Examining Variability in Seasonal Behaviors with Bayesian Cyclical $\delta^{18}O$ Regression Models

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Introduction

Isotopic profiles of stable oxygen isotopic values ($\delta^{18}O$) from animal tooth enamel can provide in-depth information about past environments and animal behavior

Cyclical regression models allow researchers to fit a specimen's isotopic profile to a particular curve, allowing quantitative comparisons between specimens

Comparing parameter values between specimens allows analysis of environmental conditions and seasonal behaviors (e.g., birth, migrations).

Issues

However, standard methods based on maximum likelihood estimation (MLE) rely on *densely sampled* specimens (e.g., Balasse, et al. 2012)

Limits sample size due to budgetary or preservation constraints

Also have no mechanism to ***summarize*** population-level parameter values to describe overall trends (though see SCEM method: Chazin, et al. 2019).

Bayesian Modeling

This poster presents a ***Bayesian multilevel regression model*** to estimate isotopic profiles from d18O of serially-sampled teeth using cyclical regression curves.

The ***multilevel*** structure provides better performance with sparse sampling strategies allows straightforward summarization

Prior distributions ensure that the model does not overfit to sparse samples and that parameter estimates are biologically interpretable

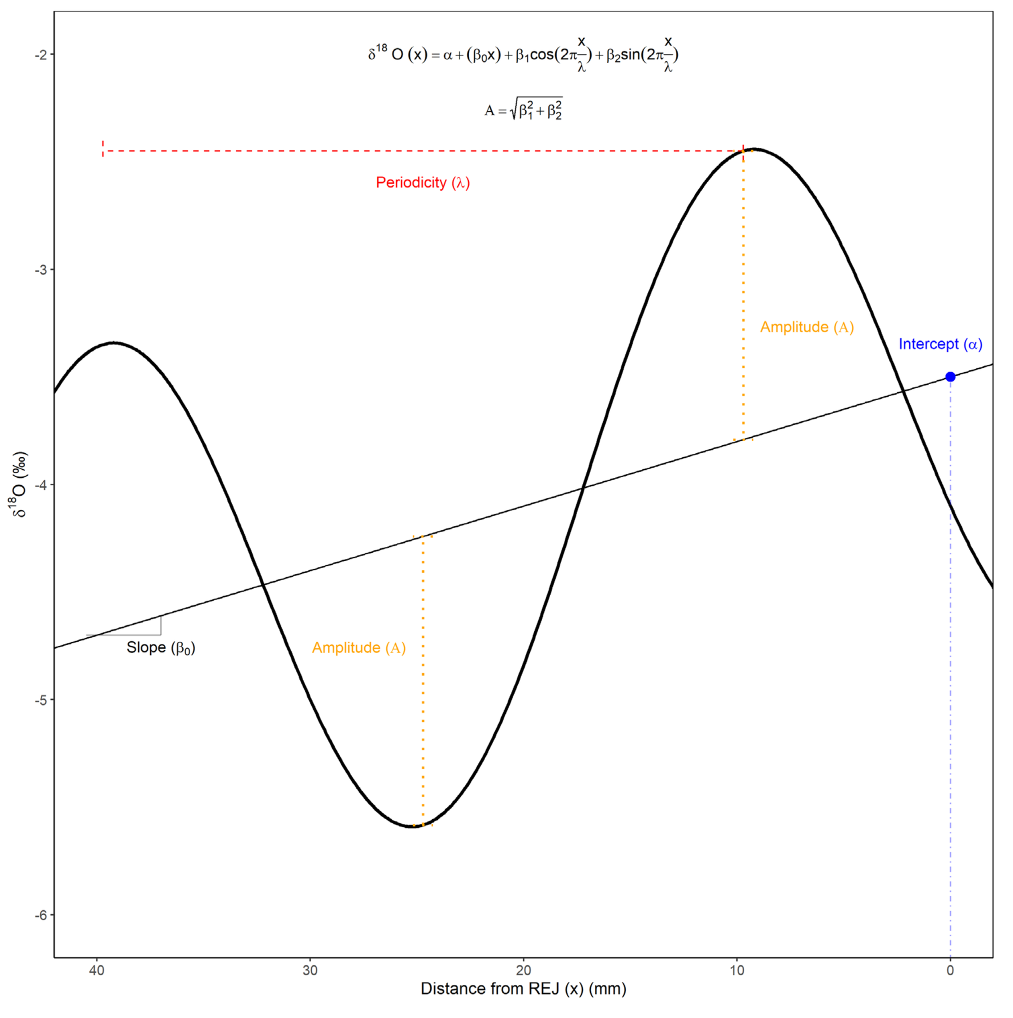
Model details, vignette, and code for application available at associated GitHub page: **https://github.com/wolfhagenj/Oxy_Cyclical_Regression**

Cyclical Regression

Models $\delta^{18}O$ data as coming from a linear regression against distance from the root enamel junction (REJ)

Regression coefficients allow sinusoidal variation around a central trend, matching seasonal fluctuation in $\delta^{18}O$ inputs

Birth seasonality can be estimated using these parameter values, estimating the relative point in the cycle that the first peak is reached



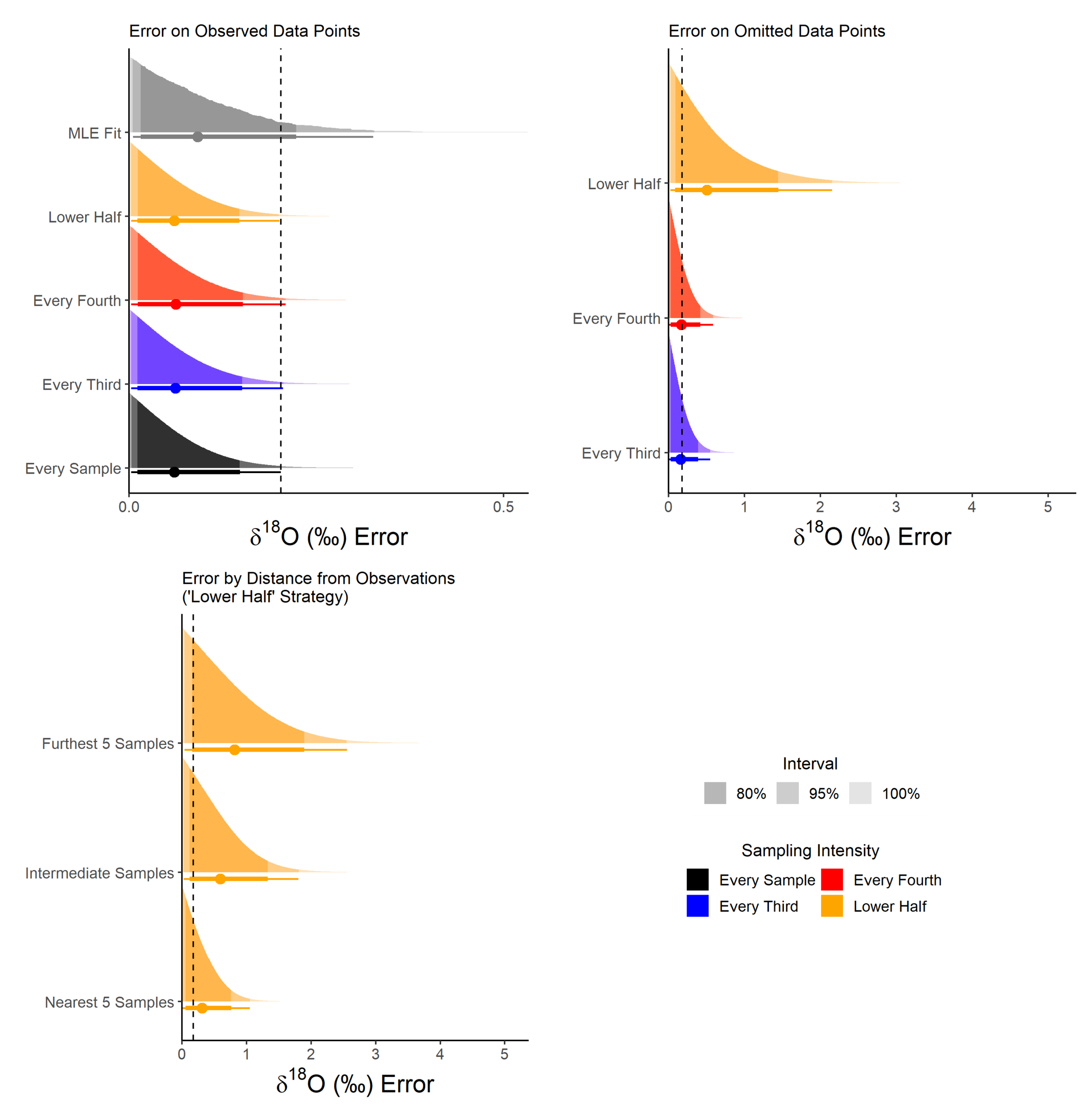
Testing

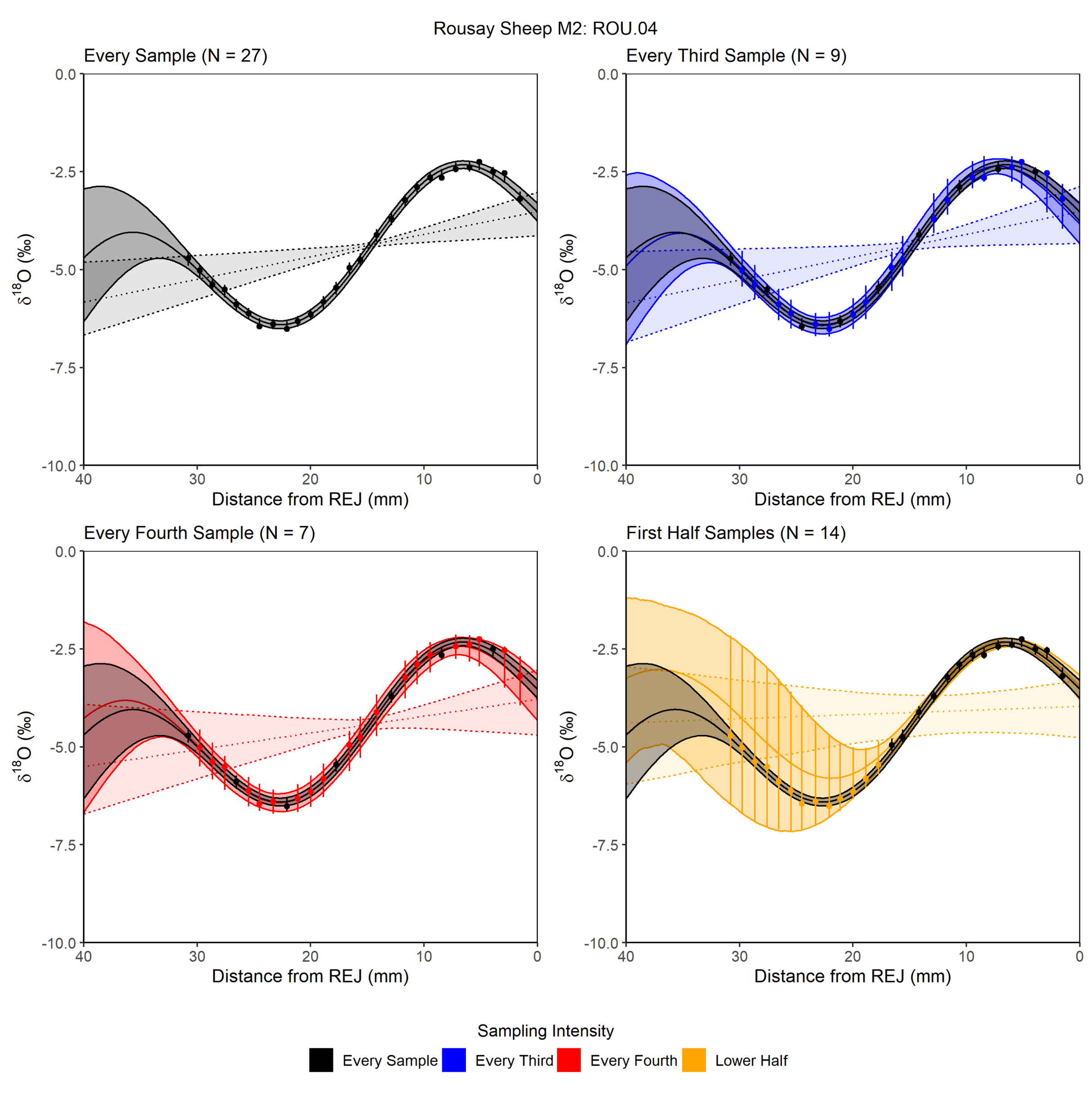
Ten modern sheep from Rousay (UK) have been used to define earlier iterations of cyclical regression models (e.g., Balasse, et al. 2012; Chazin, et al. 2019)

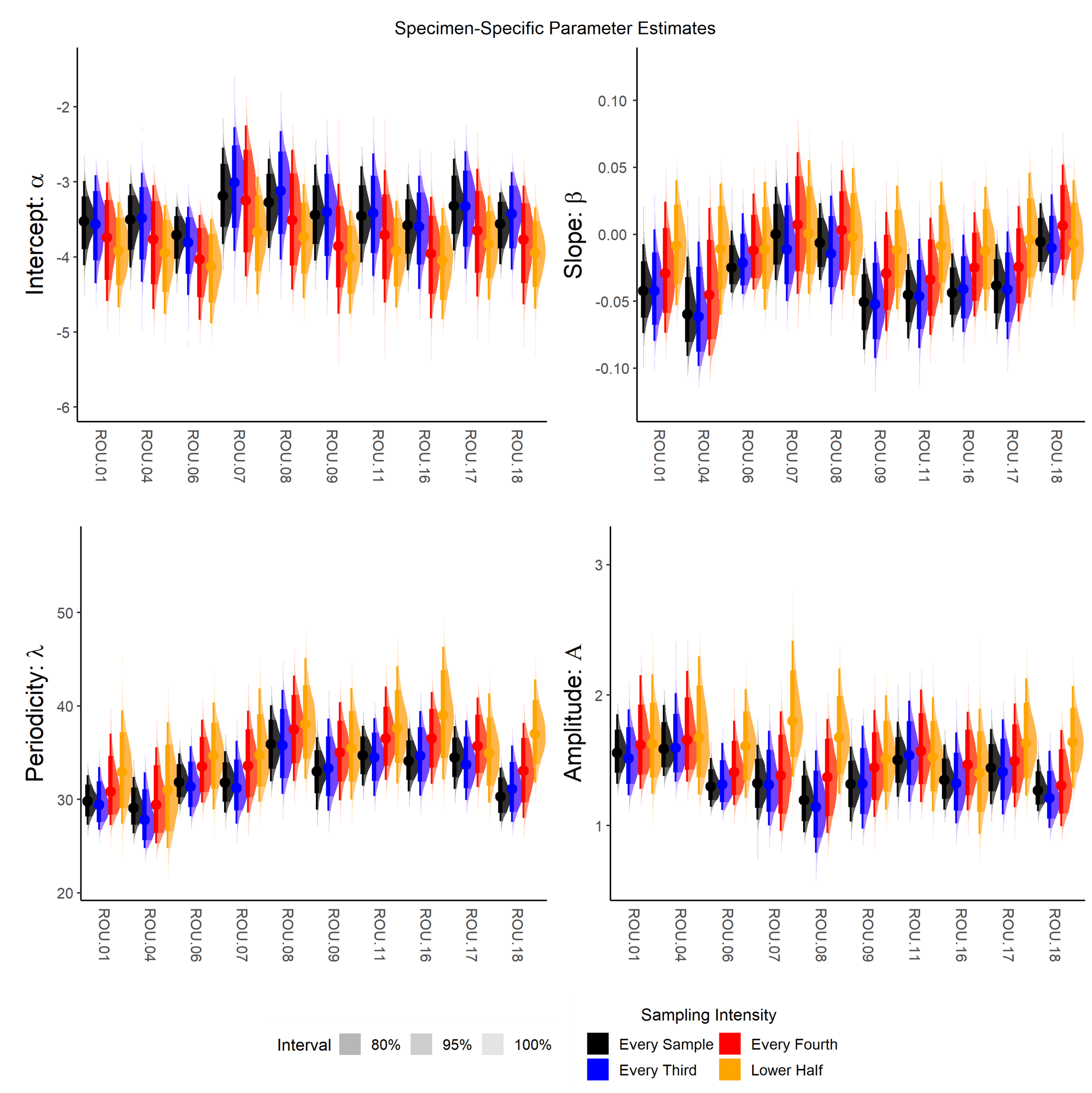
Data were sub-sampled to test Bayesian model's *accuracy* (for omitted data) and *effectiveness* at summarizing the tooth's parameter values

Sampling Intensity	Mean	Median	Minimum	Maximum
Every Sample	27.2	27.5	20	31
Every Third	9.3	9.5	7	11
Every Fourth	7.1	7	5	8
Lower Half	14.3	14.5	11	16

Sample sizes under different Sampling Intensities

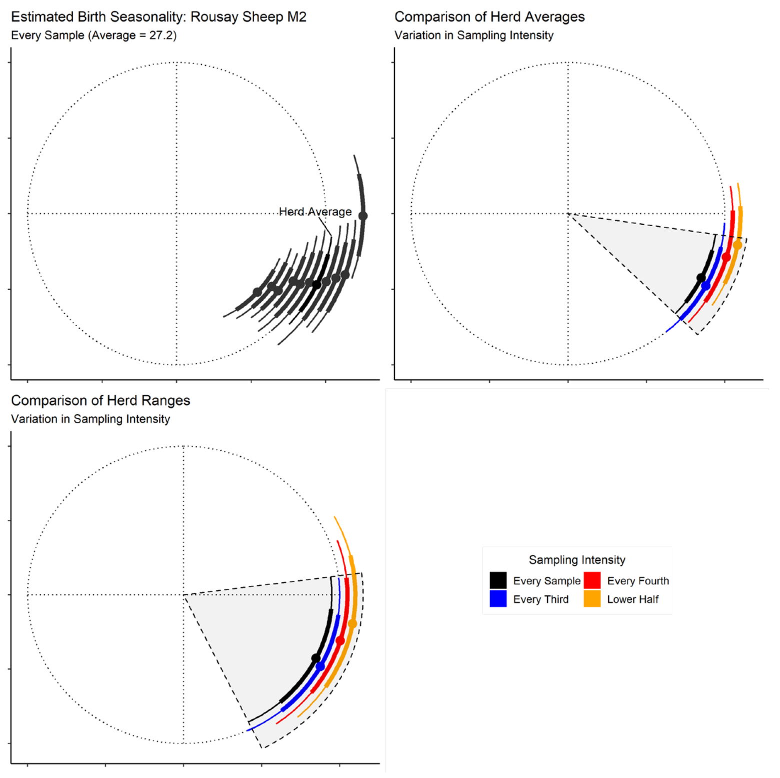






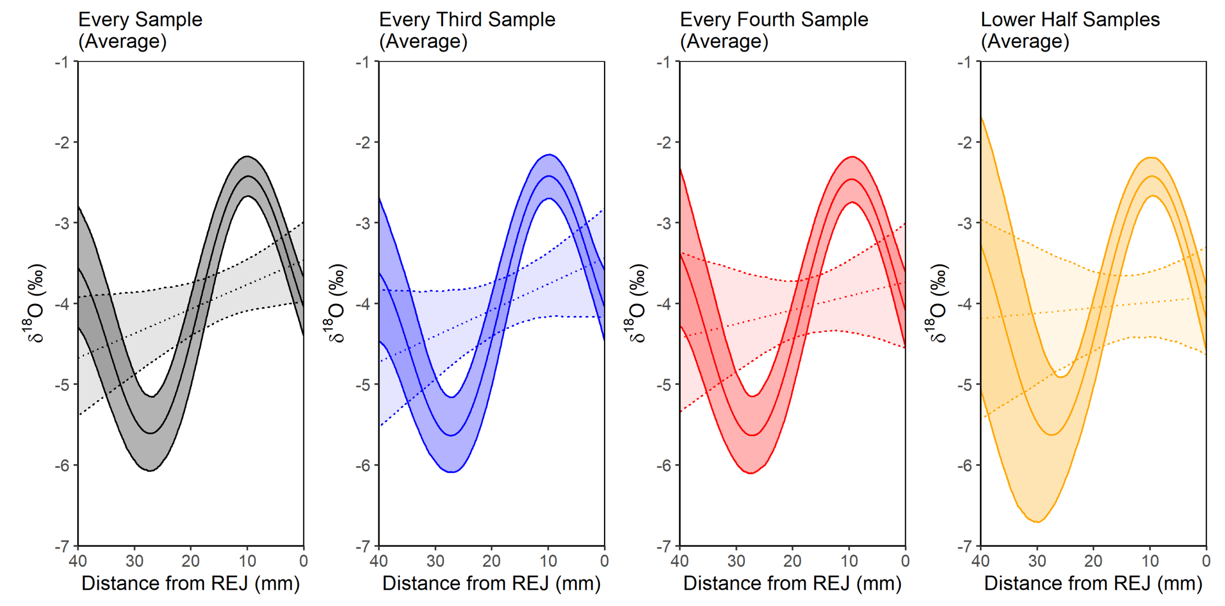
Birth Seasonality

The regression model parameters can be used to estimate birth seasonality, showing both the average relative position of the peak and the variability one would expect from the assemblage-level parameters



Summarization

Assemblage-level ("mean") model parameters can be used to draw *average* isotopic profiles for the assemblage



Conclusions

The Bayesian model has lower error on observations than the MLE model

Sparse sampling strategies can effectively estimate missing data with an **average accuracy of ~0.2 ‰**; model parameters are also broadly concordant

Estimates based on partial samples have more error, but still **largely within 2 ‰**

Bayesian approach can effectively model sparsely-sampled specimens

References

Balasse, M., Obein, G., Ughetto-Monfrin, J., & Mainland, I. (2012). Investigating Seasonality and Season of Birth in Past Herds: A Reference Set of Sheep Enamel Stable Oxygen Isotope Ratios. *Archaeometry*, *54*(2), 349-368.

Chazin, H., Deb, S., Falk, J., & Srinivasan, A. (2019). New Statistical Approaches to Intra-individual Isotopic Analysis and Modelling of Birth Seasonality in Studies of Herd Animals. *Archaeometry*, *61*(2), 478-493. https://doi.org/10.1111/arcm.12432