Monitoring peri-urbanization in the greater Ho Chi Minh City metropolitan area

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A B S T R A C T

Across the globe, urban areas are rapidly expanding, and now the majority of the world’s population lives in cities. Peri-urbanization, a specific form of urbanization characterized by rapid and fragmented growth, is also increasing, especially in developing countries. By 2030, it is anticipated that peri-urban areas in East Asia will expand by 200 million people, or 40% of total projected urban population growth, creating in these areas one of the largest and most significant land cover changes in the region. Characterizing and understanding the peri-urbanization process is critical, as these transition zones have a wide range of impacts across multiple scales, including local effects on farmer livelihoods, regional impacts to economic development, fragmented governance, as well as detrimental environmental impacts such as increased air and groundwater pollution, loss of native vegetation, and decreases in biodiversity. Yet the dynamic and piecemeal nature of peri-urbanization presents challenges for monitoring this unique process. This research combines commune-level Vietnamese census information, dense time stacks of Landsat satellite data (1990–2012), and several spatial measures to quantify urbanization and peri-urbanization in the greater Ho Chi Minh City metropolitan area from 1990 to 2012. The results indicate that 660.2 km² of cropland was converted to urban uses (a near quintupling of urban land), while 3.5 million persons moved into the region, bringing the total population to nearly 12 million by 2012. The analysis also highlights the rapid, unplanned nature of peri-urban development: approximately one-third of new urban expansion occurs in areas >40 km from the core, with nearly 50% of population expansion occurring in communes classified as peri-urban. This pattern of growth is likely linked to policies meant to spur foreign investment, and we expect that these regions will continue to attract much, if not most, of the foreign direct investment (FDI) flowing to the region, since most large manufacturing enterprises now locate in peri-urban areas.

Introduction

Of the various land use and land cover changes induced by humans, urbanization manifests itself as the most rapid and irreversible change (Schneider & Woodcock, 2008). Further, though urban areas comprise less than 0.5% of global land area (Schneider, Friedl, & Potere, 2009), more than half of the global population resides in, and depends upon, these regions (United Nations, 2011). Despite occupying a relatively small physical footprint, the ecological footprint of urban areas is vast, as these systems not only alter local ecology, but also impact broader regions via resource extraction and pollution patterns (Jin, Dickinson, & Zhang, 2005; Pickett et al., 2001; Rees, 1992).

As cities expand and populations continue to multiply, food production is becoming a paramount concern for governments, planners, and land use managers. Recent estimates indicate that the world population will surpass nine billion by 2050 (United Nations, 2011), which will require a 50% increase in agricultural production to meet the growing demand for food (Fritz et al., 2013). Some estimates project that an additional 2.7–4.9 million hectares per year will be required to meet the increasing food demand, yet productive, arable land is an increasingly scarce resource (Lambin & Meyfroidt, 2011). In recent decades, more intensive farming has resulted in greater yields per hectare (Sassenrath et al., 2008),
However there is evidence that these increases are beginning to taper off (Lobell, Cassman, & Field, 2009). It is likely that more food will need to be produced from the same amount of cropland as exists currently (Godfray et al., 2010).

In developing countries, urban expansion is often rapid and unplanned, which can lead to unintended and detrimental consequences. Cities are often located on the most productive agricultural lands (Imhoff, Lawrence, Stutzer, & Elvidge, 1997), so any expansion of built-up areas quickly consumes natural resources, compromising not only food production, but also the provision of ecosystem goods and services that are derived from these landscapes (e.g., climate regulation, water infiltration, etc.) (Foley et al., 2005).

In densely populated, rapidly developing countries such as China, India, and Vietnam, state-led industrialization and urban growth policies have compelled rural landowners to sell high-yield cropland to developers (Leaf, 2002). Moreover, explosive urban expansion in China during the last two decades has taken millions of hectares of rice out of production (Tan, Li, Xie, & Lu, 2005), and recent studies suggest that India may follow suit (Joshi, Mishra, Chattath, Ortiz Ferrara, & Singh, 2007). This has produced a ‘tele-connection’ effect whereby rice crops in other parts of the world are increasing in importance (Seto et al., 2012).

Another challenge to continued crop production in rapidly developing Southeast Asian countries is the rise of peri-urbanization (Simon, 2008; Webster, 2001). While there is no consensus in the literature on an exact definition of peri-urban land, these areas are generally regions between agricultural and urban areas, where urbanization is occurring rapidly, often due to foreign investment. Peri-urban zones have also been defined as regions outside cities where manufacturing is increasing (e.g., >20% employment in manufacturing, and climbing), as primary sector employment (e.g., agriculture, aquaculture) declines (Webster, 2001). In Asia, a specific spatial pattern of peri-urbanization called desakota has emerged, in which densely populated rural areas are urbanizing rapidly, leading to a range of social and environmental challenges (Douglas, 2006; McGee, 1991).

Peri-urban areas are beginning to appear in Vietnam, although these changes have not yet been documented spatially. Because over 70% of the total population is rural, and agricultural activities account for 60% of employment (World Bank, 2009), there is concern that urban expansion onto croplands could lead to a substantial decrease in agricultural production and detrimentally impact many livelihoods. The land surrounding Ho Chi Minh City is almost exclusively cropland, and the low-lying geography of the region also leaves it vulnerable to sea level rise, salinity intrusion, and storm surge. Thus, it is becoming increasingly important to monitor land cover changes in the region, the factors playing a role in shaping cities and peri-urban areas, and the possible drivers of arable land loss. This information will allow greater understanding of land change processes in Ho Chi Minh City and in Vietnam, and can serve as a first step toward providing local, regional and national governments with much needed information for land use planning and cropland conservation strategies at the urban–rural fringe.

This paper aims to document and analyze the rates, locations, and patterns of urbanization, peri-urbanization and cropland loss in and around Ho Chi Minh City in recent decades. The primary research questions are:

1) What factors have driven urban expansion and peri-urbanization in Vietnam between 1990 and 2012?
2) How have patterns of urban expansion and population change shifted over the last two decades, and how much of new land development has occurred in peri-urban areas?
3) How do changes in urban land compare to changes in population distribution across the region at the commune level?

To address these questions, the first section discusses the factors spurring urban expansion in Vietnam by drawing on current literature. Next, we specify our study area, and define what we consider to be the greater metropolitan area of Ho Chi Minh City. In the third section, we investigate the pattern and form of urban growth and expansion in the greater Ho Chi Minh City metropolitan region by using Landsat data to map built-up areas during three time periods (1990–2000, 2000–2006, 2006–2012), and connecting these to population estimates at the commune level. We draw on work by Saksena et al., who identified peri-urban communes in the Mekong region using Vietnamese agricultural census data (Saksena et al., 2014). Finally, the paper concludes with a discussion of possible drivers and implications of the urban spatial patterns in the region.

Background: a review of driving forces of urbanization in Vietnam

After more than 90 years of French colonization, the First Indochina War led to Vietnamese independence in 1954, at which time a strict Communist government came to power. In the North, the Communist regime was unchallenged, but South Vietnam fought against it (with the help of the United States) during a civil war that lasted from 1955 until 1975, when Saigon fell to the North. At this point, the country became unified under Communism for the first time. To offset high population densities in North Vietnam, the government orchestrated a mass population redistribution program to move people to the South and balance urban and rural areas (Jones & Fraser, 1982). In addition, the government collectivized agriculture to increase production and achieve domestic food sovereignty, but fell short of expectations, and only 60% of the production goal was achieved (Jones, 1982; Riedel & Comer, 1996). This lack of agricultural production coupled with economic stagnation led the government to institute a series of reforms in the late 1980s called doi moi (Gainsborough, 2002). Specifically, the government followed in China’s footsteps by abandoning a centrally-planned model of socialism in favor of a “market-oriented socialist economy under state guidance” (Beresford, 2008). Though effects were not instantaneous, by the early 1990s sweeping changes spread throughout the country due to the adoption of capitalist market principles (Beresford, 2008; Jones, 1982; Leaf, 2002; Pingali & Vo-Tong, 1992; Thi Ut & Kajisa, 2006).

For urban planning purposes, doi moi meant that cities were no longer centrally planned, since this system was deemed to be economically inefficient due to wasteful spending (Quang & Kammeier, 2002; Van Horen, 2005). Prior to reform, a hallmark of development in Communist-led countries was a strict divide between urban and rural areas, and underinvestment in urban cores (Leaf, 2002). However, the Land Law enacted in 1993 gave citizens more ownership of their homes by increasing the length of usufruct rights, and allowing for property transfer and inheritance (Quang & Kammeier, 2002). As a result, people began to invest in the redevelopment of their homes, while at the same time an informal land market emerged, leading to a densification of the urban core.

\[\text{footnote}{In this paper, we utilize prior commune classifications by Saksena et al. (2014), and to maintain consistency with their efforts, we employ their definition of ‘commune’. To paraphrase Saksena et al., Vietnam’s provinces and five major cities are divided into districts, provincial towns, and provincial cities. Districts are further divided into communes (rural areas) and towns, and provincial towns and cities are divided into wards (urban subdistricts) and communes. For brevity, the term ‘commune’ will be used to refer to the smallest administrative unit whether it is a commune, town, or ward.}\]
(though 70–90% of the building was unauthorized by the government) (Leaf, 2002). Further, cities became less concentrated as core urban areas expanded into pre-existing villages along the urban periphery (Leaf, 2002), and government plans focused on industrialization and urbanization of small cities to relieve congestion in major urban centers (World Bank, 2011). The creation of these extended metropolitan regions was not unique to Vietnam, but common to many Southeast Asian countries during the 1990s and 2000s, as urban areas grew rapidly and became more polycentric in form (Simon, 2008).

After doi moi, city governments were also granted more power and decision-making ability by the central government. Many district-level governments created tax incentives to appeal to corporate interests, which in turn resulted in greater foreign direct investment (FDI) (McGee, 2009). In many ways the doi moi reforms were fortuitously timed, as Malaysia, Thailand, and Singapore began to export capital for the first time in the early 1990s, and Vietnam could provide the labor and land for these intraregional FDI flows (Freeman, 2002). FDI quickly became an important part of the economy. At the end of the 1990s, foreign-invested companies accounted for 27% of exports, 35% of industrial output, and made up 13% of the country’s GDP—all while employing only 1% of the Vietnamese population (Freeman, 2002). This rapid economic growth contributed to increased rates of land use change, specifically for urbanization and industrialization purposes (Chen & Fleisher, 1996; Démurger, 2001; Gao, 2002; Seto & Kaufmann, 2003; Wu, 2008; Yeung, 2000). Moreover, in the first ten years after the doi moi liberalization policies were implemented in
Vietnam, 89.2% of foreign investment went to either Hanoi or Ho Chi Minh City, the country’s two largest urban areas (Drakakis-Smith & Dixon, 1997). By 2000, the Ho Chi Minh City region received 52% of all FDI to Vietnam and 74% of all total investment (McGee, 2009).

In Vietnam, the rapid urbanization driven by doi moi reforms has mirrored the impacts that economic liberalization has had in China, which also experienced (and continues to experience) swift development in the wake of reforms (Schneider & Mertes, 2014; Seto & Fragkias, 2005; Seto & Kaufmann, 2003). Throughout Southeast Asia, including Vietnam, increasing investment and development has led to the formation of desakota zones, a specific type of peri-urbanization that stretches along corridors connecting built-up areas (Kelly, 2011; McGee, 1991). These desakota zones are characterized by high population densities, a heterogeneous mixture of land covers and uses, extremely high population mobility, and a decrease in agricultural activities (McGee, 2009). Prior to doi moi reforms, Vietnam met all of these requirements except for a decrease in agricultural activities, which occurred in the 1990s as FDI led to new job opportunities. Increased investment in Ho Chi Minh City created an agglomeration economy, rendering the region more appealing for further FDI and development (Krugman, 1991). This has required infrastructure development, which in turn has led to the formation of peri-urban zones at the expense of cropland or rural settlements.

**Study area**

With a population of over six million people (circa 2012), Ho Chi Minh City (10°49' N, 106°37' E) is Vietnam’s largest city (Fig. 1A). Vietnam is bordered by the South China Sea to the east, China to the north, and Laos and Cambodia to the west. Since the implementation of doi moi, the population in Ho Chi Minh City has grown significantly (United Nations, 2011), and this has been accompanied by rapid industrialization. The Southeast region of Vietnam, which includes Ho Chi Minh City, has the highest employment shares in commercial services (40.4%), manufacturing (32.6%), and industry/construction (40.2%), and all of these sectors grew rapidly between 1999 and 2009 with annual growth rates of 8.4%, 11.9%, and 11.7%, respectively (World Bank, 2011). In this study we focus exclusively on urban development in the greater Ho Chi Minh City area because it has received the highest levels of FDI and has correspondingly high rates of growth in non-agricultural job sectors. Further, Ho Chi Minh City lies on the border of the Southeast region and just north of the Mekong River Delta region, the latter of which has an employment share of 58.2% in agriculture/fishery activities and produces approximately 90% of Vietnam’s rice for export (Nguyen, Do, Nguyen, & Le, 2004; Sakamoto, Van Phung, Kotera, Nguyen, & Yokozawa, 2009; Thanh & Singh, 2006). Therefore, any loss of cropland or decline in yields in the delta will not only significantly impact regional food prices and availability, but Vietnam’s economy as a whole (World Bank, 2009).

**Materials and methods**

**Defining urban extent**

Prior to analysis, it is necessary to first define ‘urban land’, and to delineate what we consider the greater Ho Chi Minh City metropolitan area. Urban land can contain many different land uses, including parks, buildings, small water bodies, and roadways. However, when assessing urban and built-up areas using remote sensing techniques (as in this paper), it is customary to define urban land as areas with impervious surface cover since this type of land cover can be distinguished from other land cover types on satellite images (Arnold & Gibbons, 1996; Schneider & Woodcock, 2008). Here, we follow this convention, and define urban and built-up land as those pixels that are composed of at least 50% built-up surfaces, including buildings, roadways, and other human-made features.

To define the greater Ho Chi Minh City metropolitan study area, a broader definition of urban land is required to ensure that all functionally ‘urban’ areas are included. Though political boundaries are often used to define urban extent, these boundaries are typically not large enough in major metropolitan areas to capture changes in population and urban area that occur outside the urban core (Cohen, 2004). Here, we consider the 50 kilometer (km) radius surrounding central Ho Chi Minh City (specifically, the original central business district) as the extent of our study area, as this distance accounts for the major land cover changes that take place in Ho Chi Minh City and surrounding provinces. This study also builds on previous methods developed to assess urban expansion using buffer analysis that extends outward from the city core (Schneider & Woodcock, 2008; Seto & Fragkias, 2005; Stewart, Yin, Bullard, & MacLachlan, 2004; Xu et al., 2007). Since the contiguous, circa-1990 urban core is encompassed within a radius of 8 km, we define 8-km buffers extending outward to 50 km (Fig. 2). Within each zone, we calculate the total urban area for each time point, and the percentage of this total that is newly built-up land.

**Remote sensing of urban expansion**

The Southeast Asian landscape is remarkably complex, with a heterogeneous mix of land cover types within a small area (Ellis & Ramankutty, 2008; Ellis et al., 2009). ‘Mixed pixels’ can arise due to the many combinations of materials present within a pixel, which can be problematic for mapping urban expansion and agricultural land loss using satellite data (Small, 2005). In addition, fallow farmland can appear identical to new urban areas, since both exhibit high reflectance in visible-infrared wavelengths. For our study area, this issue is compounded because agricultural fields support multiple crops per year, which results in high spectral variability across seasons, and from year to year. To overcome these issues, successful mapping of newly urbanized land requires data with high spatial and temporal detail, as well as a suitable historical archive. Here, we balance this trade-off by using medium spatial resolution (30-m) Landsat data, which has proven suitable for mapping changes in the complex landscapes of South and Southeast Asia (Castrence, Nong, Tran, Young, & Fox, 2014; Dewan & Yamaguchi, 2009a; Pham & Yamaguchi, 2011). We build on recent work that has shown that the use of several Landsat images, or ‘dense image stacks’, can provide added information on land cover types (Hilker et al., 2009; Huang et al., 2010; Kennedy, Cohen, & Schroeder, 2007; Verbesselt, Hyndman, Newnham, & Culfenor, 2010). The central premise of this approach is that the confusion between new urban land and other land cover types can be resolved by utilizing images from multiple seasons and multiple years (Schneider, 2012). While there may be confusion between bare ground and urban areas during the course of one year, there is a high probability that nearby fields or open areas will be vegetated during at least one season, and thus be ‘ separable’ from built-up areas that are predominantly non-vegetated year round. Since urban expansion is often unidirectional, imagery from multiple years is also beneficial because spectral information following the date of change confirms that an area has been developed. For this study, we exploit dense stacks of Landsat TM and ETM+ images (20–30 scenes per footprint) from four footprints, 1990–2012 (see Table 1 for path/row information).

All images were acquired as terrain-corrected, with minimal or no cloud cover contaminating the study area portion of each
footprint. Note that radiometric correction was not performed since this step is only necessary when images are analyzed individually, but not simultaneously as we did here (Song, Woodcock, & Seto, 2001). To analyze urban expansion, we used a supervised multi-date composite change detection technique to map areas of change and no-change. The multi-date composite approach was specifically chosen because of its superior accuracy for difficult change detection problems (Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004; Rogan & Chen, 2004), and because it provides a means to exploit dense time stacks of Landsat data. Before collecting training samples, a classification scheme was developed to include areas that did not undergo change (‘stable’ classes, including agriculture, water, mangroves, aquaculture, salt ponds, built-up land), as well as areas of urban expansion for three time periods (1990–2000, 2000–2006, 2006–2012) (Table 1).

The Landsat scenes were stacked and used as input to a supervised support vector machine (SVM) classifier. Non-parametric machine-learning algorithms derived from statistical learning theory, like SVMs, have been successful at classifying these complex areas due to their ability to handle non-linear relations between features and classes (Griffiths, Hostert, Gruebner, & der Linden, 2010; Huang, Davis, & Townshend, 2002). An SVM defines boundaries between classes using optimization algorithms (Vapnik, 1999). A multi-dimensional optimal hyperplane separates classes, and training samples closest to the hyperplane are termed ‘the support vectors.’ Decision boundaries for classes are chosen to maximize the margin between classes, where the margin is the sum of the distances to the hyperplane from the closest points of the two classes (Huang et al., 2002). Although SVMs are fundamentally a binary classifier, they are capable of classifying multiple categories by combining several binary classifications (Huang et al., 2002).

All image processing was conducted using ENVI software (Exelis Visual Information Solutions, 2011). Training samples were selected through image interpretation of Landsat and Google Earth imagery and through data gathered during a field visit in summer 2012. The field visit established that the main land cover change occurring in the area is expansion of built-up area onto agricultural land, while other changes (such as expansion of built-up area onto forested land) were negligible. Dense time stacks for each of the four Landsat footprints were processed separately, using unique sets of training samples for each image stack (Table 1). The final land cover change maps for each footprint were mosaicked together to form a single map for the study area (see Fig. 1B). Finally, post-processing of the map included sieving the classes using eight neighboring pixels to reduce speckle, and hand editing to correct minor errors.

An accuracy assessment was performed by comparing the maps to a set of randomly selected, independently labeled ‘truth sites’, and quantifying areas of agreement (Congalton, 1991). A proportional, stratified random sample of more than 400 pixels was selected for the study area, and assessment of both Landsat and Google Earth imagery was used to label the locations. The final map of the Ho Chi Minh study area has an overall accuracy of 96.6% (kappa = 0.92), indicating strong agreement between the map and ground reference information (Table 2). The multi-date composite change detection method performed particularly well for the agriculture, built-up, and water classes, all of which have user’s and producer’s accuracies above 99%. There was some confusion among the change classes, specifically between urban expansion that occurred 2000–2006 and 2006–2012. The map tends to over-classify change from earlier time periods, but these errors are small, and generally, newly built-up areas are only misclassified by period. The low accuracies on the change classes may also be an artifact of the relatively low number of test sites associated with the change classes as a result of the random sample.

Socioeconomic and demographic data

To investigate demographic trends in the study region, we rely on several datasets. First, we incorporate commune-level
population data from the decadal Vietnamese Population Census data for 1999 and 2009. Between these two time points, some commune boundaries changed slightly due to redistricting, so it was necessary to create a standard set of commune boundaries for use in the GIS. Since this work builds on a prior commune designation from the 2006 Vietnamese Agricultural Census data, and no boundary changes occurred from 2006 to 2009, we aligned all population data to the 2009 administrative boundaries. To do this, we manually merged communes (and their respective population statistics) that split into multiple communes between the two time points. In 1999, there were 648 communes within the 50 km study area boundary, and by 2009, there were 685 communes within the boundary. If a single commune in 2009 was composed of three separate communes in 1999, for example, we merged the three unique 1999 communes into a single commune for the purpose of comparing population data across time. Within each commune, the percentage population change, 1999–2009, was estimated as follows:

\[ \text{population change} = \left( \frac{\text{Pop}_{2009} - \text{Pop}_{1999}}{\text{Pop}_{1999}} \right) \times 100 \]

Second, we employ a stratification of the communes (Saksena et al., 2014) to determine which commune type (urban core, urban, peri-urban, or rural) experienced the highest rates of urban expansion and population growth. Saksena et al. (2014) used data aggregated at the commune scale from the 2006 Vietnamese Agricultural Census on the fraction of households whose main income is from agriculture, forestry and aquaculture; the fraction of land under agriculture, forestry and aquaculture; the fraction of houses using modern forms of toilet (toilet flush or septic); and the Normalized Difference Vegetation Index (NDVI) value for each commune derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery (for a detailed account of the classification methodology, see Saksena et al., 2014). Of the 676 communes mapped in this study, Saksena et al. (2014) classified 182 as urban core, 101 as urban, 239 as peri-urban, and 139 as rural (Fig. 2A). Henceforth when we speak of urban core, urban, peri-urban, and rural communes we are referencing the classification by Saksena et al. (2014).

Results

The resulting map of the greater Ho Chi Minh City area broadly illustrates the spatial patterns of urban expansion, 1990–2012. During this 22-year period, a total of 660.2 km² of cropland was converted to built-up areas, which corresponds to a near quintupling of urban land. Concurrently, almost 3.5 million persons

The classification scheme and distribution of training samples for each Landsat footprint.

<table>
<thead>
<tr>
<th>Classification scheme</th>
<th>Definition</th>
<th>Path 124, row 52</th>
<th>Path 124, row 53</th>
<th>Path 125, row 52</th>
<th>Path 125, row 53</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unchanged classes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban, built-up land</td>
<td>Non-vegetated, impervious materials &gt; 50% of land cover, with a minimum area &gt; 1800 m²</td>
<td>23</td>
<td>23</td>
<td>118</td>
<td>24</td>
</tr>
<tr>
<td>Cropland</td>
<td>Crops comprise &gt;50% of land cover</td>
<td>66</td>
<td>96</td>
<td>136</td>
<td>89</td>
</tr>
<tr>
<td>Forest</td>
<td>Woody vegetation comprises &gt;50% of the land cover</td>
<td>0</td>
<td>7</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Mangroves</td>
<td>Mangrove forest comprises &gt;50% of land cover</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Salt ponds</td>
<td>Salt extraction comprises &gt;50% of land cover</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aquaculture ponds</td>
<td>Inland aquaculture ponds comprise &gt;50% of land cover</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Water</td>
<td>Rivers, lakes, canals, ponds, seas</td>
<td>24</td>
<td>47</td>
<td>47</td>
<td>23</td>
</tr>
<tr>
<td><strong>Changed classes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cropland to urban, 1990–2000</td>
<td>Productive or fallow cropland converted to built-up land with &gt;50% non-vegetated, impervious materials and a minimum area &gt;1800 m²</td>
<td>42</td>
<td>31</td>
<td>98</td>
<td>20</td>
</tr>
<tr>
<td>Cropland to urban, 2000–2006</td>
<td>Stable urban</td>
<td>29</td>
<td>32</td>
<td>100</td>
<td>16</td>
</tr>
<tr>
<td>Cropland to urban, 2006–2012</td>
<td>Stable urban</td>
<td>5</td>
<td>19</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>189</td>
<td>293</td>
<td>587</td>
<td>229</td>
</tr>
</tbody>
</table>

Table 2
The overall, producer’s, and user’s accuracies for the final map of urban expansion.

<table>
<thead>
<tr>
<th>Class</th>
<th>Truth</th>
<th>Water</th>
<th>Agriculture</th>
<th>Mangroves</th>
<th>Stable urban</th>
<th>Change time periods</th>
<th>Ponds</th>
<th>Salt</th>
<th>Total</th>
<th>User’s accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td></td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td>28</td>
<td>100%</td>
<td></td>
<td>28</td>
<td>100%</td>
</tr>
<tr>
<td>Agriculture</td>
<td></td>
<td>299</td>
<td></td>
<td></td>
<td></td>
<td>300</td>
<td>99.7%</td>
<td></td>
<td>300</td>
<td>99.7%</td>
</tr>
<tr>
<td>Mangroves</td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>95.2%</td>
<td></td>
<td>1</td>
<td>95.2%</td>
</tr>
<tr>
<td>Stable urban</td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td>100%</td>
<td></td>
<td>7</td>
<td>100%</td>
</tr>
<tr>
<td>Change time periods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>75%</td>
<td></td>
<td>9</td>
<td>75%</td>
</tr>
<tr>
<td>1990–2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>46.1%</td>
<td></td>
<td>3</td>
<td>46.1%</td>
</tr>
<tr>
<td>2000–2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>88.9%</td>
<td></td>
<td>6</td>
<td>88.9%</td>
</tr>
<tr>
<td>2006–2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>8</td>
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moved into the region, bringing the total population to nearly 12 million. Most built-up expansion since 1990 occurred in the northeast quadrant of the study area, while to the northwest, a substantial amount of contiguous new urban land was developed (Fig. 1). During the earliest period (1990–2000), urban expansion is almost exclusively contiguous to the communes classified as urban core, while during the later two periods (2000–2006, 2006–2012), new urban land tends to be patchier, and disconnected from urban core communes.

Of the total amount of expansion, >62% occurred in communes classified as peri-urban (Figs. 2A and 3A). This amount is double the development that occurred in urban communes, and over 16 times the amount of urban expansion that occurred in rural and urban core communes. A similar pattern emerges with population, though not as extreme, with peri-urban communes absorbing ~50% of the population increase between 1999 and 2009. In comparison, all urban communes (both urban and urban core) have a combined ~34% of urban expansion and ~48% of new population.

The pattern of urban expansion within the communes also varies by time period (Fig. 4). Generally, the amount of urban and built-up land remains stable in both urban core and rural communes, with the former retaining high concentrations of built-up area (>95%) throughout the study period and the latter having relatively low concentrations (<5%). Far greater urban expansion occurs in the urban and peri-urban communes, however. In the urban communes, over half of the urban expansion (54.8%), occurs between 1990 and 2000, while in peri-urban areas, nearly half of urban expansion (46.9%) occurs between 2000 and 2006, and another third (30.6%) between 2006 and 2012. Further, each successive time period shows substantial changes in built-up concentrations for peri-urban communes, while concentrations begin to stabilize for urban communes by 2006. Note that peri-urban communes have a high number of outliers above the 90th percentile, indicating that some communes actually have concentrations of built-up area that rival or surpass urban core communes.

Interestingly, the population density patterns for each commune reveal a very different trend (Fig. 4E–H). The concentration of people is highest in urban core communes for both 1999 and 2009, although there is a slight decline in population density for the urban core. Urban communes, on the other hand, increase in population density, 1999–2009, which mirrors the increase in urban land during this period. Peri-urban communes also experience a slight increase in population density, though not to the same extent that the urban and urban core densities increased. Similar to the concentration of built-up land, rural communes have the lowest

Fig. 3. This figure illustrates (A) how much urban expansion occurred in each commune type, and (B) how much population increased in each commune type, 1990–2012.

Fig. 4. Box plots illustrating the total built-up area by commune type for 1990, 2000, 2006 and 2012 (top row, A–D), and the total population by commune type for 1999 and 2009 (bottom row, E–H).
Comparing the upper two quintiles in the two maps (Fig. 6A, B) reveals that 58 communes have both high rates of population and urban land were defined as peri-urban communes in the Saksena et al. (2014) classification. This suggests that it may be possible to characterize peri-urbanization using only population and land-use data, when more detailed census or survey data (such as those used for the Saksena et al. classification) are unavailable.

**Discussion**

Asia's population will grow by an astounding 1.4 billion people by 2050 (United Nations, 2012), and 40% of urban population growth is projected to occur in peri-urban areas (Webster, 2001). Peri-urbanization represents a new, distinct form of urban expansion that does not fit classic theories on the spatial form of urban development (e.g., polycentricity, hub-and-spoke distribution, streetcar suburbs, etc). This research documented peri-urbanization in the greater Ho Chi Minh City region by analyzing concomitant patterns of urban expansion and population change. The results highlight the rapid, unplanned nature of peri-urban development: approximately one-third of new urban expansion occurs in locations >40 km from the core, with nearly 50% of population expansion occurring in peri-urban communes. While early growth around Ho Chi Minh City is contiguous with the original urban core, later time periods are characterized by piecemeal, fragmented development often associated with investment-driven growth (Leaf, 2002; Webster, 2001).

While there is no clear pattern as to the location of peri-urban communes (other than distance), there are several factors that might explain these trends. Recent growth in Ho Chi Minh City is clearly related to doi moi reforms. Since 1994, industrial zones have been implemented throughout Vietnam that provide tax breaks on corporate profits (10% compared to the usual rate of 25%); these tax breaks are even greater if at least 80% of the profit is exported (Meyer & Nguyen, 2005). The greater Ho Chi Minh City region has 53 industrial zones designed to draw foreign investment (compared to 10 in the greater Hanoi region); these zones are concentrated in the Dong Nai and Binh Duong provinces (northern portion of the study area), as well as along major roadways that connect Ho Chi Minh City to northern Vietnam (e.g., highways QL-51, QL-13). Not surprisingly, these areas have the highest rates and amounts of both land and population change (Fig. 6), indicating that these incentives have played an important role in the overall rates and forms of urbanization and peri-urbanization. The dispersed pattern of urban expansion illustrated in this work suggests that the laws associated with liberalization (e.g., law on
foreign investment, land lease regulations, taxation policies) have been implemented unevenly by local governments, often due to ambiguity and the decentralized nature of decision-making (Meyer & Nguyen, 2005). The rates and patterns of development in Ho Chi Minh City — as well as the role of FDI in spurring large amounts of land expansion — align with conceptions of peri-urbanization in Southeast Asia, although it is important to note that this development contrasts sharply with other major metropolitan areas undergoing rapid development due to population growth at the city periphery, including Dhaka, Bangladesh (Dewan, Yamaguchi, &
rounding the core, Fig. 2B). In U.S. and European cities, it is well-known that ring roads can lead to increased rates of urban expansion, or whether newly built land spurred road development.

In recent years, the Vietnamese government has invested in road construction (General Statistics Office of Vietnam, 2011), focusing on creating four separate ring roads around Ho Chi Minh City (note that the third ring road aligns roughly with the 8 km buffer surrounding the core, Fig. 2B). In U.S. and European cities, it is well-documented that ring roads can lead to in-fill and development of low-density urban areas; however, in Vietnam, there is evidence that these roads are being built simultaneously with or after new urban and built-up areas.

Another hallmark of peri-urbanization in the greater Ho Chi Minh City region is illustrated by communes with incredibly high rates of urban land expansion relative to population growth (Fig. 6). This phenomenon has also been documented in other Asian countries undergoing peri-urbanization, notably China (Schneider & Mertes, 2014). In Vietnam, expansion of land with minimal population growth may indicate a trend toward “supply-side” development. Effectively, cropland is converted to new urban land with the expectation that new infrastructure will bring foreign investment, new firms, labor, and eventually, new residents to peri-urban zones. Because there is strong competition among provinces to attract investment, local governments often support new infrastructure that is based on targeted development goals rather than estimated demands, and declare local ad hoc investment zones to attract business ventures. Consistent with a supply-driven economy, industrial zones have not yet reached full occupancy, with zones in Ho Chi Minh City province at 63% occupancy, and those in nearby Dong Nai and Binh Duong provinces at 64% and 66% occupancy, respectively (World Bank, 2011).

Because the process of investment and land development is ongoing, the population has not necessarily moved into these newly emerging industrial areas, as indicated by Fig. 6, which illustrates that the highest rates of population change do not necessarily correspond with the highest rates of urban development. While the rate of population change is generally lower than rates of land development in most communes, in some urban core communes the number of inhabitants actually declined 1999–2009. This trend toward population decentralization was somewhat surprising, but it is not unprecedented since similar patterns have been documented in other global cities such as Cairo (Stewart et al., 2004), Beijing (Baum-Snow, Brandt, Henderson, Turner, & Zhang, 2012; Zheng & Kahn, 2013), and Hong Kong (Loo & Chow, 2011), to name a few examples. In many cities, this phenomenon is driven by a shift of high-income households to affluent neighborhoods outside of the urban core. However, in Ho Chi Minh City, this population trend could be related to recent efforts to gentrify the urban core, since the construction of large, luxury apartment buildings in place of densely-settled, traditional structures often leads to lower population densities at the neighborhood scale. Additionally, growth along the urban periphery (Fig. 1B) has led to more housing options outside of the urban core, and the movement of people into these areas would account for a decreasing rate of population change in urban core communes while surrounding communes experience an increasing rate of population change.

Though we have presented evidence that peri-urbanization occurred during the last decade, it is difficult to forecast whether peri-urbanization will continue as the dominant form of land cover change in coming decades without further inquiry into the drivers and outcomes of this process. In addition, further research is necessary to investigate social, economic and environmental impacts of peri-urban expansion. It is unclear whether peri-urbanization may be beneficial by bringing new industries to rural areas (often with young, underemployed populations) and concentrating urban impacts to specific locations (e.g., economic zones), or whether it could be considered detrimental, leading to the formation of extended urban regions, increased environmental damage and further loss of croplands. If peri-urban expansion brings negative or unintended consequences (i.e. areas of new growth remain empty, and additional FDI and local populations do not follow new land development), it is critical to determine what policies may be effective in limiting or retro-fitting this type of growth.

Because peri-urban land is often associated with cropland loss, this pattern of growth could eventually lead to lower agricultural production in Vietnam. In the last decade, cropland loss (such as shown in this work) has been accompanied by an increase in agricultural yields, indicating that an increase in cropping intensity has occurred in Vietnam (General Statistics Office of Vietnam, 2011) (Table 3). Unfortunately, it is unlikely that further intensification will increase yields in Vietnam, as the difference between the potential yields and actual yields in this region is near zero because modern agricultural technologies and management practices have already been applied (Licker et al., 2010). Although Vietnam has seen dramatic yield increases since the 1990s, practices meant to bolster yields in the short-term are not necessarily sustainable, and turning large amounts of agricultural land into built-up regions could compromise the country's future ability to produce adequate amounts of food. While this study generalizes cropland to be any sort of planted crop, it will be important to focus on the differential impacts of expansion onto various crop types (rice, vegetables) in future work, and whether or not some crops have experienced higher rates of change than others.

The research presented here illuminates recent trends in the greater Ho Chi Minh City metropolitan area, and in doing so, makes
three contributions. First, this paper adds to the literature on rapid growth and expansion of Southeast Asian cities by specifically connecting empirical data on urban land and population to the complex factors that spur rapid change in urban environments. As such, the second contribution of our work is providing up-to-date information on rates and patterns of change in Ho Chi Minh City, illustrating previously undocumented trends for the last decade in particular. While not the first paper to do so, this research also linked detailed remote sensing-estimates of land conversion, census data, and spatial analysis, to document urban and peri-urban development trends in Vietnam. As a result, the third contribution is that our approach could act as a template for further monitoring of peri-urbanization. The results here closely correspond with the independent analysis of the urban transition in Vietnam conducted by Saksena et al. (2014). The two projects provide alternative, as well as synergetic, ways to define and map the urban transition in the area surrounding Ho Chi Minh City. Where census data are available in a format that can be linked to administrative boundaries, these data provide useful insights into the socio-economic characteristics of places undergoing the rural-to-urban transition. In places where highly detailed census data are unavailable or do not exist, the work here presents a way to monitor peri-urban development using freely available satellite imagery and accessible population data.

Conclusion

The goal of this research was to characterize and understand changes in land use and population in the greater Ho Chi Minh City region between 1990 and 2012. We found that urban growth and expansion since 1990 has been rapid, with the built-up areas increasing 4.8 times their initial size in the 22-year period, and two-thirds of land development occurring outside of urban commons. Combined with population trends at the commune level, this trend can be characterized as peri-urbanization, a relatively new development phenomenon that does not fall within the definitions of traditional urban growth theories. While peri-urbanization has been documented in China, Indonesia, and other Asian countries, this work is one of the first investigations to monitor this trend in Vietnam. New FDI flows, the creation of investment zones, and infrastructure development have all likely contributed to the changes illustrated in this research. Since peri-urban expansion takes vast swaths of cropland out of production, it is critical to monitor these changes and mitigate any detrimental impacts where possible. Doing so will provide much-needed information to local governments and land use planners, so that future development may proceed in an efficient, sustainable, and inclusive manner.

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References


