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The Bolivian Radiocarbon Database: A Countrywide Compilation of Radiocarbon Dates

DATA PAPER

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ABSTRACT

The radiocarbon dating record from sites in the territory that comprises the Plurinational State of Bolivia has been previously included in datasets that are either obsolete, inaccurate, or incomplete. The Bolivian Radiocarbon Database compiles over three thousand radiocarbon dates produced in the context of archaeological and other paleo-scientific research. By conducting an exhaustive review and correcting various errors from previous regional datasets, this database currently incorporates the largest and most accurate information of radiocarbon dates from the country of Bolivia. In addition to describing how the data was collected and the structure of the database, here I also summarize some general patterns and emergent trends from this data.

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(1) OVERVIEW

CONTEXT

Since its discovery over seven decades ago, radiocarbon (^{14}C) dating has unquestionably become one of the most useful and widely applied chronometric methods for conducting archaeological and other paleo-scientific research [1, 2, 3, 4]. Although generally used to date past events and processes and address specific research questions at a site or micro-scale level, meta-analyses of aggregated and Bayesian modeling of ^{14}C dates, are increasingly facilitating reconstructing population change over time and interrogating the possible link among various climatological, environmental, and sociopolitical processes at meso and macro spatiotemporal scales [5, 6]. As radiocarbon dating enters the realm of big data, meta-analyses depend on no small measure on the quality as much as the quantity of available data [7, 8, 9, 10]. Therefore, reliable compilations or lists of available radiocarbon dates and their associated spatial and contextual information are critical [11, 12]. While there have been important efforts to compile radiocarbon data from various regions, in some cases these attempts have been rather insufficient and can incorporate various errors. Moreover, in regions where sample sizes are relatively small, such as countries where funding for research has been historically limited, disregarding existing data can be especially detrimental and accentuate certain biases. Therefore, there is an opportunity to improve these datasets by revisiting and facilitating the best information available. Here, I present the most detailed and updated database of radiocarbon dates available for the entire country of Bolivia.

Archaeological Dates

The first compilations of radiocarbon dates from Bolivia were published as lab reports in the journal *Radiocarbon*. Although some of these dates were collected in the context of integrative research efforts, others were analyzed as part of collaborations between national and foreign researchers and often correspond to small sample sizes. For instance, Alfred Kidder II conducted excavations at the sites of Chiripa and Tiwanaku in 1955 with the specific goal of resolving the chronology of these monumental sites in the Lake Titicaca basin and although he never fully published his results, part of his notes are included as part of the University of Pennsylvania's Radiocarbon lab reports [13, 14]. Around this time, the Bolivian archaeologist Carlos Ponce Sanginés [15] began reaching out to labs and researchers for analyzing samples from Tiwanaku and other sites as he advocated using radiocarbon dating as a fundamental method for building the country's deep time culture-history. Ponce Sanginés also wrote the Foreword of the Spanish edition of Willard Libby's [16] *Radiocarbon Dating* book, which cites a sample of *Sterculia excelsa* from Copacabana in Lake Titicaca to verify the uniform latitudinal and elevational concentration of modern atmospheric radiocarbon [17]. In line with a Nationalist policy of centralizing research and dictating the narrative of the country's past, Ponce created the FRB (fechado radiocarbónico boliviano) code system, which although never fully published, it included at least 63 ^{14}C dates, most of which were from Tiwanaku [18].

Rogger Ravines [19] included in his influential *Panorama de la Arqueología Andina* a ledger of 86 radiocarbon dates from Bolivia. Building on this list but expanding its associated data by consulting laboratory and archaeological reports, Ziólkowski, Krzanowski, and Michczynski [20] produced a major compilation that included 99 radiocarbon dates from Bolivia. This compilation is thorough and comprises detailed information on each sample's provenience, context, material dated, and with a few exceptions, includes accurate information about most radiocarbon dates collected in the country prior to 1990. Nevertheless, a few records that should be excluded from archaeological meta-analyses include: Patapatani (W-367), La Paz, Ri.5 (W-949), Colchani, SU-4 (W-3695), Lake Titicaca (GrN-12677), and Buena Vista Mine (Hv-87), which were collected as part of paleoecological research [21, 22, 23, 24]. A slightly updated version of this dataset is available online since 2013 as the "Andes ^{14}C Radiocarbon Database for the Central Andes" and in its most recent version includes 220 dates from Bolivia, 69 from Argentina, 266 from Chile, 783 from Ecuador and 2685 from Peru, totalizing 4023 dates [25]. For Bolivia, the recent update includes additional dates from Tiwanaku [26], Chiripa [27], Lípez [28], and Santa Lucía [29]. Although this database is a very useful resource it is incomplete and introduces a few mistakes such as the duplication of sample ETH-5639 (incorrectly included a second time as SMU-5639) and a typo on date ETH-5980 (which should be ETH-5940).

More recent compilations emphasize specific regions and time periods. For instance, in reviewing early human occupations in Bolivia, Capriles and Albarracin-Jordan [30] reference about a dozen ^{14}C dates older than 4000 years, stressing the limited research about this time period. In analyzing the temporal transition between the Archaic and Formative periods in the Altiplano, Marsh [31] lists 106 dates from Bolivia and 92 from Peru. In reconstructing south central Andean regional demography, Gayo et al. [32] introduced the South-Central Andes Radiocarbon (SCAR) including 202 dates from 58 sites in Bolivia. In modeling the synchronicity between population and climate change, de Souza et al. [33] compiled radiocarbon dates from different regions within Amazonia, including 124 from sites in the Bolivian tropical lowlands, most of which were produced in the context of the Bolivian-German archaeological project [34, 35, 36].

In terms of broader-scale compilations, [37] on their continent-wide analysis of human occupation in South America, include 109 dates from 23 sites in Bolivia. Although somewhat inconsistently referenced, all of their Bolivian dates were previously included in a few studies [31, 32, 38]. In addition, they include two dates from the nonexistent site of Cochamba (sic), which actually corresponds to plant macrofossil matter samples from a sediment core in Lake Challacaba in Cochabamba [39]. As in the case of the Patapatani date mentioned above (also incorrectly included in their dataset), these dates should be excluded from future archaeological meta-analyses. Riris and Arroyo-Kalin [40] recently published an evaluation of demographic patterns in South America that among the 111 dates from Bolivia, includes various errors in site names (e.g., Lamina (sic), Cochamba (sic), Chu'uxuqull (sic)), coordinates (e.g., Yuraj Molino, Tiwanaku), and references (e.g., Wankarani, Yuraj Molino, Khopi). This dataset also incorrectly situates the Peruvian site Grifo Virgen Copacabana M17A (Beta-120262) in Bolivia. Similarly, the most recent iteration (CARD 2.0) of the Canadian Archaeological Radiocarbon Database [41] only includes 28 radiocarbon dates from four sites assigned to Bolivia including six from the Argentinean site Cueva Yavi. In contrast, the recently published p3k14c synthetic global database of archaeological radiocarbon dates incorporates some of the corrections presented above [12], but many omissions remain including the absence of much contextual data associated with existing dates. All of this underscores the importance of generating a database with more recent, complete, and accurate information.

Paleoecological Dates

The use of ^{14}C dates for Quaternary science in Bolivia involved a relatively wide range of multidisciplinary research efforts in the fields of paleoclimatology, paleolimnology, geomorphology, glaciology, palynology, paleontology, and dendrochronology, which I label as paleoecological. Although the concept of paleoecology (and specifically Quaternary paleoecology) is often used in a somewhat narrow sense for referring to reconstructions of past biotopes, for the purposes of this review, it is used in its broadest sense to encompass both biotic (faunal, floral, fungi) and abiotic (rainfall, temperature, geochemistry, sedimentology) components of the environment. In this regard, the archaeological dates could also be considered part of the paleoecological record, and to some extent, they are, therefore warranting the need for broad-scope databases.

Paleoecological radiocarbon dates were initially reported as part of radiocarbon lab reports and this resulted in a few of them being incorporated in archaeological datasets as discussed above. Eventually they were included as part of specific research. Among notable research efforts, between the late 1970s and the early 1990s the French academic cooperation through its *Office de la recherche scientifique et technique outre-mer* (ORSTOM) and which continues today through the *Institut de recherche pour le développement* (IRD) in collaboration with Bolivian researchers, particularly from Universidad Mayor de San Andrés in La Paz, carried out significant paleoenvironmental research throughout the Bolivian Andes and particularly Lake Titicaca [42, 43].

Over time European and North American research teams approached similar and an increasing number of questions involving multiproxy approaches for reconstructing the late Quaternary paleoclimate from decadal to millennial scale including ever more abundant and precise ^{14}C dates. Whereas some projects involved significant dating programs and could be thought of as synthetic attempts on their own [44, 45, 46, 47, 48], no sweeping attempt to systematically compile all these dates together exists. However, a few regional syntheses of paleoclimatic research do provide valuable overviews [49, 50, 51]. The database presented here is the most significant attempt to revise paleoecological studies in a single place. Nevertheless, given the temporal threshold of radiocarbon decay and its constrains for dating specific materials, many studies have also relied on other relative and absolute dating methods including optical stimulated luminescence (OSL), uranium-thorium (U-Th), ^{210}Pb, ^{10}Be and ^{29}Al cosmogenic dating, and others, not included in the present database.

Radiocarbon measurements in water

A few isotopic studies in water including ^{14}C have been carried out in Bolivia to help quantify molecular movements and chemical reactions related to groundwater recharge, storage, flow, and discharge [52]. For instance, in the Chaco lowlands east of Tarija, underground water samples from 16 boreholes were sampled for both $\delta^{18}O$ and ^{14}C, producing some ages older than 10 kya [53, 54]. Similar work in the valley of Cochabamba helped to trace the origins of many of the water sources that feed this city and its countryside as well as the speed of aquifer recharge [55]. Additionally, radiocarbon measurements in particulate organic carbon in water have been carried out as part of regional surveys to address fundamental questions about the carbon and water cycles. For instance, to determine the dominant source as well as turnover rates of Amazonian riverine carbon dioxide, ^{14}C and $\delta^{13}C$ measurements were carried out on dissolved organic carbon, suspended fine particulate organic carbon, and suspended coarse particulate organic carbon samples from the Beni River, helping to verify that most oxidation derives from contemporary organic matter originated on land and rivers [56]. Additional research in the Beni River drainage used ^{14}C measurements to help estimate how much petrographic organic carbon was present in particulate organic carbon and confirming that waters from upper portions of the Amazon basin have increased proportion of petrographic organic carbon [57]. Although these studies involve important ^{14}C applications, because of incompatible reporting standards, their ^{14}C measurements are not included in the database.

Spatial and Temporal coverage

The database includes all the radiocarbon dates from the country of Bolivia, which covers a surface of 1,098,540 km^2 in surface [58]. Below are included decimal degree coordinates standardized to the World Geodetic System 1984 (WGS84) of a minimum-bounding frame that encompasses the entire country.

Northern boundary: –9.6
Southern boundary: –23.0
Eastern boundary: –57.4
Western boundary: –69.7

Temporal coverage

The database includes dates between the extent of the ^{14}C dating method (~55,000 years ago) and present times.

(2) METHODS

The database was constructed by assembling data from archaeological and other Quaternary science reports and publications as well as new and unpublished dates from ongoing research.

STEPS

The compilation began with existing lists and old reports and progressively reviewing new reports and publications. In all cases, the original source of the published radiocarbon date was consulted to verify as much as possible its associated data as well as to supplement additional information related to radiocarbon measurements, provenience, depositional context, and location. Whenever possible, the original field and lab reports were also consulted. In addition to an exhaustive revision of published literature, research reports from various research repositories and specialized libraries were consulted including the archives of the Bolivian Unit of Archaeology and Museums of the Ministry of Cultures. Because many records were originally reported in Spanish, I translated them to English. In many cases, researchers and labs were contacted for clarification, verification, and supplementary information and in most cases, very helpful responses were received.

Many of the referenced studies involved international fieldwork in sites both within and outside the Bolivian borders, but the database is limited to sites located within the country. Using modern political boundaries as a criterion for a research review is potentially problematic because of the arbitrary interruption of regions that were intrinsically integrated or belong to the same geographical, ecological, cultural, and socioenvironmental systems. Nevertheless, because scientific and particularly, archaeological research is regulated at the national level, this criterion was used to constrain the extent of the review. The resulting database was organized by site and each record represents an individual radiocarbon date associated with its specific locational, contextual, and supplementary information as described below.

Regarding locational data, each date is associated with a site, the administrative department in which it is located, a general geographic reference consisting of four macroecological regions (Lake Titicaca, highlands, inter-Andean valleys, and tropical lowlands), and three-dimensional coordinates (latitude, longitude, and elevation). Latitude and longitude coordinates are reported in decimal degrees standardized to WGS84. Sometimes the locational information found in the publications was very general but, in many cases, it was specific enough to locate most proveniences. Considering that many existing databases provide erroneous locational data, aided by maps and study area descriptions, I used Google Earth Pro to verify, refine and correct the location of every single date. For the case of elevations, standardized values were derived using an SRTM digital elevation model. In cases, where local grids were set up, this information is included in the fields for provenience and additional information.

Following Gajewski et al. [41], the database specifies if each ^{14}C date is either archaeological (cultural) or paleoecological (paleoenvironmental). Most of the time, but not always, making this distinction was straightforward. Nevertheless, in should be noted that culturally sterile layers from archaeological sites could be categorized as paleoecological and some paleoecological layers such as anthropogenic soils on incidental profiles could be labelled as archaeological so alternative possibilities are possible. Similarly, the type of site is a general category used to facilitate classifying the dates, but some sites and dates could be justifiably associated with more than one of these categories.

The type of analyses conducted as either radiometric (gas proportional counting or liquid scintillation) or accelerated mass spectrometry (AMS) are specified. The main information contained in the database are the lab code, the conventional age in ^{14}C years before present (BP) and its associated error. A great deal of work was spent trying to track down and verify this specific information ideally with original lab reports and as a result, the BRD includes various corrections from published versions. A specific field for Comments is included to point out whenever any errors (in reporting lab codes, dates or other information) were identified.

Lab codes were standardized and in cases where lab codes were unknown, arbitrary codes were added using the "nc" abbreviation. The database also notes if I was able to consult the lab report.

For dates of recent age, typically after 1950, depending on how they were reported, data is presented as either: (a) preceded by a negative sign (-) if they are reported in years after 1950 CE, (b) preceded by a parenthesis if the unit of measurement is percentage modern carbon (pMC), (c) preceded by two parentheses if the unit of measurement is the fraction of modern carbon ($F^{14}C$) measured in parts per thousand (‰), or (d) labelled as "Modern" when measurement information was not provided. Similarly, dates closer to the temporal limit of the method sometimes include a ">" sign and might not include error values as originally reported. Finally, dates that include lab codes and provenience but otherwise failed to yield an actual age are represented as "No_date".

The heavy stable isotope ^{13}C that is often reported with some ^{14}C dates is also included whenever available. These values are typically standardized to the Vienna Pee Dee Belemnite (VPDB) and reported as $\delta^{13}C$ notation in parts per thousand (‰) and rounded to the nearest decimal point. This value is helpful in verifying that the uncalibrated dates were corrected for mass fractionation [59] suggesting their overall quality. Nevertheless, recent AMS dates are generally corrected for mass fractionation but do not report $\delta^{13}C$ values. Dates produced before measuring $\delta^{13}C$ became standard have not been altered.

The dated material is specified in two fields. One is reserved for the general material processed and the other field for specifying the taxon in the case of living organisms or more specific information in the case of inorganic materials. Charcoal refers to any type of burned plant material including wood, branches, fruits, seeds, etc., which if specified, is included in the taxa and context fields. For archaeological dates that did not specify the material dated, charcoal is the default category. For paleoecological dates, specifying the material dated is often difficult and some effort was made to standardize categorization. For instance, "bulk sediment" samples were further processed to specific fractions (e.g., total organic matter, humic acids, etc.), which are specified whenever this information was available. Similarly, if the material dated was specified as "gastropods" the material was described as "shell" and gastropods was inputted in the taxa field.

The field of provenience includes as much specific contextual information as possible such as unit, level, stratum, feature, locus, bag, core, and other specific information from where the sample originated. The year the sample was recovered is also recorded as well as the depth at which the sample was collected and chronological phase. Carbon and nitrogen stable isotopes information is included whenever available.

The primary (typically the oldest but sometimes the most detailed) source of information about the radiocarbon date is specified. A second field includes additional references where the sample is mentioned. In both fields, specific page numbers are provided. Whenever possible, researchers are urged to consult these sources for further information about the samples. A complete and exhaustive bibliography including all references is part of the database.

Each date was recalibrated using the southern hemisphere calibration curve (SHCal20) [60] in OxCal 4.4.4 [61, 62] with the exception of dates postdating 1950 CE. The database includes one sigma (68.2%), and two sigma (95.4%) age ranges, means, medians, and standard deviations (SD) in calibrated years before present (cal BP) as well as in years before or during common era (BCE/CE).

CONSTRAINTS

Except for very specific cases, the database does not include actual ^{14}C measurements nor pretreatments, but I note if I was able to access the actual lab report potentially containing this information. In various cases, previously published information has been corrected or updated. For instance, after consulting original reports from the decommissioned SMU radiocarbon dating lab, small discrepancies were identified with published dates from the sites of Lukurmata and Tiwanaku [26]. Observations about the quality of the date such as typos in previous publications, duplicates or any other relevant observations are also included. For instance, some dates have been rejected by researchers for various reasons such as inconsistency with expectations about the age of the specimen or targeted event, and this is noted whenever possible. However, rejected dates are still included in the database. Because in many cases, dates are either older or younger than expected due to stratigraphic disturbance as well as possible measurement errors, future users of the dataset should be mindful of these observations.

(3) DATASET DESCRIPTION

The database consists of a set of two files including the complete dataset of radiocarbon dates (Bolivian Radiocarbon Database V1.xlsx) and a file including the full list of bibliographic sources from where the information was compiled (Bolivia Radiocarbon Bibliography V1.docx) [63]. The attributes of the variables included in the database are presented in Table 1.

OBJECT NAME

Bolivian Radiocarbon Database V1.xlsx
Bolivian Radiocarbon Bibliography V1.docx

COLUMN	VARIABLE	TYPE	DESCRIPTION
A	Site	Text	Name of the archaeological or paleoecological site
B	Department	Text	Major administrative unit within the country
C	Region	Text	Major geographical region (Highlands, Valleys, Lowlands, Titicaca)
D	Type of Site	Text	Broad category of site from where the sample was collected
E	Latitude	Number	Latitude in decimal degrees standardized to WGS84
F	Longitude	Number	Longitude in decimal degrees standardized to WGS84
G	Elevation	Number	Elevation in meters above sea level standardized from SRTM
H	Type	Text	Primary research focus of the date (Archaeology, Paleoecology)
I	Method	Text	Method of radiocarbon analysis (Radiometric, AMS)
J	Code	Text	Unique laboratory code associated with the radiocarbon date
K	^{14}C Age	Number	Conventional age of sample in radiocarbon years before present (1950 CE)
L	Error	Number	Error range associated with the reported radiocarbon date in ± years
M	δ13C	Number	δ13C associated with the date in ‰ and standardized to VPDB
N	Material	Text	General category of material processed for analysis
O	Taxa	Text	Specific organism or material analyzed
P	Depth	Number	Depth in centimeters beneath the surface or arbitrary datum
Q	Context	Text	Specific provenience information associated with the sample
R	Period	Text	General temporal category associated with the sample
S	Year	Number	Year during which the sample was collected in the field
T	Source	Text	Primary bibliographic citation where the sample is reported
U	Source 2	Text	Additional citations for more information about the samples
V	Comments	Text	Reporting errors, corrections, typos, and other observations about dates
W	Other codes	Text	Other codes associated with the sample
X	Additional info	Text	Comments on provenience information associated with the sample
Y	Report	Text	If lab report was consulted and is available
Z	$d^{13}C$	Number	$\delta^{13}C$ of collagen or in another fraction in ‰ and standardized to VPDB
AA	$d^{15}N$	Number	$\delta^{15}N$ of collagen or in another fraction in ‰ and standardized to VPDB
AB	%C	Number	Percentage of carbon measured in collagen or in another fraction
AC	%N	Number	Percentage of nitrogen measured in collagen or in another fraction
AD	C:N	Number	Carbon to nitrogen atomic mass ratio
AE	1σ cal BP from	Number	Lower range of 68.3% likelihood of calibrated date in calibrated years before present
AF	1σ cal BP to	Number	Upper range of 68.3% likelihood of calibrated date in calibrated years before present
AG	2σ cal BP from	Number	Lower range of 95.4% likelihood of calibrated date in calibrated years before present
AH	2σ cal BP to	Number	Upper range of 95.4% likelihood of calibrated date in calibrated years before present
AI	Mean cal BP	Number	Mean likelihood of calibrated date in calibrated years before present
AJ	Median cal BP	Number	Median likelihood of calibrated date in calibrated years before present
AK	SD	Number	Standard deviation of calibrated date
AL	1σ BCE/CE from	Number	Lower range of 68.3% likelihood of calibrated date in years before or during common era
AM	1σ BCE/CE to	Number	Upper range of 68.3% likelihood of calibrated date in years before or during common era
AN	2σ BCE/CE from	Number	Lower range of 95.4% likelihood of calibrated date in years before or during common era
AO	2σ BCE/CE to	Number	Upper range of 95.4% likelihood of calibrated date in years before or during common era
AP	Mean BCE/CE	Number	Mean likelihood of calibrated date in years before or during common era
AQ	Median BCE/CE	Number	Median likelihood of calibrated date in years before or during common era

Table 1 Description of the variables recorded in the Bolivian Radiocarbon Database.

DATA TYPE

Records of radiocarbon dates collected from an exhaustive review of published and unpublished reports and publications.

FORMAT NAMES AND VERSIONS

The database is currently available in .xlsx format to maximize retaining qualitative stringed information along with vector data in formatted cells.

CREATION DATES

The compilation of data was conducted between January 2017 and January 2023.

DATASET CREATORS

The database was created by José M. Capriles.

LANGUAGE

English

LICENSE

Creative Common License CC-BY 4.0: https://creativecommons.org/licenses/by/4.0/.

REPOSITORY LOCATION

The database is permanently archived at and can be downloaded from tDAR id: 472749 (dataset) and tDAR id: 472810 (document) [63].

https://core.tdar.org/collection/71234

PUBLICATION DATE

02/10/2023

GENERAL PATTERNS

The Bolivian Radiocarbon Database (BRD) consists of 3,269 dates from 745 sites. There are fewer archaeological (n = 1,582) than paleoecological (n = 1,687) dates distributed in more archaeological (n = 386) than paleoenvironmental (n = 359) sites (Figure 1). In both

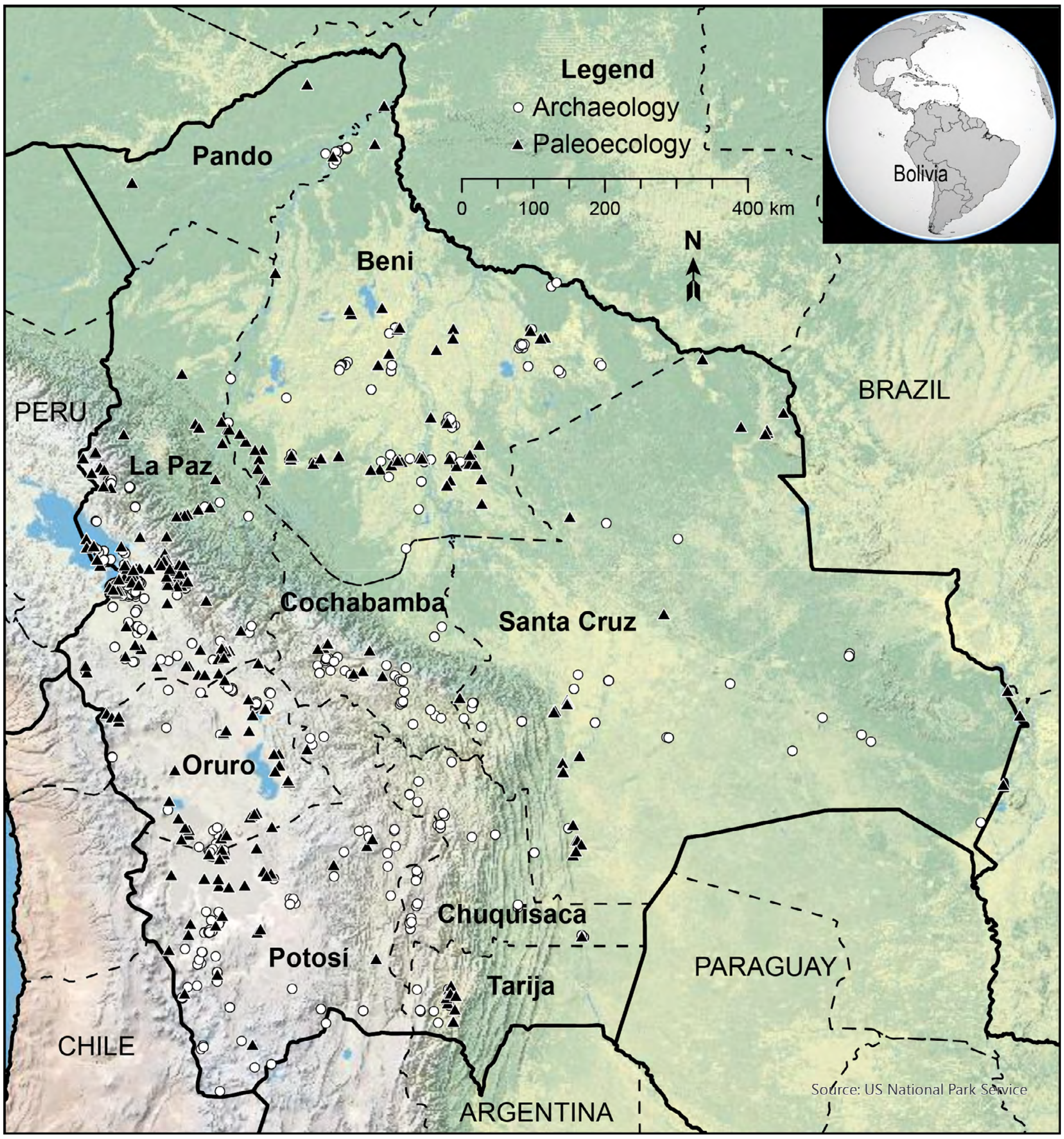

Figure 1 Map of Bolivia showing the location of all known archaeological and paleoecological ^{14}C dates overlaying a general terrain model produced by the US National Parks Service.

cases, a small number of sites have a disproportionate large number of radiocarbon dates while many just have one. Over time there is an expected positive increase in the quantity of both archaeological and paleoecological dates as well as in the preference of AMS over radiometric methods (Figure 2). However, the number of the dates reported in the last few years seems to be leveling off perhaps due to a decrease in large-scale projects in favor of smaller investigations running fewer dates, but also due to the temporal lag between the collection of the samples and their publication. A more detailed rendition of research in the country by region and over time is presented in an accompanying paper [64].

The type of sites from where these samples originated suggests that most archaeological samples originated from open air habitation sites whereas most paleoecological samples came from lake cores, sedimentary cores and profiles. The spatial dispersion of sites per region verifies that the distribution of ^{14}C is undoubtedly uneven. Archaeological sites show a clear concentration of sites in the Lake Titicaca basin, but also a wider and much more extensive coverage than previous compilations suggested. Paleoecological records are distributed following the heterogeneity of the landscape and the existence of adequate sampling locations in relation to key landscape features. Indeed, various causes underly the observed pattern including research interests, findings, and funding as well as the production and preservation of the radiocarbon record itself.

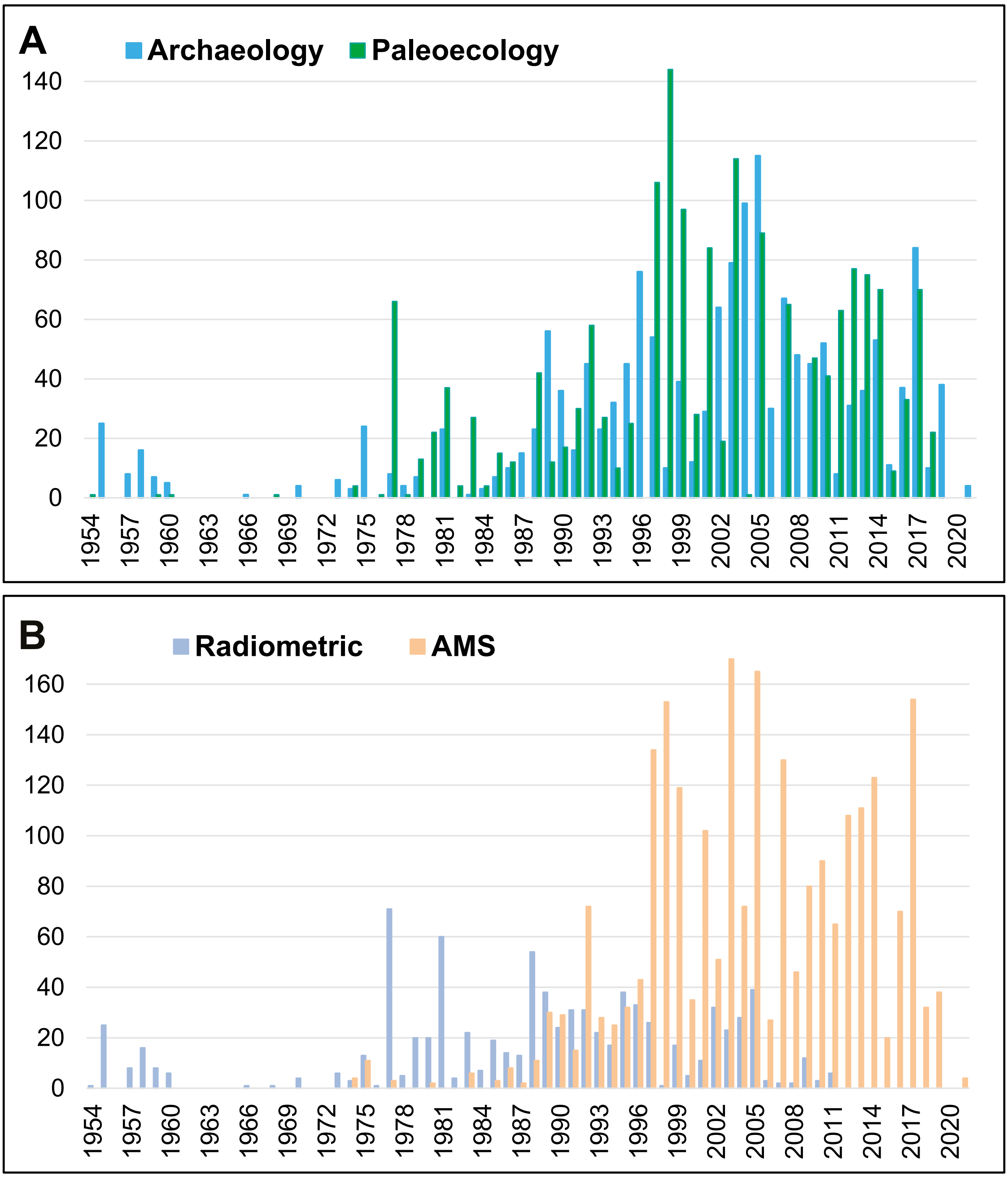

Figure 2 Bar graphs showing the number of radiocarbon dates arranged by year of sample collection and organized by **(A)** type of record (archaeological or paleoecological) and **(B)** by method of analysis.

Unsurprisingly, charcoal is the most common category of dated material, particularly among archaeological dates (Table 2). Carbonized material includes burned wood, branches, twigs, seeds, and tubers, but also dung and soot from ceramics. Unfortunately, specific taxonomic identifications are rarely available, but chenopod seeds dominate among those that are. Uncarbonized wood and dry plants are also frequent and except for tree-rings or cacti spines, they rarely include taxonomic identifications. Although a few actual artifacts have been directly dated including textiles, leather bags, and a single antique violin, a few examples of unburned wood from lintels and straw from adobes and mortar were collected to date standing architecture such as burial towers and preserved late Precolumbian buildings [65, 66].

Bone is also common, particularly among archaeological studies, and the majority corresponds to collagen fractions extracted from human teeth and bones. Among animal species, camelids are the most frequent taxon, and the 48 represented samples comprise bone, leather, and fiber. Other animal taxa include dogs, and single instances of fox, puma, jaguar, guinea pig, and killifish as well as a couple of megafaunal bones from a glyptodont and a few horses, including both paleontological and modern ones [67, 68]. No bird, amphibian or reptilian species have been directly dated. Among invertebrates, many shells of *Pomacea* apple snails (n = 18) deposited in anthropogenic middens have been dated but the majority correspond to smaller freshwater gastropods (such as *Littoridina*) used for dating lacustrine sediments, which might implicate freshwater reservoir effects. Carbonates from other sources such as calcite from tufa are also frequent. Bulk sediment and soil are the most frequent categories among paleoecological studies and typically encompass a wide range of dated substances ranging from specific humic acids to total organic carbon. Single quartz crystals have also been dated and used for ^{14}C cosmogenic dating in paleoecological research.

Temporal Trends

To initially explore some temporal trends, dates were summarized using sum probability densities (SPDs) compiling all calibrated dates including duplicates (Figure 3). Given that SPDs are affected by sampling

MATERIAL	ARCHAEOLOGY	PALEOECOLOGY	TOTAL
Charcoal	1207	72	1279
Dry plant	50		50
Wood	32	108	140
Plant matter		77	77
Cactus spines		19	19
Bone	49		49
Bone, collagen	159	5	164
Bone, apatite	10	1	11
Leather, fiber, nail	8		8
Shell	32	306	338
Macrofossils		45	45
Bulk sediment		771	771
Bulk soil	37	170	207
Carbonates		87	87
Quartz		24	24
Total	1584	1685	3269

Table 2 List of materials dated among ^{14}C dates organized by type.

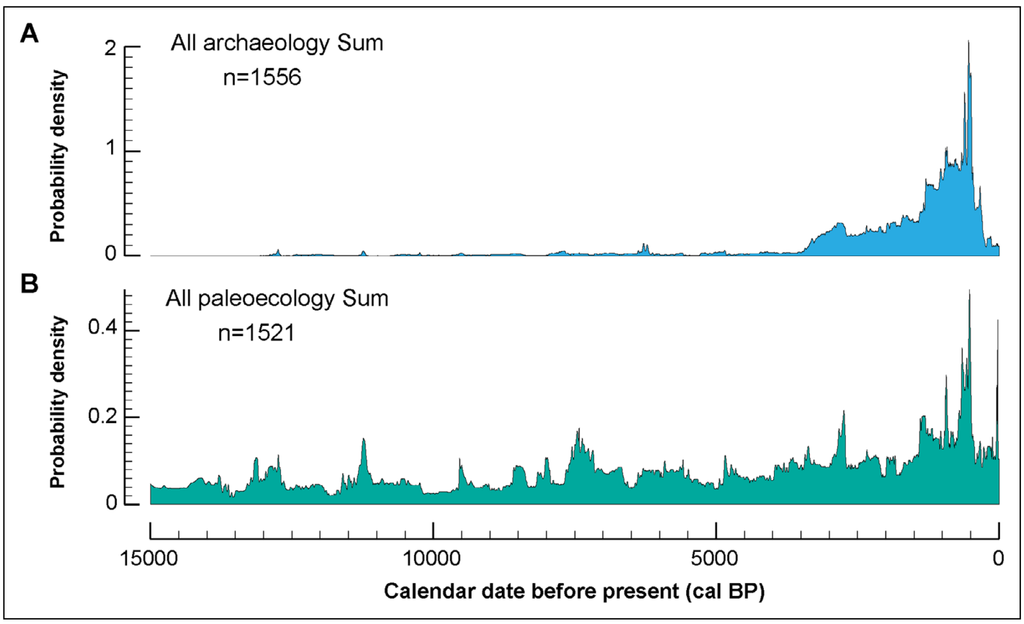

Figure 3 Aggregated sum probability distributions of ^{14}C dates for the last 15,000 years sorted by: **A)** archaeological dates, and **B)** paleoecological dates.

intensity, taphonomic biases, and ambiguity produced by the calibration curve [69, 70, 71], the SPDs are used mostly for initial data visualization. Supplementing these results, a spatial time series using calibrated means further shows the protracted growth in the number, dispersion, and density of archaeological sites over time (Table 3). Given that calibrated ^{14}C dates often result in multimodal distributions due to the temporally variable availability of radiocarbon in the atmosphere and that atmospheric circulation might have affected the distribution of radiocarbon over space [72], I recognize that means might not be the most likely age for any given sample but are mostly used for data exploration. More accurate estimates can be derived by incorporating stratigraphic and other information using Bayesian inference models and paleoecological dates can be further constrained by building age-depth models using various criteria, algorithms, and applications [6, 62, 73].

The BRD verifies that initial human peopling of the country occurred approximately 13 kya (thousand years ago). While it appears that population remained largely stagnant during most of the Early and Middle Holocene, this is probably an effect of the very limited research effort placed on studying early human occupations in the Bolivia (Figure 3).

Archaeological dates show rapid population growth during the Late Holocene and a density peak at 1.2–0.4 kya followed by rapid decline, which is also represented spatially by the greatest dispersion of sites across the country (Figure 4). In contrast paleoecological dates show a more even and perhaps stochastic distribution over time. These data are consistent with previous continental-scale paleo-demographic reconstructions that suggests population increased over time initially following a logistical trend (during initial colonization) and later at an exponential rate (with the widespread adoption of agricultural intensification) [37]. Furthermore, the European conquest in the XVI century caused abrupt and widespread population decline, which is further emphasized by the widespread practice among archaeologists working in the country to limit ^{14}C dating to pre-Hispanic contexts.

Regional SPDs restricted to the Late Holocene (4.2-0 kya) show interesting interpretative possibilities (Figure 5). For instance, in the Lake Titicaca region (separated from the highlands due to its particularly large sample size) a low signal of human presence prior to the adoption of agropastoralism contrasts with rapid growth during as many as five different episodes around 3.5 kya, 3 kya, 2 kya, 1.1 kya, and 0.4 kya years ago. Although many of these were characterized by stepwise growth, significant decline is observed, particularly at 1.6 kya, 0.9 kya, and 0.3 kya. In contrast, the highlands witnessed somewhat initial synchronous growth at 3.5, and 0.9 kya and minor transient fluctuations in the interim. The inter-Andean valleys show extended initial growth and sustained densities until approximately 1.0 kya when growth spikes rapidly follow a rapid decline after 0.4 kya.

PERIOD	ARCHAEOLOGY	PALEOECOLOGY	TOTAL
Post 1950	23	136	159
0–0.4 kya	87	47	134
0.4–1.2 kya	719	163	882
1.2–2.2 kya	354	104	458
2.2–3.2 kya	234	111	345
3.2–4.2 kya	51	86	137
4.2–8.2 kya	75	292	367
8.2–11.7 kya	25	176	201
11.7–14.9 kya	10	151	161
15–29 kya	1	276	277
30–55 kya		142	142
No date	5	1	6
Total	1584	1685	3269

Table 3 Summary of number of ^{14}C dates organized by type and temporal period.

Although the lowlands have one of the most intriguing sequences of landscape transformation prior to the Late Holocene, low density is noted until 1.9 kya when rapid growth likely connected to the integration of the mound societies of the Llanos de Moxos emerged. Stepwise growth between 1.3 kya and 1.0 kya was followed up by dramatic decline starting 0.5 kya years ago, relatively earlier than other regions. Given the empirical and methodological uncertainties associated with the SPDs, these general propositions will require analytical verification including addressing the analytical challenges introduced by the confounding effects of taphonomy, research biases, and calibration effects.

(4) REUSE POTENTIAL

The Bolivian Radiocarbon Database comprises the most exhaustive and comprehensive compilation of radiocarbon dates available from the entire country of Bolivia. This compilation was facilitated by long-term commitment with the country and direct engagement with national institutions, research organizations, local specialists, and interdisciplinary teams. By systematizing existing ^{14}C dates and their associated information, this database has the potential to significantly contribute to improving the understanding of cultural and paleoecological change in a large and diverse country. In addition to including numerous ^{14}C dates found in primary literature but unavailable in previous published

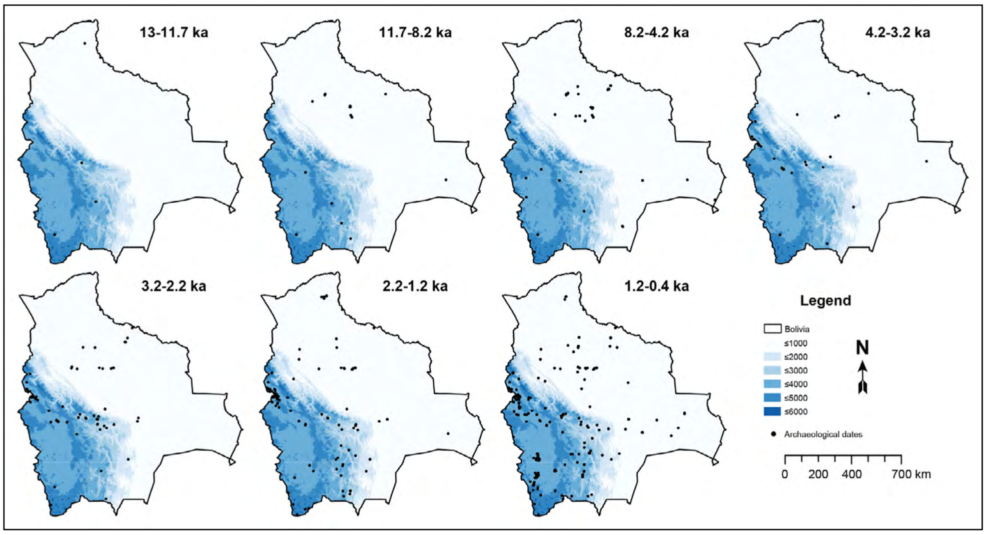

Figure 4 Spatial distribution of archaeological ^{14}C dates organized by different temporal periods.

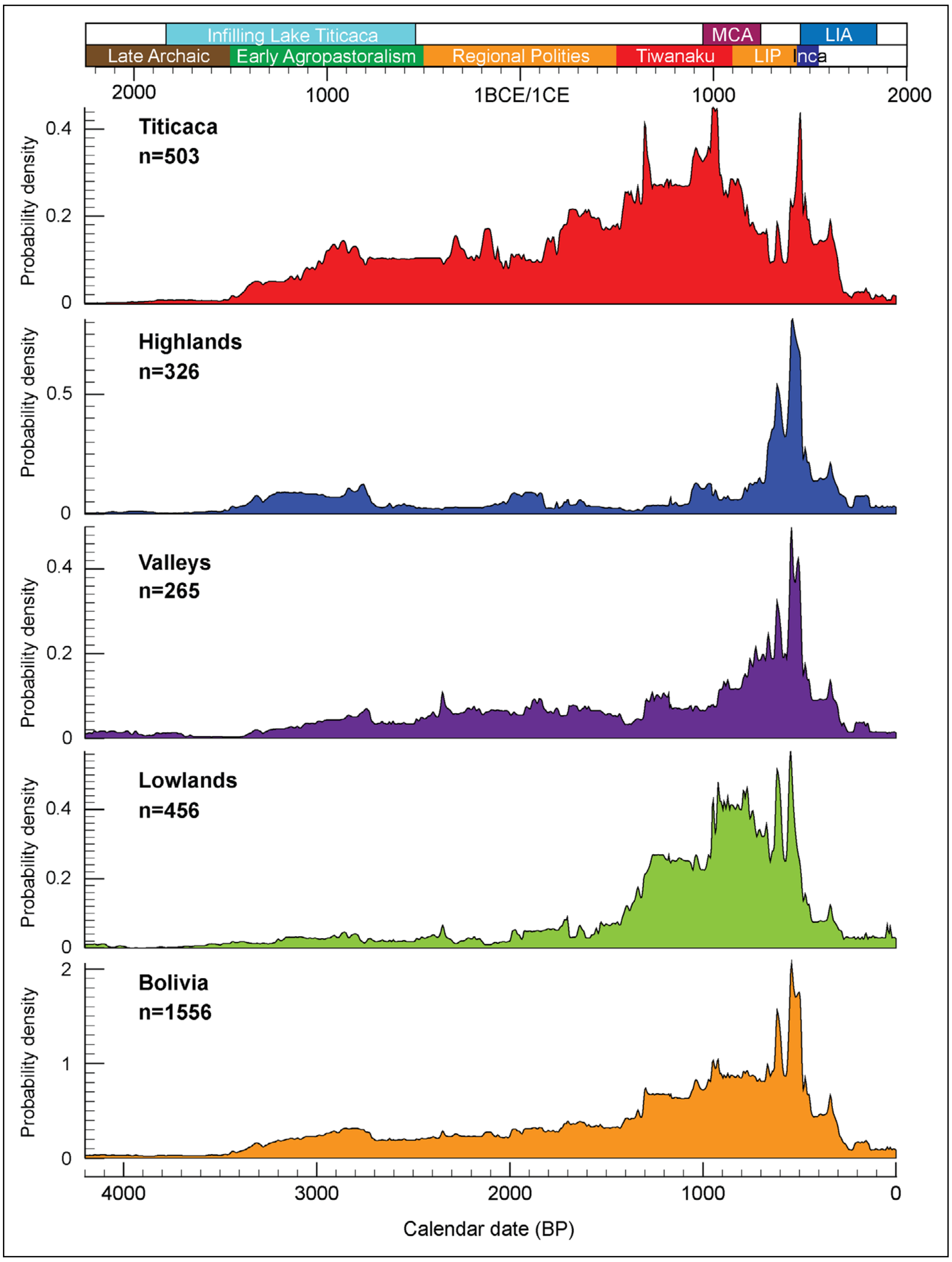

Figure 5 Sum probability distributions of archaeological ^{14}C dates organized by geographic region and limited to the late Holocene.

compilations, this database incorporates many new unpublished dates along with detailed provenience and reference information. Although the archaeological and paleoecological application of radiocarbon dating is extensive, it should be bear in mind that other Quaternary records dated with other techniques are available for many additional sites.

The BRD includes a dataset over an order of magnitude larger than previous compilations and it improves the quality of information associated with the radiocarbon dates. As such, the database should be useful for researchers interested in research at various spatial and temporal scales. Yet compared to neighboring countries such as Peru, Chile, and Argentina, the radiocarbon record from Bolivia is still smaller. In part this seems related to the country's landlocked condition, given that coastal regions have historically attracted higher intensity of archaeological research [8, 32, 69].

Differential research foci and limited funding have also shaped the structure of the compilation as outlined by the significant contribution of a few very specific projects working in very specific regions and sites. For instance, Tiwanaku, Chiripa, and other monumental sites in the Lake Titicaca have been intensively sampled and employing increasingly improved research techniques. In contrast, vast areas of the Amazonian rainforests and Chaco lowlands have not witnessed any dated sites at all. Many of these patterns and trends are explored in an accompanying article [64]. Indeed, the sum of various projects with heterogenous research questions and perspectives have produced a relatively widely dispersed radiocarbon record that has significant potential for helping to address a wide range of research questions. Certainly, the use of this record must go hand in hand with an understanding of how various research biases have affected its production, but a complete record of dates allows to visualize significantly more dated sites, regions, and temporal periods than previously known. Finally, researchers are encouraged to reach out with additional information and corrections to improve this database, which will be updated periodically.

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COMPETING INTERESTS

The author has no competing interests to declare.

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