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Invited review

Humans on Earth: Global extents of anthropogenic land cover from remote sensing

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ABSTRACT

This review provides a perspective of the current state of the art in remote sensing of anthropogenic land cover and human-modified landscapes at global scales. The fact that humans have adapted to almost all of Earth's environments, yet remain strongly clustered within each of these environments influences both the nature of anthropogenic impact on Earth's landscapes and the challenges of mapping it. Remote sensing provides a consistent synoptic view of these environments by mapping the land cover associated with the anthropogenic land uses of settlement and food production, as well as their complement in forest cover. We give brief descriptions and illustrative comparisons of several current land cover products representing the global extents of settlements, agriculture and forests derived from remote sensing. To accommodate the challenges inherent to mapping any land cover at widely varying scales, we compare size distributions of spatially contiguous land cover (rather than total area) for several global land cover products. Despite the use of different sensors and different mapping criteria, there is remarkable consistency in the size distributions of these products – both within and across land cover class. Rank-size distributions of settlements, agricultural areas and forests are all well-described by power laws spanning more than four orders of magnitude in both area and number. This consistency in the form of the distributions suggests fundamental similarities among different types of land cover. The observed similarities can be explained by depicting land cover mosaics as co-evolving spatial networks sharing common processes of nucleation, growth and connection.

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1. Introduction

Over the past ~60 years, humans' view of Earth has changed radically, from relatively narrow local perspectives based primarily on firsthand observation to broad global perspectives increasingly influenced by indirect sources of information. The parallel technological evolution of communication and imaging has contributed to this change. Improvements in imaging systems have generated an enormous volume of information not derived from direct experience. Advances in communications now allow us to disseminate, and consume, this information in volumes far exceeding those to which humans even one generation prior had been exposed. The perspectives of increasing numbers of people are influenced by remotely sensed images of Earth and the information derived from them. From meteorological satellites providing information about regional weather patterns to mobile sensors providing information about transportation network flows, remote sensing provides an increasing volume of indirect observation and perceived experience which is shaping the way humans view the world and their place in it. This review paper is an attempt to provide a perspective on the current state of the art in global land cover mapping that remote sensing provides on human-modified landscapes.

Human habitat on Earth is characterized by a duality in which humans have adapted to almost all of Earth's environments (Vitousek et al., 1997), yet remain strongly clustered within each of these environments. This duality influences both the nature of anthropogenic impact on Earth's landscapes (e.g. Ellis and Ramankutty, 2008) and the challenges of mapping it. Mapping the global distribution of human population within geophysical parameter spaces provides a simple way to quantify both aspects of this duality: the breadth of our adaptation across environments and the nature of the clustering (Cohen and Small, 1998; Small and Cohen, 2004). Fig. 1 illustrates the current distribution of human population and development relative to the climatic parameters of temperature and precipitation using a combination of population density from spatially gridded census enumerations (CIESIN, 2014) and economic development inferred from stable night lights imaged by satellites (Elvidge et al., 1999). Relative to mean annual temperature and precipitation (New et al., 1999), it is apparent that both populated land area (as enumerated by census) and lighted human settlements span all major biomes on Earth (except ice sheets). However, the spatial Lorenz curve showing the cumulative distribution of 2010 population relative to cumulative enumerated land area (excludes Antarctica and parts of Greenland) shows that populations are strongly clustered in space at both national and global scales, with more than half of global population inhabiting less than 2% of enumerated land area. This also illustrates the importance of remote sensing for accurate quantification of human-modified landscapes. For reasons of logistics and cost, census enumerations and other survey-based metrics do not provide detailed depictions of dispersed rural populations, or even urban populations in many developing countries where accurate, detailed census are not conducted. In contrast, remote sensing provides uniform global coverage but introduces the challenge of interpretation.

Large area administrative units are used to represent dispersed populations in sparsely populated areas (most of the world) but inevitably lack spatial detail to explicitly show the distribution of the smaller settlements within the unit. However, remote sensing provides a wealth of information about these dispersed populations and their interactions with the landscape. The synoptic spatial coverage provided by satellite remote sensing is complementary to detailed *in situ* surveys that cannot provide complete spatial coverage at the scale of dispersed rural settlements.

By necessity, the scope of this review is limited to global products derived from satellite remote sensing. The vast majority of the remote sensing literature is devoted to development of algorithms and their implementation at local to regional scales. For reasons explained below, products and algorithms developed for specific local and regional applications do not generally scale to global extents. In the interest of representing the global extent of human modification of Earth's landscapes rather than the myriad facets of this modification, we focus on the relatively small number of global products that attempt to map different types of anthropogenic land cover consistently at global scales.

The structure of this paper is based on a sequence of background, description, synthesis and illustration. The