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1 **Expanding the use of reindeer foetal bone measurements for zooarchaeological**  
2 **applications**

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10

11 **Abstract**

12 When foetal bones are preserved in archaeological sites, they are often used to identify the  
13 seasonality of prey acquisition by past human populations and, subsequently, to discuss their  
14 lifestyle, their management of food resources, nomadic cycles, etc. To do so,  
15 zooarchaeologists use charts to estimate foetal age based on the growth of their bones. For  
16 reindeer (*Rangifer tarandus*), a species that was widely exploited since the Palaeolithic  
17 throughout Eurasia, existing reference data are limited and require the measurement of  
18 complete bones, a procedure that is rarely applicable to archaeological contexts in which  
19 bones are often fragmented. In this study we present a wide range of measurements (9-10  
20 measurements per bone) taken on the humerus, radius, metacarpal, femur, tibia and metatarsal  
21 of 31 individuals housed at the Zoological Museum of the University of Oulu (Finland). With  
22 this large data set, a more accurate estimation of the time of death of reindeer foetus can be  
23 achieved using skeletal measurements, even in the case of fragmented bones. To facilitate the

24 use of this referential, an open-access web interface ([foetusmeteR](#)) was designed in RShiny.  
25 This interface allows for the direct estimation of foetal age and season of death by entering a  
26 single skeletal measurement, as well as the possibility of estimating if two bones might  
27 correspond to the same individual using two different measurements. This new tool should  
28 help to discuss in more detail the condition of reindeer herds hunted in the past, the hunting  
29 techniques and strategies that may have been used by human groups, and allow for a more  
30 detailed reconstruction of the seasonal nomadic cycle of past societies that focused their  
31 subsistence on *Rangifer* populations.

32 **Keywords:** foetus, seasonality, *Rangifer tarandus*, Paleolithic, subsistence, foetusmeteR

### 33 **Introduction**

34 Apart from its key role in many modern Arctic herding societies, reindeer (*Rangifer tarandus*)  
35 was also one of the most commonly hunted prey throughout the Paleolithic in Eurasia, as  
36 testified by the abundance of its skeletal remains in archaeological sites (e.g. Delpech, 1983;  
37 Discamps et al., 2011; Boyle, 2017; Yaworsky et al., 2023). When foetal bones are found  
38 amongst archaeological assemblages, they constitute a valuable asset because these skeletal  
39 elements attest to the exploitation of pregnant females by past humans and allow for an  
40 estimation of the slaughter season of these reindeer females. By combining such information  
41 with other data, it then becomes possible to reconstruct the hunting strategies and techniques  
42 employed by past societies. The presence of foetal bones can however raise questions for  
43 scholars interested in the study of past human-reindeer interactions (i.e. zooarchaeologists).

44 The literature available on societies whose economy is still (or was until recently) mainly  
45 based on hunting provides some interesting food for thought on the subject of foetuses. First  
46 of all, their presence is to be expected on kill sites, where game is usually butchered first in  
47 order to remove unwanted parts and save weight for transport to base camps. Past human  
48 populations sometimes targeted specific social groups for precise needs, and foetus bones can  
49 testify of the hunt of matriarchal groups in order to obtain young individuals with very  
50 valuable hides. Foetal bones are however also found in “secondary” sites such as base camps,  
51 where they might have been introduced deliberately. The very tender foetal meat is generally  
52 given to people who have difficulty chewing, such as young children or the elderly (Jenness,  
53 1922; Speck, 1935; Holston, 1963; Gubser, 1965; Burch, 1972; Hungry Wolf, 1980; Ingstad,  
54 1992), and can be eaten boiled or roasted. Foetal skin is also highly prized for its fineness and  
55 can be used to make children's clothing, blankets or fine summer clothes, masks and  
56 containers (e.g. Stefánsson, 1914; Curtis, 1930; Banfield, 1977; Binford, 1978, 1981;  
57 Grønnow et al., 1983; Russell, 1995; Parget, 2004; Pinson, 2004; Blackman, 2006). When

58 pregnant females are hunted, some groups (such as the Quechua), include the foetus in  
59 offerings (Froemming, 2006). All of these uses, and certainly many others, are likely to date  
60 back to prehistoric times and can provide interesting food for thought about the presence of  
61 foetuses in archaeological sites.

62 When *Rangifer* foetal bones are found on an archaeological site, zooarchaeological studies  
63 often take advantage of them to try to access precious seasonal data (e.g. Castel, 1999; Morin,  
64 2004; Paletta, 2005; Castel & Chauvière, 2007; Bemilli & Bayle, 2009; Magniez, 2009;  
65 Connet et al., 2012; Soulier, 2013, 2014; Pétilion et al., 2015; Castel et al., 2017; Fontana,  
66 2017; Costamagno, 2021). To do so, such studies referred to the few published datasets on  
67 foetal bone growth for reindeer/caribou. To our knowledge, only two works carried out  
68 measurements of *Rangifer* foetal bones:

- 69 ● Based on hindfoot length data from 4 individuals supplied by Kelsall (1957), Spiess  
70 (1979) noted a straight-line regression. Spiess proceeded to conclude that “*assuming a*  
71 *relatively constant growth rate and a relatively constant proportion between total*  
72 *hind-foot length and diaphyseal lengths of fore and hind-limb long bones, [...] simple*  
73 *regressions [can be used by zooarchaeologists] to go from the diaphyseal length of a*  
74 *given fetal long bone, to total hind-foot length, [and thus] to fetal age”* (Spiess, 1979:  
75 pp. 94-95). He then compared hind-foot lengths and diaphyseal lengths on 6 young  
76 individuals to establish correlations. From this, he developed a simple formula, based  
77 on the total length of the complete bone, to estimate foetal development from the  
78 metapodials, femur, humerus and tibia. Zooarchaeologists have since mostly used  
79 these equations for seasonal estimation (cf. references cited above).
- 80 ● Roine and collaborators (1982) studied the development of 348 reindeer foetuses from  
81 Finland, providing mean measurements of the metacarpal length per estimated age.

82           They demonstrated strong correlations between foetus age, body weight and  
83           metacarpal length. Using the equation they provide, zooarchaeologists can estimate  
84           foetal age using a length measurement of a complete metacarpal bone.

85

86   These two studies are undoubtedly of capital importance for estimating the slaughter seasons  
87   of pregnant females. They do however suffer from three major drawbacks when it comes to  
88   their use for zooarchaeological analysis. First and foremost, these two studies were not  
89   designed to work on fragmented bones, even though foetal bones are highly prone to  
90   alteration by taphonomic processes due to their fragility and low density. To compensate for  
91   this bias, one solution is to estimate the completeness of the bone fragment (e.g. Soulier,  
92   2013). However, a few millimetres of difference can alter our estimates by several weeks, or  
93   even months, which is not without consequences for discussions on the hunting techniques  
94   and strategies of prehistoric societies (depending on the season of death, zooarchaeologists  
95   would infer either hunting on isolated individuals or mass slaughters of migrating large  
96   herds). Secondly, no data is available for the radius. Given that foetal bones are not very  
97   dense and prone to destruction by taphonomic processes, the absence of one skeletal element  
98   is highly regrettable: important seasonal information cannot be accessed using radii, despite  
99   the fact that this precious and fragile material has been preserved over time. Finally, the lack  
100   of data for complete individuals in these studies (e.g. measurements of the humerus and femur  
101   of the same individual) makes it difficult to determine with a high degree of precision whether  
102   different skeletal elements could belong to the same or multiple individuals. This has  
103   implications for zooarchaeological interpretations of past hunting strategies, as well as  
104   considerations relating to the presence of fetuses in archaeological sites.

105 The objectives of our study are manifold:

- 106 - Increase the available reference measurements (currently limited, for most elements  
107 except the metacarpal, to Spiess' estimates based on the 4 individuals measured by  
108 Kelsall), in order to provide more robust correlations;
- 109 - Provide measurements on isolated elements (i.e. the bones themselves) and not from  
110 hindfoot lengths, which are *de facto* estimates;
- 111 - Obtain seasonality data on all long bones, so as to mobilise the largest possible corpus  
112 for estimating the game killing season;
- 113 - Propose easily usable measurements on fragmented material by multiplying  
114 measurement points;
- 115 - Provide correlations between elements for accurate calculation of foetal Minimum  
116 Number of Individuals (MNI) when bones are found isolated, i.e. the fewest possible  
117 number of animals in a skeletal assemblage;
- 118 - Design an easy-to-use interface for the analysis of foetal measurements.

119 To these ends, a metric analysis of 31 *Rangifer tarandus* foetal bones is presented here.

120

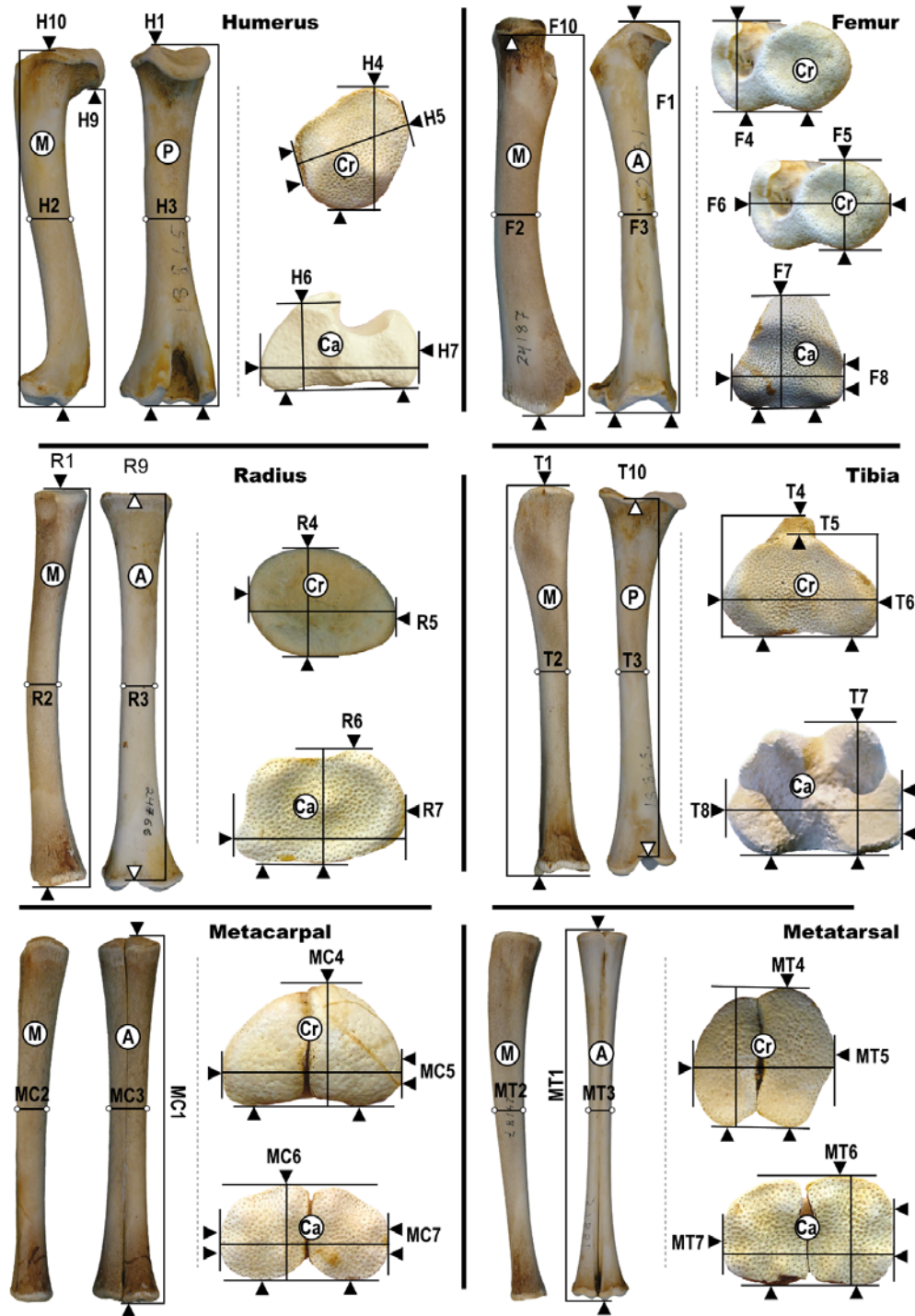
## 121 **Material and methods**

122 A total of 31 individuals stored at the Zoological Museum of the University of Oulu (Finland)  
123 were measured: 24 domesticated *Rangifer tarandus tarandus* (6 females, 11 males, 7  
124 unknown), 6 wild Finnish forest reindeer *Rangifer tarandus fennicus* (3 females, 3 males) and  
125 one hybrid *R. t. tarandus-fennicus* female. They were all collected in Finland (in the  
126 municipalities of Inari, Kivijärvi, Kuhmo, Kuivaniemi, Kuusamo, Oulu, Pudasjärvi, Salla,  
127 Suomussalmi and Yli-Ii), mostly between 1973 and 1990. Detailed information of individual

128 number, sex, finding date, municipality and additional data provided by the museum database  
129 (weight, body, tail and ear lengths, etc.) are available in the Supplementary Information #2.

130 Measurements were taken using an electronic calliper. Shreds of desiccated tendon sometimes  
131 present at the ends of bones were removed before taking measurements. To ensure replicable,  
132 usable measurements, we sought to make the measurement process as intuitive as possible,  
133 using the calliper in such a way that the gesture could easily be correctly reproduced (e.g.,  
134 two contact points on the same face, allowing the calliper to be set correctly). From 9 to 10  
135 measurements were taken for each bone, for a total of 55 measurements. All of the 55  
136 measurements are illustrated in Figure 1, and descriptions are given in Supplementary  
137 Information #1.





138

⚠ Be sure to check Supplementary Information #1 for guidelines on how to take the measurements ⚠

139 *Figure 1: Illustration of calliper positioning for measurements of Rangifer foetal bones.*

140 *Detailed descriptions and important guidelines are available in Supplementary Information*

141 *#1.*

142 The R8, H8, MC8, MT8, F9, T9 measurements correspond to the tightest point identified by  
143 sliding the calliper all along the diaphysis from top to down according to a medio-lateral axis.  
144 This point is roughly situated at mid-diaphysis but its location may vary slightly from one  
145 individual to another.

146 Statistical analysis and graphs were performed using R 4.2.2 (R Core Team, 2022) and  
147 RStudio (RStudio Team, 2020), with the packages this.path (Simmons, 2023), readxl  
148 (Wickham & Bryan, 2023), ggcorrplot (Kassambara, 2023), psych (Revelle, 2023), ggplot2  
149 (Wickham, 2016), scales (Wickham, Pedersen, et al., 2023) and dplyr (Wickham, François, et  
150 al., 2023). The interface was designed using the shiny package (Chang et al., 2023). The R  
151 codes are available at the following website: <https://github.com/ediscamps>

152

## 153 **Results**

154 To achieve the goals set in the introduction, a three-step approach was followed: 1) test  
155 whether the different measurements are correlated with each other, and thus if they can all be  
156 used to estimate one another as well as foetus overall size (i.e. which skeletal measurements  
157 are useable to assess foetus size? are long bones growing at a similar pace during foetal  
158 development?); 2) estimate how foetus skeletal measurements are correlated with foetal age;  
159 3) conceive a digital interface for the estimation of foetal age from skeletal measurements of  
160 fossil bones.

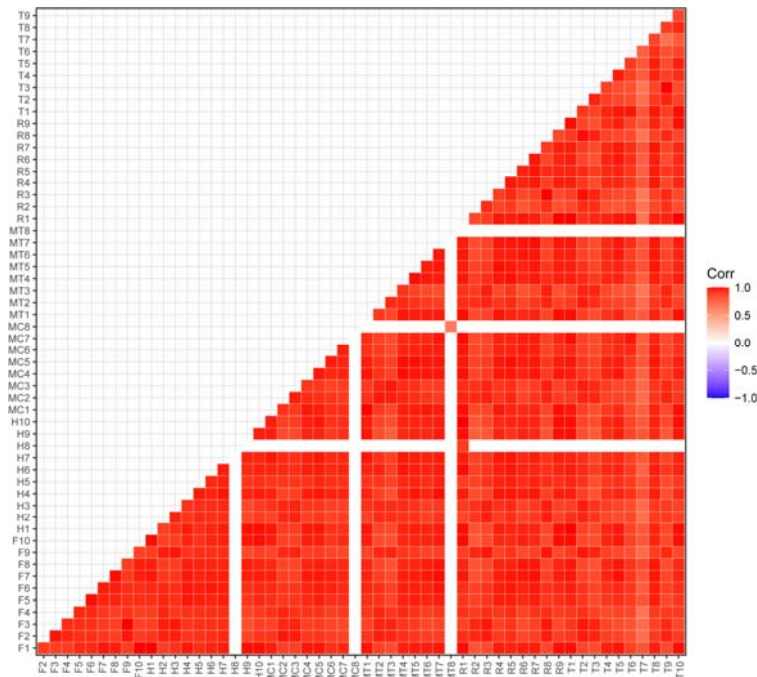
## 161 **Correlation between skeletal measurements**

162 Nearly all measurements (53 out of 55) are highly correlated between each other (Figure 2).  
163 H8, MC8 and MT8 (which are measurements taken at a variable point on the bone - the  
164 thinnest part of the diaphysis) have non-significant correlations with other measurements,

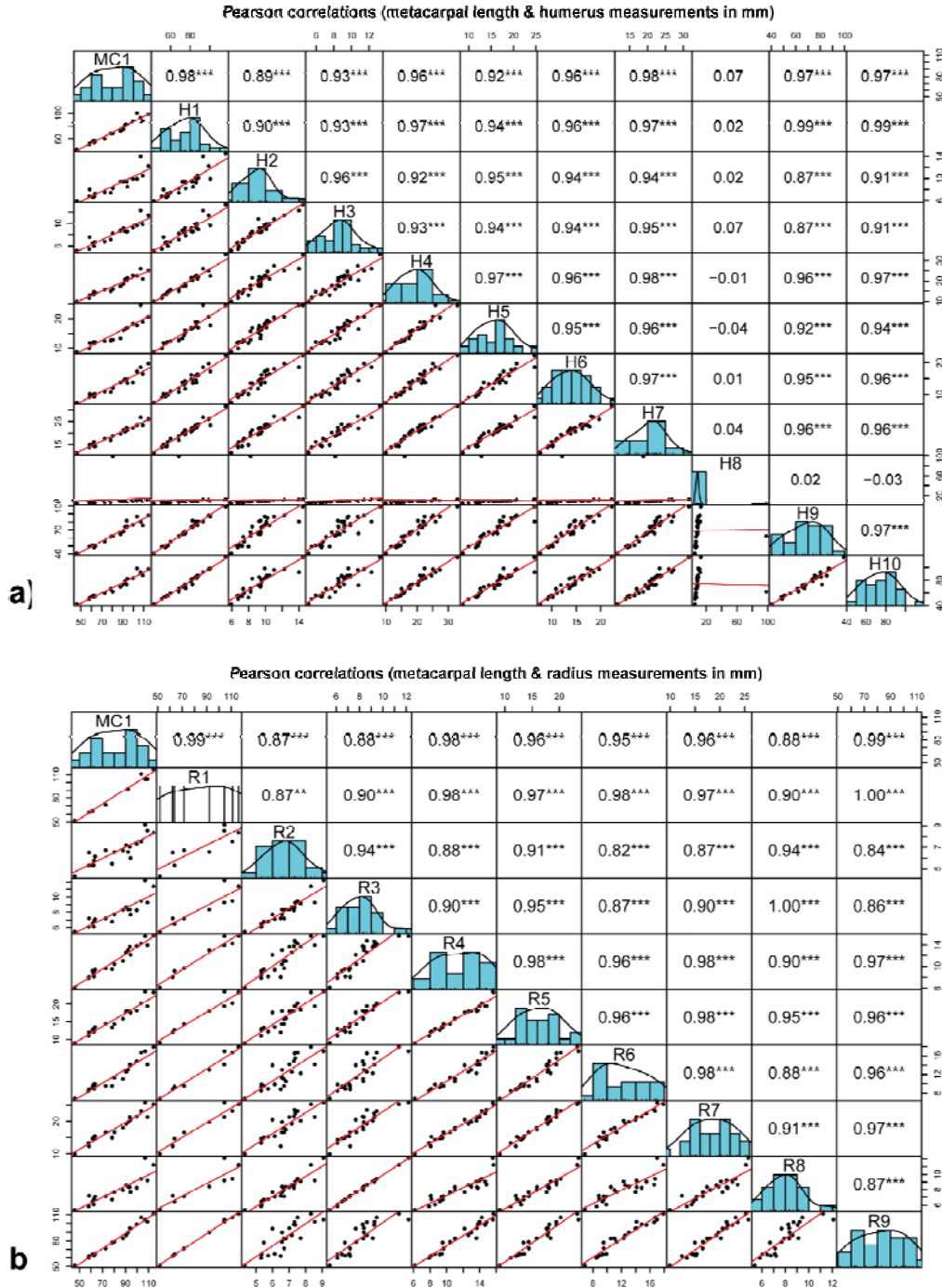
165 raising doubts on their interest as a measure of foetus overall size: they were excluded from  
166 further analyses. With these three measurements excluded, all correlations are significant ( $p <$   
167  $0.05$ ), and the Pearson  $r$  correlation statistic varies between  $0.69$  and  $0.99$  with a mean of  $0.93$ ,  
168 attesting to strong linear positive correlations. Figures 3, 4 and 5 present correlations and bi-  
169 plots between measurements in more detail. R1 stands out from others by showing a non-  
170 normal distribution (Figure 3), but this is mostly due to the fact that this measurement could  
171 only be taken on part of the specimens.

172 Overall these results show that all elements grow at a similar pace during foetal development.  
173 Apart from H8, MC8 and MT8, any measurement can be used to estimate the foetus overall  
174 size, as well as other measurements from the same bone, or from another one (e.g. for the  
175 establishment of Minimum Number of Individuals).

176



177 *Figure 2 : Pearson correlations between measurements. Statistically non-significant ( $p >$*   
178  *$0.05$ ) correlations are represented by blank cells.*

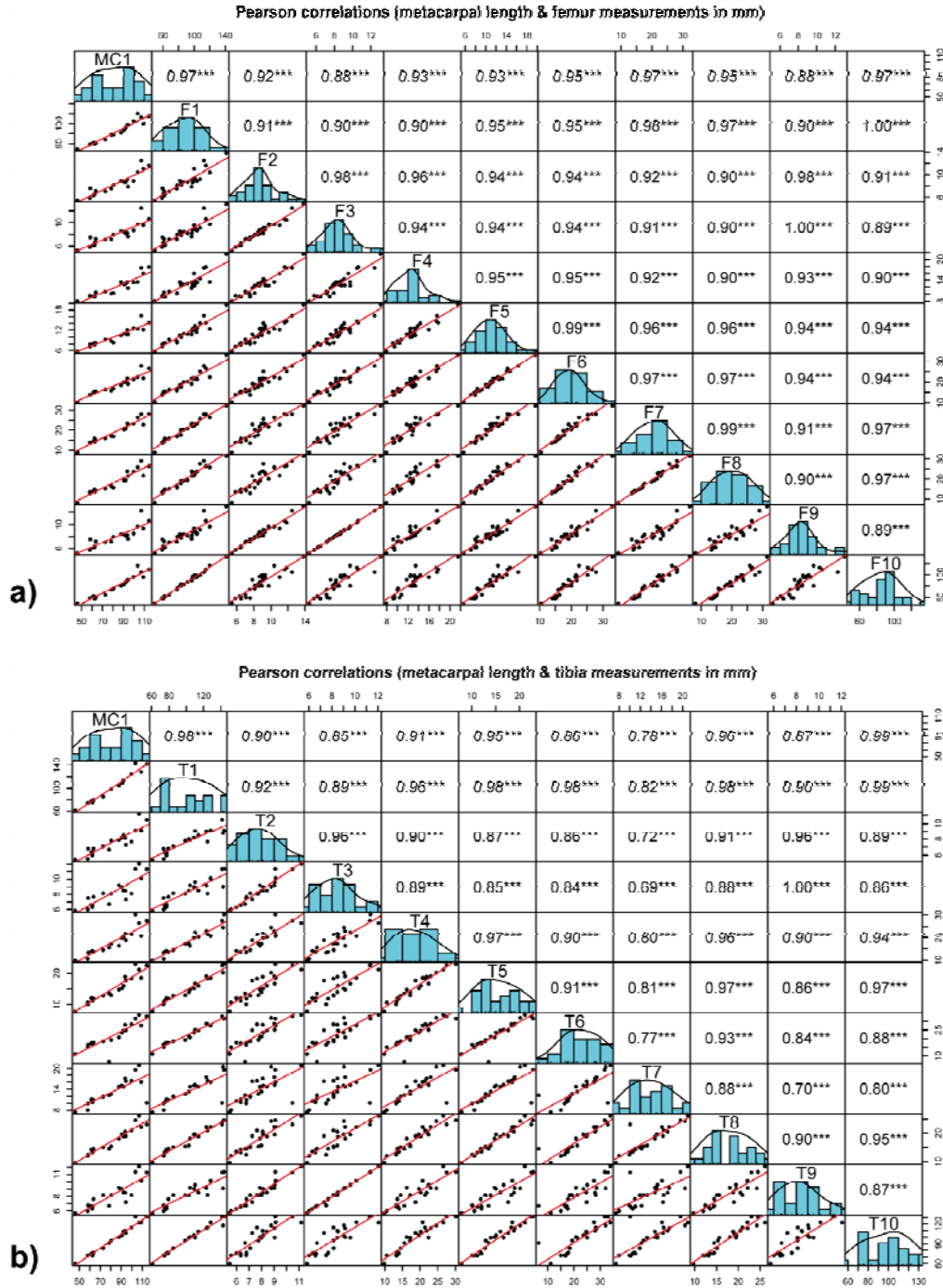


179

180 *Figure 3 : Humerus (a) and radius (b) measurements against metacarpal length. Diagonal:*

181 *histogram of measurements. Lower triangle: bivariate scatterplots of measurements. Upper*

182 *triangle: Pearson correlation statistic (\*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ ).*

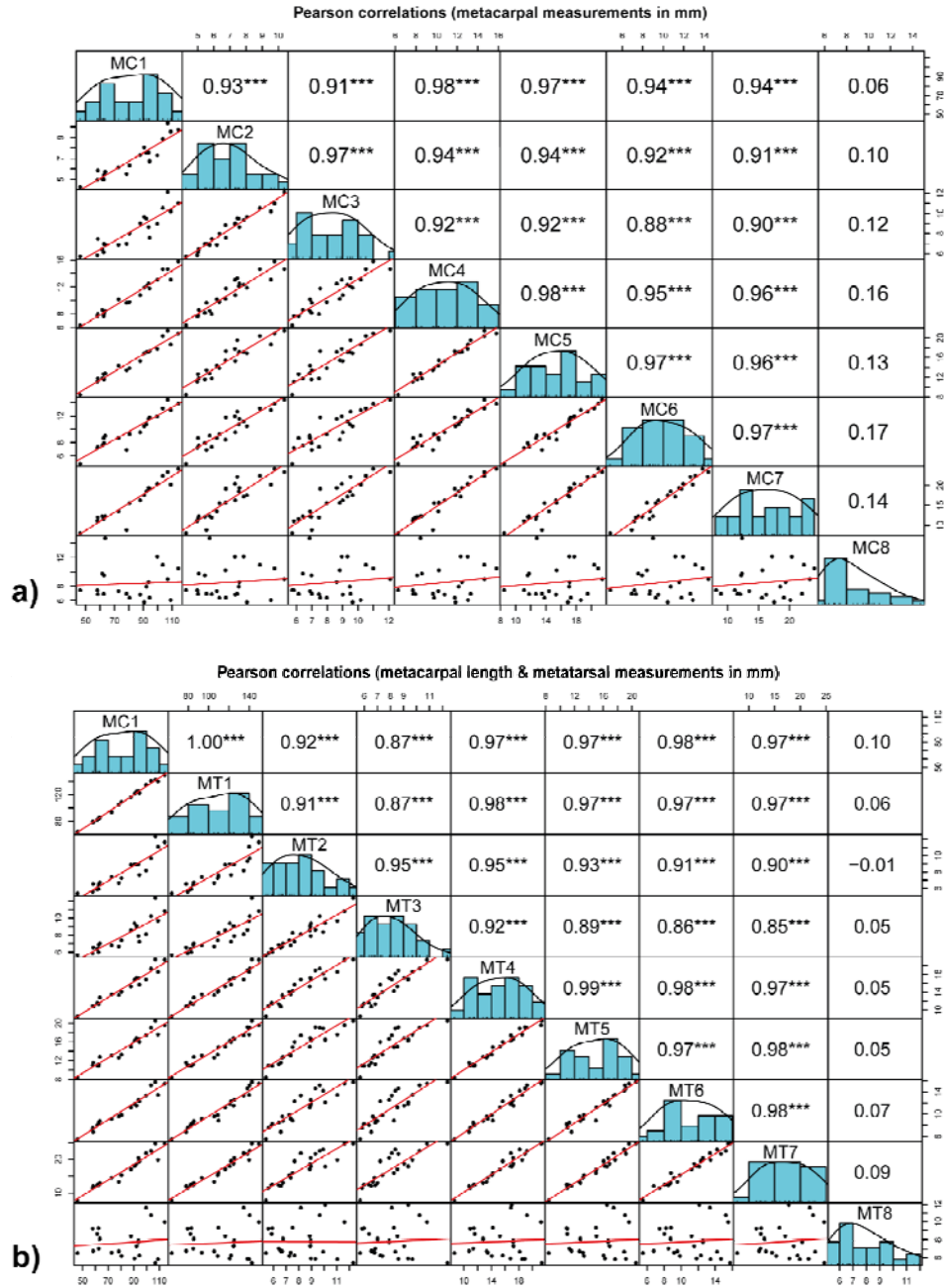


183

184 *Figure 4 : Femur (a) and tibia (b) measurements against metacarpal length. Diagonal:*

185 *histogram of measurements. Lower triangle: bivariate scatterplots of measurements. Upper*

186 *triangle: Pearson correlation statistic (\*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ ).*



187

188 *Figure 5 : Metacarpal (a) and metatarsal (b) measurements against metacarpal length.*

189 *Diagonal: histogram of measurements. Lower triangle: bivariate scatterplots of*

190 *measurements. Upper triangle: Pearson correlation statistic (\*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\* :*

191  *$p < 0.001$ ).*

192 **Estimating the foetal age of modern individuals**

193 Skeletal measurements should be strongly linked to foetal age, yet this variable is hardly ever  
194 known, even for modern individuals. Indeed, the exact foetal age depends on two events,  
195 conception date and birth, that are, especially for the former, not always known. Exploring  
196 links between foetal size and age are thus not straightforward.

197 Available data on rut and calving periods are summarised in Supplementary Information #3.  
198 In Finland, Norway (Svalbard excluded) and Sweden, rut periods reported by different  
199 authors span from the 25th of September to the 19th of October, and calving periods from the  
200 5th of May to the 7th of June, with a peak around mid-May (SI #3). For reindeer, implantation  
201 is not delayed (Leader-Williams & Rosser, 1983), and Roine *et al.* (1982) considered that the  
202 majority of hinds had conceived by the 10th of October. Estimates of the gestation period  
203 vary between 209 and 240 days (Leader-Williams & Rosser, 1983), while a mean gestation  
204 period of 221 days (211 to 229) was reported for reindeer populations at the Kutuharju Field  
205 Reindeer Research Station, in Kaamanen, Finland (Mysterud *et al.*, 2009), similar to the  
206 estimate of 220 days by Roine *et al.* (1982).

207 Thus, despite an important variability, we used in our study mean values for conception and  
208 birth around, respectively, the 10th of October and the 18th of May, with a mean of 221 days  
209 of gestation.

210 In our sample, the exact development age of each individual at death is only known for 7  
211 individuals (Table 1). A finding date was recorded in the Oulu Museum database, but the  
212 exact time span between death and foetus discovery is, in most cases, unknown (however,  
213 given that they are very attractive to predators, who would have destroyed or at least damaged  
214 the bones, it is likely that they died shortly before being found). Rather than using this small  
215 sample ( $n = 7$ ), we estimated foetal age (in weeks) using data provided by Roine *et al.* (1982),

216 who studied a much larger sample also from Finland. Using their data (Roine et al., 1982:  
217 their Table 1), the following 2-degree polynomial regression equation between mean  
218 metacarpal length (MC1) and foetal age (in weeks) was obtained:  $y = -0.0015x^2 + 0.3691x +$   
219  $7.808$  ( $R^2 = 0.9961$ ). MC1 measurements from our sample were then used to estimate foetal  
220 age (in weeks). For 11 individuals, MC1 could not be measured: F2 was thus used to estimate  
221 MC1 (F2 and MC1 are highly correlated,  $r = 0.92$  ;  $p < 0.001$ ), and subsequently the estimated  
222 age. The comparison of estimated age with the known age of 7 individuals shows good  
223 agreement, with a mean difference of 2.44 weeks, and a maximum of 5.64 weeks (Table 1).  
224 These differences could be due to a different date of conception (here, all ages using the death  
225 date assume a conception on the 10th of October) or issues with the estimated age using  
226 skeletal measurements.



227

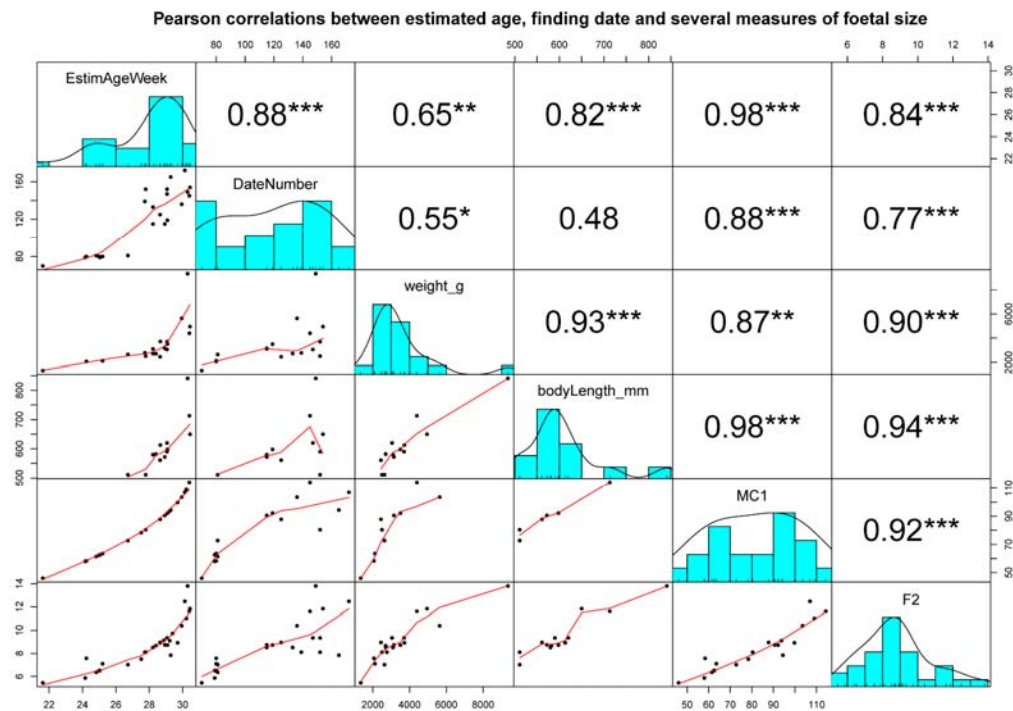
<b>Individual</b>	<b>Death information</b>	<b>Finding date</b>	<b>MeanAge<sup>1</sup></b> <b>(weeks)</b>	<b>EstimAge<sup>2</sup></b> <b>(weeks)</b>	<b>Difference</b> <b>(1 - 2)</b>
18861	in the uterus from bear-killed mother	31/05/1979	33.43	27.79	+5.64
18862	in the uterus from wolverine-killed mother	24/04/1979	28.14	28.93	-0.79
18863	in the uterus from wolverine-killed mother	28/04/1979	28.71	29.09	-0.37
18865	1 day old, killed by bear	31/05/1979	33.43	29.06	+4.36
18868	0 day old, died in labour	28/05/1982	33.00	30.30	+2.70
24273	4 days old	24/05/1989	32.43	30.40	+2.03
24766	about 1 day old	15/05/1990	31.14	29.94	+1.20

228

229 *Table 1: Summary of information provided by the Oulu Museum on the death of seven*  
 230 *individuals. 1: the “MeanAge” column corresponds to the number of weeks between a mean*  
 231 *date of conception (10th of October) and the date of death. 2: “EstimAge” is the estimated*  
 232 *age (in weeks) computed using skeletal measurements (cf. text for more details).*

233

234 Figure 6 compares finding date, estimated age and several independent measurements of  
 235 foetal size (weight and body length as recorded in the Zoological Museum of the University  
 236 of Oulu database, MC1 and F2 skeletal measurements). Estimated age and finding date are  
 237 correlated ( $r = 0.88$ ), but estimated age is more strongly correlated with the different measures  
 238 of foetal size (Figure 6). Hence, the estimated age computed in this study appears to be a  
 239 better estimation of foetal age compared to the finding date.



240

241 *Figure 6: Correlations between estimated age (weeks, cf. main text), finding date (expressed*  
 242 *as number of days since the 1st of January), foetal weight (g), body length (mm), metacarpal*  
 243 *and humerus lengths (mm). Diagonal: histogram of measurements. Lower triangle: bivariate*  
 244 *scatterplots of measurements. Upper triangle: Pearson correlation statistic (\*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ ).*

246

247 **Estimating foetal ages using skeletal measurements of fossil bones**

248 Linear modelling with 2-degree polynomial regression equations were then computed  
249 between each skeletal measurement and the estimated foetal age (in weeks). Such equations  
250 allow for the estimation of foetal age with any skeletal measurement.

251 The high number of measurements ( $n = 55$ ) renders the publication and use of regression  
252 curves highly impractical for zooarchaeologists. Thus, a R Shiny application called  
253 “foetusmeteR” was designed to allow for:

- 254 - The estimation of development age and season of death (Figure 7) using any of the  
255 measurements listed in Table 1 and Figure 1.
- 256 - The quick calculation of one measurement according to another (Figure 8), to  
257 facilitate the calculation of Minimum Number of Individuals (e.g. “can a femur of this  
258 size be attributed to a humerus of that size?”);

259 The foetusmeteR interface is freely available for download at  
260 <https://github.com/ediscamps/foetusmeteR>, or for online use at  
261 <https://ediscamps.shinyapps.io/foetusmeteR/>



foetusmeteR

[Introduction](#) [Estimating age](#) [Predicting another measurement](#)

## Estimating foetal age

Measurement used for estimation

Bone:  Measurement ID:  Measurement (mm):

Select type of interval (prediction is recommended):

Predicted age (weeks), using Roine et al. 1982 data, with lower and upper intervals

	fit	lwr	upr
age (weeks)	26.08589	25.41635	26.75543

Caution: no foetus younger than 21 weeks were observed, hence predicted age below 21 weeks is more prone to error

Similarly, estimations after 30 weeks are better considered simply as 'newborn?'

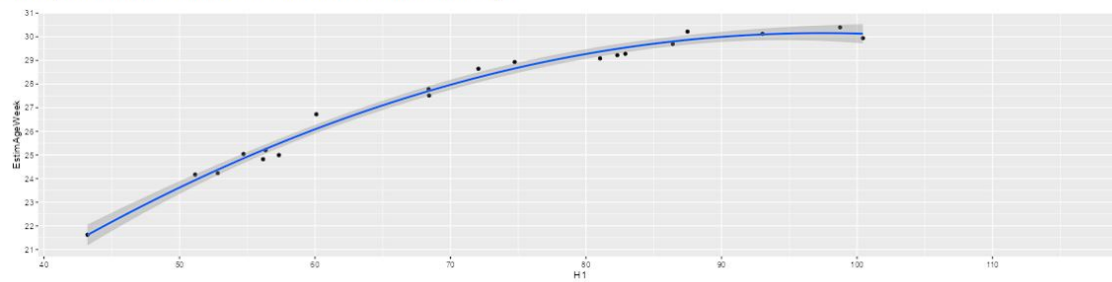
Predicted season(s) of death, with predictions for lower and upper intervals

	fit	lwr	upr
season of death	April?	April?	April?

Keep in mind that these are raw estimations, subject to error!

## Polynomial regression (degree 2)

Scatterplot of reference dataset for the selected measurement with estimated age



Break width (X axis):  Break width (Y axis):

Coefficients of polynomial regression (degree 2)

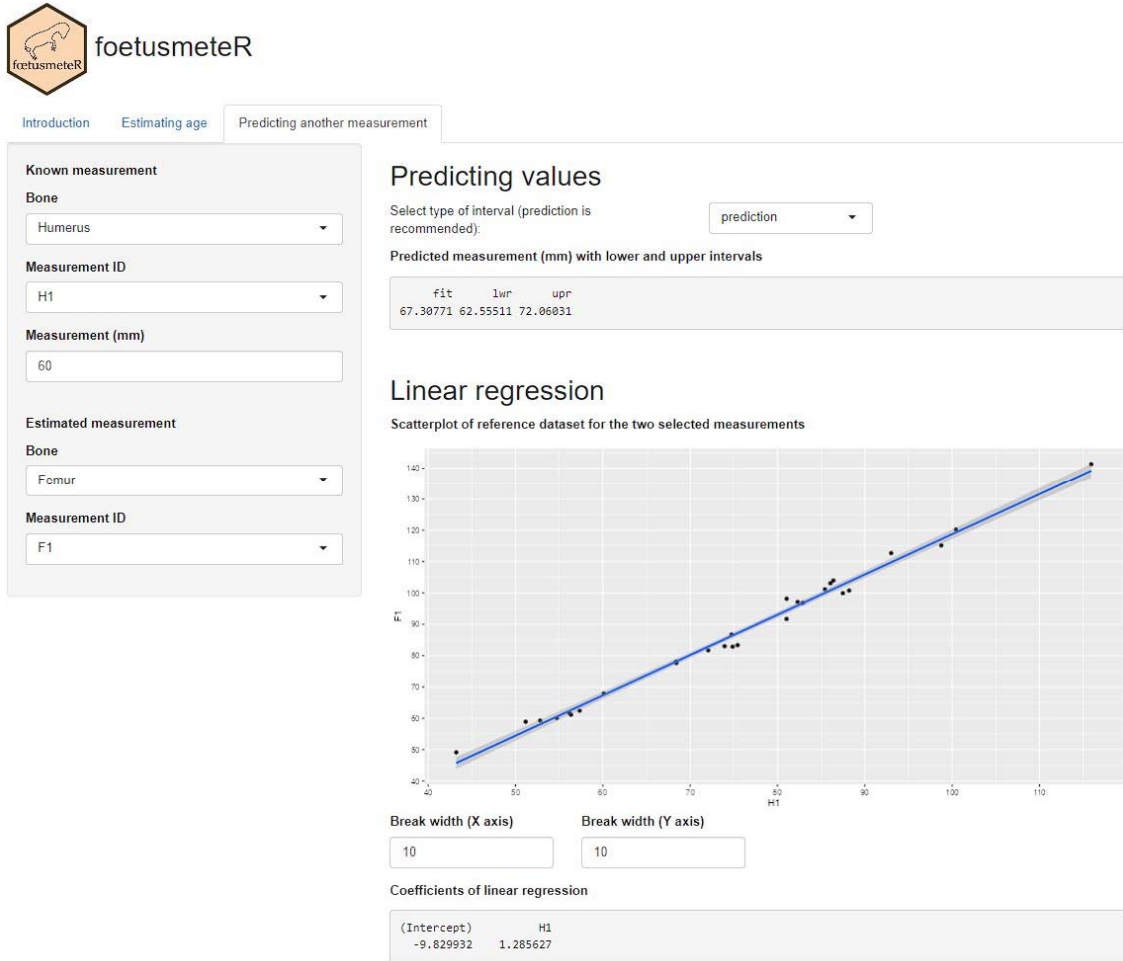
(Intercept)	poly(H1, 2)1	poly(H1, 2)2
27.383794	10.722634	-3.239409

262

263 *Figure 7: Screenshot of the first panel of the foetusmeteR interface that allows for the quick*

264 *calculation of estimated foetal age and predicted season of death.*

265

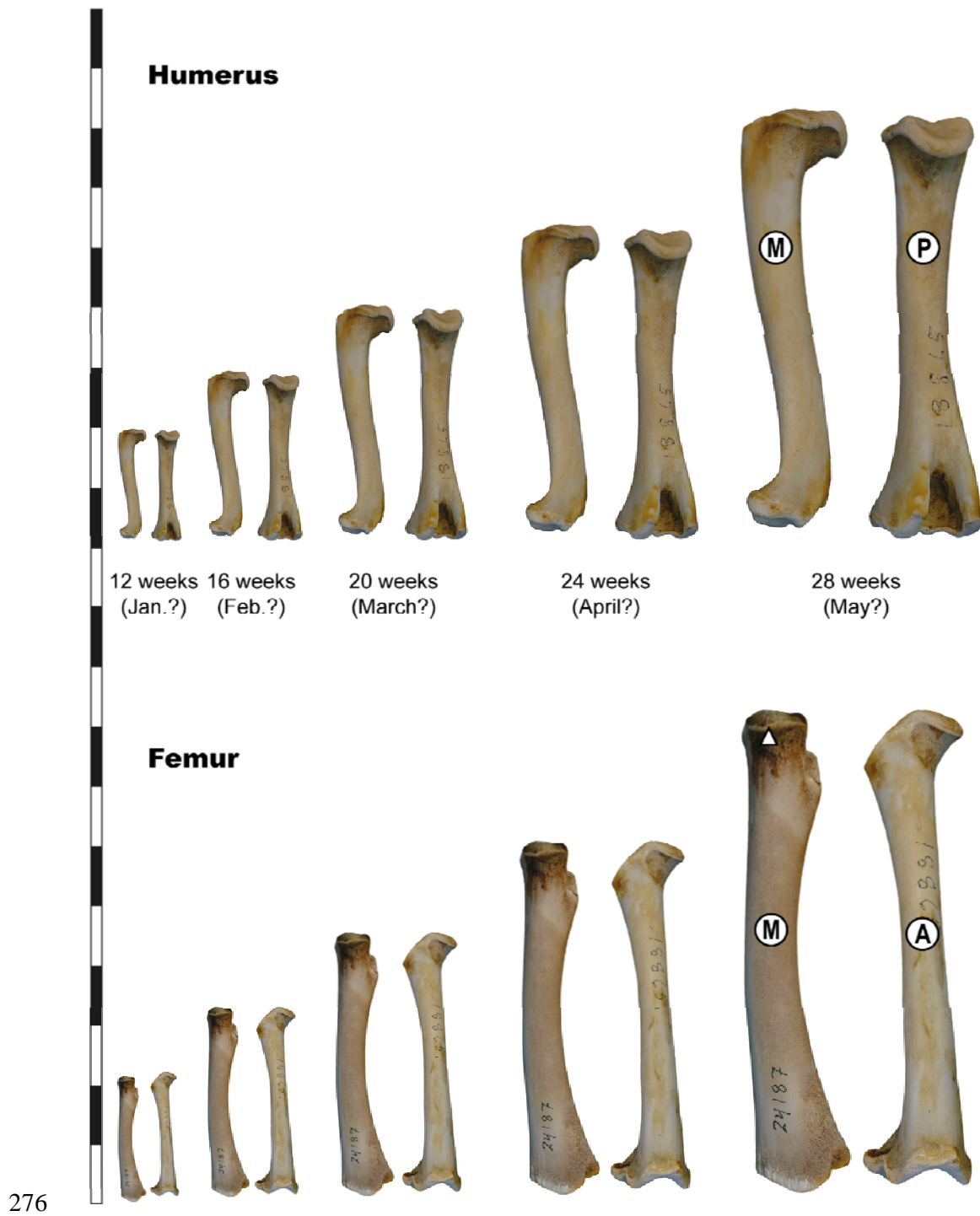


266

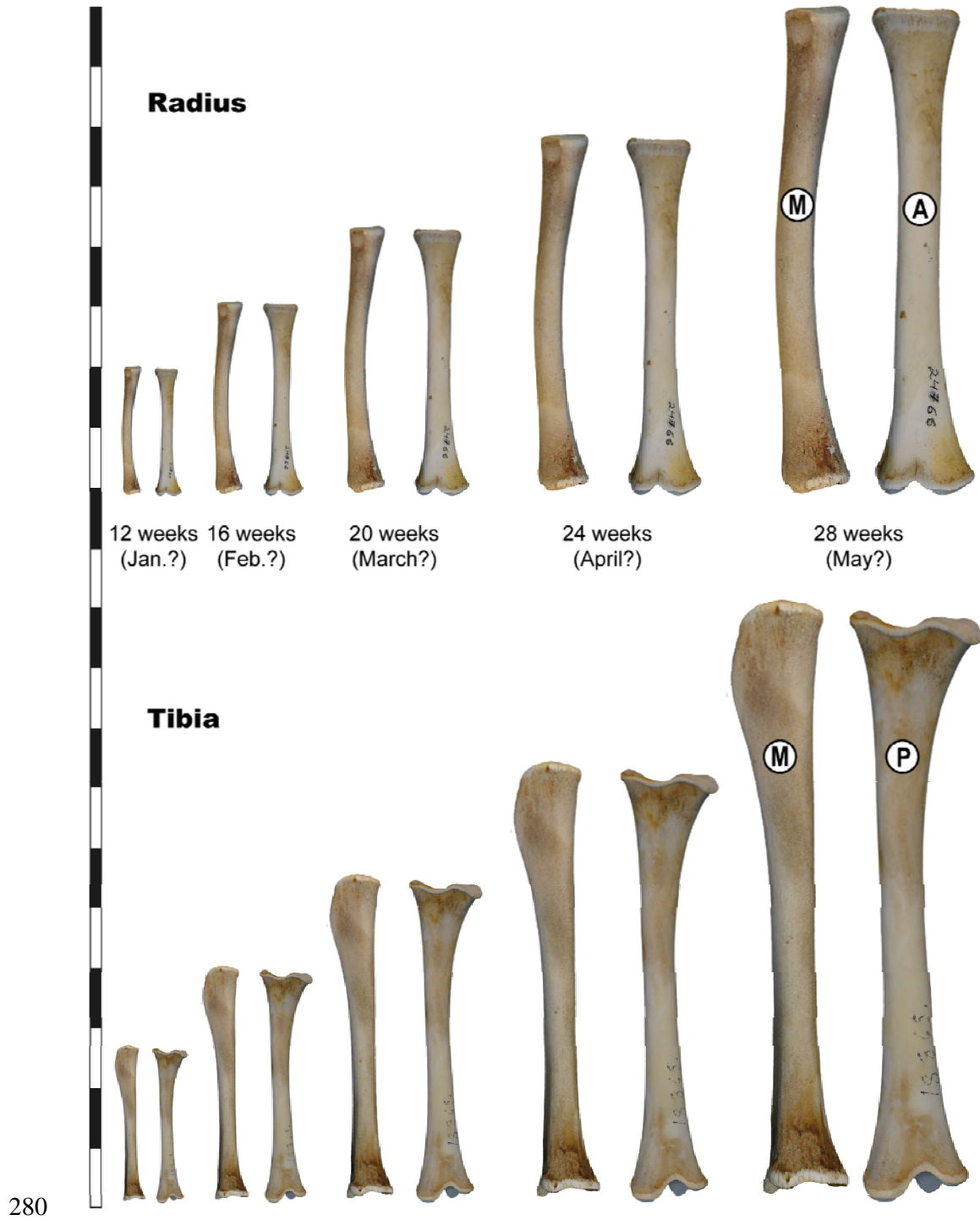
267 *Figure 8: Screenshot of the second panel of the foetusmeteR interface that allows for the*  
268 *prediction of an unknown measurement using a known measurement.*

269

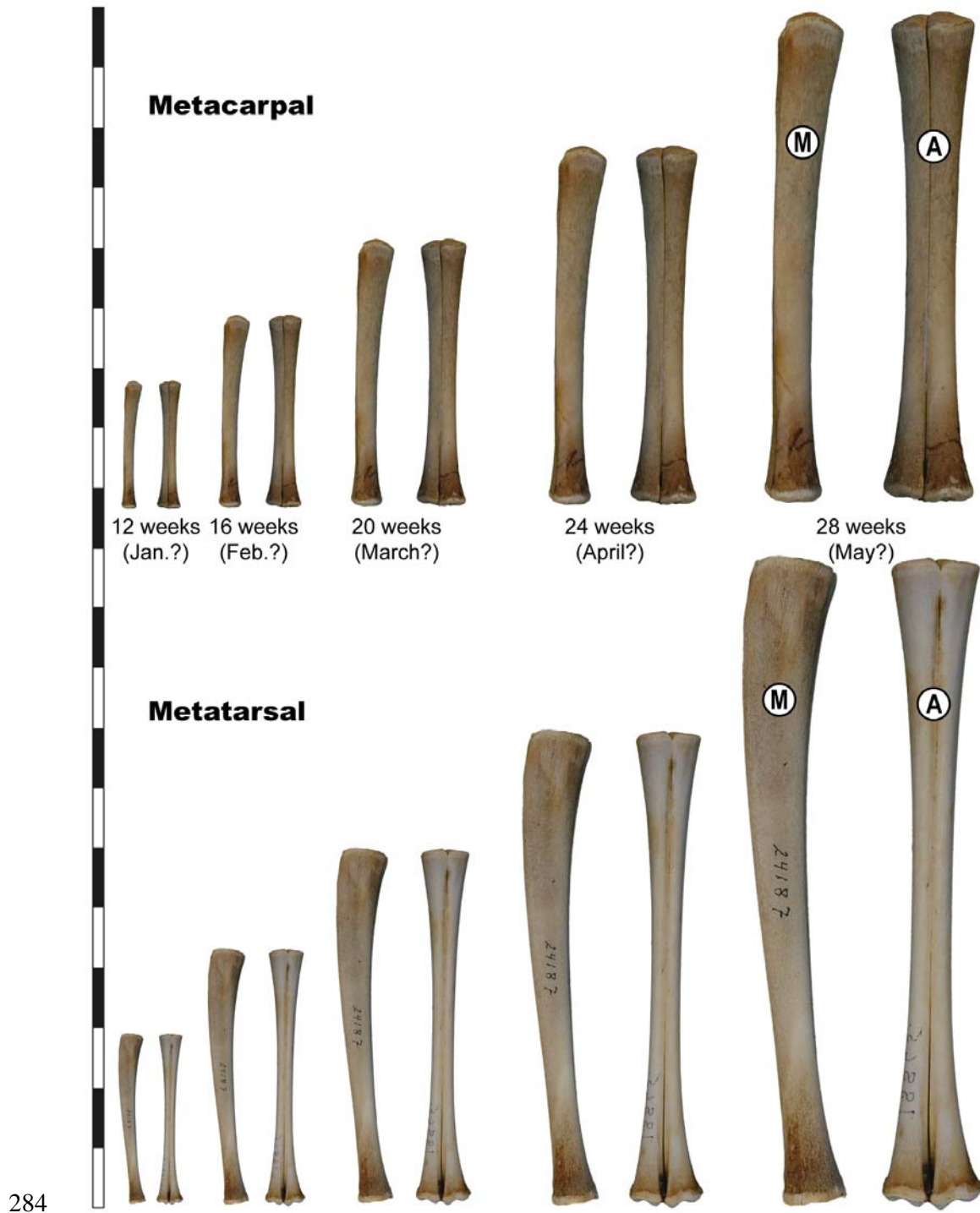
270 When only raw estimates are looked for, “cheat sheets” with scaled photographs are also  
271 made available in Figures 9 to 11: once printed, these pages can be used by simply placing the  
272 foetus bone on top of it for a quick and easy identification of season of death. Besides, for  
273 small fragments that cannot be measured, the cheat sheet can be used to estimate other  
274 measurements, giving access to the size of the complete foetal bone, and then to the age of the  
275 foetus.



277 *Figure 9: Foetus “cheat sheet” showing the average size for humerus and femur at different*  
278 *foetal ages. Once printed at the correct scale, this cheat sheet can be used to quickly assess*  
279 *the age of a foetus bone placed on top of it.*



281 *Figure 10: Foetus "cheat sheet" showing the average size for radius and tibia at different*  
282 *foetal ages. Once printed at the correct scale, this cheat sheet can be used to quickly assess*  
283 *the age of a foetus bone placed on top of it.*



285 *Figure 11: Foetus “cheat sheet” showing the average size for metacarpals and metatarsals at*  
286 *different foetal ages. Once printed at the correct scale, this cheat sheet can be used to quickly*  
287 *assess the age of a foetus bone placed on top of it.*



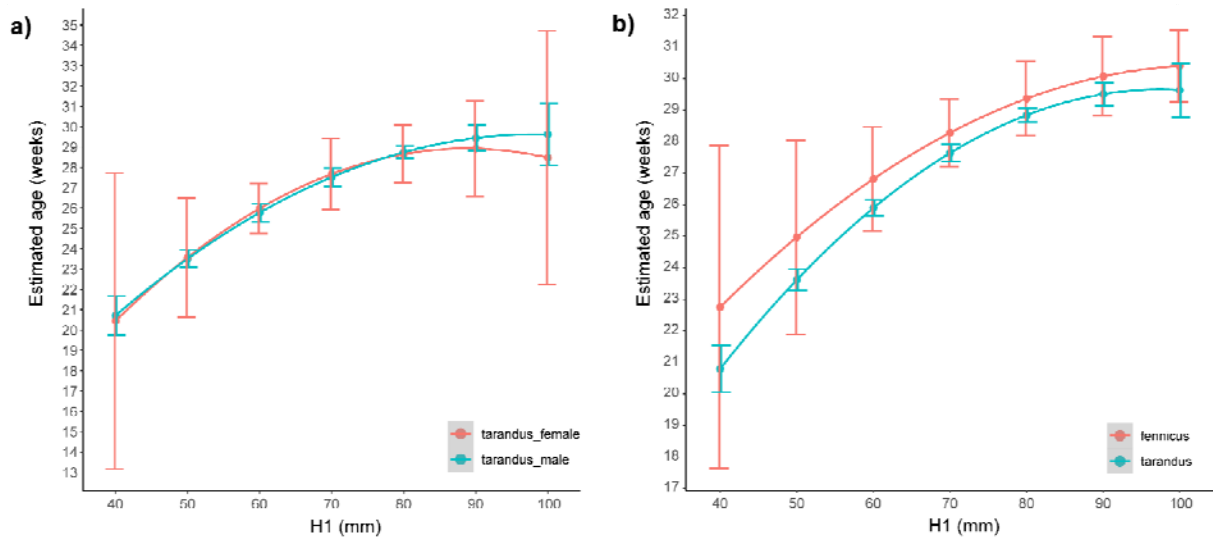
288 **Discussion**

289 Several biases affecting the method proposed here should be considered, pertaining mostly to  
290 known differences between populations, subspecies and sexes.

291 First and foremost, adult size is known to vary across *Rangifer* subspecies and sex (Geist,  
292 1999). For example, adult wild forest *R.t. fennicus* are about 11-18% taller than semi-  
293 domesticated *R. t. tarandus* (Nieminen & Helle, 1980), and these differences are reflected in  
294 skeletal measurements (Puputti & Niskanen, 2008; Pelletier et al., 2020, 2022). The same can  
295 be said between males and females. To what extent these size differences are reflected in  
296 foetal size at a given age, or foetal growth speed, is hard to grasp with the datasets at hand.  
297 Mean birth weights of Finnish *R.t. tarandus* were reported to be slightly larger for males  
298 (5.3kg) compared to females (5.0kg), thus attesting to a 6% difference at the end of foetal  
299 growth (Nieminen & Petersson, 1990).

300 In our dataset, for *Rangifer tarandus tarandus*, regression curves obtained for males (n = 11)  
301 or females (n = 11) are extremely similar, pointing to a near-zero influence of sex (Figure  
302 12a). When the dataset is split by subspecies, regression curves obtained for *Rangifer*  
303 *tarandus fennicus* (n = 6) are slightly offset from the ones obtained for *Rangifer tarandus*  
304 *tarandus*, yet confidence intervals overlap (Figure 12b). In the absence of a larger sample of  
305 *R. t. fennicus* foetus of known date of death, the influence of subspecies on foetal growth can  
306 be considered as minimal for the intended goal of the study (i.e. broadly estimating foetal  
307 age), even though *R.t. fennicus* would be expected to be slightly larger.

308



309

310 *Figure 12: Differences between regression curves (with confidence intervals) obtained*  
311 *between H1 skeletal measurement (mm) and estimated age (weeks), when the dataset is*  
312 *separated by sex (a, for R.t. tarandus) or by subspecies (b). Similar results were obtained for*  
313 *all skeletal measurements.*

314

315 Finally, one should keep in mind that, even if we assume that foetal age could be broadly  
316 assessed for all subspecies and sexes using the same equations, there is still a variability in  
317 rutting and calving periods across populations and subspecies (Supplementary Information  
318 #3). Delayed conception and calving are hypothesised to be a consequence of relatively poor  
319 physical condition of females in autumn (Reimers, 1983a; b; Flydal & Reimers, 2002). Thus,  
320 even if the foetal age is correctly predicted through skeletal measurements, the seasonality  
321 assessed from it should be regarded as an estimate.

322 In Finland, Norway and Sweden, rutting and calving periods are centred around, respectively,  
323 mid-October and mid-May. Rutting periods are overall similar for caribou populations with  
324 the following reported spans (Supplementary Information #3): early October to mid-  
325 November for *R. t. caribou* (Canada), 6th to 23th October with a peak around the 15th of

326 October for *R. t. granti* (Alaska), and 19th to 31st of October for *R. t. groenlandicus* (Alaska,  
327 Canada). Calving is, however, more variable, especially at higher latitudes (Gunn & Fournier,  
328 2000). For *R. t. caribou* (Canada), calving periods were reported from the 1st of May to 25th  
329 of June. For *R. t. granti* (Alaska), births occur from the 17th of May to the 13th of June, with  
330 a peak around the end of May. For *R. t. groenlandicus*, calving seems more centred around  
331 the third week of May (13th-21th) in Alaska, while, in Canada, births occur later, in June (8th  
332 - 15th). Accordingly, gestation (around 221 days for *R. t. tarandus*) is longer for free-ranging  
333 North American caribou (around 225 to 235 days) (Skoog, 1968; Miller, 2002). Such  
334 differences should be kept in mind when using foetusmeteR in North American contexts.

335 All in all, all these biases and limits call for caution. Pending more work on these issues (e.g.  
336 inter-population variability, sexual dimorphism), foetal age and season of death are best  
337 estimated with the method proposed here, but such figures should only be used with full  
338 knowledge of their inherent limits, especially when applied to fossil assemblages.

339

## 340 **Conclusion**

341 In the archaeological record, seasonal data is mostly obtained either by the observation of  
342 eruption and wear sequences of deciduous teeth (a method limited to very young individuals),  
343 or by carrying out cementochronological studies (a destructive method based on the  
344 observation of cementum increments along adult tooth roots). These two methods often  
345 provide relatively low resolution seasonal information, with estimations of periods of death  
346 extending over several months. The measurement of foetus bones is another method that can  
347 give fairly accurate results, and it allows the seasonality of hunting to be assessed on the basis  
348 of a different proxy (i.e. skeletal measurements) based on another sub-population of reindeer

349 herds (i.e. pregnant females). Combining seasonal data acquired from different proxies and  
350 sub-populations can give a better picture of the hunted groups.

351 According to Spiess (1979: p. 187), bones of a foetus of less than 60 days are unlikely to be  
352 preserved in archaeological sites. Thus, the presence of foetus bones can correspond to hunts  
353 between December and May, winter and spring: without measurements, the seasonal  
354 information accessible to zooarchaeologists is broad and imprecise (e.g. Castel, 1999; Bemilli  
355 & Bayle, 2009; Connet et al., 2012; Pétilion et al., 2015; Castel et al., 2017; Dachary et al.,  
356 2020) and impedes discussion about hunting strategies and techniques. Indeed, during this  
357 period of time, the sanitary condition of the reindeer undergoes major changes (e.g. Spiess,  
358 1979; Finstad & Prichard, 2000; Soppela & Nieminen, 2001) and, when hunting is your only  
359 means of subsistence, this detail is far from insignificant. Similarly, it is not the same in terms  
360 of hunting strategies and techniques to track isolated reindeer in covered areas (in winter?) as  
361 it is to plan an interception of a migrating herd (in spring?). The results of our study on foetal  
362 bones, applying a larger set of measurements on all long bones, allow for a finer estimation of  
363 prey acquisition seasonality on a wider array of archaeological contexts (e.g. even when  
364 foetus bones are fragmented). In the end, such renewed data should contribute to a better  
365 understanding of the nomadic lives of past human groups interacting with reindeer herds.

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374 **Supplementary Information**

375 Supplementary Information #1: Description of measurements by bone, in relation to the codes  
376 illustrated in Figure 1. The last column gives important guidelines for certain measurements  
377 on how to hold the bone and/or the calliper.

378 Supplementary Information #2: Detailed information on the 31 foetus measured provided by  
379 the Zoological Museum of the University of Oulu, courtesy of Tuula Pudas (species, sex,  
380 finding date, municipality, measurements, etc.).

381 Supplementary Information #3: rut (conception) and calving (birth) periods for different  
382 *Rangifer* populations.

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