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Modeling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK

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Abstract

There is a lack of information on the environmental effects of urban change and the dynamics of greenspace. Such information is essential for a better understanding of the sustainability of urban development processes, both planned and unplanned. We therefore investigated the changes in land use and land cover of 11 residential areas in Merseyside, UK, using aerial photographs taken in 1975 and 2000. We then modeled how these changes would alter three important environmental parameters: surface temperature, runoff of rainfall, and greenspace diversity. These changes were then related to the socio-economic status of the areas, as measured by an index of multiple deprivation. The comparisons revealed a loss of greenspace in all 11 case study sites Overall, the more affluent, low density areas lost more greenspace, especially of tree cover. A major cause was infill development whereby gardens were built over. However, greenspace was also lost in already densely built-up, deprived areas due to the reuse of derelict land. As a consequence, the models used in this study predicted negative environmental impacts for all areas. The results emphasize the need to critically review concepts such as urban densification and give more weight to the preservation and management of urban greenspaces.

Keywords: Compact city; Land use; Land cover; Landscape change; Environmental models; Climate; Hydrology; Biodiversity

1. Introduction

World-wide, a strong trend of urbanization can be observed (United Nations Centre for Human Settlement, 1996). For landscape and environmental planning, the ‘sprawl’ of low-density settlements and urban development along transport corridors is causing particular concern in highly-industrialized countries. It is feared that these processes lead to settlement patterns which are environmentally inefficient and have negative impacts on the surrounding countryside (e.g. Antrop, 2000; Swenson and Franklin, 2000). The compaction of existing settlements has therefore been suggested as a strategy to counter these trends. In the United Kingdom, recently published national planning policy guidance (PPG3) requires 60% of new housing to be built on derelict land, so called brownfield sites (ODPM, 2002). However, this may lead to the loss of informal open space within cities which can not only be a valuable resource for recreation but also provide important habitats for wildlife and enhance environmental services, for instance the infiltration of rainwater (e.g. Gilbert, 1989; Gibson, 1998; Harrison and Davies, 2002).

The debate on spatial models for sustainable urban development is often little substantiated by facts (e.g.

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Breheney, 1997; Haughton, 1997; Williams, 2001). In particular, little data is available to assess the extent of past and current urban development processes and predict its environmental consequences. Only recently, a study (EEA, 2002) produced comparative information on urban development in selected European cities between 1950 and 1990 based on the interpretation of satellite imagery and aerial photographs. The study provided clearly evidence for the strong growth of urban areas across Europe, resulting in loss of farmland and natural areas in the surrounding countryside, whilst the creation of greenspace within urban areas did not match the speed of urban growth. Satellite imagery is increasingly used elsewhere to assess urbanization by measuring land use and land cover change for whole cities and city regions (U.S. Geological Survey, 1999; Alberti et al., 2002; Jürgens, 2003). Attempts have also been made to develop spatially explicit models of urban land use and cover change (EEA, 2002; Parker et al., 2002; Herold et al., 2003; Jantz et al., 2003). However, there is still a scarcity of models to predict the environmental consequences of this change such as increased surface runoff and pollutant emissions into the atmosphere, water and soil (Alberti and Waddell, 2000; Weng, 2001).

More information is also required to assess land use and land cover change within existing urban areas. Research has demonstrated that important environmental parameters such as surface temperatures, stormwater run-off and carbon sequestration vary between urban land uses and are directly affected by land cover features such as building density and the provision of greenspaces (McPherson et al., 1994; American Forests, 1996; Pauleit and Duhme, 1995, 2000; Whitford et al., 2001; Nowak et al., 2002). Will the densification of urban areas that is promoted by the compact city model, therefore, have a negative impact on their environmental quality? In isolation, changes may be small and have little effect on the urban environment, however, it is hypothesized here that over longer periods of time, they may significantly alter the urban fabric and negatively affect its environmental quality.

This paper presents the results from a study undertaken in Merseyside, UK, to explore the environmental and ecological consequences of urban land use and land cover change in residential areas. The main purpose was to find out whether and how land use and land cover had changed in the selected residential areas; whether there were differences between residential areas related to their socio-economic status; and whether these changes had a significant environmental impact. We examined residential areas for two reasons. Firstly, they can account for more than 60% of land area of towns and cities in the UK (University of Sheffield, 2003) and private gardens can constitute the largest single urban greenspace type (Thompson et al., 2003). Secondly, these greenspaces can play an important ecological and environmental role. Recent research showed that private gardens can have an enormous richness in plant and animal species, and can therefore be important for urban nature conservation (Gaston and Thompson, 2002; Rudd et al., 2002; Thompson et al., 2003). Well-greened residential areas can also importantly contribute to maintain environmental services such as rainwater infiltration, and improve climatic conditions within urban areas (McPherson et al., 1994; Pauleit and Duhme, 2000; Nowak et al., 2002). Therefore, change in these areas may particularly influence urban environmental quality.

The opportunity for this research arose as land use and land cover data was available for 11 residential areas across Merseyside collected from 1975 aerial photography (Sekliziotis, 1980). Moreover, in a previous study (Whitford et al., 2001), a modeling approach had been developed and applied to four of these residential areas to estimate environmental indicators on basis of this land use and land cover data. This study was now repeated by applying the same modeling approach and it was extended to include all 11 residential areas, comparing the data from 1975 with aerial photography from 2000. In so doing, the environmental consequences of urban land use and land cover change could be studied retrospectively over a period of 25 years.

2. Methodology

2.1. Case study areas

Merseyside is a large conurbation in the Northwest of England, covering an area of 655 km^2, of which the largest city is Liverpool, with an overall population size of 1.36 million inhabitants (in 2001). The case

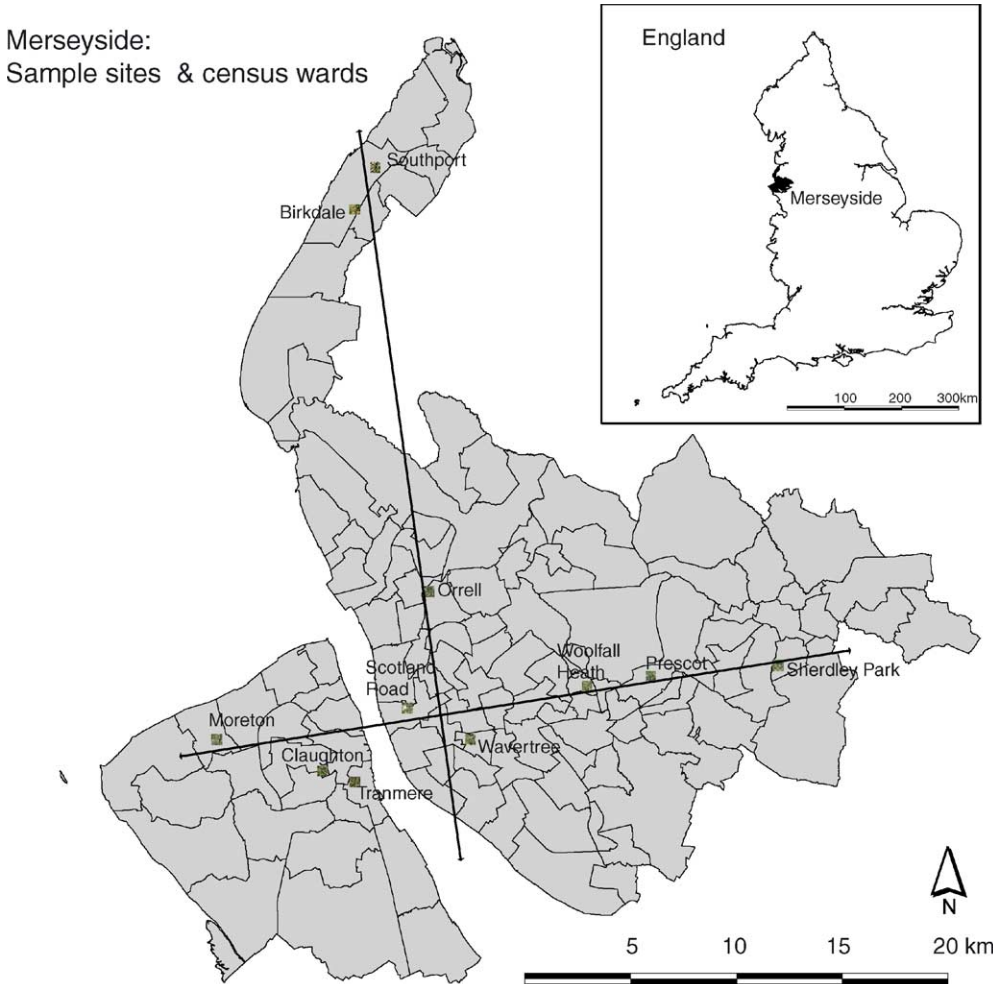

Fig. 1. Location of the 11 sample sites in Merseyside, UK.

study areas were those already surveyed by Sekliziotis (1980) who aimed to cover a broad range of residential situations across Merseyside with a limited number of sample sites. For this purpose, 11 $0.25\,km^2$ ($500\,m \times 500\,m$) squares were selected in residential areas (Fig. 1). These sites represent the main housing types, from dense terraces to low density, detached housing (Fig. 2), and were in areas of contrasting socio-economic status.

2.2. Land uses and socio-economic status

Land use is defined here as the human function of a given area. Sekliziotis (1980) determined the pattern of land use by placing a grid ($20\,m \times 20\,m$) over the $0.25\,km^2$ areas and recording the land use in each of the 625 squares using a stereoscope using colour infrared photographs taken in 1975. Eleven categories of land use were distinguished. These were the built environment, semi-natural environments; space for transportation; private gardens; amenity open space; play and recreation; cemeteries, agriculture and horticulture; neglected land; water bodies; and other land use. We repeated this method using true colour aerial photographs in digital format (ground resolution of pixels 25 cm). The photographs were imported into the geographical information system where a grid ($20\,m \times 20\,m$) was placed over the $0.25\,km^2$ areas and each of

Fig. 2. Examples of two study areas.

the 625 squares was subsequently visually assigned into one of the 11 land use categories. Where the distinction was difficult, the geographical information system allowed us to magnify small areas. If a square represented several land uses, then whatever was under the mid point of the square was recorded. Bearing in mind that 625 points were recorded and each area of land use was usually greater than 20 m × 20 m, this will result in potential errors of less than 1%. The differences of land use between the low-density housing area of Claughton and the high-density housing area of Wavertree can be clearly seen in Fig. 3.

The National Statistics Index of Multiple Deprivation, a government measure, was used to determine the socio-economic status of the study sites. It is derived from 32 variables of six domains (income, employment, health deprivation and disability, education, skills and training, housing, geographical access to services) and is computed for all census wards in England (DETR, 2000). Wards are larger than the study sites, however, so each study site was given the value of the census ward in which it was located. As wards are rarely entirely homogeneous, this might lead to some errors, however, we had to assume that the index value for the ward is sufficiently representative for the sample site placed within it.

While the wealthiest area, Birkdale, is middle ranked in the UK, Scotland Road in the centre of Liverpool is the fourth most deprived ward in the UK. Comparison of the recent index with a similar ranking used by Sekliziotis (1980; he placed them into four classes: high, etc.) showed that the socio-economic status had remained relatively unchanged at the higher and lower ends over the previous 25 years although there has been some movement in the middle. Prescot has risen in status and Orrell declined. Claughton, which in 1975 comprised many rooming houses, has become a very fashionable area once again.

To investigate the differences between changes in high and low status sites, the sample sites were designated into two approximately equal sized groups of: higher status (Birkdale, Moreton, Prescot, Southport, Claughton and Sherdley Park); and lower status sites (Orrell, Wavertree, Tranmere, Woolfall Heath and Scotland Road).

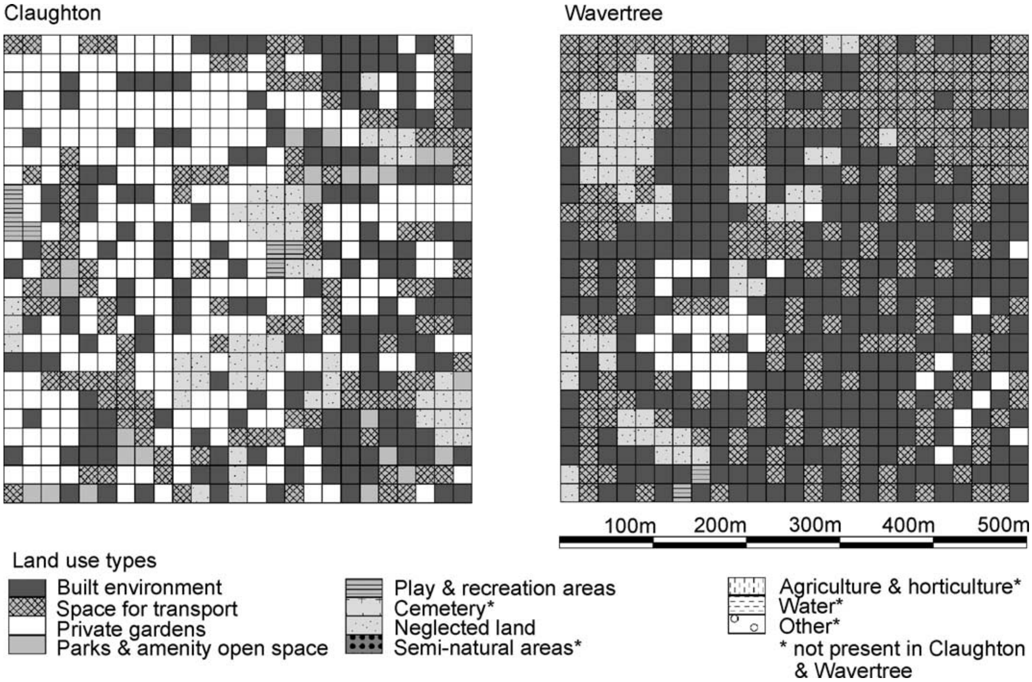

Fig. 3. Land use map for one of the sample areas.

2.3. Land cover types

Land cover is the physical surface of the land. In his survey, Sekliziotis identified land cover using the same grid method used for land use. However, he did not give the raw results but instead only gave graphs showing how land cover varied according to land use in four groups of areas of contrasting socio-economic status (low; low–medium; medium–high; high). Therefore, to calculate changes in land cover, we had to reconstruct the land cover in 1975 in each of the sites reversing Sekliziotis's process, according to their socio-economic status.

This method is clearly limited in accuracy as, in reality, the land cover may vary between different areas belonging to the same land use type. While recognizing the limitations, it was decided to replicate this process in 2000, estimating land cover from our land use data using Sekliziotis's graphs of land cover. It would require further study to assess how widely land cover varies between land use types of the same socio-economic status in order to establish the accuracy of the method used here. Such a test was not possible within the scope of this project and also not deemed necessary as we were most of all interested in the differences between the 1975 and 2000 situation. For this study the 16 land cover types of Sekliziotis were combined into ten (Annex: Table 2) because the level of detail was not needed for the environmental modeling.

2.4. Environmental performance indicators

The resulting land use and land cover data were used as input for the models derived by Whitford et al. (2001) to estimate three important environmental indicators: maximum and minimum surface temperatures, runoff coefficients, and biodiversity indicators. The differences in the two data sets were then used to predict the environmental consequences of the land use changes that had occurred over the last 25 years. The models are described in more detail in Whitford et al. (2001) and can be summarized as follows:

(a) *Surface temperature model*: Air temperatures in urban areas are elevated compared to the surrounding countryside ('urban heat island'), and this temperature increase can have negative impacts on human comfort and health (Höppe, 2002; Svensson and Eliasson, 2002). Therefore, climatic considerations should play an important role in urban planning (Eliasson, 2000). Estimation of surface temperatures from aerial or satellite thermal imagery has been frequently used as a tool to assess the climatic situation within urban areas (e.g. Eliasson, 1992; Dousset and Gourmelon, 2003; Bartholy et al., 2003; Voogt and Oke, 2003). In our study, on the other hand, a model (Whitford et al., 2001) was derived from that of Tso (1991) to predict mean maximum and minimum surface temperatures of the study sites using meteorological and land cover data.

These depended, linearly, on evaporating area (*Ef*) and built area (*Bf*) (Whitford et al., 2001). Maximum surface temperature falls with both evaporating and built area because heat is taken from the surface in the day by evaporation from greenspace, or to be stored in buildings. Minimum surface temperature rises with built area, because the heat stored in buildings remains to be radiated late into the night.

(b) *Hydrology model*: Runoff from urban areas is increased because the replacement of vegetation by impervious built and paved surfaces leads to less infiltration (Sanders, 1986; Arnold and Gibbons, 1996; Whitford et al., 2001). Because of this, urbanising watersheds are characterised by more frequent and more severe floods (Douglas, 1983). Surface runoff was therefore considered as an indicator (Whitford et al., 2001) which is particularly relevant for urban planning.

The model estimates runoff coefficients for rainstorms of 12 mm precipitation, a typical heavy rainstorm event in Northwest England (Whitford et al., 2001) and was adopted from Pandit and Gopalakrishnan (1996). Basically, the runoff coefficient increases with the amount of impermeable area (built environment) but not in such a predictable way as surface temperatures because the soil type and type of vegetation is also important. The soil types for each site were based on their drift geology association (obtained from drift maps, scale 1:25,000).

(c) *Diversity model*: Biodiversity in urban areas is affected by factors such as the overall amount, size and types of greenspaces, site factors (e.g. soil types), site history, management/use and the spatial distribution of greenspaces (Gilbert, 1989; Bastin and Thomas, 1999; Honnay et al., 1999; Mörtberg and Wallentinus, 2000; Thompson et al., 2003). The diversity models used in this study did not incorporate all of these factors but simply assessed the biodiversity potential of the sample sites as a function of greenspace cover and diversity. Neither could it take into account vertical stratification of vegetation. Three measures, which can be derived from land cover data, were used in the study.

The first was the total area of greenspace (P_T) which was calculated simply by summing all the areas of the five greenspace land cover categories (trees, shrubs, rough grass, turf grass and other green). A justification for this indicator is that a positive relationship can be observed between biodiversity in urban areas and the overall amount and size of vegetated areas (Gilbert, 1989; Honnay et al., 1999).

The second index, the structural diversity (SD) is essentially a Shannon–Weaver index but applied to habitats:

$$D = \sum_{i=1}^{5} p_i \log_2 p_i$$

where p_1 is the proportion of bare ground and turf grass; p_2 the proportion of rough grassland and herbs; p_3 the proportion of shrubs; p_4 the proportion of trees and p_5 is the proportion of built environment. This indicator assumes that biodiversity is related to the diversity and heterogeneity of the land cover types in the sample areas (Livingston et al., 2003).

The third index is the proportional area of greenspace (p_T) $\times$ the structural diversity, which therefore combines the elements of the first two, the importance of both area and diversity.

3. Results

3.1. Land use and land cover characteristics of the residential areas

The study sites comprised a wide range of residential areas, from densely built terraces to low density detached housing. In 2000, the percentage area occupied by built land use ranged from 16% in Birkdale to

40% in Orrell, whereas cover of private gardens was as high as 43% in Birkdale or as low as 6% in Wavertree. In general, high status sites had lesser areas of buildings (27 compared with 37%) and transport (24 compared with 33%), but higher areas of garden (33 compared with 18%).

Land cover attributes also widely differed between the study sites. The overall percentage cover of buildings and asphalt/concrete surfaces ranged from 38% in Birkdale to 81% in Wavertree. The cover of vegetated surfaces, on the other hand, was as high as 52% in Birkdale but only 11% in Wavertree. The tree cover was highest in Claughton (13%) and lowest in Scotland Road and Wavertree (1%). Five of the 11 residential areas had a tree cover of less than 5% surface area. On average, in high status sites the percentage cover of built and asphalt/tarmac surfaces was significantly lower than in low status sites (53 and 70%, respectively) whereas the land cover of vegetated areas was significantly higher in high status sites (42 and 23%, respectively).

3.2. Land use change 1975–2000

Several trends in land use change were apparent over the 11 sites (Table 1). One sample *T*-test of the means showed that some of these changes were highly significant ($P < 0.01$, unless otherwise stated). The built environment increased on average by about 4%, and space for transport by 5%, whereas the land cover of neglected areas fell by 3%. There had been a significant loss of open space relative to the built environment and transport in all sites during the last 25 years. The most changed was the high status area of Southport where the cover of built environment and transport increased by 16%, followed by the area of highest deprivation, Scotland Road (+13%).

Overall, higher status areas showed similar increase in buildings and transport as lower ones (Fig. 4). However, there was also a net loss of private gardens in higher status areas which contrasted with a net gain in the lower status areas. Higher status areas lost more amenity and neglected areas, but lower status areas lost more space for recreation and agricultural land.

3.3. Land cover change 1975–2000

Over all sites, there was a significant increase of 7% of area covered by buildings and asphalt/concrete surfaces from 54% (1975) to 61% (2000). On the other hand, there were significant losses of vegetated areas of 6% from an overall cover of 38% (1975) to 33% (2000) (Fig. 5).

Table 1
Percentage area of land use types for the sample sites in Merseyside

Land use types	Land use over all 11 sites			Land use, separately for high and low socio-economic status					
	Percentage area			High status[a]			Low status[b]		
	1975	2000	Difference	Percentage area			Percentage area		
				1975	2000	Difference	1975	2000	Difference
Buildings	28.05	31.81	3.75	22.62	27.12	4.50	34.58	37.44	2.86
Transport	23.04	28.35	5.31	18.72	24.23	5.52	28.22	33.28	5.06
Private gardens	26.54	26.24	−0.30	35.95	33.35	−2.60	15.24	17.70	2.46
Amenity open space	7.79	6.61	−1.18	9.75	7.30	−2.45	5.43	5.78	0.35
Cemetery	0.60	0.65	0.05	1.10	1.20	0.10	0.00	0.00	0.00
Play and recreation	2.21	1.31	−0.90	2.46	2.17	−0.30	1.90	0.28	−1.62
Agriculture/horticulture	2.40	1.64	−0.76	1.68	1.54	−0.15	3.26	1.76	−1.50
Neglected land	5.36	2.36	−3.00	7.22	2.67	−4.55	3.14	2.00	−1.14
Semi-natural land	0.05	0.07	0.03	0.08	0.13	0.05	0.00	0.00	0.00
Water	0.03	0.03	0.00	0.00	0.00	0.00	0.06	0.06	0.00
Other	3.94	0.93	−3.01	0.42	0.30	−0.12	8.17	1.70	−6.47
Total	100.00	100.00		100.00	100.00		100.00	100.00	

[a] High status sites: Birkdale, Morton, Prescott, Southport, Claughton, and Sherdley Park.
[b] Low status sites: Orrel, Wavertree, Tranmere, Woolfall Heath, and Scotland Road.

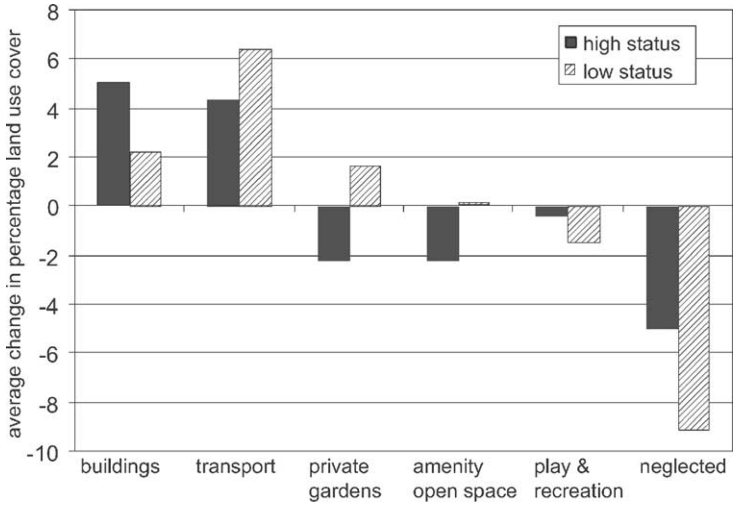

Fig. 4. Change of land use 1975–2000. Sites are ordered by socio-economic status. Semi-natural, water and agricultural features are not shown because of their overall low percentage cover and lack of representation in most of the sample areas.

These land cover changes were not evenly spread across the sites (Table 2). The overall cover of built and paved areas increased by 8% in higher status sites but only 6% in lower status areas. The land cover of vegetated areas, on the other hand, declined 7% in higher status sites but only 3% in lower status sites. The most pronounced land cover change occurred in Southport, a high status site. While the built-up area increased by only 2%, the paved land cover increased by 11%. This means that the overall cover of built and paved surfaces increased from 53 to 66%. Vegetated areas declined in Southport by 14% from 44 to 30%.

The nature of the lost vegetated areas varies, and several trends in land cover change were apparent over the 11 sites. There was little change in the ‘other green’ category over the 11 sites, but there were statistically significant changes for all the other categories: rough grass declined by just over 2%; turf grass by 1.4%; shrubs and trees by 1.7% ($P = 0.015$ and 0.028, respectively).

Most of the tree and shrub cover was lost from higher status sites (Fig. 6), where land cover of trees declined on average from 9.9 to 8.1%. The maximum tree loss occurred in Claughton where the tree

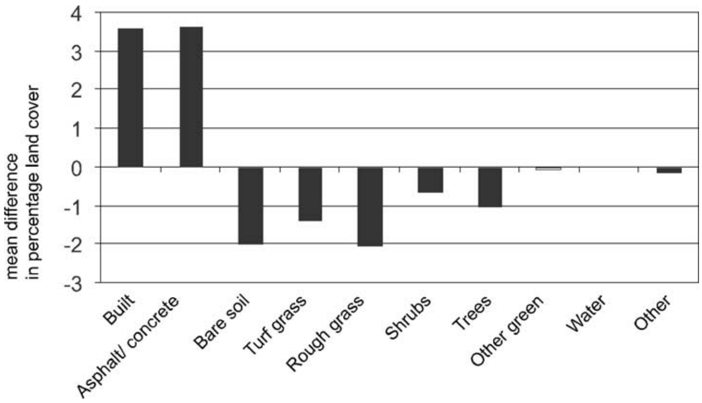

Fig. 5. Change of land cover 1975–2000.

Table 2
Percentage area of land cover types for the sample sites in Merseyside

Land cover types	Land cover over all 11 sites			Land cover, separately for high and low socio-economic status					
	Percentage area			High status[a]			Low status[b]		
	1975	2000	Difference	Percentage area			Percentage area		
				1975	2000	Difference	1975	2000	Difference
Built	28.15	31.75	3.59	22.82	27.17	4.35	34.56	37.24	2.68
Asphalt/concrete	25.36	28.98	3.63	21.62	25.54	3.92	29.84	33.12	3.28
Bare soil	6.31	4.33	−1.98	4.73	3.59	−1.15	8.21	5.23	−2.98
Turf grass	14.86	13.49	−1.38	19.00	17.40	−1.60	9.90	8.79	−1.11
Rough grass	9.71	7.68	−2.02	11.01	9.10	−1.91	8.14	5.99	−2.15
Shrubs	4.89	4.25	−0.64	5.64	4.61	−1.03	3.98	3.81	−0.17
Trees	6.71	5.70	−1.01	9.93	8.07	−1.86	2.85	2.86	0.01
Other green	2.16	2.10	−0.06	2.97	2.70	−0.27	1.19	1.38	0.19
Water	0.03	0.03	0.00	0.00	0.00	0.00	0.06	0.06	0.00
Other	1.82	1.69	−0.13	2.28	1.83	−0.45	1.27	1.52	0.24
Total	100.00	100.00		100.00	100.00		100.00	100.00	
Sum built environment[c]	53.51	60.73	7.22	44.44	52.70	8.27	64.40	70.36	5.96
Sum vegetated areas[d]	38.33	33.22	−5.11	48.55	41.88	−6.67	26.06	22.83	−3.23
Built/vegetated area ratio[e]	1.40	1.83	0.43	0.92	1.26	0.34	2.47	3.08	0.61

[a] High status sites: Birkdale, Morton, Prescott, Southport, Claughton, and Sherdley Park.
[b] Low status sites: Orrel, Wavertree, Tranmere, Woolfall Heath, and Scotland Road.
[c] Sum built environment: Built and asphalt/concrete.
[d] Sum vegetated areas: Turf grass, rough grass, shrubs, trees and other green.
[e] Built/vegetated ration: Built environment/vegetated areas.

cover declined from 16.1 to 13.0%. In lower status sites losses of trees in some sites were compensated by gains in other places. Tree cover increased most strongly in Scotland Road from 0.3% land cover to 1.0%. Higher status sites also lost more shrubs and turf grass, but lower status sites have lost slightly more rough grass.

3.4. Environmental consequences of land use and land cover change

In all sites, the models indicated a deterioration of environmental quality (Table 3):

3.4.1. Surface temperature model

In general, the lower status sites showed the highest temperatures and the higher status sites the lower temperatures. The surface temperature model predicted that, in all sites, both maximum and minimum surface temperatures increased over the last 25 years, apart from Birkdale in which minimum temperatures have remained the same. On average, for all sites, minimum temperatures rose by 0.3 °C and maximum temperatures by 0.9 °C. A one sample *T*-test showed these to be significant differences ($P < 0.01$).

The changes in surface temperature were not distributed evenly across the sites, however; lower status sites showed a smaller increase in maximum temperatures over the 25-year period (0.6 °C) than higher status sites (1.1 °C). Higher and lower status sites showed a similar, much lower increase in minimum temperatures (Fig. 7) of around 0.3 °C.

3.4.2. Hydrology model

The highest run-off values were predicted for Scotland Road and Wavertree, which would be expected as they were very densely built-up areas. The lower status sites had on average much higher values for runoff overall. The hydrology model estimated that 75% of the precipitation of a rainstorm event will runoff in lower status sites in 2000 compared with 53% in higher status sites.

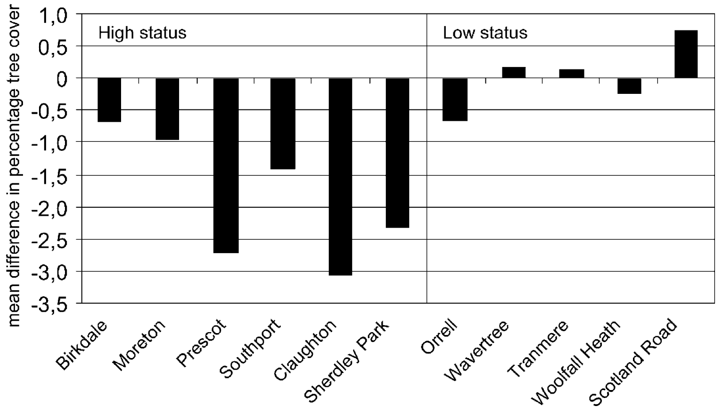

Fig. 6. Change of tree cover within the 11 sites 1975–2000. Sites are ordered by socio-economic status.

The Hydrology Model predicted an increase of surface runoff between 1975 and 2000 in all sites apart from Birkdale which had the lowest value overall (Fig. 8) because for this site a slight decrease of areas covered by asphalt/tarmac had been observed. On average, for all sites, runoff increased by 4%. A one-sample *T*-test showed this change to be statistically significant. The average increases over the last 25 years were greater for higher status (5%) than lower status sites (3%). The largest rise in runoff (10%) was seen in the affluent area of Southport. However, Scotland Road had also changed considerably with a lot of new development, but the runoff coefficient value only increased by 1% because this included new housing development with gardens.

3.4.3. Biodiversity indicators

The models predicted structural diversity which is a measure of the heterogeneity of a site reflecting the availability of different kinds of habitats. The indications are that this declined markedly in all the sites over the last 25 years. On average

Table 3
Mean values of the environmental indicators for the sample sites in Merseyside

	Climate indicators						Hydrology indicator		
	Minimum surface temperatures (°C)			Maximum surface temperatures (°C)			Runoff coefficient		
	1975	2000	Difference	1975	2000	Difference	1975	2000	Difference
All sites	13.81	14.06	0.25	25.03	25.92	0.89	0.59	0.63	0.04
High status[a]	13.43	13.72	0.28	23.15	24.28	1.13	0.49	0.53	0.05
Low status[b]	14.26	14.48	0.22	27.28	27.88	0.60	0.72	0.75	0.03
	Biodiversity indicators								
	Vegetated area (ha)			Structural diversity (Shannon–Weaver index)			Area × structural diversity		
	1975	2000	Difference	1975	2000	Difference	1975	2000	Difference
All sites	9.58	8.31	−1.27	1.19	1.09	−0.10	11.43	9.08	−2.35
High status[a]	12.14	10.47	−1.67	1.33	1.24	−0.09	16.11	12.93	−3.18
Low status[b]	6.52	5.71	−0.81	1.03	0.92	−0.11	6.72	5.26	−1.46

[a] High status sites: Birkdale, Morton, Prescott, Southport, Claughton, and Sherdley Park.
[b] Low status sites: Orrel, Wavertree, Tranmere, Woolfall Heath, and Scotland Road.

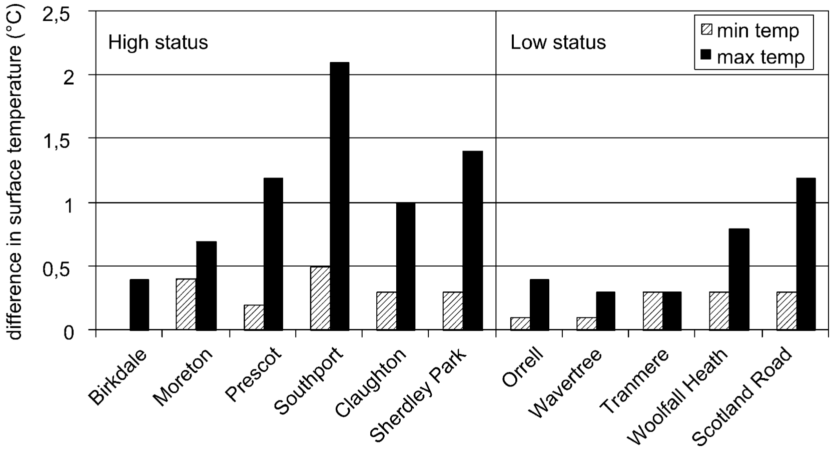

Fig. 7. Change in surface temperatures 1975–2000. Sites are ordered by socio-economic status.

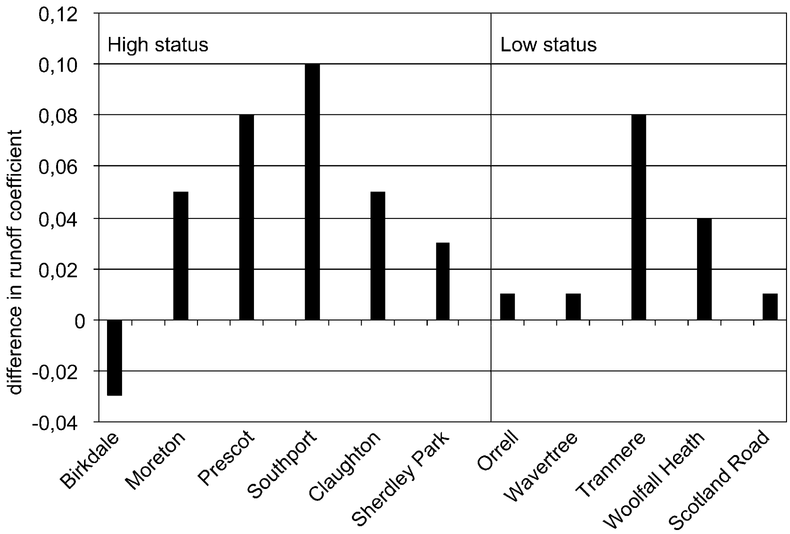

Fig. 8. Change in surface run-off 1975–2000. Sites are ordered by socio-economic status.

sites lost an index value of 0.10 but these declines were not spread equally across the sites (Fig. 9). Socio-economic status did not, however, have a significant effect on structural diversity decline. The model predicted an overall index of biodiversity by combining the indices of Greenspace and structural diversity. When the two indices are combined a different trend emerges. For all sites the values declined on average by 2.4. However, for higher status sites the decline was greater at 3.2 than for lower status sites at 1.5.

4. Discussion

4.1. Land use and land cover change

The approach adopted to assess land use and land cover developed by Sekliziotis (1980) overall worked quite well as land use could be easily mapped on screen from recent aerial photographs. Identification of the different land use types was mostly unproblematic. However, it had some limitations. For instance land cover data was extrapolated from Sekliziotis's

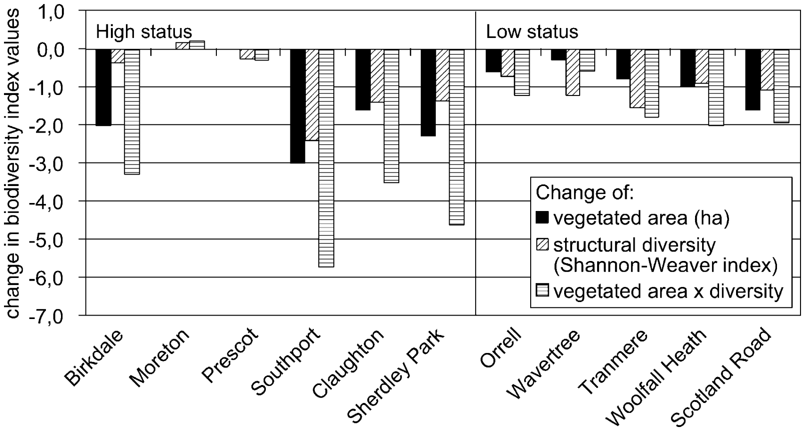

Fig. 9. Change in biodiversity indicators 1975–2000. Sites are ordered by socio-economic status.

summary graphs. It would have been desirable to map land cover directly on screen for all grids to obtain a more accurate characterization of land cover in the sample areas. Despite these limitations, repeating the method adopted by Sekliziotis produced comparable results, which allowed land cover change to be accurately determined.

With the advance of remotes sensing techniques, it will become easier to obtain land cover data from highly resolved imagery. However, the interpretation of satellite imagery requires a considerable level of expertise and technical skills while at the same time the accuracy of land cover mapping is still problematic in heterogeneous urban environments (see various papers in Jürgens, 2003). Therefore, the approach used here was the most appropriate currently available for a survey in smaller sample areas and with limited financial resources.

The results show that there has been a significant change of land use and land cover in residential areas in Merseyside, UK. The results are probably representative of the general process of land use and land cover change in residential areas of this conurbation. There was a significant increase of built and other impervious surfaces whereas greenspace was lost. Even in areas (e.g. Scotland Road) where the cover of certain types of greenspace increased, such as private gardens, the overall greenspace balance was negative because of the conversion of existing open space into new housing. The average loss of vegetation cover over all 11 sites was 5.1% and worryingly, loss of vegetated areas occurred over all of the 11 sample areas. Even areas that were already very densely built-up, such as Wavertree, lost vegetated areas.

There is a lack of studies from other cities to directly compare the results. However, unpublished data from a detailed analysis of land cover change in residential areas in Munich also revealed significant losses of greenspace due to infill densification (Wagner, 1992; cited in Pauleit and Duhme, 2000). At the same time, urban areas have rapidly expanded in Europe at the expense of agricultural land and natural areas as the recent study for the European Environmental Agency shows (EEA, 2002). The same study showed that the creation of new greenspace within urban areas did not keep pace with urban growth. Therefore, urban development has led to a decrease of greenspace at the level of the city region, as well as within the city itself. Comparable information was not available for Liverpool.

4.2. *The relation between land use/land cover change and socio-economic status*

The index of multiple deprivation (DETR, 2000) proved useful in distinguishing between the more affluent and the more deprived areas. As can be expected, high status areas had greater vegetated areas than low status areas. The cover of trees and shrubs particularly coincided with the distinction made between high and low status areas, and therefore appears to be a good indicator of the socio-economic status of residential areas in Merseyside. Studies in other cities (e.g. Pauleit, 1998; Iverson and Cook, 2000) have shown similar results.

The amount of greenspace lost was also related to socio-economic status. Interestingly, the affluent areas lost more vegetated areas. Infill densification in already built-up land was the main driver of this change. Perhaps the most surprising changes had taken place in Southport; surprising because they were not immediately obvious from aerial photographs. In Southport some buildings were replaced by others, for example a church was replaced by a block of low-rise flats and some houses demolished to make way for a large supermarket. Overall, there was only a slight increase of buildings in Southport but a strong increase of space for transport. Much of this increase was not represented by new road or house building but by paving front gardens.

The loss of tree cover in high status sites must be of particular concern as well as the conversion of front gardens into paved car parks. While these changes are fine-scale and individual in nature, they can lead to a major change of the character of residential areas with negative environmental consequences.

In low status areas, in contrast, significant amounts of open space or vacant land left from former industrial land uses were built-up over the 25-year period. Greenspace was also built over in areas where houses have been pulled down and replaced with flats, or new supermarkets with their inevitably large car parks. While the amount of greenspace in private gardens and tree cover could even increase due to new housing coming into the area the overall greenspace balance was everywhere negative. Therefore, it seems that the regeneration efforts in these areas did not lead to a measurable improvement of greenspace provision. It could be argued that Scotland Road is an exception as there was an increase of tree cover. However, with a 1% cover of trees in 2000, the level of tree provision is still well below that of higher status sites. During the field visits, it could also be observed that the quality of landscaping, notably the trees planted in the new residential areas and alongside the streets, was of a rather low standard and already showed signs of neglect.

4.3. Environmental and ecological impacts of land use and land cover change

The findings confirm the results from the previous study in Merseyside (Whitford et al., 2001), which established the close link between greenspace provision and environmental performance of residential areas, while the database is now extended from 4 to 11 study sites. Studies in other cities also show that there is an inverse relationship between greenspace cover and particularly tree cover and the environmental performance of urban land use types (e.g. Pauleit and Duhme, 2000; Nowak et al., 2002).

The environmental conditions, as measured by the environmental indicators all got worse between 1975 and 2000. Negative environmental consequences of land cover change were predicted for all study sites. However, the pattern of environmental change was unexpected. While the already lower environmental performance of low status areas declined somewhat, it was the higher status areas where environmental conditions deteriorated more strongly. The main reason was the general loss of greenspace, and particularly of trees, because of new houses developed on existing gardens, replacement of Victorian villas with apartment blocks and accompanying parking space. The results from other studies (Duhme and Pauleit, 1992; Pauleit and Duhme, 1995, 2000; McPherson, 1998; Scott et al., 1998; Nowak et al., 2002) clearly show the role of mature stands of large trees for climate improvements, reduction of surface run-off and to support biodiversity. Also, the increasing tendency to hard landscape front gardens for car parking, had an impact on the values of the environmental indicators. This was a particularly notable feature in Southport, where surface water runoff increased most strongly, although the site was situated on well draining sandy soils.

5. Conclusions

The decline in environmental quality in all residential areas included in the study due to the loss of greenspace, and specifically trees, leads to questions as regards the efficiency of greenspace policies. More attention needs to be paid to greenspace planning and management. In particular there is a need to control more carefully the process of infill densification in the more affluent residential areas with bigger gardens.

The removal of old stands of trees is worrying given that these have a high aesthetic and conservation value. Tree preservation orders do not seem to be able to effectively stop the loss of trees. However, further study would be required to arrive at a more informed assessment of this instrument. On basis of the results, it may be further questioned whether urban regeneration programs give sufficient consideration to the value of greenspace and in particular to 'brownfields' to improve the environment and provide spaces where nature can be enjoyed (e.g. Gilbert, 1989; Harrison and Davies, 2002; Pauleit et al., 2003).

Over the past 25 years, Merseyside developed into a city region while inner city greenspace was lost due to infill densification and urban regeneration programs. Both trends had negative effects on the environment. The authors acknowledge that urban development may be desirable for a variety of social and economic reasons in a region such as Merseyside, however, there seems to be a need to take environmental and landscape concerns more seriously on board to achieve a more sustainable development. Most of the changes observed in this study over the last 25 years have resulted from often small scale, individual developments, and have been constrained not directed by planning law. Recent developments of apartment blocks tend to be on a larger scale and recent change in planning policy may speed up such infill development. There is evidence that a lack of quality greenspace is an important reason why people move out of inner cities to the suburbs, thus causing urban sprawl (see Beer et al., 2003). Therefore, the very objectives of the compact city model will be compromised if more weight is not given to the preservation and management of urban greenspaces (Urban Green Spaces Task Force, 2002).

To support this task, monitoring not only at the city and city regional level but also at the neighbourhood level is required to provide a comprehensive assessment of the impacts of urbanization on the environment. Satellite based monitoring of land cover change on the city regional level could be linked with small-scale approaches as used in this study in Merseyside and extended to all urban land uses.

The environmental models used the land cover data as a main input, and only required readily available additional information. Therefore, they could be used to indicate the environmental impacts of urbanization in planning situations where the feasibility to collect large quantities of environmental data is limited. The three environmental indicators used in this study cover a range of different environmental issues, but further dimensions such as air quality would need to be added to provide a comprehensive assessment of environmental change.

The socio-economic dimension of urban landscape change warrants further exploration. The main interest here would be to gain a better understanding of the socio-economic forces driving the observed landscape change in residential areas but also to assess the impact of this landscape change on the residential population. Are these areas distinguished by the presence of residential groups particularly vulnerable to the loss of greenspace and the deterioration of environmental quality? It could also be of interest to link this study with a field survey to find out how the people living within the different sample areas perceive this change. Are the different processes of infill densification and regeneration described in this paper recognized as changing the quality of the urban landscape? Do home owners in the more affluent areas recognize that their decision to extend the house, to pave the front garden, etc. threatens the character and the environmental quality of their area? Community mapping could be a means to include local knowledge in the environmental evaluation of urbanization processes.

Finally, it needs to be asked which urban policies would be required to effectively protect and improve the greenspaces in residential areas in Merseyside. Could the designation of greenspace conservation areas (Handley, personal communication) be an instrument to control the process of infill development? Further study would be required to identify the problems of current policies and suggest ways to improve their efficiency.

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