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Research Focus

Anthropogenic biomes: a key contribution to earth-system science

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Human activities now dominate most of the ice-free terrestrial surface. A recent article presents a classification and global map of human-influenced biomes of the world that provides a novel and potentially appropriate framework for projecting changes in earth-system dynamics.

Social-ecological systems

The formal discipline of ecology has a long history of separating humans from nature [1], which leads to classifications of ecosystems and biomes in which human feedbacks are ignored [2]. As human impacts on ecosystems become increasingly pronounced, such a classification system hinders our understanding and assessment of the broad-scale dynamics of planetary change. Scientists increasingly focus on the dynamics of social-ecological systems (SESs) to describe the world around us [3]. An SES is a socially constructed system in which human and ecological systems are viewed as being tightly and inextricably linked [4]. The question of how to identify and manage SESs around the world is more pressing than ever, as the global population continues to grow and to use natural resources at unprecedented rates. Thus, the recent article by Ellis and Ramankutty [2], which provides a classification and map of human-influenced biomes of the world, is both timely and thought-provoking.

Mapping human influence

Ellis and Ramankutty [2] argued for the need to extend the global-scale ecological unit of the biome to include the human influence of ecosystems and coined the term 'anthropogenic biomes'. They described the intensity of human conversion of ecosystems and used this as the basis for a biome classification system. Using a structured geographic information system (GIS)-based mapping methodology that incorporated human population density, land use and land cover, they described anthropogenic effects on Earth. This combined an indicator of anthropogenic impact with ecological indicators, similar to those used in existing terrestrial eco-region mapping [5], and using cluster analysis revealed 18 anthropogenic biomes (Figure I, Box 1). The authors then applied this methodology to global data sets to identify natural groupings based on population density, land use (pasture, rain-fed crops, irrigated crops or urban), and land cover (bare, herbaceous or trees) to produce a global map of anthropogenic biomes, which incorporate nearly 90% of terrestrial net primary productivity. They proposed a series of hypotheses, the first two of which are centered on the human use and optimization of inherent natural landscape heterogeneity and the third of which proposes that humans create landscape heterogeneity directly through built environments. Finally, they suggested how ecosystem processes might differ across anthropogenic biomes with respect to population density and land use, the anthropogenic mechanisms for this variation (e.g. food production), and a projected increase over time in the explanatory importance of anthropogenic biomes with respect to biodiversity. A clear message is that human influence on the terrestrial biosphere is now pervasive and our current approaches to classifying biomes, in addition to our fundamental education regarding them, must adapt to this unprecedented change.

The seminal work by Ellis and Ramankutty [2] adds to the suite of global assessments of human influence that has been developed in the past two decades [6-10]. Ellis and Ramankutty's [2] effort differs from these because they have integrated their representation of anthropogenic effects with contemporary biome mapping to develop a synthetic classification. That synthesis provides a platform to refocus research efforts on human-impacted ecosystems as a basis for understanding large-scale patterns of change. Their classification and mapping of SESs is timely in showing the value of GIS in capturing the status and trends in the structure and dynamics of the planet [8]. It also fosters discussions about the feedbacks between humans and the biophysical world at the scale ofthe earth system.

Future research directions

Ideally, anthropogenic biomes should be defined by those factors that are the best predictors of change (e.g, affluence versus population). The work by Ellis and Ramankutty [2] provides a framework that could be refined by subdividing these anthropogenic biomes according to other factors of potential importance (e.g. social values). If any of these (or other) factors provide greater power than population density (the social factor used by Ellis and Ramankutty) in explaining global variation in social-ecological properties, the framework for defining anthropogenic biomes could be modified accordingly. The

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important point made by the authors is that classifications based on both social and climatic factors are likely to have greater predictive value than classifications based on climate alone.

The next step, in our view, is to develop simple rules to describe how these biomes have changed or might change in the future in response to social and environmental changes. This is analogous to dynamic vegetation models that simulate biome shifts based on scenarios of climatic change (e.g. temperature and precipitation).

Incorporating social drivers into biome models remains challenging because human behavior is obviously complex and depends on a wide range of past and unknown future events. In addition, a central challenge of incorporating social processes in efforts to understand and project changes in the distribution of anthropogenic biomes is the wide range of scales at which social-ecological feedbacks operate (Box 1; Figure I). The local scale at which people live out their daily lives is particularly important [4,11]. For example, the activity of humans and other organisms is often concentrated in hot spots of high biological activity and cultural value [4,12]. The values, understanding and perception of these hot spots by human (and non-human) communities result in specific patterns of resource use that, in turn, feed back into the overall system at local scales. How can these local human influences on ecosystems be meaningfully incorporated at biome scales? Some biophysical parameters, such as stomatal conductance, scale surprisingly well from leaves to regions [13]. Could we use social variables (e.g. population or wealth) or tools such as spatially explicit agent-based models [14] to capture the consequences of individual behaviors in ways that might be mapped at broader temporal and spatial scales [9]?

A final direction that could build on the anthropogenic-biome framework of Ellis and Ramankutty [3] is the development of policy scenarios that seek to optimize the resilience of SESs. These could help to provide specific guidance for changes in resource-use patterns (e.g. changes that result in less food waste), which depend on variables such as social values, expectations, cooperation, technology and governance [15]. As the dominant controls

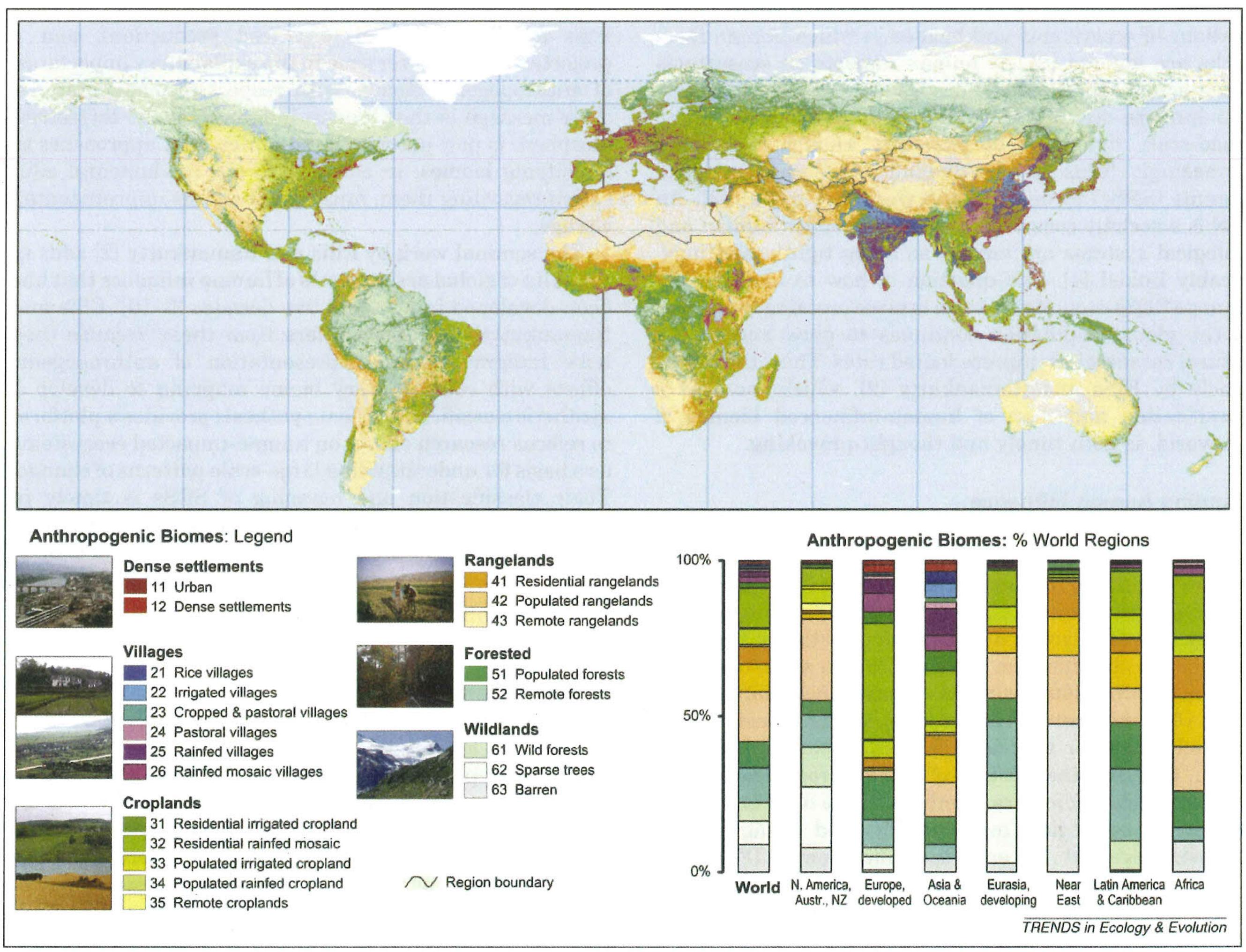

Figure 1. Anthropogenic biomes: world map and regional areas. Biomes are organized into groups and sorted in order of population density. Map scale = 1:160 000 000, Plate Carrée projection (geographic), 5 arc-minutes resolution. Reproduced, with permission, from Ref. [2].

Box 1. Why scale matters

When examining spatial data in the context of anthropogenic biomes, scale and resolution are important considerations. At the level of the globe, lower spatial resolutions are sufficient to answer certain questions about broad-scale patterns, but when studying smaller geographic areas (such as cities, villages or other anthropogenic biomes), higher resolutions are necessary but often limited by the availability of appropriate and extensive data. For larger geographic areas (Figure Ia,b) a low-resolution image can still demonstrate trends such as mountain ranges. However, for smaller geographic regions (Figure Ic), which is usually the level at which most human activities take place, a resolution such as 5 arc-minutes (~10 km, Figure Id) cannot accurately portray even the location of the largest city in Alaska. As refinements in classifying anthropogenic biomes at local scales occur, features such as coastlines, hydrography and land cover become increasingly important and finer-resolution data are needed. Global data can show large-scale trends and can have benefits that in-depth local studies do not. Conversely, anthropogenic biomes need to be refined at local and regional scales to yield a more meaningful understanding of the dynamics that occur between humans and their environments.

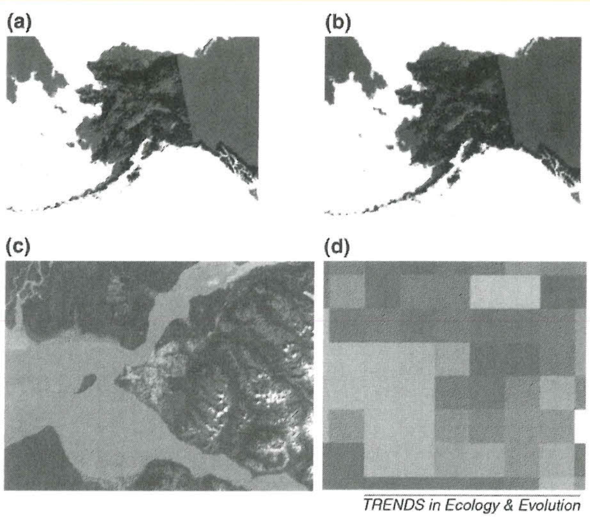

Figure I. The importance of scale. **(a)** Alaska Digital Elevation Model (DEM) portrayed at 0.2 km resolution. **(b)** Alaska DEM portrayed at 10 km resolution. **(c)** Landsat Image of the city of Anchorage, Alaska and the surrounding region at a resolution of 28.5 m, equivalent to ~1 arc-seconds. **(d)** Landsat image of Anchorage and the surrounding region at a resolution of 10 km, equivalent to ~5 arc-minutes (the resolution used by Ellis and Ramankutty).

over patterns and dynamics are elucidated, refinements at regional and national scales could provide higher-resolution representations of the anthropogenic biomes and feedbacks between scales.

Ultimately, the work conducted by Ellis and Ramankutty is crucial in shifting the focus of earth-system science from 'How will vegetation move?' to 'How will SESs be reconfigured and what are the major biophysical and societal consequences?' This is an important reminder of the fundamental importance of social---ecological coupling in describing the patterns and processes of the modern world - a framework that should redefine the ways in which we communicate the field and practice of ecology to generations that must cope with the consequences of these changes.

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