ARCHAEOLOGY

Archaeological assessment reveals Earth's early transformation through land use

ArchaeoGLOBE Project*†

Environmentally transformative human use of land accelerated with the emergence of agriculture, but the extent, trajectory, and implications of these early changes are not well understood. An empirical global assessment of land use from 10,000 years before the present (yr B.P.) to 1850 CE reveals a planet largely transformed by hunter-gatherers, farmers, and pastoralists by 3000 years ago, considerably earlier than the dates in the land-use reconstructions commonly used by Earth scientists. Synthesis of knowledge contributed by more than 250 archaeologists highlighted gaps in archaeological expertise and data quality, which peaked for 2000 yr B.P. and in traditionally studied and wealthier regions. Archaeological reconstruction of global land-use history illuminates the deep roots of Earth's transformation and challenges the emerging Anthropocene paradigm that large-scale anthropogenic global environmental change is mostly a recent phenomenon.

Human societies have transformed and managed landscapes for thousands of years, altering global patterns of biodiversity, ecosystem functioning, and climate (*1*–*6*). Despite increasing interest in the early global environmental changes caused by human activities, from changes in fire regimes and wild animal and plant populations by hunter-gatherers to increasingly intensive forms of agriculture, the global extent, intensity, temporal trajectory, and environmental consequences of Earth's transformation through human land use remain poorly understood outside the archaeological community (*7*–*9*).

Human transformation of environments around the world began with late-Pleistocene hunting and gathering societies and increased throughout the most recent interglacial interval with the emergence of agriculture and urbanized societies. Agricultural land use is implicated in anthropogenic global environmental changes ranging from greenhouse gas emissions and climate change (*5*, *6*, *10*) to widespread deforestation, soil erosion, and altered fire regimes, as well as species introductions, invasions, and extinctions (*4*, *8*, *11*). Such changes are evident even in tropical rainforests and savanna environments long considered pristine (*12*, *13*). However, existing models of long-term changes in global land use (*5*, *14*, *15*) differ substantially in their representation of these early transformations (*8*, *16*), largely owing to limited incorporation of disparate empirical data from archaeology and palaeoecology (*17*, *18*). As a result, global models and assessments of early anthropogenic influence on climate, habitats, biodiversity, and other environmental changes remain poorly characterized (*4*, *10*, *18*, *19*).

Efforts to map land-cover change over the past 10,000 years from pollen data have increased during the past decade, and high-quality regional reconstructions are now available for Europe and the Northern Hemisphere (*20*–*24*). However, global reconstructions that combine both land-use and land-cover change using a range of data sources are rare (*18*, *25*) and have difficulty incorporating environmental data from archaeological sites (*26*). Here, we present a global assessment of archaeological expert knowledge on land use from 10,000 years before the present (yr B.P.) to 1850 CE, showing that existing global reconstructions underestimate the impact of early human land use on Earth's current ecology.

A global synthesis of archaeological knowledge

Archaeologists often study human alterations of environments, but most studies are qualitative or have a local or specialized topical focus [e.g., (*27*–*33*)]. To assess and integrate archaeological knowledge toward synthesis at a global scale, the ArchaeoGLOBE Project used a crowdsourcing approach (*34*, *35*). Archaeologists with land-use expertise were invited to contribute to a detailed questionnaire describing levels of land-use knowledge at 10 time intervals across 146 regional analytical units covering all continents except Antarctica. Contributors selected individual regions where they had expertise; 255 individual archaeologists completed a total of 711 regional questionnaires, resulting in complete, though uneven, global coverage (Fig. 1 and table S1). The result is an expert-based meta-analysis that uses semi-subjective (ranked) survey data to generate regional assessments of land use over time.

Regional-scale archaeological knowledge contributions were sufficient to assess land-use changes in all 146 regions between 10,000 yr B.P. and 1850 CE (Figs. 1 and 2). Overall, self-reported regional land-use expertise increased linearly from 10,000 yr B.P., peaked for 2000 yr B.P., and dropped off sharply thereafter (Fig. 2B), reflecting the decreasing emphasis on environmental archaeological methods in time periods with more abundant material remains and/or historical records. Quality of archaeological data pertaining to past land use (Fig. 2C), determined by the pervasiveness of archaeological surveys, as well as floral and faunal analyses in each region, followed a trend similar to that for expertise, although the peak was somewhat later and more pronounced, and the drop-off was less severe.

Global trends in expertise and data quality, and in published excavations, were heterogeneous across the globe, with consistently higher expertise and data quality across time in regions including, but not limited to, sections of Southwest Asia, Europe, Northern China, Australia, and North America, almost certainly reflecting a greater intensity of archaeological research in these areas. Other areas evidenced relatively low expertise among survey respondents and data quality until the most recent periods, especially parts of Africa, Southeast Asia, and South America.

Global patterns of regional land-use change

In 120 regions (82% of all regions, 88% of inhabited regions at 10,000 yr B.P.), foraging (practices of foraging, hunting, gathering, and fishing) was common (practiced across 1 to 20% of land in region) or widespread (practiced across >20% of region) at 10,000 yr B.P. and declined thereafter (Fig. 3, A and B). Foraging was less than widespread in 40% of all regions by 8000 yr B.P., a decline that expanded to 63% of regions by 3000 yr B.P. By 1850 CE, 73% of regions were assessed with less than widespread foraging, with 51% at the "minimal" (practiced across <1% of land in region) or "none" prevalence levels.

Regional trends of foraging (Fig. 4B and fig. S6D) reveal early declines from 10,000 to 6000 yr B.P. in Southwest Asia, with other regions exhibiting declines in foraging lifeways either gradually, beginning ~4000 yr B.P., or with hardly any declines at all until after 3000 yr B.P. This pattern is congruent with recent global assessments indicating that the majority of domesticated species appeared in the interval from 8000 to 4000 yr B.P., with a smaller number in earlier intervals (*28*).

The current dataset draws attention to the prevalence of agricultural economies across the globe (Fig. 4A) rather than focusing on centers of initial domestication, of which there are now at least 11 worldwide (*28*). At 10,000 yr B.P., these centers were limited to minimal or common components in parts of Southwest Asia. Subsequently, agriculture became much more widespread both through secondary dispersal from

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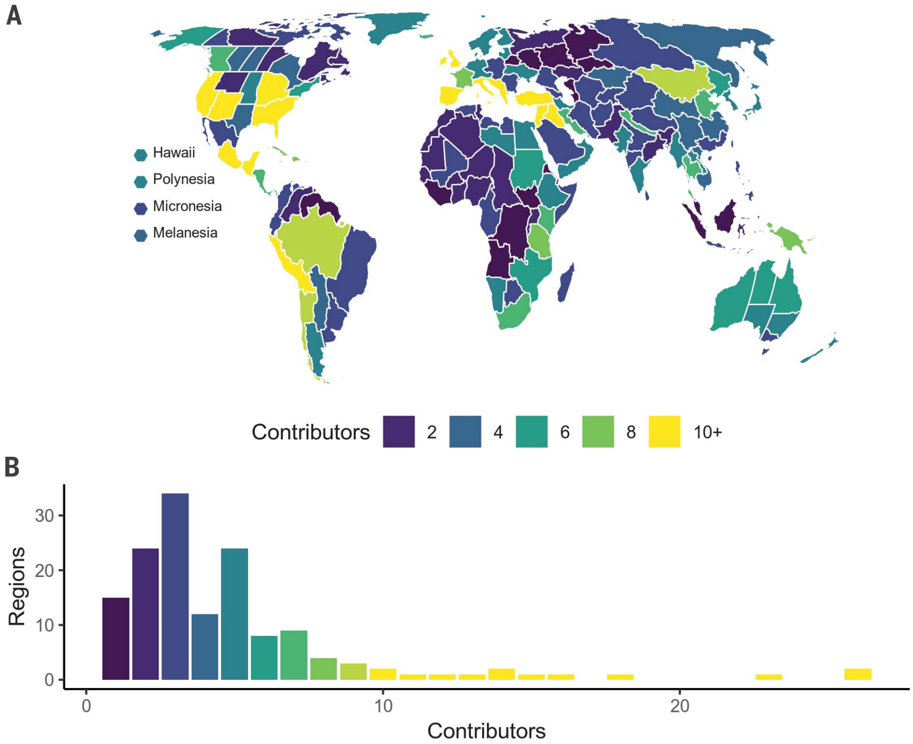

Fig. 1. Archaeological knowledge contributions. (**A**) Geographic distribution of knowledge contributions across 146 regions. The four island regions at left are aggregated into indicator panels with exaggerated areas (Eckert IV projection). (**B**) Histogram showing the distribution of 711 total contributions across regions.

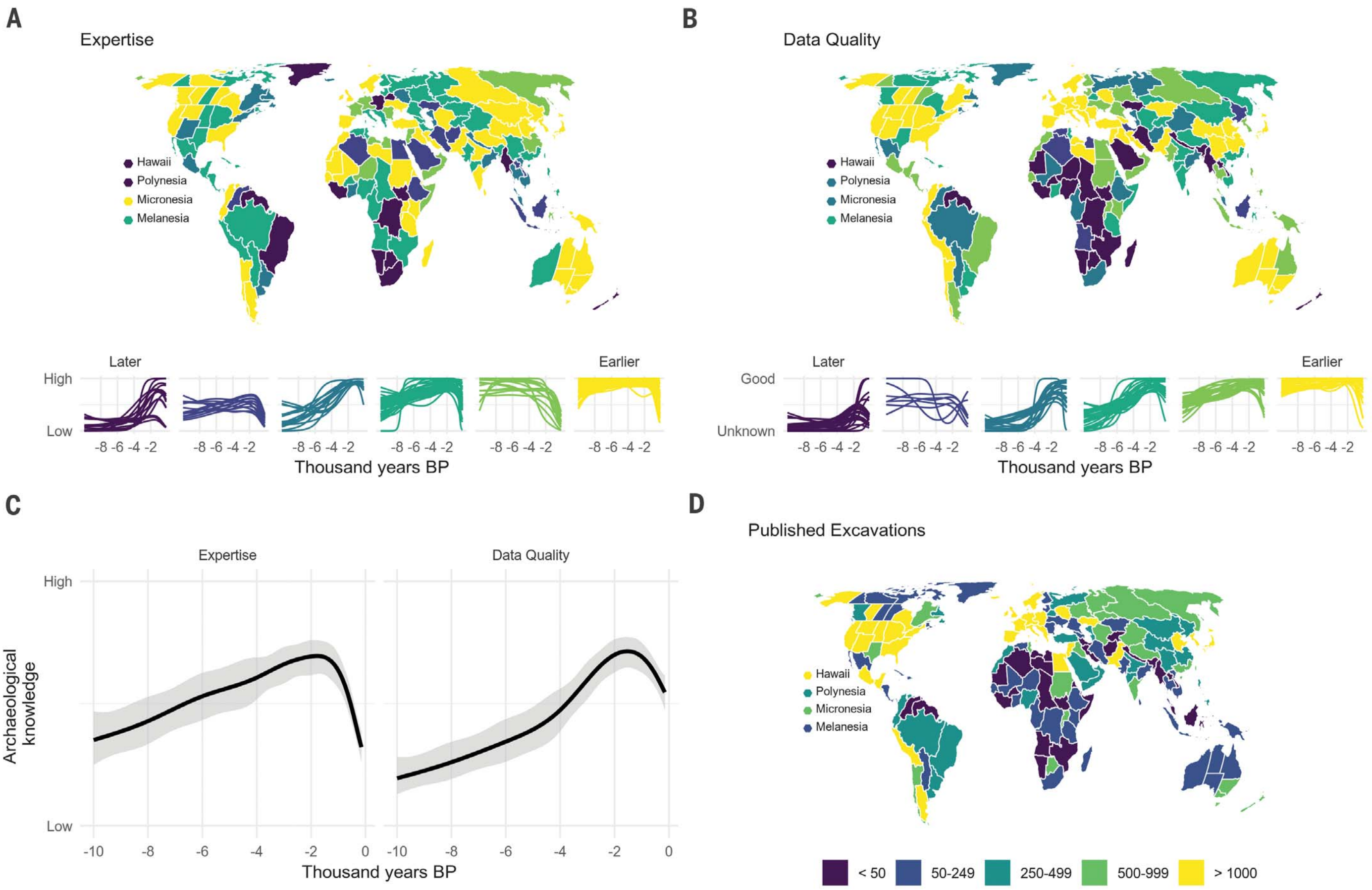

Fig. 2. Archaeological expertise, data quality, and published excavations. (**A**) Regional trends in land-use expertise estimated using a generalized additive mixed model, grouped according to a *k*-means clustering algorithm to show regions with similar temporal trends. (**B**) Regional trends in data quality. (**C**) Global trends in expertise and data quality with 95% confidence intervals. (**D**) Estimated number of published excavations per region.

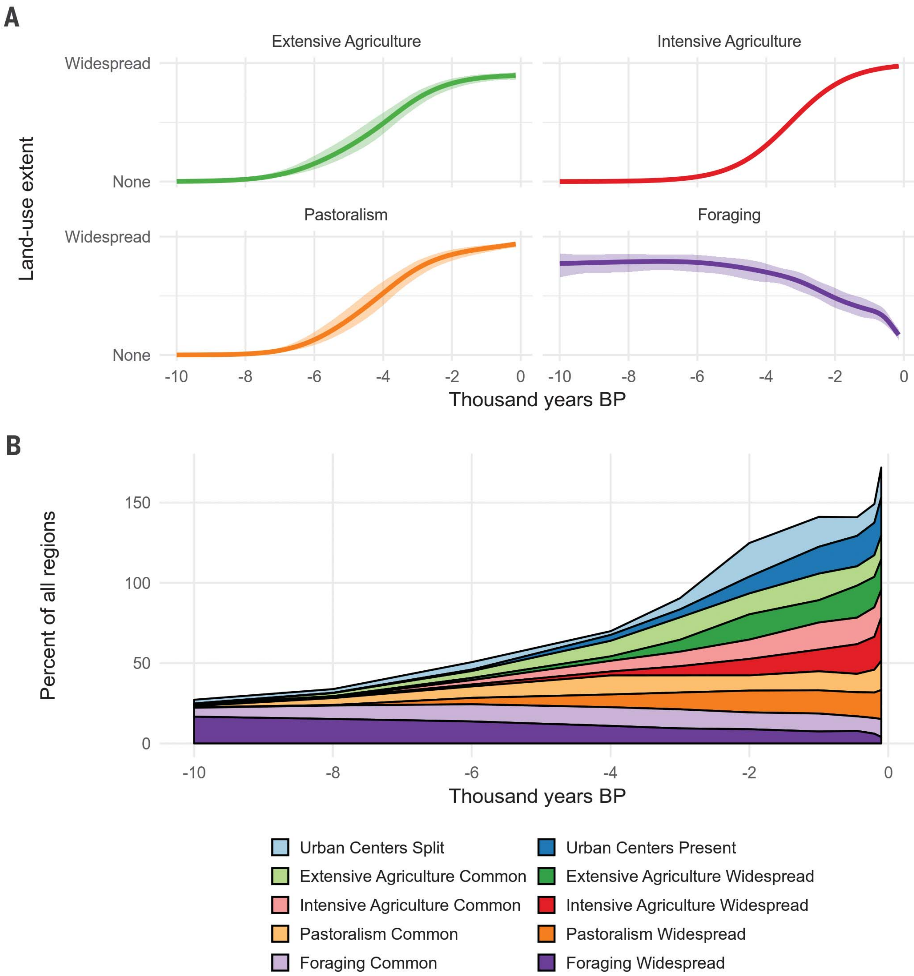

Fig. 3. Summary of global land-use trends. (**A**) Generalized additive mixed-model trends for the extent of each land-use type across all regions with 95% confidence intervals. (**B**) Cumulative summary of regions per land-use category based on consensus assessments (Common, >1 to 20% regional land area; Widespread, >20% regional land area), with presence or absence of urban centers. Categories are nonexclusive, resulting in plot values >100% for all regions.

Southwest Asia and eastern China and through new domestications in the Americas, New Guinea, and Africa. By 6000 yr B.P., 42% of land units had at least minimal extensive agriculture (swidden or shifting cultivation and other forms of noncontinuous cultivation), and it was common in >14% of units. Intensive agriculture (all forms of continuous cultivation) was geographically constricted (the Mediterranean, Southwest Asia, South Asia, and eastern China) and common in only a few regions (12 at 6000 yr B.P.) of suitable climatic conditions until 4000 to 3000 yr B.P., spreading more broadly only after 2000 yr B.P. (65 regions with at least common intensive agriculture at 2000 yr B.P.).

This study also illuminates the relationships between different modes of land use. Pastoralism was connected to agricultural centers of origin in Southwest Asia, East Asia, and the Andes, suggesting a close relationship between both types of production. By 10,000 yr B.P., both agriculture and pastoralism were established in the earliest source regions with a focus first around Southwest Asia and the Mediterranean, but by 8000 yr B.P., pastoralism had spread farther from Southwest Asia, perhaps because of the proximity of this region to arid environments where herding was more productive than farming (Fig. 4A). In the Americas, pastoralism was restricted to its origin in the Andes (present from 8000 yr B.P.) until after 1500 CE with the introduction of western domesticates.

After 6000 yr B.P., the geographic spread of extensive agriculture shows a markedly different pattern than that of pastoralism because of its dispersal from additional source locations in East Asia and the Americas. Over the same time period, pastoralism spread across northern Africa and central Asia and was common or widespread across much of Eurasia and Africa by 4000 yr B.P., including many regions where neither form of agriculture was common until between 4000 and 3000 yr B.P. Not until 3000 yr B.P. was extensive agriculture (75 regions) practiced commonly at a greater geographic scale than pastoralism (64 regions). Patterns of regional land use demonstrate the importance of pastoralist production across arid regions (Fig. 4A), including arid and northern regions where agriculture was unsuitable, and document that the type of management practiced on western Eurasian herd animals was highly adaptable and transferable.

Early onset of intensive land use: Assessments versus models

Regional onsets of intensive agriculture, described by archaeologists, were generally earlier than estimates of cultivated crop areas derived from the most commonly used, spatially explicit global reconstruction of land-use history [the HYDE dataset (*14*)]. ArchaeoGLOBE findings complement previous regional (e.g., Europe) land-cover studies based on palaeoecological data (*36*, *37*). Of the 130 ArchaeoGLOBE regions currently making up Earth's agricultural regions (regions with >1% crop area in HYDE at 2000 CE), 69 archaeological onsets were earlier when assessed at the "common" level, in regions encompassing 54% of global crop area at 2000 CE (Fig. 5C), and >67 were earlier at the "widespread" level (56% of global crop area at 2000 CE; Fig. 5D). Although 26 archaeological onsets at the common level were later than HYDE, including 13 regions later by >1000 years (8.4% of global crop area at 2000 CE), ArchaeoGLOBE onsets were >1000 years earlier in 27 regions encompassing 21.8% of global crop area in 2000. At the widespread level, archaeological onsets were later by ≤250 years in just three regions (5% of 2000 global crop area) and earlier by >1000 years in 21 regions, accounting for 22.0% of global crop area in 2000. By contrast, a comparison with KK10, a less commonly applied historical land-cover change reconstruction known for representing early agricultural transformation of land, showed generally earlier onsets of intensive land use than did ArchaeoGLOBE [fig. S7; (*15*)].

Discussion

The ArchaeoGLOBE dataset highlights broad patterns and consistencies in archaeological data while also identifying exceptions and knowledge gaps. Our data show geographical variability in total number of respondents, expertise level, and data quality, suggesting that the breadth of archaeological knowledge differs greatly from one region to another. Potential causes of geographical inconsistencies in archaeological knowledge include the varying conditions under which archaeologists work, the cumulative legacy and positive feedback of early research interests, and the physical accessibility (both real and perceived) of archaeological sites [see also (*38*)]. Although we made rigorous efforts to recruit archaeological knowledge contributions as widely as possible, biases in the dataset also derive from the anglophone orientation of key project investigators, as well as the limitations of their professional networks. These biases exacerbate historical geographical biases in the pursuit and construction of archaeological knowledge, including the application of environmental archaeological methods. ArchaeoGLOBE respondents may not form a representative sample of global archaeologists, but it is still clear that several regions have seen more intensive archaeological research. Regional hotspots of intensive study are concentrated heavily in Europe, Southwest Asia, and portions of the Americas, a pattern also observed for ecological field sites (*39*) and UNESCO World Heritage sites (*40*).

Regional cold spots that have received much less attention are concentrated in Southeast Asia and Central and West Africa, where resources available for archaeological fieldwork and training are limited. Nonetheless, experts in these regions were able to contribute generalized accounts of land-use trajectories. For instance, archaeobotanical investigations of the cultivation and domestication of indigenous cereals in sub-Saharan Africa (*41*–*43*) are beginning to shed light on earlier and more extensive forms of agriculture. Similar less-investigated indigenous agricultural practices likely characterize parts of Southeast Asia and northern India during the mid-Holocene [e.g., (*44*–*46*)]. Hence, the ArchaeoGLOBE project can help archaeologists prioritize future collection of empirical data and local capacity building to improve the reliability of global perspectives.

Deepening the Anthropocene

Archaeologists and anthropologists have broadly defined "domestication" and, to a lesser extent, "agriculture" [e.g., (*28*)]. However, "hunting and gathering" is a more varied and complex subsistence adaptation than originally conceptualized. Its definition generates debate among scholars by blurring countless variances in land use, resource management, and anthropogenic environmental change. Foraging, or "foraging/hunting/gathering/fishing," was used here to describe subsistence economies and land-use practices that generally exhibit lower amounts of direct human alteration of ecosystems and control of plant and animal life cycles [see (*47*)]. Within this broad category are many forms of resource procurement and land management that have drastically changed landscapes, and we now recognize that foragers may have initiated dramatic and sometimes irreversible environmental change [e.g., (*48*)]. In addition to altering biotic communities around the world through transport and propagation of favored species, extensive early land use by hunter-gatherers may also indicate widespread use of fire to enhance success in hunting and foraging (*49*). Systematic burning has implications for the global carbon cycle through increased greenhouse gas emissions, for water cycles through changes in vegetation and evapotranspiration, and for temperatures through changes in albedo (*50*, *51*).

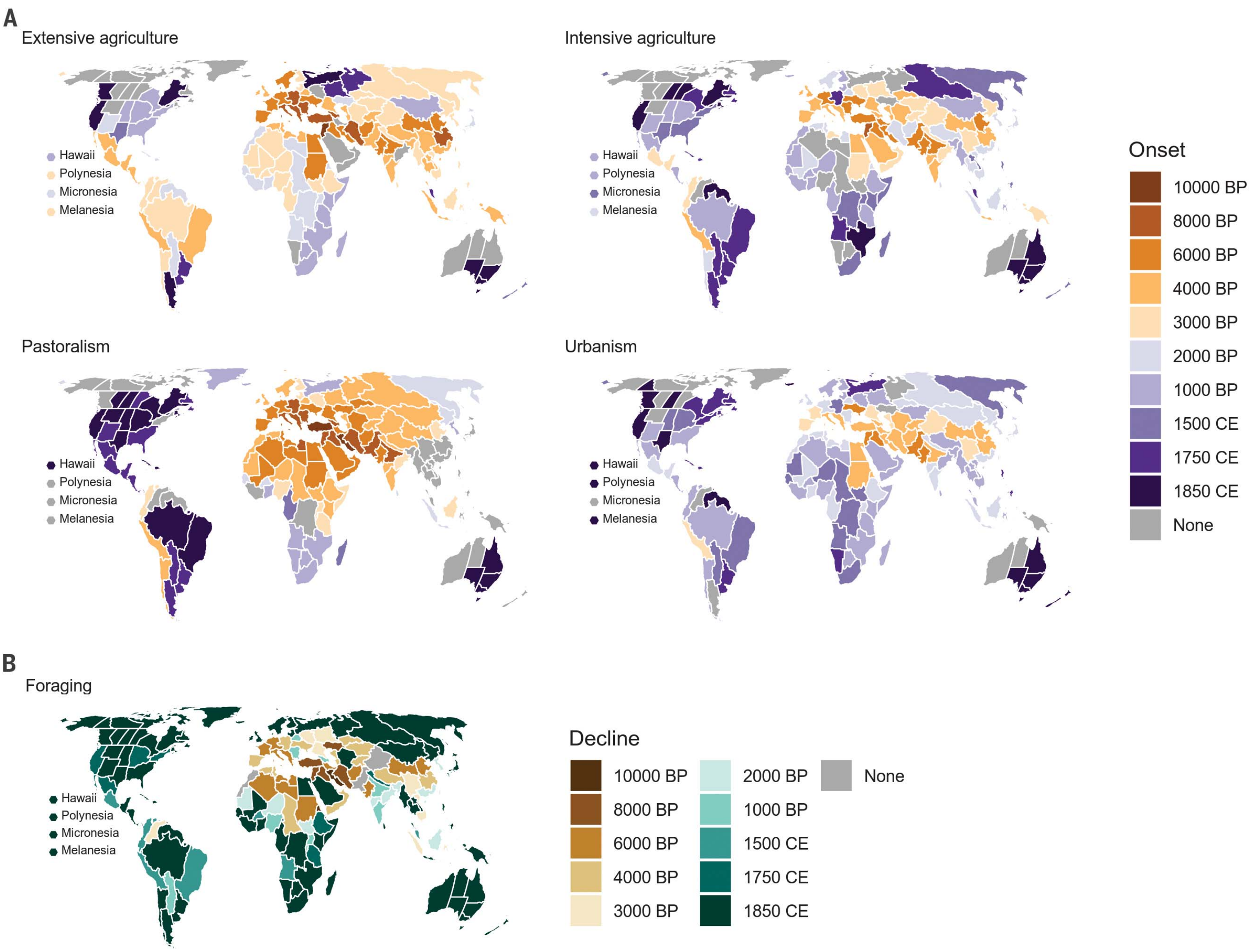

Fig. 4. Regional onsets of land-use categories and decline of foraging. (**A**) Onsets representing the earliest time step assessed at the "common" prevalence level (1 to 20% land area) for extensive agriculture, intensive agriculture, and pastoralism; the earliest time step was assessed as "present" for urbanism. (**B**) Decline representing the latest time step assessed at the "common" prevalence level for foraging.

Globally widespread evidence of hunter-gatherer land use indicates that ecological conditions across most of the terrestrial biosphere were influenced extensively by human activities even before the domestication of plants and animals. Although our dichotomous parsing of hunter-gatherers and agriculturalists is primarily operational, such divisions are still useful. Our data seem to support a unilineal trajectory toward increasingly intensive land use and the replacement of foraging with pastoralism and agriculture, a process that appears largely irreversible over the long term. Such trends also mask more complex pathways, as well as reversals at the local scale in numerous regions. In some parts of the world, agriculture did not simply replace foraging but merged with it and ran in parallel for some time, either as a

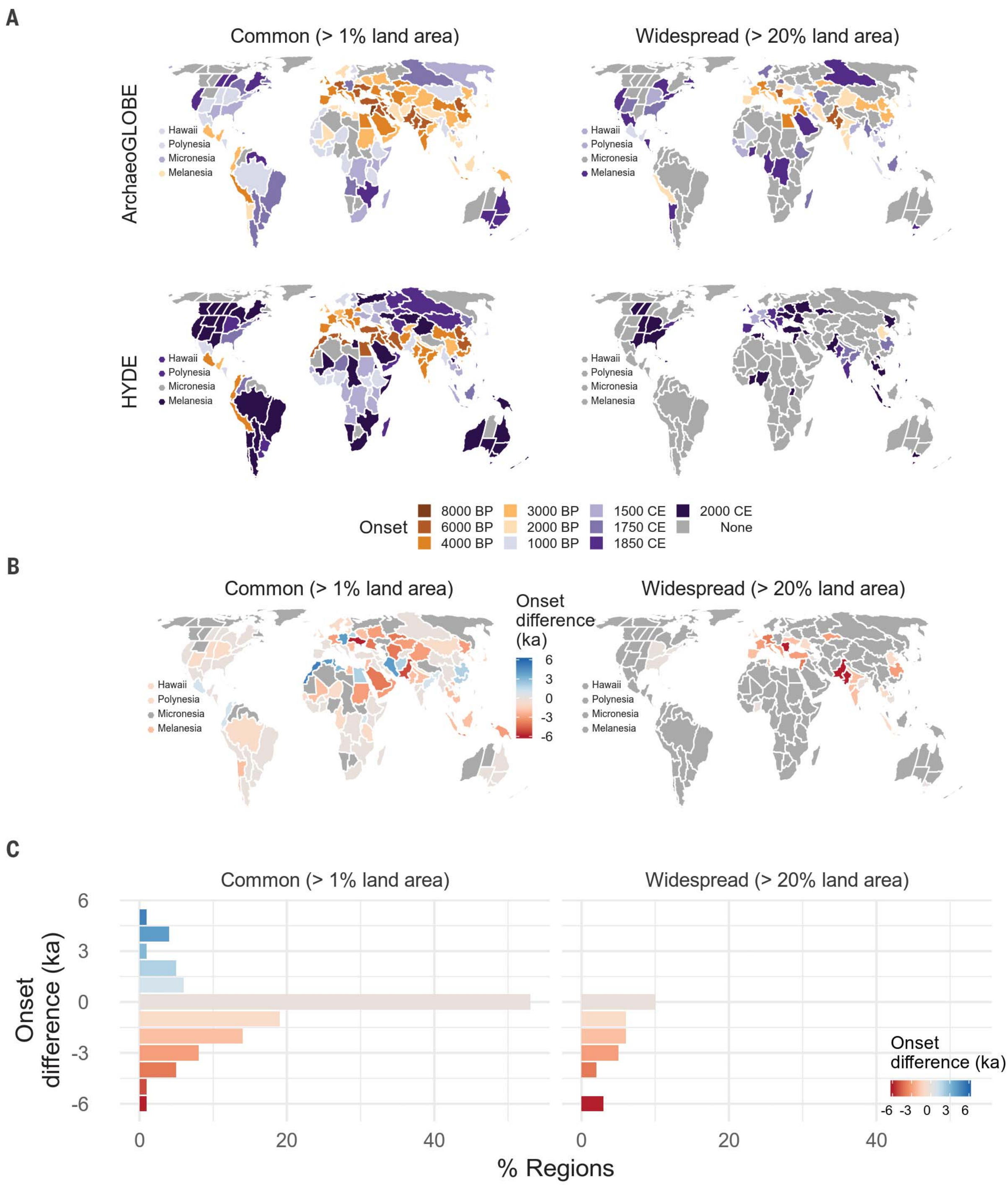

Fig. 5. Comparisons of agricultural onset in ArchaeoGLOBE versus HYDE. (**A**) Onset of intensive agriculture covering ≥1% regional area (common level) and ≥20% regional area (widespread level) in both the ArchaeoGLOBE and HYDE datasets; regions colored in gray did not surpass the associated threshold by 1850 CE for ArchaeoGLOBE and by 2000 CE for HYDE. (**B**) Map of differences in onset of intensive agriculture 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).

patchwork of different peoples or seasonal shifts. The environmental effects of such mixed-mode land use are difficult to see in the archaeological and paleoecological record and are perhaps often missed in the dichotomous view of replacement by more advanced systems. Through time, as land became increasingly densely occupied and land use more intensive, opportunities for flexibility in subsistence strategies and the resilience that this supported were reduced.

This global archaeological assessment of early land use reveals a much earlier and more widespread global onset of intensive agriculture than the spatially explicit global historical reconstruction most commonly used to inform modeling studies of preindustrial vegetation and climate change [HYDE; (*14*)]. However, archaeological onsets of intensive agriculture appeared slightly later than those reported in the less widely used KK10 reconstruction (*15*). Substantial methodological differences and uncertainties between archaeological estimates and historical reconstructions mean that comparisons among ArchaeoGLOBE, HYDE, and KK10 must be treated with caution (*52*). The regional land-use estimates of our study represent a first step toward more accurate, empirically grounded, spatially explicit global reconstructions of long-term changes in land use and provide reference points and procedural approaches to constrain and correct these biases in future work. Our hope is that our global archaeological assessment, and the collaborative approach that it represents, will help to stimulate and support future efforts, such as work currently in progress through the PAGES LandCover6k initiative (*18*, *25*), toward the common goal of understanding early land use as a driver of long-term global environmental changes across the Earth system, including changes in climate.

REFERENCES AND NOTES

1. B. D. Smith, M. A. Zeder, *Anthropocene* **4**, 8–13 (2013).
2. P. V. Kirch, *Annu. Rev. Environ. Resour.* **30**, 409–440 (2005).
3. W. F. Ruddiman, E. C. Ellis, J. O. Kaplan, D. Q. Fuller, *Science* **348**, 38–39 (2015).
4. N. L. Boivin *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **113**, 6388–6396 (2016).
5. J. O. Kaplan *et al*., *Holocene* **21**, 775–791 (2011).
6. D. Q. Fuller *et al*., *Holocene* **21**, 743–759 (2011).
7. E. C. Ellis, M. Maslin, N. Boivin, A. Bauer, *Nature* **540**, 192–193 (2016).
8. E. C. Ellis *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **110**, 7978–7985 (2013).
9. D. M. J. S. Bowman *et al*., *J. Biogeogr.* **38**, 2223–2236 (2011).
10. W. F. Ruddiman *et al*., *Rev. Geophys.* **54**, 93–118 (2016).
11. E. C. Ellis, *Philos. Trans. A Math. Phys. Eng. Sci.* **369**, 1010–1035 (2011).
12. P. Roberts, C. Hunt, M. Arroyo-Kalin, D. Evans, N. Boivin, *Nat. Plants* **3**, 17093 (2017).
13. F. Marshall *et al*., *Nature* **561**, 387–390 (2018).
14. K. Klein Goldewijk, A. Beusen, J. Doelman, E. Stehfest, *Earth Syst. Sci. Data* **9**, 927–953 (2017).
15. J. O. Kaplan, K. M. Krumhardt, The KK10 Anthropogenic land cover change scenario for the preindustrial Holocene, link to data in NetCDF format. PANGEA (2011).
16. M.-J. Gaillard *et al*., *Clim. Past* **6**, 483–499 (2010).
17. K. Klein Goldewijk, M.-J. Gaillard, K. Morrison, M. Madella, N. Whitehouse, *PAGES Mag* **24**, 81 (2016).
18. M.-J. Gaillard, K. Morrison, M. Madella, N. Whitehouse, *PAGES Mag* **26**, 3 (2018).
19. C. N. H. McMichael, F. Matthews-Bird, W. Farfan-Rios, K. J. Feeley, *Proc. Natl. Acad. Sci. U.S.A.* **114**, 522–527 (2017).
20. A. Dawson *et al*., *PAGES Mag* **26**, 34–35 (2018).
21. J. W. Williams, P. Tarasov, S. Brewer, M. Notaro, *J. Geophys. Res. Biogeosci.* **116**, G01017 (2011).
22. B. Pirzamanbein *et al*., *Ecol. Complex.* **20**, 127–141 (2014).
23. A.-K. Trondman *et al*., *Glob. Chang. Biol.* **21**, 676–697 (2015).
24. M. Zanon, B. A. S. Davis, L. Marquer, S. Brewer, J. O. Kaplan, *Front. Plant Sci.* **9**, 253 (2018).
25. K. D. Morrison *et al*., *PAGES Mag.* **26**, 8–9 (2018).
26. T. A. Kohler *et al*., *PAGES Mag* **26**, 68–69 (2018).
27. J. W. Lewthwaite, A. Sherratt, "Chronological atlas," in *Cambridge Encyclopedia of Archeology*, A. Sherrat, Ed. (Cambridge Univ. Press, 1980).
28. G. Larson *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **111**, 6139–6146 (2014).
29. J. M. Erlandson, T. J. Braje, *Anthropocene* **4**, 1–7 (2013).
30. K. W. Kintigh *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **111**, 879–880 (2014).
31. B. S. Arbuckle *et al*., *PLOS ONE* **9**, e99845 (2014).
32. S. S. Downey, W. R. Haas Jr., S. J. Shennan, *Proc. Natl. Acad. Sci. U.S.A.* **113**, 9751–9756 (2016).
33. K. W. Kintigh *et al*., *Adv. Archaeol. Pract.* **3**, 1–15 (2015).
34. Materials and methods are available as supplementary materials.
35. S. Bartling, S. Friesike, Eds., *Opening Science: The Evolving Guide on How the Internet Is Changing Research, Collaboration and Scholarly Publishing* (Springer, 2014).
36. A. Bevan *et al*., *Holocene* **29**, 703–707 (2019).
37. N. Roberts *et al*., *Sci. Rep.* **8**, 716 (2018).
38. T. A. Surovell *et al*., *Am. Antiq.* **82**, 288–300 (2017).
39. L. J. Martin, B. Blossey, E. Ellis, *Front. Ecol. Environ.* **10**, 195–201 (2012).
40. B. S. Frey, P. Pamini, L. Steiner, *Int. Rev. Law Econ.* **60**, 1–19 (2013).
41. K. Manning, R. Pelling, T. Higham, J.-L. Schwenniger, D. Q. Fuller, *J. Archaeol. Sci.* **38**, 312–322 (2011).
42. F. Winchell, C. J. Stevens, C. Murphy, L. Champion, D. Fuller, *Curr. Anthropol.* **58**, 673–683 (2017).
43. A. U. Kay *et al*., *J. World Prehist.* **32**, 179–228 (2019).
44. T. Denham, *Antiquity* **87**, 250–257 (2013).
45. C. O. Hunt, R. J. Rabett, *J. Archaeol. Sci.* **51**, 22–33 (2014).
46. D. Q. Fuller, C. Murphy, *General Anthropology* **21**, 1–8 (2014).
47. D. Rindos *et al*., *Curr. Anthropol.* **21**, 751–772 (1980).
48. H. Raymond, *Annu. Rev. Anthropol.* **36**, 177–190 (2007).
49. D. M. J. S. Bowman *et al*., *Science* **324**, 481–484 (2009).
50. M. Pfeiffer, A. Spessa, J. O. Kaplan, *Geosci. Model Dev.* **6**, 643–685 (2013).
51. N. Nakicenovic, R. Swart, *Emissions Scenarios*. *Special Report of the Intergovernmental Panel on Climate Change* (2000); https://www.osti.gov/etdeweb/biblio/20134132.
52. J. Kaplan *et al*., *Land (Basel)* **6**, 91 (2017).
53. ArchaeoGLOBE Project, ArchaeoGLOBE Public Data, Version 3, Harvard Dataverse (2019).
54. ArchaeoGLOBE Project, ArchaeoGLOBE Regions, Version 6, Harvard Dataverse (2019).
55. ArchaeoGLOBE Project, ArchaeoGLOBE Repository, Version 2, Harvard Dataverse (2019).

ACKNOWLEDGMENTS

Funding: This material is based upon work supported by the National Science Foundation under grant no. CNS 1125210 awarded to E.C.E. in 2011. The full list of author, affiliations, and contributions is in the supplementary materials. **Author contributions**: L.S. led the project team and designed the research. E.E. conceived of and designed the research. D.F., N.B., T.R., N.G., A.K., B.M., C.M.B., J.D.R., J.H., and E.B. assisted with research design. L.S., D.F., N.B., T.R., N.G., A.K., B.M., C.G.D.A., C.M.B., T.D., K.D., J.D., L.J., P.R., J.D.R., H.T., M.A., A.L.J., M.M.S.V., M.A., S.A., G.A., M.T.B., T.B., F.B., T.B., P.I.B., N.G.J.C., J.M.C., A.D.C., C.C., M.N.C., J.C., P.R.C., R.A.C., M.C., A.C., L.D., S.D.L., J.F.D., W.E.D., K.J.E., J.M.E., D.E., E.F., P.F., G.F., R.F., S.M.F., R.F., E.G., S.G., R.C.G., J.D.G., J.H., P.H., P.H., K.A.H., C.H., J.W.I., A.J., J.G.K., B.K., C.K., T.R.K., F.L., D.L., G-A.L., M.J.L., H.B.L., J.A.L-S., S.M., R.M., J.M.M., S.M., M.D.M., A.V.M., M.M., G.M.M., J.M., A.N., S.N., T.M.P., C.E.P., L.P., A.R.R., S.R., G.R.S., K.R., R.S., V.S., P.S., P.S., O.S., I.A.S., A.S., R.J.S., R.N.S., M.L.S., M.J.S., K.M.S., J.T., T.L.T., S.U. M.C.U., M.H.W., C.W., P.R.W., D.K.W., N.W., M.Z., and A.Z., contributed and interpreted data. J.O.K., M-J.G., and K.K.G. interpreted data. L.S., N.G., B.M., M.A., S.M.G., J.P., A.T., and E.E. conducted data analysis. L.S., D.F., N.B., T.R., N.G., A.K., B.M., C.G.D.A., T.D., K.D., J.D., L.J., P.R., J.D.R., H.T., A.L.J., M.M.S.V., J.O.K., M-J.G., K.K.G., and E.E. drafted the article. **Competing interests**: The authors declare no competing interests. **Data and materials availability**: All project data are in the public domain (CC-0) and available at Harvard Dataverse (*53*–*55*).

SUPPLEMENTARY MATERIALS

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22 February 2019; accepted 29 July 2019
10.1126/science.aax1192

Science

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Science **365** (6456), 897-902.
DOI: 10.1126/science.aax1192

A synthetic history of human land use

Humans began to leave lasting impacts on Earth's surface starting 10,000 to 8000 years ago. Through a synthetic collaboration with archaeologists around the globe, Stephens *et al.* compiled a comprehensive picture of the trajectory of human land use worldwide during the Holocene (see the Perspective by Roberts). Hunter-gatherers, farmers, and pastoralists transformed the face of Earth earlier and to a greater extent than has been widely appreciated, a transformation that was essentially global by 3000 years before the present.

Science, this issue p. 897; see also p. 865

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005.

science.sciencemag.org/content/365/6456/897/suppl/DC1

Supplementary Materials for

Archaeological assessment reveals Earth's early transformation through land use

ArchaeoGLOBE Project*

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Published 30 August 2019, *Science* **365**, 897 (2019)
DOI: 10.1126/science.aax1192

This PDF file includes:

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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*)).

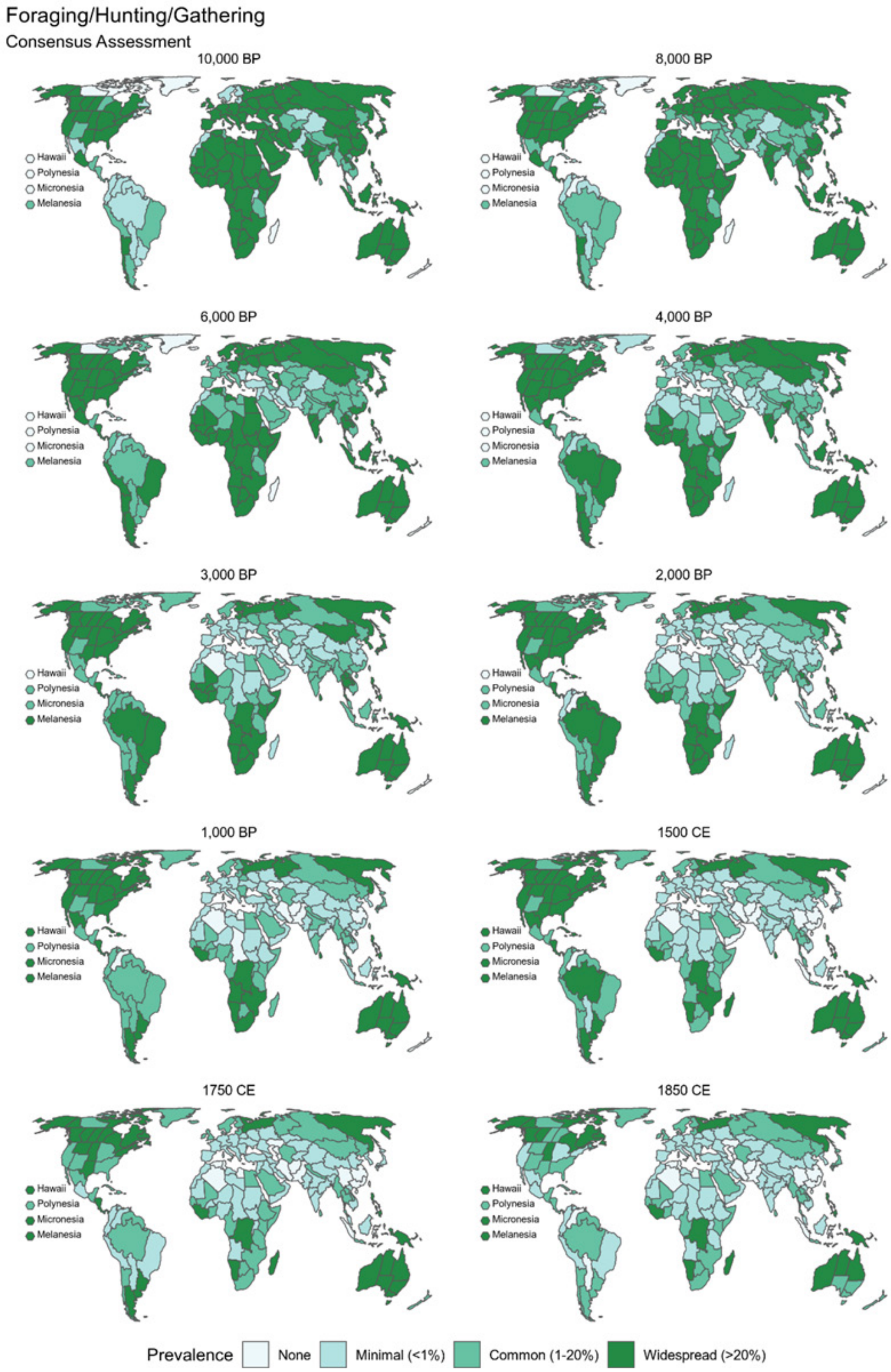

Fig. S1.

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.

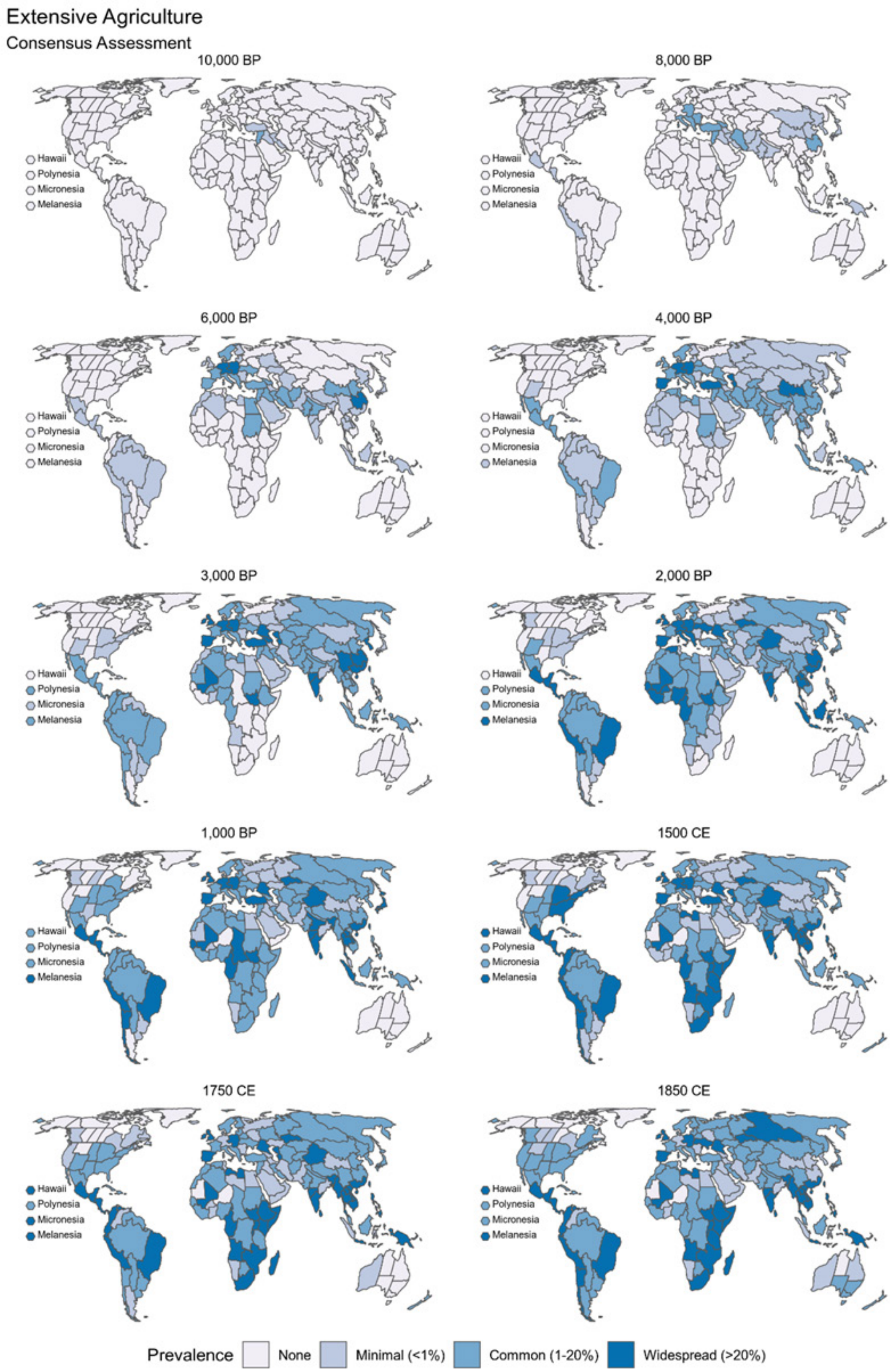

Fig. S2

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.

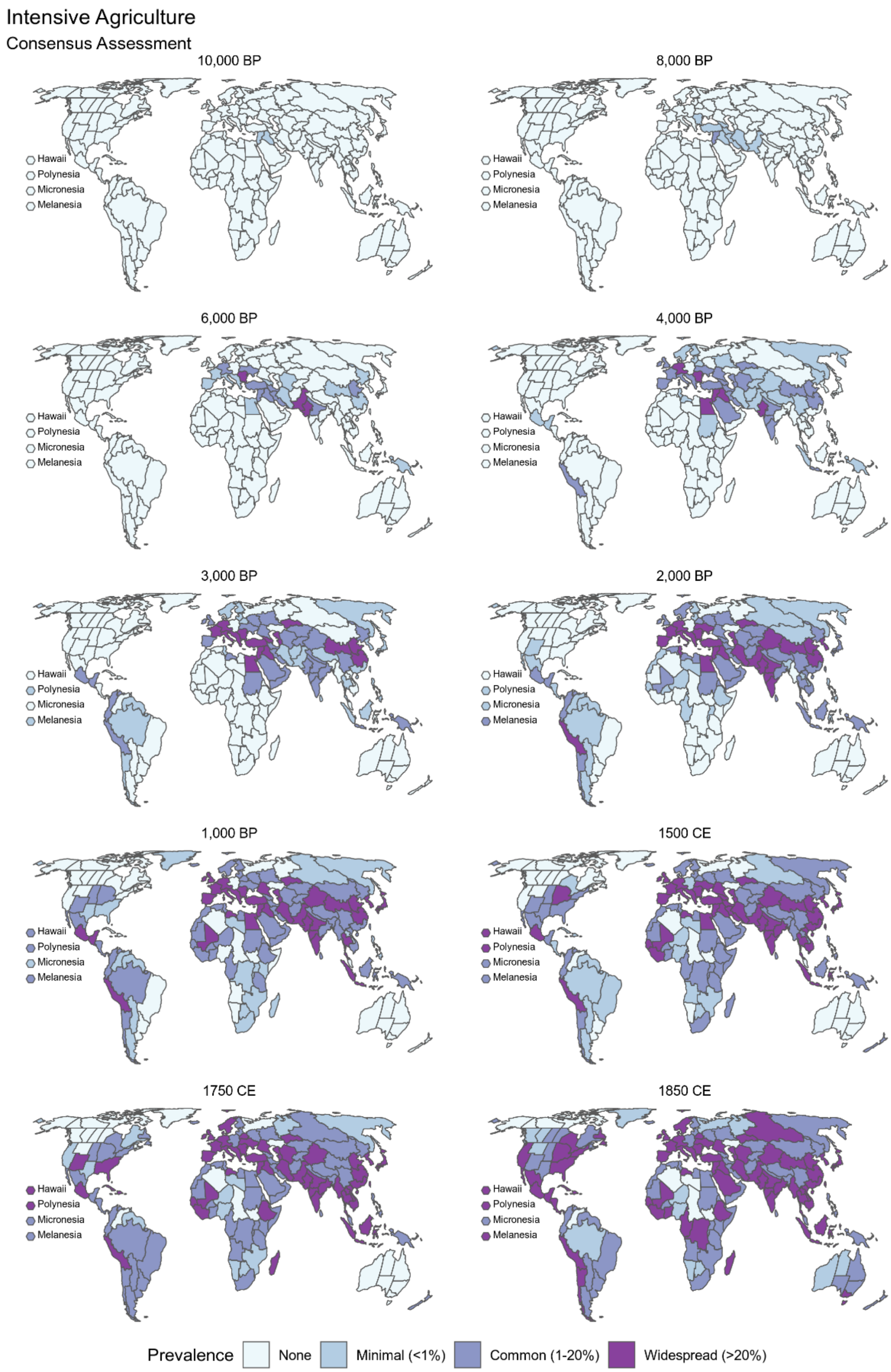

Fig. S3

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.

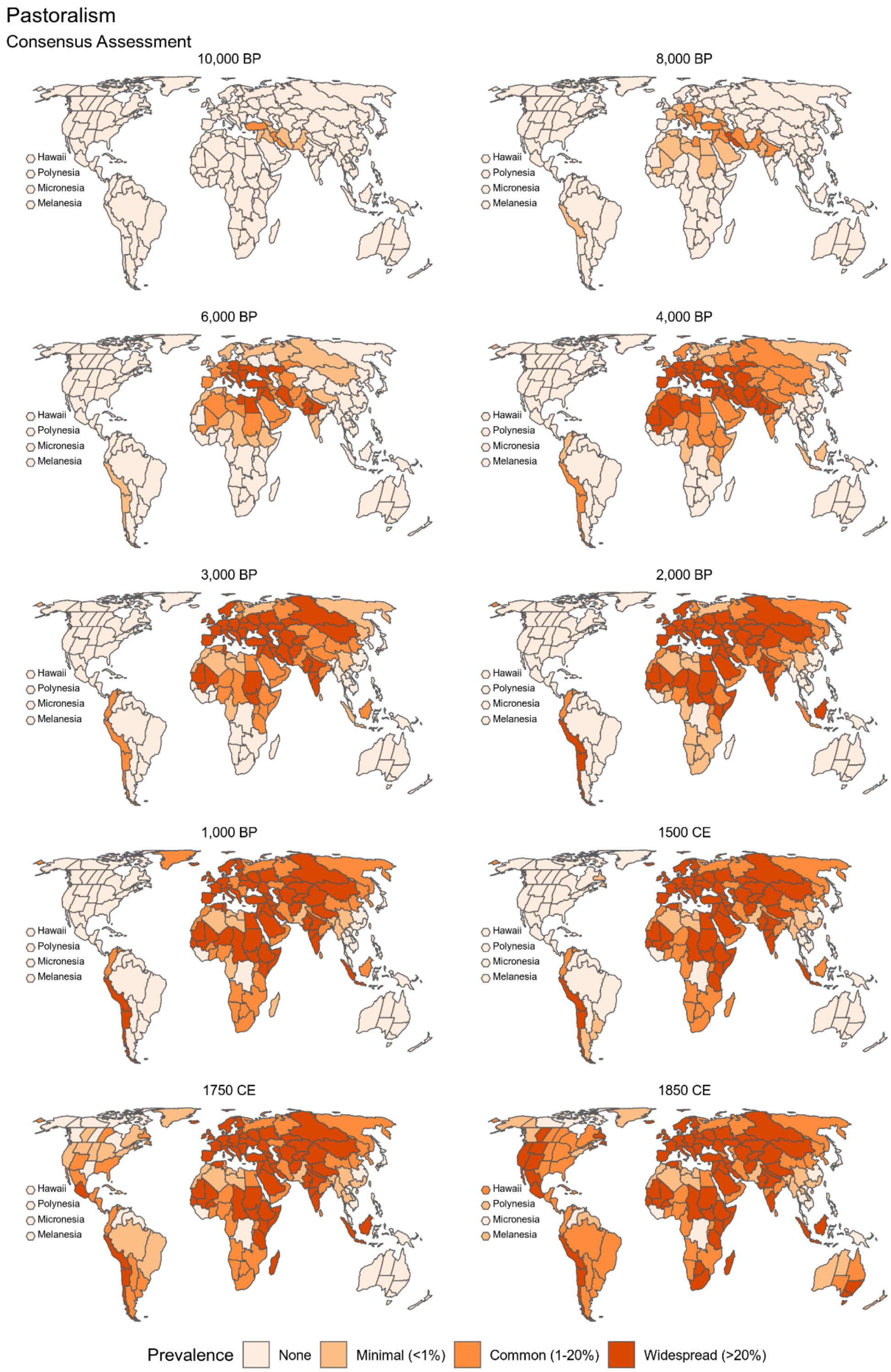

Fig. S4

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.

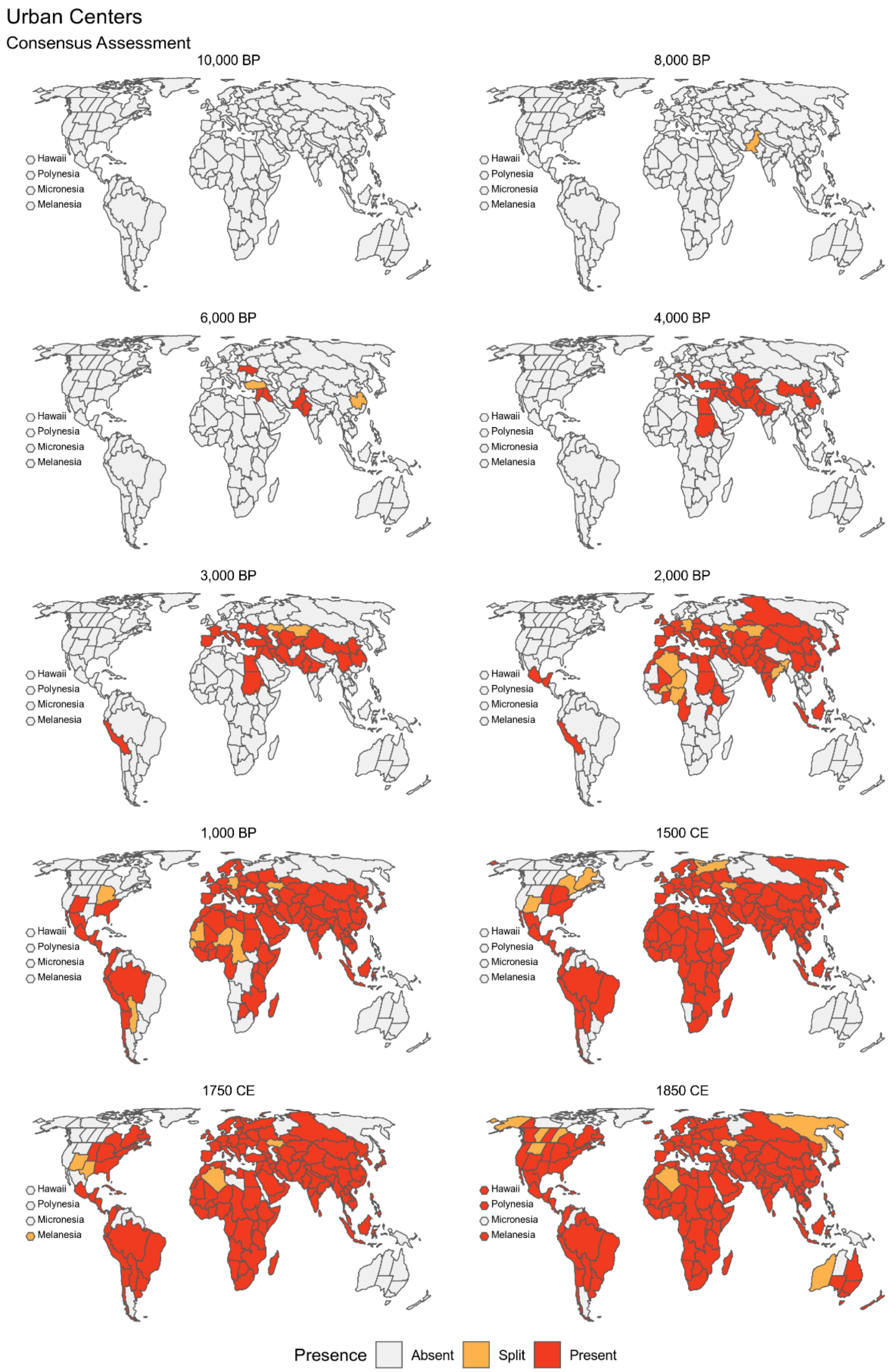

Fig. S5

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.

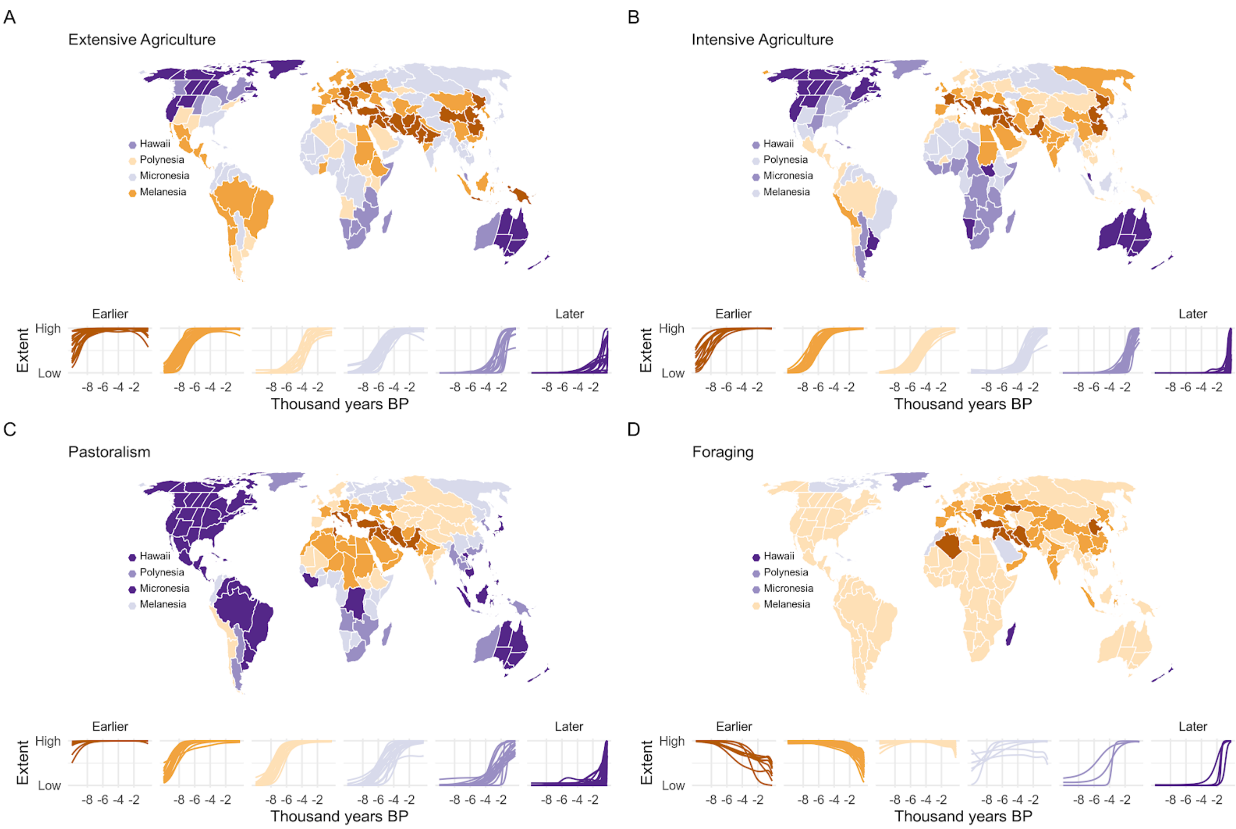

Fig. S6: Patterns of regional land use trends categorized into clusters.

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.

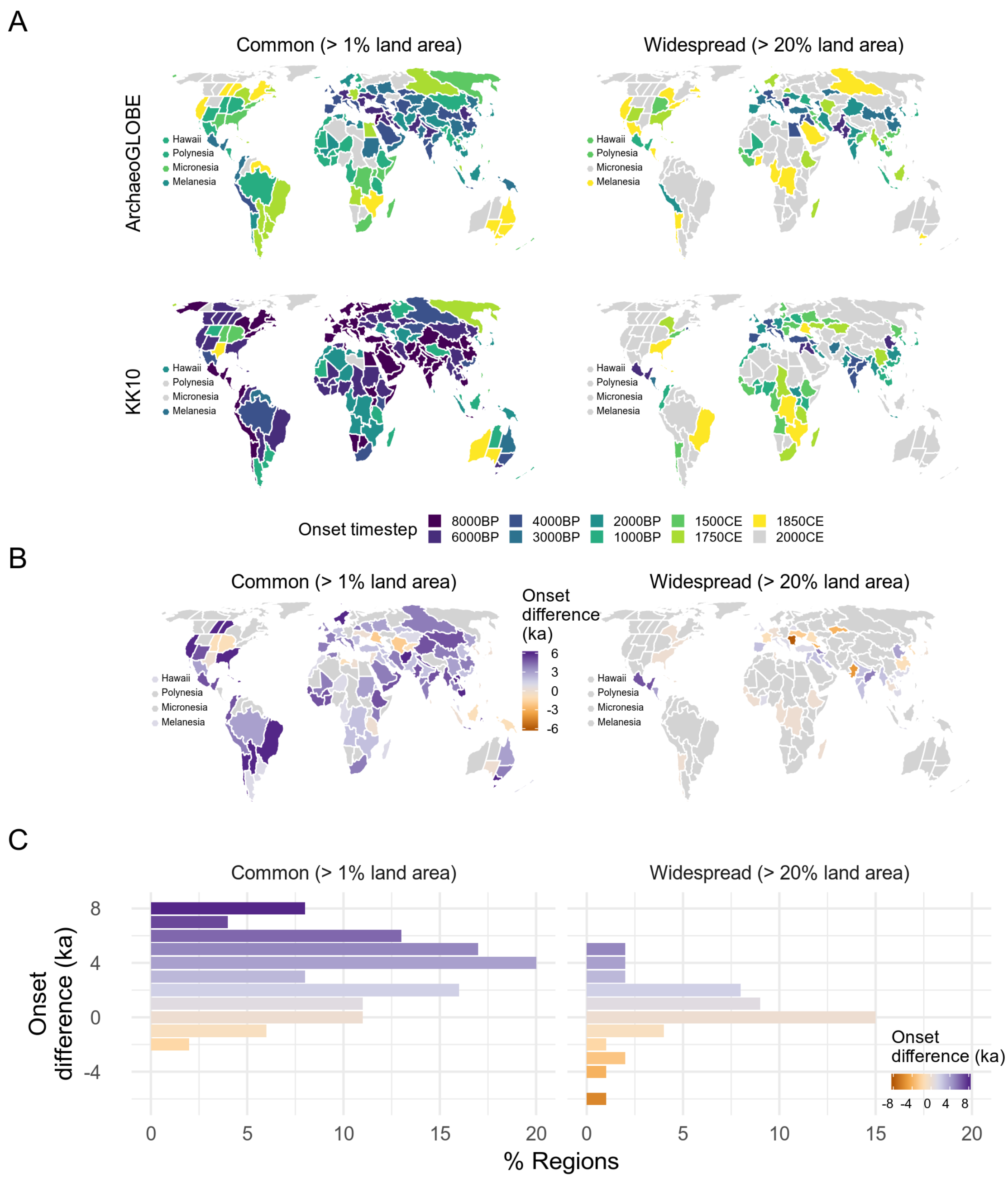

Fig. S7: Comparisons of intensive agricultural onset in ArchaeoGLOBE versus anthropogenic land use in KK10.

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.

References and Notes

1. B. D. Smith, M. A. Zeder, The onset of the Anthropocene. *Anthropocene* **4**, 8–13 (2013). doi:10.1016/j.ancene.2013.05.001

2. P. V. Kirch, Archaeology and global change: The Holocene record. *Annu. Rev. Environ. Resour.* **30**, 409–440 (2005). doi:10.1146/annurev.energy.29.102403.140700

3. W. F. Ruddiman, E. C. Ellis, J. O. Kaplan, D. Q. Fuller, Geology. Defining the epoch we live in. *Science* **348**, 38–39 (2015). doi:10.1126/science.aaa7297 Medline

4. N. L. Boivin, M. A. Zeder, D. Q. Fuller, A. Crowther, G. Larson, J. M. Erlandson, T. Denham, M. D. Petraglia, Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distributions. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 6388–6396 (2016). doi:10.1073/pnas.1525200113 Medline

5. J. O. Kaplan, K. M. Krumhardt, E. C. Ellis, W. F. Ruddiman, C. Lemmen, K. K. Goldewijk, Holocene carbon emissions as a result of anthropogenic land cover change. *Holocene* **21**, 775–791 (2011). doi:10.1177/0959683610386983

6. D. Q. Fuller, J. van Etten, K. Manning, C. Castillo, E. Kingwell-Banham, A. Weisskopf, L. Qin, Y.-I. Sato, R. J. Hijmans, The contribution of rice agriculture and livestock pastoralism to prehistoric methane levels: An archaeological assessment. *Holocene* **21**, 743–759 (2011). doi:10.1177/0959683611398052

7. E. C. Ellis, M. Maslin, N. Boivin, A. Bauer, Involve social scientists in defining the Anthropocene. *Nature* **540**, 192–193 (2016). doi:10.1038/540192a

8. E. C. Ellis, J. O. Kaplan, D. Q. Fuller, S. Vavrus, K. Klein Goldewijk, P. H. Verburg, Used planet: A global history. *Proc. Natl. Acad. Sci. U.S.A.* **110**, 7978–7985 (2013). doi:10.1073/pnas.1217241110 Medline

9. D. M. J. S. Bowman, J. Balch, P. Artaxo, W. J. Bond, M. A. Cochrane, C. M. D'Antonio, R. Defries, F. H. Johnston, J. E. Keeley, M. A. Krawchuk, C. A. Kull, M. Mack, M. A. Moritz, S. Pyne, C. I. Roos, A. C. Scott, N. S. Sodhi, T. W. Swetnam, R. Whittaker, The human dimension of fire regimes on Earth. *J. Biogeogr.* **38**, 2223–2236 (2011). doi:10.1111/j.1365-2699.2011.02595.x Medline

10. W. F. Ruddiman, D. Q. Fuller, J. E. Kutzbach, P. C. Tzedakis, J. O. Kaplan, E. C. Ellis, S. J. Vavrus, C. N. Roberts, R. Fyfe, F. He, C. Lemmen, J. Woodbridge, Late Holocene climate: Natural or anthropogenic? *Rev. Geophys.* **54**, 93–118 (2016). doi:10.1002/2015RG000503

11. E. C. Ellis, Anthropogenic transformation of the terrestrial biosphere. *Philos. Trans. A Math. Phys. Eng. Sci.* **369**, 1010–1035 (2011). doi:10.1098/rsta.2010.0331 Medline

12. P. Roberts, C. Hunt, M. Arroyo-Kalin, D. Evans, N. Boivin, The deep human prehistory of global tropical forests and its relevance for modern conservation. *Nat. Plants* **3**, 17093 (2017). doi:10.1038/nplants.2017.93

13. F. Marshall, R. E. B. Reid, S. Goldstein, M. Storozum, A. Wreschnig, L. Hu, P. Kiura, R. Shahack-Gross, S. H. Ambrose, Ancient herders enriched and restructured African grasslands. *Nature* **561**, 387–390 (2018). doi:10.1038/s41586-018-0456-9 Medline

14. K. Klein Goldewijk, A. Beusen, J. Doelman, E. Stehfest, Anthropogenic land use estimates for the Holocene–HYDE 3.2. *Earth Syst. Sci. Data* **9**, 927–953 (2017). doi:10.5194/essd-9-927-2017

15. J. O. Kaplan, K. M. Krumhardt, The KK10 Anthropogenic land cover change scenario for the preindustrial Holocene, link to data in NetCDF format. PANGEA (2011). doi:10.1594/PANGAEA.871369

16. M.-J. Gaillard, S. Sugita, F. Mazier, A.-K. Trondman, A. Broström, T. Hickler, J. O. Kaplan, E. Kjellström, U. Kokfelt, P. Kuneš, C. Lemmen, P. Miller, J. Olofsson, A. Poska, M. Rundgren, B. Smith, G. Strandberg, R. Fyfe, A. B. Nielsen, T. Alenius, L. Balakauskas, L. Barnekow, H. J. B. Birks, A. Bjune, L. Björkman, T. Giesecke, K. Hjelle, L. Kalnina, M. Kangur, W. O. van der Knaap, T. Koff, P. Lagerås, M. Latałowa, M. Leydet, J. Lechterbeck, M. Lindbladh, B. Odgaard, S. Peglar, U. Segerström, H. von Stedingk, H. Seppä, Holocene land-cover reconstructions for studies on land cover-climate feedbacks. *Clim. Past* **6**, 483–499 (2010). doi:10.5194/cp-6-483-2010

17. K. Klein Goldewijk, M.-J. Gaillard, K. Morrison, M. Madella, N. Whitehouse, Uncovering the past: Multidisciplinary research on historic land cover and land use. *PAGES Mag* **24**, 81 (2016). doi:10.22498/pages.24.2.81

18. M.-J. Gaillard, K. Morrison, M. Madella, N. Whitehouse, Past land-use and land-cover change: The challenge of quantification at the subcontinental to global scales. *PAGES Mag* **26**, 3 (2018). doi:10.22498/pages.26.1.3

19. C. N. H. McMichael, F. Matthews-Bird, W. Farfan-Rios, K. J. Feeley, Ancient human disturbances may be skewing our understanding of Amazonian forests. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 522–527 (2017). doi:10.1073/pnas.1614577114 Medline

20. A. Dawson, X. Cao, M. Chaput, E. Hopla, F. Li, M. Edwards, R. Fyfe, K. Gajewski, S. J. Goring, U. Herzschuh, F. Mazier, S. Sugita, J. W. Williams, Q. Xu, M.-J. Gaillard, Finding the magnitude of human-induced Northern Hemisphere land-cover transformation between 6 and 0.2 ka BP. *PAGES Mag* **26**, 34–35 (2018). doi:10.22498/pages.26.1.34

21. J. W. Williams, P. Tarasov, S. Brewer, M. Notaro, Late Quaternary variations in tree cover at the northern forest-tundra ecotone. *J. Geophys. Res. Biogeosci.* **116**, G01017 (2011). doi:10.1029/2010JG001458

22. B. Pirzamanbein, J. Lindström, A. Poska, S. Sugita, A.-K. Trondman, R. Fyfe, F. Mazier, A. B. Nielsen, J. O. Kaplan, A. E. Bjune, H. J. B. Birks, T. Giesecke, M. Kangur, M. Latałowa, L. Marquer, B. Smith, M.-J. Gaillard, Creating spatially continuous maps of past land cover from point estimates: A new statistical approach applied to pollen data. *Ecol. Complex.* **20**, 127–141 (2014). doi:10.1016/j.ecocom.2014.09.005

23. A.-K. Trondman, M.-J. Gaillard, F. Mazier, S. Sugita, R. Fyfe, A. B. Nielsen, C. Twiddle, P. Barratt, H. J. B. Birks, A. E. Bjune, L. Björkman, A. Broström, C. Caseldine, R. David, J. Dodson, W. Dörfler, E. Fischer, B. van Geel, T. Giesecke, T. Hultberg, L. Kalnina, M. Kangur, P. van der Knaap, T. Koff, P. Kuneš, P. Lagerås, M. Latałowa, J. Lechterbeck, C. Leroyer, M. Leydet, M. Lindbladh, L. Marquer, F. J. G. Mitchell, B. V. Odgaard, S. M. Peglar, T. Persson, A. Poska, M. Rösch, H. Seppä, S. Veski, L. Wick, Pollen-based quantitative reconstructions of Holocene regional vegetation cover (plant-functional types

and land-cover types) in Europe suitable for climate modelling. *Glob. Chang. Biol.* **21**, 676–697 (2015). doi:10.1111/gcb.12737 Medline

24. M. Zanon, B. A. S. Davis, L. Marquer, S. Brewer, J. O. Kaplan, European forest cover during the past 12,000 years: A palynological reconstruction based on modern analogs and remote sensing. *Front. Plant Sci.* **9**, 253 (2018). doi:10.3389/fpls.2018.00253 Medline

25. K. D. Morrison, E. Hammer, L. Popova, M. Madella, N. Whitehouse, M.-J. Gaillard, LandCover6k Land-Use Group Members, Global-scale comparisons of human land use: Developing shared terminology for land-use practices for global change. *PAGES Mag.* **26**, 8–9 (2018). doi:10.22498/pages.26.1.8

26. T. A. Kohler, P. I. Buckland, K. W. Kintigh, R. K. Bocinsky, A. Brin, A. Gillreath-Brown, B. Ludäscher, T. M. McPhillips, R. Opitz, J. Terstriep, Paleodata for and from archaeology. *PAGES Mag* **26**, 68–69 (2018). doi:10.22498/pages.26.2.68

27. J. W. Lewthwaite, A. Sherratt, "Chronological atlas," in *Cambridge Encyclopedia of Archeology*, A. Sherrat, Ed. (Cambridge Univ. Press, 1980).

28. G. Larson, D. R. Piperno, R. G. Allaby, M. D. Purugganan, L. Andersson, M. Arroyo-Kalin, L. Barton, C. Climer Vigueira, T. Denham, K. Dobney, A. N. Doust, P. Gepts, M. T. P. Gilbert, K. J. Gremillion, L. Lucas, L. Lukens, F. B. Marshall, K. M. Olsen, J. C. Pires, P. J. Richerson, R. Rubio de Casas, O. I. Sanjur, M. G. Thomas, D. Q. Fuller, Current perspectives and the future of domestication studies. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 6139–6146 (2014). doi:10.1073/pnas.1323964111 Medline

29. J. M. Erlandson, T. J. Braje, Archeology and the Anthropocene. *Anthropocene* **4**, 1–7 (2013). doi:10.1016/j.ancene.2014.05.003

30. K. W. Kintigh, J. H. Altschul, M. C. Beaudry, R. D. Drennan, A. P. Kinzig, T. A. Kohler, W. F. Limp, H. D. G. Maschner, W. K. Michener, T. R. Pauketat, P. Peregrine, J. A. Sabloff, T. J. Wilkinson, H. T. Wright, M. A. Zeder, Grand challenges for archaeology. *Proc. Natl. Acad. Sci. U.S.A.* **111**, 879–880 (2014). doi:10.1073/pnas.1324000111 Medline

31. B. S. Arbuckle, S. W. Kansa, E. Kansa, D. Orton, C. Çakırlar, L. Gourichon, L. Atici, A. Galik, A. Marciniak, J. Mulville, H. Buitenhuis, D. Carruthers, B. De Cupere, A. Demirergi, S. Frame, D. Helmer, L. Martin, J. Peters, N. Pöllath, K. Pawłowska, N. Russell, K. Twiss, D. Würtenberger, Data sharing reveals complexity in the westward spread of domestic animals across Neolithic Turkey. *PLOS ONE* **9**, e99845 (2014). doi:10.1371/journal.pone.0099845 Medline

32. S. S. Downey, W. R. Haas Jr., S. J. Shennan, European Neolithic societies showed early warning signals of population collapse. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 9751–9756 (2016). doi:10.1073/pnas.1602504113 Medline

33. K. W. Kintigh, J. H. Altschul, A. P. Kinzig, W. F. Limp, W. K. Michener, J. A. Sabloff, E. J. Hackett, T. A. Kohler, B. Ludäscher, C. A. Lynch, Cultural dynamics, deep time, and data: Planning cyberinfrastructure investments for archaeology. *Adv. Archaeol. Pract.* **3**, 1–15 (2015). doi:10.7183/2326-3768.3.1.1

34. Materials and methods are available as supplementary materials.

35. S. Bartling, S. Friesike, Eds., *Opening Science: The Evolving Guide on How the Internet Is*

Changing Research, Collaboration and Scholarly Publishing (Springer, 2014).

36. A. Bevan, A. Palmisano, J. Woodbridge, R. Fyfe, C. N. Roberts, S. Shennan, The changing face of the Mediterranean – Land cover, demography and environmental change: Introduction and overview. *Holocene* **29**, 703–707 (2019). doi:10.1177/0959683619826688

37. N. Roberts, R. M. Fyfe, J. Woodbridge, M.-J. Gaillard, B. A. S. Davis, J. O. Kaplan, L. Marquer, F. Mazier, A. B. Nielsen, S. Sugita, A.-K. Trondman, M. Leydet, Europe's lost forests: A pollen-based synthesis for the last 11,000 years. *Sci. Rep.* **8**, 716 (2018). doi:10.1038/s41598-017-18646-7 Medline

38. T. A. Surovell, J. L. Toohey, A. D. Myers, J. M. LaBelle, J. C. M. Ahern, B. Reisig, The end of archaeological discovery. *Am. Antiq.* **82**, 288–300 (2017). doi:10.1017/aaq.2016.33

39. L. J. Martin, B. Blossey, E. Ellis, Mapping where ecologists work: Biases in the global distribution of terrestrial ecological observations. *Front. Ecol. Environ.* **10**, 195–201 (2012). doi:10.1890/110154

40. B. S. Frey, P. Pamini, L. Steiner, Explaining the World Heritage List: An empirical study. *Int. Rev. Law Econ.* **60**, 1–19 (2013). doi:10.1007/s12232-013-0174-4

41. K. Manning, R. Pelling, T. Higham, J.-L. Schwenniger, D. Q. Fuller, 4500-Year old domesticated pearl millet (*Pennisetum glaucum*) from the Tilemsi Valley, Mali: New insights into an alternative cereal domestication pathway. *J. Archaeol. Sci.* **38**, 312–322 (2011). doi:10.1016/j.jas.2010.09.007

42. F. Winchell, C. J. Stevens, C. Murphy, L. Champion, D. Fuller, Evidence for sorghum domestication in fourth millennium BC eastern Sudan: Spikelet morphology from ceramic impressions of the Butana Group. *Curr. Anthropol.* **58**, 673–683 (2017). doi:10.1086/693898

43. A. U. Kay, D. Q. Fuller, K. Neumann, B. Eichhorn, A. Höhn, J. Morin-Rivat, L. Champion, V. Linseele, E. Huysecom, S. Ozainne, L. Lespez, S. Biagetti, M. Madella, U. Salzmann, J. O. Kaplan, Diversification, intensification and specialization: Changing land use in western Africa from 1800 BC to AD 1500. *J. World Prehist.* **32**, 179–228 (2019). doi:10.1007/s10963-019-09131-2

44. T. Denham, Early farming in Island Southeast Asia: An alternative hypothesis. *Antiquity* **87**, 250–257 (2013). doi:10.1017/S0003598X00048766

45. C. O. Hunt, R. J. Rabett, Holocene landscape intervention and plant food production strategies in island and mainland Southeast Asia. *J. Archaeol. Sci.* **51**, 22–33 (2014). doi:10.1016/j.jas.2013.12.011

46. D. Q. Fuller, C. Murphy, Overlooked but not forgotten: India as a center for agricultural domestication. *General Anthropology* **21**, 1–8 (2014). doi:10.1111/gena.01001

47. D. Rindos, H. Aschmann, P. Bellwood, L. Ceci, M. N. Cohen, J. Hutchinson, R. S. Santley, J. G. Shaffer, T. Shaw, Symbiosis, instability, and the origins and spread of agriculture: A new model. *Curr. Anthropol.* **21**, 751–772 (1980). doi:10.1086/202569

48. H. Raymond, The Ecologically Noble Savage debate. *Annu. Rev. Anthropol.* **36**, 177–190 (2007). doi:10.1146/annurev.anthro.35.081705.123321

49. D. M. J. S. Bowman, J. K. Balch, P. Artaxo, W. J. Bond, J. M. Carlson, M. A. Cochrane, C. M. D'Antonio, R. S. Defries, J. C. Doyle, S. P. Harrison, F. H. Johnston, J. E. Keeley, M. A. Krawchuk, C. A. Kull, J. B. Marston, M. A. Moritz, I. C. Prentice, C. I. Roos, A. C. Scott, T. W. Swetnam, G. R. van der Werf, S. J. Pyne, Fire in the Earth system. *Science* **324**, 481–484 (2009). doi:10.1126/science.1163886 Medline

50. M. Pfeiffer, A. Spessa, J. O. Kaplan, A model for global biomass burning in preindustrial time: LPJ-LMfire (v1. 0). *Geosci. Model Dev.* **6**, 643–685 (2013). doi:10.5194/gmd-6-643-2013

51. N. Nakicenovic, R. Swart, *Emissions Scenarios*. *Special Report of the Intergovernmental Panel on Climate Change* (2000); https://www.osti.gov/etdeweb/biblio/20134132.

52. J. Kaplan, K. Krumhardt, M.-J. Gaillard, S. Sugita, A.-K. Trondman, R. Fyfe, L. Marquer, F. Mazier, A. Nielsen, Constraining the deforestation history of Europe: Evaluation of historical land use scenarios with pollen-based land cover reconstructions. *Land (Basel)* **6**, 91 (2017). doi:10.3390/land6040091

53. ArchaeoGLOBE Project, ArchaeoGLOBE Public Data, Version 3, Harvard Dataverse (2019); https://doi.org/10.7910/DVN/CNCANQ.

54. ArchaeoGLOBE Project, ArchaeoGLOBE Regions, Version 6, Harvard Dataverse (2019); https://doi.org/10.7910/DVN/CQWUBI.

55. ArchaeoGLOBE Project, ArchaeoGLOBE Repository, Version 2, Harvard Dataverse (2019); https://doi.org/10.7910/DVN/6ZXAGT.

56. M. Kynn, The "heuristics and biases" bias in expert elicitation. *J. R. Stat. Soc. Ser. A Stat. Soc.* **171**, 239–264 (2008).

57. S. N. Wood, *Generalized Additive Models: An Introduction with R* (Chapman and Hall/CRC, 2017).

58. E. J. Pedersen, D. L. Miller, G. L. Simpson, N. Ross, Hierarchical generalized additive models: An introduction with mgcv (e27320v1, PeerJ Preprints, 2018); https://peerj.com/preprints/27320/.

59. M. Szumilas, Explaining odds ratios. *J. Can. Acad. Child Adolesc. Psychiatry* **19**, 227–229 (2010). Medline

60. B. Marwick, Computational reproducibility in archaeological research: Basic principles and a case study of their implementation. *J. Archaeol. Method Theory* **24**, 424–450 (2017). doi:10.1007/s10816-015-9272-9