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ARTIGO

USING ^{14}C DATES TO TRACK EARLY HUMAN DISPERSALS

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ABSTRACT

This paper reviews some methodological problems in the use of radiocarbon dates to reconstruct episodes of archaeologically-recorded human dispersal. Much effort has been expended estimating speeds and directions of spatial population expansion in such cases. An appropriate application for these techniques is the first peopling of the Americas. We discuss regression techniques for estimating front speeds, and consider some limitations due to incomplete archaeological sampling and imprecise radiocarbon dating. We also summarise results from a recent programme of dating of previously-excavated late Pleistocene sites in Argentina and Chile.

KEY WORDS Radiocarbon, calibration, human dispersals, Paleoindian

RESUMO

Este artigo apresenta uma revisão de algumas questões metodológicas no uso de datas radiocarbônicas para reconstrução de episódios de dispersão humana registrados arqueologicamente. Estudos sobre este tema têm investido em estimar ritmos e direções da expansão espacial de populações. Uma aplicação apropriada para estas técnicas é o povoamento inicial das Américas. Discutimos neste artigo técnicas de regressão para estimar ritmos de frentes de deslocamento e salientamos algumas limitações decorrentes de uma amostragem arqueologica incompleta e de datações radiocarbônicas imprecisas. Apresentamos também resumidamente resultados de um programa recente de datação de sítios previamente escavados na Argentina e no Chile.

PALAVRAS-CHAVE Radiocarbônico, calibragem, dispersão humana, paleoíndios

INTRODUCTION

This paper reviews some methodological problems in the use of radiocarbon dates to reconstruct episodes of archaeologically-recorded spatial population expansion. It draws on material published in previous papers by the author and his collaborators and brings that work together for the first time (for the previous publications see Glass, Steele and Wheatley 1999; Hazelwood and Steele 2004; Steele 2009; Steele and Politis 2009; and Steele 2010). It is hoped that this review may be useful to archaeologists working on population dispersal problems in South American archaeological contexts. For this overview the explicit mathematical and statistical content has been minimised and discussion has been kept to a conceptual level, but interested readers can find more technical details in the papers just cited.

In basic demographic terms, modelling large-scale human dispersals requires us to consider the rate at which the population increases locally, and the rate at which people move across the landscape. In population ecology, the simplest model of such processes is a reaction-diffusion system defined by Fisher (1937) and Kolmogoroff, Petrovsky, and Piskunov (1937), and applied to population expansion by Skellam (1951). This system predicts a constant spreading rate for an expanding population in a homogeneous habitat; this rate will vary as a function of the average reproductive rate and the average rate of mobility of the population. In recent years an enormous amount of work has been done by biologists using this system to model the spread of invasive species, and numerous modifications and extensions have been proposed to improve the match between the modelled dynamics and those observed in the real world (see recent reviews for biologists by Hastings et al. 2005; for interdisciplinary physicists by Fort and Pujol 2008; and for archaeologists by Steele 2009).

Much effort has been expended estimating speeds of spatial population expansion for archaeologically-documented dispersal episodes, initially to confirm predictions of front speeds in the Fisher-Skellam model from independently-estimated population growth and migration rates, and more recently to assess how far the classic Fisher-Skellam model falls short of reality in its treatment of human mobility patterns in a dispersal phase. In ecology, simulations have shown that regressing distance to the point of origin of the invasion as a function of time of first detection is the most robust way of estimating invasion speeds, particularly where there is only a small sample of observations (Gilbert and Liebhold 2010). Numerous archaeologists have suggested that radiocarbon dating can be used for this purpose, yielding estimates of the timing of passage of the expanding population front at different spatial locations. For the spread of farming in Europe, Ammerman and Cavalli-Sforza (1971, 1984) fitted a linear regression to dates and distances from Jericho, finding a mean front speed of about 1 km yr-1. Subsequently Pinhasi et al. (2005) fitted a linear regression to dates from a set of 735 Neolithic sites in Europe and the Near East using various origins and two possible distance measures, and found an average front speed in the range 0.6–1.3 km yr-1. For earlier episodes of hunter-gatherer dispersal, Fort et al. (2004) estimated by regression a mean speed of late glacial recolonization of northern Europe of 0.8 yr-1 (0.4–1.1 km yr-1 at the 95% confidence interval).

An appropriate case study for these techniques is the first peopling of the Americas. For the last 50 years it has been the prevalent view that the North American Clovis

culture represents the earliest successful colonization phase, in which hunter-gatherers invaded the continent south of the ice sheets from a Beringian source population. However radiocarbon dates have subsequently constrained the Clovis phase to an increasingly short interval, most recently to between ~11,050 14C yr bp and ~10,800 14C yr bp (Waters and Stafford 2007). Meanwhile dates from sites in South American, including the southernmost part of that continent, have been confirmed for the same time range (e.g. Steele and Politis 2009). This has led some scholars to propose a colonization model including multiple dispersals, perhaps synchronous but geographically separated (Steele and Politis 2009; for congruent arguments from human genetics see Hellenthal, Auton and Falush 2008 and Perego et al. 2009). Accurate reconstruction of the passage times of the expanding population front is a pre-requisite for resolving such debates and exploring the underlying demographic processes.

REGRESSION APPROACHES

A basic requirement of regression analysis for determining population front speed is the ability to estimate timing of cultural events at known spatial locations using radiocarbon dates. Obtaining archaeological estimates for first arrival times at different locations remains a very imprecise science, because of sampling biases and of uncertainties (e.g. of stratigraphy) in the documented archaeological record. However, let us assume that we have a set of dated events that we wish to analyse on the basis that they represent a set of first arrival times. We then need to assign each event a point value (a single calendar age) for our regression analysis. It was initially the practice to use the modal value of an uncalibrated radiocarbon measurement as the point value and to control for variation in precision by excluding any dates that had standard errors of measurement greater than 200 radiocarbon years (e.g. Ammerman and Cavalli-Sforza 1971, 1984). Subsequently, partly as an outcome of the extension of consensus calibration curves into the late Pleistocene, it has also become normal to check the front speeds estimated in this way against front speeds estimated using some point approximation of the most likely or mid-range value of the calibrated probability distribution for that radiocarbon measurement (e.g. Pinhasi et al. 2005; Hamilton and Buchanan 2007).

Most recently, it has become possible to estimate relationships between dates and distances from an assumed origin using as the date variable a set of single calendar year values for each radiocarbon-dated event, in each case drawn at random from its calibrated probability distribution (Steele 2010). By repeating this regression analysis many times, each time with a fresh draw of a single calendar year for each of the events in the dataset, we can estimate a confidence interval for the regression model parameters (slope, intercept, p-value, Pearson's and Spearman's correlation coefficients) that takes account of the known uncertainty (calibrated date range) in the date of each event. One method of drawing single values from the calibrated distribution is the MCMC routine in the most recent online beta-version of OxCal (Version 4.1b3; Bronk Ramsey 1995, 2001), which will take a snapshot every (user-specified) n iterations of all of the parameters of the model obtained by the MCMC analysis, and which will save a user-specified number of such snapshots to a file for subsequent analysis (cf. Steele 2010).

The speed of propagation of an expanding front is then estimated in archaeology by fitting a regression line to a set of estimated dates and of values for some measure of the dated sites'

relative position in space. Most often this is done by bivariate regression using distance as measured from a hypothesised origin point. The appropriate regression model to use when estimating this functional relationship is one which takes account of error and uncertainty in both variables. Reduced major axis regression (RMA), whose slope is the geometric mean of the two ordinary least-squares slopes, is preferable to the principal or major axis regression technique used by Ammerman and Cavalli-Sforza (1971, 1984) because RMA is scale-invariant. Simulations (Babu and Feigelson 1992) have shown that RMA performs well in recovering the true functional relationship between two error-prone variables: the angular bisector of the two ordinary least-squares regression slopes (obtained by regressing x on y and y on x) performed slightly better but given the coarse order of approximation that archaeologists require when interpreting front speeds, and given that the latter method is less widely implemented in statistics and spreadsheet packages, I think that it is satisfactory to use the reduced major axis technique. To illustrate the relevance of this choice, Cantrell (2008) has used simulations to assess the ability of ordinary least squares (OLS) regression to estimate a functional relationship between two variables where each contain error, and where the underlying relationship is unity (a slope of value 1): he found that OLS underestimated the true slope, with a systematic fractional error of underestimation of the order [1-r], where r is Pearson's correlation coefficient. RMA can easily be implemented in a spreadsheet or other computer program either by inputting the relevant formula for the slope and intercept directly, or by using for example an Excel add-in such as Sawada's (1999) which returns the full basic set of regression statistics (slope and SD, intercept and SD, r2).

It is perhaps useful to consider here why we might prefer methods of line-fitting that take account of error in both variables. The presence of sampling error and measurement uncertainty in a sample of radiocarbon dates is obvious to an archaeologist, but the presence of error and uncertainty in the estimation of distance between two locations should be equally obvious to any archaeologist who stops to consider the effects on large-scale dispersal patterns of terrain relief, of soil type and vegetation cover, and of rivers and large bodies of water. If we try to estimate front propagation speeds using great circle distances from a point origin, then clearly the distance measurements will be error-prone and a line-fitting technique such as reduced major axis should therefore be used. In practice it is commonplace for archaeologists to estimate front speeds as within the range indicated by the two OLS slopes (date on distance, and distance on date) and that is perfectly acceptable provided that this range is of the same order of approximation as the reaction-diffusion model's predictions. However, this approach yields an excessively wide range of estimates for the values of the true underlying functional relation.

Finally, in some cases, it may make sense to cluster sites into bins of equal distance from the assumed origin of the dispersal, and only take the age of the oldest early site (or the average of all their ages) for each such bin. This is because if a colonizing population expands at a constant rate, the area colonized will tend to increase as the square of time, so that the number of sites will be correlated with time and with distances from the origin. This can bias the regression results.

We should note at this point that calibration of late Pleistocene radiocarbon dates is still an inexact science. In particular, and compared with INTCAL04, the latest consensus calibration curve (INTCAL09, Reimer et al. 2009) substantially changes the

picture for dates deriving from approximately the onset of the Younger Dryas, and uses only marine data for periods before 12,550 cal BP (for the implications for dispersal chronology in North America, see e.g. Steele 2010). Meanwhile the Huon Pine (HP-40) tree-ring sequence now anchors the previously floating Late Glacial Pine (LGP) 14C sequence (Hua et al. 2009), and supports the reduction in calendar age of radiocarbon determinations (12900-12550 cal BP) obtained with INTCAL09 as compared with INTCAL04 (Reimer et al. 2009). However, a plot of the anchored LGP tree-ring 14C sequence (Hua et al. 2009: 2986) also suggests that a Pacific coral-based calibration may overestimate both that reduction in age at the younger end of the range (12700-12550 cal BP), and the associated uncertainty due to trends in atmospheric 14C concentration. Future revisions of the calibration curve incorporating the anchored LGP tree ring 14C series are therefore likely to change the picture again. Thus, even if we have a good statistical technique that enables us to make full use of the probabilistic nature of radiocarbon dates, we must remember that for such periods our conclusions remain dependent on the accuracy of the calibration curves themselves.

PROBLEMS IN RECOVERING A COHERENT SPATIAL GRADIENT IN ARRIVAL TIMES WITH SPARSE AND IMPRECISELY-DATED SAMPLES

Although careful use of regression techniques can help us to reliably detect spatial patterns in a sample of radiocarbon-dated events, failure to detect such structure is not always the fault of our statistical technique. Nor need such a failure mean that no dispersal took place at the time when we had expected to see evidence for one. In fact, for many plausible scenarios where the population spread quickly and/or where it reached its greatest density on the settled landscape at some distance from the entry point, we may find it very difficult indeed to recognize the direction of spread or the location of the entry point using archaeological data.

Let us consider the process of first detection of an archaeological marker. The Fisher-Skellam model predicts a travelling population density wave that is at carrying capacity behind the front and decreases to an infinitesimally small value ahead of the population front. At what population density would we expect to detect the arrival of the population? If the population is highly mobile and has a relatively slow reproductive rate, then it may reach local densities sufficient for first archaeological observation at similar times at very different distances from the entry point. The fact that radiocarbon dates have an intrinsic uncertainty about the precise date of any event only adds to the problem. We have explored this analytically elsewhere (Hazelwood and Steele 2004). Other things being equal, population front profiles (waves of advance) will be broad if the population was highly mobile, and narrow if the population was more restricted in mobility. If mobility is held constant, then the front will travel faster if the population reproduces rapidly. Intuitively, we might expect that narrow and slow waves will be the best for estimating the rate of population advance. By contrast, with broad and fast waves it might be expected to be more difficult to determine whether we are detecting pioneer or established phase occupation. Our intuition is usually correct in archaeological situations, because the uncertainty in radiocarbon determinations makes fast waves hard to track accurately using that method.

An additional complication arises where the population is expanding into regions

that are richer in resources, and therefore able to support higher population densities (higher carrying capacities). In such cases, if we assume that the quantity of artefacts that survives is broadly in proportion to the size of the local population at any location, then initially the archaeological record will contain more material near the entry point; but after some time the greatest density of artefacts will be in the locations which support higher population densities, and which may be considerable distance from the entry point. If we have no typological basis for differentiating artefacts of the initial spreading phase from those of the established phase, then we could easily be tricked into thinking that the population had existed longest at locations where we find the greatest quantity of archaeological material. Indeed, if the population was at very low densities in locations close to the entry point during the spreading phase, then we may fail to notice them at all unless we carry out very extensive (and also intensive) archaeological surveys and excavations. Again, we have explored this problem analytically elsewhere (Hazelwood and Steele 2004).

THE CONSTANT NEED FOR DATA REFINEMENT

In parallel with the development of statistical techniques for tracking dispersal trajectories, we must also constantly attempt to improve the quality and completeness of our archaeological samples. In our own previous studies, we have tried to reconstruct the pattern of late Pleistocene population expansion in the Americas using the above and related GIS-based techniques (e.g. Glass, Steele and Wheatley 1999, Steele 2010), but have been limited by the small size of the sample of dated sites, and by the lack of widespread consensus on which sites (and which radiocarbon dates) can be treated as a reliable record of early human occupation. Before we can analyse evidence for early human dispersal trajectories in space and time, we have to obtain a large enough sample of securely-dated observations of early human occupation. This remains a work in progress.

The obvious ideal requirements for diagnosing and dating past human activity at an archaeological location are that there should be undeniable traces of humans (artefacts or skeletons) in undisturbed geological deposits, with indisputable dates. A more detailed recent specification stipulates the following standards of validity for early Palaeoindian sites: there should be a consistent series of accurate and statistically precise radiometric dates, based on taxonomically-identified single objects of carefully cleaned cultural carbon (which will be considered especially reliable if fruit/seed remains or purified amino acid fraction of bones/teeth of prey animals), found in primary stratigraphic association with artefacts, and with the results documented by peer-review publication (Roosevelt et al 2002). Some scholars would further modify this to exclude samples with errors of more than ± 1% of the mean age, in radiocarbon years.

Our specific objectives in a recent archaeological dating project (Steele and Politis 2009) were therefore to reassess the age of the earliest cultural phases of a set of early archaeological sites in southern South America (Argentina and Chile), applying such criteria to the extent that this was possible with already-excavated material. In each case, pre-existing radiocarbon dates suggested an age contemporary with or earlier than the North American Early Palaeoindian record. We wanted, in collaboration with these sites' investigators, to submit for AMS 14C dating additional previously-excavated specimens from the same stratigraphic units that had previously yielded individual dates

suggesting a late Pleistocene human presence in the southern cone. Our preference was for single pieces of hearth charcoal and for clearly cut-marked animal bones. Where such specimens were not available we also accepted burnt animal bone, and animal bone which was helically fractured by dynamic impact (although we were aware that such fracture patterns are not necessarily anthropogenic [Haynes 1983, 1988] and that the argument for human agency must therefore be made from other aspects of the archaeological context). Finally, where no modified bone was available, we accepted specimens of unmodified animal bone; but we were aware that dates on such bone would be less reliable indicators of the age of human activity, because other taphonomic agents could have caused those bones to be present in the deposits. To control for potential error in interpreting 14C measurements on bone and charcoal specimens (for example due to the burning of old wood, or to the difficulty of eliminating diagenetic contaminants from bone samples), a combination of both materials was selected where possible.

The results were very interesting. With one possible exception, we did not obtain new results to confirm earlier observations of pre-Clovis-age cultural activity at any of the sites considered in this study. The exception, Arroyo Seco 2, is considered in detail elsewhere (Politis and Gutierrez, in press). In the light of the results of this study, which appear to have resolved many of the dating issues surrounding the Arroyo Seco 2 Pleistocene component, debate must now focus on the taphonomic arguments for humans as the agents of bone accumulation and bone modification. Leaving Arroyo Seco 2 aside, our results on the specimens which were the most preferred indicators of cultural events (hearth charcoal and cut-marked bone) do however confirm that people were in the southern cone of South America at or soon after 11,000 BP. This observation is corroborated by the new results obtained from this study for at least three of the six sites in our own sample: Cerro Tres Tetas (11,087±48 BP and 10,886±48 BP, hearth charcoal, both averaged from two replicate determinations); Cueva de Lago Sofia 1 (10,710±70 BP [OxA-8635], bone tool); Piedra Museo (10,675±55 BP [OxA-15870], cut-marked bone). In addition, Tres Arroyos has two secure hearth charcoal dates (10,600±90 BP [Beta 113171] 10,580±50 BP [Beta 113171]) obtained independently of our study but which are consistent with the results we obtained. Finally, independently-obtained hearth charcoal dates from two other sites in our sample (Cueva de Lago Sofia 1, 11,570±60 BP [PITT-0684]; Piedra Museo, 11,000±65 BP [AA-27950]) suggest somewhat earlier dates for first occupation which our own observations did not directly confirm, but which remain plausible in principle in terms of stratigraphic context (and which should now be revisited by additional determinations on charcoal from the same features).

Similar evidence to that obtained in the study by Steele and Politis (2009) has been reported from other sites in the southern cone of South America. These include - in the Humid Pampas sub region (see references in Steele and Politis 2009) - Cerro La China 1 (10,706±40 BP, average of five charcoal dates), Cerro La China 2 (with charcoal dates of 10,560±75 BP and 11,150±130 BP), Cerro La China 3 (with a single charcoal date of 10,610±180 BP), and Cerro El Sombrero (with four charcoal dates in the range 10,270±85 BP to 10,725±90 BP). In Uruguay, the site of Urupez 2 has two charcoal dates (10,690±60 BP and 11,690±80 BP; Meneghin 2004, 2006). In southern Patagonia an additional key site is Cueva Casa del Minero (10,983±39 BP, average of two charcoal dates; Paunero 2003). Cueva del Medio

has four charcoal dates in the range 10,930±230 to 9,595±115 (Nami and Makamura 1995). Finally, we also mention here two sites from lower latitudes in South America which have multiple 14C measurements that appear to be quite consistent and well-controlled, and are of similar age: in the semi-arid Andean Pacific region of Chile, a layer at Quebrada Santa Julia has recently been dated to 11,024±47 BP (average of two charcoal and one wood samples; Jackson et al. 2007); and in addition, the Initial A stratum at Caverna da Pedra Pintada in Brazilian Amazonia has a date for its basal cultural layer of 11,077±106 BP (average of four burned palm seed dates; Roosevelt et al. 2002). However, a full evaluation of the early settlement chronology in lower latitudes of South America (and in countries such as Brazil) was outside the scope of our own study.

CONCLUDING REMARKS

This paper has reviewed some robust statistical techniques for estimating the rate of expansion of a population front, but has also noted the limitations of an incomplete archaeological sample and imprecise radiocarbon dates. We have also summarised the implications of a recent study of previously-excavated sites in Argentina and Chile, where the chronology of the earliest settlement phases was revised in the light of new dates. Early human dispersals can indeed be reconstructed reliably by these means, and once we have a reliable picture of the chronology of first occupation at a sufficient sample of spatial locations, we can also begin to reconstruct the demographic and cultural dynamics of this expansion process. This kind of work is a major scientific undertaking. Modern genetics has revolutionised our understanding of modern human origins and of the timing of human dispersals out of Africa, and has contributed to a new understanding of our species' biological identity. Archaeology has a fundamental role to play, not only in providing an independent chronology to calibrate the geneticists' models, but also in reconstructing the origins of human cultural diversity. The potential scientific rewards of large-scale collaboration and data pooling, and of the establishment and application of agreed standards for data screening, will justify the hard work which such integration must inevitably involve when working with models of processes on a continental scale.

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