Supplementary Material

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**Supplementary Figure 1**. Relative abundance of the most abundant species in sediment surface samples (i.e. those with a relative abundance >3% in at least one sample) for each lake region. Area of each bar represents the fraction of a given species averaged across all samples for that lake region.

**A close up of a map

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**Supplementary Figure 2**. Lakes with LCBD (local contribution to beta diversity) significant values (without correcting for multiple testing).

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**Supplementary Figure 3.** The relationship between local contribution to beta diversity (LCBD) with local species richness across the study lakes (n=144).

A close up of a map

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**Supplementary Figure 4.** The relationship between the replacement (LCBDrepl) and richness (LCBDrich) components of the local contribution to beta diversity (LCBD) colored by lake regions.

A close up of a map

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**Supplementary Figure 5**. QQ-plots for Hierarchical Generalized Additive Models GS (a) and GI (b) fitted to beta replacement across the six lakes investigated.

**Supplementary Table 1.** List of lakes, arranged by latitude, included in the modern spatial beta diversity analysis. Regions as in Figure 1 and year of sampling are also shown.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Lake** | **Longitude** | **Latitude** | **Region** | **Year** |
| Belmira | -75.64 | 6.62 | Colombia-Andes | 2013 |
| Belmira | -75.64 | 6.62 | Colombia-Andes | 2013 |
| Belmira | -75.64 | 6.62 | Colombia-Andes | 2013 |
| Guarne | -75.52 | 6.27 | Colombia-Andes | 2001 |
| Guarne | -75.52 | 6.27 | Colombia-Andes | 2001 |
| Fuquene | -73.75 | 5.47 | Colombia-Andes | 2001 |
| Fuquene | -73.75 | 5.47 | Colombia-Andes | 2001 |
| Fuquene | -73.75 | 5.47 | Colombia-Andes | 2001 |
| Fuquene | -73.75 | 5.47 | Colombia-Andes | 2001 |
| Cucunoba | -73.78 | 5.28 | Colombia-Andes | 2001 |
| Cucunoba | -73.78 | 5.28 | Colombia-Andes | 2001 |
| Suesca | -73.78 | 5.18 | Colombia-Andes | 2001 |
| Suesca | -73.78 | 5.18 | Colombia-Andes | 2001 |
| Guatavita | -73.78 | 4.98 | Colombia-Andes | 2001 |
| Guatavita | -73.78 | 4.98 | Colombia-Andes | 2001 |
| Herrera | -74.27 | 4.69 | Colombia-Andes | 2001 |
| Herrera | -74.27 | 4.69 | Colombia-Andes | 2001 |
| Verjon | -74.02 | 4.56 | Colombia-Andes | 2001 |
| Verjon | -74.02 | 4.56 | Colombia-Andes | 2001 |
| Verjon | -74.02 | 4.56 | Colombia-Andes | 2001 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Ubaque | -73.93 | 4.50 | Colombia-Andes | 2014 |
| Yahuarcocha | -78.10 | 0.37 | Ecuador-Interandean | 2017 |
| Cuicocha | -78.37 | 0.30 | Ecuador-Andean | 2017 |
| Cunrro | -78.09 | 0.24 | Ecuador-Interandean | 2017 |
| Cubilche | -78.13 | 0.23 | Ecuador-Andean | 2017 |
| San Pablo | -78.23 | 0.22 | Ecuador-Interandean | 2017 |
| Caricocha | -78.27 | 0.14 | Ecuador-Andean | 2017 |
| Huarmicocha | -78.25 | 0.13 | Ecuador-Andean | 2017 |
| Yanacocha | -78.25 | 0.12 | Ecuador-Andean | 2017 |
| Chiriacu | -78.27 | 0.11 | Ecuador-Andean | 2017 |
| Yambo | -78.59 | -1.10 | Ecuador-Interandean | 2017 |
| Colta-2 | -78.76 | -1.73 | Ecuador-Interandean | 2017 |
| Kuyuk | -78.50 | -2.18 | Ecuador-Andean | 2017 |
| Fondococha | -79.24 | -2.76 | Ecuador-Andean | 2017 |
| Dos Chorreras | -79.16 | -2.77 | Ecuador-Andean | 2015 |
| Toreadora | -79.22 | -2.78 | Ecuador-Andean | 2014 |
| Marmolcocha | -79.22 | -2.78 | Ecuador-Andean | 2017 |
| Patoquinuas | -79.21 | -2.78 | Ecuador-Andean | 2014 |
| Llaviucu | -79.15 | -2.84 | Ecuador-Andean | 2017 |
| Lagunas de Napalé | -79.30 | -2.89 | Ecuador-Andean | 2014 |
| Jigeno | -79.29 | -2.91 | Ecuador-Andean | 2017 |
| Estrellascocha | -79.25 | -2.91 | Ecuador-Andean | 2017 |
| L. Tauli, shore | -76.07 | -10.72 | JuninPlain | 1999 |
| L. Ccochachuycho, shore | -76.07 | -10.76 | JuninPlain | 1999 |
| L. Lulicocha, shore | -76.10 | -10.78 | JuninPlain | 1999 |
| L. Lulicocha, shore | -76.10 | -10.78 | JuninPlain | 1999 |
| Junin 10, Tambo del Sol | -76.13 | -10.81 | JuninPlain | 1999 |
| Junin 10, Tambo del Sol | -76.13 | -10.81 | JuninPlain | 1999 |
| Junin 9, ditch before Shelby | -76.23 | -10.81 | JuninPlain | 1999 |
| Junin 9, ditch before Shelby | -76.23 | -10.81 | JuninPlain | 1999 |
| L. Yanacocha, shore | -76.04 | -10.83 | JuninPlain | 1999 |
| L. Yanacocha, shore | -76.04 | -10.83 | JuninPlain | 1999 |
| L. Purun, center | -76.46 | -10.84 | JuninPlain | 1999 |
| L. Purun, shore | -76.45 | -10.84 | JuninPlain | 1999 |
| L. Purun, shore | -76.45 | -10.84 | JuninPlain | 1999 |
| Yanacocha 3, spring | -75.97 | -10.86 | JuninPlain | 1999 |
| Yanacocha 3, spring | -75.97 | -10.86 | JuninPlain | 1999 |
| Yanacocha 1, wetland | -75.99 | -10.86 | JuninPlain | 1999 |
| Yanacocha 2, inflow stream | -75.98 | -10.86 | JuninPlain | 1999 |
| Yanacocha 4, outlet channel | -76.00 | -10.87 | JuninPlain | 1999 |
| Junin 14, Palcamayo R. | -76.05 | -10.91 | JuninPlain | 1999 |
| Junin 8, Upamayo Bridge | -76.26 | -10.92 | JuninPlain | 1999 |
| Junin 8, Upamayo Bridge | -76.26 | -10.92 | JuninPlain | 1999 |
| Junin 11, Gunoc Km 255 | -76.05 | -10.94 | JuninPlain | 1999 |
| Junin 11, Gunoc Km 255 | -76.05 | -10.94 | JuninPlain | 1999 |
| Junin 11, Gunoc Km 255 | -76.05 | -10.94 | JuninPlain | 1999 |
| Junin 7, San Pedro de Pari | -76.23 | -10.96 | JuninPlain | 1999 |
| Junin 13, Qda. Anascanchi | -76.04 | -10.98 | JuninPlain | 1999 |
| L. Junin, center | -76.06 | -11.00 | JuninPlain | 1999 |
| L. Junin, center | -76.06 | -11.00 | JuninPlain | 1999 |
| Junin 12, Chacpas | -76.01 | -11.00 | JuninPlain | 1999 |
| Junin 6, Chuchucancha R. | -76.19 | -11.04 | JuninPlain | 1999 |
| Junin 6, Chuchucancha R. | -76.19 | -11.04 | JuninPlain | 1999 |
| Junin 5, Conoc spring | -76.16 | -11.06 | JuninPlain | 1999 |
| Junin 5, Conoc spring | -76.16 | -11.06 | JuninPlain | 1999 |
| L. Junin, shore | -76.16 | -11.06 | JuninPlain | 1999 |
| L. Junin, shore | -76.16 | -11.06 | JuninPlain | 1999 |
| Junin 4, Ondores spring | -76.15 | -11.08 | JuninPlain | 1999 |
| Junin 4, Ondores spring | -76.15 | -11.08 | JuninPlain | 1999 |
| L. Alcacocha, shore | -75.94 | -11.08 | JuninPlain | 1999 |
| Junin 2, Warmipuquio spring | -76.09 | -11.11 | JuninPlain | 1999 |
| Junin 2, Warmipuquio spring | -76.09 | -11.11 | JuninPlain | 1999 |
| Junin 2, Warmipuquio spring | -76.09 | -11.11 | JuninPlain | 1999 |
| Junin 3, spring 2 | -76.09 | -11.12 | JuninPlain | 1999 |
| Junin 1, Chacachimpa R. | -76.02 | -11.17 | JuninPlain | 1999 |
| Huagapo Cave, inside | -75.79 | -11.27 | JuninPlain | 1999 |
| Huagapo Cave, outside | -75.79 | -11.27 | JuninPlain | 1999 |
| L. Paca, inflow stream | -75.51 | -11.72 | JuninPlain | 1999 |
| L. Paca, inflow stream | -75.51 | -11.72 | JuninPlain | 1999 |
| L. Paca, 12m deep | -75.51 | -11.73 | JuninPlain | 1999 |
| Huamanmarca | -72.37 | -13.03 | Peruvian Andes | 2009 |
| Miski | -72.37 | -13.03 | Peruvian Andes | 2009 |
| Cusco-PLS-2 | -72.13 | -13.40 | Cusco | 2011 |
| Cusco-PLS-13 | -71.69 | -13.40 | Cusco | 2011 |
| Cusco-PLS-1 | -72.05 | -13.42 | Cusco | 2011 |
| Pacucha | -73.32 | -13.62 | Peruvian Andes | 2009 |
| Cusco-PLS-11 | -71.72 | -13.62 | Cusco | 2011 |
| Cusco-PLS-5 | -70.25 | -13.86 | Cusco | 2011 |
| Cusco-PLS-7 | -70.31 | -13.86 | Cusco | 2011 |
| Cusco-PLS-8 | -70.30 | -13.91 | Cusco | 2011 |
| Cusco-CH1 | -70.87 | -13.92 | Cusco | 2011 |
| Cusco-PLS-6 | -70.31 | -13.93 | Cusco | 2011 |
| Cusco-DP1 | -70.90 | -13.94 | Cusco | 2011 |
| Cusco-YC1 | -70.87 | -13.95 | Cusco | 2011 |
| Cusco-IA1 | -70.90 | -13.95 | Cusco | 2011 |
| Acopia | -71.52 | -14.08 | Peruvian Andes | 2009 |
| Cusco-PLS-12 | -71.46 | -14.13 | Cusco | 2011 |
| Cusco-PLS-3 | -71.72 | -14.58 | Cusco | 2011 |
| Cusco-PLS-4 | -71.71 | -14.59 | Cusco | 2011 |
| Cusco-PLS-9 | -70.50 | -14.73 | Cusco | 2011 |
| Cusco-PLS-10 | -70.94 | -15.09 | Cusco | 2011 |
| Titicaca-lake | -69.21 | -15.26 | Titicaca-lake | 1996 |
| Titicaca-lake | -69.21 | -15.26 | Titicaca-lake | 1996 |
| Titicaca-lake | -69.07 | -15.37 | Titicaca-lake | 1996 |
| Titicaca-lake | -69.07 | -15.37 | Titicaca-lake | 1996 |
| Chacas | -70.20 | -15.41 | Peruvian Andes | 2003 |
| Titicaca-lake | -69.62 | -15.53 | Titicaca-lake | 1996 |
| Umapata | -70.05 | -15.54 | Peruvian Andes | 2003 |
| Pacuna | -70.21 | -15.58 | Peruvian Andes | 2003 |
| Lake 6 | -70.20 | -15.66 | Peruvian Andes | 2003 |
| Lagunillas | -70.68 | -15.75 | Peruvian Andes | 2003 |
| Sara Cocha | -70.61 | -15.78 | Peruvian Andes | 2003 |
| Ululumasa | -70.60 | -15.78 | Peruvian Andes | 2003 |
| Titicaca-lake | -69.70 | -15.81 | Titicaca-lake | 1998 |
| Titicaca-lake | -69.75 | -15.83 | Titicaca-lake | 1996 |
| Maquera | -70.56 | -15.88 | Peruvian Andes | 2003 |
| Calzada | -70.51 | -15.90 | Peruvian Andes | 2003 |
| Titicaca-lake | -69.44 | -15.96 | Titicaca-lake | 1998 |
| Titicaca-lake | -69.32 | -16.04 | Titicaca-lake | 1996 |
| Titicaca-lake | -69.32 | -16.04 | Titicaca-lake | 1996 |
| Khara Kkota (north) | -68.36 | -16.13 | Peruvian Andes | 2003 |
| Titicaca-lake | -69.15 | -16.22 | Titicaca-lake | 1996 |
| Estrellani | -68.04 | -16.34 | Peruvian Andes | 2003 |
| Jacumarini | -70.39 | -16.36 | Peruvian Andes | 2003 |
| Asiruni | -70.37 | -16.39 | Peruvian Andes | 2003 |
| Laja | -68.39 | -16.53 | Peruvian Andes | 2003 |
| Jachcha Kkota | -68.17 | -16.58 | Peruvian Andes | 2003 |
| Chara Nkkota | -68.16 | -16.58 | Peruvian Andes | 2003 |
| Lake 27 | -68.27 | -16.62 | Peruvian Andes | 2003 |
| Rio Desaguadero: downstream from Desaguadero | -68.97 | -16.64 | Desaguadero-SAltiplano | 2001 |
| Lake 23 | -68.32 | -16.68 | Peruvian Andes | 2003 |
| Rio Desaguadero: Nazacara N. | -68.80 | -16.88 | Desaguadero-SAltiplano | 2001 |
| Lake 34 | -68.95 | -16.91 | Peruvian Andes | 2003 |
| Laguna Desaguadero | -68.79 | -16.98 | Desaguadero-SAltiplano | 2001 |
| Rio Desaguadero at Parco Khota | -68.68 | -17.21 | Desaguadero-SAltiplano | 2001 |
| Rio Mauri | -68.63 | -17.29 | Desaguadero-SAltiplano | 2001 |
| Rio Desaguadero Bridge (pipeline) | -68.62 | -17.31 | Desaguadero-SAltiplano | 2001 |
| Flood Plain Pond near Pipeline | -68.62 | -17.33 | Desaguadero-SAltiplano | 2001 |
| Laguna Blanca S. Rio Jalsuri Uma | -68.55 | -17.47 | Desaguadero-SAltiplano | 2001 |
| Salcro Tarquiamaya | -68.59 | -17.48 | Desaguadero-SAltiplano | 2001 |
| Rio Quebrada Huajra Uma | -68.42 | -17.50 | Desaguadero-SAltiplano | 2001 |
| Laguna Challacaba | -65.57 | -17.60 | Desaguadero-SAltiplano | 2007 |
| Huancaroma Dairy | -67.48 | -17.66 | Desaguadero-SAltiplano | 2001 |
| Huancaroma Dairy | -67.48 | -17.67 | Desaguadero-SAltiplano | 2001 |
| Laguna Soledad (Uru Uru) | -67.31 | -17.75 | Desaguadero-SAltiplano | 2001 |
| Rio Desaguadero Balsa Crossing | -67.09 | -18.20 | Desaguadero-SAltiplano | 2001 |
| Rio Desaguadero | -67.04 | -18.35 | Desaguadero-SAltiplano | 2001 |
| Rio Desaguadero: Poopo (town) | -67.05 | -18.37 | Desaguadero-SAltiplano | 2001 |
| Rio Poopo drainage | -67.02 | -18.38 | Desaguadero-SAltiplano | 2001 |
| Road tracks & N Lago Poopo plain | -67.00 | -18.55 | Desaguadero-SAltiplano | 2001 |
| N Lago Poopo plain | -66.95 | -18.57 | Desaguadero-SAltiplano | 2001 |
| Salar de Uyuni | -67.66 | -20.14 | Sud Lipez | 1991 |
| Laguna Canapa | -68.01 | -21.51 | Sud Lipez | 2002 |
| Chulluncani | -67.88 | -21.53 | Sud Lipez | 2002 |
| Chulluncani | -67.88 | -21.53 | Sud Lipez | 2002 |
| Laguna Hedionda | -68.07 | -21.57 | Sud Lipez | 2002 |
| Chiar Kkota | -68.07 | -21.58 | Sud Lipez | 2002 |
| Honda | -68.07 | -21.62 | Sud Lipez | 2002 |
| Pujio | -68.07 | -21.62 | Sud Lipez | 2002 |
| Ballivian | -68.08 | -21.63 | Sud Lipez | 2002 |
| Laguna Ramaditas | -68.08 | -21.64 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Pastos Grandes | -67.78 | -21.65 | Sud Lipez | 2002 |
| Cachi | -67.95 | -21.72 | Sud Lipez | 2002 |
| Laguna Cachi | -67.95 | -21.73 | Sud Lipez | 1991 |
| Laguna Colorada | -67.78 | -22.18 | Sud Lipez | 2002 |
| Laguna Colorada | -67.78 | -22.18 | Sud Lipez | 2002 |
| Puripica | -67.50 | -22.52 | Sud Lipez | 2002 |
| Laguna Chairiri | -67.65 | -22.53 | Desaguadero-SAltiplano | 2001 |
| Laguna Verde | -67.80 | -22.80 | Sud Lipez | 2002 |
| Laguna Canchuca | -70.59 | -32.09 | Chile-Andean | 2013 |
| Chepical | -70.50 | -32.26 | Chile-Andean | 2013 |
| Laguna Copín | -70.56 | -32.60 | Chile-Andean | 2013 |
| Laguna del Inca | -70.13 | -32.82 | Chile-Andean | 2013 |
| Laguna Negra-Chile | -70.13 | -33.65 | Chile-Andean | 2013 |
| Laguna Ocho | -70.32 | -34.03 | Chile-Andean | 2013 |
| Laguna de Teno | -70.55 | -35.18 | Chile-Andean | 2013 |

**Supplementary Table 2.** Predictive ability (total deviance of out-of-sample) for Hierarchical Generalized Additive Models GS and GI applied to the beta replacement component.

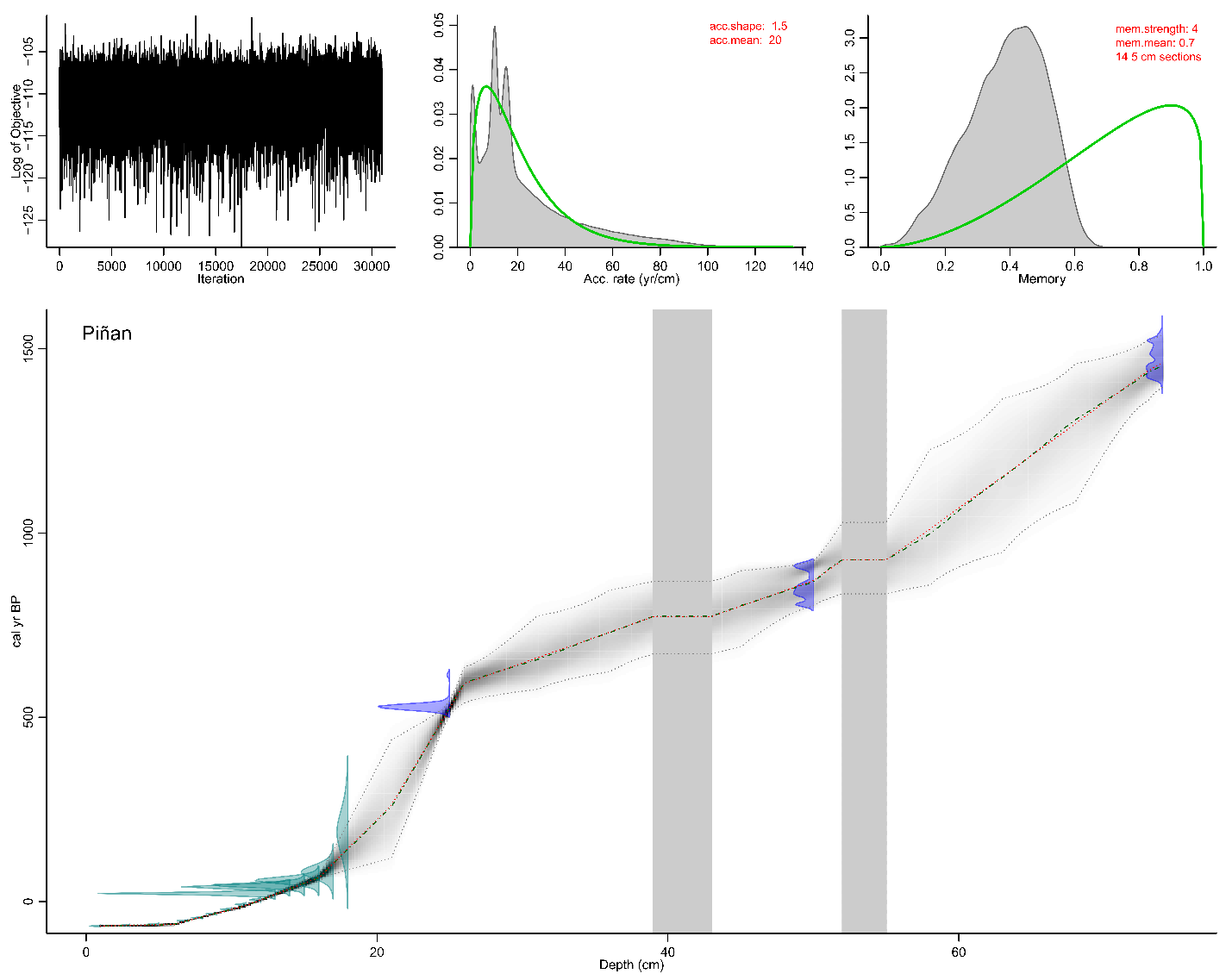
|  |  |  |  |
| --- | --- | --- | --- |
| **Lake** | **Intercept only** | **Model GS** | **Model GI** |
| Fondococha | 30 | 25 | 23 |
| Llaviucu | 11 | 8.7 | 7.4 |
| Piñan | 8.6 | 6.4 | 5.7 |
| Titicaca | 23 | 17 | 14 |
| Umayo | 6.9 | 6.2 | 5.2 |
| Yahuarcocha | 9.2 | 7.9 | 7.9 |

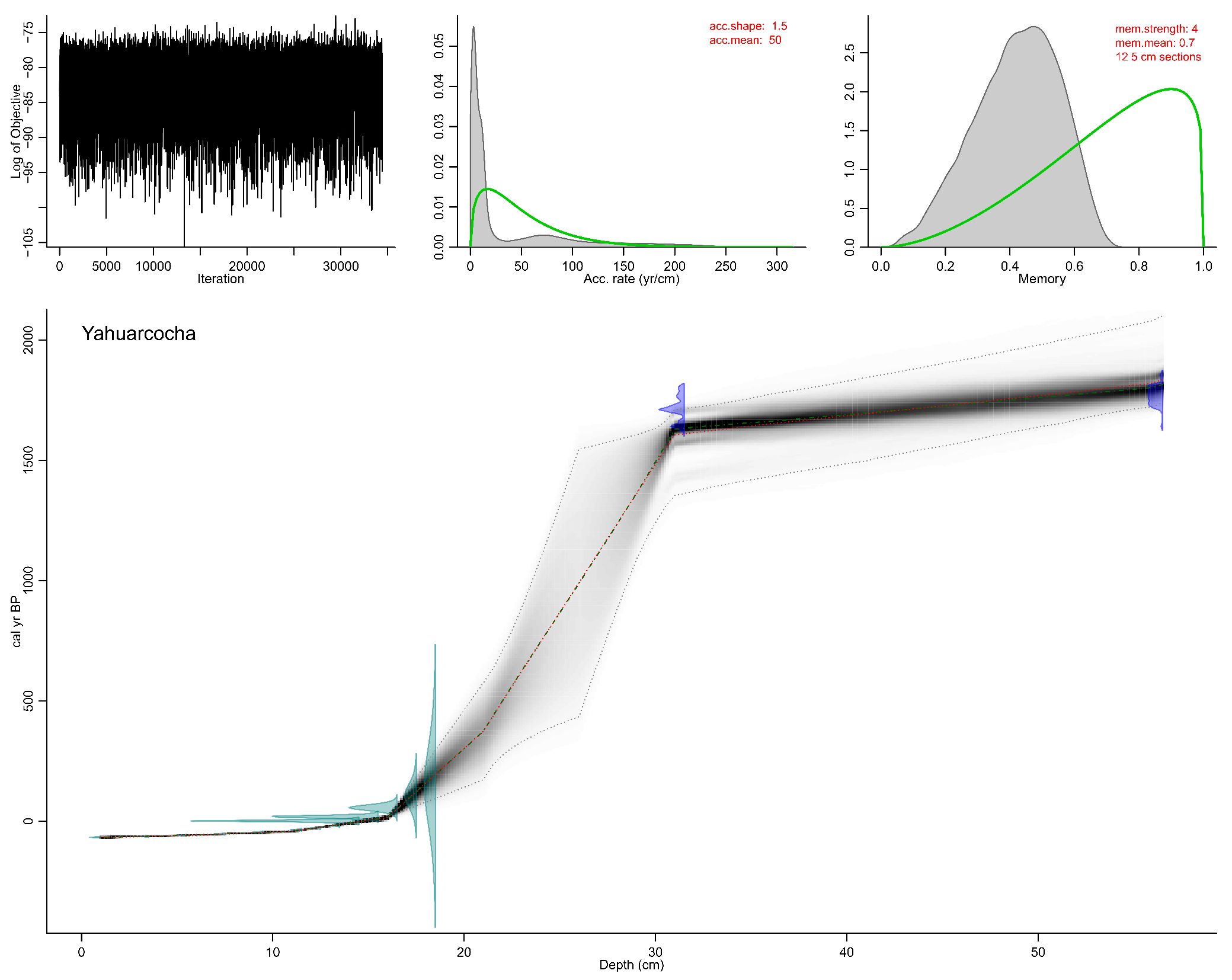
**Sediment chronologies.** Age-depth models of the investigated lakes in the Andes of Ecuador: Piñan, Yahuarcocha, Fondococha and Llaviucu. The 210Pb chronologies were calculated using the constant-rate-of-supply model (Appleby and Oldfield, 1978). In all cores, the entire inventory of unsupported 210Pb was contained within the top 20 cm. 14C ages were calibrated with the IntCal13 calibration curve (Reimer et al., 2013). For each core, a Bayesian age-depth model was generated using the R package *rbacon* (Blaauw and Christen 2018).

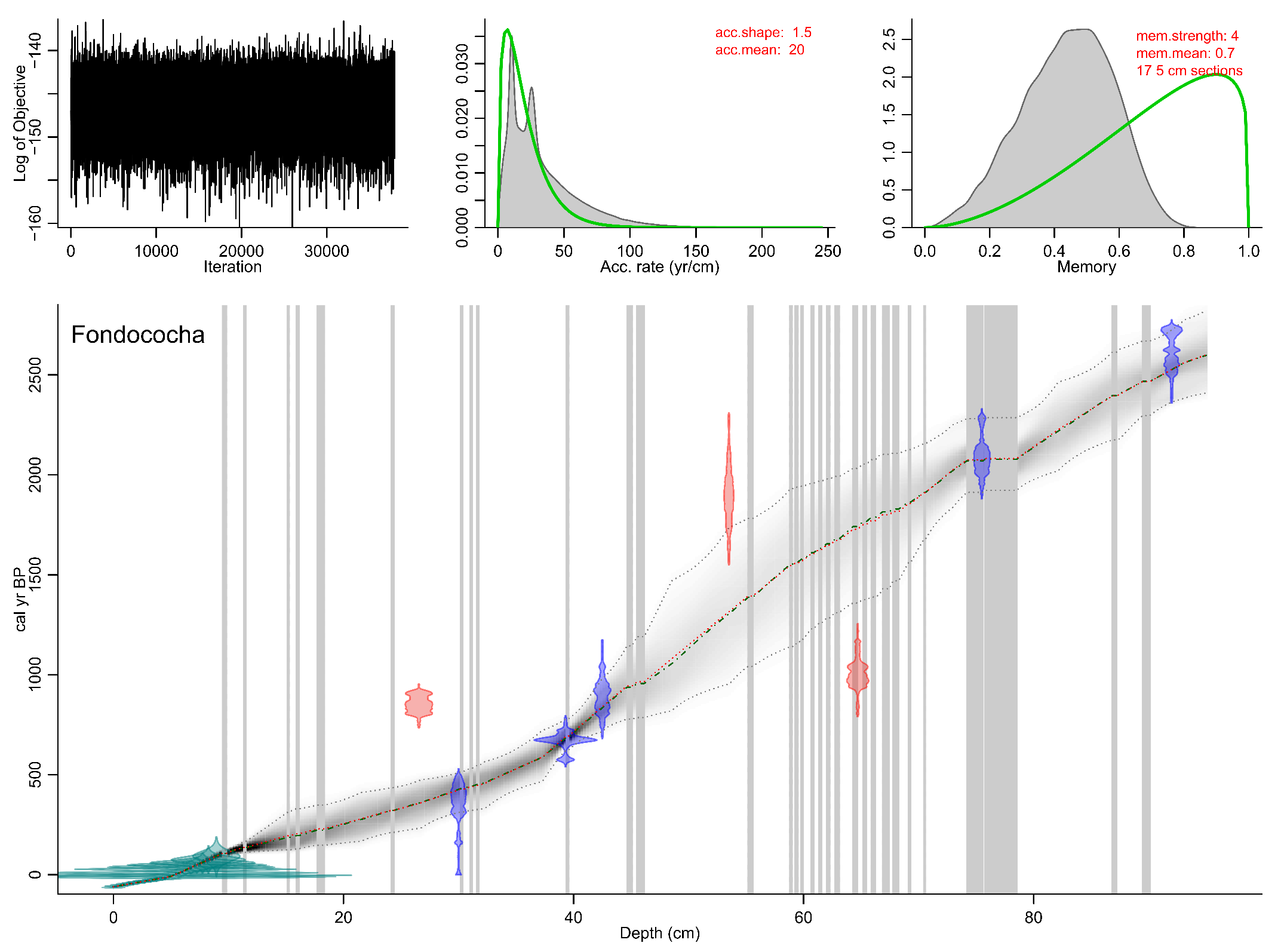
**Supplementary Table 3.** Summary of the radiocarbon data of lakes Piñan (PIN), Yahuarcocha (YAH), Fondococha (FON) and Llaviucu (LLA), including sample depth, sample type, 14C ages, and the calibrated ages. Dates reported for Lakes Fondococha and Llaviucu were taken from Arcusa et al. (2020).

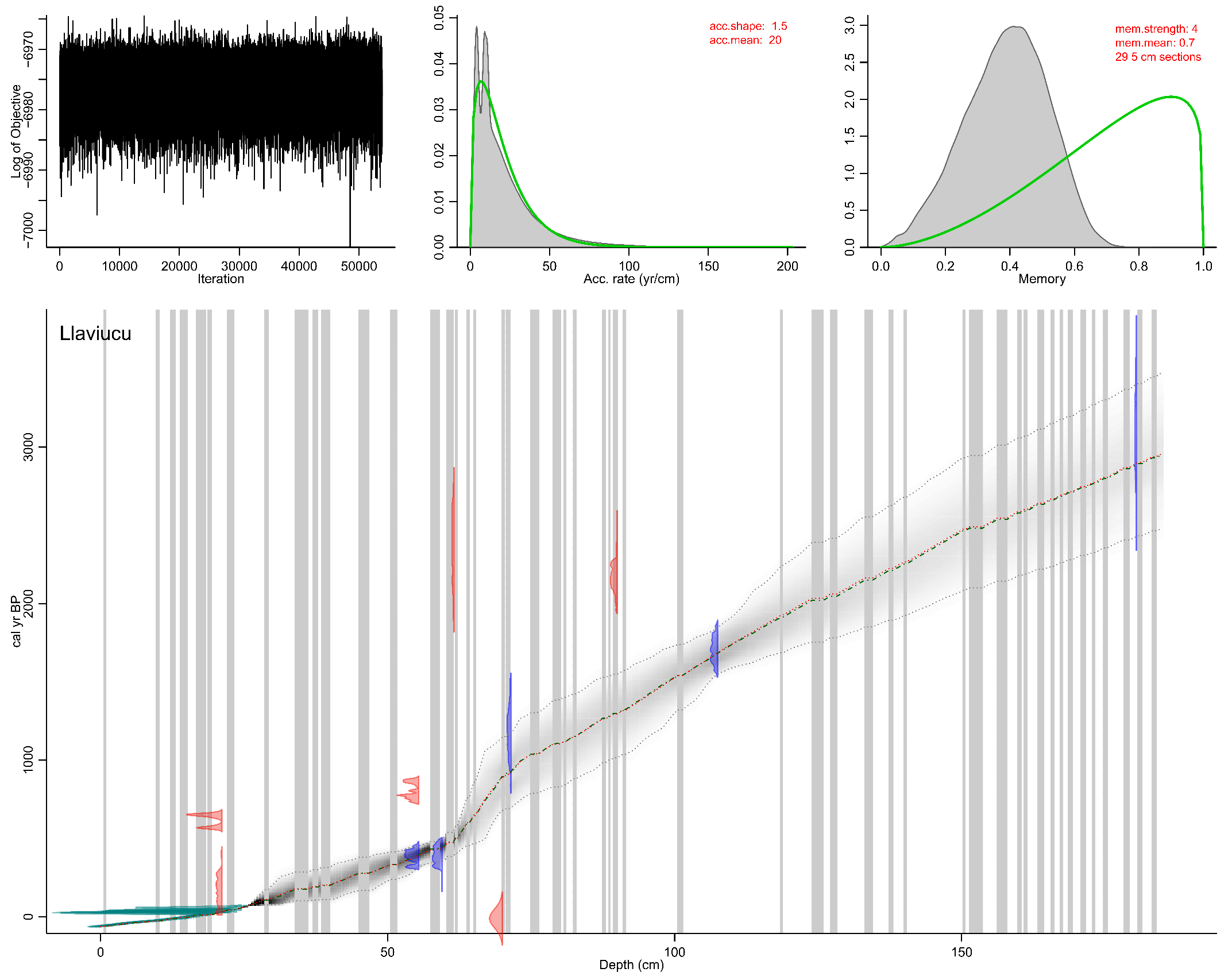
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Lake | Depth | LAB ID | Type | 14C age (yr BP) | Cal. age (cal. yr BP) |
| PIN | 24 | OS-139509 | Macrophyte | 510 ± 15 | 528 ± 13 |
| PIN | 49 | OS-139676 | Macrophyte | 950 ± 15 | 834 ± 37 |
| PIN | 73 | OS-139677 | Macrophyte | 1590 ± 15 | 1502 ± 30 |
| YAH | 31.5 | OS-141027 | Sediment organic carbon | 1790 ± 15 | 1608 ± 365 |
| YAH | 56.5 | OS-139544 | Sediment organic carbon | 1830 ± 15 | 1840 ± 416 |
| FON\*\* | 26.55 | BE-3530.1.1 | Bulk sediment | 940 ± 26 | 853 ± 39 |
| FON | 30 | BE-3520.1.1 | Seed; Carex tricuspid | 301 ± 62 | 377 ± 92 |
| FON | 39.3 | BE-4783.1.1 | *Loricaria* leaf fragment | 726 ± 38 | 675 ± 34 |
| FON | 42.5 | BE-10950.1.1 | Periderm and grass fragment | 989 ± 67 | 890 ± 75 |
| FON\*\* | 53.5 | BE-10953.1.1 | Charred twig fragments | 1943 ± 99 | 1893 ± 126 |
| FON\*\* | 64.7 | BE-4782.1.1 | *Loricaria* leaf fragment | 1080 ± 51 | 996 ± 56 |
| FON | 75.5 | BE-10952.1.1 | Charred twig fragments | 2104 ± 50 | 2079 ± 82 |
| FON | 92 | BE-10951.1.1 | Bark fragment | 2540 ± 41 | 2620 ± 85 |
| LLA\*\* | 21.15 | BE-3518.1.1 | Isolepsis and *Loricaria* fragments | 157 ± 78 | 163 ± 101 |
| LLA\*\* | 21.15 | BE-3527.1.1 | Bulk sediment | 682 ± 34 | 650 ± 41 |
| LLA | 55.45 | BE-3519.1.1 | *Loricaria* leaf fragments | 317 ± 22 | 387 ± 43 |
| LLA\*\* | 55.45 | BE-3528.1.1 | Bulk sediment | 891 ± 22 | 804 ± 52 |
| LLA | 59.5 | BE-4778.1.1 | Wood and *Loricaria* fragments | 332 ± 44 | 392 ± 55 |
| LLA\*\* | 61.6 | BE-4779.1.1 | Seed husk | 2378 ± 235 | 2438 ± 284 |
| LLA\*\* | 70 | BE-10954.1.1 | Unidentified | -24 ± 63 | 100 ± 78 |
| LLA | 71.5 | BE-4780.1.1 | *Loricaria* leaf fragment | 1274 ± 171 | 1184 ± 170 |
| LLA\*\* | 90 | BE-10956.1.1 | Grass and twig fragments | 2239 ± 85 | 2233 ± 110 |
| LLA | 107.5 | BE-10955.1.1 | Bark and grass fragments | 1781 ± 68 | 1704 ± 83 |
| LLA\*\* | 108.5 | BE-3529.1.1 | Bulk sediment | 2248 ± 23 | 2227 ± 55 |
| LLA\*\* | 180.5 | BE-4781.1.1 | Seed fragments | 2923 ± 356 | 3109 ± 445 |

\*\* dates are outliers, details in Arcusa et al., (2020)

**Supplementary Figure 6**. Age-depth model of lake Piñan. The red line indicates the mean age-depth model, the green line represents the median age-depth model. The turqoise distribution curves represent the 210Pb-samples, the blue distribution curves represent the 14C samples. Grey shades represent the 95% confidence interval and the grey vertical bars indicate masked layers.

**Supplementary Figure 7**. Age-depth model of lake Yahuarcocha. The red line indicates the mean age-depth model, the green line represents the median age-depth model. The turqoise distribution curves represent the 210Pb-samples, the blue distribution curves represent the 14C samples. Grey shades represent the 95% confidence interval and the grey vertical bars indicate masked layers.

**Supplementary Figure 8**. Age-depth model of lake Fondococha. The red line indicates the mean age-depth model, the green line represents the median age-depth model. The turqoise distribution curves represent the 210Pb-samples, the blue distribution curves represent the 14C samples, the red distribution curves show outliers that were not included in the final age-model (details can be found in Arcusa et al., 2020). Grey shades represent the 95% confidence interval and the grey vertical bars indicate masked layers.

**Supplementary Figure 9**. Age-depth model of lake Llaviucu. The red line indicates the mean age-depth model, the green line represents the median age-depth model. The turqoise distribution curves represent the 210Pb-samples, the blue distribution curves represent the 14C samples, the red distribution curves show outliers that were not included in the final age-model (details can be found in Arcusa et al., 2020). Grey shades represent the 95% confidence interval and the grey vertical bars indicate masked layers.

**Diatom stratigraphies**

**A picture containing computer

Description automatically generated**

**Supplementary Figure 10**. Lake Llaviucu’s diatom stratigraphy. Diatom species are those with a relative abundance >3% in at least one sample.

Lake Llaviucu’s diatom record was dominated by benthic taxa, including *Achnanthidium minutissimum*, and followed by the less abundant *Nupela* sp.1, *Brachysira microcephala*, *Cymbella cymbiformis*, *Encyonopsis* sp., *Denticula kuetzingii*, and *Gomphonema* spp. Planktic taxa fluctuated over the core (up to 25% relative abundance), with a clear shift towards the top of the core to planktic dominated assemblage of *Discostella stelligera* and *Tabellaria flocculosa* and benthic *Diatoma tenuis*.

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**Supplementary Figure 11.** Figure Lake Yahuarcocha’s diatom stratigraphy. Diatom species are those with a relative abundance >3% in at least one sample.

Yahuarcocha was dominated by a mixture of planktic (*Aulacoseira ambigua*, ~20-40% relative abundance), benthic (*Nitzschia* cf *archibaldii*, *Achnanthidium minutissimum*; *Nitzschia amphibia*, *Cocconeis placentula*; ~20%), and tychoplanktic (*Fragilaria tenera*, *Ulnaria* cf *ulna*; ~10-20%) taxa. The decrease of saline diatoms (*Craticula halophila*) at *ca* 1000 cal yr BP was concomitant with the increase in planktic and tychoplanktic taxa towards the top of the core.

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**Supplementary Figure 12.** Figure Lake Piñan’s diatom stratigraphy. Diatom species are those with a relative abundance >3% in at least one sample.

The dominant taxa in Lake Piñan were benthic *Nitzschia* species (~20-30% relative abundance), namely *Nitzschia* cf *clandestina*, and *Nitzschia oberheimiana*, followed by smaller proportions of the benthic species *Brachysira* *microcephala*, *Encyonopsis* cf *krammerioides, Navicula radiosa,* and *Achnanthidium minutissimum.* The planktic *Tabellaria fenestrata* showed an increase, albeit minor (~8% relative abundance), towards the top of the core, as well as other tychoplanktic species (*Staurosirella pinnata*).

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**Supplementary Figure 13.** Figure Lake Fondococha’s diatom stratigraphy. Diatom species are those with a relative abundance >3% in at least one sample.

Through the record, planktic *Aulacoseira* taxa (*A*. cf *distans* and *A. alpigena*) dominated the diatom assemblage (~40-80% relative abundance), followed by benthic *Achnanthidium minutissimum*, *Navicula* spp., and *Nitzschia oberheimiana*. The tychoplanktic *Fragilaria capucina* increased in relative abundance towards the top of the core but remained as a common component of the assemblage throughout the core.

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**Supplementary Figure 14.** Figure Lake Umayo’s diatom stratigraphy. Diatom species are those with a relative abundance >5% in at least one sample. Adapted from Ekdahl et al. (2008)

Throughout the core, eight species dominate the diatom assemblages: *Nitzschia* spp., *Denticula elegans*, *Cocconeis placentula*, *Nitzschia fonticola*/ *lacuum*, *Cyclostephanos andinus*, *Discostella stelligera*, *Pseudostaurosira zeilleri*, *Gomphonema vibrio*, and *Nitzschia* cf *frustulum*. In general, there is a decrease of benthic and saline diatom abundance from the mid Holocene to the present. Freshwater planktic diatoms began to be a significant component from the mid Holocene.

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**Supplementary Figure 15.** Figure Lake Titicaca’s diatom stratigraphy. Diatom species are those with a relative abundance >3% in at least one sample. Adapted from Weide et al. (2017)

Eight dominant species make up the majority of the flora: *Cocconeis titicaensis*, *Cocconeis* spp. (mostly *C. placentula*), *Fragilaria crotonesis, Ephitemia spp., Cyclostephanos andinus, Denticula kuetzingii,* and *Cyclotella meneghiniana*. There is a general decrease of the mesoeutrophic planktic species C. meneghiniana from the mid Holocene to the present, accompanied with increase of the epiphytic *C. placentula*, and *C. andinus*, indicating a freshening trend throughout the reminder of the record.

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