Supplementary material for MAGYARI et al. 2022 (Sci. Rep.)

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According to McInerny et al. (2006), given a set of radiocarbon dates or a series of sightings of a taxon, the probability (p) of finding another record can be estimated from the previous sighting rate n/t_n, where n is the number of records and t_n is the initial period of observations (which can be defined as the difference between the oldest and youngest records). The equation for the calculation is the following:

eq(1) $$p = \left(1 - \left(\frac{n}{t_n}\right)\right)^{t_d},$$

where t_d is the time since the last observation. For this and the following computations, we developed several easily applicable functions within the R programming environment. A specific probability value can be determined by the *prob(t_d, t_n, n)* function within the supplementary script[1].

A terminal date for a given taxon can be inferred by setting a threshold probability to a chosen value (e.g., $\alpha = 0.05$) and iterating until $p \leq \alpha$ and subtracting the resulting time since observation from the youngest record. Such a date can be calculated using the *term(t_n, n)* function within the supplementary R script[1]. Using the radiocarbon data presented in the current paper, we calculated a terminal age of 12 757 years for mammoths (that is 3 251 years after their last known record at 16 008 cal BP), and 9 219 years for reindeer (that is 4 366 years after their last known record at 13 585 cal BP; see Fig 1.). These data were based on 29 observations from a period of 31 493 years in the case of mammoths, and 18 observations from a period of 26 243 years in the case of reindeer.

Bradshaw et al. (2012) modified the McInerny et al. method by inversely weighting the contribution of each dated record to the terminal date (θ) depending on its temporal distance from the most recent record (t_1), assuming that younger records would be more influential on the sighting rate as extinction is approached. They calculated a terminal date for the two most recent data (k = 2), and then iteratively increased the number of used observations during each of the following iterative steps by one, until they reached the total number of observations ($k = n$) with a series that included the oldest record as well. For every series of the youngest k observations, they calculated a weight as well using the following equation: $\omega_k = 1 / (t_k - t_1)$, where t_k is the oldest observation in a particular series. Then they determined the final weighted terminal age ($\theta\omega$) using the following equation:

$$\text{eq(2)} \qquad \theta_\omega = \sum_{k=2}^{n} \omega_k \theta_k \, / \sum_{k=2}^{n} \omega_k$$

The inverse weighted McInerny et al. terminal ages can be calculated using the *IWM(sightings)* function within the supplementary R script[1], where *sightings* is a numeric array of radiocarbon ages. Using the radiocarbon data presented in the current paper, we estimated an extinction date of 13 830 cal BP for mammoths (that is 2 178 years younger than their last record), and 11 860 cal BP for reindeer (that is 1 725 years younger than their last record; see Fig. 2).

One problem with these estimations remains, namely that these do not consider uncertainty in radiometric dating. To address this issue, Bradshaw et al. (2012) resampled each radiometric date 10 000 times from a Gaussian distribution (because radiometric errors tend to follow a normal distribution), then calculated a terminal age for each iteration. By excluding the lower and upper 2.5% of those results, we can define a 95% confidence interval for the above calculated extinction date. This Gaussian-resampled, inverse-weighted McInerny et al. method can be determined using the *GRIWM(sightings, sdevs)* function within the supplementary R script[1]. In the case of our data, a confidence interval between 13 717 - 13 960 cal BP can be determined for the extinction of mammoths and another between 12 814 - 11 471 cal BP for the reindeer (Fig. 2).

If we treat the radiocarbon data older than the largest apparent gap in mammoth occupation between 32.5-27.4 ka separately, a possible extinction age of 30 313 can be determined for this population with the McInerny et al. method. However, the inverse weighted approach results a terminal age of 28 604 cal BP (that is 5 141 years younger than the last record of the older population, and just 1 695 years younger than the first record of the next known occupation period). With the Gaussian resampling technique, a confidence interval between 30 088 - 27 700 cal BP can be determined, which makes the assumption of a local extinction highly unlikely.

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[1]Virág, A., Szabó, B., (2022): Functions for calculating terminal ages within the R programming environment from a series of radiocarbon dates by the GRIWM method. https://github.com/paleoscript/GRIWM

References

Bradshaw, C.J.A., Cooper, A., Turney, C.S.M., Brook, B.W. (2012): Robust estimates of extinction time in the geological record. – Quaternary Science Reviews 33(6), pp.14-19. https://doi.org/10.1016/j.quascirev.2011.11.021

McInerny, G.J., Roberts, D.L., Davy, A.J., Cribb, P.J. (2006): Significance of Sighting Rate in Inferring Extinction and Threat. – Conservation Biology 20(2), pp. 562-567. https://doi.org/10.1111/j.1523-1739.2006.00377.x

Figures

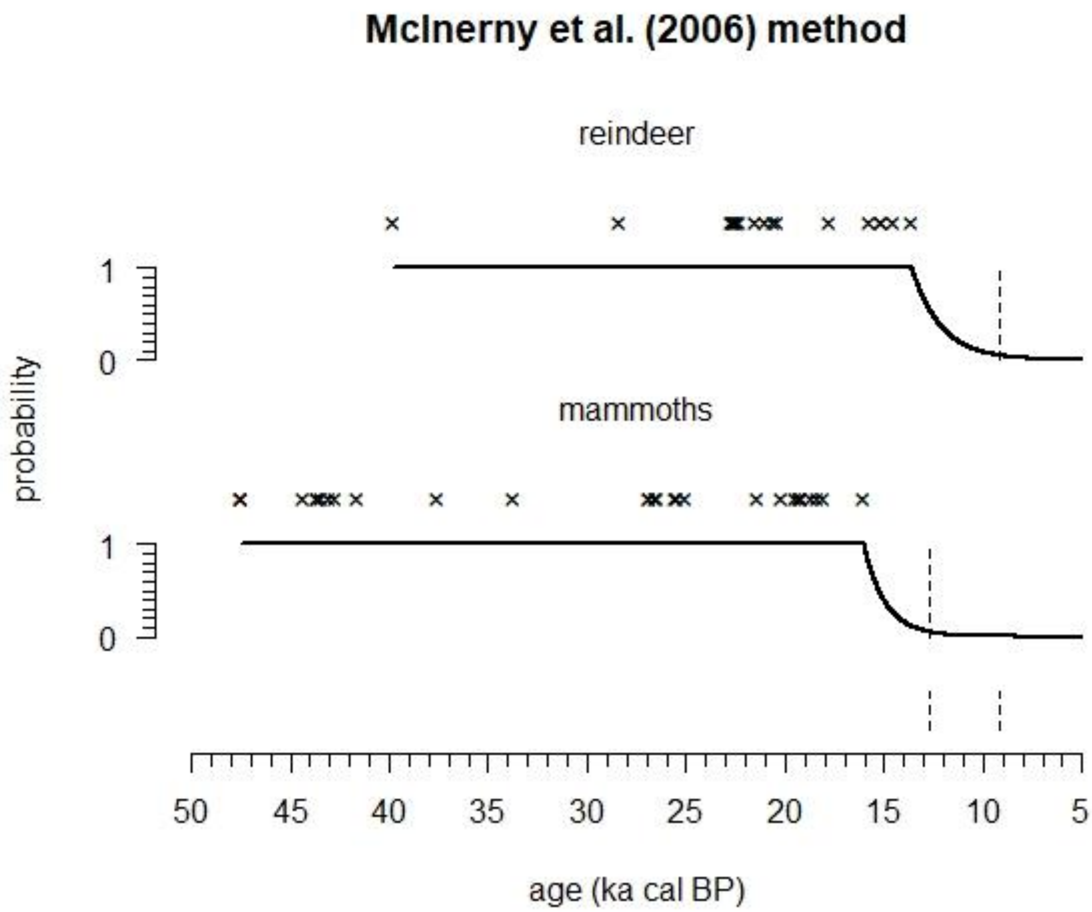

Fig 1. *Extinction time estimations for mammoths and reindeer using the method developed by McInerny et al. (2006).*

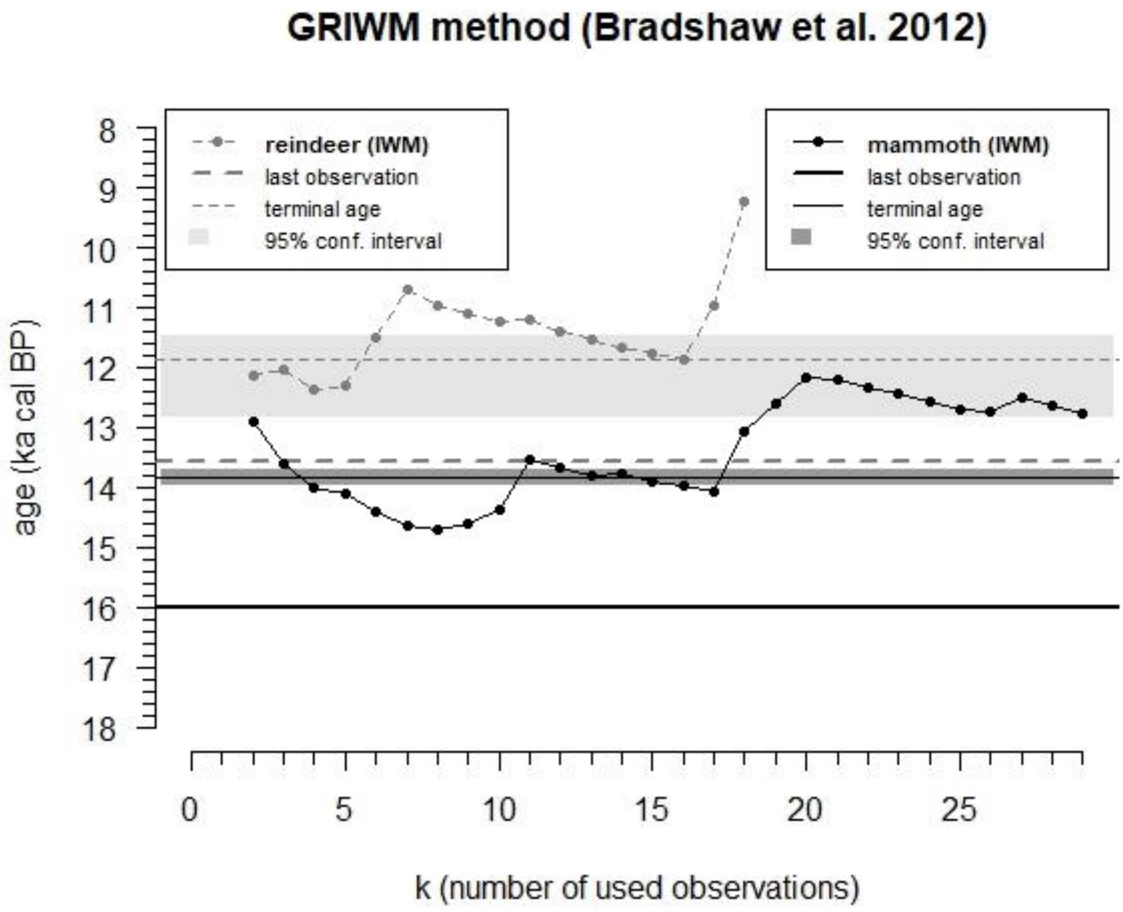

Fig 2. *Extinction time estimations for mammoths and reindeer using the Gaussian resampled, inverse weighted McInerny et al. method developed by Bradshaw et al. (2012).*

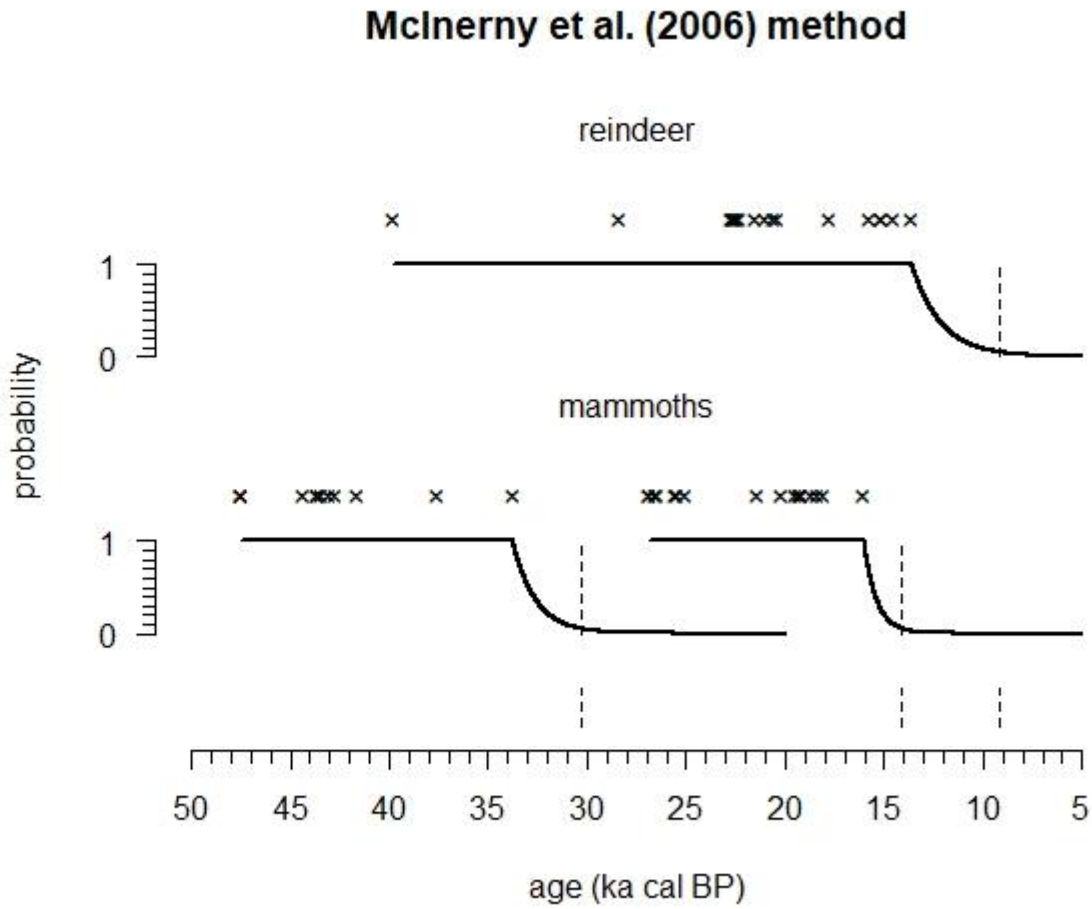

Fig 3. *Extinction time estimations for mammoths and reindeer using the method developed by McInerny et al. (2006). For this image, mammoth data form before and after their apparent absence between 32.5-27.4 ka were treated separately.*

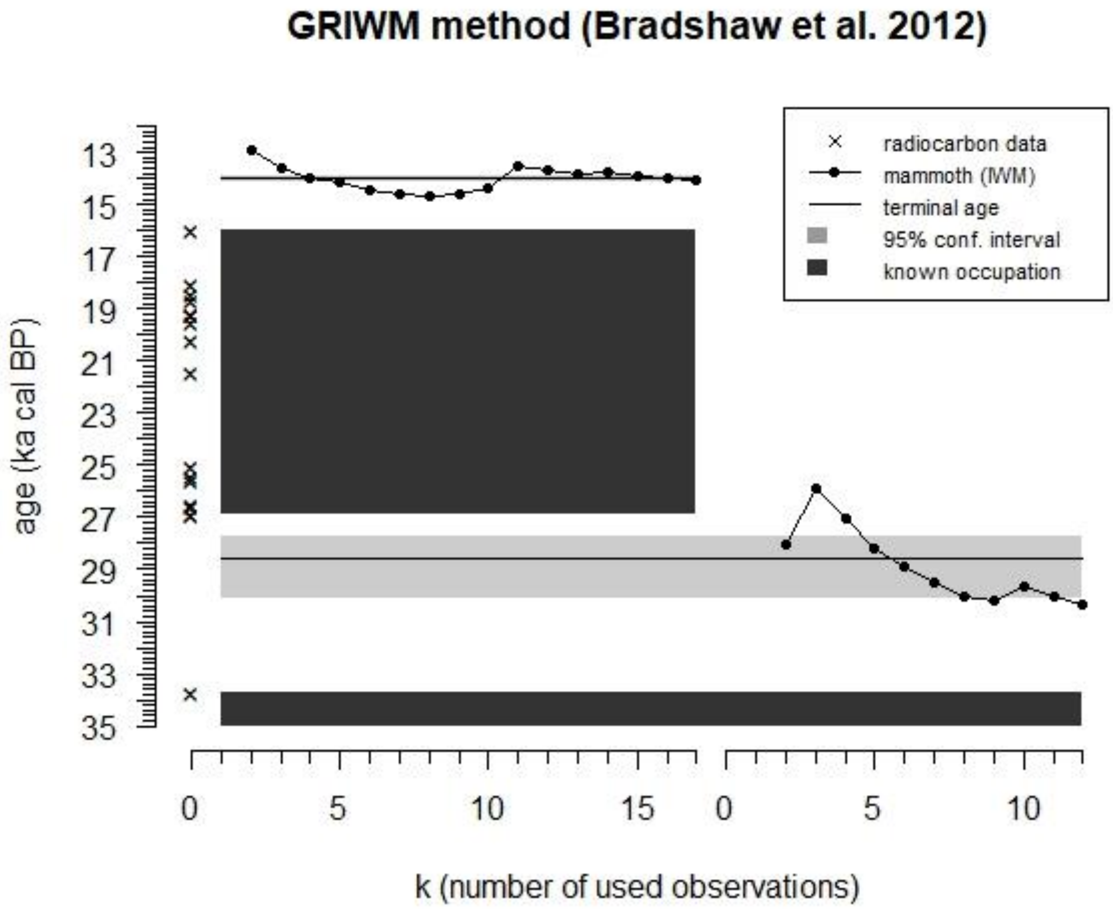

Fig 4. *Extinction time estimations for mammoths and reindeer using the Gaussian resampled, inverse weighted McInerny et al. method developed by Bradshaw et al. (2012). For this image, mammoth data form before and after their apparent absence between 32.5-27.4 ka were treated separately.*