An integrated approach to evaluating critical environmental and ecological landscape characteristics across gradients of land-sparing-sharing and urbanity

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Summary

Within urban landscape planning, debate continues around the relative merits of land-sparing (compaction) and land-sharing (sprawl) scenarios. Using part of Greater Manchester (UK) as a case-study, we present a landscape approach to mapping green infrastructure and variation in social-ecological-environmental conditions as a function of land-sparing-sharing. Results imply potential trade-offs between land-sparing-sharing scenarios relevant to characteristics critical to urban resilience. These trade-offs may be particularly complex due to the parallel influence of patch attributes such as land-cover and size and imply that both ecological restoration and spatial planning have a role to play in reconciling tensions between land-sparing and sharing strategies.

Keywords: green infrastructure; land-sparing-sharing; urban ecosystems; social-ecological systems

1. Introduction

The concept of green infrastructure has emerged as a promising framework to understand, manage and enhance the multiple benefits delivered by nature, particularly in highly fragmented landscapes (Benedict and McMahon, 2012). With the unabated growth of urban areas in terms of population and the associated sprawl of developed areas into the rural hinterland, debates surrounding the optimum spatial configuration on which to base urban planning persist. At the centre of this debate is a tension between the relative benefits (or proposed benefits) of urban densification (or the so-called compact cities approach) versus urban sprawl. This tension owes much to the effects of high versus low population density and associated housing stock (Couch and Karecha, 2006). In scenarios which involve increased urban densification, if urban residents are to have sufficient access to green spaces, a land-sparing approach, borrowed from landscape ecological studies on the effects of agricultural land-use (Phalan, 2010), is promoted where non-green land-use is compacted in order to allow for larger patches of green space. This template typically asserts large public green spaces in favour of smaller private green spaces in the form of domestic gardens. Conversely, land-sharing implies the promotion of lower-density housing, smaller patches of reduced public green space and greater cover by private domestic gardens. However, this dichotomy of public and private green land-use is still poorly understood from ecological, social and environmental points of view. This is in large part due to the low number of empirical studies, the latter being hampered by poorly conceived representations of urban green infrastructure. A key shortcoming of both the conceptualization and spatial representation of urban green infrastructure is a consideration of green space either from an anthropocentric point of view (i.e. as land-use) or from a physical-ecological point of view (i.e. land-cover). In order to understand the relative benefits of land-sparing versus sharing in urban areas, composite datasets are required which can model spatial variation in public and private land-use in tandem with their respective land-covers in order to evaluate associated ecological and socio-environmental characteristics critical to resilience in urban-ecological systems.

2. Methods

A composite spatial dataset covering the cities of Manchester, Salford and the metropolitan borough of Trafford (all part of Greater Manchester) was achieved through a combination of remote sensing and GIS techniques based on a method published by Dennis et al. (2018). Briefly, the method achieves the characterisation of discrete landscape features through an integration of land-use and land-cover data. Land-use (from OS Mastermap Greenspace Layer, 2017) and land-cover (classified primarily through open-source Planet Scope 3 m imagery) were computed for public and domestic green space, urban fabric and peri-urban areas. Classification of trees was based on a 2011 tree audit by City of Tree. Areas of canopy cover and water were additionally ratified and, where necessary corrected, using OS Open Map Local and Open Rivers Datasets (2018).

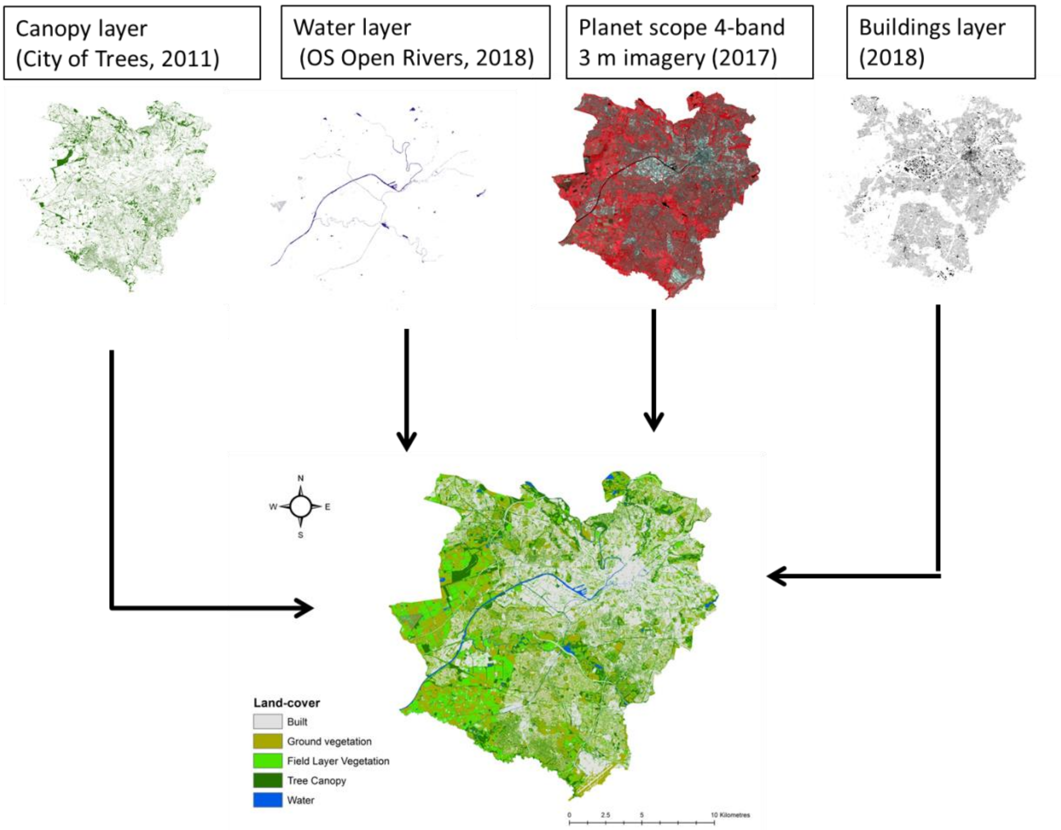

Figure 1 The spatial data layers combined for the characterisation of land-cover within the study area (images contain Ordnance Survey, Planet Scope, City of Trees data).

Landscape characteristics effective mesh size (Meff), total core area (TCA), largest patch index (LPI) and Shannon's land-cover diversity (SHDI) were calculated using the QGIS plug-in Lecos (Jung, 2015). In addition, socio-environmental variables land surface temperature (LST, derived from Landsat 8 TIRS imagery for July 2016 at 30 m resolution), background nitrogen dioxide concentration (interpolated from Defra background NO_2 data points) and population within 300 m of a recreational green space (using PopGrid 10 m data, University of Southampton) were quantified for 2, 1 and 0.5 km^2 zones created through hexagonal tessellations of the study area. Subsequently, the degree to which the tessellated regions exhibited land-cover indicative of land-sparing or land-sharing was judged according to their largest patch index (LPI), following a definition used by Soga et al. (2015). Tessellated regions were divided into three quantile groups representing low (land-sharing), medium (neither land-sparing nor land sharing) and high (land-sparing) values for LPI.

The influence of land-sharing/sparing on critical ecological and socio-environmental attributes was assessed through a series of general linear models using LPI quantile groups as fixed factors. Meff, TCA, SHDI, LST, NO_2 and population within 300 m of a recreational green space were all entered as dependent variables whilst controlling for overall green land-cover. Models were run separately using values computed at 2, 1 and 0.5 km^2. In order to permit comparability of results between scales of investigation, metrics expressed in units of area (Meff and TCA) were first standardised as percentages of the unit of analysis. Analyses were repeated at low and high levels of urbanity (defined according to percentage cover by developed – i.e. non-green – land-use) for units of 0.5 km² (as only models at this scale were significant for LST and NO_2). Finally, associations between all dependent variables and land-use-land-cover metrics (including percentage cover by vegetation by each land-use and mean patch area) were explored through multiple linear regression analysis to test for potential trade-offs and synergies.

3. Results

Land-use with the study area is presented in Figure 2

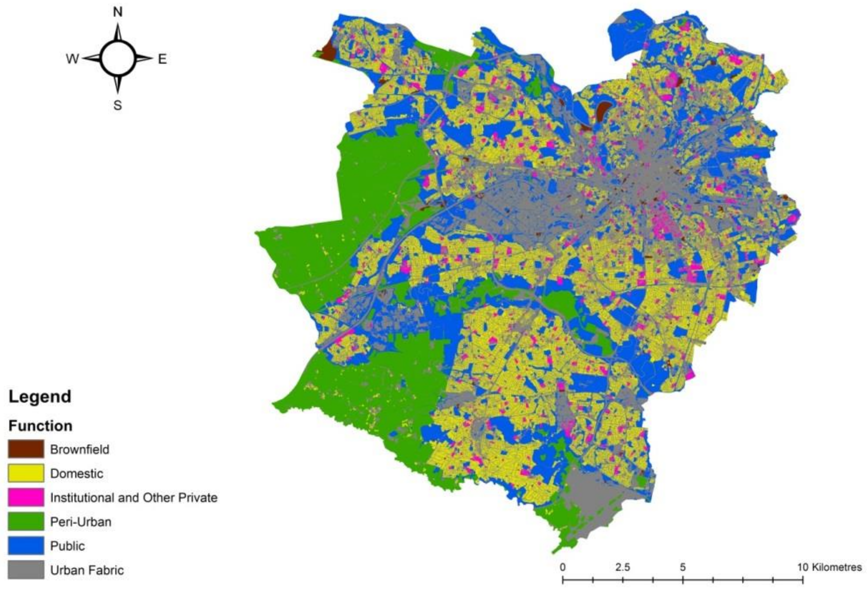

Figure 2 Land-use (function) within the study area (contains Ordnance Survey data, 2017).

The extent of public and private (domestic and institutional) green space within quartile groups according to the Largest Patch Index for 0.5 km² zones is given in Figure 3.

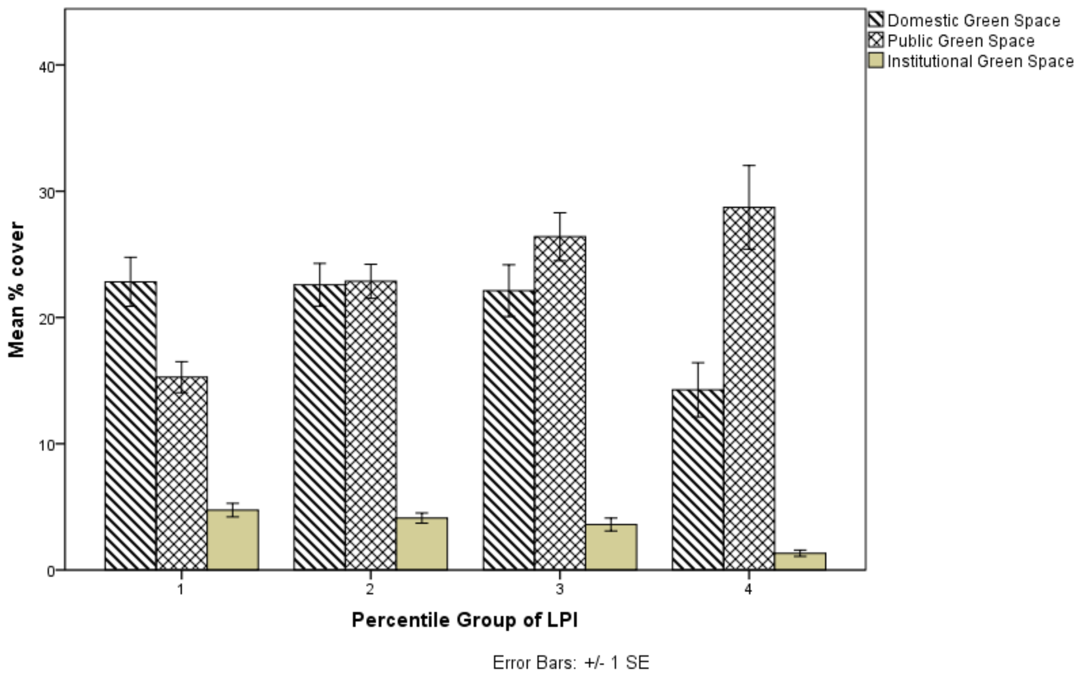

Figure 3 Relative extent of public, domestic and institutional green space across a gradient of land sparing-sharing

Ecological and socio-environmental characteristics varied as a function of land-sparing-sharing and urbanity and were further modified by the scale of analysis. Figure 4 gives the mean values for Meff, TCA and SHDI for 2, 1 and 0.5 km² units of low (land-sharing), medium (neither sharing nor sparing) and high (land-sparing) quantile groups for LPI.

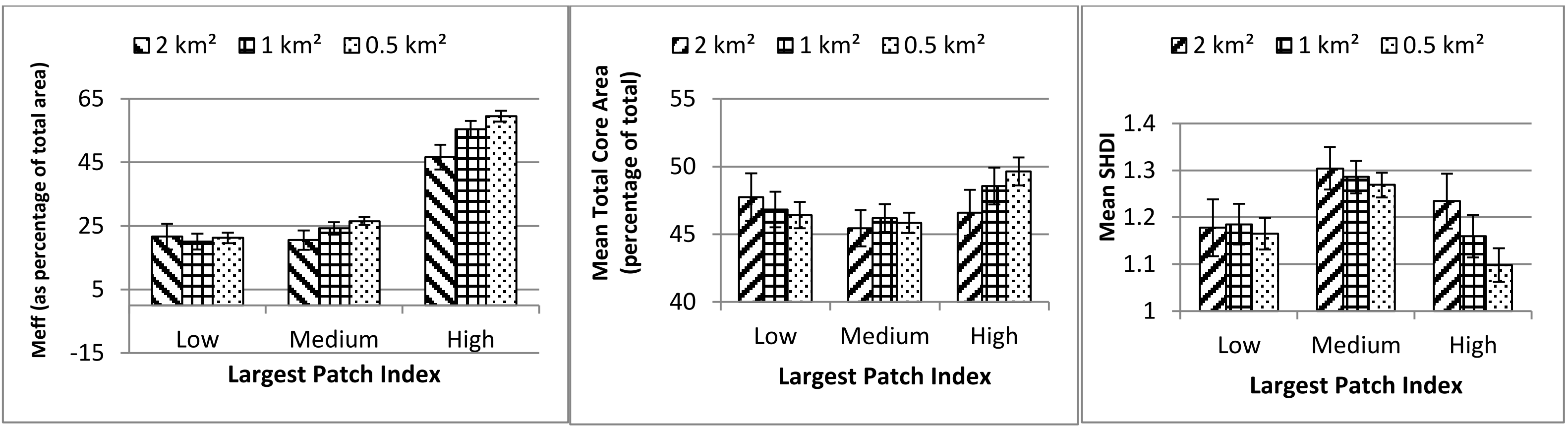

Figure 4 Mean values for Meff (left panel), TCA (centre panel) and SHDI (right panel) for low, medium and high levels of land-sparing/sharing repeated at three scales and controlling for overall green cover. Error bars represent 95% CI.

Figure 5 gives mean values for LST, ambient NO_2 concentration and population within 300 m of a recreational green space for 2, 1 and 0.5 km² units of low (land-sharing), medium (neither sharing nor sparing) and high quantile groups for LPI. Figures 6 and 7 give mean values for independent variables for areas of high and low urbanity at a scale of 0.5 km².

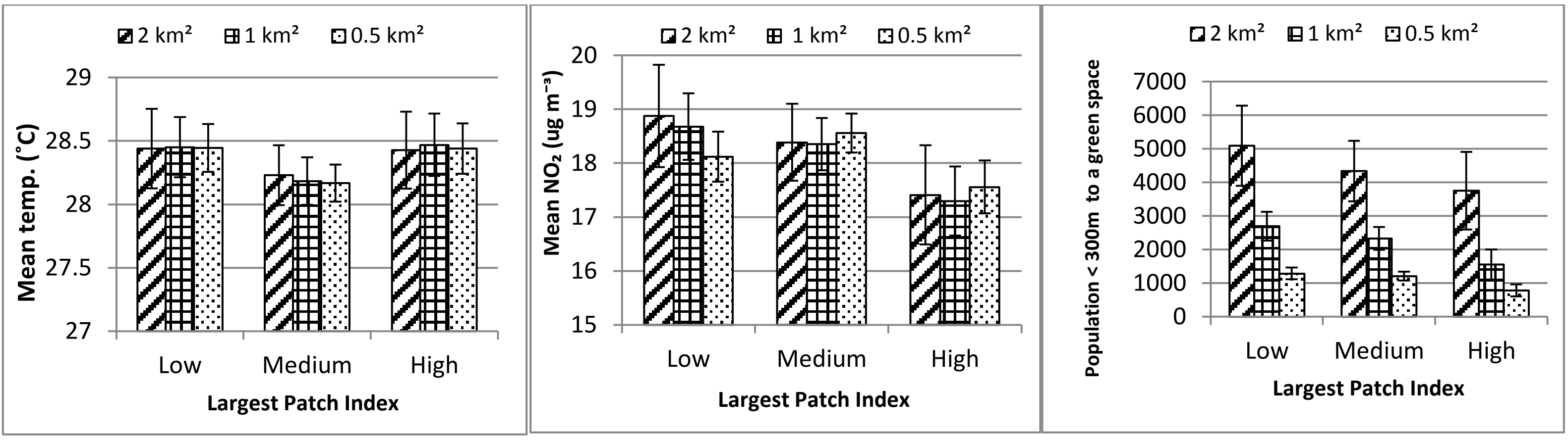

Figure 5 Mean values for LST (left panel), ambient NO_2 concentration (centre panel) and population within 300 m of a recreational green-space (right panel) for low, medium and high levels of land-sparing/sharing repeated at three scales and controlling for overall green cover. Error bars represent 95% CI.

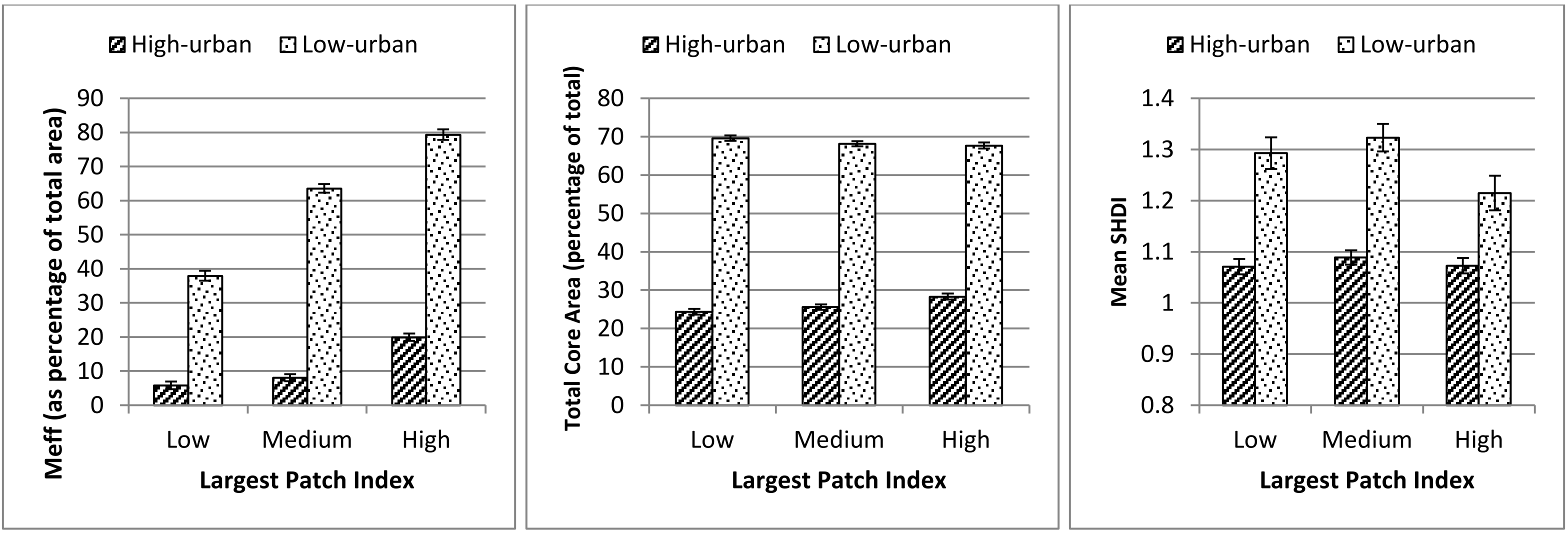

Figure 6 Mean values for Meff (left panel), TCA (centre panel) and SHDI (right panel) for low and high levels of urbanity controlling for overall green cover. Error bars represent 95% CI.

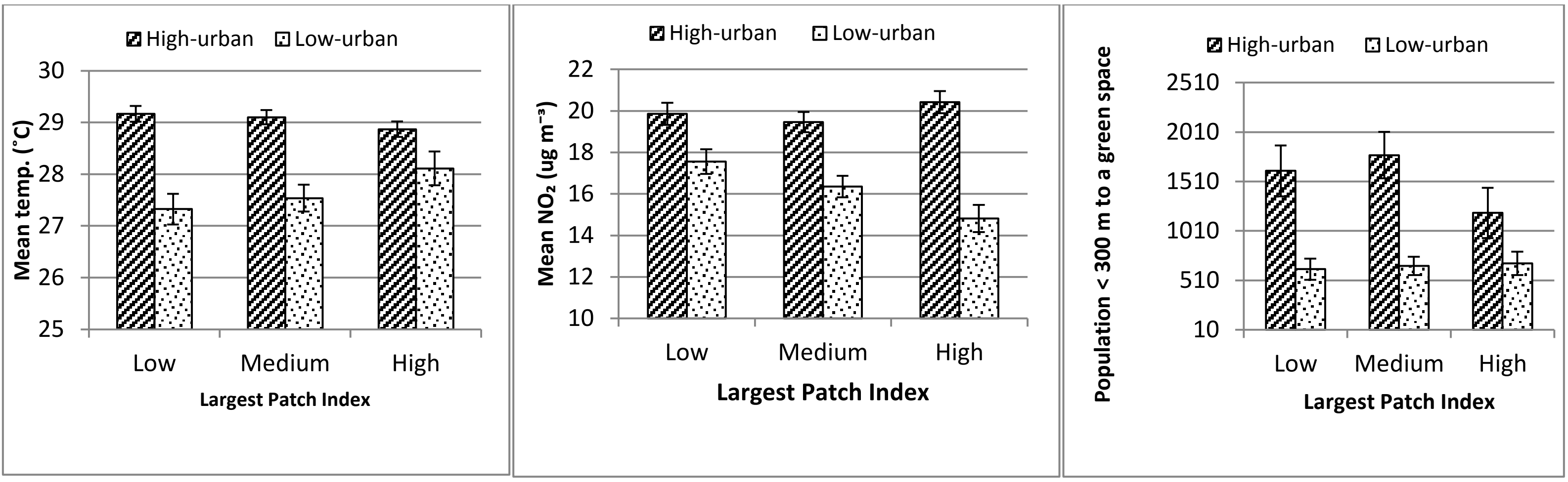

Figure 7 Mean values for LST (left panel), ambient NO_2 concentration (centre panel) and population within 300 m of a recreational green-space (right panel) for low, medium and high levels of land-sparing/sharing repeated at high and low levels or urbanity controlling for overall green cover. Error bars represent 95% CI.

Regression analyses demonstrated that public and private land-uses exhibited unique and contrasting associations with ecological and socio-environmental variables implying considerable potential trade-offs. Moreover, these associations varied as a function of level of urbanity and scale of analysis. In addition they were modified by patch characteristics (mean area and green land-cover). For example, public and domestic land-uses exhibited inverse relationships with LST and ambient NO_2 and comparable associations with proximity to recreational green space.

4. Discussion

The distribution and patch characteristics of public versus private green-spaces exhibited patterns that fulfill expectations of land-sparing-sharing scenarios with inverse trends for mean cover and patch-size of public relative to domestic green space with increasing LPI. Unique associations with social-ecological characteristics were observed as a function of degree of land-sparing and urbanisation. In addition, scale-effects were observed whereby the size of the units by which metrics were computed had significant bearing on interpretation of the results, suggesting that complex trade-offs may be implied by the ascendency of one or other of these approaches in different urbanization and planning contexts. Trade-offs were also implied by the presence of public and private land-uses where these exhibited contrasting relationships with critical urban-environmental variables. This complexity was additionally modified by land-cover, suggesting that small-scale land-cover configurations may be highly relevant, e.g. within the context of urban microclimate regulation, and that ecological restoration likely represents a critical factor alongside spatial planning methodologies. Access to recreational green-space as a function of land-sparing-sharing was only significant at the higher urbanity level with significantly lower values found in land-sharing areas.
Urban landscape planning approaches are needed which promote urban resilience through ecological diversity, connectivity and core habitat whilst ensuring access to green space and micro-climate regulation for urban residents. The analysis presented here demonstrates how a landscape approach, incorporating spatially coincident measures of land-use and land-cover, can be employed to unpick spatial and ecological complexities relevant to sustainable urban development.

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