Stephens, Lucas, Fuller, Dorian, Boivin, Nicole, Rick, Torben, Gauthier, Nicolas, Kay, Andrea, Marwick, Ben, Geralda, Chelsey, Armstrong, Denise, Barton, C. Michael, Denham, Tim, Douglass, Kristina, Driver, Jonathan, Janz, Lisa, Roberts, Patrick, Rogers, J. Daniel, Thakar, Heather, Altaweel, Mark, Johnson, Amber L., Sampietro Vattuone, Maria Marta, Aldenderfer, Mark, Archila, Sonia, Artioli, Gilberto, Bale, Martin T., Beach, Timothy, Borrell, Ferran, Braje, Todd, Buckland, Philip I., Jiménez Cano, Nayeli Guadalupe, Capriles, José M., Diez Castillo, Agustín, Çilingiroğlu, Çiler, Negus Cleary, Michelle, Conolly, James, Coutros, Peter R., Covey, R. Alan, Cremaschi, Mauro, Crowther, Alison, Der, Lindsay, di Lernia, Savino, Doershuk, John F., Doolittle, William E., Edwards, Kevin J., Erlandson, Jon M., Evans, Damian, Fairbairn, Andrew, Faulkner, Patrick, Feinman, Gary, Fernandes, Ricardo, Fitzpatrick, Scott M., Fyfe, Ralph, Garcea, Elena, Goldstein, Steve, Goodman, Reed Charles, Dalpoim Guedes, Jade, Herrmann, Jason, Hiscock, Peter, Hommel, Peter, Horsburgh, K. Ann, Hritz, Carrie, Ives, John W., Junno, Aripekka, Kahn, Jennifer G., Kaufman, Brett, Kearns, Catherine, Kidder, Tristram R., Lanoë, François, Lawrence, Dan, Lee, Gyoung-Ah, Levin, Maureece J., Lindskoug, Henrik B., López-Sáez, José Antonio, Macrae, Scott, Marchant, Rob, Marston, John M., McClure, Sarah, McCoy, Mark D., Miller, Alicia Ventresca, Morrison, Michael, Motuzaite Matuzeviciute, Giedre, Müller, Johannes, Nayak, Ayushi, Noerwidi, Sofwan, Peres, Tanya M., Peterson, Christian E., Proctor, Lucas, Randall, Asa R., Renette, Steve, Robbins Schug, Gwen, Ryzewski, Krysta, Saini, Rakesh, Scheinsohn, Vivian, Schmidt, Peter, Sebillaud, Pauline, Seitsonen, Oula, Simpson, Ian A., Sołtysiak, Arkadiusz, Speakman, Robert J., Spengler, Robert

Complete Author List with Contribution Statement

Name	Affiliation	Author Contribution
Lucas Stephens	University of Maryland Baltimore County, American Council of Learned Societies, and University of Pennsylvania	Led project team; Research design; Data analysis; Drafting of article; Contributed and interpreted data
Dorian Fuller	University College London	Assisted with research design; Drafting of article; Contributed and interpreted data
Nicole Boivin	Max Planck Institute for the Science of Human History	Assisted with research design; Drafting of article; Contributed and interpreted data
Torben Rick	Smithsonian Institution	Assisted with research design; Drafting of article; Contributed and interpreted data
Nicolas Gauthier	Arizona State University	Data analysis; Drafting of article; Contributed and interpreted data
Andrea Kay	Max Planck Institute for the Science of Human History and The University of Queensland	Assisted with research design; Drafting of article; Contributed and interpreted data
Ben Marwick	University of Washington	Data analysis; Drafting of article; Contributed and interpreted data
Chelsey Geralda Denise Armstrong	Smithsonian Institution	Drafting of article; Contributed and interpreted data
C. Michael Barton	Arizona State University	Assisted with research design; Contributed and interpreted data
Tim Denham	Australian National University	Drafting of article; Contributed and interpreted data
Kristina Douglass	The Pennsylvania State University	Drafting of article; Contributed and interpreted data
Jonathan Driver	Simon Fraser University	Drafting of article; Contributed and interpreted data
Lisa Janz	Trent University	Drafting of article; Contributed and interpreted data
Patrick Roberts	Department of Archaeology, Max Planck Institute for the Science of Human History	Drafting of article; Contributed and interpreted data
J. Daniel Rogers	Smithsonian Institution	Assisted with research design; Drafting of article; Contributed and interpreted data
Heather Thakar	Texas A&M University	Drafting of article; Contributed and interpreted data
Mark Altaweel	University College London, Institute of Archaeology	Data analysis; Contributed and interpreted data
Amber L. Johnson	Truman State University	Drafting of article; Contributed and interpreted data
Maria Marta Sampietro Vattuone	Laboratorio de Geoarqueologia, National University of Tucuman, CONICET	Drafting of article; Contributed and interpreted data
Mark Aldenderfer	University of California, Merced	Contributed and interpreted data
Sonia Archila	Department of Anthropology, University of Los Andes, Colombia	Contributed and interpreted data
Gilberto Artioli	Università di Padova	Contributed and interpreted data
Martin T. Bale	Dept. of Cultural Anthropology, Yeungnam University	Contributed and interpreted data
Timothy Beach	The University of Texas at Austin	Contributed and interpreted data
Ferran Borrell	Institución Milá y Fontanals (IMF), Consejo Superior de Investigaciones Científicas (CSIC)	Contributed and interpreted data
Todd Braje	California Academy of Sciences	Contributed and interpreted data
Philip I. Buckland	Environmental Archaeology Lab, Umeå University	Contributed and interpreted data
Nayeli Guadalupe Jiménez Cano	Universidad Autónoma de Yucatán	Contributed and interpreted data
José M. Capriles	Department of Anthropology, The Pennsylvania State University	Contributed and interpreted data
Agustín Diez Castillo	Universitat de València	Contributed and interpreted data
Çiler Çilingiroğlu	Ege University, Protohistory and Near Eastern Arhaeology	Contributed and interpreted data
Michelle Negus Cleary	University of Melbourne	Contributed and interpreted data
James Conolly	Trent University	Contributed and interpreted data
Peter R. Coutros	University of Puget Sound	Contributed and interpreted data
R. Alan Covey	University of Texas at Austin	Contributed and interpreted data

Mauro Cremaschi	Dipartimento di Scienze della Terra University of Milan	Contributed and interpreted data
Alison Crowther	The University of Queensland & The Max Planck Institute for the Science of Human History	Contributed and interpreted data
Lindsay Der	The University of British Columbia	Contributed and interpreted data
Savino di Lernia	Sapienza University of Rome, Italy	Contributed and interpreted data
John F. Doershuk	University of Iowa	Contributed and interpreted data
William E. Doolittle	The University of Texas at Austin	Contributed and interpreted data
Kevin J. Edwards	Departments of Geography & Environment and Archaeology, University of Aberdeen, UK and Scott Polar Research Institute, University of Cambridge	Contributed and interpreted data
Jon M. Erlandson	Museum of Natural & Cultural History, University of Oregon	Contributed and interpreted data
Damian Evans	École française d'Extrême-Orient	Contributed and interpreted data
Andrew Fairbairn	The University of Queensland	Contributed and interpreted data
Patrick Faulkner	The University of Sydney	Contributed and interpreted data
Gary Feinman	Field Museum of Natural History	Contributed and interpreted data
Ricardo Fernandes	Max Planck Institute for the Science of Human History, University of Oxford, Masaryk University	Contributed and interpreted data
Scott M. Fitzpatrick	University of Oregon	Contributed and interpreted data
Ralph Fyfe	University of Plymouth, UK	Contributed and interpreted data
Elena Garcea	University of Cassino and Southern Latium	Contributed and interpreted data
Steve Goldstein	Max Planck Institute for the Science of Human History, Dept. of Archaeology	Contributed and interpreted data
Reed Charles Goodman	University of Pennsylvania	Contributed and interpreted data
Jade Dalpoim Guedes	University of California, San Diego	Contributed and interpreted data
Jason Herrmann	University of Tuebingen	Contributed and interpreted data
Peter Hiscock	University of Sydney	Contributed and interpreted data
Peter Hommel	University of Oxford	Contributed and interpreted data
K. Ann Horsburgh	Southern Methodist University	Contributed and interpreted data
Carrie Hritz	Contributed and interpreted data	
John W. Ives	University of Alberta	Contributed and interpreted data
Aripekka Junno	Arctic Centre, University of Groningen	Contributed and interpreted data
Jennifer G. Kahn	Department of Anthropology, College of William and Mary	Contributed and interpreted data
Brett Kaufman	University of Illinois at Urbana-Champaign, Department of the Classics	Contributed and interpreted data
Catherine Kearns	University of Chicago	Contributed and interpreted data
Tristram R. Kidder	Department of Anthropology, Washington University in St. Louis	Contributed and interpreted data
François Lanoë	University of Arizona	Contributed and interpreted data
Dan Lawrence	Durham University	Contributed and interpreted data
Gyoung-Ah Lee	University of Oregon	Contributed and interpreted data
Maureece J. Levin	Stanford University	Contributed and interpreted data
Henrik B. Lindskoug	Departamento de Antropología, Facultad de Ciencias Sociales y Humanidades, Universidad Católica de Temuco, Chile	Contributed and interpreted data
José Antonio López-Sáez	G.I. Arqueobiología, Instituto de Historia, CSIC, Madrid, Spain	Contributed and interpreted data
Scott Macrae	Trent University	Contributed and interpreted data
Rob Marchant	KITE, University of York	Contributed and interpreted data

John M. Marston	Boston University	Contributed and interpreted data
Sarah McClure	UC Santa Barbara	Contributed and interpreted data
Mark D. McCoy	Southern Methodist University	Contributed and interpreted data
Alicia Ventresca Miller	Max Planck Institute for the Science of Human History	Contributed and interpreted data
Michael Morrison	Flinders University	Contributed and interpreted data
Giedre Motuzaite Matuzeviciute	Vilnius University	Contributed and interpreted data
Johannes Müller	University Kiel, Germany, Professor Prehistoric Archaeology	Contributed and interpreted data
Ayushi Nayak	Department of Archaeology, Max Planck Institute for the Science of Human History, Jena, Germany	Contributed and interpreted data
Sofwan Noerwidi	Balai Arkeologi Yogyakarta	Contributed and interpreted data
Tanya M. Peres	Florida State University	Contributed and interpreted data
Christian E. Peterson	University of Hawaii at Manoa	Contributed and interpreted data
Lucas Proctor	University of Connecticut	Contributed and interpreted data
Asa R. Randall	University of Oklahoma	Contributed and interpreted data
Steve Renette	University of Pennsylvania Museum of Archaeology and Anthropology	Contributed and interpreted data
Gwen Robbins Schug	Appalachian State University	Contributed and interpreted data
Krysta Ryzewski	Wayne State University	Contributed and interpreted data
Rakesh Saini	Dr Harsingh Gour Central University Sagar, MP, India	Contributed and interpreted data
Vivian Scheinsohn	Universidad de Buenos Aires	Contributed and interpreted data
Peter Schmidt	University of Florida; University of Pretoria	Contributed and interpreted data
Pauline Sebillaud	CNRS East Asian Civilization Research Centre, Jilin University Research Centre for Frontier Archaeology	Contributed and interpreted data
Oula Seitsonen	Archaeology, University of Oulu / Cultural Heritage, University of Helsinki	Contributed and interpreted data
Ian A. Simpson	University of Stirling	Contributed and interpreted data
Arkadiusz Sołtysiak	University of Warsaw, Poland	Contributed and interpreted data
Robert J. Speakman	University of Georgia	Contributed and interpreted data
Robert N. Spengler	Max Planck Institute for the Science of Human History	Contributed and interpreted data
Martina L. Steffen	University of Arizona	Contributed and interpreted data
Michael J. Storozum	Institute of Archaeological Science, Fudan University, Shanghai, China	Contributed and interpreted data
Keir M. Strickland	La Trobe University, Australia	Contributed and interpreted data
Jessica Thompson	Yale University	Contributed and interpreted data
T L Thurston	University at Buffalo, State University of New York	Contributed and interpreted data
Sean Ulm	ARC Centre of Excellence for Australian Biodiversity and Heritage, James Cook University	Contributed and interpreted data
M. Cemre Ustunkaya	McDonald Institute for Archaeological Research	Contributed and interpreted data
Martin H. Welker	Pennsylvania State University	Contributed and interpreted data
Catherine West	Boston University	Contributed and interpreted data
Patrick Ryan Williams	Field Museum	Contributed and interpreted data
David K. Wright	Seoul National University	Contributed and interpreted data
Nathan Wright	University of Cambridge	Contributed and interpreted data
Muhammad Zahir	Department of Archaeology & Department of Art and Design, Hazara University, Mansehra	Contributed and interpreted data
Andrea Zerboni	Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio"	Contributed and interpreted data

Ella Beaudoin	Smithsonian Institution	Assisted with research design
Santiago Munevar Garcia	University of Maryland Baltimore County	Data Analysis
Jeremy Powell	University of Maryland Baltimore County	Data Analysis
Alexa Thornton	University of Maryland Baltimore County	Data Analysis
Jed O. Kaplan	Institute of Geography, University of Augsburg; Department of Archaeology, Max Planck Institute for the Science of Human History	Drafting of article; Interpreted data
Marie-José Gaillard	Department of Biology and Environmental Science, Linnaeus University	Drafting of article; Interpreted data
Kees Klein Goldewijk	PBL Netherlands Environmental Assessment Agency & Utrecht University	Drafting of article; Interpreted data
Erle Ellis	University of Maryland Baltimore County	Conceived of research; Research design; Data analysis; Drafting of article

Materials and Methods

Project Design

The ArchaeoGLOBE survey collected information concerning archaeological knowledge of human land use over the past 10,000 years beginning 18 May and ending 31 July 2018, receiving contributions from 255 individuals. All survey results and other project data are in the public domain (CC-0) and available online on the project's Dataverse page (https://dataverse.harvard.edu/dataverse/ArchaeoGLOBE, specifically https://doi.org/10.7910/DVN/CNCANQ, https://doi.org/10.7910/DVN/CQWUBI).

The survey operated at a regional scale, dividing the entire Earth's surface (except Antarctica) into 146 analytical units. Each contribution was based on the contributor's selection of a single region, for which they had to answer every question. Contributors were encouraged to complete the survey for at least four regions and incentivized with the offer of co-authorship on the resulting paper for doing so. Contributors were allowed to contribute as many regions as they felt qualified. 130 individuals contributed more than one region; 111 contributed at least four.

Questions about land-use, expertise, and data quality were repeated for 10 points in time over the past 10,000 years: 10,000 BP, 8,000 BP, 6,000 BP, 4,000 BP, 3,000 BP, 2,000 BP, 1,000 BP, 1500 CE, 1750 CE, and 1850 CE.

Contributors were asked to rate the relative levels of prevalence of four land-use types: foraging/hunting/gathering/fishing, extensive agriculture, intensive agriculture, and pastoralism based on the following rubric:

None	Minimal	Common	Widespread
No evidence that any land in the region was used for the selected land-use type.	The selected land use type was present, but not significant, less than 1% of land in the region was used for the selected land-use type.	Between 1% and 20% of land in the region was used for the selected land-use type.	Greater than 20% of land in the region was used for the selected land-use type.

Regions

Defining the scale of regional study units was one of the most difficult parts of this project. We used modern administrative regions (Natural Earth 1:50m Admin1-states and provinces) in order to avoid drawing our own boundaries. We roughly grouped regions around geographic areas to serve as analytical units that would be useful in two respects: (1) for the history of land use over the past 10,000 years (a moving target) and (2) for the history of archaeological research. Some consideration was also given to creating regions that were relatively equal in size. We went through several rounds of feedback and redrawing before arriving at the 146 regions used in the survey. No bounded regional system could ever truly reflect the complex spatial distribution of archaeological knowledge on past human land use, but we determined that operating at a regional scale was the best way to facilitate timely collaboration while achieving global coverage.

Land-use Categories

The land-use categories were developed from LandCover6k land-use classifications (*25*). The following descriptions were presented to contributors to guide their interpretation of the categories.

Foraging/hunting/gathering/fishing - subsistence based on hunting wild animals, gathering wild plants, and fishing, without deliberately modifying the reproduction of plants and animals that people exploit. Abbreviated as “Foraging”.

Extensive agriculture/farming - swidden/shifting cultivation and other forms of non-continuous cultivation.

Intensive agriculture/farming - all other forms of continuous cultivation (including irrigated and nonirrigated annual cropping, tropical agroforestry, flooded field farming, and industrial monocrop/plantation agriculture).

Pastoralism - the exploitation of pasturelands for animal husbandry - including the breeding, care, and use of domesticated herd animals (e.g., sheep, goats, camels, cattle, horses, llamas, reindeer, and yaks).

A final question asked contributors to indicate the presence or absence of “high density urban center(s)” at each time slice.

The category descriptions were purposely kept as short and simple as possible, as it was not the goal of the project to arrive at definitions that would be acceptable to all archaeologists. This approach necessitated a degree of interpretation and estimation on the part of the contributors. There are certainly differences in how researchers within and between regions understand concepts like "urban center" and "agriculture.” The lack of terminological and interpretive consensus on key concepts causes a degree of heterogeneity in the survey data.

The divisions are not appropriate for all past land-use systems, which were often mixes of different land-use types. This system does not capture information about environmental

transformation by hunter-gatherers, involving the use of fire, resource depression and extinction, creation of landscape features, modification of hydrology, management and relocation of plants, all without the development of agriculture. Furthermore, it may not adequately cater for hybrid subsistence forms, such as seasonal resource selection between hunting/fishing and cultivation, or cultures integrating aspects of either over longer periods of time. Changes in the relative prevalence of subsistence modes may not always be a progressive intensification of land use.

Expertise

Contributors were asked to rate their own expertise at each time slice based on the following rubric:

None	Low	High
You are unfamiliar with the archaeology of the region.	You have a general knowledge of the archaeology of the region and are aware of the sources of information concerning past land use, though you do not actively engage with the scholarship of the region.	You have conducted or currently conduct fieldwork in the region, or you actively engage with the scholarship concerning past land use. You are up to date on the published findings of other archaeological projects in the region.

Data quality

Contributors were asked to rate the quality of archaeological data pertaining to past land use at each time slice based on the following rubric:

Unknown	Moderate	Good
The region is unstudied archaeologically, or you are unaware of any published scholarship pertaining to past land use.	A few areas may be well studied, but large areas of spatial uncertainty remain. Detailed analyses of floral and faunal remains have been limited to several sites.	Many areas have been surveyed, producing a good understanding of where sites are located. Many sites have been well-studied with modern methods, yielding secure dates and analysis of floral and faunal remains. There is broad consensus about such topics as mode of subsistence and the use of specific domesticates.

This rubric does not capture the full range of scenarios for data quality or sources of information bearing on past land use in every region. For example, in certain regions at certain time periods much information on past patterns of subsistence is solely known from textual sources rather than the archaeological record. The system also does not differentiate between data from archaeological sites and Quaternary science research (e.g. lake cores, peat profiles) which may provide relevant data, but with different temporal

resolution, spatial relevance, biases, and implications for interpretation. Respondents almost certainly relied on their knowledge of multiple data sources in their assessments of land use and data quality, yet the relative importance and quality of different data sources was not measured.

To serve as another indicator of the amount of archaeological data in each region, contributors were asked to estimate the total number of published archaeological excavations based on five options: None, < 50, 50-249, 250-499, 500-999, or > 1000. Such estimations are difficult in regions where there is a rapid pace of development and results are not widely published or circulated. These estimations, therefore, have a lower degree of certainty than others, as incomplete knowledge is likely for most contributors.

Sampling Strategy

An email list of 1,380 contacts was developed before and during the survey period using multiple strategies (Table S1). The goal was to include as many contributors as possible from the population of archaeologists with expertise on past land use across the world. This is subject to the caveat that archaeologists working outside the published English-language journal literature might not be effectively reached by the strategies available to us.

Responded to announcement: Announcements about the project, seeking participants, were sent out through the Past Global Changes (PAGES) and ZOOARCH email listservs, and published in the PAGES newsletter (e-news, vol. 2018, no. 5). Recipients of the announcement were encouraged to email ArchaeGLOBE's project coordinator to indicate their interest in participating. These communities were targeted because of the similarity between their interests and the goals and subject matter of the project.

Journal search: We collected initial contacts by searching archaeological journals (*Journal of Field Archaeology, Journal of Archaeological Research, Journal of Archaeological Science, Journal of World Prehistory, Antiquity, Journal of Anthropological Archaeology*) for articles published in the last 10 years with any of the following keywords: land use, landscape, Neolithic, subsistence, agriculture, pastoralism. We then attempted to find publicly available email addresses for each author of relevant articles. Contacts were also added from a list of presenters at the most recent Landscape Archaeology Conference. Three weeks into the survey period, many regions remained unassessed, especially in Africa, Russia, and Southeast Asia. We, therefore, made specific efforts to target researchers with expertise in those areas by performing another keyword search of geographically relevant journals (*Journal of African Archaeology, Azania: Archaeological Research in Africa, African Archaeological Review, Archaeology, Ethnology and Anthropology of Eurasia*). This regionally specific journal search produced an additional 116 contacts.

Contributor suggestion: The core authors added to the contact list from our own personal networks and individuals whom we identified as leading researchers in the field of past land use. Throughout the survey period we encouraged and received suggestions from

respondents for any additional archaeologists who they thought would be interested in participating, especially those with expertise in underrepresented areas.

It is impossible to know how many of the invitations were received. At least 92 email addresses on the list were inactive. Spam filters likely intercepted many invitations. Timing was also an issue. The survey was conducted over the summer in the northern hemisphere (May 18 - July 31) when many archaeologists conduct fieldwork in areas with little or no internet access.

The self-selected group of respondents to the public announcements had the highest participation rate at 65.5%, but this relatively small group accounted for only 9.1% of the total completed contributions. Compared to the other sampling methods, the core authors and contributors were the most effective at identifying large numbers of likely participants. Together they supplied 112 participants from 468 effective contacts for a participation rate of 23.9%. While the journal search method produced a greater number of overall contributors (124), it had the lowest participation rate at 15.7%, and those contributors accounted for a lower percentage of the total responses. Over half (51.1%) of the total contributions came from individuals identified by a core author or contributor.

Analytical and statistical methods

Surveying archaeological knowledge at this meta-scale is imprecise and implies a number of important qualifications. While expert elicitation is generally less susceptible to systemic bias than estimations by non-experts (*56*), the expertise employed must be well-matched to the requested tasks. Respondents were asked to rate their expertise for each region and time slice, but the expertise of most archaeologists is more geographically and temporally limited than the regions and time slices replicate. Respondents were encouraged to generalize based on their knowledge of smaller areas within the regions and on their understanding of the scholarly literature pertaining to the region as a whole. This may have introduced a bias towards overestimating the extent of land use. All the regions exhibit a great degree of internal ecological and cultural variability, but not equally. Therefore, some regions were likely easier to generalise for than others. These factors imply significant variation in the precision of the data, and quantitative claims about past global land use should only be made with careful consideration of the quality of the data.

Following initial data collection, co-authors participated in an open, iterative, two-month process of identifying and correcting for "anomalous" contributions, to produce a set of "consensus" assessments (Figs. S1-5, Table S4). All co-authors were invited to evaluate maps depicting the median assessments for each land-use type, highlight assessments that were not supported by current scholarship, and amend them to produce a set of results for each region and time slice, providing a consensus view of archaeological research on which to base analysis and discussion.

Only a subset of co-authors ultimately participated in three rounds of review and amendment, producing 58 individual changes from the original median assessments across 25 regions, 21 of which received three or fewer survey responses (Table S4). In

disputed cases and in cases of ongoing debate among researchers, preference was given to the original median assessments. The consensus assessments may underestimate the true variance in expert opinion, however the full set of responses, including maps of the original median assessments, as well as maps of the minimum and maximum assessments are available online on the project's Dataverse page (https://dataverse.harvard.edu/dataverse/ArchaeoGLOBE).

We estimated smooth, time-varying trends from the raw survey responses using a generalized additive mixed model, a type of nonlinear, multilevel regression model. The ordered categorical survey data were assumed to arise from a latent variable following a logistic distribution, and the model identified a series of cut points corresponding to the probabilities of the latent variable falling within each of possible response categories (*57*). The influence of individual survey contributors was modelled with a contributor-specific random intercept.

Separate models were fit for each of the land-use and archaeological knowledge variables. Two sets of trends were estimated for each variable type: a global trend fit to all archaeological regions simultaneously, and region-specific deviations from the global trend (*58*). The regional trends were "penalized" towards the global trend, meaning that the model shared information across regions in order to reduce its sensitivity to regions with exceptionally low or noisy responses. The resulting regional and global trends were then clustered using a k-means clustering in order to visualize geographic patterning in regions with similar trends in land use, self-reported expertise, and perceived data quality (Figs. 2, 3, and S6).

The deviance explained by each model (an R^2 analogue preferred for non-normal distributions) is shown in Table S2. All models were fit using the "bam" function in the R package **mgcv** (version 1.8-28), using restricted maximum likelihood to estimate the smooth functions and random effects simultaneously.

HYDE and KK10 land use was compared with ArchaeoGLOBE assessments by computing crop areas in the case of HYDE, and anthropogenic land use in the case of KK10, for each ArchaeoGLOBE region at different time intervals based on HYDE 3.2 and KK10 data (*14*, *15*). Land-use areas for each region at each time slice were then computed relative to total land areas and classified into prevalence levels as a proxy for comparison to ArchaeoGLOBE intensive agricultural area estimates (Figs. 5 & S7).

To investigate whether the abandonment of widespread foraging was more closely correlated with the spread of pastoralism than agriculture, we computed an odds ratio using the consensus responses for foraging, pastoralism and agriculture for all regions during the middle and late Holocene. Odds ratios are used to compare the relative odds of the occurrence of an outcome of interest (i.e spread of pastoralism), given a condition of the variable of interest (i.e. abandonment of widespread foraging (*59*)). We created a table of counts of regions that show a decline in foraging over time (from 10,000 BP to 2,000 BP), and counts of regions where pastoralism is more widespread than intensive agriculture at an arbitrary time point, in this case 2,000 BP. We then computed an odds

ratio for this table, and if the result is greater than one, we can conclude that the outcome of pastoralism more widespread than agriculture after widespread foraging is abandoned is more likely than an alternative outcome.

We input these regions into a generalized linear model and computed a likelihood ratio test to obtain a statistic and p-value. The odds ratio for this table is 2.267, with a p-value of 0.022. This indicates that that claim of pastoralism being more widespread than agriculture after widespread foraging is abandoned is supported by the data.

To enable re-use of our materials and improve reproducibility and transparency according to the principles outlined in (*60*), we include the entire R code used for all the analysis and visualizations contained in this paper in our repository at https://doi.org/10.7910/DVN/6ZXAGT. All of the figures presented here can be independently reproduced with the code and data in this repository. In our repository our code is released under the MIT licence, our data as CC-0, and our figures as CC-BY, to enable maximum re-use (for more details, see (*60*)).

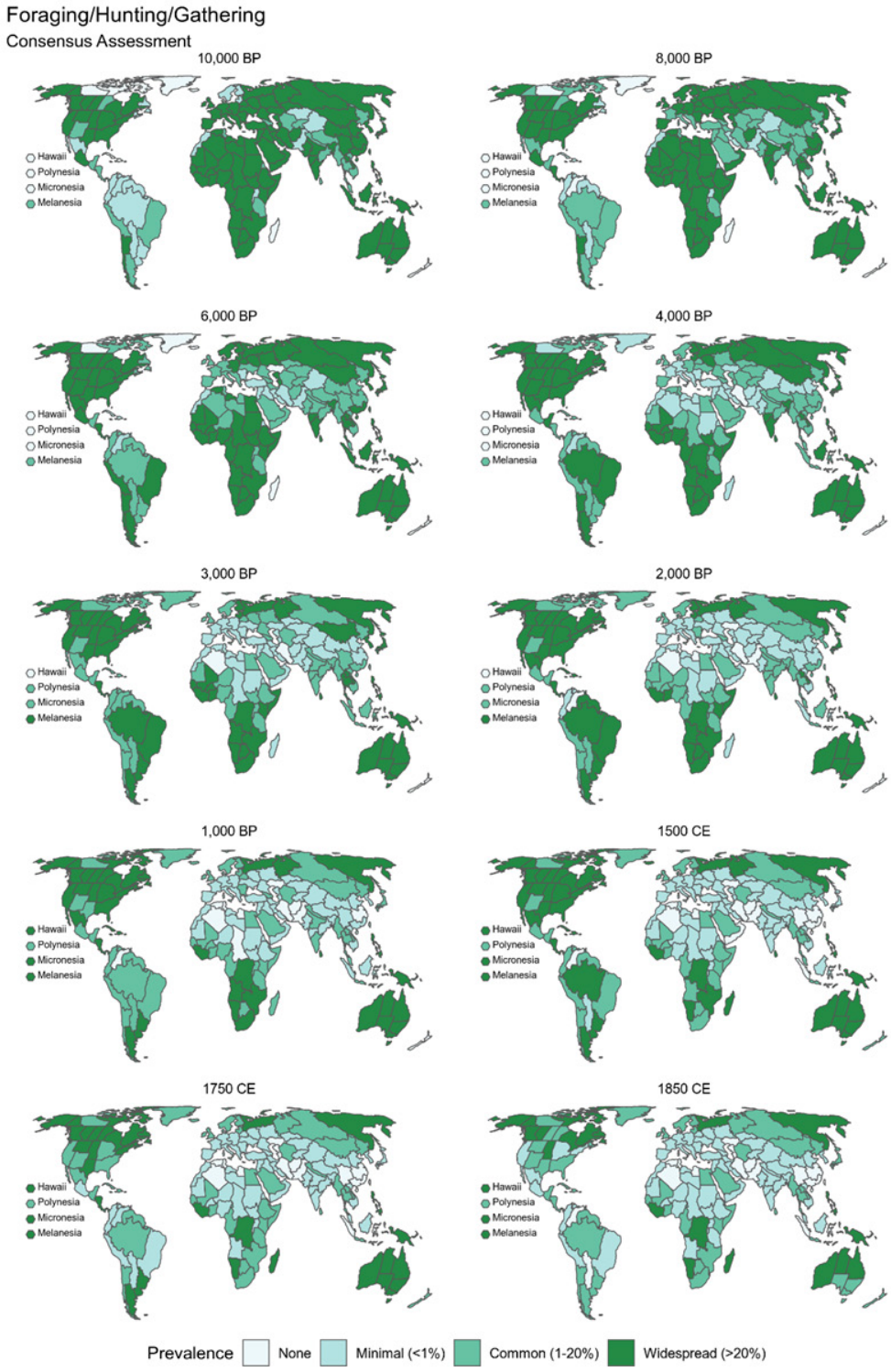

Fig. S1.

Consensus assessment for Foraging/Hunting/Gathering per region for each time slice. Four island regions at left are aggregated into indicator panels; areas are greatly exaggerated. Eckert IV projection.

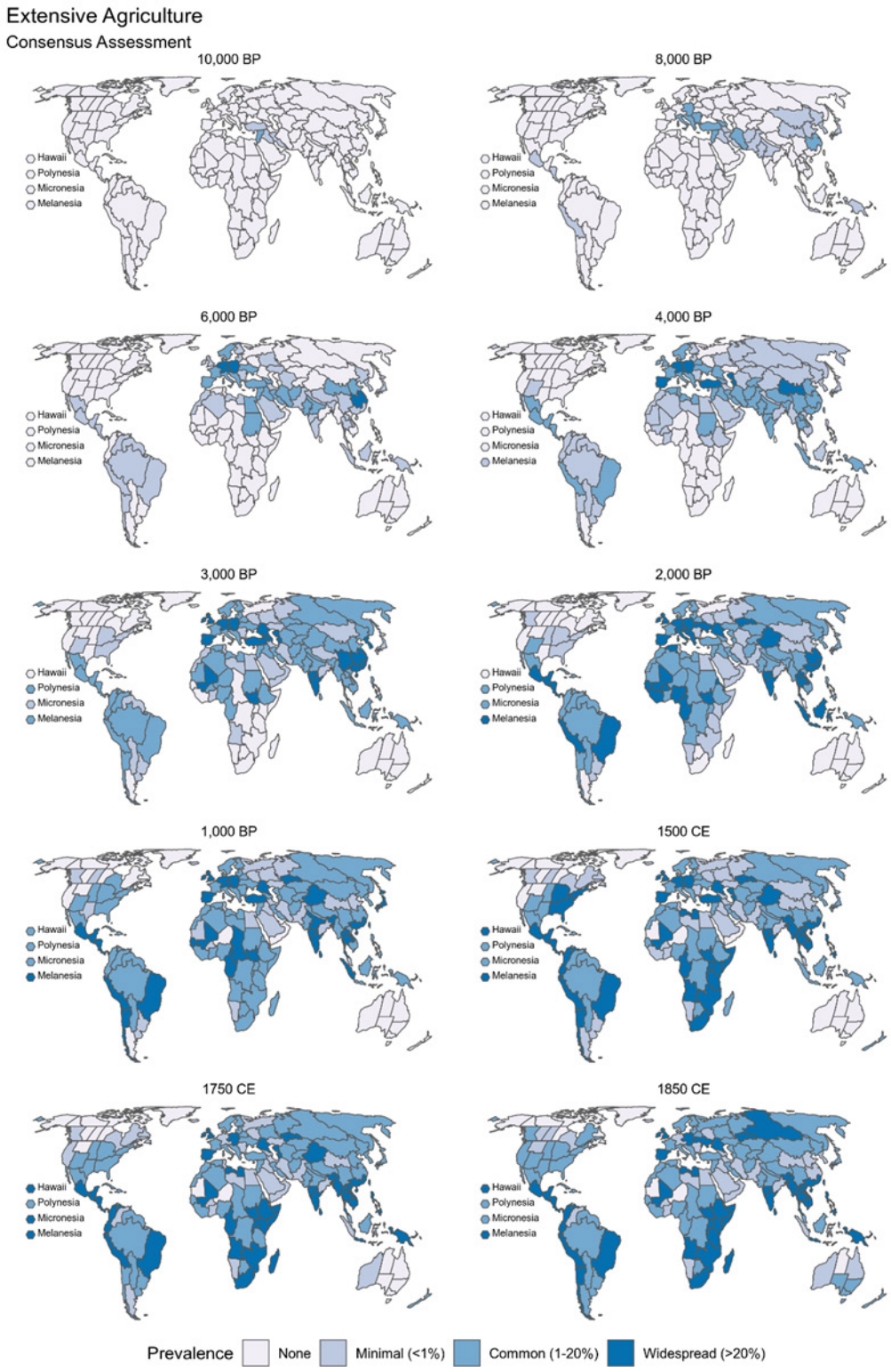

Fig. S2

Consensus assessment for Extensive Agriculture per region for each time slice. Four island regions at left are aggregated into indicator panels; areas are greatly exaggerated. Eckert IV projection.

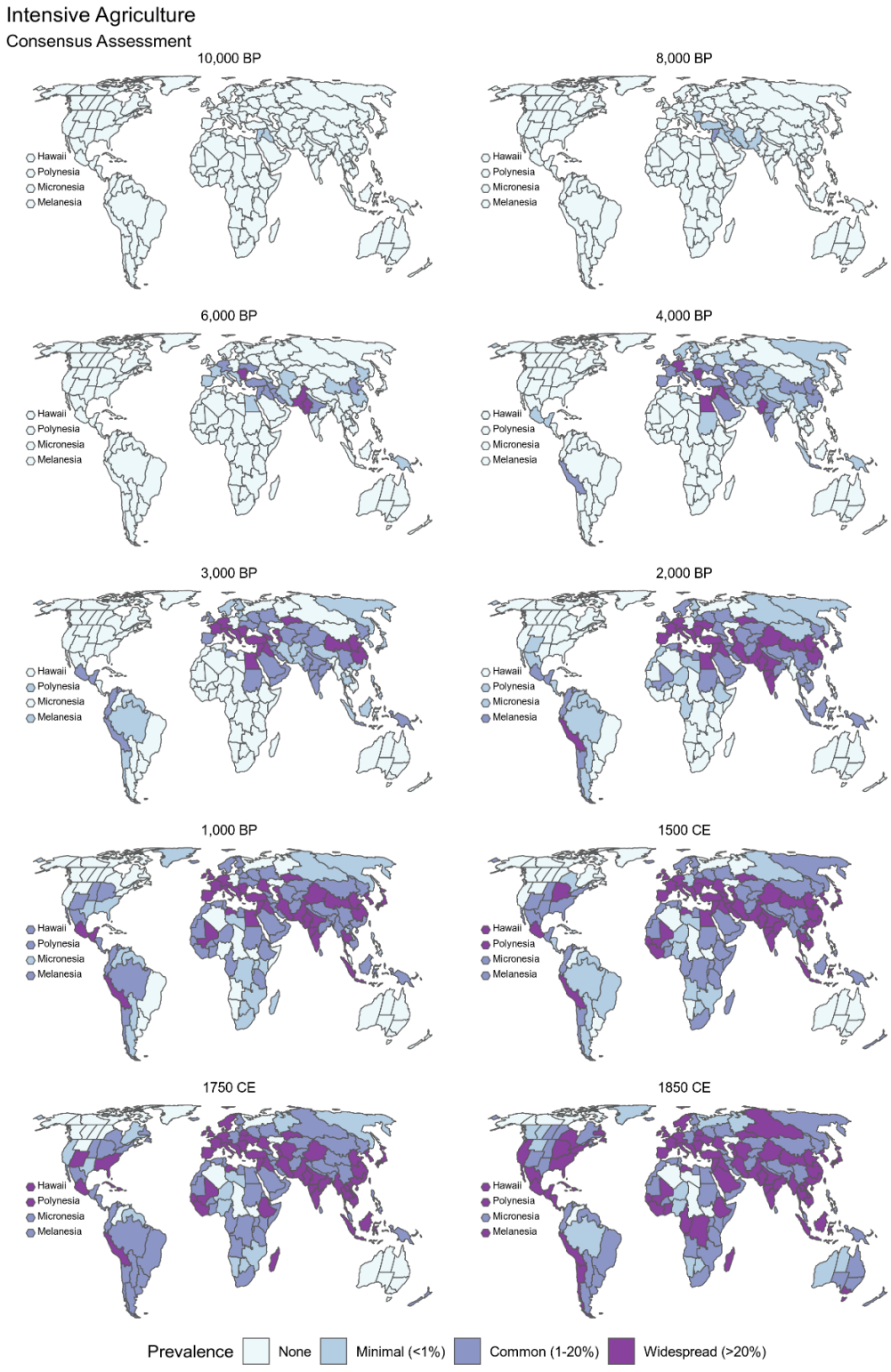

Fig. S3

Consensus assessment for Intensive Agriculture per region for each time slice. Four island regions at left are aggregated into indicator panels; areas are greatly exaggerated. Eckert IV projection.

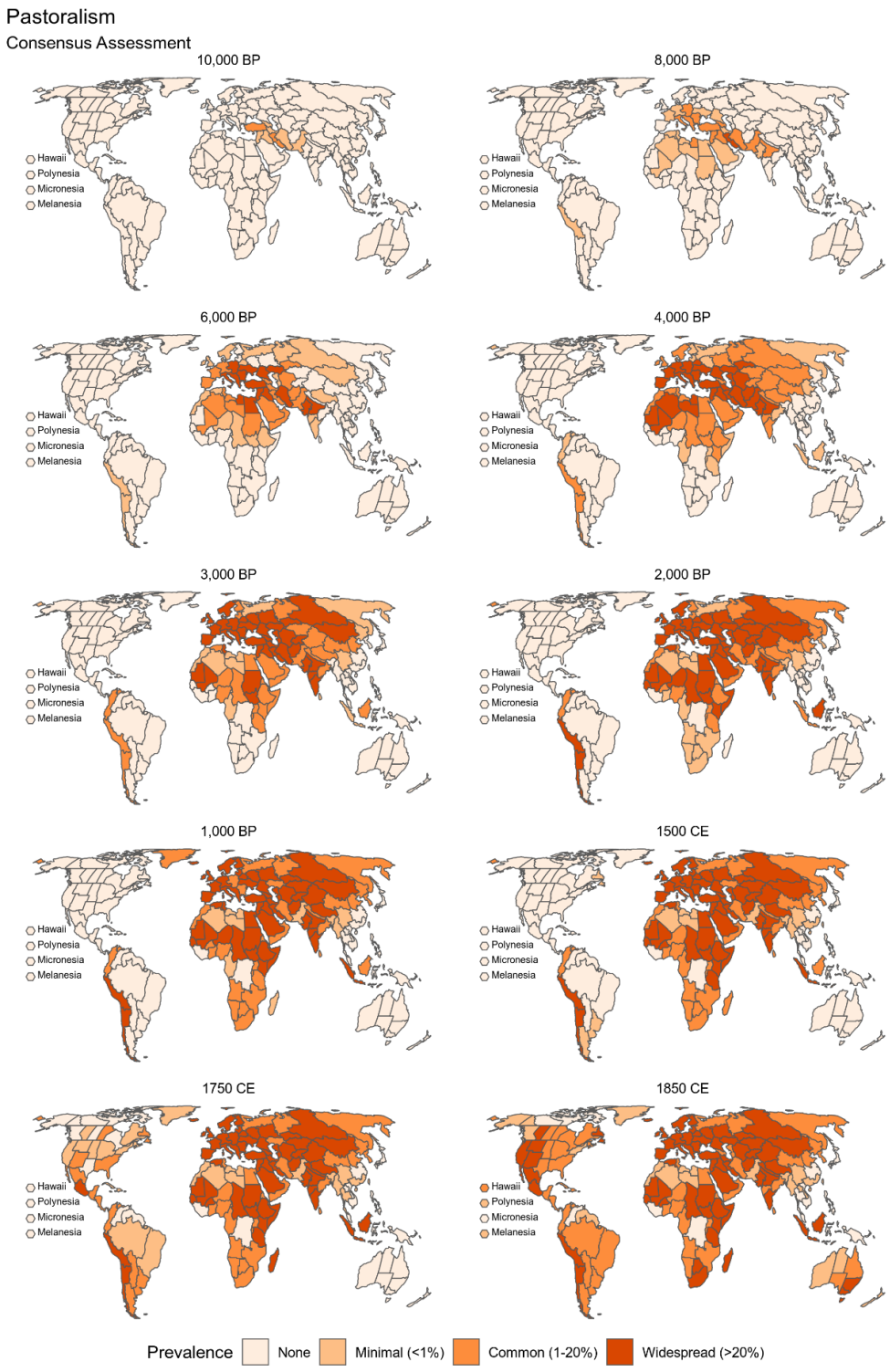

Fig. S4

Consensus assessment for Pastoralism per region for each time slice. Four island regions at left are aggregated into indicator panels; areas are greatly exaggerated. Eckert IV projection.

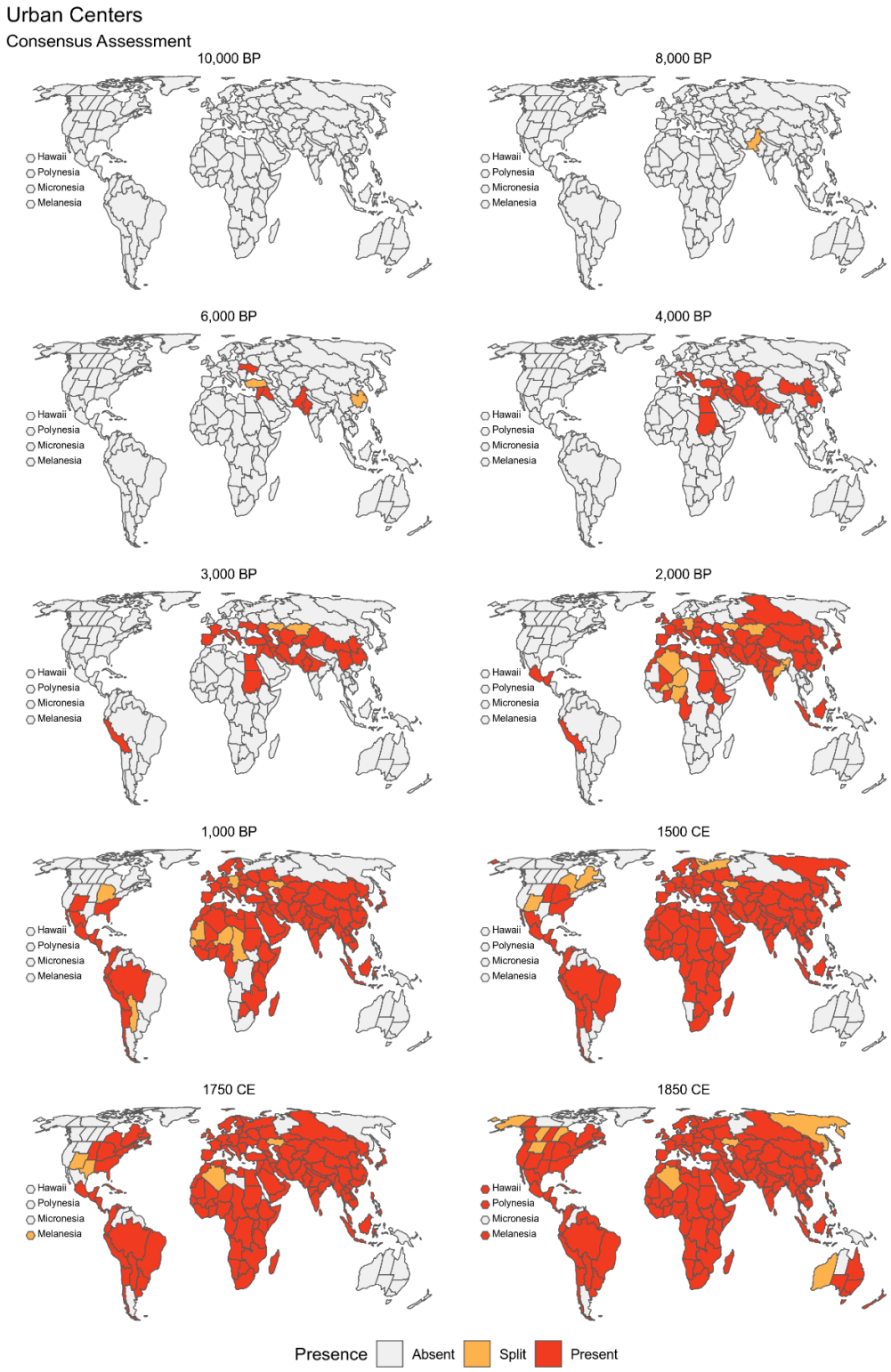

Fig. S5

Consensus assessment for Presence or Absence of High Density Urban Centers for each time slice. Four island regions at left are aggregated into indicator panels; areas are greatly exaggerated. Eckert IV projection.

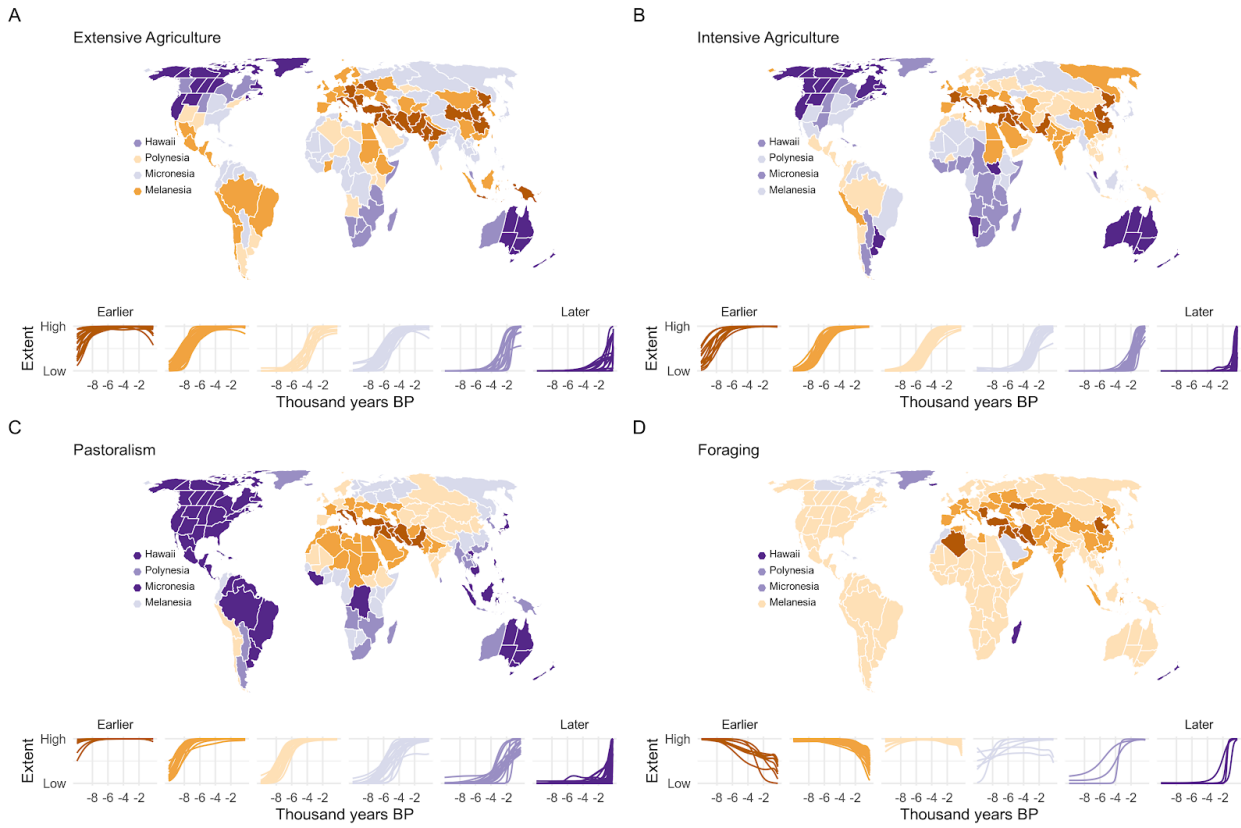

Fig. S6: Patterns of regional land use trends categorized into clusters.

A) Extensive Agriculture, B) Intensive Agriculture, C) Pastoralism, D) Foraging. Regional trends for each land-use type were estimated using a generalized additive mixed model, and regions experiencing similar land-use trajectories were grouped using a k-means clustering algorithm.

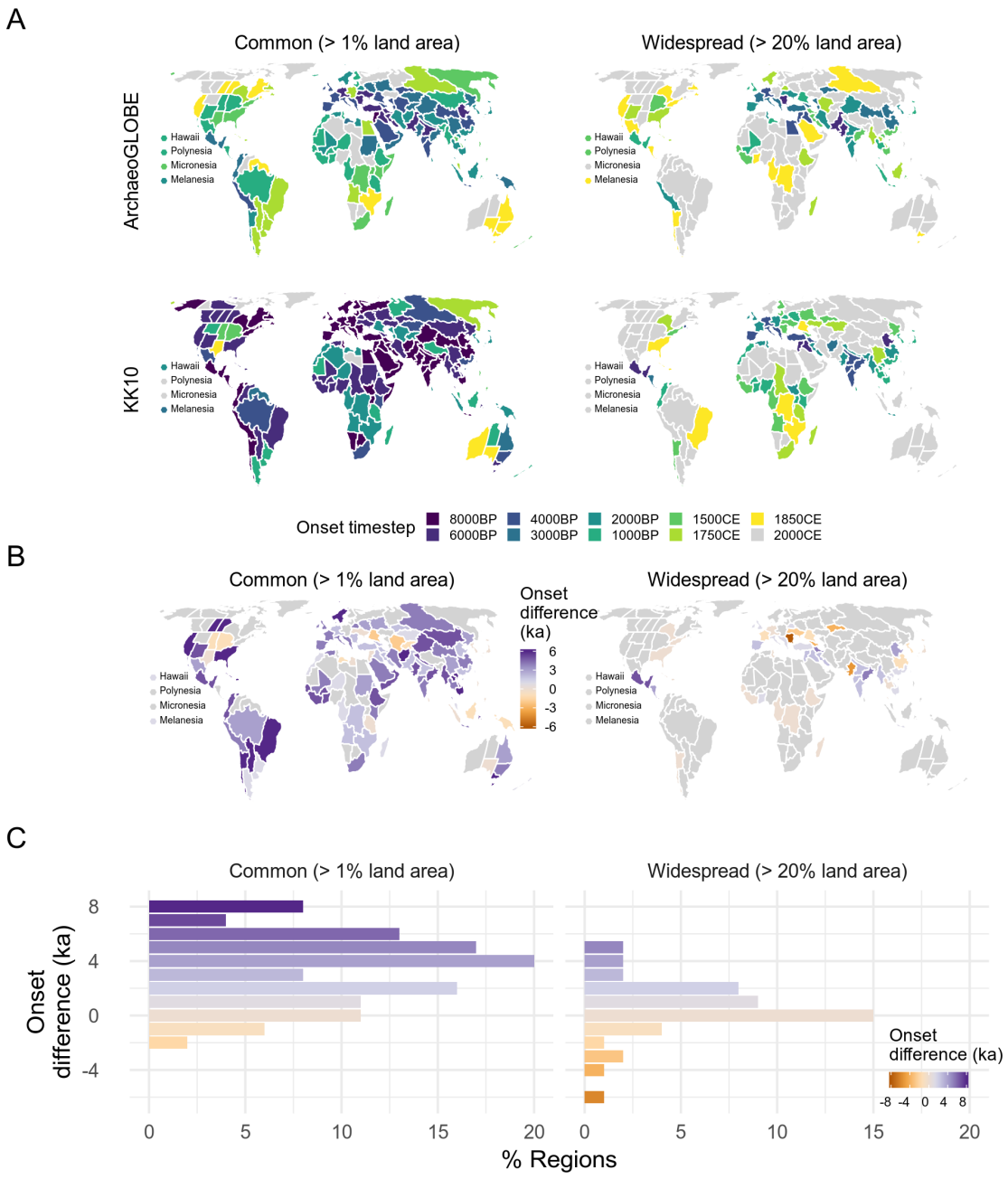

Fig. S7: Comparisons of intensive agricultural onset in ArchaeoGLOBE versus anthropogenic land use in KK10.

A) Onset of intensive agriculture covering >=1% regional area (common level) and >=20% regional area (widespread level) in ArchaeoGLOBE and onset of anthropogenic land use at same prevalence levels in KK10; regions colored in grey did not surpass the associated threshold by 1850CE for ArchaeoGLOBE and 2000CE for KK10. B) Map of differences in onset of intensive agriculture vs. anthropogenic land use at common and widespread levels, in thousands of years; negative numbers highlight earlier ArchaeoGLOBE estimates. C) Distributions of onset timing differences at common and widespread levels, same data and scale as B.

Source	Contacts (% of Total)	Contributors (% of Total)	Contributions Completed (% of Total)	Inactive Email	Incomplete Response	Declined/ Unsubscribed	No Response
Responded to Announcement	30 (2.2%)	19 (7.5%)	65 (9.1%)	1	6	0	4
Journal Search	863 (62.5%)	124 (48.6%)	281 (39.5%)	72	78	17	572
Contributor Suggestion	487 (35.3%)	112 (43.9%)	365 (51.3%)	19	47	13	296
Grand Total	1380 (100%)	255 (100%)	711 (100%)	92	131	30	872

Table S1.
Strategies for identifying possible contributors.

Expertise	41.4%
Data Quality	49.9%
Foraging	57.8%
Extensive Agriculture	65.0%
Intensive Agriculture	86.0%
Pastoralism	92.6%
Urbanism	93.7%

Table S2.

Deviance explained by GAM models.

	Regions where pastoralism was more widespread than agriculture	Regions where pastoralism was less widespread than agriculture
Regions showing a decline in foraging over time	28	39
Regions showing no decline in foraging over time	19	60

Table S3.
Two-by-two frequency table for computing odds ratio.

Region	Name	Land Use & Time Slice	Amendment
2	Yukon Territory	Foraging/Hunting/Gathering 10KBP	Consensus: Widespread Median: Minimal
45	Eastern Europe	Urban Centers 2KBP	Consensus: Split Median: Present
45	Eastern Europe	Urban Centers 1KBP	Consensus: Split Median: Absent
46	Belarus	Extensive Agriculture 8KBP	Consensus: None Median: Minimal
46	Belarus	Extensive Agriculture 6KBP	Consensus: None Median: Common
50	Central Russia	Extensive Agriculture 8KBP	Consensus: None Median: Minimal
50	Central Russia	Extensive Agriculture 6KBP	Consensus: None Median: Minimal
50	Central Russia	Extensive Agriculture 4KBP	Consensus: None Median: Common
50	Central Russia	Intensive Agriculture 4KBP	Consensus: None Median: Minimal
50	Central Russia	Urban Centers 2KBP	Consensus: Absent Median: Present
51	Southern Russia	Extensive Agriculture 6KBP	Consensus: None Median: Minimal
51	Southern Russia	Intensive Agriculture 6KBP	Consensus: None Median: Minimal
52	Volga	Urban Centers 2KBP	Consensus: Absent Median: Present
57	The Caucasus	Extensive Agriculture 10KBP	Consensus: None Median: Minimal
63	Arabia	Foraging/Hunting/Gathering 10KBP	Consensus: Widespread Median: Common
63	Arabia	Extensive Agriculture 6KBP	Consensus: Minimal Median: None
68	Southern Algeria	Pastoralism 3KBP	Consensus: Minimal Median: Widespread
68	Southern Algeria	Pastoralism 2KBP	Consensus: Minimal Median: Widespread

68	Southern Algeria	Pastoralism 1KBP	Consensus: Minimal Median: Widespread
68	Southern Algeria	Pastoralism 1500CE	Consensus: Minimal Median: Widespread
68	Southern Algeria	Pastoralism 1750CE	Consensus: Minimal Median: Widespread
68	Southern Algeria	Pastoralism 1850CE	Consensus: Minimal Median: Widespread
69	Northwestern Libya	Pastoralism 3KBP	Consensus: Minimal Median: Common
69	Northwestern Libya	Pastoralism 2KBP	Consensus: Minimal Median: Widespread
69	Northwestern Libya	Pastoralism 1KBP	Consensus: Minimal Median: Widespread
69	Northwestern Libya	Pastoralism 1500CE	Consensus: Minimal Median: Widespread
69	Northwestern Libya	Pastoralism 1750CE	Consensus: Minimal Median: Widespread
69	Northwestern Libya	Pastoralism 1850CE	Consensus: Minimal Median: Widespread
70	Southern Libya	Pastoralism 3KBP	Consensus: Minimal Median: Common
70	Southern Libya	Pastoralism 2KBP	Consensus: Minimal Median: Widespread
70	Southern Libya	Pastoralism 1KBP	Consensus: Minimal Median: Widespread
70	Southern Libya	Pastoralism 1500CE	Consensus: Minimal Median: Widespread
70	Southern Libya	Pastoralism 1750CE	Consensus: Minimal Median: Widespread
70	Southern Libya	Pastoralism 1850CE	Consensus: Minimal Median: Widespread
71	Northeastern Libya	Pastoralism 3KBP	Consensus: Minimal Median: Widespread
71	Northeastern Libya	Pastoralism 2KBP	Consensus: Minimal Median: Widespread
71	Northeastern Libya	Pastoralism 1KBP	Consensus: Minimal Median: Widespread
71	Northeastern Libya	Pastoralism 1500CE	Consensus: Minimal Median: Widespread

71	Northeastern Libya	Pastoralism 1750CE	Consensus: Minimal Median: Widespread
71	Northeastern Libya	Pastoralism 1850CE	Consensus: Minimal Median: Widespread
74	Mauritania	Urban Centers 6KBP	Consensus: Absent Median: Split
74	Mauritania	Urban Centers 4KBP	Consensus: Absent Median: Split
74	Mauritania	Urban Centers 3KBP	Consensus: Absent Median: Split
76	Mali	Extensive Agriculture 6KBP	Consensus: None Median: Minimal
83	Cameroon, Equatorial Guinea, Gabon, and Republic of the Congo	Intensive Agriculture 3KBP	Consensus: None Median: Minimal
83	Cameroon, Equatorial Guinea, Gabon, and Republic of the Congo	Extensive Agriculture 4KBP	Consensus: None Median: Minimal
85	Angola	Urban Centers 1500CE	Consensus: Present Median: Absent
87	Botswana	Pastoralism 3KBP	Consensus: None Median: Minimal
90	Eritrea and Djibouti	Intensive Agriculture 3KBP	Consensus: None Median: Common
90	Eritrea and Djibouti	Pastoralism 10KBP	Consensus: None Median: Minimal
91	Ethiopia	Intensive Agriculture 3KBP	Consensus: None Median: Minimal
105	Pakistan	Intensive Agriculture 10KBP	Consensus: None Median: Minimal
105	Pakistan	Urban Centers 10KBP	Consensus: Absent Median: Split
119	North Central China	Extensive Agriculture 10KBP	Consensus: None Median: Minimal
120	Northern China	Extensive Agriculture 10KBP	Consensus: None Median: Minimal
123	Eastern China	Extensive Agriculture 10KBP	Consensus: None Median: Minimal
130	Sumatra	Pastoralism 6KBP	Consensus: None Median: Minimal

132	Borneo	Pastoralism 6KBP	Consensus: None Median: Minimal

Table S4.
Differences between consensus and median values for land-use categories.

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