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Population density, mobility, and cultural transmission

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ABSTRACT

Prompted by the results of a series of recently published simulation models, there is an increasing tendency for archaeologists to invoke demographic variables as explanations for changes in the sophistication or complexity of material culture. Whilst these models are undoubtedly valuable, this paper draws attention to persistent failings in the interpretation and application of these models by archaeologists. Despite having quite different effects, variables such as population size and population density are often used interchangeably; and whilst increasing mobility has an effect broadly equivalent to that of increasing population density, it is rarely given sufficient weight in archaeological explanations of cultural change. The analyses reported here develop a series of new simulations based on the ideal gas model, allowing for an explicit prediction of the encounter rate – the variable for which population density and mobility are proxies, and which ultimately governs the rate of cultural transmission. This model supports the predictions of earlier studies on the effects of population density and mobility, but suggests that population size will have no effect on rates of cultural transmission. These simulations are coupled with analyses that demonstrate a reciprocal correlation between population density and mobility in a large hunter-gatherer dataset. Given this correlation, it is argued that archaeological inferences about cultural transmission based on just one of these variables are unlikely to be valid. These findings are discussed in the context of previous research, and it is suggested that future studies would gain greater explanatory power by focusing explicitly on the social network structures likely to have characterised a particular archaeological population.

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1. Introduction

Over the past 15 years, an increasing number of archaeologists have invoked variables such as population density or population size as explanations for changes in material culture. Increases in these variables, it is argued, will lead to greater sophistication or complexity in toolkits, in individual tools, or in methods of tool manufacture (e.g. Shennan, 2001; Henrich, 2004; James and Petraglia, 2005; Zilhão 2007; Powell et al., 2009; Langley et al., 2011). The current trend can be traced to the fall of the 'human revolution' model, and in particular to the failure of the associated theory that the fluorescence of artistic and symbolic expression during the Upper Palaeolithic of Europe could be attributed to a sudden and dramatic increase in cognitive abilities (e.g. Klein, 2000). Given that *Homo sapiens* appears shortly after 200 ka, the sporadic appearance (and disappearance) of apparently 'modern' technologies prior to c.60 ka requires a set of candidate explanations that are extrinsic to the biology of our species; demographic variables are rapidly colonising this niche, to the extent that Palaeolithic archaeology appears to be approaching a new orthodoxy (see Collard et al., 2013; French, 2016).

Citations demonstrate that three papers have been instrumental in influencing archaeological thought on the relationship between cultural change and demography in recent years: those of Shennan (2001), Henrich (2004), and Powell et al. (2009). Shennan (2001) adapted a genetic model of the evolution of sex (Peck et al., 1997), allowing oblique transmission (i.e. transmission of cultural information from an elder who is not necessarily a genetic parent) to influence the 'fitness' of a series of cultural traits. Varying the effective population size – taken in this model to be the subset of the overall population that are likely to act as 'cultural parents' – and running the models until they reached stationary distributions, Shennan (2001) found that the geometric mean fitness taken across all traits was higher in larger populations. This relationship is approximately logarithmic, with the greatest increases in fitness occurring when very small populations increase in size. Despite the potential archaeological salience of Shennan's (2001) model,

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subsequent research has focused on overall skill levels rather than multiple cultural traits. Shennan's (2001) explicit assumption that cultural change is an evolutionary process, however, remains implicit in more recent work.

Henrich (2004) develops a model in which each individual attempts to copy the most skilful member of the population in each iteration. Although the model assumes that the most skilful individual is always accurately identified, copying is subject to error, and more complex skills are harder to copy. By analogy with the genetic process most copying errors are detrimental, but occasionally "through a combination of imperfect imitation, experiments, errors, bad memories and ill fortune" (Henrich, 2004:200) an individual will produce a copy that is better than the original. Given an original skill value z, the possible outcomes of copying are given by a Gumbel (extreme value) distribution with location parameter $z-\alpha$ and scale parameter β. The complexity of a skill – how hard it is to imitate – is thus measured by α, whilst the extent to which the skill is subject to copying error is governed by β. (For those unfamiliar with the Gumbel distribution, the most relevant description for the purposes of Henrich's (2004) model is that it is the distribution created by repeatedly choosing the highest value (the 'extreme value') from a series of normally distributed random numbers; if one were to generate 100 random numbers from a normal distribution, then discard all but the single highest number among them, and repeat this process multiple times, the numbers retained would follow a Gumbel distribution.) Using a simplified but accurate approximation of the Gumbel distribution, Henrich (2004:202) demonstrates that $\Delta\bar{z} = -\alpha + \beta(\varepsilon + \ln(N))$, where $\Delta\bar{z}$ is the average change in skill level per iteration, N is population size, and ε is the Euler-Mascheroni constant. Skill level thus increases logarithmically with increasing population size. This result is remarkably close to that of Shennan (2001) despite the considerable differences between the two models.

Powell et al. (2009) introduced a stochastic meta-population simulation analogous to Henrich's (2004) analytical model. This simulation employs a series of equally sized subpopulations and examines the effects of variation in the number and density of subpopulations and the extent of migratory activity between them. Three particularly important results arise from this simulation. Firstly, increasing the number of subpopulations only causes increases in skill level whilst the number of subpopulations is less than approximately 50, indicating that "the accumulation, or maintenance, of culturally inherited skill is not dependent on the absolute meta-population size" (Powell et al., 2009:1300). Whilst 'cultural fitness' increases approximately logarithmically with population size in Shennan's (2001) model, and skill level increases exactly logarithmically with population size in Henrich's (2004) model, Powell et al. (2009) demonstrate that in a structured meta-population skill level approaches an asymptote relatively quickly, and is unaffected by further increases in population size.

Secondly, Powell et al. (2009) demonstrate that sub-population density has a far more consistent effect on the accumulation of skill than does meta-population size; skill levels in high density areas were consistently higher in these simulations, regardless of the values of the parameters α and β. Thirdly, and perhaps most importantly for archaeological interpretation, these authors find that greater migratory activity also leads to higher skill levels, and that this effect is particularly pronounced when the skill being copied is of greater complexity (i.e. when α is higher). These simulations thus provide a series of insights that are of vital importance to archaeological interpretation, and they have, accordingly, been widely utilised.

A number of researchers have identified problems with the models of Shennan (2001), Henrich (2004), and Powell et al. (2009); broadly speaking, these problems can be divided into the theoretical and the empirical. From a theoretical perspective, Vaesen (2012) has noted a series of mathematical issues with the performance of the Henrich (2004) equation. Several authors have also noted that none of these models make reference to the underlying ecology (Vegvari and Foley, 2014; Collard et al., 2013). Empirically, Collard et al. (2013), and Vaesen et al. (2016) note that, of the studies examining both demographic variables and variables indexing material culture complexity in extant hunter-gatherer populations, few have found positive correlations between the two. Whilst these problems merit further attention, the purpose of the current paper is to draw attention to a further issue which stems from the interpretation and application of the models by archaeologists rather than from the models themselves. This issue arises from the neglect of migration (or, on a smaller scale, mobility) in the vast majority of archaeological analyses that have made use of the results of these models.

In the most comprehensive model published to date, Powell et al. (2009:1300) make it abundantly clear that "migratory activity among a set of subpopulations can have the same effect on skill accumulation as increasing the size of a single population". These authors are also explicit about the limited effect of overall population size. Yet archaeological analyses seeking explanations for cultural change focus primarily on population size, secondarily on population density, and rarely, if at all, discuss mobility (e.g. Zilhão 2007; Langley et al., 2011). While there are some more nuanced applications in the archaeological literature – Riede (2008), for example, stresses the sudden decrease in connectedness following the Lacher See eruption of 12,920 BP, and Hopkinson (2011; Hopkinson et al., 2013) focuses on the spatial interaction of locally and regionally separated populations – the majority of studies opt for population size *or* density (often inter-changeably) as the sole explanation. As the analyses reported below demonstrate, population *density* and mobility must be considered as joint, interacting factors in any valid explanation of cultural change.

2. Deriving predictions

The hypothesis that high population densities will increase rates of cultural transmission has a clear intuitive appeal: when population densities are high, individuals will encounter one another more often, with each encounter affording an opportunity to transmit cultural information. The same logic underlies the related hypothesis that high mobility rates will increase rates of cultural transmission. Both population density and mobility, therefore, are proxies for the individual encounter rate: it is this latter variable that actually controls the rate of cultural transmission. Following similar logic, although population size is not a direct proxy for an individual's encounter rate, it might affect the number of encounters that occur at the *population level* per unit time. Encounter rates can be modelled directly via the ideal gas model (IGM) developed originally by particle physicists but employed routinely by primatologists (e.g. Waser, 1976; Dunbar, 1995; Harcourt and Greenberg, 2001; Gursky, 2005) and increasingly by anthropologists (e.g. Grove, 2010; Grove et al., 2012; Pearce, 2014). The IGM is used here to derive predictions about the relationships between population density, mobility, and population size on the one hand, and encounter rates and rates of cultural transmission on the other.

The gas model states that an individual's encounter rate is $E_{ind} = \frac{8\rho D v}{\pi}$, where ρ is density, v velocity and D is the radius within which the individual can detect other individuals. For current purposes, the constants 8 and π are ignored, and we replace detection distance and velocity with a single mobility parameter $M = Dv$. In this simplified form, $E_{ind} \propto \rho M$, the IGM provides a very basic but useful prediction:

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