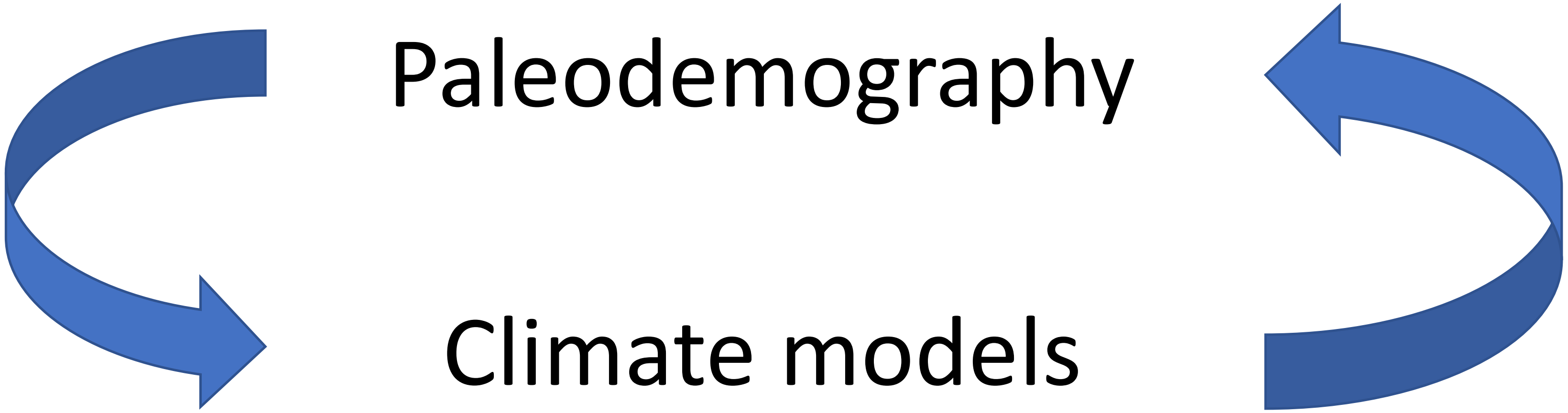
Radiocarbon Data and Human Demography during the Holocene: NSF and PAGES projects

Erick Robinson and Robert Kelly (Dept. of Anthropology, U Wyoming)

Chris Nicholson (Water Resources Data System and Wyoming State Climate Office, U Wyoming)

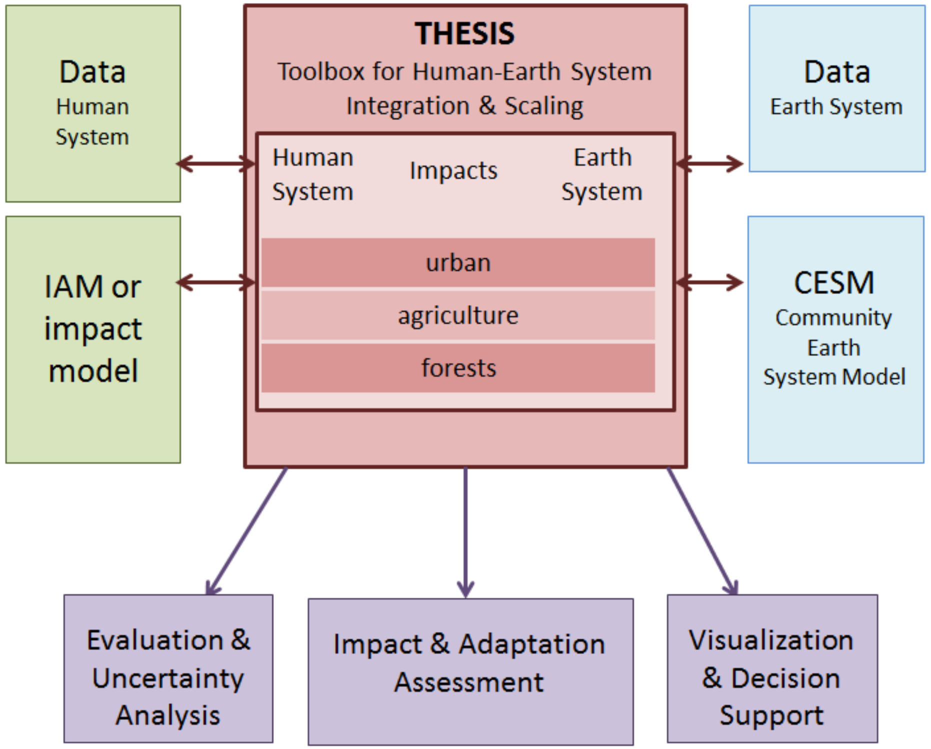
Jacob Freeman (Dept. of Sociology and Anthropology, Utah St. U)

Integrating paleoclimate and archaeological records



1. Paleodemography contributions to climate models

Population and climate at NCAR



POLICY FORUM

CLIMATE CHANGE

Global warming policy: Is population left out in the cold?

Population policies offer options to lessen climate risks

By **John Bongaarts**[1] *and* **Brian C. O'Neill**[2,3]

Would slowing human population growth lessen future impacts of anthropogenic climate change? With an additional 4 billion people expected on the planet by 2100, the answer seems an obvious "yes." Indeed, substantial scientific literature backs up this intuition. Many nongovernmental organizations undertake climate- and population-related activities, and national adaptation plans for most of the least-developed countries recognize population growth as an important component of vulnerability to climate impacts (*1*). But despite this evidence, much of the climate community, notably the Intergovernmental Panel on Climate Change (IPCC), the primary source of scientific information for the international climate change policy process, is largely silent about the potential for population policy to reduce risks from global warming. Though the latest IPCC report (*2*) includes an assessment of technical aspects of ways in which population and climate change influence each other, the assessment does not extend to population policy as part of a wide range of potential adaptation and mitigation responses. We suggest that four misperceptions by many in the climate change community play a substantial role in neglect of this topic, and propose remedies for the IPCC as it prepares for the sixth cycle of its multiyear assessment process.

Population-related policies—such as offering voluntary family planning services as well as improved education for women and girls—can have many of the desirable characteristics of climate response options: benefits to both mitigation and adaptation, co-benefits with human well-being and other environmental issues, synergies with Sustainable Development Goals (SDGs), and cost effectiveness. These policies can also enable women to achieve their desired family size, and lead to lower fertility and slower population growth (*3*). The resulting demographic changes can not only lessen the emissions that drive climate change but also improve the ability of populations to adapt to its consequences.

MISPERCEPTION 1: POPULATION GROWTH IS NO LONGER A PROBLEM

The population growth rate of the developing world increased sharply in the 1950s and 1960s, resulting in a doubling of the world population from 3 billion in 1960 to over 6 billion in 2000 (*4*). The main cause of this acceleration was the spread of public health measures, which rapidly reduced death rates while birth rates remained high. Slowing this population expansion became a top priority for the global development agenda. In the 1970s and 1980s, substantial international assistance was invested in voluntary family planning programs to reduce fertility.

This early consensus on population policy ended in the 1990s when interest and international support waned for rea-

[1]Population Council, New York, NY, USA. [2]National Center for Atmospheric Research, Boulder, CO, USA. [3]University of Denver, Denver, CO, USA. Email: jbongaarts@popcouncil.org

Vulnerability assessments of prehistoric populations

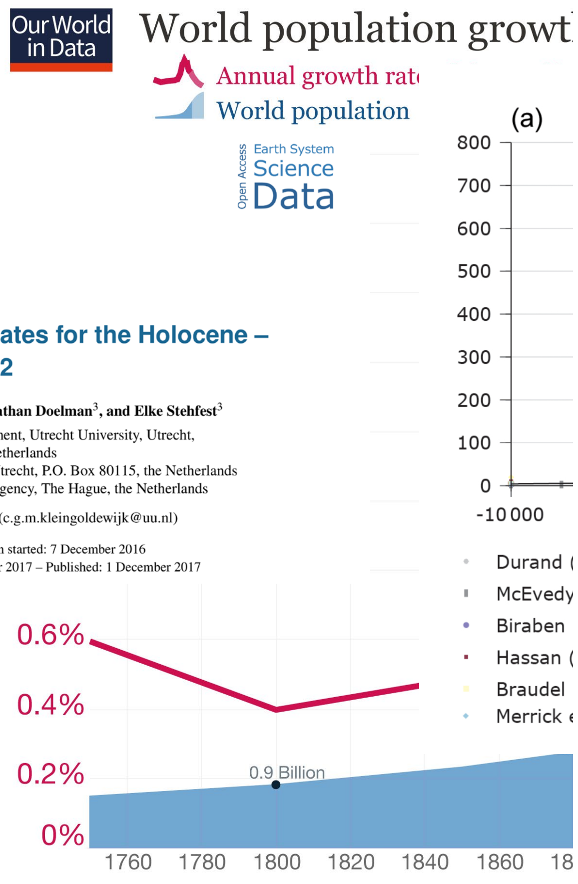
Earth Syst. Sci. Data, 9, 927–953, 2017
https://doi.org/10.5194/essd-9-927-2017

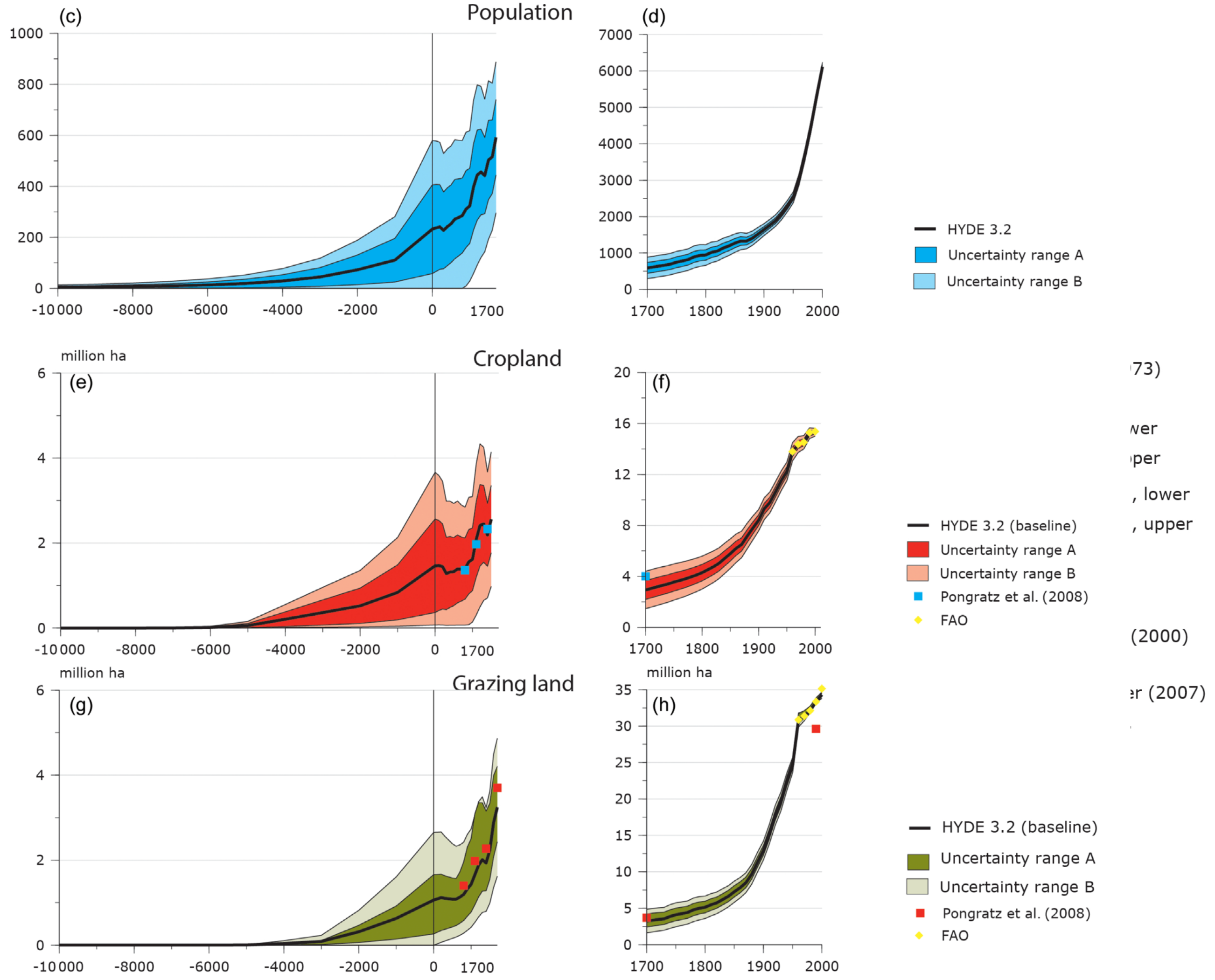
Open Access Earth System Science Data

Anthropogenic land use estimates for the Holocene – HYDE 3.2

Kees Klein Goldewijk[1,3], Arthur Beusen[2,3], Jonathan Doelman[3], and Elke Stehfest[3]
[1]Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, P.O. Box 80115, the Netherlands
[2]Department of Earth Sciences, Utrecht University, P.O. Box 80115, the Netherlands
[3]PBL Netherlands Environmental Assessment Agency, The Hague, the Netherlands
Correspondence to: Kees Klein Goldewijk (c.g.m.kleingoldewijk@uu.nl)

Received: 21 November 2016 – Discussion started: 7 December 2016
Revised: 28 September 2017 – Accepted: 10 October 2017 – Published: 1 December 2017





Data sources: Up to 2015 OurWorldInData series based on UN and HYDE. Projections for 2015 to 2100: UN Population Division (2015) – Medium Variant.
The data visualization is taken from OurWorldinData.org. There you find the raw data and more visualizations on this topic. Licensed under CC-BY-SA by the author Max Roser.

Reconstructing prehistoric populations

- Radiocarbon date frequencies (i.e. more trash=more people)

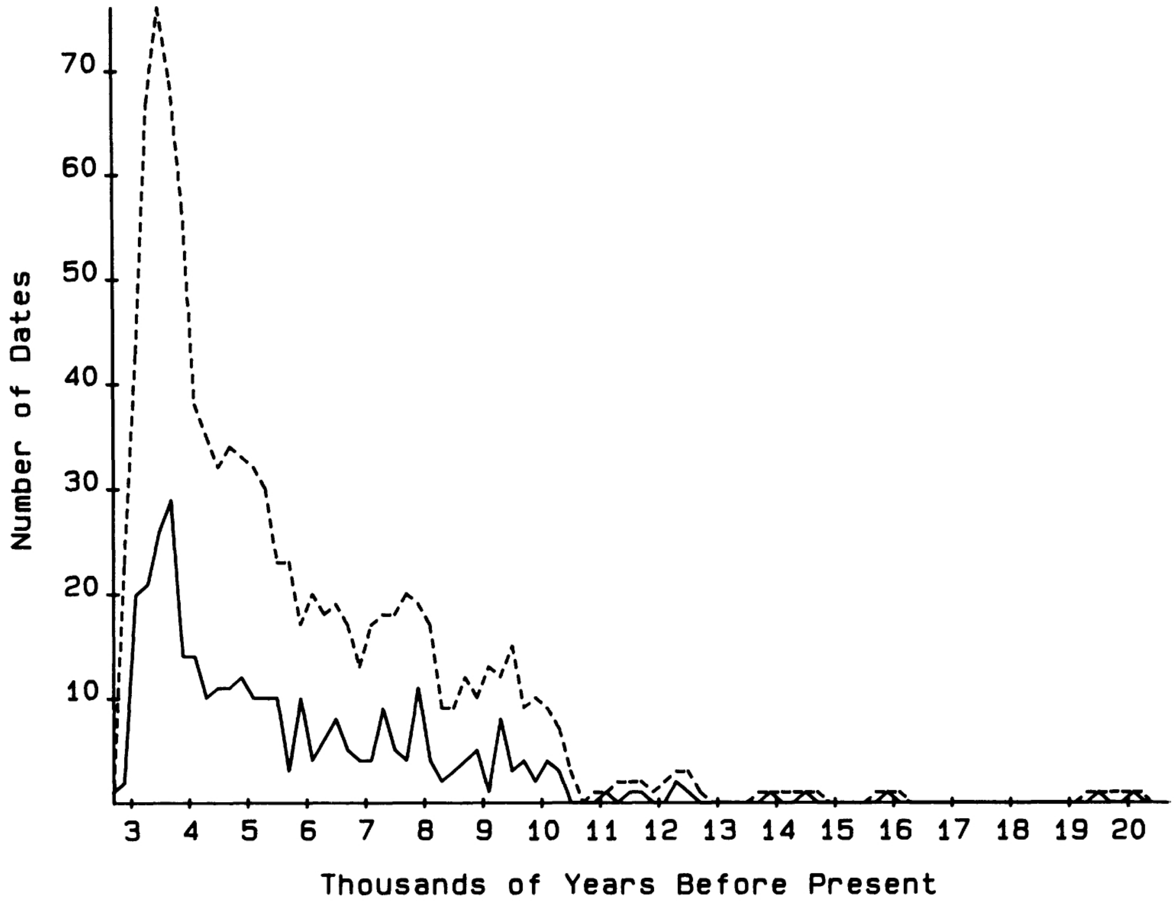
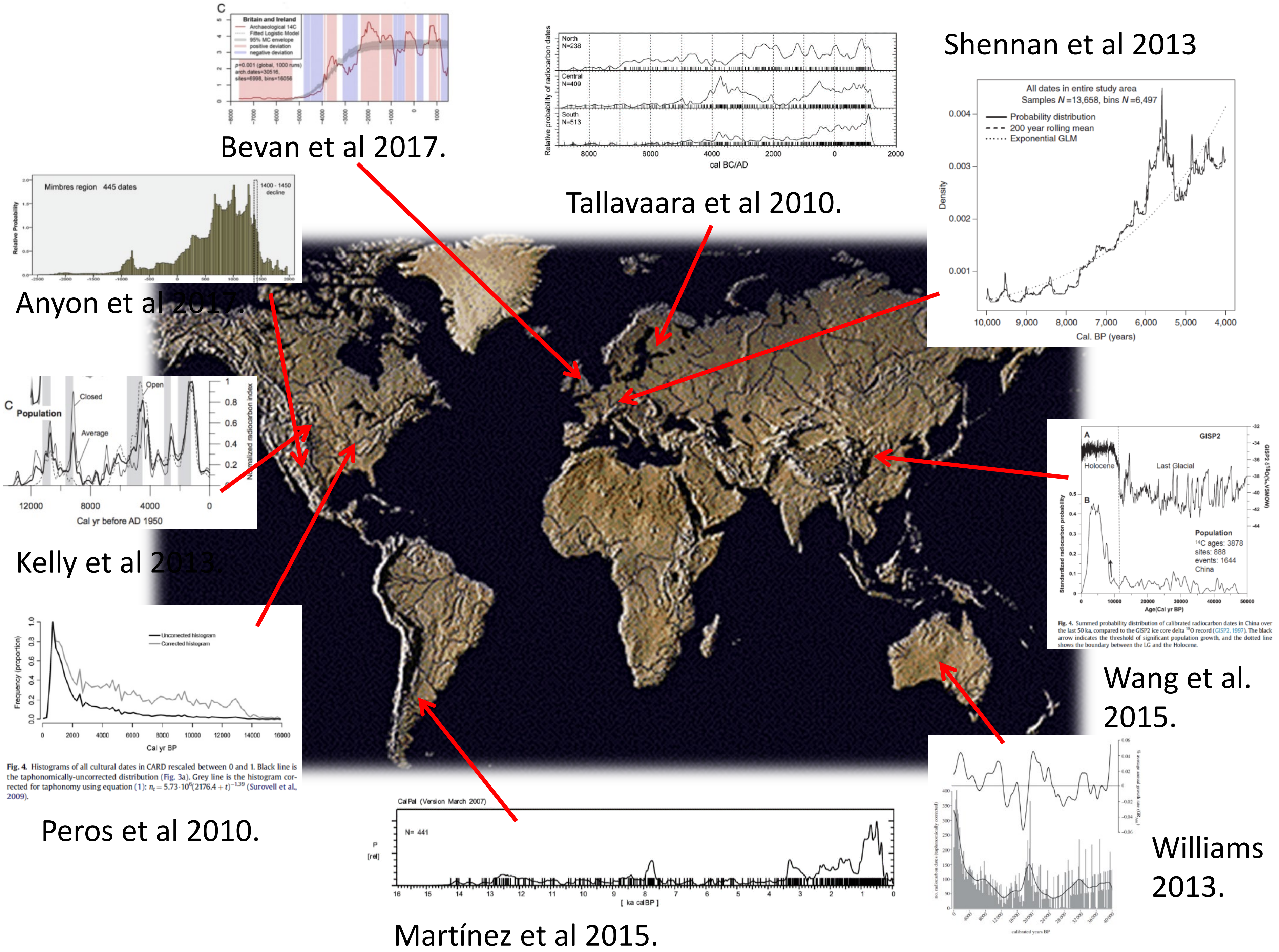
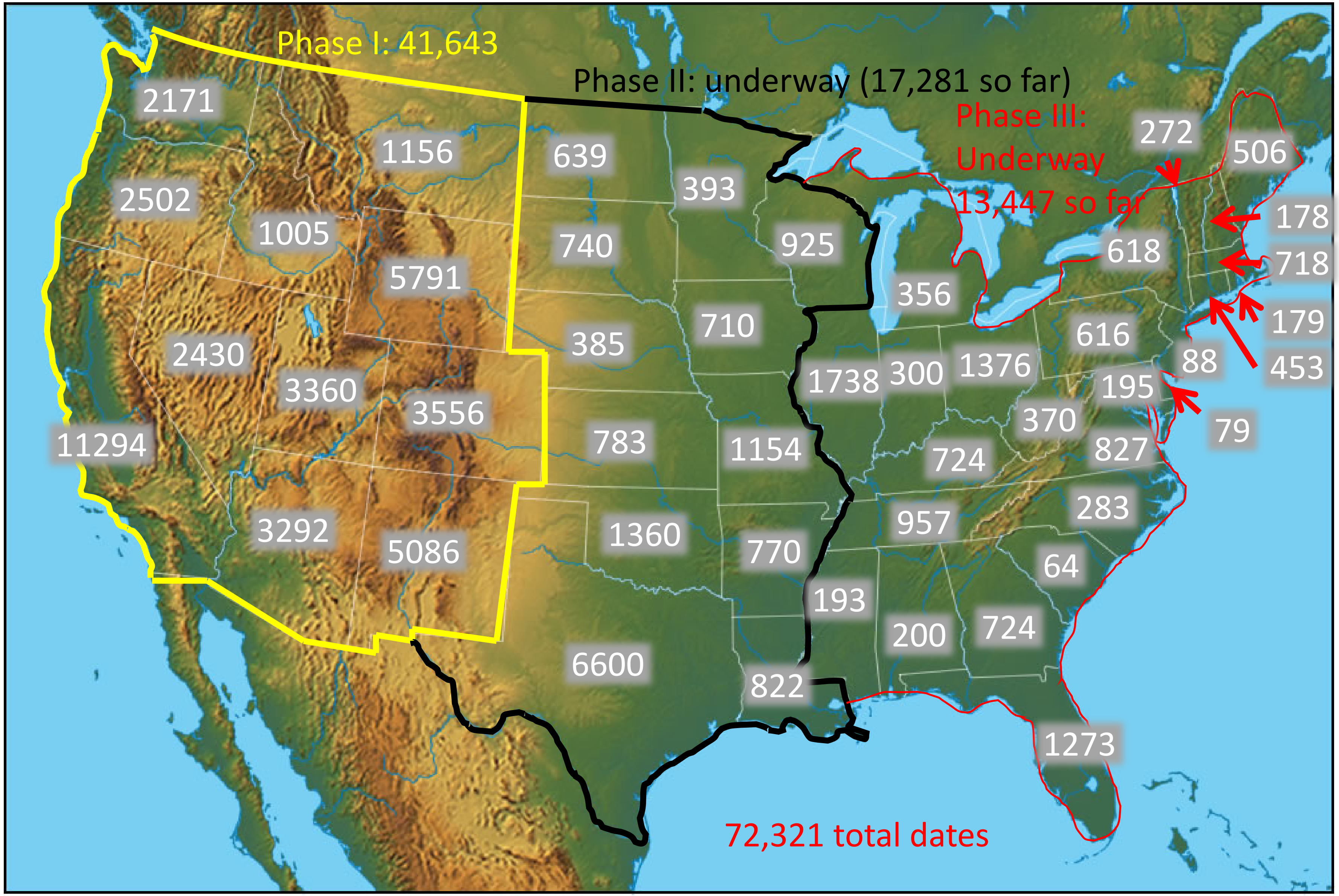


Figure 3. Overall chronological distribution of radiocarbon dates from preceramic Perú. Solid line is number of dates per 200 year interval; dashed line is number of dates per 600 year interval, measured every 200 years.

Rick, *Amer. Antiq.*, 1987


Bevan et al 2017.
Britain and Ireland
Archaeological 14C
Fitted Logistic Model
95% MC envelope
positive deviation
negative deviation
Tallavaara et al 2010.
North N=238
Central N=409
South N=513
Relative probability of radiocarbon dates
cal BC/AD
Shennan et al 2013
All dates in entire study area
Samples N =13,658, bins N =6,497
Probability distribution
200 year rolling mean
Exponential GLM
Density
Cal. BP (years)
Anyon et al 2017.
Mimbres region 445 dates
1400 - 1450 decline
Relative Probability
Kelly et al 2013.
Population
Closed
Open
Average
Normalized radiocarbon index
Cal yr before AD 1950
Wang et al. 2015.
GISP2
Holocene
Last Glacial
Population
sites: 888
events: 1644
China
Standardized radiocarbon probability
Age(Cal yr BP)
Fig. 4. Summed probability distribution of calibrated radiocarbon dates in China over the last 50 ka, compared to the GISP2 ice core delta 18O record (GISP2, 1997). The black arrow indicates the threshold of significant population growth, and the dotted line shows the boundary between the LG and the Holocene.
Peros et al 2010.
Uncorrected histogram
Corrected histogram
Frequency (proportion)
Cal yr BP
Fig. 4. Histograms of all cultural dates in CARD rescaled between 0 and 1. Black line is the taphonomically-uncorrected distribution (Fig. 3a). Grey line is the histogram corrected for taphonomy using equation (1): $n_t = 5.73 \cdot 10^6 (2176.4 + t)^{-1.39}$ (Surovell et al., 2009).
Martínez et al 2015.
CalPal (Version March 2007)
N= 441
P [rel]
[ka calBP]
Williams 2013.
calibrated years BP

NSF radiocarbon project progress 10-2014 to 01-2019



Quantitative comparison of dates at a global scale


CrossMark
click for updates

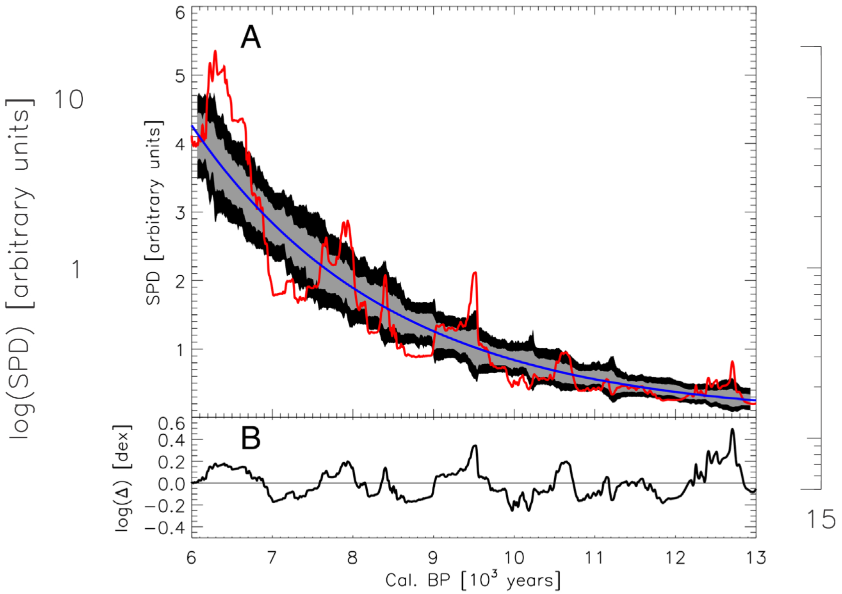
PNAS

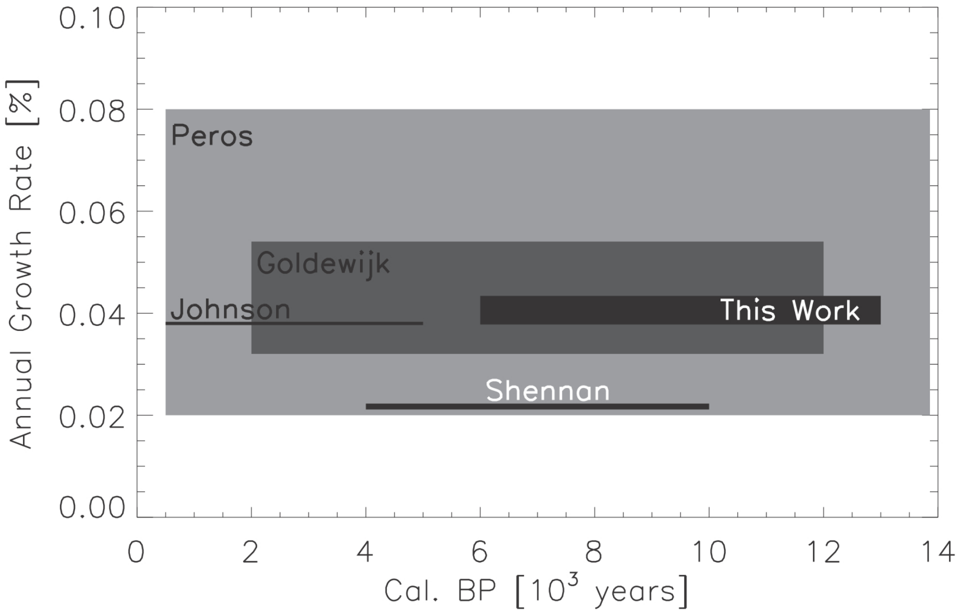
Agriculture, population growth, and statistical analysis of the radiocarbon record

H. Jabran Zahid[a,1], Erick Robinson[b,1], and Robert L. Kelly[b]

[a]Smithsonian Astrophysical Observatory, Harvard–Smithsonian Center for Astrophysics, Cambridge, MA 02138; and [b]Department of Anthropology, University of Wyoming, Laramie, WY 82071

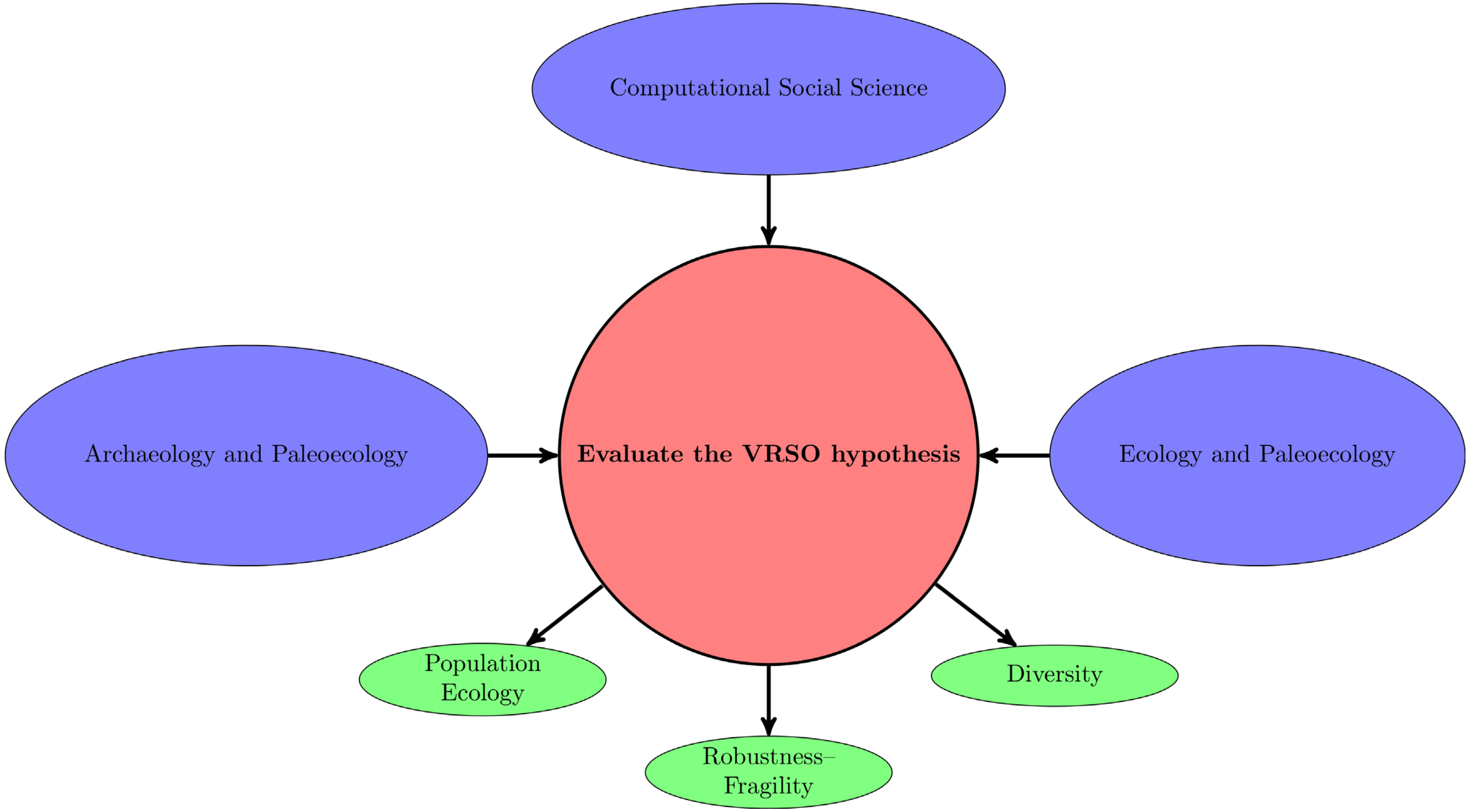
Edited by Stephen J. Shennan, University College London, London, United Kingdom, and accepted by the Editorial Board November 10, 2015 (received for review September 4, 2015)



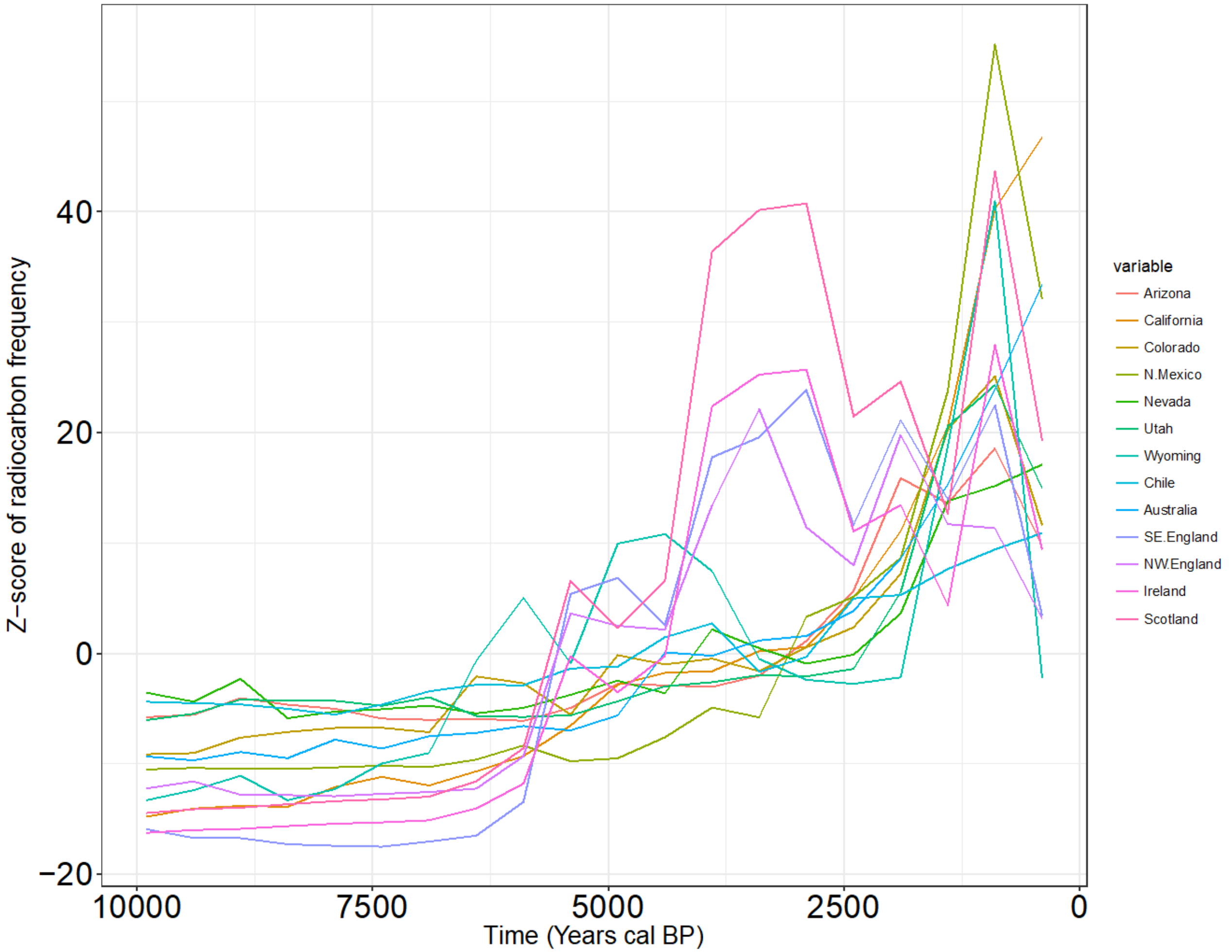


Zahid et al., *PNAS*, 2016

Strategies to investigate this problem



Comparing energy consumption of Holocene populations across the world



Similarities in the growth of human societies at a global scale

- Human societies show synchroneity at two scales throughout the Holocene
- Synchroneity not correlated with global scale forcing (Holocene records of solar energy output)

Synchronization of energy consumption by human societies throughout the Holocene

Jacob Freeman[a,b,1], Jacopo A. Baggio[c,d], Erick Robinson[e], David A. Byers[a], Eugenia Gayo[f], Judson Byrd Finley[a], Jack A. Meyer[g], Robert L. Kelly[e], and John M. Anderies[h]

[a]Department of Sociology, Social Work, and Anthropology, Utah State University, Logan, UT 84322; [b]Ecology Center, Utah State University, Logan, UT 84322; [c]Department of Political Science, University of Central Florida, Orlando, FL 32816; [d]Sustainable Coastal Cluster, National Center for Integrated Coastal Research, Orlando, FL 32816; [e]Department of Anthropology, University of Wyoming, Laramie, WY 82071; [f]Center for Climate and Resilience Research, Santiago 8370449, Chile; [g]Far Western Anthropological Research Group, Inc., Davis, CA 95618; and [h]School of Sustainability, Arizona State University, Tempe, AZ 85287

Edited by Timothy A. Kohler, Washington State University, Pullman, WA, and accepted by Editorial Board Member James F. O'Connell August 15, 2018 (received for review February 15, 2018)

We conduct a global comparison of the consumption of energy by human populations throughout the Holocene and statistically quantify coincident changes in the consumption of energy over space and time—an ecological phenomenon known as synchrony. When populations synchronize, adverse changes in ecosystems and social systems may cascade from society to society. Thus, to develop policies that favor the sustained use of resources, we must understand the processes that cause the synchrony of human populations. To date, it is not clear whether human societies display long-term synchrony or, if they do, the potential causes. Our analysis begins to fill this knowledge gap by quantifying the long-term synchrony of human societies, and we hypothesize that the synchrony of human populations results from (*i*) the creation of social ties that couple populations over smaller scales and (*ii*) much larger scale, globally convergent trajectories of cultural evolution toward more energy-consuming political economies with higher carrying capacities. Our results suggest that the process of globalization is a natural consequence of evolutionary trajectories that increase the carrying capacities of human societies.

sustainability | radiocarbon | globalization | synchrony | human ecology

Among many species, changes in the attributes of populations coincide over space and time—a phenomenon known as synchrony (1). To date, it is not clear whether human societies display synchronous changes in population attributes or, if they do, what mechanisms might cause synchrony at different scales of space and time. To help fill this knowledge gap, we conduct a global comparison of historical and radiocarbon records over the last 130 and 10,000 y, respectively. These records provide an opportunity to study the long-term synchrony of human energy consumption (e.g., refs. 2–5). The consumption of energy refers to the conversion of biomass into work and waste. In any human population, some proportion of the energy consumed over time goes to meeting the subsistence needs of a population and building infrastructure related to the political-economic activity underlying social organization. Larger populations or greater political-economic activity require more energy during any given time period. Thus, energy consumption provides a metric of the expansion and contraction of human systems.

Investigating the long-term causes of synchrony among human populations complements more traditional studies in sustainability that focus on the potential for a single human population to overshoot the carrying capacity of an environment and collapse or on social institutions that lessen the impacts of large populations on ecosystems (e.g., refs. 6–11). Among synchronous populations, the potential exists for adverse changes in ecosystems and social systems to cascade from society to society, leading to widespread social disruption. Hence, policies designed to promote the sustainable use of resources may benefit from understanding the processes that cause the synchrony of human populations over the long term. In the end, we document significant, long-term synchrony among human systems. The causes of this synchrony may include the creation of trade and migration flows via more local-scale social networks and much longer term, globally convergent trajectories of cultural evolution toward political economies that consume more energy and raise the carrying capacities of human societies. Our study illustrates the enormous potential for radiocarbon records to serve as the basis for millennial-scale, global comparisons of human energy dynamics unprecedented for most other species and raises critical methodological challenges for achieving this potential.

To investigate the synchronous consumption of energy by human populations over the long term, we use two datasets. First, the radiocarbon records of the western United States, British Isles, Australia, and Northern Chile aggregate thousands of radiocarbon ages on preserved organic items from the trash deposits of past human societies, such as wood, charcoal, small seeds, and animal bones. These data provide estimates of changes in the production of waste by populations over time due to the consumption of energy and may be used to infer changes

Significance

We report coincident changes in the consumption of energy by human populations over the last 10,000 y—synchrony—and document patterns consistent with the contemporary process of globalization operating in the past. Our results suggest that the process of globalization may display great antiquity among our species, and this knowledge provides an entry point for integrating insights from archaeological research into discussions on the long-term consequences of globalization for building sustainable societies. Our results demonstrate the potential for archaeological radiocarbon records to serve as a basis for millennial-scale comparisons of human energy dynamics and provide a baseline for further cross-cultural research on the long-term growth and decline trajectories of human societies.

Author contributions: J.F., J.A.B., E.R., D.A.B., and J.M.A. designed research; J.F., D.A.B., E.G., J.B.F., J.A.M., and R.L.K. performed research; J.F., J.A.B., and E.R. analyzed data; and J.F., J.A.B., E.R., D.A.B., R.L.K., and J.M.A. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. T.A.K. is a guest editor invited by the Editorial Board.

Data deposition: All data, scripts, and instructions for running our analysis have been deposited on Github (https://github.com/people3k/pop-solar-sync; doi: 10.5281/zenodo.1340714).

[1]To whom correspondence should be addressed. Email: jacob.freeman@usu.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1802859115/-/DCSupplemental.

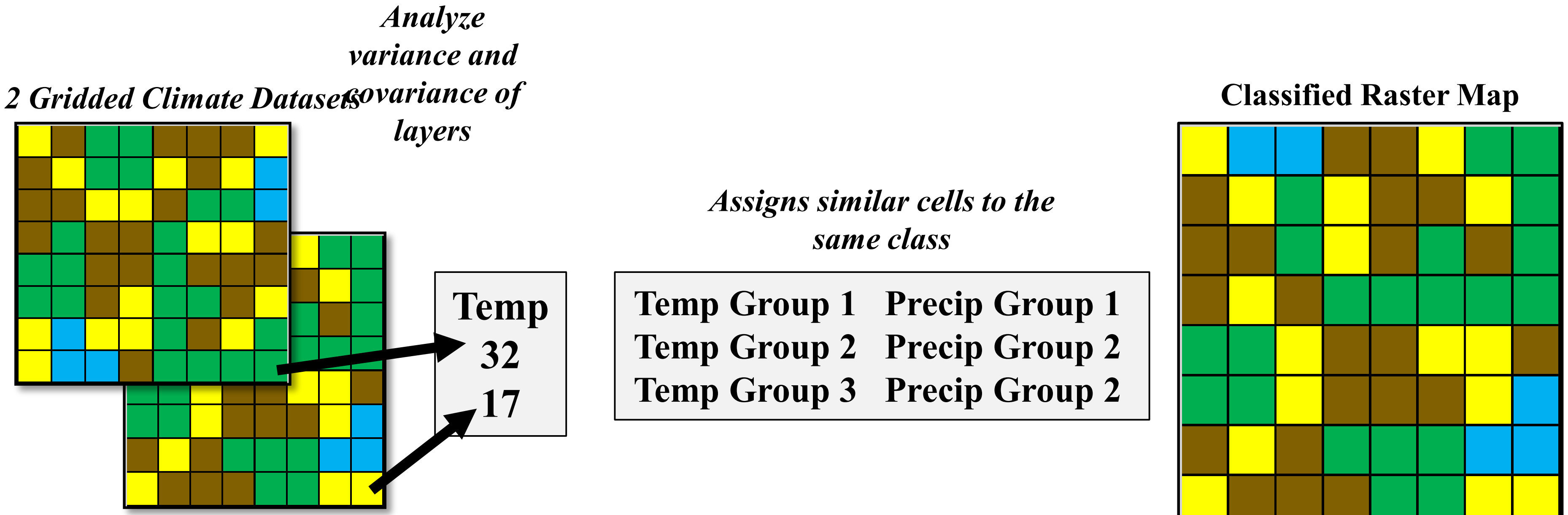
2. Climate model contributions to paleodemography

Climate Zone Methods

Maximum Likelihood Classification (MLC)
Remote Sensing Technique

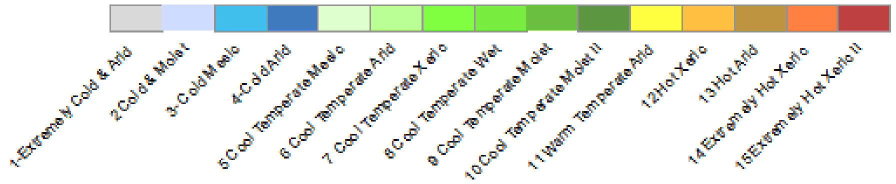
Gridded GCM data used to create paleoclimate zones in 500 year intervals

- CCSM3 (Community Climate System Model 3)
    - Digitally downscaled and Debiased by Lorenz et al. 2013
    - 0.5° spatial resolution
    - 500 year intervals
- Average Annual Precipitation and Growing Degree Days (5°C Base)

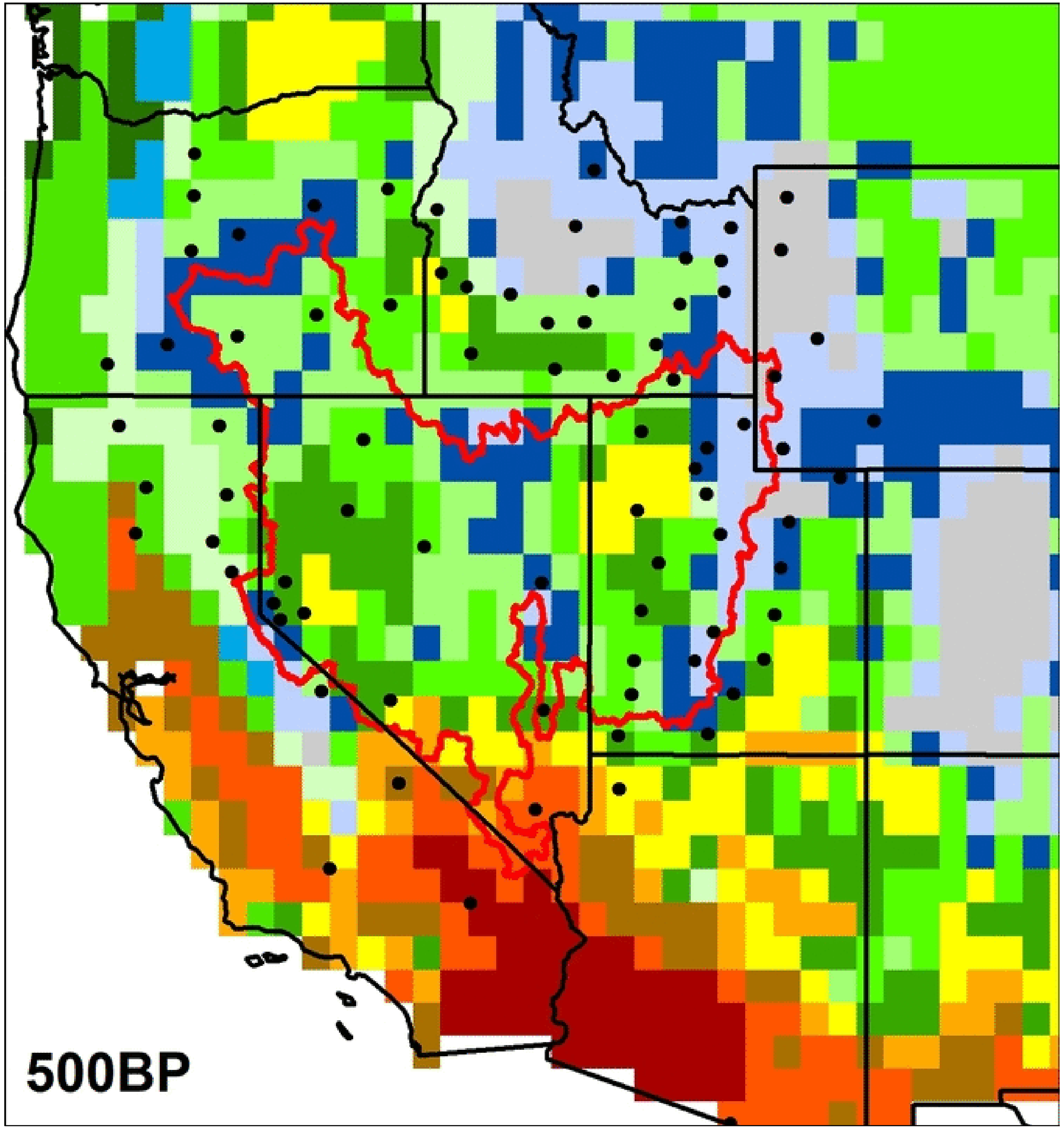


Paleoclimate Zones

20 paleoclimate zone maps
15 zones
500 year intervals
(500BP to 10,000BP)



In 2 cases (CTM & EHX) 2 zones were combined into 1



SPD’s of Cooler Climates