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A veritable confusion: use and abuse of isotope analysis in archaeology

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ABSTRACT
The expansion of isotope analyses has transformed the study of past migration and mobility, sometimes providing unexpected and intriguing results. This has, in turn, led to media attention (and concomitant misrepresentation) and scepticism from some archaeologists. Such scepticism is healthy and not always without foundation. Isotope analysis is yet to reach full maturity and challenging issues remain, concerning diagenesis, biosphere mapping resolution and knowledge of the drivers of variation. Bold and over-simplistic interpretations have been presented, especially when relying on single isotope proxies, and researchers have at times been accused of following specific agendas. It is therefore vital to integrate archaeological and environmental evidence to support interpretation. Most importantly, the use of multiple isotope proxies is key: isotope analysis is an exclusive approach and therefore single analyses provide only limited resolution. The growth in isotope research has led to a growth in rebuttals and counter-narratives. Such rebuttals warrant the same critical appraisal that is applied to original research, both of evidence for their assertions and the potential for underlying agendas. This paper takes a case study-based approach focusing on pig movements to Neolithic henge complexes to explore the dangers encountered in secondary use of isotope data.

Introduction

Isotope analysis and the study of aDNA are firmly established as tools to explore mobility and migration in the past. These methods make distinct contributions and operate at different scales, with aDNA providing evidence for ancestry and population histories, and isotope analysis revealing individual origins and lifetime mobility. They are both umbrella terms for a wide suite of methods, some of which are long established and others in initial development. These methods provide powerful interpretative tools, especially when used in combination, and can offer complementary narratives at different scales for patterns of mobility in the same population (e.g. Olalde et al. 2018; Parker Pearson et al. 2019). The positive impacts of these approaches have been

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wide-ranging, but they are not flawless. Findings have sometimes substantially changed long-standing narratives: such reworkings of accepted histories need a critical eye from archaeologists, who are now better informed on the problems and potential of aDNA and isotope analysis than they have ever been and are more frequently at the centre, rather than the periphery, of this type of research.

The difficulties for non-scientists in understanding not only these methods, but also the objectivity or bias of reporting, and the potential misuse of findings to support specific agendas are causes for concern. Scientific research must not be accepted uncritically and scholars are becoming more proactive in promoting wider (e.g. archaeological, historical and environmental) evidence to support or refute particular science-based narratives (Eisenmann et al. 2018). Responses that refute potentially flawed interpretations of data have become more common (e.g. Millard and Schroeder 2010; Rowley-Conwy and Zeder 2014). Important critical and discursive reviews have been published, especially in relation to genetics (e.g. Booth 2019a; Crellin and Harris 2020; Hofmann 2015; Palsdottir et al. 2019; Sykes, Spriggs, and Evin 2019; Vander Linden 2016), including warnings against nationalist narratives that try to draw on archaeological science (Frieman and Hofmann 2019; Hakenbeck 2019; Richardson and Booth 2017).

However, critiques of scientific research must themselves be subject to careful scrutiny. It is essential to interrogate such critiques, as the secondary use of scientific data (i.e. by people other than those who produced it) can easily suffer from misunderstandings and misinterpretations, and has equally high potential for bias and agenda-driven misuse. In the rush to critique studies that support narratives some researchers dislike, there is a danger that gaps in knowledge are plugged with bias. As one of the anonymous reviewers of this paper stated, it is clear that the isotope specialist community has a long way to go to ensure archaeologists are aware of the intricacies of multi-isotope interpretations, so that the technique becomes more widely understood and accessible, and so that rebuttals made by non-specialists do not suffer from the type of misunderstanding discussed here. This paper explores some of the negative outcomes secondary research can be subject to by focusing on a specific case study.

Barclay and Brophy's (2020) paper *'A veritable chauvinism of prehistory': nationalist prehistories and the 'British' late Neolithic mythos* claims to have discovered in our published research (Madgwick et al. 2019a) a case of '*interpretative inflation*' for a '*far reaching re-interpretation of British prehistory*'. Their basic premise is that research on Stonehenge and other Wessex monument complexes dominates the archaeological narrative and that, in our paper, we present interpretations of the evidence for animals' geographic origins that propagate an '*unacknowledged nationalist and neocolonialist*' agenda. In this article, we highlight systematic bias in their approach, demonstrating serious errors in the representation of our findings and fundamental misunderstandings of other research.

Barclay and Brophy do raise some critical points that are valuable and provide a springboard for wider discourse. For example, the articulation between archaeological research and the media has always been problematic and warrants deeper consideration, as does the potential for unconscious bias to impact on archaeological narratives. We do not wish to detract from the importance of these points and we comment below on the media's reporting of our research, as well as the profession's problems with Stonehenge's high public profile. However, we focus principally on errors and omissions in Barclay and Brophy's understanding of isotope data and our fundamental disagreement with important aspects of their description of Late Neolithic Britain.

The dataset: Late Neolithic henge complexes of Wessex

Our original paper presents the isotope composition of teeth and jaws from 131 pig remains excavated at Mount Pleasant (Dorset), Durrington Walls, Marden and West Kennet Palisade Enclosures at Avebury (Wiltshire), examining strontium ($^{87}Sr/^{86}Sr$), oxygen ($\delta^{18}O$), sulphur ($\delta^{34}S$), carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$). Our interest was to understand the resources needed to support the feasting that occurred at these sites (Albarella and Serjeantson 2002; Chan et al. 2016; Craig et al. 2015; Richards and Thomas 1984; Wright et al. 2014). The Wessex animal bone material provides an unparalleled opportunity to attempt such a study, unique in Britain in quantity, recording standards and preservation.

We examined whether there was evidence for local production of meat to support such celebrations, or whether the pigs were sourced widely. In the latter possibility, animal movement can be considered a proxy for human movement (i.e. people coming to these gatherings). Our results show that:

- As with the Durrington Walls cattle (Viner et al. 2010; Evans et al. 2019), there is wide diversity in the isotopic composition of the pigs from these sites: they were not all raised in a single area.
- They were not all raised on/near the Chalklands upon which the four henge complexes stand.
- There is more diversity in the strontium data from these Neolithic pigs than is seen in animal data from any other site or phase in Britain, including the Roman period where there is evidence for animal mobility on a large scale (Madgwick et al. 2019b; Minniti et al. 2014; see Figure 1).
- Some of the pigs in the dataset have radiogenic strontium values (five with Sr values >0.714) that are very rare or absent from England and Wales on the basis of current mapping. When combined with other isotope data such as sulphur and oxygen, we cannot rule out a possible origin for some animals in parts of Scotland (or indeed in almost any part of Britain and Ireland).

Multi-isotope interpretation

Much of Barclay and Brophy's critique appears to be based on fundamental misunderstandings about how to interpret isotope data and it is thus necessary here to review the principles of a multi-isotope approach.

Our research presented the largest multi-isotope dataset (using at least five methods) on fauna yet delivered in archaeological research globally. To our knowledge it is exceeded in archaeology by only a single study on humans (Parker Pearson et al. 2019). In total we present 778 values across six isotope methods ($^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{34}S$, $\delta^{15}N$, $\delta^{13}C_{collagen}$, $\delta^{13}C_{carbonate}$). Barclay and Brophy choose to focus on only

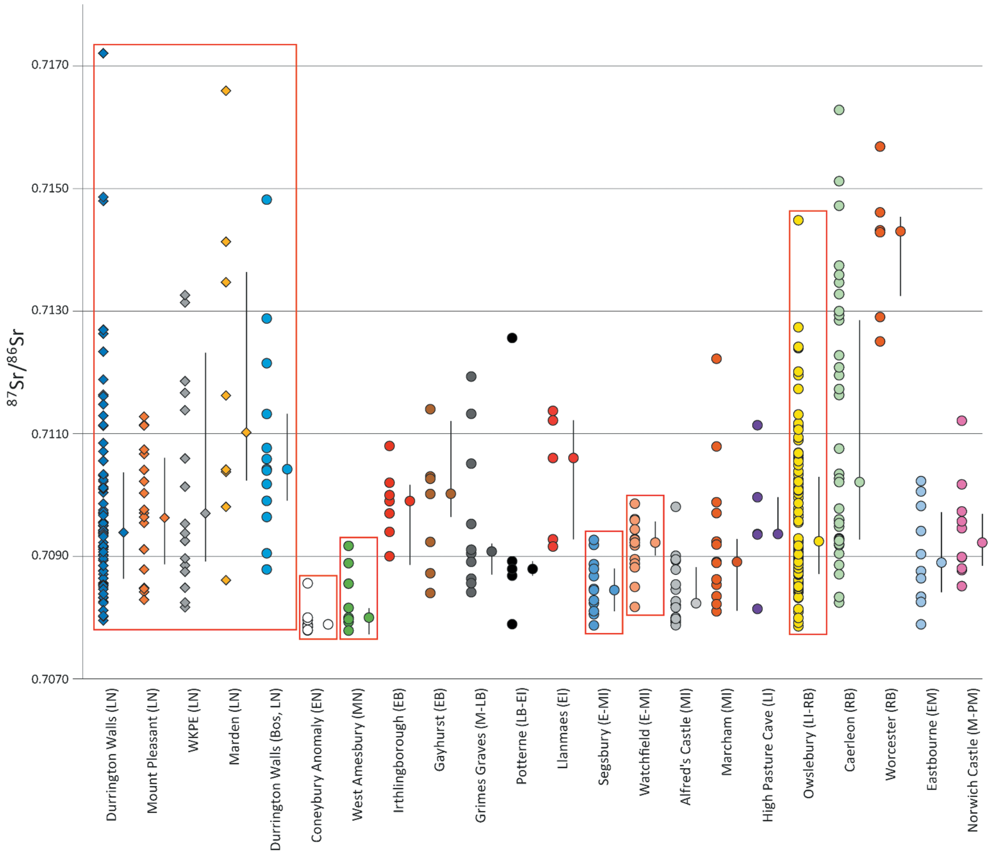

Figure 1. Strontium isotope data from mainland British domestic fauna. Median and IQR values are presented adjacent to the raw values for each site. The first four datasets (from the left, represented by diamonds) are pigs from Late Neolithic Wessex (Madgwick et al. 2019a), with the fifth being cattle from Durrington Walls (Viner et al. 2010). Wessex chalkland sites are outlined with a box for comparison. The Late Neolithic data are most diverse and the only datasets from Britain that come close in terms of diverse values are from Roman Caerleon and Owslebury (adapted from Madgwick et al. 2019a, with additional data from Gron et al. 2018; Schulting et al. 2019).

a handful of values (five) from a single proxy (strontium), in stark contrast to our approach which bases interpretation on a much wider dataset.

In our view, the absence of any engagement with the data beyond a few strontium values suggests a failure to understand the method or the results. Barclay and Brophy state '*The weight given to interpretation of the strontium (Sr) data in the 2019 paper which prompted this response is in our view too great* [p15]'. Our approach could not be more explicit – even the title of our 2019 paper starts with the words '*Multi-isotope*'. We fully agree with the quote they use from Janet Montgomery (2010, 336): '*Isotope analysis is an exclusive technique. It can only rule out places of origin …* '. It is precisely because this technique is '*exclusive*' that it is essential to use multiple methods where available, as we explain in our paper: '*The multi-isotope method can, however, refine provenance by discounting more potential source areas and by demonstrating the diversity of areas of origin* [p8]'. Barclay and Brophy fail to acknowledge this since they discuss strontium values in isolation.

The value of a multi-isotope approach can be recognised through the distinct and complementary information each element can provide.

- Strontium isotope analysis provides a link between the complex patchwork of regional geology in Britain and the animals feeding on that region's vegetation. The technique exploits the transfer of strontium from underlying rocks into soils, waters and finally plants that are consumed by animals. It provides a useful method for exploring geographic origins but is far more powerful when combined with other isotope results.
- Sulphur isotope values vary mainly according to coastal proximity, with exposed coasts facing prevailing winds having the highest values, although diet and geology also have an impact (Guiry and Szpak 2020; Nehlich 2015; Zazzo et al. 2011). It has become an increasingly useful provenancing tool in multi-isotope strategies (e.g. Lamb et al. 2012; Madgwick et al. 2013, 2019c; Nehlich et al. 2014; Parker Pearson et al. 2019; Smits et al. 2010; Towers et al. 2011; Worley et al. 2019).
- Oxygen isotope data have long been used in conjunction with strontium for exploring origins (e.g. Evans, Chenery, and Fitzpatrick 2006). These principally vary according to climate, with a well-defined southwest to northeast gradient of decreasing values in British groundwaters (Darling, Bath, and Talbot 2003). Foodways (Brettell, Montgomery, and Evans 2012) and seasonality also have an impact, though the latter has a negligible effect on pig molars (Frémondeau et al. 2012). Oxygen isotopes provide a complex source of information and various papers have stressed caution in the use of drinking water corrections (which we avoided: Bentley and Knipper 2005) and in relation to analytical method variation (e.g. Demény et al. 2019; Lightfoot and O'Connell 2016; Pederzani and Britton 2019; Pellegrini et al. 2016; Pollard, Pellegrini, and Lee-Thorp 2011).

Three further proxies ($\delta^{15}N$, $\delta^{13}C_{collagen}$, $\delta^{13}C_{carbonate}$) are principally useful for examining diet:

- They are invaluable in ensuring confidence in other isotope proxies for exploring origins, especially in omnivores such as pigs, as unusual diets can impact on provenancing isotope data.
- For example, marine or estuarine foods will produce relatively high sulphur values (Nehlich 2015), suggestive of coastal origins, even if animals are raised inland.
- Similarly, marine-dominated diets will shift biogenic strontium values closer to 0.7092 (the seawater value), regardless of geology and the local biosphere (Montgomery 2010).
- The processing of dietary sources can also affect oxygen values, with boiling, stewing and fermenting causing an increase in some circumstances (Brettell, Montgomery, and Evans 2012).

The benefits of using multiple proxies to explore provenance are best demonstrated with an example. Various restricted areas of radiogenic geology outwith Scotland are highlighted in our paper, including parts of the Lake District, and limited zones in parts of Wales and the Marches (including the Malvern Hills). But it is not acceptable to base interpretations on radiogenic strontium isotope values in isolation: the other proxies can assist in excluding some of these locations. For example, pig MD129 (high Sr value of 0.7141) has one of the lowest oxygen values in our dataset, strongly suggestive of an origin in the east or highland east of Britain. The only areas that are consistent with *both* the low oxygen value *and* the high strontium value are in Scotland. In their rejection of a Scottish origin for the Wessex pigs, Barclay and Brophy argue that such an origin is unlikely because these areas would have been sub-optimal for pig husbandry. However, much of the region was densely forested and would have provided important seasonal fodder for pigs, a forest foraging strategy common in the past and evidenced isotopically in prehistory (Hamilton, Hedges, and Robinson 2009; Madgwick, Mulville, and Stevens 2012).

The biosphere map reveals that these areas of very old lithology in eastern Scotland would likely produce strontium values higher than 0.714 in an animal (see Evans et al. 2018a). Therefore, the strontium value of pig MD129 is consistent with some (seasonal) exploitation of these forested zones, combined with management in more hospitable environments of less radiogenic geology. Again, another isotopic value contributes to the interpretation: pig MD129 has a low sulphur value (6.5‰), suggesting an inland area (probably eastern, given prevailing winds causing higher values in the west). Such evidence from **multiple** isotopic values – not from the strontium isotopes alone – suggests that an origin in inland, eastern Scotland for MD129 cannot be excluded.

It is beyond the limits of this paper to provide numerous further examples, but four other pigs with radiogenic strontium values (>0.713) also have relatively low oxygen values (≤25.2‰ $\delta^{18}O_{carbSMOW}$, in the lowest 30% of the dataset) that suggest origins in western Britain are unlikely. Whilst this approach is exploratory, northern areas must at least be considered for these pigs (DW31, DW60, WK118, WK121). There is a clear lack of radiogenic biosphere in southern Britain, other than the western areas that provide unlikely sources based on oxygen isotope data. In addition, these pigs have varied sulphur values indicating multiple regions are represented. The eight pigs in the dataset with high radiogenic strontium (>0.713, Table S8 in Madgwick et al. 2019a) have sulphur values ranging from 6.5‰ to 15.6‰ (indicating variously coastal and inland origins) and oxygen values from 23.9‰ to 26.5‰ (indicating a spread of east to west origins). Multiple radiogenic lithologies are thus represented, providing evidence for origins across Britain for this subset of Neolithic pigs. This multi-isotope process of analysis and interpretation also extends to less radiogenic values.

If relying on strontium alone, the 29 pigs with strontium values consistent with chalk lithology (0.7079–0.7086) would, following Occam's Razor, be interpreted as local to their henge-complex findspots in Wessex. However, these animals have vast sulphur (3.4‰–19.6‰) and oxygen (23.6‰–27.6‰) ranges, providing unequivocal evidence that many were **not** local and must have come from diverse areas of chalk (or lithologies of a similar isotopic composition) from east to west, both inland and coastal. Only the use of multiple isotope analyses can reveal this.

Turning to the dietary isotopes, none of the pigs in the dataset consumed substantial amounts of marine protein and therefore their strontium and sulphur values can confidently be used for exploring origins. Dietary isotopes did identify a single pig with an oxygen value affected by diet. This pig (MP107) has by far the highest oxygen value in the dataset, potentially suggestive of origins in a warmer area. However, this is coupled with by far the highest nitrogen value in the dataset. Both values together can be explained by the nature of the diet and its processing (e.g. waste from dairy production) and therefore this value was discarded from considerations of origins. This demonstrates the importance of dietary baseline data when using other isotope proxies to explore origins.

As described by Montgomery (2010), one must take an 'exclusive' approach to isotope data. We were unable to exclude almost any location in Britain and Ireland for the pigs' origins, despite using three isotope proxies (strontium, sulphur and oxygen) supported by dietary isotope data. This was a startling result. The data in all three elements are exceptionally diverse:

- All major biosphere zones in Britain are represented in the strontium data, except for small basaltic areas on the Lizard peninsula in Cornwall (Evans et al. 2018a).
- The sulphur values are also exceptionally diverse, ranging from the negative (−1.6‰), characteristic of wetland areas and/or impervious lithologies (Krouse 1989) to +19.6‰, one of the highest values produced in Britain and certain to derive from an exposed western coast.
- The oxygen data from the pigs have a comparable data range to that of multi-period human data from across Britain (pigs: $\delta^{18}O_{carbVSMOW}$ = 25.5 ± 2.0‰, 2SD, n = 130, MP107 excluded, humans $\delta^{18}O_{carbVSMOW}$ 26.5 ± 1.4‰ 2SD, n = 615, Evans, Chenery, and Montgomery 2012). There are many caveats in comparing the two data sets, such as species differences and drinking habits, but the human dataset is certain to be more affected (and likely more diverse) due to processing (Brettell, Montgomery, and Evans 2012), especially as we have excluded the one pig (MP107) with an unusual diet. Both the human and pig teeth are brachydont (i.e. low-crowned) and the sampling was considered to provide a time-averaged value in all cases. Thus, it seems reasonable to suggest that the diversity of the pig oxygen data supports a wide diversity of sources and hence geographic origins.

Our approach to the multi-isotope data was not to attempt to pinpoint precise locations, as this is not the function of isotope analysis, but to assess diversity across the dataset and we used multivariate statistical analysis to explore this. We used K-means cluster analysis to group pigs. The cluster analysis (see Madgwick et al. 2019a Supplementary Material) demonstrated a minimum of 24 distinct multi-isotope biosphere zones, as combining any of these clusters creates variation (in one or more proxies) that is too great to come from a single area. Our approach is conservative and some of the clusters are already too heterogeneous in terms of sulphur data (based on Zazzo et al. 2011) to realistically come from a single region. In reality, therefore, more than 24 areas are represented, as some geographically disparate zones are undifferentiable using these isotope proxies (and therefore show as a single cluster), although others may be isotopically different yet geographically adjacent (e.g. on two sides of a geological boundary). Barclay and Brophy do not refer to the use of multivariate statistical analysis at all as they focus on only a handful of strontium values, a very selective use of data, appearing to omit evidence that undermines their preferred narrative.

These wide ranges in the isotope data do not result from polarised high- and low-value clusters, but rather a continuum of values, across much of the expected spectrum for the entirety of Britain and Ireland. Such diversity across three proxies provides very strong evidence for diverse origins of the pigs. Barclay and Brophy challenge our title that asserts that animals came from '*throughout Britain*'. However, the evidence is overwhelming: our pig dataset produced a greater diversity of values, crucially in all three proxies, than all British comparative sites (see Madgwick et al. 2019a, 7) and numerous and wide-ranging multivariate clusters, supported by detailed mapping (Evans et al. 2018a). In our view, based on current mapping, it would not be parsimonious to suggest anything less than origins throughout Britain.

Strontium isotopes

Barclay and Brophy argue that we have indulged in '*interpretative inflation*' when we suggest that some of the pigs are likely to have come from Scotland. In an attempt to refute the possibility that any pig in southern Britain came from Scotland, they focus exclusively on the strontium and more specifically on a subset of five high values (>0.714).

Geologically, some areas of Wales and Southwest England produce high strontium values up to 0.7136, whereas granites in the Lake District have upper domain values of 0.7140 and, in England and Wales, only the Malvern Hills (a 12sq km outcrop 100 km from Stonehenge) yield domain values up to 0.7149 (but see Johnson 2018). Figure 2 demonstrates just how sparse areas with more radiogenic domain values are in the British biosphere. Some areas can be excluded for certain samples using the multi-isotope approach, as described above. The two highest strontium values of 0.7166 and 0.7172 in our dataset cannot be accommodated in England or Wales using current domain mapping.

Our paper contains one sentence suggesting Scotland as a likely location of origin for five pigs with very high strontium values: '*On the basis of the current mapping, the other five animals, with values ranging from 0.7141 to 0.7172, are likely to derive from Scotland* [p9]'. This single sentence forms the entirety of our suggestion of origins in Scotland. Some media reports sensationalised this (see below). Barclay and Brophy object to this suggestion of Scottish origins but the basis of their counter-argument is a misuse (or perhaps misunderstanding) of the data.

In fact, we do mention Scotland twice. Our description of the five highly radiogenic strontium values as likely to be from Scotland has been erroneously conflated by Barclay and Brophy with a description of an entirely different subset of lower strontium values (0.711–0.713) ascribed **explicitly** to a possible Welsh origin, to which we attached the caveat '*potentially southern Scotland or southwest England* [p9]'.

This conflation of two subsets of data – with different strontium values – by Barclay and Brophy may have arisen from a misreading or misunderstanding of the original article. They have used this misunderstanding to suggest we inflate interpretation through the course of our paper. On the contrary, we cautiously entertain various possible areas of origin for the lower strontium values (0.711–0.713), as even with multiple proxies it is not possible to confidently assign origins to the particular region of west Wales: '*However, equifinality remains an interpretative issue* … .[p9]'. The interpretive inflation is entirely of their making.

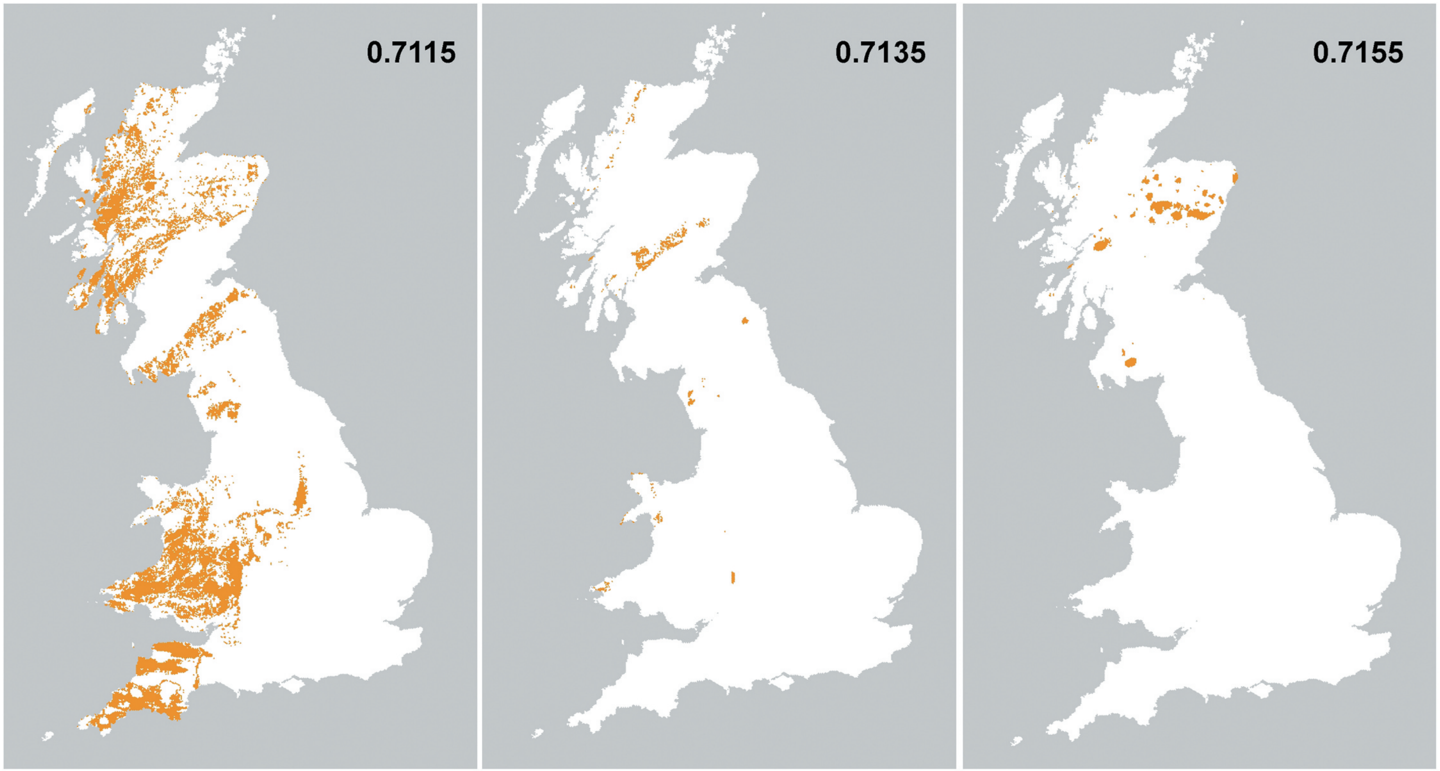

Figure 2. Maps showing areas where domains include values of 0.7115 (left), 0.7135 (middle) and 0.7155 (right), demonstrating how sparse highly radiogenic domains are in the British biosphere based on current mapping (following Evans et al. 2018a). N.B. These maps were not used to pinpoint locations in Madgwick et al. (2019a), but the interactive tool was used to explore the diversity of origins created using BGS Open Access biosphere map https://www.bgs.ac.uk/datasets/biosphere-isotope-domains-gb/.

Barclay and Brophy's account of our arguments is thoroughly muddled: when discussing evidence from strontium isotopes, they repeatedly take quotes out of context and attach them to the wrong data. For example, in their confused account of research by Evans et al. (2019) on cattle from Durrington Walls, they specify five instances in which a Scottish origin is mentioned as possible for a subset of the cattle, and state that the variant phrasing describing these five instances is proof of '*internal inconsistencies . . . . that hint at issues with both peer review and editorial oversight* [p22]' in the research. This is desperately wrong.

- One of these instances, which reads '*unlikely* [to originate in Scotland] … *on archaeological grounds* [p12]', does not even relate to the Durrington Walls cattle at all, but rather to radiogenic values at Roman Caerleon, Worcester and Early Neolithic Penywyrlod.
- Three of the quotes relate to high strontium values in the cattle dataset and are entirely consistent with each other: '*potentially including Scotland* [p12]', '*cannot be excluded from a Scottish origin* [p13]' and '*origins in Scotland seem likely for at least some animals* [p15]'.
- A fifth mention '*probably not represented* [p15]' does not contrast with the three statements above as they suggest, as it explicitly rules out highland north-east Scotland (based on oxygen values); it does not discount the rest of Scotland.

Barclay and Brophy also misrepresent our research on the potential origins in Ireland of any of the animals in the dataset, stating '*the study was constrained by an untested presumption, and no evidence from Ireland … was considered* [p14]'. This is incorrect. We **explicitly** refuse to discount origins in Ireland: '*the diversity of values makes it difficult to exclude any areas of origin in Britain and Ireland from the dataset* [p8]'. Indeed, we can now say this with greater confidence following the recent publication of a strontium biosphere map for Ireland (Snoeck et al. 2020), which shows that only some northern Basaltic areas can be excluded.

Barclay and Brophy assert that we base our interpretations on Evans et al.'s (2010) lower-resolution strontium biosphere map. This is simply wrong. We compared our data to (and cite) the more comprehensive interactive resource (Evans et al. 2018a). The 2018 strontium reference map for Great Britain is based predominantly on the analysis of plant samples as they represent the base of the food chain. However, the isotope value of a single plant cannot be equated with that of the growth of tooth enamel, which derives from months/years of dietary averaging. The domain-based map (Evans et al. 2018a) thus presents the interquartile range of the data collected for each domain as the best equivalence of what would be expected in a human or an animal sourcing food in the defined area. The map is based on c. 850 analyses, and the area of Great Britain is subdivided into 56 domains that are created from 1 km hexagons. This enables the user to enter a value and obtain a map showing all areas of Great Britain in which the input values fall within the interquartile range of the domain, i.e. areas that cannot be excluded as possible origins for strontium in the tooth enamel. Barclay and Brophy also cite this resource (albeit incorrectly), but appear to have failed to understand its value, casually discounting the 2018 map as one of a number of '*tools based on this* [Evans et al. (2010)] *research* [p17]'. The 2018 map is a major development over the flat-form 2010 map which was based on only 313 sample sites (presented in our paper as indicative, due to the 2018 resource not being print-friendly).

The 2018 map recognises the high strontium values of the Malvern Hills (which give an upper quartile value of 0.715). Barclay and Brophy state that we ignore the Malverns. This is not true. On the contrary, we explicitly discuss the radiogenic areas of geology here and elsewhere ('*isolated areas of southeast, southwest, and northwest Wales, the Malvern Hills in central western England, and the Lake District* [p8]', '*Caerleon and Worcester* [p5]'). The interactive map also provides information on other isotope proxies, though we used the map not to define origins (although there is a function for mapping provenance) but rather to explore diversity.

Some of the confusion in Barclay and Brophy's paper stems from lacunae in their understanding of the basic underlying principles of the map/s (see Holt, Evans, and Madgwick 2021). By taking the plant dataset and directly comparing it to pig enamel strontium, they ignore the very basic principle that plant strontium isotope composition **does not** equate to enamel strontium isotope composition and, according to the law of averaging, the enamel will **never** record the extreme values seen in single plant samples. Humans and animals simply cannot sustain themselves on single anomalous plants. Biosphere domain maps do not characterise landscapes (and diet) on the basis of extreme plant values, but by using measures such as inter-quartile range (e.g. Evans et al. 2018a) or median absolute deviation (e.g. Snoeck et al. 2020). Some also use a mixed plant method (Johnson 2018), an approach that has challenged the consistency of radiogenic values in the Malvern Hills (a point expanded below). We fully acknowledge that the resolution of strontium biosphere mapping will improve and may bring about alterations to our interpretation in the future. We say explicitly that origins in Scotland are possible '*On the basis of the current mapping* [p9]'. Our interpretation is equivocal and, of course, open for revision if new data become available.

Further errors and misrepresentation of evidence

In arguing against potential origins in Scotland for any of the pigs in the dataset, Barclay and Brophy place considerable emphasis on research that points to other areas of radiogenic geology, leading to some misrepresentation of other researchers' work. For example, by analysing averaged modern plants, Johnson's (2018) research sought to characterise areas of radiogenic biosphere in Britain that could produce high strontium values in archaeological enamel. In a study explicitly seeking high strontium values, only 20 of 152 analysed values were >0.714, mostly in Scotland, with only seven in England and Wales. Barclay and Brophy imply that there were 36 such values in England and Wales. This is not true – these other measurements from previous research cited by Johnson (2018) include single plant and water analyses that are not representative of diet or enamel values, as explained above (see also Warham 2011). Johnson's (2018) mixed plant approach provides more valid, archaeologically relevant characterisation (see below). This again shows Barclay and Brophy's poor understanding of basic principles of isotope systematics and biosphere mapping (see Holt, Evans, and Madgwick 2021).

Johnson's research emphasises that high strontium values are rare in the British biosphere, and Barclay and Brophy rightly highlight that very confined areas of Powys and the Welsh Marches can produce plant strontium isotope values up to 0.716. Other parts of Johnson's (2018) work that fail to align with Barclay and Brophy's agenda are entirely ignored, for example in relation to the Malvern Hills. Barclay and Brophy place great emphasis on this area as a potential zone of origin for the Wessex pigs with high radiogenic values. In our paper, we explicitly acknowledge the potential for the Malvern Hills to produce high values and both our paper and Barclay and Brophy (2020) also cite high values from nearby Worcester (Gan et al. 2018). However, Johnson (2018, 86) found no unusually high values (>0.714) in 21 plant samples from around the Malvern Hills. This is the most comprehensive study of the Malvern Hills biosphere, as it not only includes more samples from the immediate environs but also uses a 'mixed plant' approach to characterise 1 km^2 patches of landscape. This is a far more valid characterisation of potential pig diet than the single plant approach that has previously yielded high values in the area (Chenery et al. 2010) and casts doubt on the Malvern Hills being a potential place of origin for the high strontium pigs in the dataset. Note further that the Malvern Hills are a small outcrop of just 12sq km, and animals raised on the hills are likely to have ranged into adjacent areas with potentially lower strontium isotope values.

Secondly, Johnson (2018, 227) discusses strontium values >0.716, listing several geological regions **exclusively** across Scotland and stating '*These are the only areas at present that humans excavated in Britain with $^{87}Sr/^{86}Sr$ values >0.716 could have originated from, if they are believed to have originated from Britain*'. The statement is as valid for pigs as it is for humans: our dataset has two pigs in this range. Barclay and Brophy do not remark on this. These high values relate to 1.5% of the dataset (2 out of 131) and we must bear in mind that, among many thousands of pigs consumed at these Late Neolithic henge complexes, pigs with these high strontium values could have numbered in the hundreds. Johnson's (2018) research thus supports the suggestion of an origin in Scotland for pigs with such values.

Other researchers' work has been misrepresented to bolster the argument against origins in Scotland for the pigs. Barclay and Brophy summarise the work of Neil et al. (2017) by saying: '*Similar* [strontium] *values have been found in Neolithic humans at Ty Isaf, south-east Wales (*Neil et al. 2017*) … without the authors feeling it necessary to look to distant places for origins* [p23]'. This is, again, simply not true. The values for six of the eight Neolithic individuals (with values ≤0.7137; Neil et al. 2017) are not 'similar' to the Late Neolithic pigs: all have lower values than the pigs we suggest as likely deriving from Scotland. The other two individuals (>0.714) **do** have similar strontium values to these pigs and distant origins **are** considered for these by Neil et al. (2017).

The strontium values from humans at a further site (Penywyrlod) reported by Neil et al. (2017) are entirely omitted by Barclay and Brophy. Neil et al. (2017) recorded one individual from Penywyrlod with values of 0.7165 and 0.7170 and interpreted them as being from **outside** England and Wales. Other examples of such values being interpreted as being from outside England and Wales are published in Neil et al. (2020). These values are directly comparable to the two most radiogenic pigs in our dataset. The other ten Penywyrlod individuals have similar values (0.7132 to 0.7158) to the larger group of eight radiogenic pigs, for five of which we consider distant origins. Neil et al. (2017, 13) also firmly consider distant origins for these individuals: ' … *the majority of those buried at Penywyrlod could have obtained their childhood diet outside*

England and Wales', favouring origins in mainland Europe on the basis of Early Neolithic archaeological evidence, but not ruling out more distant areas of Wales. We similarly draw on archaeological evidence for the Late Neolithic to argue that the high strontium pigs are highly unlikely to be from mainland Europe (see below) and Scotland is a more likely origin. In conclusion, by failing to consider all the evidence presented by Johnson and by Neil *et al.*, Barclay and Brophy have omitted those data that do not support their narrative. In short, sources that Barclay and Brophy draw on to try and refute our interpretations, in fact do the reverse and provide strong support for them.

Connections within and beyond Britain

When considering the geographical origins of the Late Neolithic pigs, we excluded the possibility that they were brought to Wessex from the European mainland. Barclay and Brophy's paper finds a problem with this exclusion, stating that this '*pillar is insufficiently strong to bear the interpretative weight being placed upon it* [p10]'. In fact, this rejection of mainland Europe origins for Late Neolithic pigs is based on overwhelming archaeological evidence of interruption of cross-Channel cultural transmission, transportation or exchange during the Late Neolithic (c. 3000–2450 BC) despite extensive interaction along other European seaways at that time.

During the Early Neolithic in Britain, connections with mainland Europe included the movement of Alpine jadeitite axeheads and of styles of portable and monumental material culture of mainland Europe origin such as Carinated Plain Bowl pottery, long barrows and dolmens, causewayed enclosures and domestic architecture (Sheridan 2010). Domestic animals and crops were also brought across the sea. Yet, during the Middle Neolithic (c. 3400–3000 BC), these cultural links disappeared as material culture styles diverged on both sides of the Channel. This was a period with very few direct imports to mainland Britain (and specifically Wessex) of either architectural styles or portable artefacts from mainland Europe (Ard and Darvill 2015; Bradley et al. 2016, 116–17; Walker 2018). In the opposite direction, there is just one instance of a mainland European site with Middle Neolithic Peterborough Ware, from Spiennes, Belgium (Verheyleweghen 1964; Ard and Darvill 2015).

The new styles of monuments were of insular inspiration: ditched cursuses and circular monuments of earth, timber and stone. Loose resemblances among certain axehead forms and other lithic artefacts suggest possible stylistic influence from across the North Sea to eastern Britain in that period (Walker 2018). Only in western Britain and Ireland do large passage tombs and their associated art demonstrate stylistic links with Brittany and Iberia across the Celtic Sea (Bradley 1997; O'Sullivan 1997, 2006; Sheridan 2014). Other than in the far west, Britain reveals no substantiated overseas links during the Middle Neolithic.

During the Late Neolithic, distinct and separate provinces of material culture – Grooved Ware-users and the Seine-Oise-Marne culture – developed on either side of the Channel, suggesting distinct cultural identities. With no shared monument styles or cross-Channel imports into Britain, this appears to have been a period of insularity (Bradley et al. 2016; Vander Linden 2012; Walker 2018; Wilkin and Vander Linden 2015). The lack of evidence for cross-Channel interaction has been demonstrated on both sides of the Channel (Brunet et al. 2004; Mallet, Pelegrin, and Verjux 2019; Walker 2018), and is particularly striking as long-distance movement by sea is well documented in other regions of Western Europe (Bradley et al. 2016, 117). We are unaware of even a single sherd of Grooved Ware having been recovered from mainland Europe or a single sherd of contemporaneous wares from mainland Europe being recovered from Britain. Indeed, there is no evidence for any form of material culture having crossed the Channel in either direction: in the Late Neolithic, the Channel appears to have acted as a barrier not a conduit. This is in contrast to the Irish Sea over which connectivity is clearly evidenced (Carlin 2017; Sheridan 2004).

Of course, culturally isolated communities may still engage in exchanges that leave no archaeological trace – of cattle and other domesticates, for example – while strictly maintaining their cultural identities, as Hodder (1982) documented in his ethnoarchaeological study of the Baringo region of East Africa. It is thus theoretically possible that Late Neolithic communities were interacting in such a way across the Channel but that is to stretch the Baringo case study well beyond its conditions of applicability. Hodder was documenting the specific circumstances of land-based interaction between different ethnic groups competing in close proximity for scarce resources under conditions of social and economic stress (Hodder 1979).

With unambiguous evidence for an interruption in cross-Channel contact during the Late Neolithic, there is no basis from which to argue for origins in mainland Europe for the pigs excavated in Wessex. Wilkin and Vander Linden (2015, 100) address this issue succinctly:

'There has traditionally been a compulsion (still felt today) to relate British and European artefacts or else face the charge of insularity – a kind of archaeological 'Euroscepticism' and a failure of academic reach. While a parochial outlook is certainly unhelpful, so too is an unqualified stress placed on cross-Channel connections in order to justify the international 'impact' of archaeological objects and research'

Barclay and Brophy offer no evidence at all for the arrival of pigs from mainland Europe into Britain during the Late Neolithic. It is just possible that the arrival of the Beaker people and their distinctive material culture in Britain (*2460–2330 cal BC at 95% probability*; Parker Pearson et al. 2019, 75) might have been preceded in the previous hundred years by an archaeologically invisible first-contact phase. This is, however, unlikely since it would mean Beaker arrivals at the Durrington Walls feasts were accompanied by a few pigs but not by their distinctive material culture – even though their pastoral economy was based primarily on sheep and cattle (Parker Pearson et al. 2019, 83–4). Whilst we cannot entirely rule out mainland European origins for these pigs, the balance of probabilities is overwhelmingly on the side of all of them originating from somewhere in Britain, based on the very strong archaeological evidence summarised above.

Turning to Barclay and Brophy's distaste for any hypothesis proposing the existence of a shared culture in Late Neolithic Britain, we maintain that the most parsimonious explanation of island-wide similarities in styles of material culture across Britain – e.g. Grooved Ware, mortuary practice, house architecture and circular monuments – is an island-wide commonality during this period (Parker Pearson 2012; Thomas 2010; Vander Linden 2012; Wilkin and Vander Linden 2015). To take just one example, Barclay and Brophy say: '*cremation as a practice may have been widespread in the late*

Neolithic but we have no evidence to sustain this [p8]'. This is wrong: we can list 34 Late Neolithic sites which have produced 259 cremation burials distributed widely from northern Scotland to southern England (Willis 2020). The majority of these burials are from circular monuments (ring-ditches, henges and stone circles), architectural traditions, developed from the Middle Neolithic, with a similar geographical distribution to the cremations (*ibid.*).

Equally poor understanding of the results of widely available research appears in Barclay and Brophy's discussion of Grooved Ware, burials, house plans and henges. The wide geographical distribution and stylistic homogeneity of Grooved Ware (see Barclay 1999; Cleal 1999; MacSween 1995) cannot be ignored. Common architectural principles have been recognised for plans of Late Neolithic houses, as well as timber circles, henges and related monumental structures, across Britain (Bradley 2007, 119–20, fig. 3.16; Pollard 2009; Ray and Thomas 2018, 245–6, fig. 5.10). Greaney et al. (2020, 228) discussion of ceremonial enclosures notes that '*These similarities imply some degree of contact or movement of people between far-flung parts of Britain and Ireland in the late Neolithic . . . likely to be closely related to similar worldviews and religious beliefs*'. They point out that 'pan-British' connectivity is problematic (because some areas of Britain do not have such enclosures) and we agree that not everywhere in Britain used the same repertoire of architectural styles and material culture. We are not arguing that the inhabitants of Britain lived by a regimented and standardised set of rules controlled from Wessex.

As Cummings (2017, 232) summarises, '*these were monuments built by communities who were clearly aware of traditions of practice across wide areas of Britain and Ireland*'. Harding (2003, 56–8) has proposed that the widespread adoption of henges within Britain reveals a shared understanding of what Bradley (1998) has termed 'the circular world'.

Whilst researchers have described these commonalities as forming a cultural 'package' in certain regions or among certain classes of evidence, there is recognition that people drew upon ideas and practices across wide geographical areas yet used them in localised and idiosyncratic ways within social networks that were overlapping and varied (Bradley 2007, 121; Cummings 2017, 232; Harding 2003, 106). For example, Orkney retained collective tombs and inhumation burial – mortuary practices once common in parts of Early Neolithic Britain but at odds with the widespread shift to single burial and cremation – yet its people contributed to, if not pioneered, other widespread practices and styles such as Grooved Ware and 'classic' henges (with the ditch inside the bank). Similarly, Orkney's multi-cellular house styles are absent from elsewhere in Britain and yet floor plans of houses at Skara Brae share remarkable and undeniable similarities in shape, size and interior layout with those at Durrington Walls (Parker Pearson 2007). These long-distance similarities are all the more extraordinary given that this sub-rectangular type of plan is not common among the predominantly circular house plans found in the regions in between (Bullmore Forthcoming). Bearing in mind the different uses, different contexts and regional variations in material culture, it is possible to have Britain-wide commonality without uniformity.

Ancient DNA evidence is also consistent with island-wide links, as the relative genetic homogeneity of Early Neolithic populations in Britain persists into samples we have from the Late Neolithic and demonstrates a lack of external genetic input (Brace et al. 2019; Cassidy 2020; Cassidy et al. 2020). Much of the genetic variation within Neolithic Britain and Ireland appears to form a northeast–southwest cline, in which the ancestry of those from Wales and the west owes less to western European hunter-gatherers and more to European farmers, most similar to Early Neolithic Iberians (Booth 2019b; Cassidy 2020). Consequently, Neolithic populations in northern Scotland and eastern England shared similar genomes despite the geographical distance. Whilst this need not have translated into close cultural links, voyaging by boat between these regions along the North Sea coast may have been easier and quicker than travel by land. None of these proxies alone provide irrefutable evidence for island-wide links, but together (and including the isotope data) the case is compelling. The Late Neolithic in Britain shows greater geographical homogeneity in the archaeological record than in any other post-Mesolithic phase of prehistory. Of course there were variations and differences in material culture and architecture but the overarching pattern of commonality is clear.

Media coverage

It is beyond the scope of this response to go into detail on the extensive reporting of our original paper. We must, however, challenge Barclay and Brophy's account of the media coverage and its underlying meanings. Inevitably, different media outlets emphasised different elements of the research and in several instances strayed well beyond the research in their reporting. The Sun led with '*Stoner-Henge: Ancient ravers "av it"*,' with the Mirror going for '*Stonedhenge: Ancient site was Glastonbury Festival of its time*', neither of which had much to do with the research. Most had more balanced headlines, such as the Guardian's '*Ancient Feasts: Bones offer clues to Neolithic party rules*'.

The misrepresentation of archaeological research in the media is nothing new (see Booth 2019a; Brophy 2018; Hakenbeck 2019; Clack and Brittain 2007; Maldonado 2016; Prendergast and Sawchuk 2018; Richardson and Booth 2017). Journalists have their own agendas and, at the time our press release went out, the entire nation was focused on Brexit. The Daily Telegraph's '*Neolithic Brexit Unearthed at Stonehenge*' was the most apparent example of this. This headline links to the absence of evidence for Late Neolithic contact with mainland Europe that has been examined in detail by other researchers (see above) and briefly cited in our paper, rather than referring to any new research we carried out. It was just too obvious a topical link for some reporters to ignore. However good one's press release, one's research will be garbled, slanted and misquoted across the media. At any moment in time, one would be hard-pressed to find any reporting of archaeology that was entirely satisfactory to the profession. The media add the errors and spin, and that is the challenge we must face. Barclay and Brophy make important points and a '*pre-empt and pushback* [p24]' strategy may have reduced misappropriation in the media following the publication of our article.

Designing a one size fits all 'pre-empt and push back' strategy that will be effective for all outlets is, however, a very challenging task. More than 40 media interviews were conducted in relation to this paper and the same summary was provided in all. It is telling that only a tiny minority of the hundreds of media reports took an offensive line. Brexit was raised frequently in media interviews, but by the interviewer, not a member of the research team. As soon as it was stated that there is no evidence for contact with mainland Europe during this phase, numerous interviewers made a link to Brexit. This was even the case in live radio interviews, for example on Talk Radio (13th March), where Paul Ross (the interviewer) independently stated, ‘so this was a prehistoric Brexit’ on air after it was stated that there was no evidence for contact with mainland Europe. If the interviewer did not make this link, then there was no mention of Brexit (e.g. BBC Radio 4’s Inside Science [14 March 2019], BBC Wiltshire’s Foodie Wednesday [13 March 2019] and BBC Wales’ Good Evening Wales [14 March 2019]).

Our job as archaeologists is to tell the public about our common past. There are inherent challenges in relaying the complexities of archaeological interpretations to the media, but that is no reason to give up – archaeology needs to be at the centre of our shared cultural life and it is our job to put it there. The media seize on any story about Stonehenge because it makes for easy copy, probably because reporters think it is the only prehistoric site in Britain identifiable by most of their readership. Archaeologists themselves may be thoroughly exasperated by the media focus on Stonehenge but, rather than denying the importance of Wessex in the Late Neolithic, we need to embrace the fact that we have a ‘gateway’ site through which the public find out about prehistory. It is up to archaeologists to open that gateway wider and feed engaging information on other sites and periods to the media.

As well as being reported in print, digital and radio media, our paper received considerable coverage across social media. Barclay and Brophy [p19] think that it was widely criticised on social media, though of the 167 tweets that link directly to the paper,[1] the only partially negative one comes from Brophy himself. Many tweets mention the press coverage (which many found objectionable, not least the research team) and its misalignment with the research.

Summary

Barclay and Brophy accuse us of skewing the archaeological narrative towards the ‘*luminous centre*’ of Stonehenge. The luminosity of Wessex for isotope studies does not relate to ‘*an outdated vision of prehistory* [p23]’, but rather to superb bone preservation and an abundance of well-stratified faunal remains. At no point in our paper do we suggest that such lynchpins in the landscape do not exist in other parts of Britain. It is just that very few areas (not including, unfortunately, most of mainland Scotland) have a faunal record that allows such hypotheses to be tested. Our research redressed the imbalanced emphasis on Stonehenge by exploring several major henge complexes of Wessex. Our results show that people and animals came from afar to all the henges, thus demonstrating that research focusing on Stonehenge in isolation is potentially misleading.

Barclay and Brophy object to our research in Wessex as being skewed by a ‘*neocolonialist*’ agenda. Their argument is based on a garbled version of the isotope evidence and on the media coverage of our results. Their attempt to use these isotope results to create a new narrative describing Neolithic Scotland as somehow disconnected from the rest of Britain relies on misrepresentation of our results (presenting quotes as relating to the same dataset, when they do not) and our methods (ignoring the multi-isotope approach and suggesting we used low-resolution mapping), and on the highly selective and often confused use of data from other research (Johnson 2018; Neil et al. 2017).

It is worth noting that all reviewers of this paper (who had the added task of reading Madgwick et al. 2019a; Barclay and Brophy 2020) highlighted or confirmed the selective and/or muddled use of data by Barclay and Brophy and one explicitly noted an underlying agenda in their work. Not a single comment disagreeing with our interpretation of the isotope data was offered, whilst there was a total of 29 comments either explicitly agreeing with points or praising the approach to, and interpretation of, the data. Original reviews of Madgwick et al. (2019a) were similarly positive. Barclay and Brophy's claims of '*failures of the peer-review and editorial process* [p15]' in the publication of our research are entirely unsupported.

Barclay and Brophy's paper is firmly focused on Scotland. They mention Scotland 40 times in their paper, an over-emphasis that is analogous to the selective and sensationalist path that some of the media took. However, what is presented as a redressing of the balance (taking the focus off Wessex) is effectively a selective and inaccurate narrative. The selective use of data to bolster this alternative narrative is again evident in their appraisal of a range of work on the Stonehenge environs, notably Evans et al. (2019), Madgwick et al. (2019a), Parker Pearson (2012, 2015), Snoeck et al. (2018) and Viner et al. (2010). Very little attention is paid to the data in these papers, but the weaker any link to Scotland is in the interpretation of evidence, the more positive Barclay and Brophy are about the study. They cite a range of studies that supposedly disprove our hypotheses or provide examples of best practice in cautious interpretation of isotope values. These are presented as being delivered by wiser, unbiased research groups, yet, oddly enough, our team was involved in practically every study cited (e.g. Chenery et al. 2010; Johnson 2018; Montgomery, Budd, and Evans 2000; Neil et al. 2017; Snoeck et al. 2018; Viner et al. 2010). The differences in interpretation in these research reports derive solely from the data available to each study. These various contributions show an evolution of our thinking and a collective aspiration to explore new evidence, rather than dogmatically pursue any one particular narrative. Barclay and Brophy's preferred interpretations of the research in the literature cited are those that do not make strong connections between Scotland and the rest of Britain. We raise these points to highlight how inaccurate scholarship and the misuse of isotope data can be used to create an alternative narrative of our past.

Turning very briefly to Barclay and Brophy's analysis of the media coverage, we insist that any attempt to conflate our research with a media-driven Brexit agenda which distorts facts to feed a far-right sentiment is frankly poisonous. To present the lives of the people of Neolithic Britain as relevant to contemporary political debate, as some of the media have attempted, is an absurdity. Researchers who seek to critique studies need to be careful not to fall into the trap created by media sensationalism and must distinguish judiciously between archaeological evidence (and its authors), and media misinformation (and its proponents).

Returning to the substantial evidence we have presented, we remain cautious about the suggestion that some of the Late Neolithic pigs found in Wessex cannot be excluded from originating in Scotland. As explained in the original paper and throughout this article, this interpretation of the multi-isotope evidence relies on current mapping and we are very open to interpretative revision as new data come to light. We are already aware of new unpublished biosphere data pointing to radiogenic areas on Dartmoor (see Rippon et al. 2021 for faunal summary) that may account for some, but certainly not all, of the pigs with high strontium values. Using isotope analysis to explore origins is an exclusive approach and equifinality remains a challenge, even when using multiple proxies. We are currently working to refine interpretation further by adding an additional proxy of lead isotope analysis (following Evans et al. 2018b). Whist pinpointing precise locations will almost always be an impossibility, the evidence for diverse origins across Britain for the Wessex pigs is overwhelming and it is difficult to interpret the diversity of values across isotope proxies in any other way.

Barclay and Brophy's misrepresentation of our data, and their methodological error of selecting and interpreting only strontium, may be uncritically recycled. There is already evidence of this. In the Society of Antiquaries of Scotland 2020 Rhind lectures, it was stated that our paper claimed animals came from Scotland 'on the basis of the strontium isotope ratios', again ignoring the wide-ranging isotope data we used. Slides showed no supporting images from our paper, but instead relied on a map including both cattle and pigs that was published in Barclay and Brophy's paper and was not produced by us. Barclay and Brophy's skewed narrative could thus become more widespread, especially when it is repeatedly recycled in the potentially malicious and solipsistic environment of social media. Such a narrative, founded on errors and misunderstandings, cannot be left unchallenged.

By using a case study-based approach, this paper seeks to warn against the dangers of secondary use of isotope data. Such secondary critiques are arguably by their very nature more susceptible to errors in interpretation and even to agenda-driven bias. Reappraisal and critique of archaeological evidence are central to the development of the discipline and the cycle of interpretative refinement, and such re-assessments of data are generally healthy. Uncritical acceptance poses a danger to archaeological discourse and detailed scrutiny is essential, but attempts to re-evaluate technical data and firmly-grounded archaeological evidence become unethical when they rely on incoherent use of the available evidence and veer into unfounded and ill-judged accusations of political bias.

Note

1. https://scienceadvances.altmetric.com/details/56,971,674/twitter.

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