

The scaling of green space coverage in European cities

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Most people on the planet live in dense aggregations, and policy directives emphasize green areas within cities to ameliorate some of the problems of urban living. Benefits of urban green spaces range from physical and psychological health to social cohesion, ecosystem service provision and biodiversity conservation. Green space coverage differs enormously among cities, yet little is known about the correlates or geography of this variation. This is important because urbanization is accelerating and the consequences for green space are unclear. Here, we use standardized major axis regression to explore the relationships between urban green space coverage, city area and population size across 386 European cities. We show that green space coverage increases more rapidly than city area, yet declines only weakly as human population density increases. Thus, green space provision within a city is primarily related to city area rather than the number of inhabitants that it serves, or a simple space-filling effect. Thus, compact cities (small size and high density) show very low *per capita* green space allocation. However, at high levels of urbanicity, the green space network is robust to further city compaction. As cities grow, interactions between people and nature depend increasingly on landscape quality outside formal green space networks, such as street plantings, or the size, composition and management of backyards and gardens.

Keywords: urban green space; scaling; human population density

1. INTRODUCTION

For the first time in human history, more than 50 per cent of the world's population now lives in towns and cities. Urban areas are proportionally the fastest growing land cover type, the largest cities are becoming yet larger, and the number of megacities (cities with more than 10 million inhabitants) has increased nearly 10-fold since 1950 (United Nations 2007). This rapid urbanization has ignited concern about the potential effects on biodiversity conservation and quality of human life from scientists and policy makers alike (Dye 2008).

Foremost among these concerns is maintaining human well-being. Contact with the natural environment is a fundamental component of well-being (Wilson 1984; Miller 2005), yet opportunities for such contact are dramatically limited in urban areas,

and there is a significant variation even within the urbanized population in access to green spaces (Barbosa *et al.* 2007). The benefits of access to local green spaces are well documented, including among many others, those to physical health (Maas *et al.* 2006), stress recovery (Van den Berg *et al.* 2007), mental well-being (Fuller *et al.* 2007), social cohesion (Coley *et al.* 1997), provision of ecosystem services such as stormwater run-off, temperature regulation and carbon sequestration (Bolund & Hunhammar 1999), and biodiversity conservation (Gilbert 1989).

Predictions of the consequences of rapid ongoing urbanization for human well-being require information on how green space provision will change as cities grow. One way to achieve this is to study variation in green space provision within and among present-day cities. Certainly, existing green space networks vary enormously in their level of overall coverage among cities. Published estimates, calculated in various ways, range from, for example, 11 per cent in Birmingham, UK (Angold *et al.* 2006), 39 per cent in Stockholm, Sweden (Bolund & Hunhammar 1999) to 45 per cent in Sheffield, UK (Fuller *et al.* in press). Similarly, estimates of urban tree cover in the USA vary by more than two orders of magnitude (Nowak *et al.* 1996). Such uneven coverage by non-built surfaces can be interpreted as a social and economic inequality (Burton 2000), the determinants or geography of which are poorly known.

Europe is a crowded continent, and issues of urban density are being urgently debated at all levels of government (European Environment Agency 2006). For example, the UK government has recommended increasing the density of new housing from 2000 to 2500 to at least 3000 dwellings km⁻² (Department of Communities and Local Government 2006). Such policies have unknown consequences for green space provision and hence one component of human well-being. Intuition suggests that increasing urban density will result in a decline in green space coverage, but to our knowledge this has never been tested. The thought experiment is complicated by the fact that city area can also change as housing density increases in particular parts of a city. Here, we study the extent of green space provision among European cities, and test whether city area or human population density are more importantly related to green space coverage. We also examine data from the UK separately to investigate whether the patterns persist in a highly urbanized nation.

2. MATERIAL AND METHODS

We used the urban morphological zones (UMZs) 2000 vector dataset prepared by the European Environment Agency (EEA; <http://www.eea.europa.eu/>) to delineate urban areas across 31 European countries. UMZs are urban agglomerations of a minimum 25 ha in area with more than 100 000 inhabitants (hereafter termed 'cities'), and were derived by the EEA from Corine Land Cover (CLC) 2000 data (Milego 2007; Corine has an official classification accuracy of 87%; Muecher 2000). They are areas comprising any of the following urban CLC classes: continuous urban fabric (class 111), discontinuous urban fabric (112), industrial or commercial units (121), road and rail networks and associated land (122), green urban areas (141) and sport and leisure facilities (142). Continuous blocks of 100 m CLC pixels comprising any of these land cover types were buffered by one additional pixel to prevent narrow gaps separating UMZs. Road and rail more than 300 m from the other urban land cover classes were clipped and discarded to ensure UMZs were not merged via

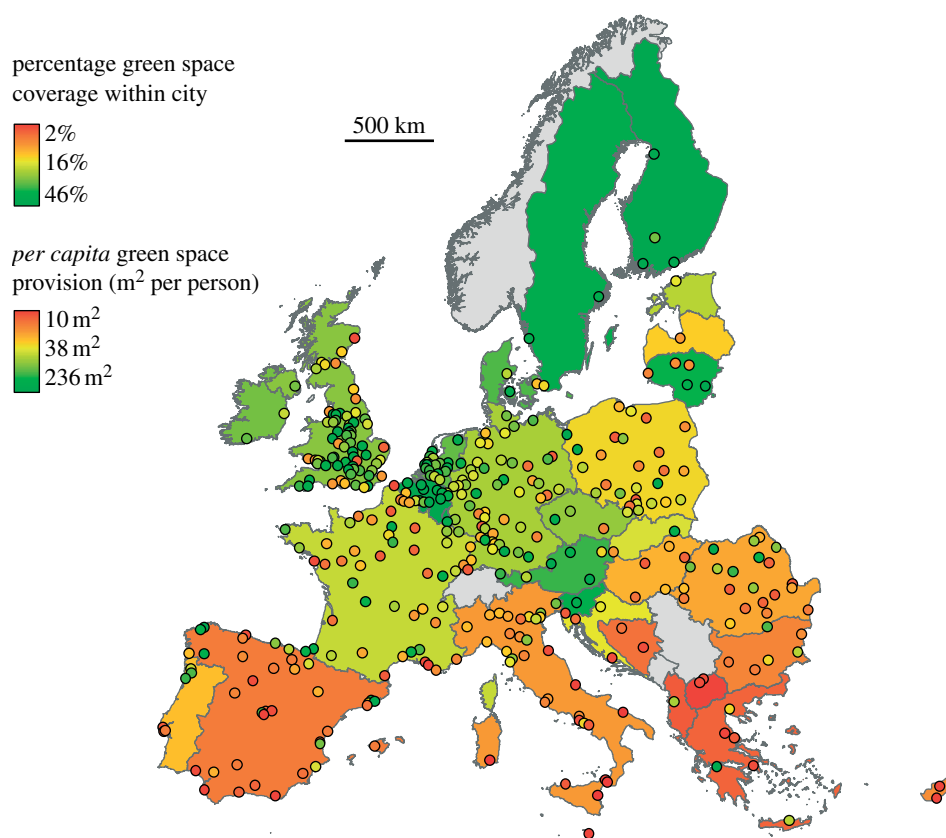


Figure 1. Urban green space coverage in Europe. Points representing cities are coloured according to proportional coverage by urban green space within the city. Country polygons are coloured according to *per capita* green space provision for its urban inhabitants. Data unavailable for countries shaded grey.

transport networks. This resulted in a set of urban areas defined according to land cover, and not administrative boundaries. Human population estimates for 2001 in each city were available within the dataset (Milego 2007).

To map urban green spaces we used the green urban areas within UMZs 2000 dataset (version 12/2005) prepared by the EEA. This derives from 25 m resolution Landsat imagery collected between 1999 and 2001.

Little spatial autocorrelation in city area, green space area and human population size was evident. Values of Moran's I were below 0.2 for all distance lags, so we did not explicitly account for spatial autocorrelation in further analyses. We used standardized major axis regression (Warton *et al.* 2006) to explore log–log relationships among green space coverage, human population size and city area. We calculated confidence intervals around estimates of slope (β) using the exact method, and used one-sample tests of slope with a null hypothesis $\beta = 1$.

3. RESULTS

The 386 European cities accounted for 170.6 million inhabitants in 2001 (34% of Europe's population). Green space coverage varied markedly, averaging 18.6 per cent and ranging from 1.9 (Reggio di Calabria, Italy) to 46 (Ferrol, Spain) per cent. This coverage showed a clear central tendency, and its frequency distribution among cities was not distinguishable from a normal distribution (Kolmogorov–Smirnov $Z = 1.107$, $p = 0.172$). Some 45.2 million people inhabited cities in the lowest quartile (2–13%) of green space coverage, indicating limited green space availability for a significant proportion of Europe's population. Proportional green space coverage in the cities increased with latitude ($r = 0.434$, $n = 386$, $p < 0.001$; figure 1). *Per capita* green space provision varied by two orders of magnitude, from 3 to 4 m²

per person in Cádiz, Fuenlabrada and Almería (Spain) and Reggio di Calabria (Italy) to more than 300 m² in Liège (Belgium), Oulu (Finland) and Valenciennes (France). This variation formed a clear spatial pattern at country level, with lowest provision in the south and east of Europe, increasing to the north and northwest (figure 1).

The slope of the relationship between city area and human population size was not distinguishable from unity ($\beta = 0.986$, 95% CI = 0.939–1.036, $p = 0.584$; figure 2a); larger cities were no more or less densely populated than smaller cities. By contrast, green space area increased more rapidly than city area, the relationship between the two variables showing a slope significantly greater than unity ($\beta = 1.179$, 95% CI = 1.127–1.233, $p < 0.001$; figure 2b). Thus, cities differing in area by an order of magnitude will have a 15-fold difference in green space area. Despite excellent fit by linear models, both relationships showed signs of weak nonlinearity, with values at low levels of city area tending towards the origin of the plots (figure 2). Generally then, cities large in area had greater green space coverage despite the fact that the human population density was similar to cities smaller in area.

Among the 67 UK cities, human population size increased more rapidly than city area ($\beta = 1.057$, 95% CI = 1.008–1.107, $p = 0.021$), and the slope of the relationship between the city area and the green space area did not differ significantly from unity ($\beta = 1.013$, 95% CI = 0.931–1.103, $p = 0.757$). Green space

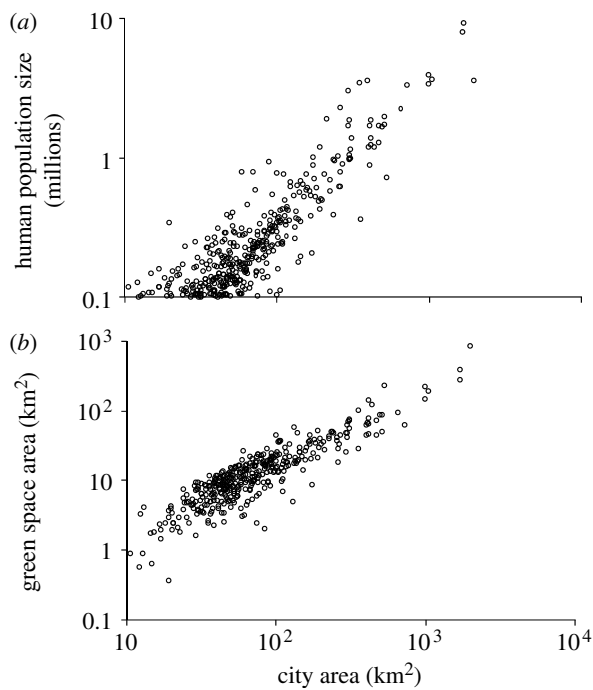


Figure 2. Relationships between city area and (a) human population size (standardized major axis regression: $r^2=0.760$, $p<0.001$) and (b) green space area ($r^2=0.802$, $p<0.001$).

provision in the UK therefore increased only at the same rate as city area, a bleaker picture than across Europe as a whole.

Across European cities, proportional green space coverage declined with increasing human population density ($r=-0.350$, $n=386$, $p<0.001$), although there was a weak 'space-filling' effect in the relationship driven by a decline in upper levels of coverage as density increased. In an ordinary least squares regression fitting linear and square terms for population density, both predictors were significant, with negative and positive slopes, respectively ($p<0.001$ in both cases). Thus, the decline in green space availability *per capita* accelerates with increasing population density. By contrast, the relationship between these two variables was not significant for the UK ($r=-0.165$, $n=69$, $p=0.174$), confirming that further increases in density in already compacted urban landscapes are not achieved by further reductions in green space provision.

4. DISCUSSION

We document a dramatic drop in *per capita* green space provision in cities with greater population densities. This association appears to involve more people being packed into the urban matrix, rather than buildings replacing existing green spaces, and as urbanicity reaches extreme levels the green space network becomes robust to further compaction. Indeed, in the UK, the most densely populated major country in Europe, population density and proportion of cover by urban green space are uncoupled.

There are clear advantages to concentrating people into small areas, including economies of scale, reduced *per capita* resource requirements, lower transport costs and easier communication and collaboration. In fact, wealth creation and innovation scale superlinearly

with city population size (Bettencourt *et al.* 2007). However, our analyses suggest that access to green space could decline rapidly as cities grow, increasing the geographical isolation of people from opportunities to experience nature. More generally, contact with urban biodiversity can be interpreted as a quality of life indicator distinct from the biological value of an area. Maintaining green space quantity and quality in the face of increasing urbanization is therefore a pressing global challenge. As cities grow, interactions between people and nature will depend increasingly on landscape quality outside formal green space networks, such as street plantings, or the size, composition and management of backyards and gardens.

City shape, as well as the size will affect proximity to green space outside the city boundary. For example, as a city's edge to area ratio increases, proportionately more people will live close to the boundary and the non-urban area beyond it. Some of the latitudinal variation in green space provision that we detect might arise from sparser vegetation types in drier climates. However, while spontaneous growth of vegetation accounts for some urban green space in southern Europe, most is planned and managed. For example, few urban parks in Barcelona are xericaped, and 30 per cent are irrigated above agronomic requirements (Parés-Franzi *et al.* 2006).

In response to increasing sprawl on the margins of cities as they have grown in the past few decades (Marshall 2007), policy is driving increased urban density in many developed nations. While this slows the rate of land take, there is concern that the consequences of such compaction are too poorly understood to warrant this large-scale experiment (Burton 2000). We have shown that compaction is likely to have a significant impact on urban green space provision, and a clear analysis of the costs and benefits of urban compaction is now urgently required. For example, the application of systematic conservation planning could revolutionize urban green space provision and the optimal distribution of human population density (Polasky *et al.* 2008). Tools are needed that can simultaneously optimize benefits to biodiversity value, human well-being and economic output, and we urge their development and use in planning future human settlement patterns.

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