Anthromes

John E. Quinn and Erle C. Ellis

Abstract Anthromes, or anthropogenic biomes, characterize the globally significant ecological patterns shaped by sustained direct human interactions with ecosystems, including agriculture, urbanization, and other land uses. The emergence of anthromes has literally paved the way for the Anthropocene, and now cover more than three quarters of Earth's ice-free land surface, including dense settlements, villages, croplands, rangelands, and cultured lands; wildlands untransformed by agriculture and settlements cover the remaining area.

Human societies and their use of ecosystems have transformed ecological patterns and processes globally for thousands of years (Ellis, 2021). Lands used to sustain hunter gatherers, farmers, pastoralists, foresters, and others have been extensive for millennia, covering nearly three quarters of Earth's land surface for at least 12,000 years (Ellis et al., 2021). Likewise, the cities and towns where most people now live, though less extensive, have an outsized influence on the landscapes around them (McDonald et al., 2016), Consequently, ecosystems, at local to global extents, can no longer be understood without considering how humans have altered them. To address this gap, efforts to deepen scientific understanding of the ecological patterns and processes shaped and sustained by human societies are ongoing at global, regional and local scales, (Ellis, 2015, 2018; Brown & Quinn, 2018; Waters et al., 2016; Stephens et al., 2019).

Anthromes, or anthropogenic biomes, have aided this process by characterizing globally significant ecological patterns created by sustained direct human interactions with ecosystems, including agriculture, urbanization, and other land uses

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N. Wallenhorst, C. Wulf (eds.), *Handbook of the Anthropocene*,
https://doi.org/10.1007/978-3-031-25910-4_32

(Ellis & Ramankutty, 2008). Defined as dense settlements, villages, croplands, rangelands, and cultured lands, anthromes have been mapped across Earth's land surface with remaining areas then identified as wildlands without evidence of human populations or intensive land use.

Global changes in anthromes have been mapped based on an increasing wealth of spatial data from remote sensing, government statistics, archaeological evidence, and other sources, including human-altered vegetation cover, built structures, crops, livestock grazing, irrigation, roads and the varying densities of human populations (Ordway et al., 2021). Leveraging these data in 2008, Ellis and Ramankutty made the first map of anthromes using a statistical approach called cluster analysis (Ellis & Ramankutty, 2008). Using this approach, the globally significant patterns of human shaped ecosystems were mapped from data on human populations, land use and vegetation cover. This effort complemented classic maps of natural biomes, from tundra to tropical rainforests, in relation to the globally significant patterns of climate, terrain, and other natural environmental conditions. In 2010, this approach was updated to allow anthromes to be mapped globally over time, from 1700 to 2000 (Ellis et al., 2010). Anthrome maps based on this system of classification have been used widely in teaching, research, and conservation (e.g. Chapin III et al., 2012; Martin et al., 2014; Merritts et al., 2014; National Geographic Society, 2014; Quinn et al., 2014; Miraldo et al., 2016; Gibson & Quinn, 2017; Dinerstein et al., 2017; Smith et al., 2019).

More recently, this system of classification was extended further back in time to map anthromes across the 12,000 years from 10,000 BCE to 2017 CE at 60 time points (Fig. 1, Ellis et al., 2021). Using this system of anthrome classification, six "levels" along a gradient of intensiveness were recognized and mapped globally, as illustrated in Fig. 1. This classification was used recently to show the temporal extent of transformation and the legacy of past changes on nature (Ellis et al., 2021) and to describe variations in birds, mammals, and amphibians between anthromes globally and regionally (Quinn et al., 2021).

Anthromes Along a Gradient of Transformation and Intensification

Urban and other densely settled anthromes are the most highly transformed, sustaining urban population densities well over 1000 persons per square kilometer in landscapes largely converted into cities, suburbs, and other residential and industrial infrastructure. Village anthromes are also highly transformed and densely populated (above 100 persons per square kilometer), but their mostly agricultural landscapes sustain largely rural populations, often in regions inhabited and farmed since ancient times. While these urban and village anthromes covered only about 8% of Earth's ice-free land in 2000 CE, more than 80% of Earth's human populations lived in them. Moreover, ongoing migrations from rural areas into cities are making urban

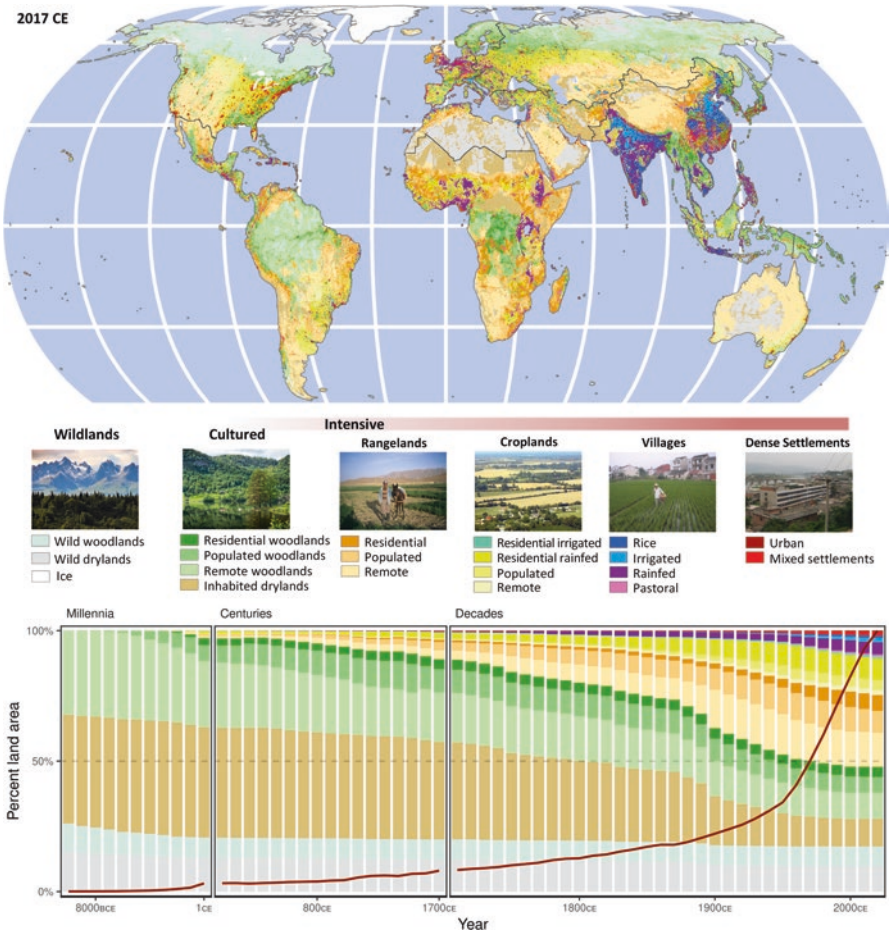

Fig. 1 Global map of anthromes for 2017 CE, and estimated global changes in anthrome areas from 10,000 BCE to 2017 CE, based on Ellis et al., 2021. Red line is global population. Map in Eckert 4 projection (BCE; Before the Common Era, CE; Common Era)

anthromes even denser as human populations continue to concentrate into and expand Earth's relatively small but dynamic area of urban anthromes.

The arable farm fields that produce most food, fibre, and fuel are mostly found in croplands anthromes. In some croplands, crops cover the land almost completely. More commonly though, are croplands formed of a complex mix of crops and settlements together with patches of grass, shrubs, and tree cover managed at lower intensities. Rangeland anthromes sustain grazing livestock and are the most extensive of the intensive anthromes. While these cover more than a quarter of Earth's ice-free land, they also tend to be lower productivity areas with relatively low human population densities and are usually less transformed by human use.

Cultured anthromes are relatively lightly populated and less intensively used landscapes, with a majority of their areas composed of habitats either remaining without direct human use, or modified through uses that maintain native vegetation cover. The spatial extent of these anthromes have declined greatly overtime, mostly through the appropriation, colonization, and intensification of use in lands inhabited and used by prior societies.

Wildlands, without human populations or intensive use of land, have always been rare, covering only about one quarter of Earth's ice-free land over the past 12,000 years, and tend to remain mostly in relatively low productivity regions, like deserts and tundra. As a result, wildlands account for only about 10% of Earth's terrestrial net primary productivity (NPP) even less than one would expect based on their area (Ellis et al., 2010).

Anthromes Are Mosaics of Used and Novel Ecosystems

Scaling down from global patterns, anthromes are best described as heterogeneous multifunctional mosaics combining different land uses and land covers. Today, anthromes retain a greater global area of lightly used habitats, about 37% globally, than the total area remaining in wildlands (around 23%). Moreover, these areas tend to be both ecologically productive and highly biodiverse (Ellis et al., 2012, 2021; Ellis, 2021; Quinn et al., 2021). Remarkably, in 2000, the total area of wild forests remaining on Earth was less than the total area of densely populated village and urban anthromes. More remarkable still, more than 25% of Earth's tree cover is embedded within cropland anthromes, a greater extent than the total area of forests remaining in wildlands (Ellis et al., 2010). This landscape-scale heterogeneity supports biodiversity patterns that vary within and between anthromes with lower species richness in barren and wildlands and higher richness in villages and rangelands (Ellis, 2013; Quinn et al., 2021). Clearly, the intensively used and heterogeneous working landscapes of anthromes demand serious attention in understanding and conserving Earth's ecology (Garibaldi et al., 2021).

Visualizing landscapes across the anthromes (Fig. 1) we see mixtures of native, cultured, and intensively used vegetation that offer diverse benefits to people and other living organisms. Even within cities and intensive farmland, the most densely populated and transformed anthromes, humans rarely convert all land for direct uses leaving small pockets of sometimes unexpected biodiversity (Ellis, 2013, 2019). While transformation and direct use of a given landscape tends to be mostly concentrated in areas where it will be most valuable (e.g., rich grassland soils, floodplains, and wetlands), in adjacent areas people cultivate trees and tend preferred species, create open space, alter fire patterns, and harvest fuelwood, timber, wildlife, plants and other natural resources. Similarly, because of global trade, many ecosystems have increased exposure to and invasion by exotic species. Because of these changes even the least disturbed areas of anthrome landscapes generally have novel biotic communities and ecosystem processes that differ substantially and potentially irreversibly from their

prior historical states, broadly fitting the definition of novel ecosystems (Hobbs et al., 2009; Ellis et al., 2010; Ellis, 2015). These novel cultural ecological patterns and processes of anthrome landscapes now represent the terrestrial biosphere in its current, human-altered form, and provide the basis for research, education, and application of ecology and conservation in the Anthropocene (Ellis, 2015).

Ecological Science, Theory, and Education in the Anthropocene

From the basic theoretical view, the anthrome model of global ecology has implications for understanding the fundamentals of ecological science from local landscapes to regional and global scales. Anthromes move ecology away from an outdated view of the world as "natural ecosystems with humans disturbing them" and towards a vision of "human systems entangled with ecosystems" (also known as social-ecological systems, anthroecosystems, or coupled human and natural systems) (Ellis & Ramankutty, 2008; Ellis, 2015). This is a major paradigm shift for most natural scientists concerned with ecology and environment, but it is a shift that will be critical to advance efforts to better understand and help to guide more beneficial human interactions with the biosphere today and in the future.

By incorporating human transformation of terrestrial ecology into a global framework, anthromes offer a more objective view of the contemporary biosphere compared with the traditional biome frameworks taught in classes and emphasized in research (Martin et al., 2012). Nevertheless, anthromes should not be seen as a replacement for the classic biome model, but rather a complimentary model, and this is increasingly being presented and discussed in biology and ecology textbooks (Chapin III et al., 2012; Merritts et al., 2014; Freeman et al., 2016), and in references across a wide range of over 100 different academic disciplines (Fig. 2).

Conservation in the Anthropocene

Human transformation of this planet is causing unprecedented and accelerating changes in Earth's ecology, from climate change to the massive losses of habitat that are causing species extinctions and alarming declines in wildlife populations. While focusing on the negative consequences of human transformation of Earth can help to eliminate or avoid some of these, it is equally, if not more important, to emphasize the unprecedented powers of contemporary human societies to create a better future for both people and nonhuman nature on the only planet we share; the vision of Earth stewardship (Chapin III et al., 2012; DeFries et al., 2012).

With anthromes covering more than three quarters of the terrestrial biosphere, the need to conserve biodiversity and nonhuman habitats in anthrome landscapes is

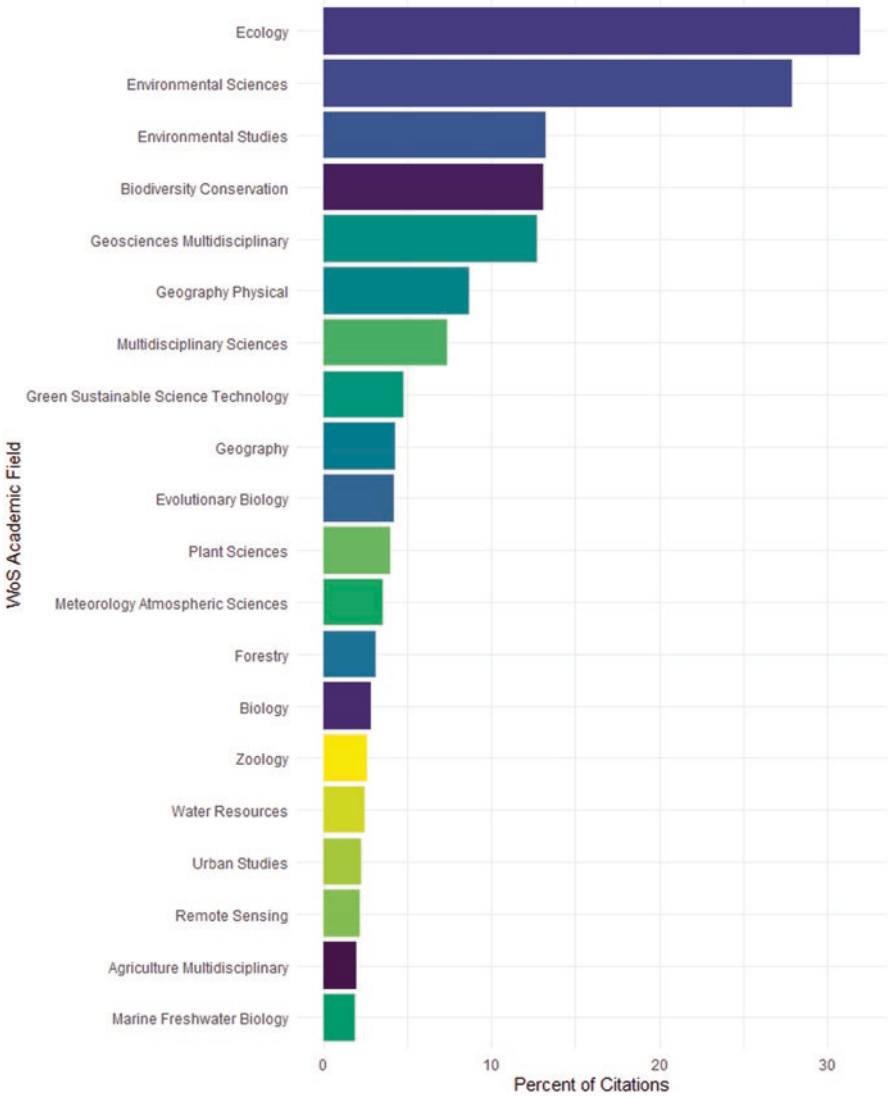

Fig. 2 Variation in the top 20 academic fields that have cited the anthrome literature. (Data from web of science)

increasingly recognized as critical (Martin et al., 2014). Though wildlands are important habitats for biodiversity conservation in large-scale protected areas, anthromes have largely replaced wildlands in Earth's most biodiverse and productive regions (Ellis et al., 2021). Even though many species are poorly adapted to living in close proximity with human societies (and vice versa), recent studies indicate that under appropriate conditions, most native taxa may be sustainable within anthromes, even while increasing anthrome productivity in support of human populations (Ellis et al., 2012, 2021; Quinn et al., 2014, 2017, 2021; Ellis, 2013, 2021).

One key principle of sustainable ecosystem management in the Anthropocene is to develop and sustain pluralistic value structures (Allen et al., 2018; Ellis, 2019). Anthromes can play a key role in this, helping to move conservation discussions beyond the outdated paradigm that human use of ecosystems can only "destroy" them, and to embrace a proactive human role in shaping and sustaining biodiverse and productive ecosystems. There are certainly many examples of human degradation of ecosystems without any long-term benefits to anyone or any being. Nevertheless, human use of land, including traditional hunting and foraging, farming, settlements and other uses are the basis for sustaining human societies, and have also sustained wildlife and habitats for centuries to millennia, long before recent expansion of conservation through protected areas and other strategies.

Earth stewardship in the Anthropocene requires envisioning the future "we" want and strategies to get there (Ellis, 2019). Already, international organizations, agreements and scientific collaborations are focusing on creating a future where people and nature can thrive together over the long term. Making such better futures possible involves negotiations across diverse populations of stakeholders, the "we," who must work together towards these better futures—from farmers to ranchers, urbanists and conservationists, to Indigenous Peoples and governments, nongovernmental organizations and international corporations, and will need to engage multilevel governance solutions that bring people together to negotiate productively across the global supply chains, producers, consumers and conservationists that are now shaping the biosphere (Ellis, 2019).

Do "we" want a sprawling world of human infrastructure that consumes most of Earth's land, or a dense urban world that leaves plenty of shared and wild spaces to sustain the rest of life? The answer will come from all of us, and it will require much more than saving nature in places far away. Ecology and conservation in the Anthropocene will mean governing anthromes to more effectively serve human needs while sharing space to sustain the rest of nature in an increasingly anthropogenic biosphere.

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