 1999.

Behling, H. and Hooghiemstra, H.: Holocene Amazon rainforest-savanna dynamics and climatic implications: high-resolution pollen record from Laguna Loma Linda in eastern Colombia, J. Quaternary Sci., 15, 687–695, 2000.

Behling, H., Hooghiemstra, H., and Negret, A.: Holocene history of the Chocó rain forest from Laguna Piusbi, Southern Pacific lowlands of Colombia, Quaternary Res., 50, 300–308, 1998a.

Behling, H., Negret, A. J., and Hooghiemstra, H.: Late Quaternary vegetational and climatic change in the Popayán region, southern Colombian Andes, J. Quaternary Sci., 13, 43–53, 1998b.

Behling, H., Berrío, J. C., and Hooghiemstra, H.: Late Quaternary pollen records from the middle Caquetá river basin in central Colombian Amazon, Palaeogeogr. Palaeoecol., 145, 193–213, 1999.

Bennett, K. D.: Confidence intervals for age estimates and deposition times in late-Quaternary sediment sequences, Holocene, 4, 337–348, doi:10.1177/095968369400400401, 1994.

Berrío, J. C.: Historia de clima y vegetación del Holocene medio y superior, a partir del registro palinologico en la laguna de Ubaque, Cundinamarca, Master thesis, Universidad de la Javeriana, Bogotá, Colombia, 1995.

Berrío, J. C.: Lateglacial and Holocene vegetation and climate change in lowland Colombia, Ph.D. dissertation, University of Amsterdam, Amsterdam, The Netherlands, 2002.

Berrìo, J. C., Arbeláez, M. V., Duivenvoorden, J. F., Cleef, A. M., and Hooghiemstra, H.: Pollen representation and successional vegetation change on the sandstone plateau of Araracuara, Colombian Amazonia, Rev. Palaeobot. Palynol., 126, 163–181, doi:10.1016/S0034-6667(03)00083-6, 2003.

Berrío, J. C., Behling, H., and Hooghiemstra, H.: Tropical rainforest history from the Colombian Pacific area: a 4200-year pollen record from Laguna Jotaordó, Holocene, 10, 749–756, doi:10.1191/09596830094999, 2000a.

Berrío, J. C., Hooghiemstra, H., Behling, H., and Van der Borg, K.: Late Holocene history of savanna gallery forest from Carimagua area, Colombia, Rev. Palaeobot. Palynol., 111, 295–308, 2000b.

Berrío, J. C., Boom, A., Botero, P. J., Herrera, L. F., Hooghiemstra, H., Romero, F., and Sarmiento, G.: Multi-disciplinary evidence of the Holocene history of a cultivated floodplain area in the wetlands of Northern Colombia, Veg. Hist. Archaeobot., 10, 161–174, 2001.

Berrío, J. C., Hooghiemstra, H., Behling, H., Botero, P., and Van der Borg, K.: Late-Quaternary savanna history of the Colombian Llanos Orientales from Lagunas Chenevo and Mozambique: a transect synthesis, Holocene, 12, 35–48, doi:10.1191/0959683602hl518rp, 2002a.

Berrío, J. C., Hooghiemstra, H., Marchant, R., and Rangel, O.: Late-glacial and Holocene history of the dry forest area in the south Colombian Cauca Valley, J. Quaternary Sci., 17, 667–682, doi:10.1002/jqs.701, 2002b.

Blaauw, M.: Methods and code for "classical" age-modelling of radiocarbon sequences, Quat. Geochronol., 5, 512–518, doi:10.1016/j.quageo.2010.01.002, 2010.

Blaauw, M.: Out of tune: the dangers of aligning proxy archives, Quaternary Sci. Rev., 36, 38–49, doi:10.1016/j.quascirev.2010.11.012, 2012.

Blaauw, M. and Christen, J.A.: Radiocarbon peat chronologies and environmental change, J. R. Stat. Soc. Ser. C Appl., 54, 805–816, doi:10.1111/j.1467-9876.2005.00516.x, 2005.

Blaauw, M. and Christen, J. A.: Flexible paleoclimate age-depth models using an autoregressive gamma process, Bayesian Anal., 6, 457–474, doi:10.1214/ba/1339616472, 2011.

Blaauw, M. and Heegaard, E.: Estimation of age-depth relationships, in: Tracking environmental change using lake sediments, edited by: Birks, H. J. B., Lotter, A. F., Juggins, S., and Smol, J. P., Springer Netherlands, Dordrecht, the Netherlands, 379–413, 2012.

Blaauw, M., Christen, J. A., Mauquoy, D., Van der Plicht, J., and Bennett, K. D.: Testing the timing of radiocarbon-dated events between proxy archives, Holocene, 17, 283–288, doi:10.1177/0959683607075857, 2007.

Blaauw, M., Wohlfarth, B., Christen, J. A., Ampel, L., Veres, D., Hughen, K. A., Preusser, F., and Svensson, A.: Were last glacial climate events simultaneous between Greenland and France? A quantitative comparison using non-tuned chronologies, J. Quaternary Sci., 25, 387–394, doi:10.1002/jqs.1330, 2010.

Blaauw, M., Holliday, V. T., Gill, J. L., and Nicoll, K.: Age models and the Younger Dryas impact hypothesis, P. Natl. Acad. Sci. USA, 109(, 2240, doi:10.1073/pnas.1206143109, 2012.

Blaauw, M., Christen, J. A., Bennett, K. D., and Reimer, P. J.: Double the dates and go for Bayes – impacts of model choice, dating density and quality on chronologies, Geology, submitted, 2016.

Blockley, S. P. E., Lane, C. S., Turney, C. S. M., and Bronk Ramsey, C.: The INTegration of Ice core, MArine and TErrestrial records of the last termination (INTIMATE) 60 000 to 8000 BP, Quaternary Sci. Rev., 36, 1, doi:10.1016/j.quascirev.2011.10.001, 2012.

Blois, J. L., Williams, J. W., Grimm, E. C., Jackson, S. T., and Graham, R. W.: A methodological framework for assessing and reducing temporal uncertainty in paleovegetation mapping from late-Quaternary pollen records, Quaternary Sci. Rev., 30, 1926–1939, doi:10.1016/j.quascirev.2011.04.017, 2011.

Bogotá-Angel, R.: Pleistocene centennial-scale vegetational, environmental and climatic change in the Colombian Andes: based on biotic and abiotic proxy analyses from Lake Fúquene sediments, Ph.D. dissertation, University of Amsterdam, Amsterdam, The Netherlands, 2011.

Bogotá-Angel, R. G., Groot, M. H. M., Hooghiemstra, H., Lourens, L. J., Van der Linden, M., and Berrio, J. C.: Rapid climate change from north Andean Lake Fúquene pollen records driven by obliquity: implications for a basin-wide biostratigraphic zonation for the last 284 ka, Quaternary Sci. Rev., 30, 3321–3337, doi:10.1016/j.quascirev.2011.08.003, 2011.

Bosman, A. F., Hooghiemstra, H., and Cleef, A. M.: Holocene mire development and climatic change from a high Andean Plantago rigida cushion mire, Holocene, 4, 233–243, doi:10.1177/095968369400400302, 1994.

Bowman, S. (Ed.): Radiocarbon dating, University of California Press/British Museum, Berkeley and Los Angeles, USA, 1990.

Bradbury, J., Leyden, B., Salgado-Labouriau, M. L., Lewis, W. M., Schubert, C., Binford, M. W., Frey, D. G., Whitehead, D. R., and Weibezahn, F. H.: Late Quaternary environmental history of Lake Valencia, Venezuela, Science, 214, 1299–1305, 1981.

Branch, N. P., Kemp, R. A., Silva, B., Meddens, F. M., Williams, A., Kendall, A., and Pomacanchari, C. V.: Testing the sustainability and sensitivity to climatic change of terrace agricultural systems in the Peruvian Andes: a pilot study, J. Archaeol., 34, 1–9, doi:10.1016/j.jas.2006.03.011, 2007.

Brauer, A., Hajdas, I., Blockley, S. P. E., Bronk Ramsey, C., Christl, M., Ivy-Ochs, S., Moseley, G. E., Nowaczyk, N. N., Rasmussen, S. O., Roberts, H. M., Spötl, C., Staff, R. A., and Svensson, A.: The importance of independent chronology in integrating records of past climate change for the 60–8 ka INTIMATE time interval, Quaternary Sci. Rev., 106, 47–66, doi:10.1016/j.quascirev.2014.07.006, 2014.

Brenner, M. and Binford, M. W.: A sedimentary record of human disturbance from Lake Miragoane, Haiti, J. Paleolimnol., 1, 85–97, 1988.

Bronk Ramsey, C.: Radiocarbon calibration and analyses of stratigraphy: the OxCal Program, Radiocarbon, 37, 425–430, 1995.

Bronk Ramsey, C., Housley, R. A., Lane, C. S., Smith, V. C. and Pollard, A. M.: The RESET tephra database and associated analytical tools, Quaternary Sci. Rev., 118, 33–47, doi:10.1016/j.quascirev.2014.11.008, 2015.

Brunschön, C. and Behling, H.: Late Quaternary vegetation, fire and climate history reconstructed from two cores at Cerro Toledo, Podocarpus National Park, southeastern Ecuadorian Andes, Quaternary Res., 72, 388–399, doi:10.1016/j.yqres.2009.07.001, 2009.

Brunschön, C. and Behling, H.: Reconstruction and visualization of upper forest line and vegetation changes in the Andean depression region of southeastern Ecuador since the last glacial maximum – A multi-site synthesis, Rev. Palaeobot. Palynol., 163, 139–152, doi:10.1016/j.revpalbo.2010.10.005, 2010.

Brunschön, C., Haberzettl, T., and Behling, H.: High-resolution studies on vegetation succession, hydrological variations, anthropogenic impact and genesis of a subrecent lake in southern Ecuador, Veg. Hist. Archaeobot., 19, 191–206, doi:10.1007/s00334-010-0236-4, 2010.

Buck, C. E., Christen, J. A. and James, G. N.: BCal: An online Bayesian radiocarbon calibration tool, Internet Archaeol. 7, available at: http://intarch.ac.uk/journal/issue7/buck/ (last access: January 2015), 1999.

Burbridge, R. E., Mayle, F. E., and Killeen, T. J.: Fifty-thousand-year vegetation and climate history of Noel Kempff Mercado National Park, Bolivian Amazon, Quaternary Res., 61, 215–230, doi:10.1016/j.yqres.2003.12.004, 2004.

Bush, M. B. and Colinvaux, P. A.: A 7000-year pollen record from the Amazon lowlands, Ecuador, Vegetatio, 76, 141–154, 1988.

Bush, M. B., Colinvaux, P. A., Wiemann, M. C., Piperno, D. R., and Liu, K.-B.: Late Pleistocene temperature depression and vegetation change in Ecuadorian Amazonia, Quaternary Res., 34, 330–345, 1990.

Bush, M. B., Silman, M. R., and Urrego, D. H.: 48 000 years of climate and forest change in a biodiversity hot spot, Science, 303, 827–829, doi:10.1126/science.1090795, 2004.

Bush, M. B., Hansen, B. C. S., Rodbell, D. T., Seltzer, G. O., Young, K. R., León, B., Abbott, M. B., Silman, M. R., and Gosling, W. D.: A 17 000-year history of Andean climate and vegetation change from Laguna de Chochos, Peru, J. Quaternary Sci., 20, 703–714, doi:10.1002/jqs.983, 2005.

Bush, M. B., Silman, M. R., and Listopad, C. M. C. S.: A regional study of Holocene climate change and human occupation in Peruvian Amazonia: Amazonian climate change and settlement, J. Biogeogr., 34, 1342–1356, doi:10.1111/j.1365-2699.2007.01704.x, 2007a.

Bush, M. B., Silman, M. R., de Toledo, M. B., Listopad, C., Gosling, W. D., Williams, C., de Oliveira, P. E., and Krisel, C.: Holocene fire and occupation in Amazonia: records from two lake districts, Philos. T. Roy. Soc. B, 362, 209–218, doi:10.1098/rstb.2006.1980, 2007b.

Buylaert, J.-P., Murray, A. S., Gebhardt, A. C., Sohbati, R., Ohlendorf, C., Thiel, C., Wastegård, S., and Zolitschka, B.: Luminescence dating of the PASADO core 5022-1D from Laguna Potrok Aike (Argentina) using IRSL signals from feldspar, Quaternary Sci. Rev., 71, 70–80, doi:10.1016/j.quascirev.2013.03.018, 2013.

Cardenas, M. L., Gosling, W. D., Sherlock, S. C., Poole, I., Pennington, R. T., and Mothes, P.: The response of vegetation on the Andean flank in western Amazonia to Pleistocene climate change, Science, 331, 1055–1058, doi:10.1126/science.1197947, 2011.

Cardona-Velásquez, L. C. and Monsalve, C. A.: Evidencias paleoecológicas del manejo del bosque subandino. Ocupaciones humanas durante el Holoceno en la cuenca media del río Porce (Antioquia, Colombia), Boletín de Antropología, 23, 229-258, 2009.

Castañeda Riascos, I. C.: Paleoecología de alta resolución del Holoceno (11000 Años), en el Páramo de Belmira, Antioquia (Colombia), Master thesis, Universidad Nacional de Colombia, Medellín, Colombia, 2013.

Castillo, N., Aceituno, J., Cardona, L. C., García, D., Pino, J., Forero, J., and Gutierrez, J.: Entre el bosque y el río, 10 000 años de historia en el Valle Medio del río Porce, Universidad de Antioquia – Empresas Públicas de Medellín, Medellín, Colombia, 2002.

Chambers, F. M., Mauquoy, D., Brain, S. A., Blaauw, M., and Daniell, J. R. G.: Globally synchronous climate change 2800 years ago: Proxy data from peat in South America, Earth Planet. Sci. Lett., 253, 439–444, doi:10.1016/j.epsl.2006.11.007, 2007.

Chepstow-Lusty, A. J., Bennett, K. D., Fjeldsa, J., Kendall, A., Galiano, W., and Herrera, A. T.: Tracing 4,000 years of environmental history in the Cuzco area, Peru, from the pollen record, Mt. Res. Dev., 18, 159–172, doi:10.2307/3673971, 1998.

Chepstow-Lusty, A. J., Bush, M. B., Frogley, M. R., Baker, P. A., Fritz, S. C., and Aronson, J.: Vegetation and climate change on the Bolivian Altiplano between 108 000 and 18 000 yr ago, Quaternary Res., 63, 90–98, doi:10.1016/j.yqres.2004.09.008, 2005.

Chepstow-Lusty, A. J., Frogley, M. R., Bauer, B. S., Leng, M. J., Boessenkool, K. P., Carcaillet, C., Ali, A. A., and Gioda, A.: Putting the rise of the Inca Empire within a climatic and land management context, Clim. Past, 5, 375–388, doi:10.5194/cp-5-375-2009, 2009.

Clapperton, C. M., Sugden, D. E., Kaufman, D. S., and McCulloch, R. D.: The last glaciation in central Magellan Strait, southernmost Chile, Quaternary Res., 44, 133–148, 1995.

Cleef, A. M., Noldus, G. W., and Van der Hammen, T.: Estudio palinologico del Pleniglacial Medio de la seccion Rio Otono-Manizales Enea (Cordillera Central, Colombia), in: Studies on Tropical Andean Ecosystems/Estudios de Ecosistemas Tropandinos, edited by: Van der Hammen, T. and dos Santos, A. G., Cramer (Borntraeger), Berlin/Stuttgart, Germany, 441–449, 1995.

Colinvaux, P. A. and Schofield, E. K.: Historical ecology in the Galapagos Islands: I. A Holocene pollen record from El Junco Lake, Isla San Cristobal, J. Ecol., 989–1012, 1976.

Colinvaux, P. A., Miller, M. C., Liu, K., Steinitz-Kannan, M., and Frost, I.: Discovery of permanent Amazon lakes and hydraulic disturbance in the upper Amazon Basin, Nature, 313, 42–45, doi:10.1038/313042a0, 1985.

Colinvaux, P. A., Olson, K., and Liu, K.-B.: Late glacial and Holocene pollen diagrams from two endorheic lakes of the inter-Andean plateau of Ecuador, Rev. Palaeobot. Palynol., 55, 83–99, 1988a.

Colinvaux, P. A., Frost, M., Frost, I., Liu, K.-B., and Steinitz-Kannan, M.: Three pollen diagrams of forest disturbance in the western amazon basin, Rev. Palaeobot. Palynol., 55, 73–81, 1988b.

Colinvaux, P. A., Bush, M. B., Steinitz-Kannan, M., and Miller, M. C.: Glacial and Postglacial Pollen Records from the Ecuadorian Andes and Amazon, Quaternary Res., 48, 69–78, 1997.

Correa-Metrio, A., Cabrera, K. R., and Bush, M. B.: Quantifying ecological change through discriminant analysis: a paleoecological example from the Peruvian Amazon, J. Veg. Sci., 21, 695–704, doi:10.1111/j.1654-1103.2010.01178.x, 2010.

Davies, S. M., Abbott, P. M., Pearce, N. J. G., Wastegård, S., and Blockley, S. P. E.: Integrating the INTIMATE records using tephrochronology: rising to the challenge, Quaternary Sci. Rev., 36, 11–27, doi:10.1016/j.quascirev.2011.04.005, 2012.

Delgado, M., Aceituno, F. J., and Barrientos, G.: ^{14}C data and the early colonization of northwest South America: a critical assessment, Quat. Int., 363, 55–64, doi:10.1016/j.quaint.2014.09.011, 2015.

de Oliveira, M. A. T., Porsani, J. L., de Lima, G. L., Jeske-Pieruschka, V., and Behling, H.: Upper Pleistocene to Holocene peatland evolution in southern Brazilian highlands as depicted by radar stratigraphy, sedimentology and palynology, Quaternary Res., 77, 397–407, doi:10.1016/j.yqres.2011.12.006, 2012.

Drake, B. L.: Using models of carbon isotope fractionation during photosynthesis to understand the natural fractionation ratio, Radiocarbon, 56, 29–38, doi:10.2458/56.16155, 2014.

Dull, R. A.: A Holocene record of Neotropical savanna dynamics from El Salvador, J. Paleolimnol., 32, 219–231, 2004a.

Dull, R. A.: An 8000-year record of vegetation, climate, and human disturbance from the Sierra de Apaneca, El Salvador, Quaternary Res., 61, 159–167, doi:10.1016/j.yqres.2004.01.002, 2004b.

Epping, I.: Environmental change in the Colombian upper forest belt, Master thesis, University of Amsterdam, Amsterdam, The Netherlands, 2009.

Flantua, S. G. A., Hooghiemstra, H., Grimm, E. C., and Markgraf, V.: Updated Latin American Pollen Database: Version 2013 in preparation for Neotoma, PAGES News, 21, 88, 2013.

Flantua, S. G. A., Hooghiemstra, H., Grimm, E. C., Behling, H., Bush, M. B., González-Arango, C., Gosling, W. D., Ledru, M. P., Lozano-García, S., Maldonado, A., Prieto, A. R., Rull, V., and Van Boxel, J. H.: Updated site compilation of the Latin American Pollen Database, Rev. Palaeobot. Palynol., 223, 104–115, doi:10.1016/j.revpalbo.2015.09.008, 2015.

Flantua, S. G. A., Hooghiemstra, H., Vuille, M., Behling, H., Carson, J. F., Gosling, W. D., Hoyos, I., Ledru, M. P., Montoya, E., Mayle, F., Maldonado, A., Rull, V., Tonello, M. S., Whitney, B. S. and González-Arango, C.: Climate variability and human impact on the environment in South America during the last 2000 years: synthesis and perspectives from pollen records, Clim. Past, accepted, 2016

Fritz, S. C., Baker, P. A., Lowenstein, T. K., Seltzer, G. O., Rigsby, C. A., Dwyer, G. S., Tapia, P. M., Arnold, K. K., Ku, T.-L., and Luo, S.: Hydrologic variation during the last 170 000 years in the southern hemisphere tropics of South America, Quaternary Res., 61, 95–104, doi:10.1016/j.yqres.2003.08.007, 2004.

Fritz, S. C., Baker, P. A., Seltzer, G. O., Ballantyne, A., Tapia, P., Cheng, H., and Edwards, R. L.: Quaternary glaciation and hydrologic variation in the South American tropics as reconstructed from the Lake Titicaca drilling project, Quaternary Res., 68, 410–420, doi:10.1016/j.yqres.2007.07.008, 2007.

Fritz, S. C., Baker, P. A., Ekdahl, E., Seltzer, G. O., and Stevens, L. R.: Millennial-scale climate variability during the Last Glacial period in the tropical Andes, Quaternary Sci. Rev., 29, 1017–1024, doi:10.1016/j.quascirev.2010.01.001, 2010.

Frost, I.: A Holocene Sedimentary Record from Anangucocha in the Ecuadorian Amazon, Ecology, 69, 66–73, doi:10.2307/1943161, 1988.

Fyfe, R. M., Beaulieu, J.-L. de, Binney, H., Bradshaw, R. H. W., Brewer, S., Flao, A. L., Finsinger, W., Gaillard, M.-J., Giesecke, T., Gil-Romera, G., Grimm, E. C., Huntley, B., Kunes, P., Kühl, N., Leydet, M., Lotter, A. F., Tarasov, P. E., and Tonkov, S.: The European Pollen Database: past efforts and current activities, Veg. Hist. Archaeobot., 18, 417–424, doi:10.1007/s00334-009-0215-9, 2009.

Gajewski, K., Viau, A. E., Sawada, M., Atkinson, D. E., and Fines, P.: Synchronicity in climate and vegetation transitions between Europe and North America during the Holocene, Clim. Change, 78, 341–361, doi:10.1007/s10584-006-9048-z, 2006.

García Castro, Y. C.: Reconstrucción paleoambiental del Holoceno tardío con base en el análisis de palinofacies de la terraza de San Nicolás, registro del paleolago Cauca, Colombia, Master thesis, University EAFIT, Medellín, Colombia, 2011.

García-M., Y. and Rangel-Ch, J.O.: Cambios en la vegetacion y en las condiciones del clima durante el Holoceno en Cienagas de Córdoba, Colombia, in Colombia, Diversidad biótica XII: La región Caribe de Colombia, edited by: Rangel-Ch, J. O., Universidad Nacional de Colombia, Bogotá, Colombia, 165–198, 2012.

Giesecke, T., Bennett, K. D., Birks, H. J. B., Bjune, A. E., Bozilova, E., Feurdean, A., Finsinger, W., Froyd, C., Pokorný, P., Rösch, M., Seppä, H., Tonkov, S., Valsecchi, V., and Wolters, S.: The pace of Holocene vegetation change – testing for synchronous developments, Quaternary Sci. Rev., 30, 2805–2814, doi:10.1016/j.quascirev.2011.06.014, 2011.

Giesecke, T., Davis, B., Brewer, S., Finsinger, W., Wolters, S., Blaauw, M., Beaulieu, J.-L. de, Binney, H., Fyfe, R. M., Gaillard, M.-J., Gil-Romera, G., Van der Knaap, W. O., Kuneš, P., Kühl, N., van Leeuwen, J. F. N., Leydet, M., Lotter, A. F., Ortu, E., Semmler, M., and Bradshaw, R. H. W.: Towards mapping the late Quaternary vegetation change of Europe, Veg. Hist. Archaeobot., 23, 75-86, doi:10.1007/s00334-012-0390-y, 2014.

Giraldo, C., Van der Hammen, T., and Rangel-Ch, J. O.: Manacaro I Una secuencia de polen del tardiglacial en el valle inferior del Río Caquetá, Amazonía Colombiana: sucesión rivereña y cambios del clima, in Colombia Diversidad Biótica VII, Vegetación, palinología y paleoecología de la Amazonia Colombiana, edited by: Rangel-Ch, J. O., Universidad Nacional de Colombia, Bogotá, Colombia, 119–144, 2008.

Gladenkov, Y. B.: Zonal biostratigraphy in the solution of the fundamental and applied problems of geology, Stratigraphy and Geological Correlation, 18, 660–673, doi:10.1134/S0869593810060055, 2010.

Gómez, A., Berrío, J. C., Hooghiemstra, H., Becerra, M., and Marchant, R.: A Holocene pollen record of vegetation change and human impact from Pantano de Vargas, an intra-Andean basin of Duitama, Colombia, Rev. Palaeobot. Palynol., 145, 143–157, doi:10.1016/j.revpalbo.2006.10.002, 2007.

González, C., Urrego, L. E., and Martínez, J. I.: Late Quaternary vegetation and climate change in the Panama Basin: palynological evidence from marine cores ODP 677B and TR 163–38, Palaeogeogr. Palaeoecol., 234, 62–80, doi:10.1016/j.palaeo.2005.10.019, 2006.

González, C., Dupont, L. M., Behling, H., and Wefer, G.: Neotropical vegetation response to rapid climate changes during the last glacial period: Palynological evidence from the Cariaco Basin, Quaternary Res., 69, 217–230, doi:10.1016/j.yqres.2007.12.001, 2008.

González, C., Urrego, L. E., Martinez, J. I., Polania, J., and Yokoyama, Y.: Mangrove dynamics in the southwestern Caribbean since the "Little Ice Age": A history of human and natural disturbances, Holocene, 20, 849–861, doi:10.1177/0959683610365941, 2010.

González, E., Van der Hammen, T., and Flint, R. F.: Late Quaternary glacial and vegetational sequence in Valle de Lagunillas, Sierra Nevada del Cocuy, Colombia, Leidse Geol. Meded., 32, 157–182, 1966.

González-Carranza, Z., Berrío, J. C., Hooghiemstra, H., Duivenvoorden, J. F., and Behling, H.: Changes of seasonally dry forest in the Colombian Patía Valley during the early and middle Holocene and the development of a dry climatic record for the northernmost Andes, Rev. Palaeobot. Palynol., 152, 1–10, doi:10.1016/j.revpalbo.2008.03.005, 2008.

González-Carranza, Z., Hooghiemstra, H., and Velez, H.: Major altitudinal shifts in Andean vegetation on the Amazonian flank show temporary loss of biota in the Holocene, Holocene, 22, 1227–1241, 2012.

Gosling, W. D., Bush, M. B., Hanselman, J. A., and Chepstow-Lusty, A.: Glacial-interglacial changes in moisture balance and the impact on vegetation in the southern hemisphere tropical Andes (Bolivia/Peru), Palaeogeogr. Palaeoecol., 259, 35–50, doi:10.1016/j.palaeo.2007.02.050, 2008.

Gosling, W. D., Hanselman, J. A., Knox, C., Valencia, B. G., and Bush, M. B.: Long-term drivers of change in *Polylepis* woodland distribution in the central Andes, J. Veg. Sci., 20, 1041–1052, doi:10.1111/j.1654-1103.2009.01102.x, 2009.

Grabandt, R. A. J.: Pollen rain in relation to vegetation in the Colombian Cordillera Oriental, Ph.D. dissertation, University of Amsterdam, Amsterdam, The Netherlands, 1985.

Graf, K.: Palynological investigations of two post-glacial peat bogs near the boundary of Bolivia and Peru, J. Biogeogr., 8, 353, doi:10.2307/2844756, 1981.

Graf, K.: Palinología del cuaternario reciente en los Andes del Ecuador, del Perú, y de Bolivia, Boletin Servicio Geologico Bolivia, 4, 69–91, 1989.

Graf, K.: Pollen diagramme aus den Anden, Eine Synthese zur Klimageschichte und Vegetationsentwicklung seit der letzten Eiszeit, Physische Geographie 34, University of Zurich, Switzerland, 1992.

Graf, K.: Algunos apuntes sobre el paleoclima en Los Andes Venezolanos hace 13 000 años, Plantula, 1, 95–106, 1996.

Grimm, E. C., Bradshaw, R. H. W., Brewer, S., Flantua, S., Giesecke, T., Lézine, A.-M., Takahara, H., and Williams, J. W.: Pollen methods and studies, Databases and their application, in: Encycl. Quat. Sci. (2nd Edition), edited by: Elias, S. A., Elsevier, Amsterdam, The Netherlands, 831–838, 2013.

Grimm, E. C., Blaauw, M., Buck, C. E., and Williams, J. W.: Age models, chronologies, and databases workshop, PAGES Mag., 22, 104, available at: http://www.pages-igbp.org/calendar/127-pages/826-age-models-chronologies-and-databases (last access: 28 January 2015), 2014.

Groot, M. H. M., Bogotá, R. G., Lourens, L. J., Hooghiemstra, H., Vriend, M., Berrio, J. C., Tuenter, E., Van der Plicht, J., Van Geel, B., Ziegler, M., Weber, S. L., Betancourt, A., Contreras, L., Gaviria, S., Giraldo, C., González, N., Jansen, J. H. F., Konert, M., Ortega, D., Rangel, O., Sarmiento, G., Vandenberghe, J., Van der Hammen, T., Van der Linden, M., and Westerhoff, W.: Ultra-high resolution pollen record from the northern Andes reveals rapid shifts in montane climates within the last two glacial cycles, Clim. Past, 7, 299–316, doi:10.5194/cp-7-299-2011, 2011.

Groot, M. H. M., Van der Plicht, J., Hooghiemstra, H., Lourens, L. J., and Rowe, H. D.: Age modelling for Pleistocene lake sediments: A comparison of methods from the Andean Fúquene basin (Colombia) case study, Quat. Geochronol., 22, 144–154, doi:10.1016/j.quageo.2014.01.002, 2014.

Hanselman, J. A., Gosling, W. D., Paduano, G. M., and Bush, M. B.: Contrasting pollen histories of MIS 5e and the Holocene from Lake Titicaca (Bolivia/Peru), J. Quaternary Sci., 20, 663–670, doi:10.1002/jqs.979, 2005.

Hanselman, J. A., Bush, M. B., Gosling, W. D., Collins, A., Knox, C., Baker, P. A., and Fritz, S. C.: A 370 000-year record of vegetation and fire history around Lake Titicaca (Bolivia/Peru), Palaeogeogr. Palaeoecol., 305, 201–214, doi:10.1016/j.palaeo.2011.03.002, 2011.

Hansen, B. C.: A review of lateglacial pollen records from Ecuador and Peru with reference to the Younger Dryas event, Quaternary Sci. Rev., 14, 853–865, 1995.

Hansen, B. C. and Rodbell, D. T.: A Late-Glacial/Holocene Pollen Record from the Eastern Andes of Northern Peru, Quaternary Res., 44, 216–227, 1995.

Hansen, B. C., Wright Jr., H. E., and Bradbury, J. P.: Pollen studies in the Junin area, central Peruvian Andes, Geol. Soc. Am. Bull., 95, 1454–1465, 1984.

Hansen, B. C., Seltzer, G. O., and Wright Jr., H. E.: Late Quaternary vegetational change in the central Peruvian Andes, Palaeogeogr. Palaeoecol., 109, 263–286, 1994.

Hansen, B. C., Rodbell, D., Seltzer, G., León, B., Young, K., and Abbott, M.: Late-glacial and Holocene vegetational history from two sites in the western Cordillera of southwestern Ecuador, Palaeogeogr. Palaeoecol., 194, 79–108, doi:10.1016/S0031-0182(03)00272-4, 2003.

Helmens, K. F.: Neogene-Quaternary geology of the high plain of Bogota, Eastern Cordillera, Colombia (stratigraphy, paleoenvironments and landscape evolution), J Cramer, Berlin, Germany, 1990.

Helmens, K. F. and Kuhry, P.: Middle and late quaternary vegetational and climatic history of the Páramo de Agua Blanca (Eastern Cordillera, Colombia), Palaeogeogr. Palaeoecol., 56, 291–335, 1986.

Helmens, K. F., Kuhry, P., Rutter, N. W., Van Der Borg, K., and De Jong, A. F.: Warming at 18,000 yr BP in the tropical Andes, Quaternary Res., 45, 289–299, 1996.

Herd, D. G.: Glacial and volcanic geology of the Ruiz-Tolima volcanic complex Cordillera Central, Colombia, INGEOMINAS, Bogotá, Colombia, 1982.

Hillyer, R., Valencia, B. G., Bush, M. B., Silman, M. R., and Steinitz-Kannan, M.: A 24 700-yr paleolimnological history from the Peruvian Andes, Quaternary Res., 71, 71–82, doi:10.1016/j.yqres.2008.06.006, 2009.

Hodell, D. A., Anselmetti, F. S., Ariztegui, D., Brenner, M., Curtis, J. H., Gilli, A., Grzesik, D. A., Guilderson, T. J., Müller, A. D., and Bush, M. B.: An 85-ka record of climate change in lowland Central America, Quaternary Sci. Rev., 27, 1152–1165, doi:10.1016/j.quascirev.2008.02.008, 2008.

Hogg, A. G., Hua, Q., Blackwell, P. G., Niu, M., Buck, C. E., Guilderson, T. P., Heaton, T. J., Palmer, J. G., Reimer, P. J., Reimer, R. W., Turney, C. S. M., and Zimmerman, S. R. H.: SHCal13 Southern Hemisphere calibration, 0–50 000 cal yr BP, Radiocarbon, 55, 1889–1903, 2013.

Hooghiemstra, H. and van der Hammen, T.: Late Quaternary vegetation history and paleoecology of Laguna Pedro Palo (subandean forest belt, Eastern Cordillera, Colombia), Rev. Palaeobot. Palynol., 77, 235–262, 1993.

Hooghiemstra, H., Wijninga, V. M., and Cleef, A. M.: The Paleobotanical Record of Colombia: Implications for Biogeography and Biodiversity, Ann. Mo. Bot. Gard., 93, 297–324, 2006.

Hua, Q., Barbetti, M., and Rakowski, A. Z.: Atmospheric radiocarbon for the period 1950–2010, Radiocarbon, 55, 2059–2072, 2013.

Israde-Alcántara, I., Bischoff, J. L., Domínguez-Vázquez, G., Li, H.-C., DeCarli, P. S., Bunch, T. E., Wittke, J. H., Weaver, J. C., Firestone, R. B., West, A., Kennett, J. P., Mercer, C., Xie, S., Richman, E. K., Kinzie, C. R., and Wolbach, W. S.: Evidence from central Mexico supporting the Younger Dryas extraterrestrial impact hypothesis, P. Natl. Acad. Sci. USA, 109, 738–747, doi:10.1073/pnas.1110614109, 2012a.

Israde-Alcántara, I., Bischoff, J. L., DeCarli, P. S., Domínguez-Vázquez, G., Bunch, T. E., Firestone, R. B., Kennett, J. P., and West, A.: Reply to Blaauw et al., Boslough, Daulton, Gill et al., and Hardiman et al.: Younger Dryas impact proxies in Lake Cuitzeo, Mexico, P. Natl. Acad. Sci. USA 109, 2245–2247, doi:10.1073/pnas.1209463109, 2012b.

Jantz, N. and Behling, H.: A Holocene environmental record reflecting vegetation, climate, and fire variability at the Páramo of Quimsacocha, southwestern Ecuadorian Andes, Veg. Hist. Archaeobot., 21, 169–185, doi:10.1007/s00334-011-0327-x, 2012.

Jara, I. A. and Moreno, P. I.: Climatic and disturbance influences on the temperate rainforests of northwestern Patagonia (40° S) since ∼14 500 cal yr BP, Quaternary Sci. Rev., 90, 217–228, doi:10.1016/j.quascirev.2014.01.024, 2014.

Jennerjahn, T. C., Ittekkot, V., Arz, H. W., Behling, H., Pätzold, J., and Wefer, G.: Asynchronous terrestrial and marine signals of climate change during Heinrich events, Science, 306, 2236–2239, doi:10.1126/science.1102490, 2004.

Juvigné, É., Thouret, J. C., Gilot, É., Gourgaud, A., Graf, K., Leclercq, L., Legros, F., and Uribe, M.: Étude téphrostratigraphique et bio-climatique du Tardiglaciaire et de l'Holocène de la Laguna Salinas, Pérou meridional, Géographie physique et Quaternaire, 51, 221–233, 1997.

Kuentz, A., Ledru, M.-P., and Thouret, J.-C.: Environmental changes in the highlands of the western Andean Cordillera, southern Peru, during the Holocene, Holocene, 22, 1215–1226, doi:10.1177/0959683611409772, 2012.

Kuhry, P.: A paleobotanical and palynological study of Holocene peat from the El Bosque mire, located in a volcanic area of the Cordillera Central of Colombia, Rev. Palaeobot. Palynol., 55, 19–72, 1988a.

Kuhry, P.: Palaeobotanical – palaeoecological studies of tropical high Andean peatbog sections Cordillera Oriental, Colombia. Diss. Bot., 116, 1–241, 1988b.

Kuhry, P., Salomons, J. B., Riezebos, P. A., and Van der Hammen, T.: Paleoecologia de los últimos 6000 años en el area de la Laguna de Otun-El Bosque, in: Studies on Tropical Andean Ecosystems/Estudios de Ecosistemas Tropandinos 1, edited by: Van der Hammen, T., Perez, P. A., and Pinto, P., Cramer, Vaduz, Liechtenstein, 227–261, 1983.

Kuhry, P., Hooghiemstra, H., Van Geel, B., and Van der Hammen, T.: The El Abra stadial in the Eastern Cordillera of Colombia (South America), Quaternary Sci. Rev., 12, 333–343, 1993.

Lane, C. S., Brauer, A., Blockley, S. P. E., and Dulski, P.: Volcanic ash reveals time-transgressive abrupt climate change during the Younger Dryas, Geology, 41, 1251–1254, doi:10.1130/G34867.1, 2013.

Leal, A. V. and Bilbao, B. A.: Cambios de vegetación durante el Holoceno Tardío en un morichal de los Llanos del Orinoco, Venezuela, Acta Bot. Venez., 34, 237–256, 2011.

Leal, A. V., Bilbao, B. A., and Berrío, J. C.: A contribution to pollen rain characterization in forest-savanna mosaics of the Venezuelan Guayana and its use in vegetation reconstructions from sedimentary records, Am. J. Plant Sci., 4, 33–52, doi:10.4236/ajps.2013.47A1006, 2013.

Leal Rodríguez, A. V.: Historia Holocena de la vegetación y el fuego en bordes sabana/bosque y turberas de la Gran Sabana, Guayana Venezolana, Ph.D. dissertation, Universidad Simon Bolivar, Caracas, Venezuela, 2010.

Ledru, M.-P., Jomelli, V., Bremond, L., Ortuno, T., Cruz, P., Bentaleb, I., Sylvestre, F., Kuentz, A., Beck, S., Martin, C., Pailles, C., and Subitani, S.: Evidence of moist niches in the Bolivian Andes during the mid-Holocene arid period, Holocene, 23, 1547–1559, doi:10.1177/0959683613496288, 2013a.

Ledru, M.-P., Jomelli, V., Samaniego, P., Vuille, M., Hidalgo, S., Herrera, M., and Ceron, C.: The Medieval Climate Anomaly and the Little Ice Age in the eastern Ecuadorian Andes, Clim. Past, 9, 307–321, doi:10.5194/cp-9-307-2013, 2013b.

Leyden, B. W.: Late Quaternary aridity and Holocene moisture fluctuations in the Lake Valencia basin, Venezuela, Ecology, 66, 1279, doi:10.2307/1939181, 1985.

Leyden, B. W., Brenner, M., Hodell, D. A., and Curtis, J. H.: Late Pleistocene climate in the central American lowlands, Geophys. Monogr., 78, 165–178, 1993.

Liu, K.-B. and Colinvaux, P. A.: A 5200-year history of Amazon rain forest, J. Biogeogr., 15, 231–248, doi:10.2307/2845412, 1988.

Lim, S., Ledru, M.-P., Valdez, F., Devillers, B., Houngnon, A., Favier, C., and Bremond, L.: Ecological effects of natural hazards and human activities on the Ecuadorian Pacific coast during the late Holocene, Palaeogeogr. Palaeoecol., 415, 197–209, doi:10.1016/j.palaeo.2013.12.021, 2014.

Lowe, D. J.: Tephrochronology. SUPRAnet consortium workshop "Studying uncertainty in palaeoclimate reconstruction", Sheffield, UK, 23–27 June 2008, available at: http://caitlin-buck.staff.shef.ac.uk/SUPRAnet/ (last access: September 2015), 2008.

Lowe, D. J.: Project 0907: INTREPID – Enhancing tephrochronology as a global research tool through improved fingerprinting and correlation techniques and uncertainty modelling, University of Waikato Research Commons available at: http://researchcommons.waikato.ac.nz/handle/10289/4183 (last access: 9 October 2015), 2010.

Lowe, D. J.: Tephrochronology and its application: a review, Quat. Geochronol., 6, 107–153, doi:10.1016/j.quageo.2010.08.003, 2011.

Lowe, D. J.: Connecting and dating with tephras: principles, functioning, and application of tephrochronology in Quaternary Res., Conference: 12th Quaternary Techniques Short Course "Techniques of Palaeoclimatic and Palaeoenvironmental Reconstruction" (21–22 May, 2015), At National Isotope Centre, GNS Science, Lower Hutt, New Zealand, available at: http://researchcommons.waikato.ac.nz/handle/10289/9338, last access: 10 July 2015.

Lozano-Garcìa, M. S. and Ortega-Guerrero, B.: Late Quaternary environmental changes of the central part of the Basin of Mexico; correlation between Texcoco and Chalco basins, Rev. Palaeobot. Palynol., 99, 77–93, 1998.

Lozano-García, M. S., Ortega-Guerrero, B., Caballero-Miranda, M., and Urrutia-Fucugauchi, J.: Late Pleistocene and Holocene paleoenvironments of Chalco Lake, Central Mexico, Quaternary Res., 40, 332–342, doi:10.1006/qres.1993.1086, 1993.

Maezumi, S. Y., Power, M. J., Mayle, F. E., McLauchlan, K. K., and Iriarte, J.: Effects of past climate variability on fire and vegetation in the cerrãdo savanna of the Huanchaca Mesetta, NE Bolivia, Clim. Past, 11, 835–853, doi:10.5194/cp-11-835-2015, 2015.

Matthias, I.: Rekonstruktion der Umwelt- und Siedlungsgeschichte von Loja durch Multiproxy-Analysen an limnischen Sedimenten der Laguna Daniel Alvarez in Südecuador, Ph.D. dissertation, University of Göttingen, Göttingen, Germany, 2008.

Markgraf, V. and Huber, U. M.: Late and postglacial vegetation and fire history in Southern Patagonia and Tierra del Fuego, Palaeogeogr. Palaeoecol., 297, 351–366, doi:10.1016/j.palaeo.2010.08.013, 2010.

Mayle, F. E., Burbridge, R., and Killeen, T. J.: Millennial-scale dynamics of southern Amazonian rain forests, Science, 290, 2291–2294, doi:10.1126/science.290.5500.2291, 2000.

Mayle, F. E., Langstroth, R. P., Fisher, R. A., and Meir, P.: Long-term forest-savannah dynamics in the Bolivian Amazon: implications for conservation, Philos. T. Roy. Soc. B, 362, 291–307, doi:10.1098/rstb.2006.1987, 2007.

McCormac, F. G., Hogg, A. G., Higham, T. F. G., Lynch-Stieglitz, J., Broecker, W. S., Baillie, M. G. L., Palmer, J., Xiong, L., Pilcher, J. R., Brown, D., and Hoper, S. T.: Temporal variation in the interhemispheric 14C offset, Geophys. Res. Lett., 25, 1321–1324, doi:10.1029/98GL01065, 1998.

McCormac, F. G., Hogg, A. G., Blackwell, P. G., Buck, C. E., Higham, T. F., and Reimer, P. J.: SHCal04 Southern Hemisphere calibration, 0–11.0 cal kyr BP, Radiocarbon, 46, 1087–1092, 2004.

McGee, D., Donohoe, A., Marshall, J., and Ferreira, D.: Changes in ITCZ location and cross-equatorial heat transport at the Last Glacial Maximum, Heinrich Stadial 1, and the mid-Holocene, Earth Planet. Sci. Lett., 390, 69–79, doi:10.1016/j.epsl.2013.12.043, 2014.

Melief, A.: Late Quaternary paleoecology of the Parque Nacional Natural los Nevados (Cordillera Central) and Sumapaz (Cordillera Oriental) areas, Colombia, Ph.D. dissertation, University of Amsterdam, Amsterdam, The Netherlands, 1985.

Melief, A.: Late Quaternary history of vegetation in the Parque Los Nevados and surroundings (Cordillera Central), in: La Cordillera Central de Colombiana Transecto Parque Nevados (second part), Studies on Tropical Andean Ecosystems/Estudios de Ecosistemas Tropandinos 3, edited by: Van der Hammen, T., Diaz-Piedrahita S., and Alvarez, V. J., Cramer Borntraeger, Berlin/Stuttgart, Germany, 537–588, 1989.

Melief, A. and Cleef, A. M.: Results of the pollen analysis of peat and lake deposits in the Sumapaz area, in: La Cordillera Oriental Colombiana, Transecto Sumapaz, Studies on Tropical Andean Ecosystems/Estudios de Ecosistemas Tropandinos 7, edited by: Van der Hammen, T., Rangel-Ch, J. O., and Cleef, A. M., Cramer Borntraeger, Berlin/Stuttgart, Germany, 395–485, 2008.

Millard, A. R.: Conventions for reporting radiocarbon determinations, Radiocarbon, 56, 555–559, doi:10.2458/56.17455, 2014.

Mommersteeg, H.: Vegetation development and cyclic and abrupt climatic changes during the late Quaternary: palynological evidence from the Colombian Eastern Cordillera, University of Amsterdam, Amsterdam, The Netherlands, 1998.

Montoya, E.: Paleoecology of the southern Gran Sabana (SE Venezuela) sinde the Late Glacial to the present, Ph.D. dissertation, Universitat Autónoma de Barcelona, Barcelona, Spain, 2011.

Montoya, E. and Rull, V.: Gran Sabana fires (SE Venezuela): a paleoecological perspective, Quaternary Sci. Rev., 30, 3430–3444, doi:10.1016/j.quascirev.2011.09.005, 2011.

Montoya, E., Rull, V., Nogué, S., and Díaz, W. A.: Paleoecología del Holoceno en la Gran Sabana, SE Venezuela: Análisis preliminar de polen y microcarbones en la Laguna Encantada, Collectanea Botanica, 28, 65–79, doi:10.3989/collectbot.2008.v28.005, 2009.

Montoya, E., Rull, V., Stansell, N. D., Bird, B. W., Nogué, S., Vegas-vilarrúbia, T., Abbott, M. B., and Díaz, W. A.: Vegetation changes in the Neotropical Gran Sabana (Venezuela) around the Younger Dryas chron, J. Quaternary Sci., 26, 207–218, doi:10.1002/jqs.1445, 2011a.

Montoya, E., Rull, V., Stansell, N. D., Abbott, M. B., Nogué, S., Bird, B. W., and Díaz, W. A.: Forest–savanna–morichal dynamics in relation to fire and human occupation in the southern Gran Sabana (SE Venezuela) during the last millennia, Quaternary Res., 76, 335–344, doi:10.1016/j.yqres.2011.06.014, 2011b.

Montoya, E., Rull, V., and Nogué, S.: Early human occupation and land use changes near the boundary of the Orinoco and the Amazon basins (SE Venezuela): Palynological evidence from El Paují record, Palaeogeogr. Palaeoecol., 310, 413–426, doi:10.1016/j.palaeo.2011.08.002, 2011c.

Mook, W. G. and Van der Plicht, J.: Reporting 14C activities and concentrations, Radiocarbon, 41, 227–239, 1999.

Moscol Olivera, M. C. M.: Holocene upper forest line dynamics in the Ecuadorian Andes: a multiproxy study, Ph.D. dissertation, University of Amsterdam, Amsterdam, 2010.

Moscol Olivera, M. C. and Hooghiemstra, H.: Three millennia upper forest line changes in northern Ecuador: Pollen records and altitudinal vegetation distributions, Rev. Palaeobot. Palynol., 163, 113–126, doi:10.1016/j.revpalbo.2010.10.003, 2010.

Mourguiart, P. and Ledru, M.-P.: Last glacial maximum in an Andean cloud forest environment (Eastern Cordillera, Bolivia), Geology, 31, 195–198, 2003.

Muller, J.: Palynology of recent Orinoco delta and shelf sediments: Reports of the Orinoco shelf expedition, Micropaleontology, 5, 1–32, doi:10.2307/1484153, 1959.

Muñoz Uribe, P. A.: Holocene climate variability in tropical South America: case history from a high-mountain wet zone in NW Colombia based on palynology and X-ray microfluorescence, University of Geneva, Geneva, Switserland, 2012.

Naranjo, J. A. and Stern, C. R.: Holocene tephrochronology of the southernmost part (42°30′–45° S) of the Andean Southern Volcanic Zone, Rev. Geológica Chile, 31, 224–240, doi:10.4067/S0716-02082004000200003, 2004.

Niemann, H. and Behling, H.: Late Quaternary vegetation, climate and fire dynamics inferred from the El Tiro record in the southeastern Ecuadorian Andes, J. Quaternary Sci., 23, 203–212, doi:10.1002/jqs.1134, 2008a.

Niemann, H. and Behling, H.: Past vegetation and fire dynamics, in: Gradients in a tropical mountain ecosystem in Ecuador, edited by: Beck, E. Bendix, J., Kottke, I., Makeschin, F., and Mosandl, R., Springer Verlag, Berlin, Heidelberg, Germany, 101–112, 2008b.

Niemann, H. and Behling, H.: Late Pleistocene and Holocene environmental change inferred from the Cocha Caranga sediment and soil records in the southeastern Ecuadorian Andes, Palaeogeogr. Palaeoecol., 276, 1–14, doi:10.1016/j.palaeo.2009.02.018, 2009.

Niemann, H. and Behling, H.: Late Holocene environmental change and human impact inferred from three soil monoliths and the Laguna Zurita multi-proxi record in the southeastern Ecuadorian Andes, Veg. Hist. Archaeobot., 19, 1–15, doi:10.1007/s00334-009-0226-6, 2010.

Niemann, H., Haberzettl, T., and Behling, H.: Holocene climate variability and vegetation dynamics inferred from the (11 700 cal. yr BP) Laguna Rabadilla de Vaca sediment record, southeastern Ecuadorian Andes, Holocene, 19, 307–316, doi:10.1177/0959683608100575, 2009.

Niemann, H., Matthias, I., Michalzik, B., and Behling, H.: Late Holocene human impact and environmental change inferred from a multi-proxy lake sediment record in the Loja region, southeastern Ecuador, Quat. Int., 308–309, 253–264, doi:10.1016/j.quaint.2013.03.017, 2013.

Nogué, S., Rull, V., Montoya, E., Huber, O., and Vegas-Vilarrúbia, T.: Paleoecology of the Guayana Highlands (northern South America): Holocene pollen record from the Eruoda-tepui, in the Chimantá massif, Palaeogeogr. Palaeoecol., 281, 165–173, doi:10.1016/j.palaeo.2009.07.019, 2009.

Otero, H. and Santos, G.: Las ocupaciones prehispánicas del cañon del río Porce, Prospección, rescate y monitoreo arqueolción, Universidad de Antioquia, Centro de Investigaciones Ciencias Sociales y Humanas CISH, Proyecto Hidroeléctrico Porce III - Obras de Infraestructura, Contrato 030417922, Tomos I II y II III ¸Empresas Públicas de Medellín E. S. P, Subgerencia de Proyectos Genera, Medellín, Colombia, 2006.

Ortega-Guerrero, B. and Newton, A. J.: Geochemical characterization of late Pleistocene and Holocene tephra layers from the basin of Mexico, Central Mexico, Quaternary Res., 50, 90–106, doi:10.1006/qres.1998.1975, 1998.

Paduano, G. M., Bush, M. B., Baker, P. A., Fritz, S. C., and Seltzer, G. O.: A vegetation and fire history of Lake Titicaca since the Last Glacial Maximum, Palaeogeogr. Palaeoecol., 194, 259–279, doi:10.1016/S0031-0182(03)00281-5, 2003.

Palacios, L. P.: Cambios en la vegetación y en el clima en áreas estuarinas del norte del caribe Colombiano, Master thesis, Universidad Nacional de Colombia, Bogotá, Colombia, 2011.

Palacios, L. P., Rodríguez, P., and Rangel-Ch, J. O.: Cambios en el clima y en la vegetacion en ambientes estuarinos de la Bahia de Cispata (Córdoba, Caribe Colombiano), in: Colombia Diversidad Biótica XII, Universidad Nacional de Colombia, Bogotá, edited by: Rangel-Ch, J. O., 145–164, 2012.

Parnell, A. C., Haslett, J., Allen, J. R. M„ Buck, C. E., and Huntley, B.: A flexible approach to assessing synchroneity of past events using Bayesian reconstructions of sedimentation history, Quaternary Sci. Rev., 27, 1872–1885, doi:10.1016/j.quascirev.2008.07.009, 2008.

Parra, L. N., Rangel-Ch, J. O., and Van der Hammen, T.:, Cronología e isotopía C de la Turbera Llano Grande del Páramo de Frontino, in: Colombia Diversidad Biótica X, Cambio global (natural) y climático (antrópico) en el páramo Colombiano, edited by: Rangel-Ch, J .O., Universidad Nacional de Colombia, Bogotá, Colombia, 43–66, 2010.

Parra Sanchez, L. N.: Análisis facial de alta resolución de sedimentos del Holoceno tardío en el Páramo de Frontino, Antioquia, Ph.D. dissertation, Universidad Nacional de Colombia, Bogotá, Colombia, 2005.

Povinec, P. P., Litherland, A. E., and Von Reden, K. F.: Developments in radiocarbon technologies: from the Libby counter to compound-specific AMS analyses, Radiocarbon, 51, 45–78, 2009.

Punyasena, S. W., Jaramillo, C., de la Parra, F., and Du, Y.: Probabilistic correlation of single stratigraphic samples: a generalized approach for biostratigraphic data, AAPG Bulletin, 96, 235–244, doi:10.1306/06201111026, 2012.

R Development Core Team: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, available at: http://www.R-project.org/ (last access: January 2015), 2014.

Rangel-Ch, J. O., Moyano, E., and Van der Hammen, T.: Estudio palinológico del Holoceno de la parte alta del macizo del Tatamá, in: La Cordillera Occidental Colombiana Transecto Tatamá, Studies on Tropical Andean Ecosystems/Estudios de Ecosistemas Tropandinos 6, edited by: Van der Hammen, T., Rangel-Ch, J. O., and Cleef, A. M., J Cramer/Bornträger, Berlin/Stuttgart, 757–795, 2005.

Rangel-Ch., J. O., Van der Hammen, T., and Espejo, N. E.: Cambios en la vegetación y en el clima durante los últimos 60,000 años en el valle inferior del Río Caquetá, Amazoná Colombiana, in: Colombia Diversidad Biótica VII, Vegetación, palinología y paleoecología de la amazonía colombiana, edited by Rangel-Ch, J. O.,Universidad Nacional de Colombia, Bogotá, Colombia, 2008.

Rasmussen, S. O., Andersen, K. K., Svensson, A. M., Steffensen, J. P., Vinther, B. M., Clausen, H. B., Siggaard-Andersen, M.-L., Johnsen, S. J., Larsen, L. B., Dahl-Jensen, D., Bigler, M., Röthlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M. E., and Ruth, U.: A new Greenland ice core chronology for the last glacial termination, J. Geophys. Res., 111, D06102, doi:10.1029/2005JD006079, 2006.

Recasens, C., Ariztegui, D., Gebhardt, C., Gogorza, C., Haberzettl, T., Hahn, A., Kliem, P., Lisé-Pronovost, A., Lücke, A., Maidana, N., Mayr, C., Ohlendorf, C., Schäbitz, F., St-Onge, G., Wille, M., Zolitschka, B., and Science Team: New insights into paleoenvironmental changes in Laguna Potrok Aike, southern Patagonia, since the late Pleistocene: The PASADO multiproxy record, Holocene, 22, 1323–1335, doi:10.1177/0959683611429833, 2012.

Recasens, C., Ariztegui, D., Maidana, N. I., and Zolitschka, B.: Diatoms as indicators of hydrological and climatic changes in Laguna Potrok Aike (Patagonia) since the late Pleistocene, Palaeogeogr. Palaeoecol., 417, 309–319, doi:10.1016/j.palaeo.2014.09.021, 2015.

Reese, C. A.: Pollen dispersal and deposition in the high-central Andes, South America, Louisiana State University, Baton Rouge, USA, 2003.

Reese, C. A., Liu, K. B., and Thompson, L. G.: An ice-core pollen record showing vegetation response to Late-glacial and Holocene climate changes at Nevado Sajama, Bolivia, Ann. Glaciol., 54, 183–190, doi:10.3189/20113AoG63A375, 2013.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C. J. H., Blackwell, P. G., Buck, C. E., Burr, G. S., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Hogg, A. G., Hughen, K. A., Kromer, B., McCormac, G., Manning, S., Ramsey, C. B., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., Van der Plicht, J., and Weyhenmeyer, C. E.: IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP, Radiocarbon, 46, 1029–1058, 2004a.

Reimer, P. J., Brown, T. A., and Reimer, R. W.: Discussion: Reporting and calibration of post-bomb 14C data, Radiocarbon, 46, 1299–1304, 2004b.

Restrepo, A., Colinvaux, P., Bush, M., Correa-Metrio, A., Conroy, J., Gardener, M. R., Jaramillo, P., Steinitz-Kannan, M., and Overpeck, J.: Impacts of climate variability and human colonization on the vegetation of the Galápagos Islands, Ecology, 93, 1853–1866, 2012.

Rodbell, D. T., Seltzer, G. O., Anderson, David M., Abbott, M. B., Enfield, D. B., and Newman, J. H.: An 15 000-year record of El Niño-driven alluviation in southwestern Ecuador, Science, 283, 516–520, doi:10.1126/science.283.5401.516, 1999.

Rodbell, D. T., Bagnato, S., Nebolini, J. C., Seltzer, G. O., and Abbott, M. B.: A late Glacial–Holocene tephrochronology for glacial lakes in southern Ecuador, Quaternary Res., 57, 343–354, doi:10.1006/qres.2002.2324, 2002.

Rodríguez, F.: Reconstruction of late Quaternary landscape dynamics in the Podocarpus National Park region Southern Andes of Ecuador, Ph.D dissertation, University of Göttingen, Göttingen, 2012.

Rodríguez, F. and Behling, H.: Late Holocene vegetation, fire, climate and upper forest line dynamics in the Podocarpus National Park, southeastern Ecuador, Veg. Hist. Archaeobot., 20, 1–14, doi:10.1007/s00334-010-0252-4, 2011.

Rodríguez, F. and Behling, H.: Late Quaternary vegetation, climate and fire dynamics, and evidence of early to mid-Holocene Polylepis forests in the Jimbura region of the southernmost Ecuadorian Andes, Palaeogeogr. Palaeoecol., 350–352, 247–257, doi:10.1016/j.palaeo.2012.07.004, 2012.

Rodríguez-Vargas, A., Koester, E., Mallmann, G., Conceição, R. V., Kawashita, K., and Weber, M. B. I.: Mantle diversity beneath the Colombian Andes, Northern Volcanic Zone: Constraints from Sr and Nd isotopes, Lithos, 82, 471–484, doi:10.1016/j.lithos.2004.09.027, 2005.

Roucoux, K. H., Lawson, I. T., Jones, T. D., Baker, T. R., Coronado, E. N. H., Gosling, W. D., and Lähteenoja, O.: Vegetation development in an Amazonian peatland, Palaeogeogr. Palaeoecol., 374, 242–255, doi:10.1016/j.palaeo.2013.01.023, 2013.

Rull, V.: Contribución a la paleoecología de Pantepui la Gran Sabana (Guayana Venezolana): clima, biogeografía, y ecología, Scientia Guaianae, 2, 1–133, 1991.

Rull, V.: Successional patterns of the Gran Sabana (Southeastern Venezuela) vegetation during the last 5000 years, and its responses to climatic fluctuations and fire, J. Biogeogr., 19, 329–338, 1992.

Rull, V.: Holocene vegetational succession in the Guaiquinima and Chimantá massifs (SE Venezuela), Interciencia, 21, 7–20, 1996.

Rull, V.: Palaeoclimatology and sea-level history in Venezuela, Interciencia, 24, 92–101, 1999.

Rull, V.: Is the "Lost World" really lost? Palaeoecological insights into the origin of the peculiar flora of the Guayana Highlands, Naturwissenschaften, 91, 139–142, doi:10.1007/s00114-004-0504-1, 2004a.

Rull, V.: An evaluation of the Lost World and Vertical Displacement hypotheses in the Chimantá Massif, Venezuelan Guayana, Glob. Ecol. Biogeogr., 13, 141–148, doi:10.1111/j.1466-882X.2004.00073.x, 2004b.

Rull, V.: Palaeovegetational and palaeoenvironmental trends in the summit of the Guaiquinima massif (Venezuelan Guayana) during the Holocene, J. Quaternary Sci., 20, 135–145, doi:10.1002/jqs.896, 2005a.

Rull, V.: Vegetation and environmental constancy in the Neotropical Guayana Highlands during the last 6000 years?, Rev. Palaeobot. Palynol., 135, 205–222, doi:10.1016/j.revpalbo.2005.03.008, 2005b.

Rull, V. and Schubert, C.: The little ice age in the tropical Venezuelan Andes, Acta Cient. Venez., 40, 71–73, 1989.

Rull, V., Salgado-Labouriau, M. L., Schubert, C., and Valastro Jr, S.: Late Holocene temperature depression in the Venezuelan Andes: Palynological evidence, Palaeogeogr. Palaeoecol., 60, 109–121, 1987.

Rull, V., Abbott, M. B., Polissar, P. J., Wolfe, A. P., Bezada, M., and Bradley, R. S.: 15,000-yr pollen record of vegetation change in the high altitude tropical Andes at Laguna Verde Alta, Venezuela, Quaternary Res., 64, 308–317, doi:10.1016/j.yqres.2005.08.014, 2005.

Rull, V., López-Sáez, J. A., and Vegas-Vilarrúbia, T.: Contribution of non-pollen palynomorphs to the paleolimnological study of a high-altitude Andean lake (Laguna Verde Alta, Venezuela), J. Paleolimnol., 40, 399–411, doi:10.1007/s10933-007-9169-z, 2008.

Rull, V., Stansell, N. D., Montoya, E., Bezada, M., and Abbott, M. B.: Palynological signal of the Younger Dryas in the tropical Venezuelan Andes, Quaternary Sci. Rev., 29, 3045–3056, doi:10.1016/j.quascirev.2010.07.012, 2010.

Rull, V., Montoya, E., Nogué, S., and Huber, O.: Preliminary palynological analysis of a Holocene peat bog from Apakará-tepui (Chimantá Massif, Venezuelan Guayana), Collect. Bot., 30, 79–88, doi:10.3989/collectbot.2011.v30.008, 2011.

Salamanca, S. and Noldus, G. W.: Paleoecological analysis of the Lagunares de Santa Isabel Section, in: Studies on Tropical Andean Ecosystems/Estudios de Ecosistemas Tropandinos 5, edited by: Van der Hammen, T. and dos Santos, A. G., Cramer/Borntraeger, Berlin/Stuttgart, Germany, 393–420, 2003.

Salgado-Labouriau, M. L.: A pollen diagram of the Pleistocene Holocene-boundary of Lake Valencia, Venezuela, Rev. Palaeobot. Palynol., 30, 297–312, 1980.

Salgado-Labouriau, M. L.: Sequence of colonization by plants in the Venezuelan Andes after the last Pleistocene glaciation, J. Palynol., 23, 189–204, 1988.

Salgado-Labouriau, M. L. and Schubert, C.: Palynology of Holocene peat bogs from the central Venezuelan Andes, Palaeogeogr. Palaeoecol., 19, 147–156, 1976.

Salgado-Labouriau, M. L. and Schubert, C.: Pollen analysis of a peat bog from Laguna Victoria, Venezuelan Andes, Acta Cient. Venez., 28, 328–332, 1977.

Salgado-Labouriau, M. L., Bradley, R. S., Yuretich, R., and Weingarten, B.: Paleoecological analysis of the sediments of Lake Mucubaji, Venezuelan Andes, J. Biogeogr., 4, 317–327, 1992.

Salgado-Labouriau, M. L., Rull, V., Schubert, C., and Valastro Jr, S.: The establishment of vegetation after late Pleistocene deglaciation in the Paramo de Miranda, Venezuelan Andes, Rev. Palaeobot. Palynol., 55, 5–17, 1988.

Salomons, J. B.: Paleoecology of volcanic soils in the Colombian Central Cordillera. Diss. Bot. 95, 1–212, 1986.

Salomons, J. B. and Noldus, G.: Description and interpretation of the pollen diagram Quebrada Africa, in Pollen rain in relation to vegetation in the Colombian Cordillera Oriental, edited by Grabandt, R.A.J., University of Amsterdam, Amsterdam, The Netherlands, 15–35, 1985.

Schittek, K., Forbriger, M., Mächtle, B., Schäbitz, F., Wennrich, V., Reindel, M., and Eitel, B.: Holocene environmental changes in the highlands of the southern Peruvian Andes (14° S) and their impact on pre-Columbian cultures, Clim. Past, 11, 27–44, doi:10.5194/cp-11-27-2015, 2015.

Schreve-Brinkman, E.: A paynological study of the upper Quaternary sequence in the El Abra Corridor and rock shelters (Colombia), Palaeogeogr. Palaeoecol., 25, 1–109, 1978.

Schubert, C.: Contribution to the paleolimnology of lake Valencia, Venezuela: Seismic stratigraphy, Catena, 7, 275–292, 1980.

Seddon, A. W. R., Mackay, A. W., Baker, A. G., Birks, H. J. B., Breman, E., Buck, C. E., Ellis, E. C., Froyd, C. A., Gill, J. L., Gillson, L., Johnson, E. A., Jones, V. J., Juggins, S., Macias-Fauria, M., Mills, K., Morris, J. L., Nogués-Bravo, D., Punyasena, S. W., Roland, T. P., Tanentzap, A. J., Willis, K. J., Aberhan, M., van Asperen, E. N., Austin, W. E. N., Battarbee, R. W., Bhagwat, S., Belanger, C. L., Bennett, K. D., Birks, H. H., Bronk Ramsey, C., Brooks, S. J., de Bruyn, M., Butler, P. G., Chambers, F. M., Clarke, S. J., Davies, A. L., Dearing, J. A., Ezard, T. H. G., Feurdean, A., Flower, R. J., Gell, P., Hausmann, S., Hogan, E. J., Hopkins, M. J., Jeffers, E. S., Korhola, A. A., Marchant, R., Kiefer, T., Lamentowicz, M., Larocque-Tobler, I., López-Merino, L., Liow, L. H., McGowan, S., Miller, J. H., Montoya, E., Morton, O., Nogué, S., Onoufriou, C., Boush, L. P., Rodríguez-Sanchez, F., Rose, N. L., Sayer, C. D., Shaw, H. E., Payne, R., Simpson, G., Sohar, K., Whitehouse, N. J., Williams, J. W., and Witkowski, A.: Looking forward through the past: identification of 50 priority research questions in palaeoecology, J. Ecol., 102, 256–267, doi:10.1111/1365-2745.12195, 2014.

Stansell, N. D., Abbott, M. B., Rull, V., Rodbell, D. T., Bezada, M., and Montoya, E.: Abrupt Younger Dryas cooling in the northern tropics recorded in lake sediments from the Venezuelan Andes, Earth Planet. Sci. Lett., 293, 154–163, doi:10.1016/j.epsl.2010.02.040, 2010.

Steinitz-Kannan, M., Riedinger, M. A., Last, W., Brenner, M., and Miller, M. C.: Un registro de 6000 años de manifestaciones intensas del fenómeno de El Niño en sedimentos de lagunas de las Islas Galápagos, Bull. Inst. Fr. Etudes Andin., 27, 581–592, 1998.

Stern, C. R.: Active Andean volcanism: its geologic and tectonic setting, Rev. Geológica Chile, 31, 161–206, doi:10.4067/S0716-02082004000200001, 2004.

Stuiver, M. and Polach, H. A.: Discussion; reporting of C-14 data, Radiocarbon, 19, 355–363, 1977.

Sundqvist, H. S., Kaufman, D. S., McKay, N. P., Balascio, N. L., Briner, J. P., Cwynar, L. C., Sejrup, H. P., Seppä, H., Subetto, D. A., Andrews, J. T., Axford, Y., Bakke, J., Birks, H. J. B., Brooks, S. J., de Vernal, A., Jennings, A. E., Ljungqvist, F. C., Rühland, K. M., Saenger, C., Smol, J. P., and Viau, A. E.: Arctic Holocene proxy climate database – new approaches to assessing geochronological accuracy and encoding climate variables, Clim. Past, 10, 1605–1631, doi:10.5194/cp-10-1605-2014, 2014.

Taylor, Z. P., Horn, S. P., Mora, C. I., Orvis, K. H., and Cooper, L. W.: A multi-proxy palaeoecological record of late-Holocene forest expansion in lowland Bolivia, Palaeogeogr. Palaeoecol., 293, 98–107, doi:10.1016/j.palaeo.2010.05.004, 2010.

Telford, R. J., Heegaard, E., and Birks, H. J. B.: All age–depth models are wrong: but how badly?, Quaternary Sci. Rev., 23, 1–5, doi:10.1016/j.quascirev.2003.11.003, 2004.

Thompson, L. G., Davis, M. E, Mosley-Thompson, E., Sowers, T. A., Henderson, K. A., Zagorodnov, V. S., Lin, P-N., Mikhalenko, V. N., Campen, R. K., Bolzan, J. F., Cole-Dai, J., and Francou, B.: A 25 000-year tropical climate history from Bolivian ice cores, Science, 282, 1858–1864, doi:10.1126/science.282.5395.1858, 1998.

Torres, V., Vandenberghe, J., and Hooghiemstra, H.: An environmental reconstruction of the sediment infill of the Bogotá basin (Colombia) during the last 3 million years from abiotic and biotic proxies, Palaeogeogr. Palaeoecol., 226, 127–148, doi:10.1016/j.palaeo.2005.05.005, 2005.

Traverse, A.: Paleopalynology, Unwin/Hyman Ltd., Boston-London, 1988.

Tsudaka, M.: The pollen sequence, in: The history of Laguna Petenxil, a small lake in northern Guatemala, Memoir 17, edited by: Cowgill, U., Goulden, C. E., Hutchinson, G. E., Patrick, R., Racek, A. A., and Tsudaka, M., Mem. Conn. Acad. Arts Sci., New Haven, USA, 63–66, 1967.

Turney, C. S. M. and Palmer, J. G.: Does the El Niño-Southern Oscillation control the interhemispheric radiocarbon offset?, Quaternary Res., 67, 174–180, doi:10.1016/j.yqres.2006.08.008, 2007.

Urrego, D. H., Silman, M. R., and Bush, M. B.: The Last Glacial Maximum: stability and change in a western Amazonian cloud forest, J. Quaternary Sci., 20, 693–701, doi:10.1002/jqs.976, 2005.

Urrego, D. H., Bush, M. B., and Silman, M. R.: A long history of cloud and forest migration from Lake Consuelo, Peru, Quaternary Res., 73, 364–373, doi:10.1016/j.yqres.2009.10.005, 2010.

Urrego, D. H., Bush, M. B., Silman, M. R., Niccum, B. A., De La Rosa, P., McMichael, C. H., Hagen, S., and Palace, M.: Holocene fires, forest stability and human occupation in south-western Amazonia, J. Biogeogr., 40, 521–533, doi:10.1111/jbi.12016, 2012.

Urrego, D. H., Bernal, J. P., Chiessi, C. M., Cruz, F. W., Sanchez Goñi, M. F., and Power, M.: Hooghiemstra and LaAcer participantes: Millennial-scale climate variability in the American tropics and subtropics, PAGES Mag., 22, 94–95, 2014.

Urrego, L. E., Molina, L. A., Urrego, D. H., and Ramírez, L. F.: Holocene space–time succession of the Middle Atrato wetlands, Chocó biogeographic region, Colombia, Palaeogeogr. Palaeoecol., 234, 45–61, doi:10.1016/j.palaeo.2005.10.018, 2006.

Urrego, L. E., Correa-Metrio, A., González, C., Castaño, A. R., and Yokoyama, Y.: Contrasting responses of two Caribbean mangroves to sea-level rise in the Guajira Peninsula (Colombian Caribbean), Palaeogeogr. Palaeoecol., 370, 92–102, doi:10.1016/j.palaeo.2012.11.023, 2013.

Urrego Giraldo, L. E.: Los bosques inundables del medio Caquetá (Amazonia Colombia), Caracterización y succesión, Ph.D. dissertation, University of Amsterdam, Amsterdam, The Netherlands, 1994.

Urrego Giraldo, L. E. and del Valle A. J. I.: Reconstrucción de la sucesión de un bosque de “Guandal”(Pacífico Colombiano) durante el Holoceno reciente, Caldasia, 24, 425–443, 2002.

Urrego Giraldo, L. E. and Berrío Mogollon, J. C.: Los estudios paleoecológicos en el Chocó biogeográfico durante el Holoceno medio y reciente, in: Colombia Diversidad Biótica IV, El Chocó biogeográfico/Costa Pacífica, edited by: Rangel-Ch., J. O., Universidad Nacional de Colombia, Conservación Internacional. Bogotá, Colombia, 23–38, 2011.

Valencia, B. G., Urrego, D. H., Silman, M. R., and Bush, M. B.: From ice age to modern: a record of landscape change in an Andean cloud forest: Cloud forest history: from ice age to modern, J. Biogeogr., 37, 1637–1647, doi:10.1111/j.1365-2699.2010.02318.x, 2010.

Van der Hammen, T.: Palinología de la región de la Laguna de los Bobos: Historia de su clima, vegetación y agricultura durante los últimos 5.000 años, Revista Acad. Colomb. Ci. Exact., 11, 359–361, 1962.

Van der Hammen, T.: The Pleistocene changes of vegetation and climate in tropical South America, J. Biogeogr., 1, 3–26, doi:10.2307/3038066, 1974.

Van der Hammen, T.: Data on the history of climate, vegetation and glaciation of the Sierra Nevada de Santa Marta, in: La Sierra Nevada de Santa Marta (Colombia), Transecto Buritaca-La Cumbre, Estudios de ecosistemas tropandinos, edited by: Van der Hammen, T. and Ruiz, P. M., Cramer (Borntraeger), Berlin/Stuttgart, Germany, 561–580, 1984.

Van der Hammen, T.: Stratigraphic dating and cultural sequences of Pre-hispanic northern South America, in: Archaeometry of Pre-Colombian Sites and artifacts, edited by: Scott, D. A. and Meyers, P., Proceedings of a Symposium, Los Angeles, Calofornia, USA 1992, 381–394, 1994.

Van der Hammen, T. and González, E.: Holocene and Late Glacial climate and vegetation of Paramo de Palacio (Eastern Cordillera, Colombia, South America), Geol. Mijnbouw 39, 737–746, 1960.

Van der Hammen, T. and González, E.: A late-glacial and Holocene pollen diagram from Cienaga del Visitador, Dep. Boyacá, Colombia, Leidse Geol. Meded., 32, 193–201, 1965a.

Van der Hammen, T. and González, E.: A pollen diagram from “Laguna de la Herrera” (Sabana de Bogota), Leidse Geol. Meded., 32, 183–191, 1965b.

Van der Hammen, T. and Hooghiemstra, H.: Cronostratografia y correlacion del Plioceno y Cuaternario en Colombia, Análisis Geográficos, 24, 51–67, 1995a.

Van der Hammen, T. and Hooghiemstra, H.: The El Abra stadial, a Younger Dryas equivalent in Colombia, Quaternary Sci. Rev., 14, 841–851, 1995b.

Van der Hammen, T. and Hooghiemstra, H.: Interglacial–glacial Fúquene-3 pollen record from Colombia: an Eemian to Holocene climate record, Global Planet. Change, 36, 181–199, doi:10.1016/S0921-8181(02)00184-4, 2003.

Van der Hammen, T., Barelds, J., De Jong, H., and De Veer, A. A.: Glacial secuence and Environmental History in the Sierra Nevada del Cocuy (Colombia)., Palaeogeogr. Palaeoecol., 32, 287–340, 1980/1981.

Van der Hammen, T., Urrego, L. E., Espejo, N., Duivenvoorden, J. F., and Lips, J. M.: Late-glacial and Holocene sedimentation and fluctuations of river water level in the Caquetá River area (Colombian Amazonia), J. Quaternary Sci., 7, 57–67, 1992.

Van der Hammen, T., Noldus, G., and Salazar, E.: Un diagrama de polen del Pleistoceno final y Holoceno de Mullumica, Maguaré, 17, 247–259, 2003.

Van Geel, B. and Van der Hammen, T.: Upper Quaternary vegetational and climatic secuence of the Fúquene area (Eastern Cordillera, Colombia), Palaeogeogr. Palaeoecol., 14, 9–92, 1973.

Van Meerbeeck, C. J., Renssen, H., and Roche, D. M.: How did Marine Isotope Stage 3 and Last Glacial Maximum climates differ? – Perspectives from equilibrium simulations, Clim. Past, 5, 33–51, doi:10.5194/cp-5-33-2009, 2009.

Vaughan, H.H., Deevey, E. S. J., and Garrett-Jones, S. E.: Pollen stratigraphy of two cores from Petén lake district, in: Prehistoric lowland Maya environment and subsistence economy, edited by: Pohl, M. D., Harvard University, Cambridge, USA, 73–89, 1985.

van’t Veer, R., Islebe, G. A., and Hooghiemstra, H.: Climatic change during the Younger Dryas chron in northern South America: a test of the evidence, Quaternary Sci. Rev., 19, 1821–1835, 2000.

Velásquez Montoya, R. E: Paleoecología de alta resolución del final de la última glaciación y la transición al Holoceno en el Páramo de Belmira (Antioquia), Master thesis, Universidad Nacional de Colombia, Medellín, Colombia, 2013.

Velásquez, R. C. A.: Paleoecología de alta resolución del Holoceno tardío en el Páramo de Frontino Antioquia, Ph.D. dissertation, Universidad Nacional de Colombia, Medellin, Colombia, 2004.

Velásquez, R. C. A. and Hooghiemstra, H.: Pollen-based 17-kyr forest dynamics and climate change from the Western Cordillera of Colombia; no-analogue associations and temporarily lost biomes, Rev. Palaeobot. Palynol., 194, 38–49, doi:10.1016/j.revpalbo.2013.03.001, 2013.

Velásquez, R. C. A., Parra, L. A., Sánchez, D., Rangel-Ch, J. O., Ariza, C. L., and Jaramillo, A.: Tardiglacial y Holoceno del norte de la Cordillera Occidental de Colombia, Universidad Nacional de Colombia, Medellín, 1999.

Vélez, M. I., Wille, M., Hooghiemstra, H., Metcalfe, S., Vandenberghe, J., and Van der Borg, K.: Late Holocene environmental history of southern Chocó region, Pacific Colombia; sediment, diatom and pollen analysis of core El Caimito, Palaeogeogr. Palaeoecol., 173, 197–214, 2001.

Vélez, M. I., Hooghiemstra, H., Metcalfe, S., Martínez, I., and Mommersteeg, H.: Pollen- and diatom based environmental history since the Last Glacial Maximum from the Andean core Fúquene-7, Colombia, J. Quaternary Sci., 18, 17–30, doi:10.1002/jqs.730, 2003.

Vélez, M. I., Berrío, J. C., Hooghiemstra, H., Metcalfe, S., and Marchant, R.: Palaeoenvironmental changes during the last ca. 8590 calibrated yr (7800 radiocarbon yr) in the dry forest ecosystem of the Patía Valley, Southern Colombian Andes: a multiproxy approach, Palaeogeogr. Palaeoecol., 216, 279–302, doi:10.1016/j.palaeo.2004.11.006, 2005.

Villota, A. and Behling, H.: Late quaternary vegetation, climate, and fire dynamics: human impact and evidence of past Polylepis populations in the Northern Andean Depression inferred from the El Cristal record in Southeastern Ecuador, Ecotropica, 19, 49–68, 2013.

Villota, A., León-Yánez, S., and Behling, H.: Vegetation and environmental dynamics in the Páramo of Jimbura region in the southeastern Ecuadorian Andes during the late Quaternary, J. South Amer. Earth Sci., 40, 85–93, doi:10.1016/j.jsames.2012.09.010, 2012.

Vogel, J. C. and Lerman, J. C.: Groningen radiocarbon dates VIII., Radiocarbon, 11, 351–390, 1969.

Weng, C., Bush, M. B., and Athens, J. S.: Holocene climate change and hydrarch succession in lowland Amazonian Ecuador, Rev. Palaeobot. Palynol., 120, 73–90, 2002.

Weng, C., Bush, M. B., and Chepstow-Lusty, A. J.: Holocene changes of Andean alder (Alnus acuminata) in highland Ecuador and Peru, J. Quaternary Sci., 19, 685–691, doi:10.1002/jqs.882, 2004.

Weng, C., Bush, M. B., Curtis, J. H., Kolata, A. L., Dillehay, T. D., and Binford, M. W.: Deglaciation and Holocene climate change in the western Peruvian Andes, Quaternary Res., 66, 87–96, doi:10.1016/j.yqres.2006.01.004, 2006.

Wigley, T. M. L. and Muller, A. B.: Fractionation correction in radiocarbon dating, Radiocarbon, 23, 173–190, 1981.

Wijninga, V. M.: A Pliocene Podocarpus forest mire from the area of the high plain of Bogotá (Cordillera Oriental, Colombia), Rev. Palaeobot. Palynol., 92, 157–205, 1996.

Wille, M.: Vegetation history and climate records of Colombian lowland areas: rain forest, savanna and intermontane ecosystems, Ph.D. dissertation, University of Amsterdam, Amsterdam, The Netherlands, 2001.

Wille, M. Negret, J. A., and Hooghiemstra, H.: Paleoenvironmental history of the Popayán area since 27 000 yr BP at Timbio, Southern Colombia, Rev. Palaeobot. Palynol., 109, 45–63, 2000.

Wille, M., Hooghiemstra, H., Behling, H., van der Borg, K., and Negret, A. J.: Environmental change in the Colombian subandean forest belt from 8 pollen records: the last 50 kyr, Veg. Hist. Archaeobot., 10, 61–77, 2001.

Wille, M., Hooghiemstra, H., Hofstede, R., Fehse, J., and Sevink, J.: Upper forest line reconstruction in a deforested area in northern Ecuador based on pollen and vegetation analysis, J. Trop. Ecol., 18, 409–440, doi:10.1017/S0266467402002286, 2002.

Wille, M., Hooghiemstra, H., van Geel, B., Behling, H., de Jong, A., and van der Borg, K.: Submillennium-scale migrations of the rainforest–savanna boundary in Colombia: ^{14}C wiggle-matching and pollen analysis of core Las Margaritas, Palaeogeogr. Palaeoecol., 193, 201–223, doi:10.1016/S0031-0182(03)00226-8, 2003.

Williams, J. J., Gosling, W. D., Brooks, S. J., Coe, A. L., and Xu, S.: Vegetation, climate and fire in the eastern Andes (Bolivia) during the last 18,000years, Palaeogeogr. Palaeoecol., 312, 115–126, doi:10.1016/j.palaeo.2011.10.001, 2011a.

Williams, J. J., Gosling, W. D., Coe, A. L., Brooks, S. J., and Gulliver, P.: Four thousand years of environmental change and human activity in the Cochabamba Basin, Bolivia, Quaternary Res., 76, 58–68, doi:10.1016/j.yqres.2011.03.004, 2011b.

Winsborough, B. M., Shimada, I., Newsom, L. A., Jones, J. G., and Segura, R. A.: Paleoenvironmental catastrophies on the Peruvian coast revealed in lagoon sediment cores from Pachacamac, J. Archaeol., 39, 602–614, doi:10.1016/j.jas.2011.10.018, 2012.