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Correspondence

Extinction chronology of the woolly rhinoceros *Coelodonta antiquitatis*: reply to Kuzmin

Before responding to Dr Kuzmin's detailed comments, we expand on our approach to auditing radiocarbon dates. This issue has been the subject of much discussion, with many authors suggesting criteria by which the quality of dates can be evaluated (e.g. Meltzer and Mead, 1985; Pettitt et al., 2003; Graf, 2009; Barnosky and Lindsey, 2010; Krasinski and Haynes, 2010). While these schemes have features in common, no consensus has been reached. Many schemes assign a score (e.g. from 1 to 5) to a date on each of several criteria, and assess the date from its summed scores. In our studies of Late Quaternary megafauna (e.g. Stuart and Lister, 2011, 2012), we utilise a series of criteria with a simple 'pass' or 'fail' score, and reject (or at least exclude from analysis) a date that fails on any criterion. This scheme applies to our studies of named vertebrate taxa, and we accept that it may require modification in other contexts (e.g. providing chronological context to artefacts not directly dateable themselves).

1. We reject 'associated' dates, accepting only dates made on remains of the target species itself. Experience shows that the direct date on a fossil can be very different from that of its 'context'. For example, dates on *Coelodonta antiquitatis* and *Megaloceros giganteus* said to have come from a 'Magdalenian' horizon at Vogelherd, Germany, instead gave AMS dates in the range 26–40 uncal ka BP (Stuart et al., 2004; Niven, 2006). At this site, excavated in the 1930s, mixing of layers and/or stratigraphic uncertainties are probably responsible for these discrepancies. As a further example, a *Coelodonta* molar from the well-stratified Magdalenian site of Gönnersdorf, Germany gave a date more than 500 years (calibrated) older than the oldest date for the occupation of the site (Stuart and Lister, 2012). In this case the most likely explanation is that older material was brought to the site by Palaeolithic humans.
2. Dated remains must be adequately identified taxonomically. In the case of dating that we initiate ourselves, we confirm species identity either by direct observation of the fossil or from photographs. In the case of published dates, only occasionally are dated bones or teeth illustrated, posing a problem for application of this criterion. Where the original specimen is still available, it may be possible to examine it or obtain images. If not, we rely on the published description, with a minimum requirement that the species is named and the bodily element identified. Thus, a date stated to have been made on '*C. antiquitatis* radius' is accepted, but '*C. antiquitatis* bone' or simply '*C. antiquitatis*' is not. The logic is that if a bone is complete enough to be identified to element, it is likely to have been identifiable to species or at least genus. This is a somewhat crude tool and will lead to the rejection of some 'good' dates and in rare instances acceptance of a date where the bone or species was wrongly identified, but in our experience it is an effective and workable compromise. It excludes cases, for example, where at a site rich in a species (e.g. caves rich in cave bear *Ursus spelaeus*, or mammoth-bone sites rich in *Mammuthus primigenius*), an essentially indeterminate bone fragment has been selected for dating and assumed to represent the dominant taxon at the site.
An additional and very important recent development is the identification of faunal material by DNA sequence analysis. Data from a competent ancient DNA laboratory (i.e. where contamination or other artefacts are scrupulously avoided) can allow the secure identification of fragments whose identity would otherwise be uncertain.
3. Beginning with our paper on *C. antiquitatis* (Stuart and Lister, 2012), we accept only dates known to have been undertaken since 1980. Techniques of radiocarbon dating, especially the pre-treatment of bone samples, and particularly the thorough cleaning of collagen, have advanced greatly since the early days of the method (Stafford et al., 1987; Hedges and van Klinken, 1992; Bronk Ramsey et al., 2004). Ideally, assessment of individual dates would include an objective scoring of pre-treatment method. However, while there are many scattered descriptions of laboratory methods in the published and grey literature, the application of such a criterion would require a running account of the changing procedures of each laboratory through its period of operation, an impossible aim. In many laboratories, exclusive use of collagen and its adequate pre-cleaning began in the early 1980s (Stafford et al., 1987; Russ Graham, pers. comm. 2011). We therefore take 1980 as our cut-off. This, again, undoubtedly excludes some 'good' dates, but in practice the net gain in quality is clear: for example, various dates on mammoth (*Mammuthus* spp.) performed in the 1960s and 1970s suggested Holocene survival in the continental United States (Meltzer and Mead, 1985), but very few undertaken since 1980 have confirmed this, and none, to our knowledge, that meets all other criteria of reliability. Krasinski and Haynes (2010) also applied a "recency-of-analysis" criterion in their assessment of dates, though on a graduated scale by decade.

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4. We reject dates known to have been made on burnt bone, bulk samples from more than one fossil, and apatite (as opposed to collagen). This is in common with other authors, although we apply it as an absolute rule (date rejected if it fails one of these criteria) rather than allowing them to contribute to a point-scoring system as described above. We also reject dates issued with a warning by the laboratory as a result of suspected contamination, low collagen, unexpected $\delta^{13}C$ value, and so on, as well as dates where basic information such as laboratory number or error term are absent or ambiguous
5. We treat with suspicion a date that is a strong outlier to an otherwise established pattern. This is the least satisfactory criterion because it inevitably involves a subjective judgement, and may also inhibit the discovery of new information. The rule, therefore, is that if a date is an outlier (i.e. in comparison with a reasonably large set of dates, it significantly extends a species' range in time and/or space), it should be corroborated by repeat dating in another laboratory before it can be accepted. For example, two dates suggesting Holocene survival of *Megaloceros giganteus* in north-west Britain (Gonzales et al., 2000) were not corroborated by repeat dating at the same and another laboratory (Stuart et al., 2004). An outlying date is not so much 'rejected' as considered uncorroborated and so not justifying discussion of range extension.

All dates in our paper are calibrated (using the IntCal09 curve), and comparisons made on the basis of their calibrated 95% confidence interval. This policy, now commonplace, takes account of the 'stretching' or 'compressing' of intervals 'radiocarbon time' relative to calendar age. We place no particular emphasis on the calibrated median, since the probability density function of the calibration is often strongly non-Gaussian, but medians are indicated on our maps and charts as convenient markers in addition to the 95% ranges.

In our recent paper (Stuart and Lister, 2012), we strove to be as transparent as possible – our Supplementary Table 2 lists all dates that failed one or more of the above criteria, and indicates on which criteria they failed. These dates are not utilised in our mapping but are available for others to reinstate if they wish to apply different criteria.

We now turn to the specific comments made by Dr Kuzmin:

1. **Dates rejected because of unknown skeletal element**. We thank Dr Kuzmin for pointing out the skeletal parts dated in the case of Orda River (SOAN-6385 and 6386) and Zlatouskova. The latter is, however, somewhat confusing in that it is given as BashGI-107 (Ufa) at one point in the source paper (Latypova and Yakheemovich, 1993), and as LU-1668 (Leningrad University) in another, leading to doubt whether it is one and the same date. Also, the sample is described by Dr Kuzmin as 'teeth', so could be from more than one individual and if so would not meet our criteria.
2. **Dates accepted even though specimens identified only as 'bone'**. As indicated in Suppl. Table 1, these specimens were identified as *C. antiquitatis* from diagnostic DNA sequence data (Lorenzen et al., 2011). For dates where only 'bone' is indicated and there is no aDNA evidence, we did not, for the reasons discussed above, consider the species adequately identified and they were rejected.
3. **Attempts to clarify details of dates**. As part of our broader study of megafaunal extinction (including *C. antiquitatis*) we employed a research assistant in 2011 who emailed 39 extant radiocarbon laboratories, each with a tailored spreadsheet of their dates for which we lacked data (e.g. skeletal element dated, or co-ordinates of source locality), or where published data were contradictory (e.g. a different error term or lab number in different publications). If there was no initial response, each laboratory was emailed again. Twenty-three laboratories responded. In the case of Russian dates queried by Dr Kuzmin, GIN and IGAN (Moscow) responded with valuable information, but we did not receive a reply from LE and LU (St Petersburg) or SOAN (Novosibirsk).
4. **Lugovskoe date**. The date from Lugovskoe, western Siberia (10,770 ± 250 uncal BP; SOAN-4757), was excluded because, following the criteria above, the material dated has not, to the best of our knowledge, been indicated (Orlova et al., 2004a,b; Orlova et al., 2008; Kuzmin, 2010), so we do not consider its identity as *C. antiquitatis* securely demonstrated. While we do not, of course, exclude the possibility of late survival of *C. antiquitatis* in this region, we are not persuaded that the Lugovskoe date, even if reliably identified, is adequately corroborated by other dates from the site. While two dates on mammoth in the range 14–13 uncal ka BP (SOAN-4940 & SOAN-4942) were corroborated at ORAU with non-significant differences (Orlova et al., 2004a), none of the SOAN Lugovskoe dates younger than 11 ka BP has been corroborated, specifically the *C. antiquitatis* date 10,770 ± 250 BP (SOAN-4757), and mammoth dates 10,210 ± 135 BP (SOAN-4752) and 10,820 ± 170 BP (SOAN-4943). A sample said to be from the latter specimen (molar fragments) was submitted for re-dating at the ORAU, where it produced a date of 13,205 ± 160 BP (OxA-12031), leading Orlova et al. (2004a) to suggest that "the difference in the results raises the possibility that they may have come from different individuals. Alternatively, the samples may have come from the same tooth, in which case there is a significant disagreement between the two laboratories." Either way, the late date was not corroborated.
5. **Ultrafiltered vs. non-ultrafiltered dates**. We do not exclude non-ultrafiltered dates from consideration; all were included in our analysis provided they fulfilled the selection criteria outlined above. Thus, ultrafiltered and non-ultrafiltered dates are both plotted on our maps and charts (Stuart and Lister, 2012: Figs. 1 and 2), and as we pointed out, the patterns are for the most part consistent. The only possibly significant exception is the non-ultrafiltered date KIA-5670, 12,275 ± 55 uncal BP (13,925–14,850 cal BP) from Lobvinskiy Grotto (Urals), which we accepted as suggesting later persistence of *C. antiquitatis* in the region than indicated by available ultrafiltered dates. We of course agree with Dr Kuzmin that in many cases ultrafiltered and non-ultrafiltered dates on the same specimen will give a similar result, usually where the bone is well-preserved, but we find the comparisons of Jacobi et al. (2006) and Higham (2011) persuasive that, where dates differ, the ultrafiltered date is likely to be the more reliable. The example cited by Dr Kuzmin (the Kostenki I human skeleton) is a case in point. As discussed by Higham et al. (2006), this specimen was very well preserved, so no significant difference was observed with ultrafiltration. They concluded: "This result demonstrates that not all Paleolithic bone dates obtained using an AG (gelatin) pretreatment are problematic. The major shifts in age identified above tend to be associated with those bones producing often very low collagen yields or those that were probably contaminated, or both".
   Only in two cases did we apply this criterion in our paper, where two non-ultrafiltered AMS dates on British *C. antiquitatis*, OxA-2509 & OxA-6108, were considered superseded by ultrafiltered dates OxA-16647 & OxA-13965, respectively (Stuart and Lister, 2012, Suppl. Table 2).
6. **Dates obtained by Russian laboratories**. We scored all dates on the same set of criteria (listed above), irrespective of the country or laboratory of origin. In our *C. antiquitatis* paper, it happened

that 30% (18/60) of dates from Russian laboratories were excluded, most of them for lack of specimen identification. In our much larger database of *Mammuthus primigenius* dates, only ca 13% of dates from Russian labs are excluded, similar to other laboratories. We ourselves organised a cross-comparison of mammoth dates between the ORAU and GIN laboratories in 2003, finding close concordance in eight out of nine samples tested.

7. **Pattern of distributional change in *C. antiquitatis***. Our suggestion of a progressive contraction to the East was based on the latest dates in each region (Stuart and Lister, 2012, Suppl. Table 1), as follows (approximate median calibrated dates): Britain 35.7 ka BP, West/Central Europe 16.8 ka BP, Eastern Europe (European Russia) 15.1 ka BP, Urals 14.2 ka BP, north-east Siberia 14.0 ka BP. With one questionable exception (see below), the 'new' or newly-acceptable dates cited by Dr Kuzmin do not alter this picture. The two western Siberian dates from Orda River predate this contraction and, while providing valuable points geographically in between the Urals and eastern Siberia, they do not alter the overall distribution across Russia in the respective intervals. In the Urals, the date from Zlatoustovka (12,330 $\pm$ 120 uncal BP), even if we set aside its ambiguous material and laboratory number, compares closely to the record from Lobvinskiy Grotto of 12,275 $\pm$ 55 uncal BP (KIA-5670), extending the longitudinal range only from one side of the Urals to the other. We accept that the latest of our plotted dates from the Urals/W. Siberia (Lobvinskiy Grotto) on the one hand, and Eastern Siberia (Lena-Amga interfluve, combined 12,155 $\pm$ 37 uncal BP) on the other, are close, with significant overlap of their 95% calibrated ranges (Stuart and Lister, 2012, Figs. 1 and 2 and Suppl. Table 1). Concerning the date of 10,770 $\pm$ 250 uncal BP (SOAN-4575) on unspecified material from Lugovskoe, W. Siberia (12,029–13234 cal BP, median 12,668 BP), this if corroborated would extend the known range in the Urals/Western Siberia by ca 1500 years (median calibrated dates). It would also, as pointed out by Dr Kuzmin, imply a terminal refugium in western, rather than eastern, Siberia. We acknowledged this point in our paper (p. 12). However, while we readily accept that the model of final contraction to the East is a hypothesis requiring corroboration, we do not accept that it is falsified by SOAN-4575, for the reasons discussed above.

Finally, the other possibly late records of *C. antiquitatis* mentioned by Dr Kuzmin, at Verkholenskaya Gora 1 (Irkutsk) and from Markova et al. (2011), are based on associated dates and, while they point to *C. antiquitatis* remains worthy of direct dating, do not in themselves constitute evidence according to our criteria.

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Adrian M. Lister*
Department of Earth Sciences, Natural History Museum, Cromwell Road, London SW7 5BD, UK

Anthony J. Stuart
School of Biological and Biomedical Sciences, Durham University, South Road, Durham DH1 3LE, UK

* Corresponding author. Tel.: +44 (0)20 7942 5398; fax: +44 (0)20 7942 5546.
E-mail address: A.Lister@nhm.ac.uk (A.M. Lister)