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Food Climate Research Network

Environmental *Change* Institute

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ANNEXES

Grazed and confused?

Ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question – and what it all means for greenhouse gas emissions

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Annex 1: Grasslands terminology – some regional and agro-ecological variants

Table A1: Different kinds of grasslands

Desertland	Land on which vegetation is sparse or absent and is characterised by an arid climate. Deserts maybe classified as hot or cold deserts depending on latitude and elevation.
Native or natural grassland	Natural ecosystem dominated by indigenous or naturally occurring grasses and other herbaceous species used mainly for grazing by livestock and wildlife
Campos	Grassland consisting mainly of grasses, along with herbs, small shrubs and occasional trees; on undulating and hilly landscape, with variable soil fertility. Differs from Cerrado in having a longer and more severe winter and a relative abundance of native legumes. The campos is the northern part of the Pampa. The sub-tropical climate is humid, warm in summer and mild in winter. (Examples: Uruguay, southern Brazil and north-eastern Argentina).
Cerrado	Savanna with varying amounts of trees and shrubs along rivers and in valley bottoms. It is characterised by a tropical climate with alternating wet and dry seasons. The wet season lasts usually 6 months. (Example: central Brazil).
Llanos	Extensive system of grasslands, seasonally flooded, with infertile and acidic soils. The tropical climate is characterised by alternating wet and dry seasons. (Examples: plains east of the Andes in Bolivia, Colombia and Venezuela).
Pampa	Treeless grasslands on flat and fertile plains. The Pampa is a temperate grassland or a sub-tropical steppe. The climate is humid to arid; summers are warm and winters are mild. (Examples: eastern and central Argentina).
Prairie	Nearly level or rolling grassland, originally treeless or with a few scattered trees, and usually on fertile soils. It may be characterised as a short-grass, intermediate-grass, or tall-grass prairie depending on the influence of a continental climate and variation in total summer precipitation, rate of evapo-transpiration, periodic fire and soil depth. Soil depth and precipitation generally increase from west to east and vegetation changes from short-grass prairie in the west to tall-grass prairie in the east. (Example: North America).
Sahelian steppe	Discontinuous vegetation dominated by annual C4 plants, especially grasses, and scattered shrubs. The arid or semi-arid tropical climate with alternating wet and dry seasons is characterised by a strong variability in rainfall patterns and one short rainy season. The soils are generally poor. (Example: Sahel at the south margin of the Sahara in Africa).
Savanna	Grassland characterised by precipitation between 375 and 1,500 mm year), variable proportions of trees or large shrubs, especially in tropical and sub-tropical regions. It is often a transitional vegetation type between grassland and forestland. Tropical savannas are characterised by a climate with alternating wet and dry seasons. The wet season usually ranges between 5 and 9 months. Sub-tropical savannas have a wet climate with warm summers and mild winters. (Example: South America, Afric, Australia, sub-tropical and tropical regions of North America).

Steppe	Semi-arid, sparse to rolling grassland characterised by short to medium-height grasses occurring with other herbaceous vegetation and occasional shrubs. Russian steppes are characterised by the high severity and length of continental winters with precipitation between 250 and 500 mm year) Forest- steppe soils are black or brown-earth with high to medium contents of organic matter and high mineral contents. (Examples: south-eastern Europe, Asia, North America).
Veld	Indigenous vegetation used as grazing and/or browsing which may be composed of any of a number of plant growth forms (predominantly C4 grasses and Acacia or broad-leaf trees) and need not necessarily be climax vegetation. (Example: South Africa).
Marshland	Flat, wet, treeless wetland usually covered by shallow water and dominated by marsh grasses, rushes, sedges, other grass-like plants and forbs.
Shrubland	Land on which the vegetation is dominated by low-growing woody plants.
Tundra	Land areas in arctic and alpine regions devoid of large trees, varying from bare ground to various types of vegetation consisting of grasses, sedges, forbs, dwarf shrubs and trees, mosses and lichens.

Sources:

Adapted from Allen *et al.* (2011)

Allen, V.G., Batello, C., Berretta, E.J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A., Sanderson, M. (2011). An international terminology for grazing lands and grazing animals. *Grass Forage Sci.*, 66, pp. 2-28. doi:10.1111/j.1365-2494.2010.00780.x

Annex 2: Carbon sequestration estimates in studies – geographical extent and methods

Table A2: Soil carbon sequestration estimates and their assumptions (further information on data points presented in Figure 9 of the main report).

Reference	Farming practices considered	Study geographical extent	Methods
Conant and Paustian (2002)	Universal rehabilitation of overgrazed grasslands, most of which can be achieved simply by cessation of overgrazing and implementation of moderate grazing intensity.	World	Field data from literature and statistical relationships to extrapolate from data points to the world. The authors extrapolated carbon sequestration estimates globally based on the relationship between reviewed data and climatic variables. All data were then integrated to produce a global estimate of potential for carbon sequestration in soils of overgrazed grasslands following cessation of overgrazing and restoration of moderate grazing intensity.
Conant *et al.* (2001)	Fertilisation (39% of the data points), improved grazing management (24%), conversion from cultivation (15%) and native vegetation (15%), sowing of legumes (4%) and grasses (2%), earthworm introduction (1%), and irrigation (1%).	World	Field data from literature. The study reviewed 115 studies containing 364 data points which examine the influence of improved grassland management practices and conversion into grasslands on soil C.
Conant *et al.* (2017)	Fertiliser (31.7% of the data points), conversion: cultivation to grass (24.6%), grazing (21.0%), conversion: native to grass (16.2%), sowing legumes (2.9%), sowing improved grass species (0.9%), grass ley in rotation (0.9%), fire (0.8%), earthworms (0.3%), irrigation (0.3%), reclamation (0.15%), silvopastoralism (0.15%).	World	Field data from literature. The study integrated the 115 studies considered in Conant et al. (2001) as well as 64 additional studies. 696 data points were analysed.
Henderson *et al.* (2015)	Improved grazing management, legume sowing and nitrogen fertilisation.	World	Modelling . The authors modelled the linkage between soil, forage and animals.

Reference	Farming practices considered	Study geographical extent	Methods
Lal (2004)	Grazing management, improved species, fire management and nutrient management.	On 3.7 billion ha in semi-arid and sub-humid regions	Literature review.
Ogle *et al.* (2004)	Management practices that either degraded or improved conditions.	United States of America	Field data from literature and development of grassland management factors. Ogle *et al.* (2004) identified 49 studies worldwide dealing with effects of management practices that either degraded or improved conditions. They derived grassland management factors that represent the effect of changing management on carbon storage. Based on these factors, they analysed carbon sequestration potential for managed grasslands in the U.S.A.
Smith *et al.* (2008)	Improved grazing land management.	World	Mixed-effect modelling on a large dataset of long-term agricultural soil carbon experiments from a variety of countries, though temperate studies were more prevalent in the database.
Soussana *et al.* (2007)	Rotational grazing, continuous grazing and mowing.	Europe	Field data. Fluxes of greenhouse gases (carbon dioxide, nitrous oxide and methane) were measured in nine European grassland sites with different management during a period of two years. Based on these indirect measurements, Soussana et al. (2007) estimated an average annual soil carbon sequestration rate.
Savory Institute (2013)	Holistic grazing.	Over 5 billion hectares worldwide	The claims have not undergone scientific peer-review. The estimate was presented without support or references.
Itzkan (2014)	Holistic grazing.	Over 3.5 billion hectares worldwide	The study has not undergone scientific peer-review. The upper sequestration rate was based on visual inspections of before-and-after photographs by Itzkan himself. It is unclear what the lower sequestration rate is based on.

Sources:

Conant, R.T., Cerri, C.E.P., Osborne, B.B., and Paustian, K. (2017). Grassland management impacts on soil carbon stocks: a new synthesis. *Ecological Applications*, 27(2), pp. 662-668. https://doi.org/10.1002/eap.1473

Conant, R.T., and Paustian, K. (2002). Potential soil carbon sequestration in overgrazed grassland ecosystems. *Global Biogeochemical Cycles*, 16(4), pp. 1-9. https://doi.org/10.1029/2001GB001661

Conant, R.T., Paustian, K., and Elliott, E.T. (2001). Grassland Management and Conversion Into Grassland: Effects on Soil Carbon. *Ecological Applications*, 11(2), pp. 343-355. Retrieved from http://www.esajournals. org/doi/abs/10.1890/1051-0761%282001%29011%5B0343%3AGMACIG%5D2.0.CO%3B2

Henderson, B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, M., and Conant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems & Environment*, 207, pp. 91–100. https://doi.org/10.1016/j. agee.2015.03.029

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123, pp. 1-22. https://doi.org/ DOI: 10.1016/j.geoderma.2004.01.032

Ogle, S.M., Conant, R.T. and Paustian, K. (2004). Deriving grassland management factors for a carbon accounting method developed by the Intergovernmental Panel on Climate Change. *Environmental Management*, 33(4), pp. 474-484. https://doi.org/10.1007/s00267-003-9105-6

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., ... Smith, J. (2008). Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society of London. Series B, *Biological Sciences*, 363, pp. 789-813. https://doi.org/10.1098/rstb.2007.2184

Soussana, J.F., Allard, V., Pilegaard, K., Ambus, P., Amman, C., Campbell, C., ... Valentini, R. (2007). Full accounting of the greenhouse gas (CO2 , N2O , CH4) budget of nine European grassland sites. *Agriculture, Ecosystems and Environment*, 121, pp. 121–134. https://doi.org/10.1016/j.agee.2006.12.022

Itzkan, S. (2014). Upside (Drawdown) The Potential of Restorative Grazing to Mitigate Global Warming by Increasing Carbon Capture on Grasslands. Accessible at: http://www.savoryinstitute.com/current-news/ current-news/upside-(drawdown)-the-potential-of-restorative-grazing-to-mitigate-global-warming-by- increasing-carbon-capture-on-grasslands-planettech/

Savory Institute (2013). Restoring the climate through capture and storage of soil carbon through holistic planned grazing – White paper. Accessible at: http://www.savoryinstitute.com/media/40739/

Annex 3: Past land use changes and historical land use reconstruction models

Figure A1 illustrates the results of two well-known land use reconstruction models which support opposing views as to the recency of human induced land use change.[1] The left image visualises results from HYDE, which suggests that our impacts have for the most part started just a few centuries ago, except in Europe and the Mediterranean and in small pockets of East and South Asia and West Africa. Not much happened to the earth's surface until the start of the industrial revolution about 250 years ago; after which trees were cut down to feed the newly discovered steam engine, to build railways, to obtain rubber, and to make available the agricultural land needed for a growing population.

The second model, KK10, illustrated on the right, tells a radically different story of ancient use and more recently, signs of land abandonment. According to this narrative – which the most recent evidence supports – humanity's impact on the planet dates back to at least the beginning of the Holocene 11–12,000 years ago, a time when our ancestors started to grow in numbers and spread across the globe.[2] The changes began as we started to use fire and to hunt wild herbivore populations, sometimes to extinction. The effects of increased fire and reduced livestock trampling altered the dynamics of forest and grasslands in complex ways and may even have had climate changing consequences, although how significant these were is a subject for debate. Later on we made clearances for attracting game, and later still prepared land for crops and to rear animals. Landscapes that we now think of as natural – even in remote regions of the Amazon – may in fact be the product of ancient transformations, now overlaid by secondary vegetative growth.

Figure A1: Time period of first significant land use and recovery from peak land use, 6000 B.C. to A.D. 2000, based on historical reconstructions from the HYDE (A) and KK10 (B) models. From Ellis _et al._ (2013).
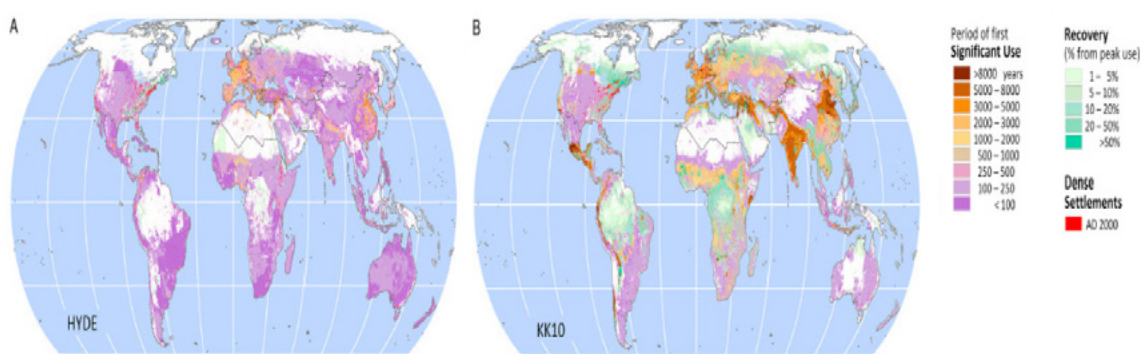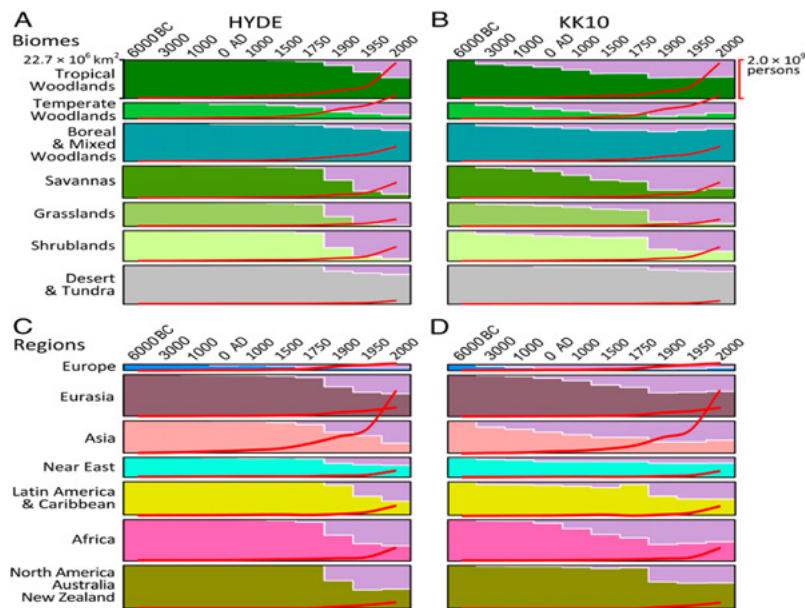

Source: Ellis E.C., Kaplan J.O., Fuller D.Q., Vavrus S., Klein Goldewijk K. and Verburg P.H. (2013). Used planet: A global history, PNAS, 110, 20, pp. 7978–7985.

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[1] Ellis E.C., Kaplan J.O., Fuller D.Q., Vavrus S., Klein Goldewijk K. and Verburg P.H. (2013). Used planet: A global history, _PNAS_, 110(20), pp. 7978–7985.

[2] Boivin N.L., Zeder M.A., Fuller Dq, Crowther A., Larson G., Erslandson J.M., Denham T. and Petraglia M. D. (2016). Ecological consequences of human niche construction: Examining long-term anthropogenic shaping of global species distribution. _PNAS_, 113(23), pp. 6388–6396.

Figure A2, from the same study illustrates the point further – HYDE dates the start of biome transformation at around the start of the industrial revolution whereas KK10 pushes things much further (by human standards) back into the past.

Figure A2: Figure A2: Global areas of significant land use (purple) and total population (red line) within biomes, 6000 B.C. to A.D. 2000, based on the HYDE (A) and KK10 (B) historical land-use

Source: Ellis E.C., Kaplan J.O., Fuller D.Q., Vavrus S., Klein Goldewijk K. and Verburg P.H. (2013). Used planet: A global history, PNAS, *110(20), pp. 7978–7985*

But these two different models also tell different stories of where we are heading, and where, perhaps, we 'ought' to go. The KK10 model suggests that we have become better at using land over time. As societal and resource pressures increased people responded by figuring out ever more effective ways of producing more with less, and (the thinking goes) so we will continue: high yielding industrialised agriculture is just the latest in a series of innovations. And indeed the evidence does find that per capita land use for food production is falling, as is the rate of global population increase. A conclusion one might draw, therefore, is that the 'worst' may be over: the beginnings of a new era are in sight, one where we release land back to nature.[3] Whatever that actually means: because according to this narrative, the notion of the 'pristine wilderness' is untenable. Practically all landscapes we know and value have been modified in one way or another by our ancestors. There is no authentic past to which we ought to return so in principle we can decide for ourselves.

The HYDE 'recent destruction' narrative by contrast posits a wilderness for most of humanity's history, one whose devastation is fairly recent. And it also suggests that our impacts are growing, despite relative efficiency gains, since in absolute terms our

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[3]   Asafu-Adjaye, J. *et al.*, (2015). An Ecomodernist Manifesto, Available at: http://www.ecomodernism.org/

population continues to rise, and our consumption patterns are growing ever more resource-hungry. The sweeping optimism of the KK10 projections hides all important detail under the carpet – while a 20% gain in forest and a 10% loss in a different forest will register as a gain in natural cover, there may have been important and damaging alterations, and irreparable losses. While some land abandonment could be construed as positive ("we are using our land more productively and so need less") in many parts of the world land may be left alone because it simply too degraded to be used any more. It has not been released for nature so much as flogged to death.[4] The worst is, in fact, worsening.[5,6,7] At the same time, since wilderness did indeed exist until quite recently, a meaningful ecological baseline lies within our conceptual and practical grasp, to which we ought to return.

Box: How do people figure out what went on in the past?

Methods used to reconstruct past land use and impact vary depending on how far back one goes. For the recent period – that is, from the 1970s onwards – models draw upon remote sensing observations and statistical data. These recent reconstructions are of course much more accurate than reconstructions of more distant time periods but even here, accuracy can be a problem as discussed in Chapter 1 above.

For what is sometimes called the "historical period," the period starting around 1700, statistical data for land use and population may be available, but will vary by region and time period. Further back, for the 'prehistorical period,' reconstructions will be based on whatever population estimates are available; and a relationship between population and per capita land use is then specified. How this is specified (which itself will be determined by assumptions about trends in technological progress), will influence the model results. Data on the biophysical suitability of land areas for agricultural production (soils, rainfall, elevation and so forth) may also aid reconstructions. Evidently the further one goes back in time, the more uncertain the reconstructions.

Sources:

Ellis E.C, Kaplan J.O., Fuller D.Q., Vavrus S., Klein Goldewijk K. and Verburg P.H. (2013). Used planet: A global history, *PNAS*, 110(20), pp. 7978–7985.

Klein Goldewijk, K., Beusen, A., and van Drecht, G. (2011). The HYDE 3.1 spatially explicit database of human-induced global land-use change over the past 12,000 years. *Global Ecology and Biogeography*, v. 20, pp. 73–86.

Kaplan JO, Krumhardt KM, Zimmermann N (2009). The prehistoric and preindustrial deforestation of Europe. *Quat Sci Rev* 028(27-28): pp. 3016–3034.

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[4]   Hooke, R. LeB, Martín-Duque J.F. and Pedraza J. (2012). Land transformation by humans: A review, *GSA Today*, 22(12), doi: 10.1130/GSAT151A.1.

[5]   Steffen W., Crutzen P.J., McNeill J.R. (2007). The Anthropocene: Are humans now overwhelming the great forces of nature. *AMBIO* 36(8), pp. 614–621.

[6]   Ellis E.C., Kaplan J.O., Fuller D.Q., Vavrus S., Klein Goldewijk K. and Verburg P.H. (2013). Used planet: A global history, *PNAS*, 110(20), pp. 7978–7985.

[7]   Steffen, W., Richardson, K.,Rockstrom, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R.; De Vries, W., De Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*. 347 (6223).

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