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Comments on: "Estimating the body mass of the Late Pleistocene megafauna from the South America Intertropical Region and a new regression to estimate the body mass of extinct xenarthrans"

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Body mass has important ecological and evolutionary implications (e.g., Damuth, 1981; Marroig and Cheverud, 2005), and estimating body mass for extinct species has been a topic of intense research (e.g., Campione, 2017; Campione and Evans, 2012). Estimating body mass for the extinct specious Xenarthra has been particularly challenging, given unique morphological adaptations and no close modern analogs for several lineages in terms of size and shape (Farina et al., 1998).

Recently (Dantas, 2022), published the paper "Estimating the body mass of the Late Pleistocene megafauna from the South America Intertropical Region and a new regression to estimate the body mass of extinct xenarthrans" in which one of the major goals is "to propose a new regression to estimate the body mass of xenarthrans" (p. 1). The other major objective is to present body mass estimations for several extinct species, including Xenarthra. Although we value Dantas (2022) effort in bringing a fresh approach to the contentious task of providing body mass estimates for several extinct Xenarthra, our aim in this reply is to call attention to issues in the adopted approach that ultimately undermine the scientific validity of Dantas (2022) results.

Dantas (2022) stated that he used the reduced (or standardized) major axis regression (RMA) estimation (see a didactic discussion in Warton et al., 2006 about this method; notice that Dantas (2022) equation on p. 3 actually reports the major axis regression, and not the RMA) to determine the body mass of extinct Xenarthra. Dantas (2022) calculated the regression equation based on measurements of humerus and femur minimum diaphyses' circumferences and body masses for five Xenarthran species (four genera, and two orders) presented by Campione and Evans, 2012). There are two main problems with the approach adopted by Dantas (2022). First, the equation on p. 3 was determined based on only five species. Second, the equation on p. 3 was used to estimate the body mass of species outside, and in some cases (e.g., *Eremotherium*), far outside the range of body mass of the species used to calculate the equation. The heaviest species in the Dantas (2022) sample is the armadillo *Priodontes maximus* (Kerr, 1792) which had a weight of 29.5 kg (Campione and Evans, 2012). All extinct species studied in Dantas (2022) are presumed heavier than that.

We believe that a combination of an insufficient sample and a sample biased to smaller sizes makes the equation derived by Dantas (2022) unreliable to estimate Xenarthran body masses (see the discussion in Smith, 2009 for the matter of extrapolations). To illustrate this, we performed a rarefection study to evaluate the statistical proprieties of the RMA regression equation under the circumstances described by Dantas (2022). We studied all mammals (with the exception of moles, as in Campione, 2017) from the dataset from Campione and Evans (2012), totalizing 198 species. This dataset was divided into two: i) one composed of 188 species with body mass <500 kg (i.e., lighter species) that was used to generate RMA regression equations, and ii) the other one with the 10 species with body mass >500 kg (i.e., heavier species), for which we extrapolated their body masses based on the equation obtained from the lighter species. We did the rarefection analysis for two target sample sizes, five and 35. For each target sample size, we sampled 100 times species without replacement from the species dataset and calculate the RMA equation on the Log_{10} scale. This equation was used to estimate the body mass of the heavier species. Then we calculated the percent prediction error (PPE) for the heavier species. PPE is a standardized measure of the difference between real and estimated body masses. If the real and estimated body masses are the same (which will never be), PPE equals zero, otherwise, it gives the percentage of the absolute difference between real and estimated body masses. For instance, a PPE = 50 means that the estimated body mass is either 50% lighter or heavier than the real body mass.

Since Dantas (2022) stated that the equation on p. 3 was reliable to infer the body mass of the extinct species based on results from the

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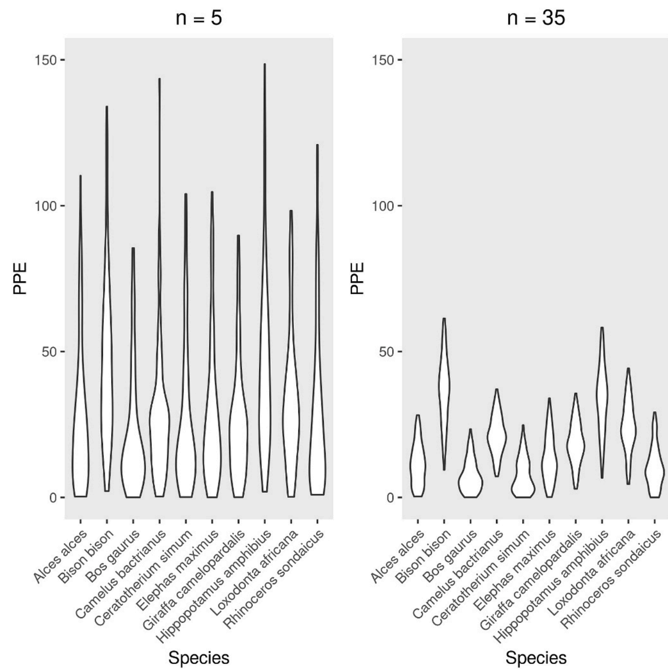

Fig. 1. The distribution of 100 PPE for RMA equations generated from sampling five or 35 species without replacement. 26 extreme PPE values (ranging between >150 and ~320) are not represented on the left side graph.

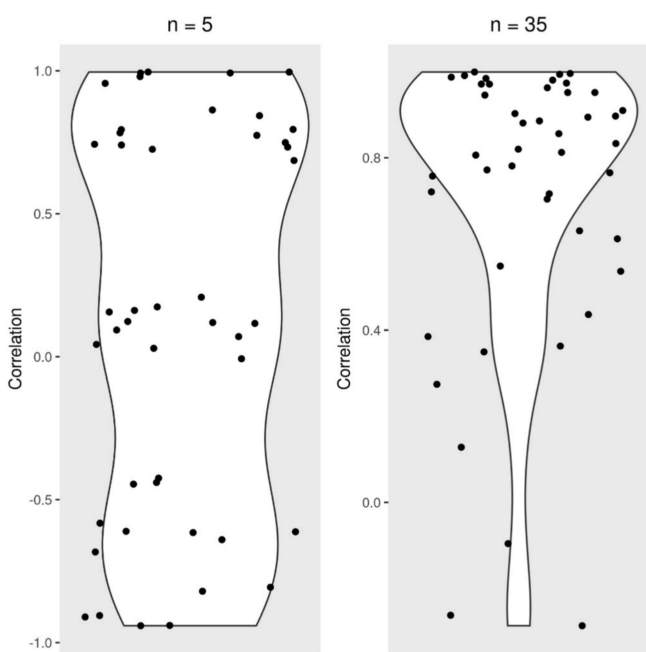

Fig. 2. Pair-wise correlation between PPE for the heavier species between the 100 resamplings. In other words, each dot represents the correlation between the PPE obtained from two resampling.

coefficient of determination of the equation (r^2), and the standard error of the estimate (SEE), and the mean PPE for the species used to generate the model, we graphically observed the relationship between these statistics and the mean PPE obtained for the heavier species on each of our models. The reasoning behind this approach is that if the statistics related to the model are good predictors of the body mass predicted for the heavier species, a strong relationship should be observed between them over our rarefaction analysis. All analyses were run under the R Core Team (2022) programming environment using the packages lmodel2 (Legendre, 2018), and MASSTIMATE (Campione, 2020).

Our results show that with five species one may frequently estimate body masses more than 50% different from the real body mass for heavier species (Fig. 1). In contrast, differences in estimated and real body masses are much more constrained with an increased sample size (Fig. 1). Therefore, body masses presented in Dantas (2022) may or may not represent good estimates of body mass for extinct Xenarthra, and there is no way to determine that based on the available data. Our results also support that depending on the few species selected to generate the equation, the ordering of species from lightest to heaviest changes (Fig. 2). For instance, based on one model species A is lighter than species B, while in another model the opposite is observed. Once again, results are more consistent with an increase in the number of species used to calculate the equation, but are far from ideal (Fig. 2). Consequently, Dantas (2022) body masses estimated from the equation on p. 3 cannot be interpreted with any certainty in a relative body weight scale, from the lightest to the heaviest species.

Dantas (2022) argued that the equation on p. 3 had good support based on three statistics obtained from equation on p. 3 (r^2, SEE, and PPE), and, therefore, could be used with confidence to estimate body masses of species outside the range of body masses from the species used to calculate the RMA equation. Our results do not support this interpretation (Fig. 3). Values that would suggest that the model based on lighter species is reliable do not translate necessarily into reliable estimates for heavier species. In other words, even high r^2 and low SEE, and mean PPE can generate high mean PPE for the heavier species. Furthermore, given the notorious size and shape diversity of humeri and femora among Xenarthra (Amson and Nyakatura, 2018), the above problem is likely exacerbated in Xenarthra.

From the above, it is evident that there is little reliability in the approach presented by Dantas (2022). Therefore, there is no reason to consider valid the regression proposed by Dantas (2022) to estimate Xenarthra body masses, and, consequently, the body mass estimates presented in the paper for this taxon.

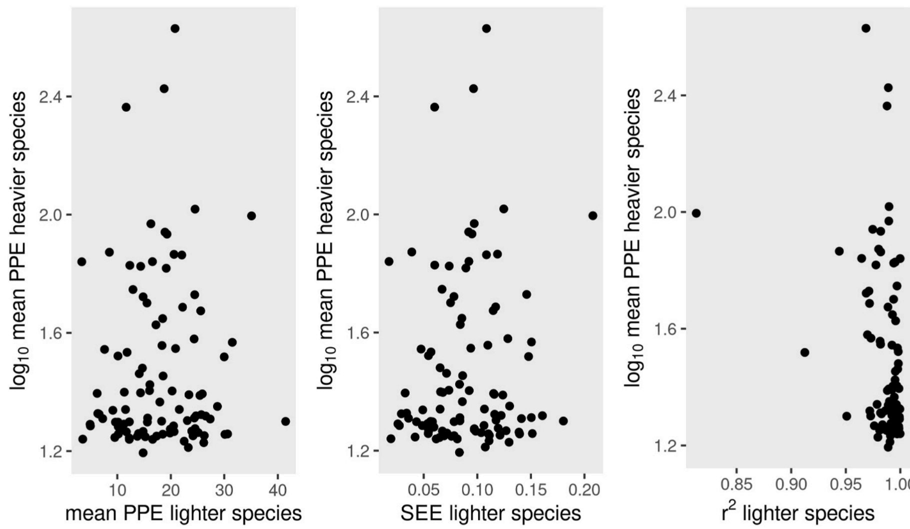

Fig. 3. Relationship between different statistics obtained from the model generating species (lighter species) and the $\log_{10}$ mean PPE for the species that had their body masses estimated (heavier species) for the resamples.

CRediT authorship contribution statement

Alex Hubbe: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Fabio A. Machado:** Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We used published data available online

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