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Urban morphological determinants of temperature regulating ecosystem services in two African cities

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ABSTRACT

Urban green infrastructure provides important regulating ecosystem services, such as temperature and flood regulation, and thus, has the potential to increase the resilience of African cities to climate change. Differing characteristics of urban areas can be conceptualised and subsequently mapped through the idea of urban morphology types (UMTs) – classifications which combine facets of urban form and function. When mapped, UMT units provide biophysically relevant meso-scale geographical zones which can be used as the basis for understanding climate-related impacts and adaptations. For example, they support the assessment of urban temperature patterns and the temperature regulation services provided by urban green structures. UMTs have been used for assessing regulating ecosystem services in European cities but little similar knowledge is available in an African context. This paper outlines the concept of UMTs and how they were applied to two African case study cities: Addis Ababa, Ethiopia and Dar es Salaam, Tanzania. It then presents the data and methods used to understand provision of temperature regulation services across the two cities.

In total, 35 detailed UMT classes were identified for Addis Ababa and 43 for Dar es Salaam. Modelled land surface temperature profiles for each of these UMTs are presented. The results demonstrate that urban morphological characteristics of UMTs, such as land surface cover proportions and associated built mass, have a much larger potential to alter neighbourhood level surface temperatures compared to projected climate changes. Land surface cover differences drive land surface temperature ranges over 25 °C compared to climate change projections being associated with changes of less than 1.5 °C.

Residential UMTs account for the largest surface area of the cities, which are rapidly expanding due to population increase. Within the Residential UMTs, informal settlements and traditional housing areas are associated with the lowest land surface temperatures in Addis Ababa. These have higher proportions and better composition of green structures than other residential areas. The results have implications for planning policies in the cities. In Addis Ababa, the current urban renewal strategy to convert high density informal unplanned settlements into formal planned housing needs to explicitly account for green structure provision to avoid adverse effects on future supply of temperature regulation services. In Dar es Salaam, condominium UMTs have some of the largest proportions of green structures, and the best provision of temperature regulation services. In this case the challenge will be to maintain these into the future.

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1. Introduction

Africa is a continent particularly at risk from climate change. Temperature increases during the 21st century are expected to be in the range 3–4 °C – about 1.5 times larger than the projected increase in global mean temperatures (Christensen et al., 2007; Gualdi et al., 2013). Furthermore, by 2035, around 50% of Africa's population is expected to live in urban areas (United Nations, 2012). Rates of urban development are still outpacing those of economic growth and infrastructure development in many urban areas. This, coupled with high levels of unemployment and inadequate standards of housing and services, means that those living in African cities are among the most vulnerable to climatic extremes and natural disasters such as heat waves, droughts, flooding, erosion and sea level rise.

The fast rate of urban development in response to rising demographic pressure – Africa is around 40% urban, growing at 1.27% per annum (United Nations, 2012) – and in particular, unplanned development, also threatens urban ecosystems. This is a particularly topical issue since urban ecosystems can provide a range of benefits for human health and wellbeing that arise as a result of ecosystem structure and functioning. The Millennium Ecosystem Assessment frames these ecosystem services as being associated with supporting, cultural, provisioning and regulating roles (MEA, 2005). The regulating roles of urban ecosystems are of particular relevance for meeting the challenges of planning for future climate variability. Regulating services encompass benefits obtained from the regulation of ecosystem-related processes, including those of climate, water, carbon and some human diseases (MEA, 2005). This paper focuses specifically on local climate regulating services.

Despite the recognised importance of climate regulation services, such non-marketed services provided by ecosystems remain unrecognised due to their less tangible nature, and as a result are regularly degraded (MEA, 2005; Busch et al., 2012). Adebayo (1990) notes that building and urban design in tropical Africa rarely takes account of local climatic conditions, due to a history of external influence, the rapid increase of slums, planners lacking training and knowledge, the political environment, and a lack of research on local urban climates. Unplanned development (e.g. when this acts as a barrier to sea breeze or rapidly converts green space to impervious surfaces) is potentially the biggest threat to climate regulating services for human thermal comfort (Emmanuel and Johansson, 2006). Unplanned development may heighten the risk of heat-related mortality (McMichael et al., 2008), particularly given the association between high excess mortality for heat-related deaths and informal housing (Scovronick and Armstrong, 2012). Improving thermal performance of low cost housing – formal and informal – was identified as an important modifier in reducing heat-related mortality (Scovronick and Armstrong, 2012), but changes to other facets of the built environment that act to mitigate the Urban Heat Island (UHI) effect are also important, including the role of urban green space.

The value of urban green spaces in providing local climate regulation services is widely recognised (Bolund and Hunhammar, 1999; Gill et al., 2007; Bowler et al., 2010; Niemelä et al., 2010; Cavan et al., 2011; Cilliers et al., 2012). Specific direct and indirect benefits of green space associated with climate include flood water retention, improved infiltration, ground stabilisation, and heat stress relief through evapotranspiration and shading (Anderson et al., 2006; Lafortezza et al., 2009; Bartens et al., 2009). The composition of land cover, in particular, the percentage cover of buildings, is known to have a significant effect on land surface temperatures (Zhou et al., 2011). The spatial configuration of green space also affects land surface temperatures, though to a lesser extent (Zhou et al., 2011). Further, the combination of land surface cover types also has an effect on reducing temperatures, with shade trees over grass found to be the most effective landscape strategy in an arid environment (Shashua-Bar et al., 2009). At even finer scales, different plant species exhibit micro-environments, and trees and plants with a high level of evapotranspiration are associated with the lowest levels of human thermal discomfort (Georgi and Dimitriou, 2010).

Supply and delivery of sustainable ecosystem services depends upon the health, integrity and resilience of the ecosystem (Kumar and Wood, 2010; Bastian et al., 2012; Burkhard et al., 2012). Climate and extreme weather events can affect the condition of green structure and therefore the provision of ecosystem services. The availability of water resources is an important issue for urban green space in equatorial climates. For example, water stress during monsoonal dry periods is one of the most challenging threats for both semi-naturalised parks and street trees, and selection of species is important to adapt to the climate appropriately (Thaiutsa et al., 2008). Additionally, invasive species can affect the functionality and quality of green structure, and have a detrimental effect on the delivery of ecosystem services (Shackleton et al., 2007; McConnachie et al., 2008).

The disappearance of green space from urban areas is a significant threat globally and African cities are no exception. Fast urban expansion threatens the destruction of green space as land cover gradually changes from bushland, grassland and crops, to bare land, as trees are felled for construction and fuel, and areas are cleared for residential and industrial development. Given the high pace of change in African cities, it is important to develop a current understanding of the urban fabric and the ecosystem services associated with its green structures. Understanding of the baseline ecological and social fabric is also an essential element of any study investigating the impacts of climate change on an urban area. A baseline assessment can also be used to devise indicators for assessing trends in the quantity and quality of ecosystem services to understand the extent to which these are being sustained or lost over time, in order to inform appropriate policy responses (Layke et al., 2012). Such indicators can then be used to develop scenarios for spatial planning (Lindley et al., 2007), for example, to highlight the impact of different spatial planning policies on service provision (Schwarz et al., 2012). Despite the growing literature on the value of ecosystem services, Layke et al. (2012) find that indicators developed for most regulating services are weak at both global and sub-global scales, in part due to the higher priority given to quantifying marketed provisioning services, and fewer indicators exist for regional and local climate regulation. Moreover, very little analysis on climate regulation services has been undertaken in African cities (Roth, 2007; Cavan et al., 2011; Cilliers et al., 2012).

Since ecosystem service delivery is strictly linked to particular areas (Busch et al., 2012), it is necessary to utilise a spatial framework that connects urban form, social, cultural and biophysical processes. The framework of urban morphology types (UMTs) or structural types has previously been applied in Europe to connect social and ecological states and drivers to establish a sound basis for green space planning (e.g. Pauleit and Duhme, 2000; Gill et al., 2007, 2008; Pauleit et al., 2010; La Rosa and Privitera, 2013). UMT units can be seen as "*integrating spatial units linking human activities and natural processes*" (Gill et al., 2008, p. 211), useful since biophysical units such as discrete green spaces may not be very well represented by existing administrative units and existing land use frameworks do not normally consider aspects of urban form and structure together. As urban morphology or structural units and types are the expression of past and recent human decisions on the use and form of land, they offer the potential to serve as an interface between natural and social sciences and planning (Breuste, 2006).

The objective of the study is to investigate the urban morphological characteristics of two African cities, with a focus on the spatial composition of urban green structures, in order to assess its impact