Anthromes

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Abstract

Human societies and their use of land have transformed ecology across this planet for thousands of years. As a result, the global patterns of life on Earth, the biomes, can no longer be understood without considering how humans have altered them. Anthromes, or anthropogenic biomes, characterize the globally significant ecological patterns created by sustained direct human interactions with ecosystems, including agriculture, urbanization, and other land uses. Anthromes now cover more than three quarters of Earth's ice-free land surface, including dense settlements, villages, croplands, rangelands, and seminatural lands; wildlands untransformed by agriculture and settlements cover the remaining area.

Introduction

Human societies and their use of land have transformed ecology across this planet for thousands of years (Ellis, 2015; Stephens et al., 2019). As a result, the global patterns of life on Earth, the biomes, can no longer be understood without considering how humans have altered them. Anthromes, or anthropogenic biomes, characterize the globally significant ecological patterns created by sustained direct human interactions with ecosystems, including agriculture, urbanization, and other land uses (Ellis and Ramankutty, 2008). Anthromes now cover more than three quarters of Earth's ice-free land surface, including dense settlements, villages, croplands, rangelands, and seminatural lands; wildlands untransformed by agriculture and settlements cover the remaining area.

Look out of any airplane window or at imagery from any Earth satellite and the signs of human transformation are everywhere. From the farms, grazing lands, plantations and managed forests that sustain our societies to the settlements and cities where we live and the roads, railroads and paths that crisscross the continents and connect us all together. Using spatial data from remote sensing, government statistics, and other sources, these global fingerprints of human societies, including human-altered vegetation cover, built structures, crops, livestock grazing, irrigation, roads and the varying densities of human populations can be brought together, characterized, and mapped using Geographic Information Systems (GIS). The first such effort in this direction, the Human Footprint, used these data to assess human influences on ecology as a single number varying from high to low (Sanderson et al., 2002). But is it truly possible to capture the rich diversity of human transformation of ecology across this entire planet using a single number?

In 2008, Ellis and Ramankutty set out to map the globally significant patterns of human altered and managed ecosystems through a statistical approach called cluster analysis (Ellis and Ramankutty, 2008). Using this approach, the globally significant patterns of human shaped ecosystems could be mapped from data on human populations, land use and vegetation cover, just as the natural biomes, in all their rich diversity from tundra to tropical rainforests, are mapped 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 are now 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; Freeman et al., 2016; Miraldo et al., 2016; Dinerstein et al., 2017; Smith et al., 2019). Using this system of anthrome classification, five "levels" of are recognized and mapped globally, as described in Table 1 and illustrated in Fig. 1.

Anthromes and the Anthropogenic Biosphere

Urban and other dense settlement anthromes are the most highly transformed anthromes on Earth and sustain population densities well over 1000 persons per square kilometer in landscapes largely converted into settlements 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 anthromes even

Table 1 Anthrome classes within five anthrome levels, with global areas for 2015 CE in square kilometers (percent in parentheses; based on Ellis et al., 2020; Fig. 1).

Area (%)	*Name*	*Description*
2,237,074 (1.7%) Dense settlements: Urban and other nonagricultural dense settlements		
723,555 (0.5%)	Urban	Densely built-up environments with very high populations
1,513,519 (1.1%)	Mixed settlements	Suburbs, towns and rural settlements with high but fragmented populations
9,365,333 (7.1%) Villages: Densely populated agricultural settlements		
1,078,848 (0.8%)	Rice villages	Villages characterized by paddy rice
1,974,819 (1.5%)	Irrigated villages	Villages characterized by irrigated crops
5,436,990 (4.1%)	Rainfed villages	Villages characterized by rainfed agriculture
874,677 (0.7%)	Pastoral villages	Villages characterized by pasture and rangeland
19,379,053 (14.7%) Croplands: Lands used mainly for annual crops		
1,048,619 (0.8%)	Residential irrigated croplands	Irrigated croplands with substantial human populations
9,998,304 (7.6%)	Residential rainfed croplands	Rainfed croplands with substantial human populations
5,550,446 (4.2%)	Populated rainfed croplands	Croplands with significant human populations
2,781,684 (2.1%)	Remote croplands	Croplands without significant populations (irrigated and rainfed)
34,900,571 (26.5%) Rangelands: Lands used for pasture and livestock grazing		
6,905,141 (5.2%)	Residential rangelands	Rangelands with substantial human populations
10,656,903 (8.1%)	Populated rangelands	Rangelands with significant human populations
17,338,527 (13.2%)	Remote rangelands	Rangelands without significant human populations
31,963,461 (24.3%) Seminatural lands: Inhabited lands with minor use for permanent agriculture and settlements		
4,302,009 (3.3%)	Residential woodlands	Forest biome regions with minor land use and substantial populations
7,342,981 (5.6%)	Populated woodlands	Forest biome regions with minor land use and significant populations
8,749,492 (6.6%)	Remote woodlands	Forest biome regions with minor land use without significant populations
11,568,978 (8.8%)	Inhabited treeless and barren lands	Regions without natural tree cover having only minor land use and a range of populations
33,958,547 (25.8%) Wildlands: Lands without human populations or substantial land use		
15,399,162 (11.7%)	Wild woodlands	Forests and savanna
16,001,211 (12.1%)	Wild treeless and barren lands	Regions without natural tree cover (grasslands, shrublands, tundra, desert and barren lands)
2,558,174 (1.9%)	Ice, uninhabited	Regions covered by permanent ice
131,804,039 (100%)	Global land	

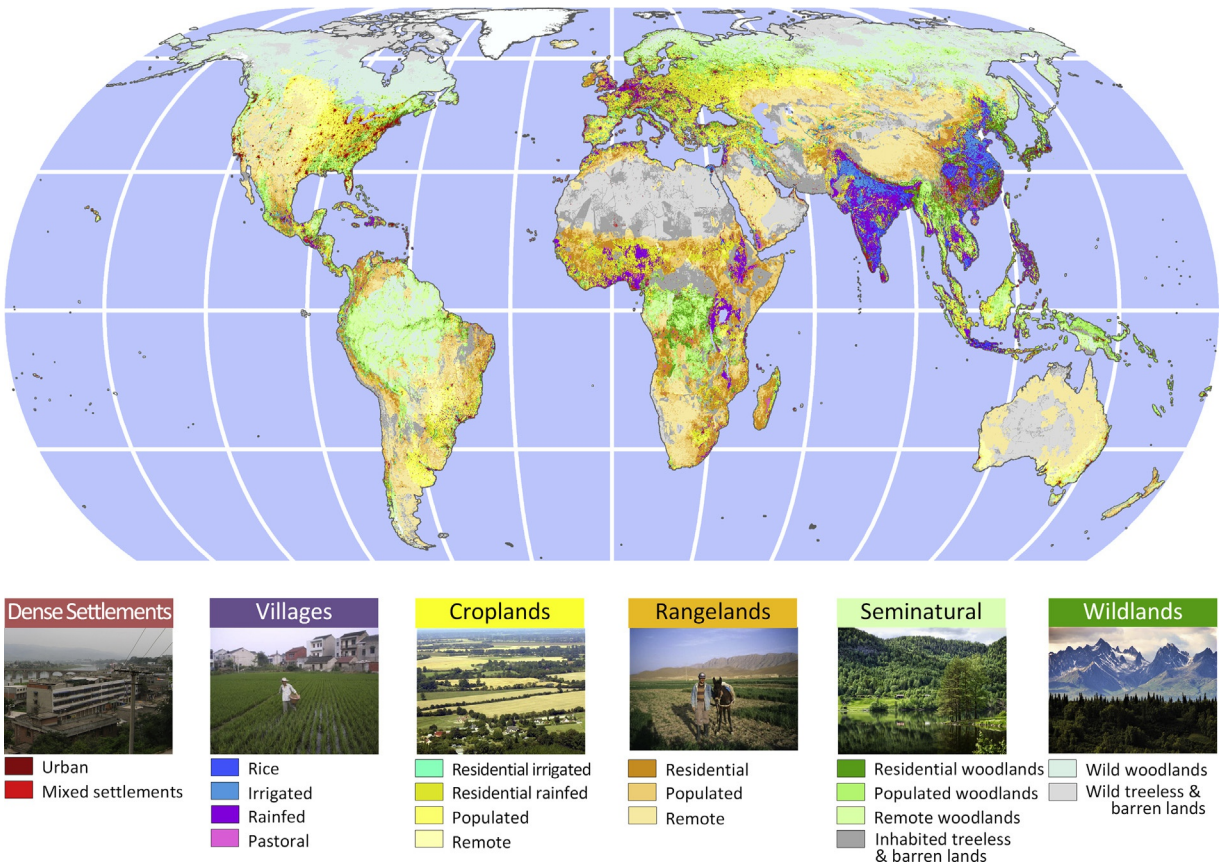

Fig. 1 Global map of anthromes in 2015 CE. Eckert Equal Area projection (Ellis et al., 2020).

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

The farm fields that produce most of our food are mostly found in croplands anthromes. In some croplands, crops cover the land almost completely. More common though, are croplands formed of a complex mix of crops, settlements, and patches of tree cover and other less intensively managed habitats. Rangeland anthromes sustain grazing livestock and are the most extensive of the used anthromes. While these cover nearly one third of Earth's ice-free land, they also tend to be lower productivity areas that sustain relatively low population densities and are usually less transformed by human use. Seminatural anthromes are relatively lightly populated and used landscapes, with a majority of their areas composed of remnant lightly used, and recovering habitats.

Wildlands without human populations or intensive use of land still cover nearly one quarter of Earth's ice-free land. Yet only about 20% of Earth's tree cover is in wildlands and more than one third of wildlands are in relatively barren regions, like deserts and tundra. As a result, wildlands account for only about 10% of Earth's terrestrial net primary productivity (NPP)—the photosynthetic production of plants that supports the rest of life on Earth—even less than one would expect based on their area. 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. The same holds for NPP, with more net primary production occurring within the densely populated anthromes than in Earth's last remaining wild forests. 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. Clearly, the intensively used anthromes deserve serious attention in understanding Earth's ecology, and their global area and ecological importance are vast and growing.

Anthromes Are Mosaics of Used and Novel Ecosystems

While about 40% of Earth's land is used directly for crops, pastures and settlements, a nearly equivalent area is neither used directly for agriculture and settlements nor left behind in large wild areas without these uses. What is the ecology of these areas? The answer requires a deeper understanding of the way landscapes tend to be transformed and managed by human societies.

Even within the most densely populated and intensively used anthromes, including urban areas and ancient village landscapes, humans rarely convert all land into agricultural and residential uses, but rather, selectively concentrate these uses in areas where they will be most productive, while also planting and retaining trees and other green spaces in association with settlements and infrastructure. When viewed from high above, we see urban areas and settlements embedded within seas of agricultural land, with patches of trees interspersed within and among croplands and residential areas, and managed vegetation is mixed with natural and seminatural vegetation. For this reason, anthrome landscapes tend to be more complex than those of the classic biomes, and are best characterized as heterogeneous multifunctional mosaics of different land uses and land covers, especially where terrain is complex and populations are dense.

Productive level terrain is generally the focus of agriculture and settlements, while hillier, drier, mountainous, and remote terrain tends to be left unused or less used, even when surrounding areas are used intensively. Patches of used land are often abandoned and left to recover within used anthromes, and even remnant patches of habitat within anthromes that have never been managed for production tend to become transformed by human influences ranging from more frequent fires and fire suppression, to harvests of fuelwood, timber and other natural resources, hunting, foraging, increased exposure to exotic species, pollution, and other human influences. Even the isolation of remnant patches from other habitat patches within the used landscape can alter rates of species extinctions and invasions. As a result of these pervasive human influences, even the least disturbed areas of anthrome landscapes generally have biotic communities and ecosystem processes that differ substantially and potentially irreversibly from their prior historical state, broadly fitting the definition of novel ecosystems (Hobbs et al., 2009; Ellis et al., 2010; Ellis, 2015).

Thus considered at a landscape scale, the used and seminatural anthromes are multifunctional mosaics of ecosystems used for production, within which islands of remnant, recovering, and lightly used novel ecosystems are embedded (Fig. 2). For this reason, anthromes are far more than just the used areas of the planet. In fact, they retain a greater global area of lightly used habitats, about 37%, than the total area remaining as wildlands (around 23%). Moreover, these areas tend to be both ecologically productive and highly biodiverse, even though their habitats show clear legacies of human influence and their biological communities tend to be composed of novel assemblages of native, introduced and invading species (Ellis, 2013). The novel ecological patterns and processes of anthromes, which now cover more than three quarters of Earth's terrestrial surface, represent the terrestrial biosphere in its current, human-altered form, and provide the basis for an ecology of the anthropogenic biosphere (Ellis, 2015).

Ecological Science, Theory, and Education in an Anthropogenic Biosphere

Biomes are introduced as the fundamental units of the biosphere in nearly every introductory biology, Earth science, and environmental science textbook. While anthromes should not be thought of as a replacement for existing biome systems based on vegetation and climate, anthromes offer a more objective view of the terrestrial biosphere in its contemporary anthropogenic state. This new model of the biosphere moves us away from an outdated view of the world as "natural ecosystems with humans disturbing them" and towards a vision of "human systems with natural ecosystems entangled with them" (also known as social-ecological systems, anthroecosystems, or coupled human and natural systems) (Ellis and Ramankutty 2008; Ellis, 2015). This is a major change in paradigm for most natural scientists concerned with ecology and environment, but it remains a critical advance in

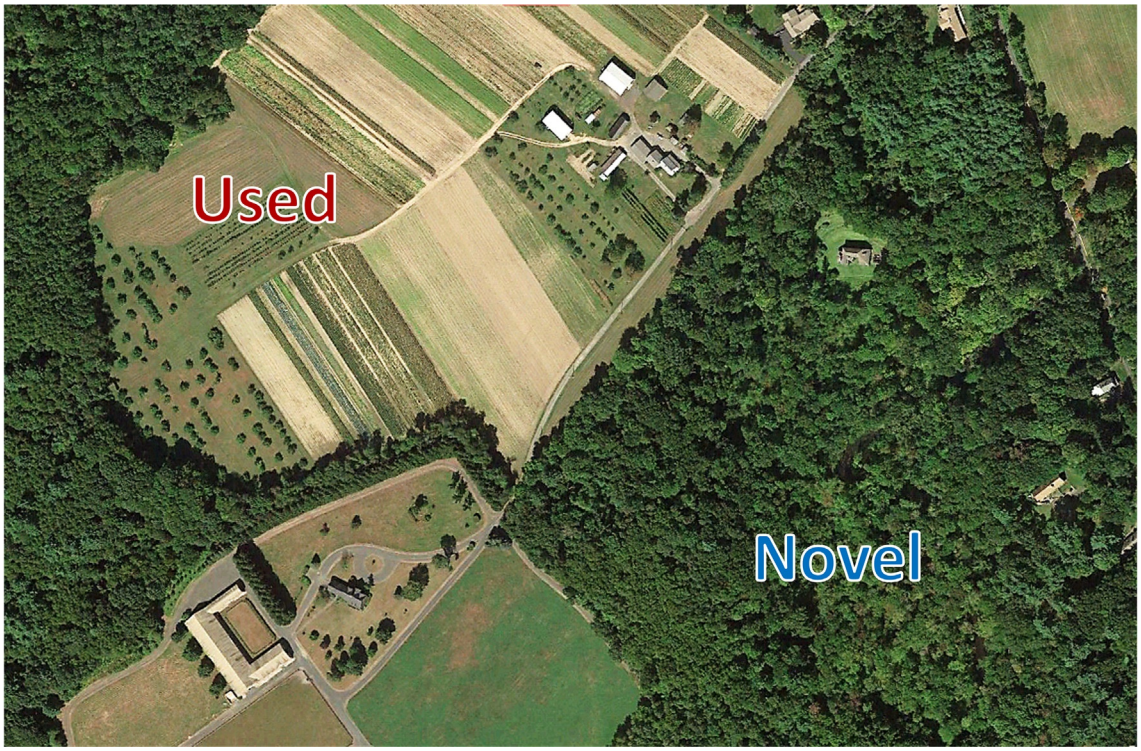

Fig. 2 Anthromes are heterogeneous landscape mosaics composed of used lands and novel ecosystems.

efforts to better understand the biosphere as it exists today, and even in the deeper past. Increasingly, anthrome maps and global data on human transformation of ecology are helping to accomplish this, as part of basic curriculum in biology and ecology textbooks (Chapin III et al., 2012; Merritts et al., 2014; Freeman et al., 2016). Anthromes have also been called "human biomes," a less precise term, and a related term, "indoor biomes" is also increasingly used (Martin et al., 2015).

From the basic theoretical view, the anthrome model of ecological pattern and process has implications for understanding the fundamentals of ecological science from global to regional and even local scales. This general understanding has been integrated within the theory of anthroecology which aims to investigate, understand, and address the ultimate causes of anthropogenic ecological change that shape the emergence of anthromes at global scale, and the ecological patterns, processes and dynamics within anthromes over time under different social and ecological conditions (Ellis, 2015). Fig. 3 illustrates the different conditions of population density and land use under which the different anthromes form, and how these conditions in turn shape the patterns and processes of net primary production (NPP), carbon storage or emissions from soils and vegetation, reactive nitrogen (from natural, agricultural and industrial processes), and the patterns of biodiversity in terms of species richness of both native and introduced species.

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, including recent efforts to define a new "human age" of geologic time, the Anthropocene epoch (Ellis, 2011, 2015, 2018; Waters et al., 2016; Stephens et al., 2019). Though the Anthropocene remains an informal term and a work in progress (Ellis, 2018), interest in better understanding human transformation of the biosphere is growing almost as fast as human societies are transforming the planet.

Earth Stewardship 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 at alarming rates. While focusing on the negative consequences of human transformation of Earth can help to eliminate some of these, it is equally, if not more important, to focus on efforts to guide the unprecedented powers of contemporary human societies towards creating a better future for both people and nonhuman nature on the only planet we share; the vision of Earth stewardship (Chapin III et al., 2011; DeFries et al., 2012).

Now that humans have reshaped more than three quarters of the terrestrial biosphere into anthromes, the need to conserve biodiversity and nonhuman habitats in the working landscapes of anthromes is increasingly recognized as critical (Martin et al., 2014). Though wildlands are critical habitats for biodiversity conservation in large-scale protected areas, anthromes have largely replaced wildlands in Earth's most biodiverse and productive regions; the novel ecosystems embedded within anthrome landscapes

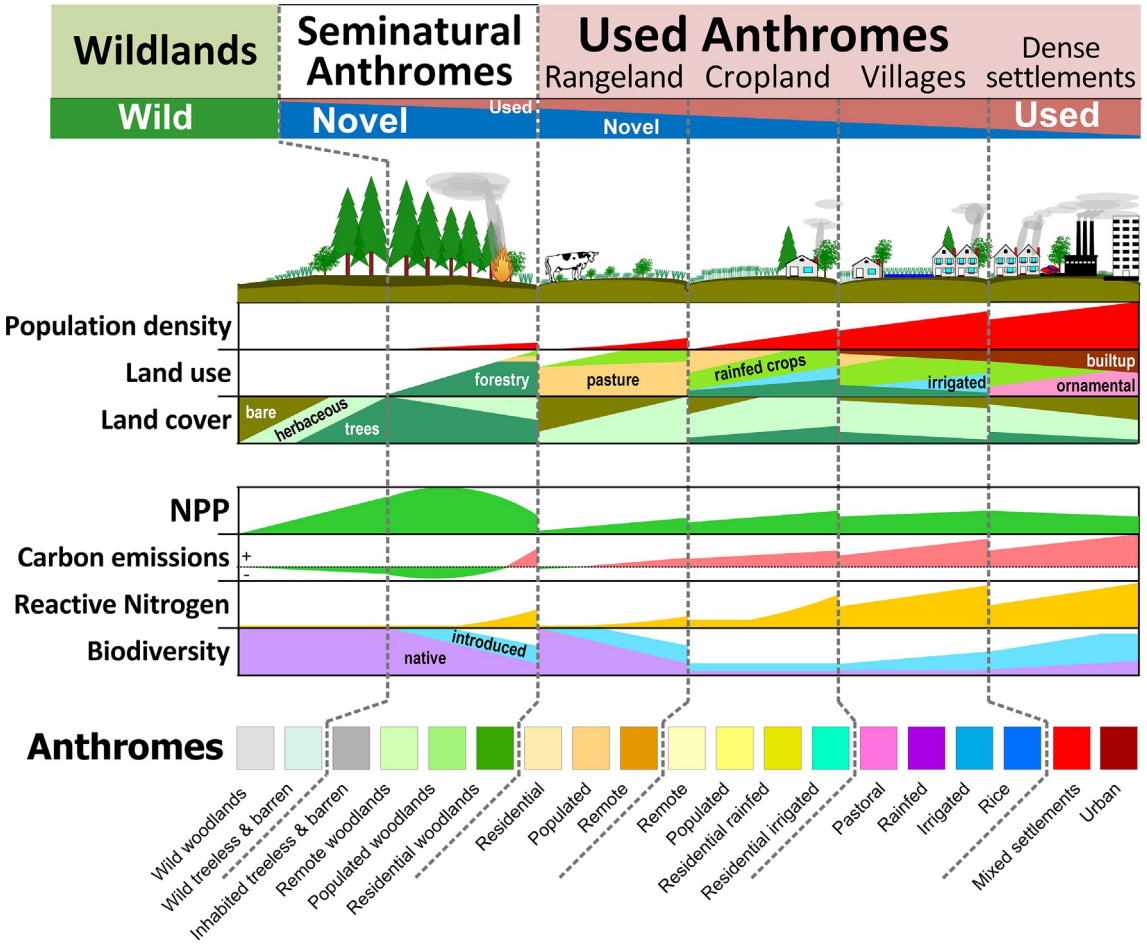

Fig. 3 Conceptual diagram illustrating patterns of populations, land use, novel habitats and biotic communities and ecosystem properties within and across anthromes.

now cover nearly twice the global area of wildlands. 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, 2013; Quinn et al., 2014).

One key principle of sustainable ecosystem management in the anthropogenic biosphere of the Anthropocene is to develop and sustain beneficial or at least nonharmful interactions between human and nonhuman species and habitats, because avoiding these interactions entirely is simply not a practical strategy in most areas. In working towards more effective environmental governance strategies, anthromes can play a key role in moving conservation discussions beyond the outdated paradigm that human use of ecosystems merely "destroys" them. While there are certainly many examples of human degradation of ecosystems without any long-term benefits to anyone or any being, the conversion of natural habitats into farms, settlements and other infrastructure, creating anthromes, is the basis for sustaining human societies. There are better and worse ways to manage Earth's ecology, but the notion of "going back to nature" to sustain human populations is no longer an option.

Earth stewardship in the Anthropocene has to be about much more than just "preventing humans from destroying the planet." The way forward will depend on visions of the future "we" want and strategies to get there: a future where people and nature can thrive together over the long term (Fig. 4). Yet there is no "we," no singular "humanity" working the levers of planetary governance in the cockpit of spaceship Earth. Making a better future possible will require negotiations across our diverse populations of stakeholders, the "we," who must work together towards these better futures—from farmers ranchers, urbanists and conservationists, to Indigenous Peoples and governments, nongovernmental organizations and international corporations. The challenges of creating a better future will require multi-level 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. Earth stewardship in the Anthropocene will mean governing anthromes to more effectively serve human needs while making space to sustain the rest of nature in an increasingly anthropogenic biosphere.

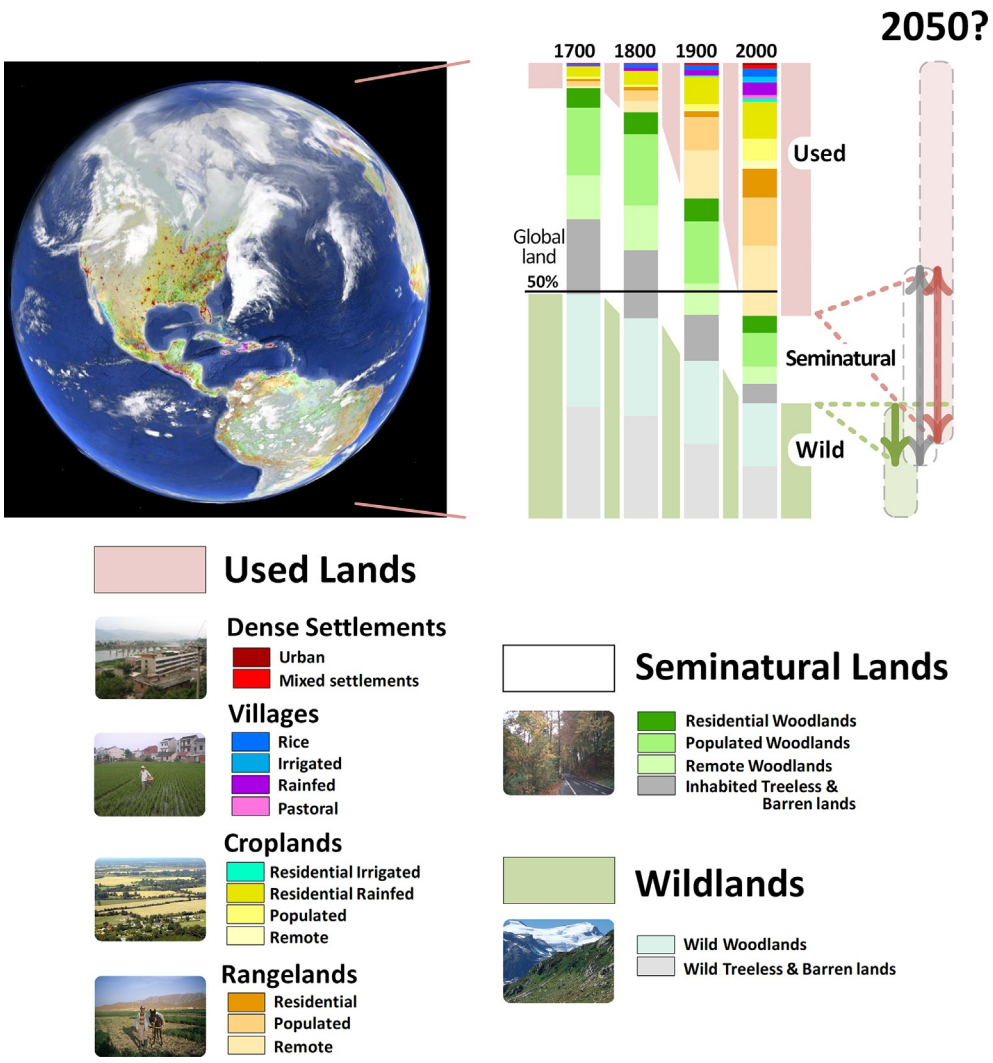

Fig. 4 Earth stewardship in an anthropogenic biosphere. What kind of biosphere do "we" want?

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Relevant Website

http://anthrome.org—link to anthromes project web site hosted by the author, including educational materials, maps, and downloadable datasets.