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# Managing urban coastal areas through landscape metrics: An assessment of Mumbai's mangrove system

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A B S T R A C T

The loss of coastal landscapes resulting from urban sprawl has become a growing concern that is difficult to manage. The consequences of sprawl are often lasting, leading to the irreversible loss of vulnerable and valuable natural landscapes in favour of urban land. In this paper I analyse the spatiotemporal differences of the urban footprint in Mumbai, India, and compare these changes to the existent mangrove systems in the coastal stretches of metropolitan Mumbai. Based on the extracted urban footprint of the coastal mangrove regions, landscape metrics are performed to understand the impacts of urbanisation on the relative increase and decrease of mangrove systems. Of the entire mangrove system in the Mumbai Metropolitan Area, 36% has been lost to urban land since 1973. Over the four time periods studied, an area of urban sprawl comprises the southeastern border of Mumbai, where, since 2000, pressure on the wetlands has been largely aggravated. The high correlation of coastal stretches and urbanisation is one of the main reasons for the current fragile state of Mumbai's mangroves. A combination of a decrease and an increase in mangrove sites suggests that certain urban typologies, such as denser urban areas and older urban regions, are more prone to mangrove recovery, whereas unplanned urban settlements and highly fragmented urban areas lead to a less favourable mangrove landscape. A spatial accounting of the distribution of landscape metrics is proposed in this paper to understand land use transitions where (1) a significant increase of dense urban areas along Mumbai's fragile coastal stretches is reported; (2) this loss of mangroves is underpinned by urban typology over time; and (3) a combination of metrics vis-à-vis zones where mangroves increase and decrease are spatially and temporally addressed. With the increase in economic development that Mumbai has exhibited in recent decades, it is important to monitor the impacts on natural regions. This is a challenging task where spatial metrics combined with urban footprints may lead to a better understanding of the environmental impacts on coastal stretches. The current planning policies suggest that attention has been given to the mangrove systems of the MMR, equating to beneficial results if economic prosperity and preservation measures in Mumbai continue to take place.

## 1. Introduction

The so-called "urban century" in which more than half of the world population is found in urban areas has led to dramatic changes in the configurations of land use (Foley et al., 2005). The increasing growth of cities is leading to more megacities that command the landscape (Griffiths et al., 2010). Polycentric urban agglomerations shape a new trend in urban patterns, especially in developing countries. These new urban agglomerations bring unprecedented challenges for urban planning and land use management. These challenges are chiefly a product of the nature of the agglomeration of urban areas, and the combination of anthropogenic activity in fragile ecological areas (Zhang and Seto, 2011). Advances in land use and spatial analysis have led to a better understanding of the underlying patterns, helping to create more sustainable urban regions (Lambin et al., 2001). In particular, when facing urban change in suburban and rural areas and accentuated population dynamics, spatial modelling has brought significant advances. The detailed information of the spatial distribution of environmental and natural land use has supported the optimal planning of urban regions (Verburg et al., 2002; Pettit et al., 2013). Spatial analysis has the possibility of being transferred to legislators and planners, as well as to state and local governmental entities,

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allowing these individuals and entities to (i) determine better land use policies and improve transportation and utility demand (Waddell, 2002), (ii) identify future development pressure points (Barredo and Demicheli, 2003), and (iii) implement effective plans for regional development through integrated support systems (Vaz et al., 2012; Geertman et al., 2013). The long-term effect of these actions can support sustainable development at the regional level, providing a systemic control that optimises the use of available resources as drivers of sustainable decision-making practices (Nijkamp et al., 1992; McGee et al., 2012). Significant contributions in the field of Geographic Information Systems (GIS) that relate land use/land cover change (LULC) (Koomen et al., 2007) have allowed for a bridge thorough empirical analysis of the consequences of urban change on different scales (Mahiny and Clarke, 2012). This has been a result of the growing number of remote sensing techniques, which aid in more accurate satellite imagery (Wentz et al., 2008) that, when allied to spatial analysis, provide more accurate methods for understanding the spatial morphology of cities and the environment and can subsequently lead to more sustainable urban regions. In developing countries, urban regions currently face a bottleneck: on one hand, cities act as engines of socio-economic growth and development (Richardson, 1989), but on the other hand, cities escort environmental degradation, including the surrounding natural land, heritage, and biodiversity. The consequence is an irreversible loss of the natural environment and an increase in urban pressure (Fazal, 2000; Gowda et al., 2000). This is particularly realized in vulnerable coastal areas, where ecological diversity is higher and integrated systemic assessments are very beneficial for optimal land use distribution (Pourebrahim et al., 2011), supporting local and regional planning (Turner et al., 1998). Systemic assessment becomes even more important in the context of megacities, where urban changes often have irreversible results on the environment. The available data sources compiled from remote sensing imagery and land use databases support planners in the process of adopting suitable regional policies (Dühr and Müller, 2012). Such combined techniques lead to a better understanding of the intrinsic complexity between urban growth and the negative externalities of excessive urban pressure on fragile environments (Newman, 2006). These applications are particularly welcomed in developing countries, where an unprecedented expansion of the urban footprint has occurred in recent decades (Cohen, 2004). This increase in the urban footprint has a direct impact on land use and results partially from increased population growth (Brockerhoff, 1999), socioeconomic dynamics, and economic disparity. It is expected that 60 per cent of the world's population will be living in urban areas by 2030, and most of the urban growth will occur in developing countries (Hall, 2003; Girard et al., 2007). Monitoring the pressure on environmental resources is thus of utmost importance in such regions facing urban sprawl (Bhatta et al., 2010), making India and, in particular, Mumbai a very important region to assess such phenomenon. Measuring sprawl is important to plan whether the city is becoming compact or dispersed, as well as to identify areas of pressure that affect different attributes of urban and rural interactions including growth, density, occupation typology, accessibility, fragmentation and decentralisation (Torrens, 2008). This makes the phenomenon of urban sprawl rather difficult to define (Wilson et al., 2003). For the purpose of this paper, a spatial and ecological perspective is adopted, where the impact of density and fragmentation as well as decentralisation are of utmost importance for the environmental stability of fragile ecological areas (Nagendra et al., 2004); a particular focus is on Mumbai's mangrove system and its surrounding landscape. The physical characteristics and patterns of sprawl on urban landscapes can be detected, mapped, and analysed using remote sensing and geographical information system (GIS) technologies in conjunction with secondary and ground truth data. This allows for a better understanding of urban sprawl in combination with spatial techniques (Sun et al., 2007). The integration of spatial accounting methods, such as deriving landscape metrics, allows for the quantification of urban sprawl and the ability to register a better understanding of the urban form (Yeh and Li, 2001), as well as to generate a better understanding of the landscape fragmentation induced by anthropogenic activities that often create conflicting trade-offs (Setälä et al., 2013). Comparison of this information on wetland systems and mangroves, therefore, permits an accurate observation of the loss of mangrove systems and a better understanding of the long-term impacts along vulnerable mangrove stretches (Vaz et al., 2013).

## 2. Study area

The megacity of Mumbai extends from 18° 53′ to 19° 16′ N and 72°–72° 59′ E. It is one of the most emblematic cities in India as well as the main city of the western state of Maharashtra. Currently ranked as the fifth largest city in the world, it had a total population of 12.5 million inhabitants in 2011. Consisting of a peninsula originally composed of seven islets, drainage and reclamation have caused the islets to join and form the Bombay (Mumbai) Island, which is bordered by the Arabian Sea to the west and Bombay harbour and the Thane Creek inlet to the east. In addition to being India's leading economic and financial district, Mumbai (Fig. 1) is also strongly linked to the new, modern and industrialised India, having been one of the main regions responsible for India's booming economy, holding over 40 000 industries in the region alone. The total urban area of Mumbai is 466.35 km$^2$, with a maximum width of 17 km east to west and 42 km north to south.

The availability of good infrastructure supported by the government and local authorities has facilitated Mumbai's economic prosperity. The abundance of different modes of transportation (railway networks, airways, sea transportation, ports, and the recent national four lane golden quadrilateral road), as well as an ample supply of electricity and water, has further supported the current economic growth of the Mumbai Metropolitan Region (MMR). Mumbai has a tropical savannah climate with a heavy southwest monsoon rainfall, measuring 2166 mm annually. The temperature ranges from 16.5 °C to 34.7 °C with only marginal changes between summer and winter months. The relative humidity is quite high, ranging between 54.5 per cent and 85.5 per cent. The city has an abundant natural landscape consisting of natural resources such as lakes, coastal waters, forest areas, wetland systems and mangroves. The wetlands and mangroves serve as an important part of the coastal ecosystem and offer natural protection as an erosion barrier, preserving the shoreline against tidal currents. Currently, however, much of the marine wildlife species and their natural habitats have been decimated and become greatly endangered because of the massive urban expansion, which has resulted in excessive waste and debris from dumping as well as several industries that threaten Mumbai's ecological carrying capacity. An assessment conducted by the United Nations (2012) predicts continuous growth of Mumbai's urban area, leading to an increase in the total population to 27 million people by 2025, becoming one of the largest urban regions worldwide and creating a dysfunctional enclave in the region (Wissink, 2013).

## 3. Data

### 3.1. Mumbai's urban footprint

An “urban footprint” represents the extent of artificial urban land use at the regional level (Landis and Reily, 2003). This