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Biol. Lett. 2011 **7**, 763-766 first published online 23 March 2011
doi: 10.1098/rsbl.2011.0025

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Temporal changes in greenspace in a highly urbanized region

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The majority of the world's population now lives in towns and cities, and urban areas are expanding faster than any other land-use type. In response to this phenomenon, two opposing arguments have emerged: whether cities should 'sprawl' into the wider countryside, or 'densify' through the development of existing urban greenspace. However, these greenspaces are increasingly recognized as being central to the amelioration of urban living conditions, supporting biodiversity conservation and ecosystem service provision. Taking the highly urbanized region of England as a case study, we use data from a variety of sources to investigate the impact of national-level planning policy on temporal patterns in the extent of greenspace in cities. Between 1991 and 2006, greenspace showed a net increase in all but one of 13 cities. However, the majority of this gain occurred prior to 2001, and greenspace has subsequently declined in nine cities. Such a dramatic shift in land use coincides with policy reforms in 2000, which favoured densification. Here, we illustrate the dynamic and policy-responsive nature of urban land use, thereby highlighting the need for a detailed investigation of the trade-offs associated with different mechanisms of urban densification to optimize and secure the diverse benefits associated with greenspaces.

Keywords: urbanization; ecosystem services; human population density; urban densification; urban ecology; urban greenspace

1. INTRODUCTION

A growing proportion of the Earth and its people are becoming urbanized, with more than half of the world's population now living within towns or cities [1]. As urban areas continue to expand at a faster rate than any other land-use type [2], two powerful opposing arguments have emerged, particularly in Europe, in relation to land-use management.

Electronic supplementary material is available at <http://dx.doi.org/10.1098/rsbl.2011.0025> or via <http://rsbl.royalsocietypublishing.org>.

Received 9 January 2011
Accepted 28 February 2011

On one hand, policy has increasingly emphasized the desirability of the compact, densified city [3,4]. The primary aims of increasing urban density are to slow land-use conversion of the wider countryside, reduce energy use and decrease pollution. All of these factors are associated with progressively more dispersed forms of urban settlement, referred to as 'urban sprawl' (e.g. [5,6]).

However, densification of urban areas may have profound impacts on both biodiversity conservation (e.g. [7]) and ecosystem services (the wide array of benefits humans derive from ecosystems; [8,9]). Indeed, as more people's lives are dominated by urban experiences, opportunities for interaction with the natural world decline, with potentially serious knock-on effects for human health and well-being [10,11]. Local greenspaces within towns and cities are, therefore, a critical resource to ameliorate the personal and societal issues associated with urban living.

To date, there has been little appreciation of how such urban land-use intensification policies may have impinged upon urban greenspaces, and hence the ecosystem services they underpin. Here, for the first time to our knowledge, we examine temporal patterns in greenspace across cities with varying socioeconomic characteristics, consider how these relate to urban density, and assess whether the observed changes coincide with shifts in national-level policy that were introduced in 2000. To do this, we use historical data from a range of sources pertaining to the 13 largest cities in England, an already highly urbanized region (electronic supplementary material, appendix S1, figure S1 and table S1).

2. MATERIAL AND METHODS

Landsat Thematic Mapper data from 1991, 2001 and 2006 were used to assess temporal changes in the extent of developed (hereafter referred to as 'built-up') and undeveloped (hereafter referred to as 'greenspace') land within each of the 13 study cities (electronic supplementary material, appendix S2). At a 30 × 30 m resolution, the imagery allows the detection of land-use changes such as the expansion of a housing estate (conversion from greenspace to built-up), or an industrial site becoming vacant land (conversion from built-up to greenspace).

We complement this approach by examining annual patterns of 'greenness' using moderate resolution imaging spectroradiometer Enhanced Vegetation Index (EVI) data for these same cities, from 2000 (when EVI data first became available) to 2008 (electronic supplementary material, appendix S3). Cities comprise complex mosaics of land uses, with patch sizes often below the resolution of the Landsat imagery. Although the spatial scale of EVI data is coarser than that of Landsat, EVI provides a continuous measure and hence responds to small changes in land use, even if the extent of such change is not large enough to imply a shift from 'built-up' to 'greenspace' or vice versa [12]. For instance, EVI may decrease in time owing to the loss of street trees, infill development within domestic gardens and the conversion of front gardens to hard-standing for off-road parking, or because the growth of remaining urban vegetation is being limited by factors such as pollution.

To control for potentially confounding interannual variation in EVI, which may result from large-scale processes (e.g. a poor growing season because of climatic factors), we examine trends in the difference in EVI (EVI_{diff}) between each city and its adjacent rural zone (electronic supplementary material, appendix S3) through time. If the EVI_{diff} for a particular city is constant over the years, the 'greenness' of the urban area remains in line with that in neighbouring rural zones. In England, urban EVI will always be lower because of the large coverage of biologically inactive sealed surface. We also assess temporal patterns in rural EVI using linear regression to exclude the possibility that these zones were becoming greener as a result of land use (e.g. owing to tree planting) and thus driving any observed patterns in EVI_{diff}; as such, an increase in EVI_{diff} indicates that the urban areas are becoming less green owing to a loss of

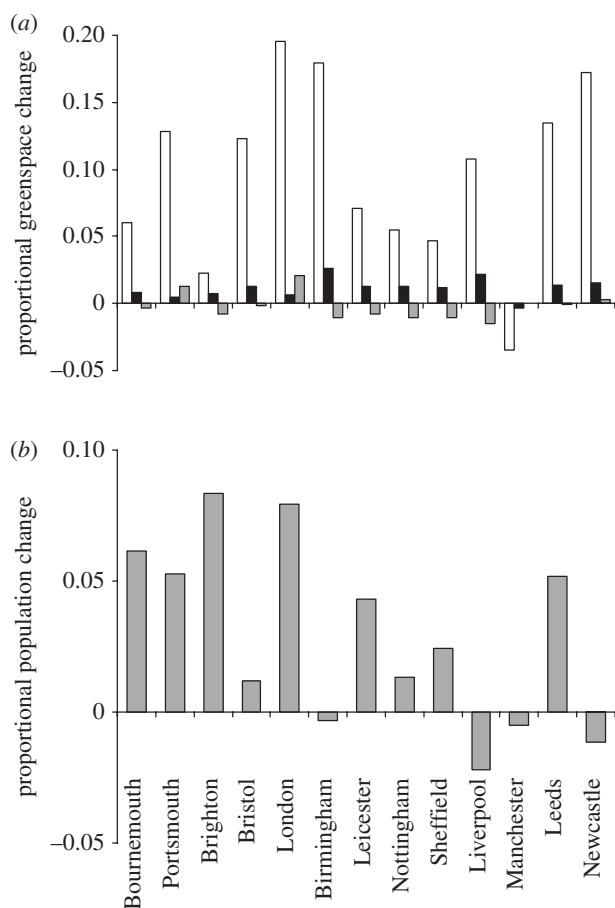


Figure 1. The proportional change, for 13 English cities, in: (a) greenspace area between 1991 and 2006 (white bars), annual average 1991–2001 (black bars) and 2001–2006 (grey bars); (b) human population between 1991 and 2001. Cities are ordered left to right, according to their geographical location from south to north.

vegetation cover. Linear regression models were used to test for temporal changes in EVIDiff for each city individually, and trends through time were also investigated for all 13 cities across England combined using an ANCOVA with city as a fixed factor.

Growth in the number of households is frequently seen as the key driver of urban land use [13]. We therefore consider change in the human population (from the three most recent censuses in 1981, 1991 and 2001) and in the number of dwellings (recorded in 1981, 1991, 2001, 2006 and 2008) within our 13 study cities (electronic supplementary material, appendix S4).

3. RESULTS

In 2006, greenspace coverage in the urban core of our 13 study cities varied markedly, averaging 24.2 per cent (range: 16.9% in Brighton to 40.7% in Leeds; electronic supplementary material, table S2). Between 1991 and 2006, greenspace showed a net increase in all but one of the 13 cities (figure 1a), with the largest changes evident in London, Birmingham and Newcastle. However, the majority of this expansion occurred prior to 2001 and, subsequently, nine of these cities have undergone a reduction in the extent of greenspace.

Across all cities when considered together, EVIDiff increased during the study period (table 1), indicating that urban centres across England have become less green since 2000; no significant trend in rural EVI

Table 1. Linear regression examining temporal trends in EVIDiff for 13 English cities between 2000 and 2008. (Figures in bold italic indicate cities where the relationship between EVIDiff and year was more parsimonious than the null model based on Akaike's information criterion comparisons. When modelled across all cities, using an ANCOVA with year as a continuous response variable and city as a fixed factor, both year and city were retained in the most parsimonious model.)

city	<i>b</i> (s.e.)	<i>r</i> ²
Bournemouth	13.34 (15.65)	0.09
Portsmouth	14.04 (18.33)	0.08
Brighton	65.50 (27.86)	0.44
Bristol	19.51 (23.24)	0.09
London	10.23 (5.36)	0.34
Birmingham	49.97 (27.98)	0.31
Leicester	24.73 (29.04)	0.09
Nottingham	−0.56 (23.75)	0
Sheffield	3.42 (14.98)	0.01
Liverpool	30.11 (17.03)	0.31
Manchester	4.62 (6.13)	0.08
Leeds	37.39 (9.17)	0.70
Newcastle	36.31 (38.78)	0.11
across all cities	23.54 (5.42)	0.88

was apparent ($b = 13.24$, $s.e. = 11.83$, $r^2 = 0.002$, $p = 0.27$). When examined on an individual city basis, no temporal pattern was exhibited in EVIDiff in 10 of the urban areas.

Human population growth was greatest between 1991 and 2001 in four southern cities (Bournemouth, Portsmouth, Brighton and London; figure 1b). The population fell in four others (Birmingham, Liverpool, Manchester and Newcastle), but this was offset by falling household size [13] so that the number of dwellings rose across all cities (figure 2a). Indeed, the rate of change in the number of dwellings outpaced the conversion of land use from greenspace to built-up between 1991 and 2006 (figure 2b).

4. DISCUSSION

Despite the human population growing in nine out of 13 of England's largest cities (figure 1b), accompanied by a substantial rise in the number of dwellings (figure 2a), the extent of greenspace in all but one of these urban areas increased between 1991 and 2006 (figure 1a). However, when changes in greenspace coverage within this 15 year period were examined corresponding to shifts in UK government planning policy in 2000, we observe opposing trends in nine of the urban cores; a rise 1991–2001, followed by a decline 2001–2006 (figure 1a).

Prior to 2000, the increase in greenspace could potentially be attributed to the large areas of industrial land that were abandoned in many English cities through the 1980s and 1990s (e.g. much of the lower Don Valley in Sheffield lay vacant by the late 1980s owing to a rapid fall in industrial output [14]). Unfortunately, however, reliable data do not exist to corroborate this assertion (electronic supplementary material, appendix S5).

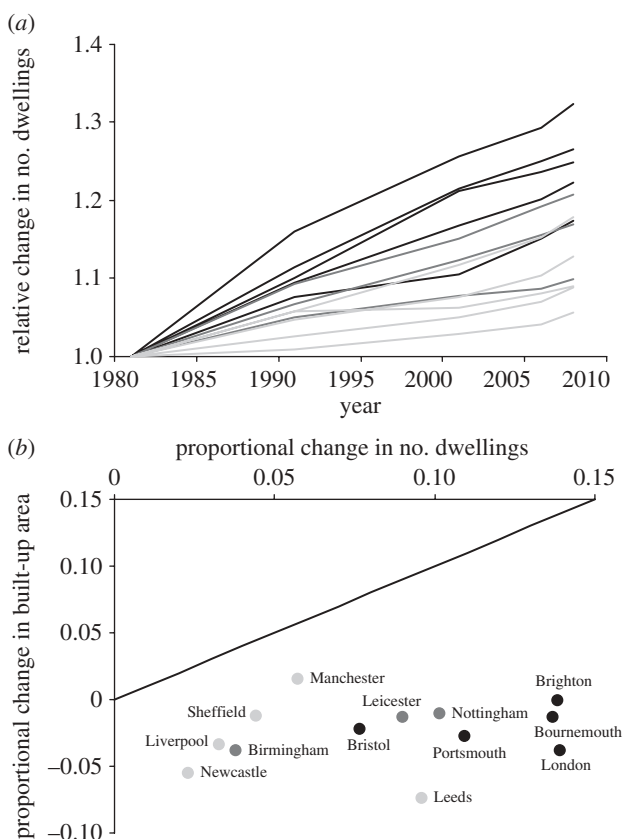


Figure 2. Densification across 13 cities in southern (black), central (mid-grey) and northern (light-grey) England: (a) relative change in the number of dwellings between 1981 and 2008, (b) proportional change in the number of dwellings and extent of the built-up area between 1991 and 2006. The solid line indicates $y = x$.

In order to limit urban expansion, policy guidelines released in 2000 [15] recommended that brownfield sites (which include urban greenspaces such as parks, recreation grounds, allotments and domestic gardens, as well as former industrial sites) should be favoured for new residential development, and that dwelling densities should increase to at least 30 units ha^{-1} . The new policy target, which sought to ensure that 60 per cent of all new dwellings occupied brownfield sites, was met by 2004 and dwelling densities rose rapidly, soon exceeding 40 ha^{-1} (electronic supplementary material, figure S3a,b). Indeed, all of the cities have become more dense through time (figure 2b), with the number of dwellings expanding faster than the extent of the built-up area. The general trend in EVIDiff supports this conclusion, indicating that urban 'greenness' has decreased as a result of such infill development from 2000 to 2008 (table 1). Population growth and urban densification have generally been greatest in the southern cities, where the proportion of greenspace coverage is smallest (in common with Europe as a whole [16], greenspace provision increased with latitude: Spearman's rank correlation $r_s = 0.626$, $n = 13$, $p = 0.025$; electronic supplementary material, table S2).

In 2010, further changes to government planning policy were announced. Despite the emphasis on the

re-use of brownfield sites remaining (though domestic gardens are no longer included in the definition), the minimum new-build density of 30 dwellings ha^{-1} has been retracted [17]. As highlighted by the results of this paper, land-use change in cities is dynamic and policy-responsive. Predicting the impact of such policy alterations on the extent of greenspace is therefore difficult, especially given the complexities and contrasting forces at work in urban planning and development. However, one possible consequence of the removal of gardens from the brownfield land category is increased development pressure on land in the wider countryside, outside current urban boundaries.

As the continent of Europe gets ever more crowded, the conflict between urban densification and greenspace provision within cities is set to continue, and a careful balance between the two opposing pressures must be sought to ensure an equitable quality of life for all urban residents. Previous research has demonstrated that, even within neighbourhoods of similar urban form, the delivery of ecosystem services can vary considerably [9]. A detailed investigation of the trade-offs associated with different mechanisms of urban densification is thus urgently required in order to account for, protect and maximize all the potential benefits associated with greenspaces in the long term.

M.D. was funded by EPSRC grant EP/F007388/1 to the URSULA consortium. Z.Y.T. is a China Scholar Council fellow. K.J.G. holds a Royal Society-Wolfson Research Merit Award. Z.G.D. was supported by EPSRC grant EP/F007604/1 to the 4M consortium.

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