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A global analysis of land take in cropland areas and production displacement from urbanization

Jasper van Vliet*, David A. Eitelberg, Peter H. Verburg

Faculty of Earth and Life Sciences, VU University Amsterdam, De Boelelaan 1085, 1081 HV, Amsterdam, The Netherlands

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ABSTRACT

Urban growth has received little attention in large-scale land change assessments, because the area of built-up land is relatively small on a global scale. However, this area is increasing rapidly, due to population growth, rural-to-urban migration, and wealth increases in many parts of the world. Moreover, the impacts of urban growth on other land uses further amplified by associated land uses, such as recreation and urban green. In this study we analyze urban land take in cropland areas for the years 2000 and 2040, using a land systems approach. As of the year 2000, 213 Mha can be classified as urban land, which is 2.06% of the earth's surface. However, this urban land is more than proportionally located on land that is suitable and available for crop production. In the year 2040, these figures increase to 621 Mha, or 4.72% of all the earth's surface. The increase in urban land between 2000 and 2040 is also more than proportionally located on land that is suitable and available for crop production, thus further limiting our food production capacity. The share of urban land take in cropland areas is highest in Europe, the Middle-East and Northern Africa, and China, while it is relatively low in Oceania and Sub-Saharan Africa. Between 2000 and 2040, urban growth caused the displacement of almost 65 Mton of crop production, which could yield an expansion of up to 35 Mha of new cropland. Land-use planning can influence both the location and the form of urbanization, and thus appears as an important measure to minimize further losses in crop production.

1. Introduction

Urbanization is taking place at unprecedented rates, due to global population growth and ongoing rural-to-urban migration (Angel et al., 2011; Jiang and O'Neill, 2015). For example, Lambin and Meyfroidt (2011), expect that between 2000 and 2030 land taken by urbanization will be of the same order of magnitude as the area required for cropland expansion, pastures, or biofuels in the same period. Similarly, Seto et al. (2011) project that the urban area will more than double in the majority of their global scenarios. The growing amount of land that is taken by urbanization also increases the competition with other land uses. This competition is particularly well documented for China, where unprecedented urban growth is threatening food security as increasing amount of cropland is converted (Jiang et al., 2013; Liu et al., 2005). As a consequence, a number of targeted policies have been implemented to prevent a further decline in cropland area and assure a minimum level of food security (Lichtenberg and Ding, 2008; Lu et al., 2015). However, cropland losses due to urbanization have been reported in other regions as well, including India (Pandey and Seto, 2015), Puerto Rico (del Mar López et al., 2001), Africa (Nkeki, 2016), and selected cities globally (Bagan and Yamagata, 2014).

Because built-up area covers only a small fraction of the earth, few global assessments include urban land (Alexander et al., 2017). A recent overview by Prestele et al. (2016) shows that five out of eleven global-scale land change projections represent built-up area, while the other six include only natural and agricultural land. However, the impact of urbanization on food production might be underestimated for several reasons. First, many urban areas are allocated in fertile (delta) areas, which means that food production and urbanization are in direct competition for land (Bren d'Amour et al., 2016; Thebo et al., 2014). Because urban growth typically takes place at the edge of existing urban areas (van Vliet et al., 2013), this competition is likely to continue in the near future. Second, urban growth is often assessed using built-up area, while a much larger amount of land is lost for crop production upon urbanization. This includes non-productive uses, such as golf courses, gardens, and sports areas, which are particularly found in more prosperous countries (Plieninger et al., 2015; Zasada et al., 2013). Third, urban growth is not only manifested by an expansion

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* Corresponding author.
E-mail address: jasper.van.vliet@vu.nl (J. van Vliet).

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of metropolises and other conurbations, but increasingly also as peri-urbanization and villages, which can take more land area per person. These processes are not frequently represented in large scale land assessments, as built-up area is rarely the predominant land cover at the level of a pixel (Verburg et al., 2013). Moreover, the impacts of urban land extend beyond the reduction of food production only, as it has been associated with fragmentation and habitat loss (McKinney, 2008), temperature increases by means of urban heat islands (Buyantuyev and Wu, 2010), changes in the provisioning of ecosystem services (Schneider et al., 2012), and alterations of the hydrological cycle (Shuster et al., 2005).

In this paper, we assess the amount of urban land take in the year 2000 and in the year 2040, using a projection from the CLUMondo land systems change model (van Asselen and Verburg, 2013). Land systems denote typical combinations of land covers and land usages, and thus allow to go beyond built-up areas strictly by assessing the influence of urban land systems as well as peri-urban and village systems. These impacts are compared against global estimates of land that is suitable for crop production as well as land that is available for crop production. Furthermore, we calculate the displacement of crop production between 2000 and 2040 as a consequence of urbanization, in order to quantify its contribution in global cropland expansion.

2. Methods

2.1. Mapping global land systems for 2000 and 2040

The analysis of urban land take is based on land systems maps for the years 2000 and 2040 (see Figs. S1 and S2). The use of land systems instead of land cover allows the depiction of typical combinations of land cover and land use intensity that exist in the landscape, while respecting the sub-pixel information (van Asselen and Verburg, 2012). The land systems approach is similar to the frequently used Anthromes (Ellis and Ramankutty, 2008), but, in contrast to Anthromes, land systems are mainly defined by their agricultural use.

The land system map for the year 2000 was created using a hierarchical classification tree as described in Eitelberg et al. (2016). This classification uses the pixel shares of forest, built-up, grassland, and cropland (Hansen et al., 2010; Ramankutty et al., 2008; Schneider et al., 2009), in combination with ruminant livestock density (FAO, 2007), and land management intensity (Neumann et al., 2010). Each of the 24 different classes is characterized by the average land cover composition, ruminant livestock density and crop production of all pixels with that particular land system within the same model region. Crop production is based on the regional specific mix of crops in the data provided in Monfreda et al. (2008), and specific crop types are not further assigned to specific locations. The land system map for the year 2000 is created at a spatial resolution of 5′, in the WGS 1984 Eckert IV equal area projection. All other spatial data in this study are converted into this projection and resolution. Two land systems are classified based on their share of built-up area: *urban* systems and *peri-urban and village* systems. Urban systems are defined by more than 25% built-up area, while peri-urban and village systems have more than 5% but less than 25% built-up land. We will hereafter refer to the combination of these two as ‘urban land’, and use ‘urban system’ only when referring to this particular land system. All other land systems can also contain small amounts of built-up land, but never more than 5% of the pixel area, and typically much less. At the same time, while the amount of built-up area is their defining characteristic, urban systems and peri-urban and village systems also contain other land cover types, produce crops, and contain livestock.

The land systems map for 2040 was generated using the CLUMondo land system change model (van Asselen and Verburg, 2013). In CLUMondo, changes are driven by an exogenous demand for goods and services, and allocated in yearly steps according to the local suitability, land system specific rules (including the neighborhood effect, conversion resistance, constraints for crop production, and land system specific conversions possibilities), and the competition between land systems based on the goods and services they provide. Local suitability is determined by empirical relationships between a given land system and a set of explanatory biophysical and socioeconomic variables, derived from a logistic regression analysis. We use the results of the baseline scenario presented in Eitelberg et al. (2016), which starts from the land system map for the year 2000, as described above. This scenario is based on the United Nations Food and Agriculture Organization’s

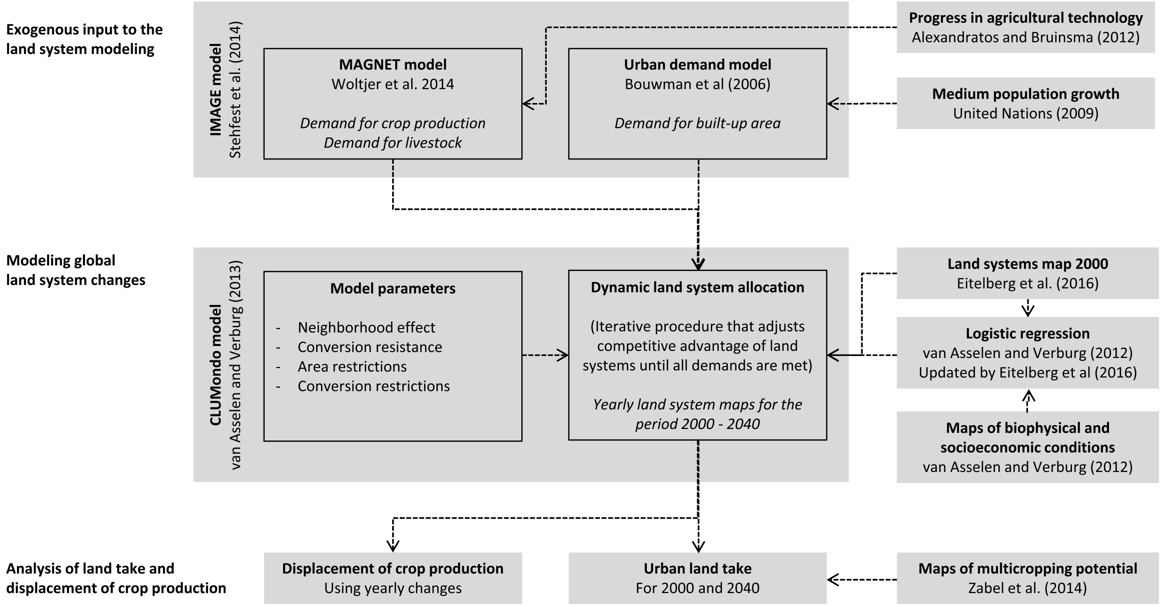

Fig. 1. Schematic representation of the study design, with the modeling and analysis in the center and data that is used as input on the right-hand side. Intermediate results that used in this study are indicated in Italics.