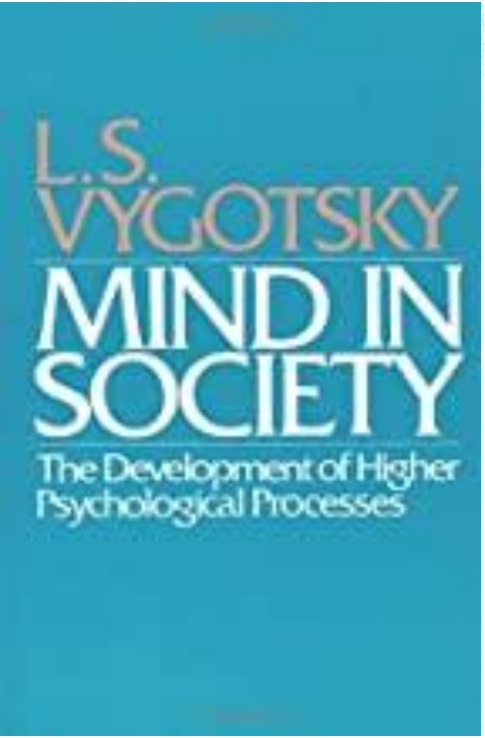
The epidemiology of rock art

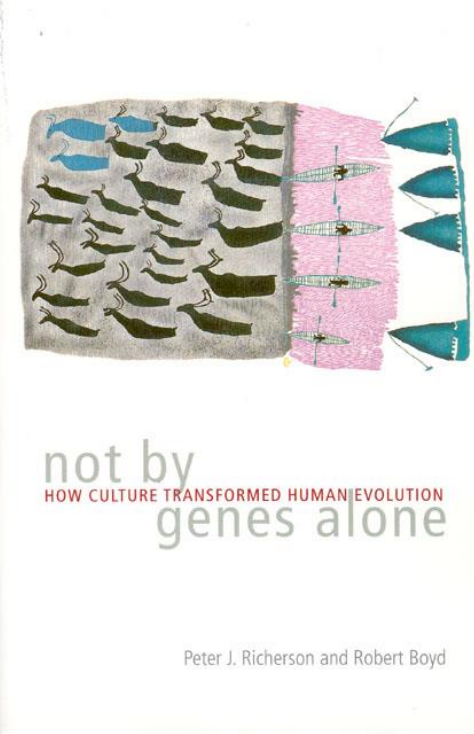
Richard Walker
July 31, 2020



L.S. VYGOTSKY

MIND IN SOCIETY

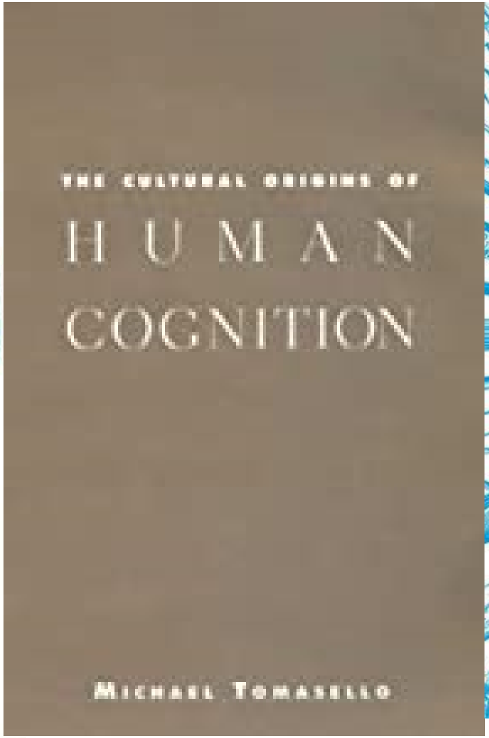
The Development of Higher Psychological Processes



not by genes alone

HOW CULTURE TRANSFORMED HUMAN EVOLUTION

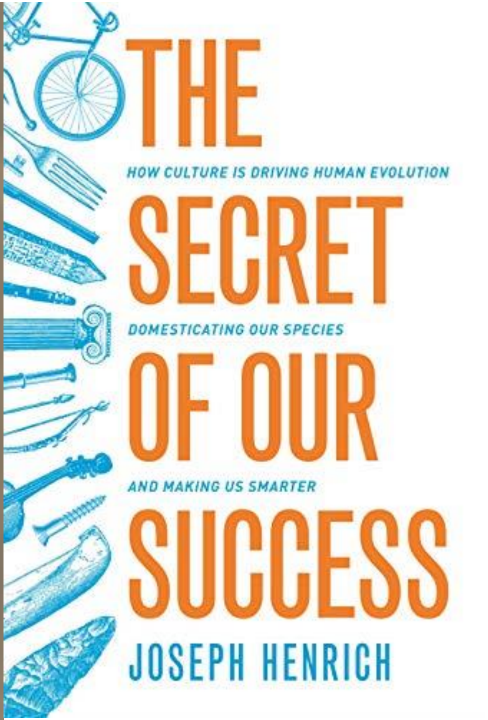
Peter J. Richerson and Robert Boyd



THE CULTURAL ORIGINS OF

HUMAN COGNITION

MICHAEL TOMASELLO



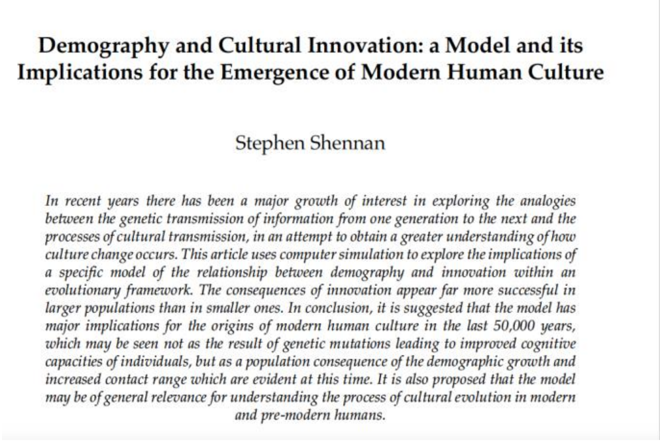
THE SECRET OF OUR SUCCESS

HOW CULTURE IS DRIVING HUMAN EVOLUTION

DOMESTICATING OUR SPECIES

AND MAKING US SMARTER

JOSEPH HENRICH

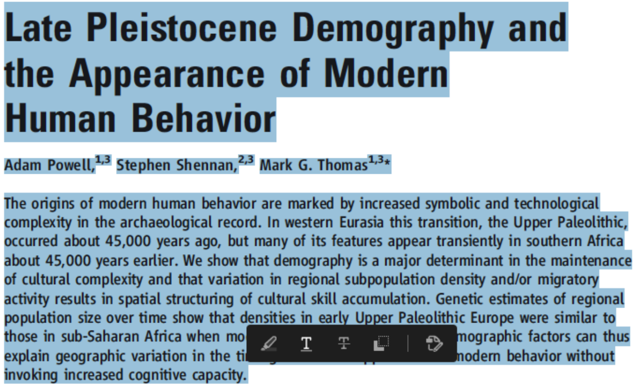


Demography and Cultural Innovation: a Model and its Implications for the Emergence of Modern Human Culture

Stephen Shennan

In recent years there has been a major growth of interest in exploring the analogies between the genetic transmission of information from one generation to the next and the processes of cultural transmission, in an attempt to obtain a greater understanding of how culture change occurs. This article uses computer simulation to explore the implications of a specific model of the relationship between demography and innovation within an evolutionary framework. The consequences of innovation appear far more successful in larger populations than in smaller ones. In conclusion, it is suggested that the model has major implications for the origins of modern human culture in the last 50,000 years, which may be seen not as the result of genetic mutations leading to improved cognitive capacities of individuals, but as a population consequence of the demographic growth and increased contact range which are evident at this time. It is also proposed that the model may be of general relevance for understanding the process of cultural evolution in modern and pre-modern humans.

Shennan, Stephen. “Demography and Cultural Innovation: A Model and Its Implications for the Emergence of Modern Human Culture.” Cambridge Archaeological Journal 11, no. 01 (2001): 5–16.

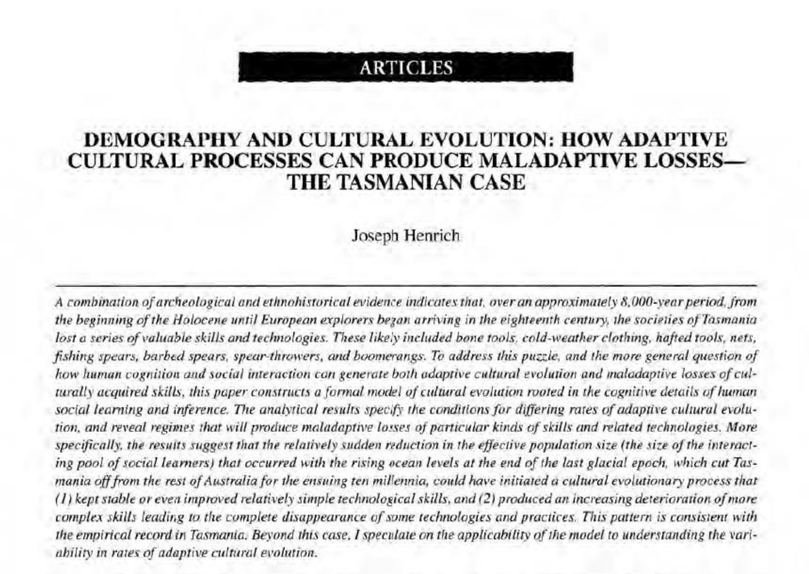


Late Pleistocene Demography and the Appearance of Modern Human Behavior

Adam Powell,[1,3] Stephen Shennan,[2,3] Mark G. Thomas[1,3]*

The origins of modern human behavior are marked by increased symbolic and technological complexity in the archaeological record. In western Eurasia this transition, the Upper Paleolithic, occurred about 45,000 years ago, but many of its features appear transiently in southern Africa about 45,000 years earlier. We show that demography is a major determinant in the maintenance of cultural complexity and that variation in regional subpopulation density and/or migratory activity results in spatial structuring of cultural skill accumulation. Genetic estimates of regional population size over time show that densities in early Upper Paleolithic Europe were similar to those in sub-Saharan Africa when mo[illegible]mographic factors can thus explain geographic variation in the ti[illegible] modern behavior without invoking increased cognitive capacity.

Powell, Adam, Stephen Shennan, and Mark G Thomas. “Late Pleistocene Demography and the Appearance of Modern Human Behavior.” Science 324, no. 5932 (2009): 1298–1301.



ARTICLES

DEMOGRAPHY AND CULTURAL EVOLUTION: HOW ADAPTIVE CULTURAL PROCESSES CAN PRODUCE MALADAPTIVE LOSSES— THE TASMANIAN CASE

Joseph Henrich

A combination of archeological and ethnohistorical evidence indicates that, over an approximately 8,000-year period, from the beginning of the Holocene until European explorers began arriving in the eighteenth century, the societies of Tasmania lost a series of valuable skills and technologies. These likely included bone tools, cold-weather clothing, hafted tools, nets, fishing spears, barbed spears, spear-throwers, and boomerangs. To address this puzzle, and the more general question of how human cognition and social interaction can generate both adaptive cultural evolution and maladaptive losses of culturally acquired skills, this paper constructs a formal model of cultural evolution rooted in the cognitive details of human social learning and inference. The analytical results specify the conditions for differing rates of adaptive cultural evolution, and reveal regimes that will produce maladaptive losses of particular kinds of skills and related technologies. More specifically, the results suggest that the relatively sudden reduction in the effective population size (the size of the interacting pool of social learners) that occurred with the rising ocean levels at the end of the last glacial epoch, which cut Tasmania off from the rest of Australia for the ensuing ten millennia, could have initiated a cultural evolutionary process that (1) kept stable or even improved relatively simple technological skills, and (2) produced an increasing deterioration of more complex skills leading to the complete disappearance of some technologies and practices. This pattern is consistent with the empirical record in Tasmania. Beyond this case, I speculate on the applicability of the model to understanding the variability in rates of adaptive cultural evolution.

Henrich, Joseph. “Demography and Cultural Evolution: How Adaptive Cultural Processes Can Produce Maladaptive Losses: The Tasmanian Case.” American Antiquity, 2004, 197–214.

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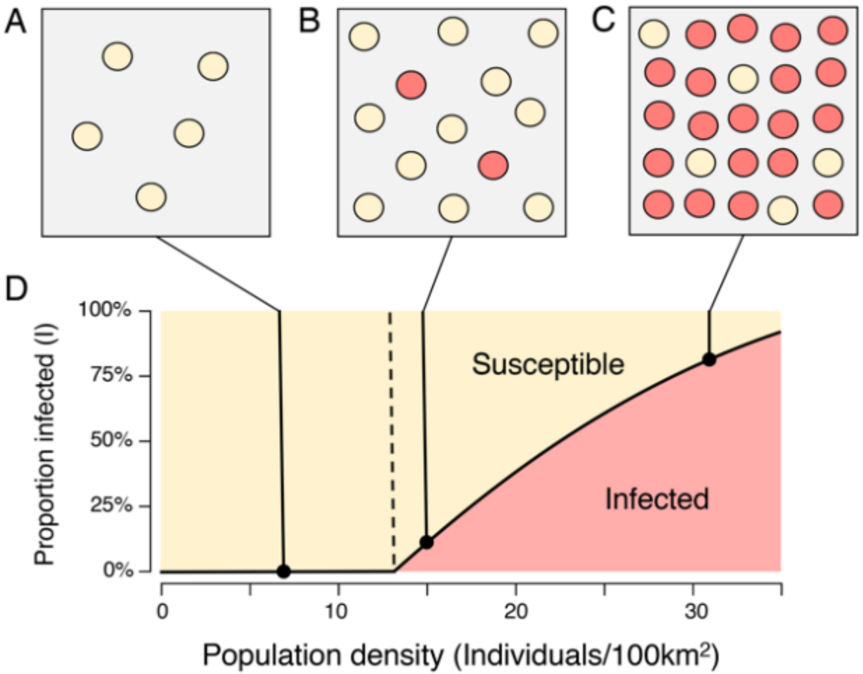
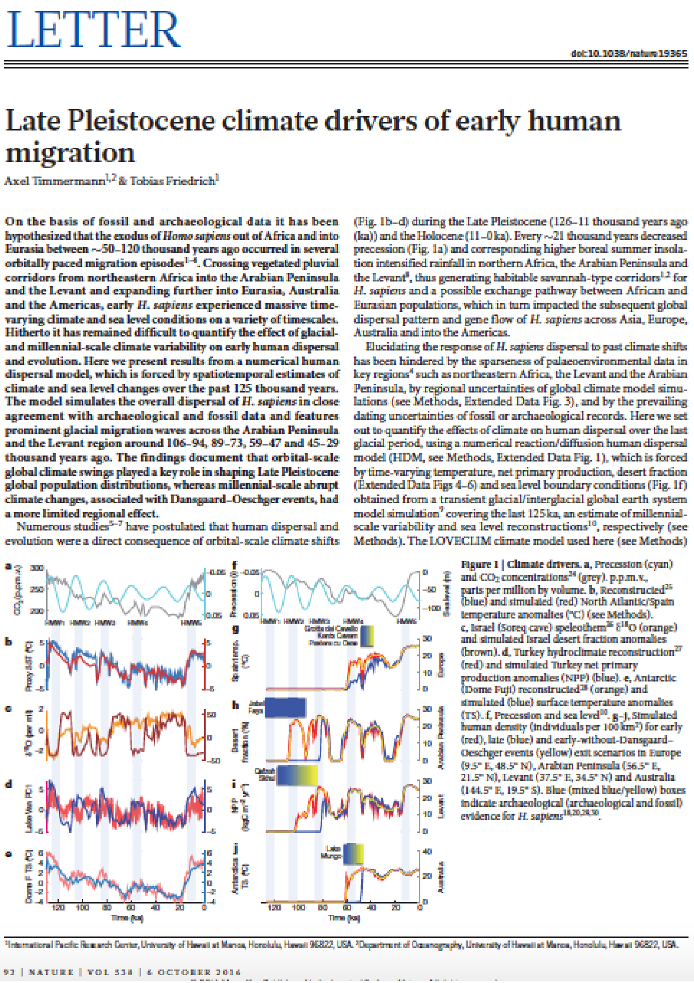


Fig 1. The epidemiological model. As population density increases, opportunities for transmission between subpopulations also increase. A: Below the critical threshold ρ^*, the innovation is rapidly extinguished. B-C: Above the critical threshold, the proportion of infected subpopulations is an increasing function of population density.



LETTER

doi:10.1038/nature19365

Late Pleistocene climate drivers of early human migration

Axel Timmermann[1,2] & Tobias Friedrich[1]

On the basis of fossil and archaeological data it has been hypothesized that the exodus of *Homo sapiens* out of Africa and into Eurasia between ~50–120 thousand years ago occurred in several orbitally paced migration episodes[1–4]. Crossing vegetated pluvial corridors from northeastern Africa into the Arabian Peninsula and the Levant and expanding further into Eurasia, Australia and the Americas, early *H. sapiens* experienced massive time-varying climate and sea level conditions on a variety of timescales. Hitherto it has remained difficult to quantify the effect of glacial- and millennial-scale climate variability on early human dispersal and evolution. Here we present results from a numerical human dispersal model, which is forced by spatiotemporal estimates of climate and sea level changes over the past 125 thousand years. The model simulates the overall dispersal of *H. sapiens* in close agreement with archaeological and fossil data and features prominent glacial migration waves across the Arabian Peninsula and the Levant region around 106–94, 89–73, 59–47 and 45–29 thousand years ago. The findings document that orbital-scale global climate swings played a key role in shaping Late Pleistocene global population distributions, whereas millennial-scale abrupt climate changes, associated with Dansgaard–Oeschger events, had a more limited regional effect.

Numerous studies[5–7] have postulated that human dispersal and evolution were a direct consequence of orbital-scale climate shifts (Fig. 1b–d) during the Late Pleistocene (126–11 thousand years ago (ka)) and the Holocene (11–0 ka). Every ~21 thousand years decreased precession (Fig. 1a) and corresponding higher boreal summer insolation intensified rainfall in northern Africa, the Arabian Peninsula and the Levant[8], thus generating habitable savannah-type corridors[1,2] for *H. sapiens* and a possible exchange pathway between African and Eurasian populations, which in turn impacted the subsequent global dispersal pattern and gene flow of *H. sapiens* across Asia, Europe, Australia and into the Americas.

Elucidating the response of *H. sapiens* dispersal to past climate shifts has been hindered by the sparseness of palaeoenvironmental data in key regions[4] such as northeastern Africa, the Levant and the Arabian Peninsula, by regional uncertainties of global climate model simulations (see Methods, Extended Data Fig. 3), and by the prevailing dating uncertainties of fossil or archaeological records. Here we set out to quantify the effects of climate on human dispersal over the last glacial period, using a numerical reaction/diffusion human dispersal model (HDM, see Methods, Extended Data Fig. 1), which is forced by time-varying temperature, net primary production, desert fraction (Extended Data Figs 4–6) and sea level boundary conditions (Fig. 1f) obtained from a transient glacial/interglacial global earth system model simulation[9] covering the last 125 ka, an estimate of millennial-scale variability and sea level reconstructions[10], respectively (see Methods). The LOVECLIM climate model used here (see Methods)

Figure 1 | Climate drivers. a, Precession (cyan) and CO_2 concentrations[24] (grey). p.p.m.v., parts per million by volume. **b**, Reconstructed[25] (blue) and simulated (red) North Atlantic/Spain temperature anomalies (°C) (see Methods). **c**, Israel (Soreq cave) speleothem[26] $\delta^{18}O$ (orange) and simulated Israel desert fraction anomalies (brown). **d**, Turkey hydroclimate reconstruction[27] (red) and simulated Turkey net primary production anomalies (NPP) (blue). **e**, Antarctic (Dome Fuji) reconstructed[28] (orange) and simulated (blue) surface temperature anomalies (TS). **f**, Precession and sea level[10]. **g–j**, Simulated human density (individuals per 100 km^2) for early (red), late (blue) and early-without-Dansgaard–Oeschger events (yellow) exit scenarios in Europe (9.5° E, 48.5° N), Arabian Peninsula (56.5° E, 21.5° N), Levant (37.5° E, 34.5° N) and Australia (144.5° E, 19.5° S). Blue (mixed blue/yellow) boxes indicate archaeological (archaeological and fossil) evidence for *H. sapiens*[18,20,28,30].

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[1]International Pacific Research Center, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA. [2]Department of Oceanography, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA.

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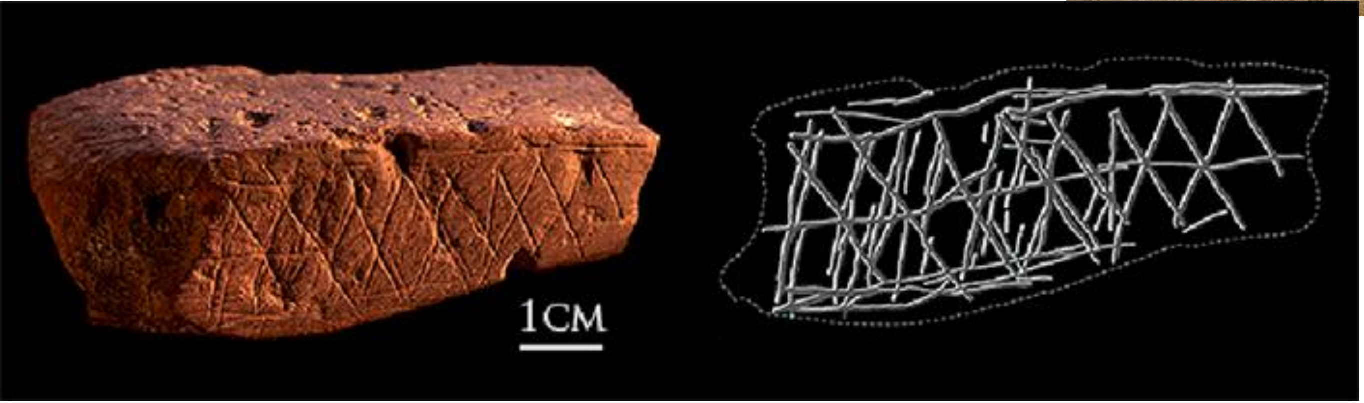
- Climate-based estimates of Net Primary Productivity for the whole globe for last 120,000 years (100km hectagons, 1000 year intervals)
  - Constraint on max possible population per hectagon
- Model of human dispersion
  - Growth up to carrying capacity
  - Dispersal to neighboring hexagon
- Estimates of population density for each hectagon



1CM

The epidemiological model

$$I + S = 1$$

$$\frac{dI}{dt} = \beta I S - \gamma I$$

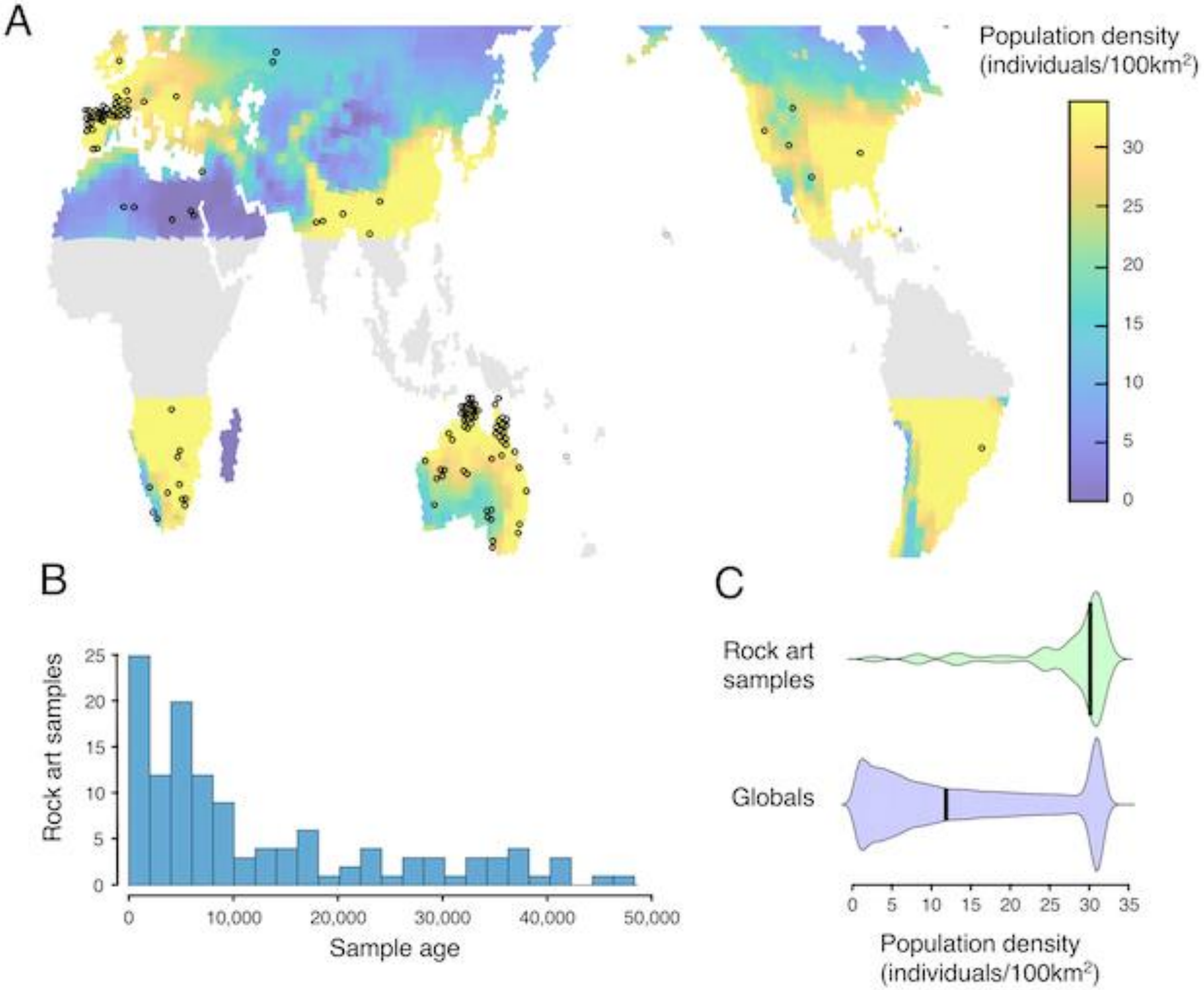
$$\rho^* = \left(\frac{\gamma}{\beta}\right)^2$$

$$I^* = \begin{cases} 0, \rho \leq \rho^* \\ 1 - \sqrt{\frac{\rho^*}{\rho}}, \rho > \rho^* \end{cases}$$

$$P \cong \zeta I^* \rho$$

Supplementary Information Table 1: Rock art dataset (133 sites)

Name	Latitude	Longitude	Earliest age in sample	Latest age in sample	Modern Country	Date of reference	Dating method/comments	Calibrated	Kind	Figurative	Reference
Abri Castanet, Dordogne, France	44.999272	1.101261	37"205	36'385	France	2012	accelerator mass spectrometry (AMS), indirect (bone samples)	Yes	Petroglyphs	Yes	(1)
Altamira, Spain	43.377452	-4.122347	36"160	2'850	Spain	2013	Uranium-series dating	N/A	Petroglyphs Decorated ceiling in cave	Yes, not all. One is linear red line.	(2)
Altxerri B, Spain	43.2369	-2.148555	39'479	34'689	Spain	2013	Indirect radiocarbon dating	Yes	Painting	Yes	(3)
Anbarndarr I. Australia/Anbarndarr II, Australia/Gunbirdi I, Gunbirdi II, Gunbirdi III, Northern Territory Australia	-12.255207	133.645845	1'704	111	Australia	2010	Direct radiocarbon dating of beeswax sample	Yes	Beeswax	No	(4)


A
Population density
(individuals/100km²)
0
5
10
15
20
25
30
B
Rock art samples
0
5
10
15
20
25
0
10,000
20,000
30,000
40,000
50,000
Sample age
C
Rock art samples
Globals
0
5
10
15
20
25
30
35
Population density
(individuals/100km²)

Verification methodology

- Use Eriksson population data
- Bayesian likelihood estimation
    - Calculate probability a cell with a given pop. density contains a rock art cell
    - Estimate likelihood of model with different parameter values
    - Estimate posterior distributions for parameters
    - Compare to alternative models (null model, proportional model)

Late Pleistocene climate change and the global expansion of anatomically modern humans

Anders Eriksson[a,1], Lia Betti[b], Andrew D. Friend[c], Stephen J. Lycett[b], Joy S. Singarayer[d], Noreen von Cramon-Taubadel[b], Paul J. Valdes[d], Francois Balloux[e], and Andrea Manica[a,1]

[a]Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, England; [b]Department of Anthropology, University of Kent, Kent CT2 7NR, England; [c]Department of Geography, University of Cambridge, Cambridge CB2 3EN, England; [d]School of Geographical Sciences, University of Bristol, Bristol BS8 1SS, England; and [e]Department of Genetics, Environment and Evolution, University College London, London WC1E 6BT, England

Edited by James O'Connell, University of Utah, Salt Lake City, UT, and approved August 17, 2012 (received for review June 6, 2012)

The extent to which past climate change has dictated the pattern and timing of the out-of-Africa expansion by anatomically modern humans is currently unclear [Stewart JR, Stringer CB (2012) *Science* 335:1317–1321]. In particular, the incompleteness of the fossil record makes it difficult to quantify the effect of climate. Here, we take a different approach to this problem; rather than relying on the appearance of fossils or archaeological evidence to determine arrival times in different parts of the world, we use patterns of genetic variation in modern human populations to determine the plausibility of past demographic parameters. We develop a spatially explicit model of the expansion of anatomically modern humans and use climate reconstructions over the past 120 ky based on the Hadley Centre global climate model HadCM3 to quantify the possible effects of climate on human demography. The combinations of demographic parameters compatible with the current genetic makeup of worldwide populations indicate a clear effect of climate on past population densities. Our estimates of this effect, based on population genetics, capture the observed relationship between current climate and population density in modern hunter–gatherers worldwide, providing supporting evidence for the realism of our approach. Furthermore, although we did not use any archaeological and anthropological data to inform the model, the arrival times in different continents predicted by our model are also broadly consistent with the fossil and archaeological records. Our framework provides the most accurate spatiotemporal reconstruction of human demographic history available at present and will allow for a greater integration of genetic and archaeological evidence.

human dispersals | colonization | population bottlenecks |
net primary productivity | most recent common ancestor

Anatomically modern humans (AMHs) first appear in the fossil record almost 200 kya in Africa (1), but all remains found in other continents are considerably more recent (2, 3). Based on existing fossil and archaeological records, it has been proposed that AMHs left Africa 60–70 kya and spread across Asia relatively quickly (2, 3), reaching Southeast Asia at least 45 kya (4) and crossing into Sahul (Australia, New Guinea, and Tasmania) at some point between 60 and 40 kya (3). The similarity of the tropical climate in the southern part of Asia to the ancestral home in sub-Saharan Africa has been suggested as an important factor aiding the fast rate of spread (5). Movement into Southern Europe was also relatively fast, with AMHs reaching Italy 45 kya (6), and Northern Europe was reached as early as 42–43 kya (7). Conversely, the spread into North Asia and eventually, the Americas was considerably slower, possibly because of the large ice sheets that covered North America (8). However, after AHMs reached the plains of North America, their spread accelerated again, and they expanded rapidly into South America (9). Although many key events during the spread of AMHs seem to coincide with favorable climatic conditions and the occurrence of land bridges because of low sea levels, the incompleteness of the fossil record during the initial stages of human arrival into different areas makes it difficult to formally quantify the effect of climate on past human demography. Moreover, archaeological assemblages do not always provide unequivocal evidence in terms of the taxonomic status of their makers, further exacerbating the task of understanding the role of climate change in the demographic expansion of AMHs.

In this paper, we take a unique approach to this problem (a schematic representation is shown in Fig. S1). We quantify the effects of past climate change on the demography of AMHs by exploiting the signals left in the worldwide distribution of genetic variation in modern human populations. Past demographic events, such as colonization events, migrations, population bottlenecks, and expansions, have affected genetic variation within populations as well as genetic differences between populations. Thus, any estimated effect of climate on such events need to be compatible with the distribution of these genetic metrics in modern populations. To describe the global patterns of neutral genetic variation, we used the human genome diversity panel-Centre d'Etude du Polymorphisme Humain (HGDP-CEPH) panel of 51 populations distributed around the world (10) (Fig. S2), a dataset that has been used several times in the past to investigate past human demography (11, 12). We built a detailed reconstruction of worldwide climate for the last 120 ky based on the Hadley Centre model HadCM3 (based on ref. 13; details in *Materials and Methods*). To link climate to human demography, we used annual net primary productivity (NPP), which provides a general proxy for food availability, and it has been shown to be a powerful predictor of demographic patterns in many ecological studies (14). Estimates of temperature and precipitation from our climate reconstructions were used to predict annual NPP based on the Miami vegetation model (15). The world was represented by a hexagonal lattice with cells of equal area (~100 km wide). The human expansion out of sub-Saharan Africa was computed over the lattice using a model of local population growth and dispersal (a schematic representation is shown in Fig. S3). This approach is analogous to the approach adopted by ref. 16, but in our model, demographic parameters were linked to primary productivity. We explored a wide range of parameter values, representing scenarios that spanned from climate having no effect on demography (the standard approach used by most population genetics models) to primary productivity having a strong positive effect on population density. Model fit was assessed using approximate Bayesian computation (ABC) (17) based on

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Author contributions: A.E., F.B., and A.M. designed research; A.E., L.B., A.D.F., S.J.L., J.S.S., N.v.C.-T., P.J.V., F.B., and A.M. performed research; A.E. and A.M. contributed new reagents/analytic tools; A.E. and A.M. analyzed data; and A.E. and A.M. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

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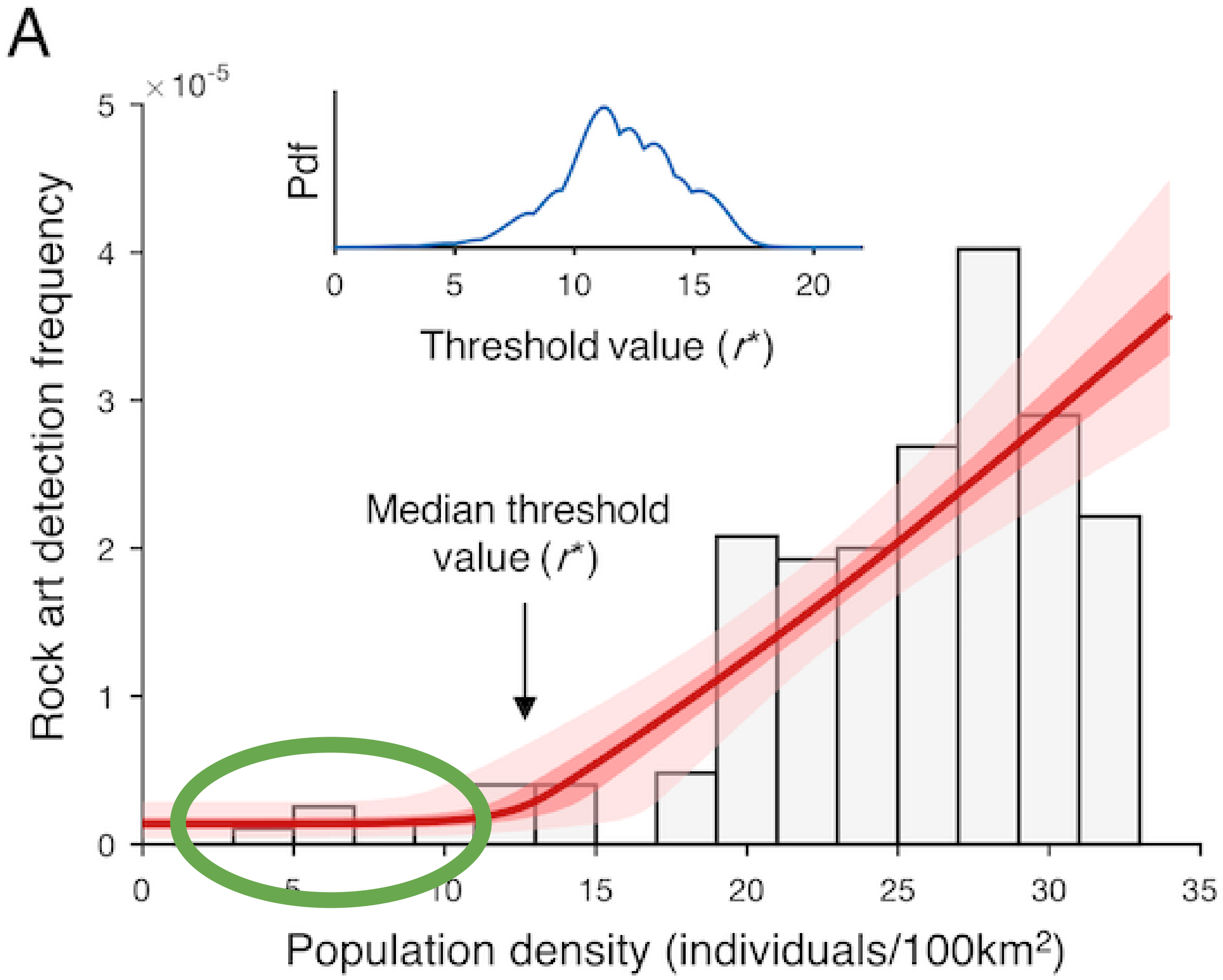
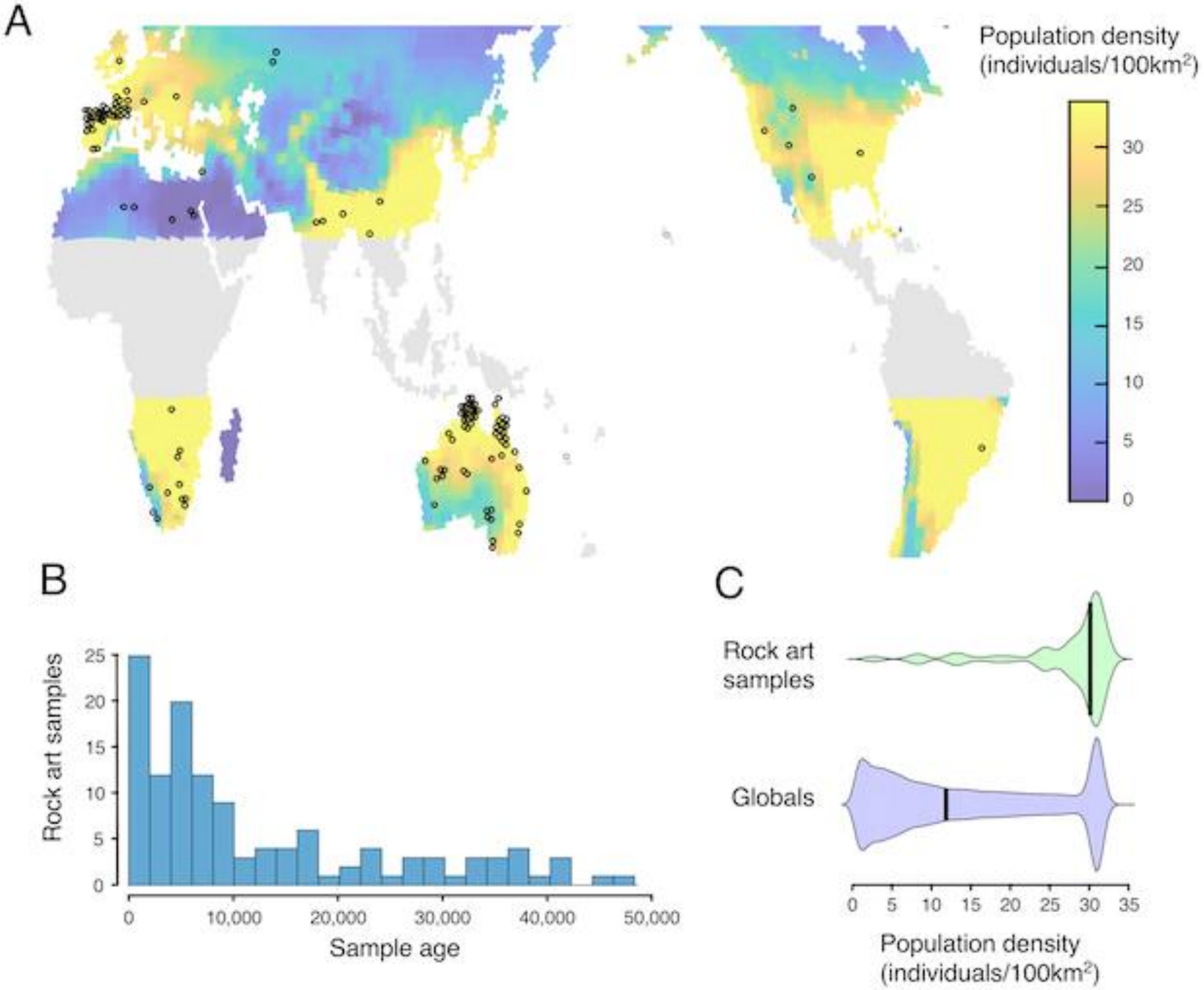
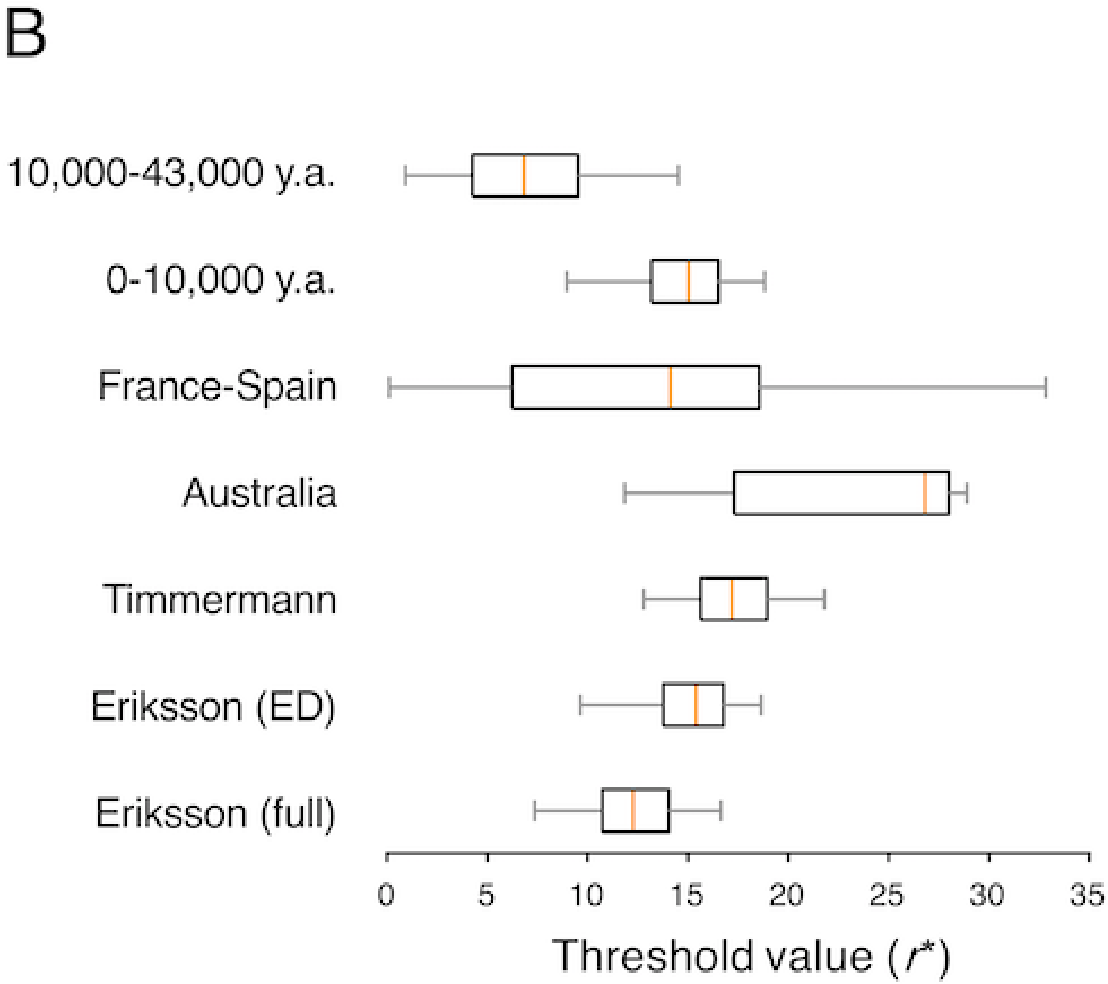
This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1209494109/-/DCSupplemental.

Eriksson, Anders, et al.. “Late Pleistocene Climate Change and the Global Expansion of Anatomically Modern Humans.” *Proceedings of the National Academy of Sciences* 109, no. 40 (2012): 16089–94.

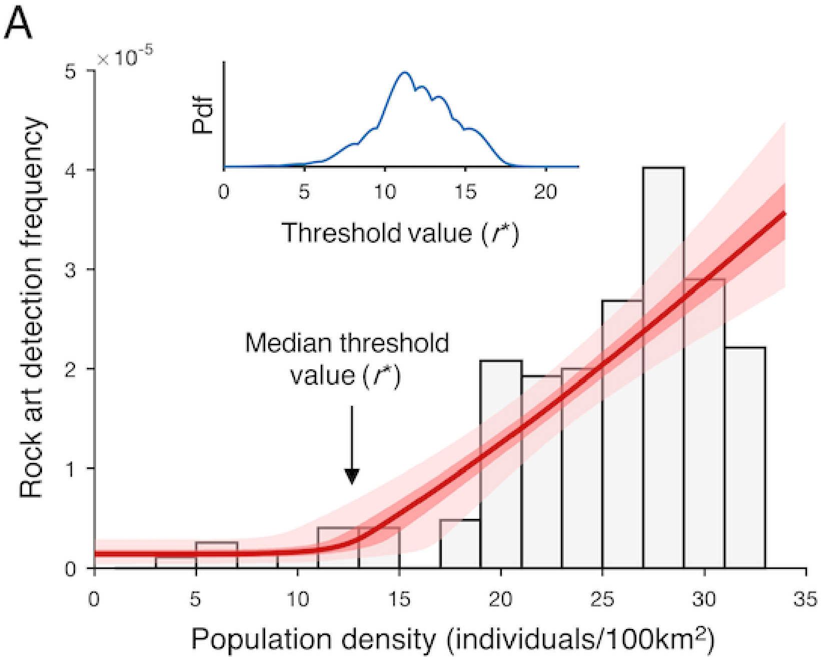

A
× 10^-5
5
4
3
2
1
0
Rock art detection frequency
Pdf
0
5
10
15
20
Threshold value (r*)
Median threshold value (r*)
0
5
10
15
20
25
30
35
Population density (individuals/100km²)


A
Population density
(individuals/100km²)
30
25
20
15
10
5
0
B
Rock art samples
25
20
15
10
5
0
0
10,000
20,000
30,000
40,000
50,000
Sample age
C
Rock art samples
Globals
0
5
10
15
20
25
30
35
Population density
(individuals/100km²)


B
10,000-43,000 y.a.
0-10,000 y.a.
France-Spain
Australia
Timmermann
Eriksson (ED)
Eriksson (full)
0
5
10
15
20
25
30
35
Threshold value (r*)

Conclusions

- **The null hypothesis is disproved!!!** Detection rates for rock art strongly related to population density.
- **The epidemiological model has strong empirical support**

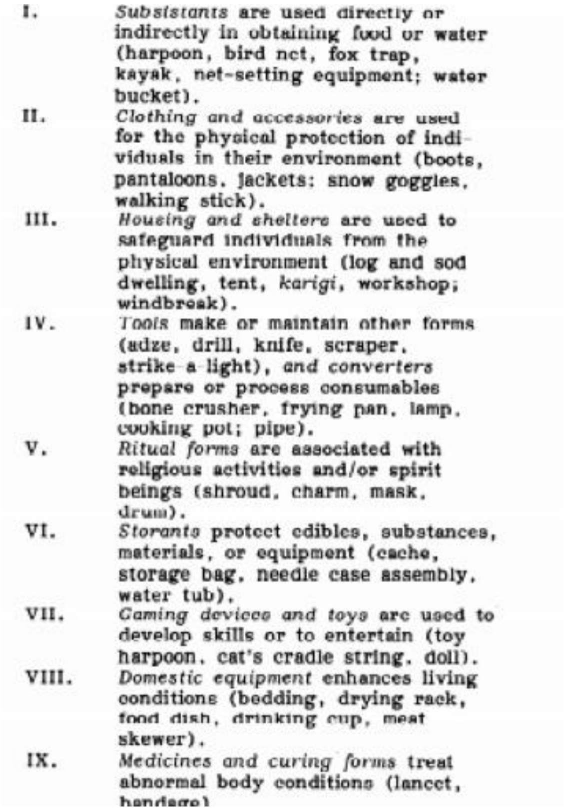


But...

- There are many areas of the world with very high population densities and zero rockart
- Population density above the critical threshold is a *necessary* condition for rock art, not a *sufficient* condition
- We need other models - not just the epidemiological model
- Our model is complementary to demographic models proposed by other authors.

Methodology

- Culturally effective populations
- Cultural complexity



I. *Subsistants* are used directly or indirectly in obtaining food or water (harpoon, bird net, fox trap, kayak, net-setting equipment; water bucket).

II. *Clothing and accessories* are used for the physical protection of individuals in their environment (boots, pantaloons, jackets; snow goggles, walking stick).

III. *Housing and shelters* are used to safeguard individuals from the physical environment (log and sod dwelling, tent, *karigi*, workshop; windbreak).

IV. *Tools* make or maintain other forms (adze, drill, knife, scraper, strike-a-light), *and converters* prepare or process consumables (bone crusher, frying pan, lamp, cooking pot; pipe).

V. *Ritual forms* are associated with religious activities and/or spirit beings (shroud, charm, mask, drum).

VI. *Storants* protect edibles, substances, materials, or equipment (cache, storage bag, needle case assembly, water tub).

VII. *Gaming devices and toys* are used to develop skills or to entertain (toy harpoon, cat's cradle string, doll).

VIII. *Domestic equipment* enhances living conditions (bedding, drying rack, food dish, drinking cup, meat skewer).

IX. *Medicines and curing forms* treat abnormal body conditions (lancet, bandage).

W. H. Oswalt, "Technological complexity: the polar eskimos and the tareumiut," Arctic anthropology, pp. 82-98, 1987.

Map 1. First acceleration in the use of iron across Afro-Eurasia

Turner, Edward AL. “Anvil Age Economy: A Map of the Spread of Iron Metallurgy across Afro-Eurasia.” Cliodynamics 11, no. 1 (2020).

The Human Exception (again)

Walker, Richard, Anders Eriksson, Camille Ruiz, Taylor Howard Newton, and Francesco Casalegno. “Stabilization of Cultural Innovations Depends on Population Density: Testing an Epidemiological Model of Cultural Evolution against a Global Dataset of Rock Art Sites and Climate-Based Estimates of Ancient Population Densities.” *BioRxiv*, June 8, 2020, 705137. https://doi.org/10.1101/705137.

Thank you!

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