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Graying, greening and fragmentation in the rapidly expanding Indian city of Bangalore

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ABSTRACT

Urbanization in Asia exhibits some distinctive patterns of change that are not observed in other Western countries. The south Indian city of Bangalore is India's second fastest growing city, and has witnessed the large scale destruction of vegetation in recent years for urban development. This research uses satellite imagery to study changes in vegetation cover in Bangalore between 2000 and 2007. We find anomalous patterns of vegetation change. The core is relatively well protected due to high land prices and the presence of large public institutions due to its historical pattern of development as a military station, but is undergoing fragmentation. Peripheral areas are undergoing rapid urbanization, vegetation clearing and fragmentation. Although greening is taking place in the landscape surrounding the city limits, this appears to be short term, largely consists of fast growing water hungry exotic species, and presages further rapid and large scale development as the city expands even further. The findings presented here have important implications for policy and planning at the local, city and regional level. These suggest that an especial emphasis needs to be made on understanding the role and importance of vegetation in rapidly expanding cities, to achieve a healthy urban environment.

1. Introduction

Urbanization represents perhaps the most dominant anthropogenic modifier globally, with a large part of the world's rural populations migrating to large and small urban agglomerations. City expansion and urban growth is most obvious in countries like India and China, which have experienced unprecedented economic prosperity in recent years. Urbanization in these countries, as in other parts of South and South-east Asia, exhibits some distinctive patterns of change that are not observed in other Western countries (Murakami, Zain, Takeuchi, Tsunekawa, & Yokota, 2000). Perhaps most obvious, much of the growth in many Asian cities has been so rapid that it has been largely unplanned, and somewhat chaotic: this is especially observed in many parts of India as well as China (Taubenböck, Wegmann, Roth, Mehl, & Dech, 2009; Wu et al., 2006).

The problems caused by unplanned urbanization are many and diverse, but one major issue is that of ecological and environmental degradation. As cities expand, vegetation, wetlands, and other natural ecosystems shrink in area, and degrade in quality, creating urban heat islands (Zhou, Huang, & Cadenasso, 2011), contributing to pollution and flooding, and impacting human health and well-being (Tzoulas et al., 2007). Unfortunately, city planners are unable to deal with these issues, often because they lack basic data to monitor rates and patterns of change, and to understand the driving processes of change so that these can be better managed.

Satellite imagery provides an excellent source of data for such monitoring of the extent, location and spatial patterns of change due to urbanization. Many studies of urban change have focused their attention on understanding patterns of urban sprawl and increase in built areas (e.g. Irwin & Bockstael, 2007; Schneider & Woodcock, 2008; Taubenböck et al., 2009). There is simultaneously a real need to understand the extent, location and patterns of change in urban ecosystems, particularly urban vegetated areas, as these represent an important category that can significantly influence and impact the quality of life for most urban residents (Luck, Smallbone, & O'Brien, 2009; Tzoulas et al., 2007). Knowing where green spaces are present and well protected, and where they are endangered or absent, can help planners to design well connected greenways and other corridors and belts for comprehensive planning at the city wide scale, making cities more healthy and inhabitable for humans and other species (Jim & Chen, 2003).

Urban vegetation is diverse, often exhibiting greater heterogeneity and species richness compared to rural and forested areas (McDonnell & Hahs, 2008). Cities contain a diversity of green

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spaces including parks, home gardens, office complexes, wooded streets, wetlands, and remnant forests (Nagendra & Gopal, 2010, 2011). While some patches of remnant natural vegetation may exist within cities, many of the other patches of vegetation in cities owe their origin or current form to human influence, whether planned or unintended. Thus, urban vegetation is significantly modified by human influence, responding to social preferences, physical constraints and ecological influences (Nagendra & Gopal, 2011). Understanding patterns of tree cover change in cities can be a complex issue, and using a landscape ecological framework can be very helpful in developing a better understanding (Breuste et al., 2008; Wu, 2008). For instance, the size and accessibility of urban green areas is known to have an important impact on human well-being, and it is important for city planners to have adequate information on spatial aspects of location and distribution (Oh & Jeong, 2007). Further, it is also critical to assess changes in spatial connectivity of vegetated habitats, as these can have an important influence on the persistence of other urban biodiversity (Hepinstall, Alberti, & Marzluff, 2008). Incorporating an explicit focus on understanding the human drivers of urban vegetation change should form an integral part of such evaluations, as such an interdisciplinary approach throws important light on the social processes and ecological outcomes of urbanization (Davies et al., 2008; Luck et al., 2009; Zipperer, Sissini, Pouyat, & Foresman, 1997).

Many Indian cities have witnessed the large scale destruction of tens of thousands of street trees, and the clearing of vegetated plots, wetlands and other natural habitats within the city to make way for buildings, industries and infrastructure projects (Kumar, Mukherjee, Sharma, & Raghubanshi, 2010; Nagendra & Gopal, 2010). Indian cities, and indeed most cities from economically developing countries, also tend to differ from better researched North American and European cities in the density and spatial form of urban land cover distribution, with greater compactness and population density, lower patch complexity and less open space (Huang, Lu, & Sellers, 2007). Urban growth in India is also much less directed by state policies or colonial legacies than for many other parts of the world, resulting in patterns of growth that are irregular and complex, particularly in newer urban settlements located at the periphery. Yet, even within Indian cities, there can be significant differences in the planned new extensions at the periphery, which tend to have more open space and vegetated areas, as compared to the densely built inner city areas that tend to be more congested (Kumar et al., 2010).

The south Indian city of Bangalore is India's second fastest growing city, and has in recent years witnessed unprecedented expansion of urban areas, at the expense of its greenery (Sudhira, Ramachandra, & Subrahmanya, 2007). This study uses two-date satellite imagery to investigate changes in green cover and spatial connectivity following urbanization in the area surrounding the fast expanding south Indian city of Bangalore. Focusing on a time period between 2000 and 2007, when much of the rapid expansion and change in the city has taken place, we hypothesize that (a) green cover has been protected by public institutions in the city; (b) overall, however, green cover has reduced over time both within the city limits and in the surrounding landscape; (c) the extent of vegetation loss has been especially rapid in the peripheral areas of the city when compared to the core; (d) fragmentation of green spaces follows the same trends as losses in green area.

2. Study area

Bangalore has been on the global map in recent years for its technologically intensive industries. It is now the second fastest growing city in India, with a population approaching 9 million (Sudhira et al., 2007). The city has always been a favored place to settle in, and many of India's well known educational institutions, public sector industries and manufacturing industries have been located here, long before the information technology boom. The city has a welcoming climate, and was once well known for having a large number of open spaces including two historic parks and botanical gardens, and a number of wetlands and water bodies, as well as a protected tiger reserve at its periphery (Nagendra, 2010; Nair, 2005; Sudhira et al., 2007). In the past decade, Bangalore has witnessed widespread cutting of trees and clearing of vegetation for urban expansion and infrastructure activities. The city has also expanded to cover an area of 741 km^2. The Bruhat Bengaluru Mahanagara Palike (BBMP) is the agency responsible for the governance of the Greater Bangalore Metropolitan area. Within the city boundary, 198 administrative sub-divisions or wards are further located.

A recent comparative study of 25 cities in different parts of the world (Schneider & Woodcock, 2008) suggests that Bangalore follows a high growth path that is quite different from cities in the USA, with urbanization being constrained in the core due to lack of space, but with rapid spatial expansion of urban areas in the city periphery. Taubenböck et al. (2009) corroborate this in a large study of multiple Indian cities, suggesting that Bangalore is transitioning from a formerly mononucleated growth pattern to a polycentric pattern, with the fastest growth taking place around multiple peripheral areas. This pattern of growth, with the city core becoming increasingly saturated, and new urbanization centers developing at the periphery, can be traced to multiple factors. The high land prices in the city center and the lack of large spaces that are available for further urbanization have led to the location of many public sector, local and multinational companies, and prominent educational institutions at the city periphery (Shaw & Satish, 2006). This suggests that patterns of change in green areas may be similarly constrained, and may in fact follow an anomalous form with increased loss in vegetation area and loss of green connectivity taking place in peripheral areas, while the city core may be retaining its greenery reasonably effectively. If so, this would indicate that urban planning needs to concentrate on the city periphery, where unplanned and undirected development is occurring at an extremely rapid rate.

One factor that has not been mentioned in these discussions is the role of public institutions. The city of Bangalore has a long colonial history as a military settlement, as a consequence of which a number of areas within the city are under the ownership of the military, police and various defense establishments. Apart from this, there are a number of other campuses owned and managed by public sector industries and educational institutions. In addition to city parks, which have been relatively well studied in Bangalore (Swamy & Devy, 2010; Nagendra & Gopal, 2011), the role of these public institutions in protecting green spaces in the city needs to be further explored. This is a further objective of our study.

3. Methods

Two satellite images were used for this analysis. A Landsat ETM+ image of November 2000 was downloaded from the Global Land Cover Facility at the University of Maryland. A May 2007 IRS LISS 3 image was also acquired from the National Remote Sensing Agency of India. The 2000 image was spatially registered to four 1:50,000 Survey of India topographic sheets, after which the 2007 image was registered to the 2000 image. The 23 m IRS image was resampled to 30 m pixels during registration, in order to match with the pixel size of the ETM image. Care was taken to ensure that spatial overlays were well matched, with root mean square registration errors less than half a pixel, followed by careful visual examination of the overlaid images across a number of well distributed locations using swiping.