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Modelling human presence and environmental dynamics during the Mid-Pleistocene Revolution: New approaches and tools

J. Rodríguez [a, *], A. Mateos [a], C. Hertler [b], M.R. Palombo [c]

[a] National Research Center on Human Evolution (CENIEH), Paseo Sierra de Atapuerca, 3, 09002 Burgos, Spain
[b] The Role of Culture in Early Expansions of Humans (ROCEEH), Senckenberg Forschungsinstitut, Senckenberganlage 25, 60325 Frankfurt/M, Germany
[c] Dipartimento di Scienze della Terra, Sapienza Università di Roma, Piazzale A. Moro, 5, I-00185 Roma, Italy

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A B S T R A C T

Drastic changes, driven by variations in orbital forcing, occurred in the Earth's climate system around 1.0 Ma. As a consequence, a marked reorganization of the ecosystems took place in Europe between 1.2 and 0.6 Ma. Arrival of hominins to Western Eurasia occurred at this time or slightly earlier, and many questions related to their time and mode of arrival, their survival opportunities, their distribution across Europe and their cultural evolution, remain unsolved. We present here a research project supported by the INQUA Human and Biosphere Commission aimed to address the ecological and behavioural dynamics of hominin populations in Western Europe during the late Early and the early Middle Pleistocene. The project emphasises the use of formal modelling approaches to test specific hypotheses about the causal mechanisms promoting variation in the distribution and behaviour of those ancient human populations.

1. Introduction

Presence of human populations in Europe at the end of the Early Pleistocene is currently a widely documented fact (Moncel, 2010; Allué et al., 2013; Mosquera et al., 2013), although the exact time of the arrival of humans to Europe is still under debate. Although a body of evidence (absolute dating, magnetostratigraphical and biochronological correlations) confirms that between about 1.4 and 1.1 Ma archaic human groups were present in Southern Europe (see e.g. Arzarello et al., 2007; Bermúdez de Castro and Martinón-Torres, 2013; Parés et al., 2013; Toro-Moyano et al., 2013; Lozano-Fernández et al., 2014; López-García et al., 2015; Palmqvist et al., 2015), this fact was recently questioned by Muttoni et al. (2013, 2015), who stated that “evidence of hominin presence in Europe before the Jaramillo (>1 Ma), … is … very tenuous and frequently based on problematic ESR dating” (Muttoni et al., 2013, 748). However, Rodriguez et al. (2015) recently showed that human presence in Europe at the end of the Early Pleistocene cannot be considered scarce, in comparison with the abundance of other large mammals, particularly carnivores, during the same period. A diffusion into Central Europe at the time of the Jaramillo event (Untermassfeld, Germany; Landeck, 2010; Garcia et al., 2013) is also under debate (Baales, 2014), while strong evidence demonstrates that *Homo* was able to colonize northern Europe shortly after the Matuyama/Brunhes boundary as evidenced by the sites of Happisburgh (Parfitt et al., 2010; but see also; Westaway, 2011), and Pakefield (Parfitt et al., 2005). However, the number of sites with evidence of human presence in Europe during the subsequent period (0.7–0.5 Ma) is scarce, leading some authors to propose a depopulation of the continent during that time interval (Moncel et al., 2013; Mosquera et al., 2013).

The question arises whether a hominin presence was continuous during the Early Pleistocene (in the face of dramatic changes of climate, environment and mammalian palaeocommunities), or whether multiple dispersal events occurred, perhaps originating from a source population persistently inhabiting the West or South-West Asia (see e.g. Bermúdez de Castro and Martinón-Torres, 2013; Bermúdez de Castro et al., 2013 for a discussion).

Moreover, although the artefacts recovered from most archaeological sites younger than 0.6 Ma have generally been attributed to Oldowan technological complexes or Mode 1, the discovery of Large Cutting Tools (LCTs) at the late Early Pleistocene site of Barranc de la Boella (Vallverdú et al., 2014), and La Noira, dated to the beginning of the Middle Pleistocene (Moncel et al., 2013), suggest that Mode 2 was already present in Europe at the transition from Early to Middle

* Corresponding author.
E-mail addresses: jesus.rodriguez@cenieh.es (J. Rodríguez), ana.mateos@cenieh.es (A. Mateos), christine.hertler@senckenberg.de (C. Hertler), mariarita.palombo@uniroma1.it (M.R. Palombo).

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Pleistocene. An Early Pleistocene age has also been claimed for the Mode 2 artefacts from Solana del Zamborino (Scott et al., 2007), but this site is actually Middle Pleistocene (Jiménez-Arenas et al., 2011). The presence of Acheulean tool types in Early Pleistocene deposits of southern Europe challenges the long lasting concept that in the European Early Palaeolithic, Mode 1 technology (seen as a prerogative of *Homo* sp. and *H. antecessor* humans) predates the appearance of Mode 2 technology of *H. heidelbergensis* (Jiménez-Arenas et al., 2011). The latter was widespread over Western Europe from 0.5 to 0.3 Ma although, surprisingly, Mode 2 complexes were absent from Eastern Europe (Doronichev, 2010). Accordingly, a second question arises whether a discontinuity existed in Europe between Mode 1 and Mode 2 technologies and these cultural changes were paralleled by a replacement of the hominin species inhabiting Europe, i.e. the disappearance of *Homo antecessor* and the eventual appearance of *Homo heidelbergensis* at 0.5 Ma (Hublin, 2009; Condemi and Weniger, 2011; Manzi, 2011; Stringer, 2012). With these data in mind, a complex scenario arises for the early colonization of the continent, with phenomena such as dispersal events, replacements of species and abandonment of territories with unfavourable conditions for human colonization playing a significant role.

2. A strategic guide to examine the interactions between humans and shifting environments

Interestingly, the complex history of human colonization in Europe was marked by a period of drastic climatic changes, driven by variations in orbital forcing, known as the Mid-Pleistocene Revolution (MPR), promoting a marked environmental instability from about 1.2 to 0.6 Ma, particularly evident from the time of the Jaramillo submagnetochron to the end of the Early Pleistocene, when the frequency of Glacial–Interglacial oscillations became less stable, amplitudes increased, with melting periods lasting significantly less than anaglacial phases (Head and Gibbard, 2005; Maslin and Ridgwell, 2005). This transition in the climate system promoted the expansion of more open environments and trigged a reorganization of the European ecosystems (Palombo et al., 2005; Suc and Popescu, 2005; Bertini et al., 2010; Croitor and Brugal, 2010; Kahlke et al., 2011; Leroy et al., 2011; Palombo, 2014a). A comparison of the vegetation and faunal records in SW Europe indicates that both vegetation and animal communities significantly varied during the MPR, though the timing and extent of the changes were different and varied across the studied region (Magri and Palombo, 2013). Those environmental changes likely affected the survival opportunities of the European humans, not only because the rather unpredictable climatic changes they had to cope with, but also because the new environments provided different qualities and quantities of trophic resources. The profoundly rearranged large mammal communities offered to hominins a renewed spectrum of potential prey and competitors (Kahlke et al., 2011; Palombo, 2014a). Moreover, the new ecosystems, dominated by more open environments, also altered the amount and quality of vegetable resources available to those early hunter–gatherer populations. All these changes could have affected human populations in different ways. Climate factors, temperature in particular, are major constraints for the distribution of any organism, and hominins are not an exception, especially because there is no evidence for the use of fire in Europe older than 500 ka, and its use is not generalized until about 250 ka (deLumley, 2006; Roebrooks and Villa, 2011; Mosquera et al., 2013). The faunal reconfiguration during the MPR involved a significant increase in the body size of potential prey, the extinction of several species that were presumably competitors for hominins and the arrival of other ones (Croitor and Brugal, 2010; Rodríguez et al., 2012; Palombo, 2014a). The body size rearrangement in the guild of primary consumers was not trivial for hominins because, generally speaking, it is not a simple task for predators to subdue and kill large herbivores. However, given its highly adaptive behavior, hominins may have developed new strategies to take advantage of these new trophic resources. Alternatively, reorganization of the carnivore guild may have trigged corresponding shifts in hominin behavior. In order to test the consequences of both of the alternative hypotheses in the archaeological record, it is required to develop formalized models for the respective behavioral responses. However, as we will see below, quantitative descriptive models allow us to evaluate the feasibility of several competing hypotheses. Validating alternative models include test whether the archaeological record is compatible with the parameters specified and predicted by the models themselves.

Although most scholars will agree that environmental changes affected human survival and distribution in Europe, it is not well established how, where, when and to what extent the environment affected human population dynamics. The study of such complex phenomena requires the contribution and cooperation of researchers from several fields. During the last decades, palaeontologists, palaeoanthropologists and archaeologists have produced spatio-temporal and taxonomically organized datasets describing hominin distribution. In parallel, several conceptual models have been proposed to explain the dynamics of the human colonization of Europe in this period (Palombo, 2010; Bermúdez de Castro and Martinón-Torres, 2013; Dennell et al., 2011; Mosquera et al., 2013; O'Regan et al., 2014), but often they reflect the actual data only loosely or are only based on data provided from a specific research field. It becomes increasingly clear that complex questions, like understanding the dynamics of the early colonization of the continent, requires multidisciplinary synergic approaches.

During the last five-year period, the amount and quality of data available for this period has been continuously increasing (Fig. 2). This evidence opens a new window to the use of quantitative methodologies, beyond the traditions of Palaeolithic archaeology or Pleistocene palaeontology. Furthermore, mathematical modelling has revealed itself as an extremely helpful tool to describe complex systems dynamics in other disciplines, but it has been rarely used in terrestrial Quaternary palaeoecology or Palaeolithic archaeology. However, in the relatively few occasions in which the dynamics or eco-dynamics of Palaeolithic humans has been modelled in a formal and/or quantitative way this approach has shown its great potential (Banks et al., 2006, 2008a, 2008b, 2008c; Fernandez et al., 2006; Fernandez and Legendre, 2003; Holmes, 2007; Palombo, 2014b; Rodríguez-Gómez et al., 2014; Rodríguez-Gómez et al., 2013; Romanowska, 2014). The project on "Modelling human settlement, fauna and flora dynamics in Europe during the Mid-Pleistocene Revolution (1.2–0.4 Ma)" funded by the INQUA Human and the Biosphere Commission (HabCom) is a pilot initiative which will be developed into an International Focus Group (IFG) that will be active during the period 2016–2020. This IFG intends to bridge the gap between the researchers interested in understanding the behavioural and ecological dynamics of the first European humans, the specialists on dynamic shifts in ecology and environments, and the people with the skill to build mathematical models developed in order to test hypotheses about the interactions among the different factors (Fig. 1). The key feature of this project is to incorporate researchers from disciplines not directly linked to the study of the Quaternary, like mathematicians, physicists or engineers with experience in the study of complex systems through mathematical modelling. Considering the type of questions the MPR project intends to address, the models to be developed will be descriptive models. Descriptive models are representations of a phenomenon or a complex system that allow the researcher to

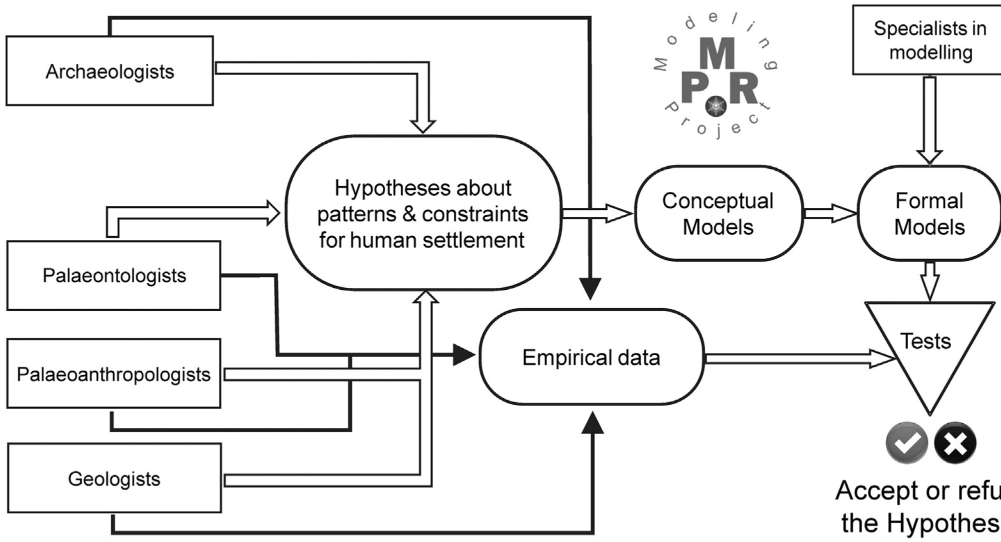

Fig. 1. Structural model for the project (see text).

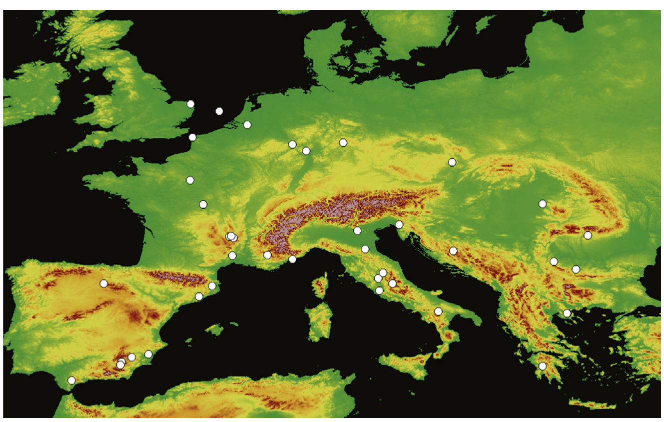

Fig. 2. Palaeontological sites dated to the 1.2–0.6 Ma interval with faunal data included in the NQMDB database. The NQMDB is one of the Databases included in the project, it focuses on mammals and it is located and managed at the National Center for the study of Human Evolution (Burgos, Spain).

analyse the essential features of the phenomenon or system in a feasible way. A simple case would be the production of biome distribution maps for different periods of the 1.2–0.4 Ma time interval, based on palynological and palaeontological data. This map will be a model against which to compare the distribution of archaeological sites in the Early and Middle Pleistocene. A step towards potential explanations consists in using a descriptive model to simulate the dynamics of a complex system. Rodríguez-Gómez et al. (2013) developed a model to describe the trophic dynamics of a palaeocommunity of large mammals and to obtain estimations of the availability of trophic resources and the intensity of competition between secondary consumers. This model allows comparing the availability of resources for a hunter gatherer population between either different regions and/or time periods (Rodríguez-Gómez et al., 2014). The model of Rodríguez-Gomez et al. (2013) is not a representation of the trophic dynamics of the community, since it only intends to approach the average conditions on the long term, under the assumption of equilibrium. However, simulation of the dynamics of a complex system, like a palaeocommunity, is straightforward using other modelling approaches like Agent-Based Modelling (Bonabeau, 2002; Hölzchen et al., 2014; Romanowska, 2014). One of the most exciting possibilities of the use of functional models in archaeology is the comparison of different scenarios in a “what if” approach. The parameters of the model may be changed and the effect of these changes on the behaviour of the system can be examined. As an example, Rodriguez-Gomez et al. (2013) applied this approach to evaluate the effects that the presence of various large carnivores would have on the availability of resources for a *Homo antecessor* population at Sierra de Atapuerca.

Models should be fed with data and databases are fundamental to store, manage and share information composed of interrelated data. Several databases, containing quantitative palaeoenvironmental and palaeoecological data derived from diverse proxies, have been produced by the research community, although in most cases each of these databases is available only to a limited number of researchers. The MPR project implies the collection and management of large amounts of data, including hominins, cultural complexes, palaeovegetation, and faunal distributions on a site by site basis. The Out of Africa Database (ROAD) (www.roceeh.net/road/roceeh-out-of-africa-database/) developed and maintained by the ROCEEH (“The Role of Culture in Early Expansions of Humans”) Research Center (Haidle et al., 2010) constitutes a major effort to build a geo-relational spatial information system where geological, geomorphological, palaeontological, palaeobotanical, palaeoanthropological and archaeological data may be incorporated. The MPR project intends to use ROAD as a meta-tool for access to several databases administered by their members. In this way each database will be maintained locally by its local host, who keeps control on the distribution of his data yet providing a shared basis ready for evaluation.

The main objective of the project is to investigate the continuity and/or discontinuity in human populations of Europe in relation to the Mid-Pleistocene Revolution, its timing and mode, and the coupled effects of climate change and ecosystems on the evolution and distribution of humans and their culture in Europe. This goal requires a preliminary phase of data analyses aimed at describing the distribution of *Homo* populations before, during, and after the Mid-Pleistocene Revolution (MPR). This will help to determine whether a collapse of human populations occurred in the 0.5–0.7 Ma interval and to establish the existence of continuity or discontinuity between the late Early and early Middle Pleistocene European human populations. During this preliminary phase the distribution of fauna and vegetation before, during, and after the MPR will be also mapped and shifts in ecological structure and functional diversity of the mammalian palaeocommunities will be identified. This will be the basis for mapping the biomes present in Europe before and after the MPR. Eventually, the hypotheses proposed to explain the variation in the distribution of *Homo*, and the associated cultural changes, during the 1.2 to 0.4 Ma in Europe should be tested by aid of a limited number of conceptual models. At this stage, the feasibility of different mathematical modelling approaches to translate each conceptual model into a formal model is evaluated. Finally, each hypothesis is tested using the appropriate approach, or approaches. For example, the hypothesis that human populations collapsed as a direct consequence of climate changes may be tested by mapping the distribution of biomes before and after the MPR and comparing it with the distribution of *Homo* in the different periods. Palaeoclimate maps may also be produced by applying transfer functions to the palynological and palaeontological record (Peyron et al., 1998; Blain et al., 2009). The influence of changes in the composition of the mammalian communities on human survival opportunities may be evaluated comparing the distribution of *Homo* with the distribution of communities. Alternatively, or complementarily, it may be also evaluated by developing a model to simulate the competition and trophic relationships inside any given community, and by comparing the behaviour of several communities differing in species composition. Hypotheses involving alternative dispersal routes may be tested by creating dispersal models in a GIS environment (Holmes, 2007; Romanowska, 2014). This last example also illustrates one of the most appealing features of the modelling approach, the dispersion routes may be simulated on the basis of palaeogeographic and palaeoclimatic maps and on the distribution of fauna and/or vegetation. Thus, the feasibility of a route may be evaluated even for areas or periods without archaeological record. Predictive maps result from such an approach which can subsequently be used for site exploration.

The project focuses on Europe because the quality and quantity of available data are significantly higher for the Western Palaearctic than for other regions. Thus, Europe constitutes the most appropriate empirical background to explore the application of quantitative approaches and the specific contributions of mathematical models to the study of the oldest human dispersals. However, the approaches and methodologies developed in this project will be equally profitable for researchers addressing similar questions in other time periods or different geographical regions.

3. Conclusion

Despite the growing amount of data and an increasing interest in establishing the baseline factors that may have promoted the dynamics of hominin populations in Western Europe during the late Early and the early Middle Pleistocene, a number of questions as to the causal mechanisms promoting human dispersal and permanent settlement in focal areas still remain open to discussion. Nonetheless, the amount and quality of data currently available for this period unlocks new perspectives for the use of quantitative methodologies and formal modelling that is an extremely helpful tool to describe complex systems dynamics and integrate results contributed by a multitude of disciplines.

The project on “Modelling human settlement, fauna and flora dynamics in Europe during the Mid-Pleistocene Revolution (1.2–0.4 Ma)” involves the contribution and cooperation of researchers from several fields. It models and examines the coupling of at least five different components, i.e. 1) climate shifts, and 2) corresponding changes in vegetation and the development of landscapes, 3) faunal shifts as a primary response to changes in the environment and respective ecological reorganisations in the communities, 4) hominins as part of the faunas constituting a specific element with its own population dynamics and 5) adaptations in the behaviour of hominin groups as a response to such shifts.

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