Uncertainties in Radiocarbon Dating

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Background

Radiocarbon (or 14C) is a radioactive isotope of carbon that becomes fixed in organisms as they exchange carbon with the atmosphere (Bronk Ramsey, 2008). Like all radioactive substances, 14C has a decay rate called a “half-life” which refers to the number of years (~5,730 for 14C) it takes to reduce its radioactivity by half (Van Strydonck, 2016). By comparing the 14C levels in a material with a known age (such as tree rings, where each ring represents one year of growth) to the left over radiocarbon levels in a material with an unknown age, scientists are able to determine the age of the latter material as far back as ~60,000 years ago (Van Strydonck, 2016).

Radiocarbon dating has proven to be a valuable tool in understanding how climate change will affect our current ecosystems by giving scientists a glimpse into how rapid climate change has shaped ecosystems in the past (Blois et al., 2011). For our project, we focused on pollen cores taken from lake sediment, which reflect what types of vegetation lived around the sampled lake at the time that the pollen entered the sediment. By comparing the types of pollen found at different times and sites, scientists are able to understand how different flora reacted to changes in climate (such as moving north or south over a time period in response to rising or falling temperatures) (Blois et al., 2011). However, pollen grains contain very little 14C in them, making them impossible to date, which is why scientists instead date the larger organic materials (leaves, seeds, etc.) that are found in the same layer of sediment. In addition to studying the dated materials in the pollen cores, we analyzed lake sizes in order to determine how far away the deposited pollen may have come from (regional or local samples).

But because of events such as the dilution of 14C in the atmosphere by CO2 emissions (Seuss effect), cyclical solar activity (De Vries effect), and fluctuations in the Earth’s magnetic field, 14C is not produced at a constant rate, so radiocarbon levels do not always directly correlate with calendar years (Taylor, 2000). To solve this problem, scientists have created “calibration curves'' that reflect these fluctuations in 14C levels so materials can be properly aged. Even with these calibration curves, the ages assigned to dated materials often include uncertainties. These uncertainties occur for a number of reasons, including contamination with new/more carbon in the lab, a difference between when the material was deposited in the sediment and when it stopped exchanging carbon with the environment, and redeposition of materials from one sediment layer to another (Blois et al., 2011).

The purpose of this research was to investigate uncertainties in radiocarbon dating in order to determine how they may cause errors in paleodata, and therefore, uncertainties in how we apply Earth’s climate past to our rapidly approaching climate future.

Methods and Data

Pollen core data was collected from the Neotoma Paleoecological Database. This data included information such as the calibrated age of the materials, the error associated with the calibrated ages, the depth at which they were found, and the method of radiocarbon dating. Additionally, a set of accuracy rankings from Blois et al., 2011 based on expert opinion were assigned to the materials dated. The accuracy ranks range from 1 through 8, 1 being the most accurate (less than or equal to one year of offset between the true age and estimated age), and 8 being the least accurate (greater than five-thousand years between the true age and estimated age). Once this data was gathered, it was read into R Studio (a development environment for the programming language R) so it could be analyzed and visuals could be produced from the data. We defined “error” values as the difference between the oldest radiocarbon age limit of the sample and the estimated radiocarbon age.

We removed any negative depth values, negative error values, depths over 5000 cm, and errors over 2000 years. The negative depths were in the database to account for an irregular slump at one data site. Only one site included negative errors for an unknown reason. The depths over 5000 cm were an error in the database. There was no information to support large error values (over 2,000 years). As errors this large are outliers in the data set, we decided to exclude them.

Google Earth Pro was used to produce the data on lake sizes. The names and coordinates of the sample lakes were input into Google Earth Pro, where a rough polygon was created on top of the map of the lake and measurements were taken. From there, after analyzing Sugita, 2007a and 2007b, we defined the lake sizes into the following categories: small (area <10 ha, representing a source area of 700m), medium (area <50 ha, > or equal to 10 ha, representing a source area of 10km), and large (area > or equal to 50 ha, representing a source area of 100 km).

Results

We had lake size data for 2,206 lakes (a total surface area of ~4,422,638 ha^2). Of those lakes, 379 were small, 1,598 were medium, and 229 were large. The total area of vegetation signal represented is ~7,165,618 km^2.

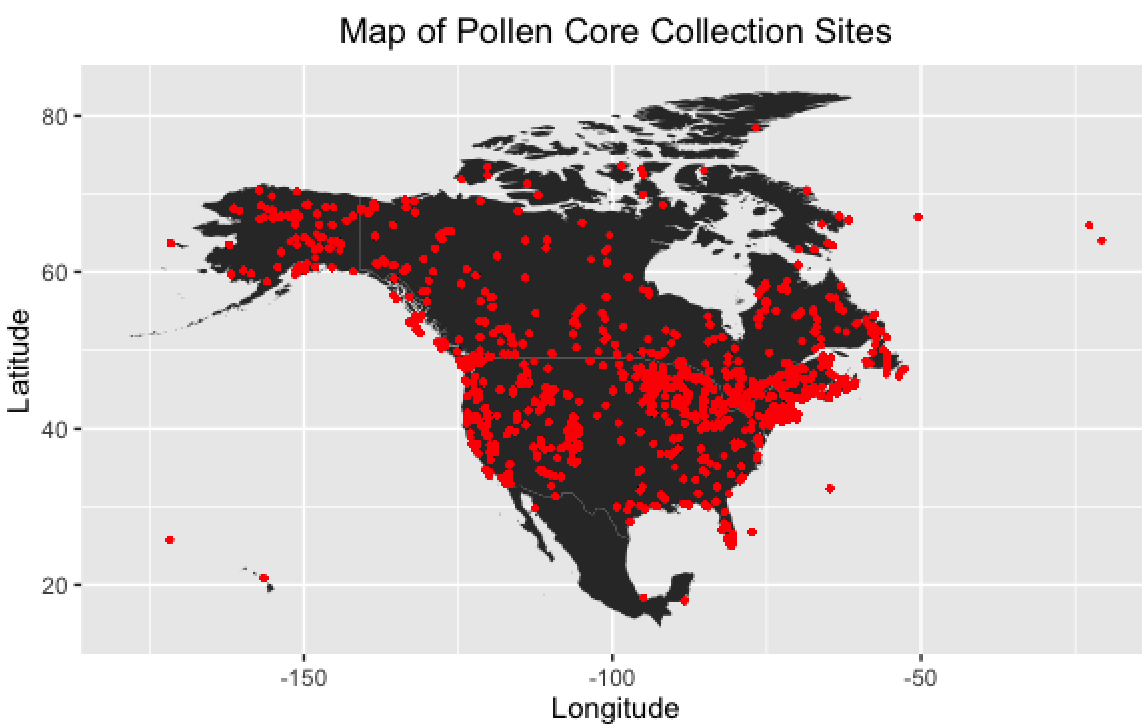

Fig. 1: A map of North America showing each site where a pollen core was taken

Our analysis of the data revealed that uncertainties in radiocarbon ages increased as ages increased. This is true across the methods of accelerator mass spectrometry, conventional radiometric dating, liquid scintillation, and proportional gas counting, although liquid scintillation increases in error the fastest. (Figure 2)

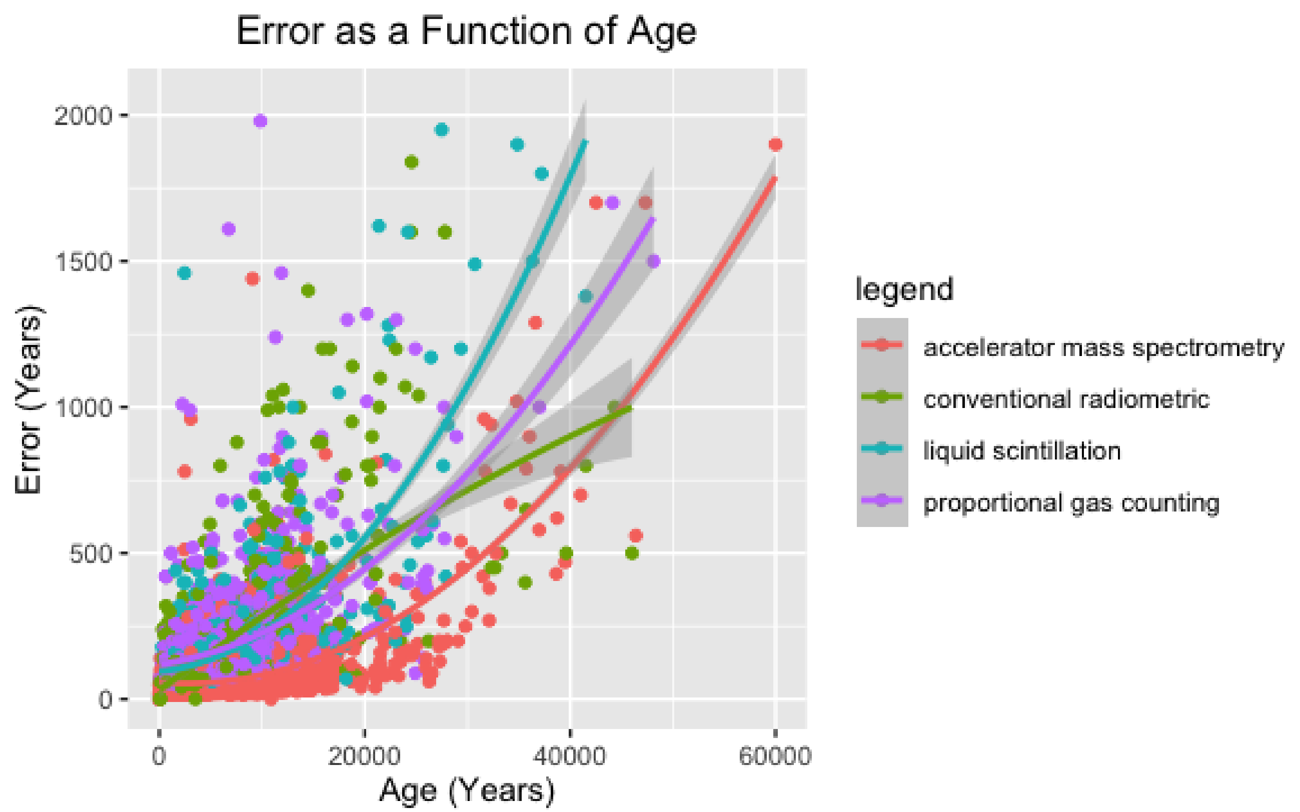

Fig. 2: scatterplot of error as a function of age by dating method

Additionally, our research shows that accuracy rank (based on expert opinion, referring to the offset between the true age and estimated age, defined in Blois et al., 2011) is not a factor that affects errors in 14C dating. (Figure 3)

Accuracy Rank	Mean Error	Median Error	Minimum Error	Maximum Error	Standard Deviation of Error	Number of Materials
2	89.1	60	0	1900	124	696
3	70.1	50	15	820	74.9	330
4	67.8	40	0	1600	127	288
5	151	100	0	1900	180	3743
6	86.5	70	0	900	93.9	164
7	50.0	45	40	80	15.5	6

Fig 3: A table summarising data segregated by accuracy rank

Conclusion

Uncertainties are bound to occur during the process of radiocarbon dating. They are unavoidable, appearing in all dating methods and across all accuracy rankings of materials. Acknowledging and investigating uncertainties in the data provides a clearer picture of Earth's past and equips scientists to provide an informed response that will lead into Earth's future.

Acknowledgements

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