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Research paper

Socio-economic inequalities in access to nature on public and private lands: A case study from Brisbane, Australia

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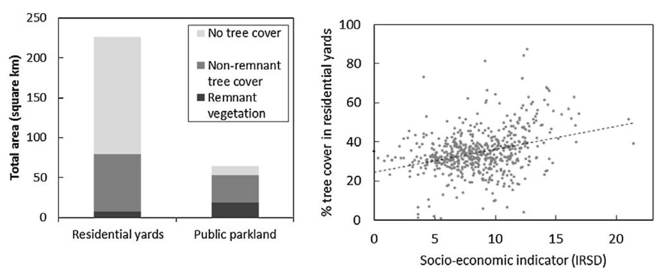
HIGHLIGHTS

- Tree cover is higher in more socio-economically advantaged neighbourhoods in Brisbane, Australia.
- This socio-economic bias occurs on both public parkland and residential yards.
- High quality remnant vegetation is much more even shared across the socio-economic gradient.
- Most tree cover across the city occurs within residential yards.
- Thus, greening efforts on private land could help promote equal access to nature.

GRAPHICAL ABSTRACT



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ABSTRACT

Opportunities to experience nature are important for human wellbeing, yet they are often inequitably distributed across society. Socio-economic variation can explain some of this inequity, but there has been relatively limited consideration of how access to different kinds of nature experiences varies across society. Here we examine how tree cover (as a measure of the general 'greenness' of urban environments) and native remnant vegetation cover (as a measure of access to higher quality natural areas) varies across the socio-economic gradient within public parkland and residential yards in Brisbane, Australia. We found that most tree cover was provided on residential land, and spatial regression models revealed that tree cover in both public parkland and private spaces was strongly positively related to socio-economic advantage. Conversely, most remnant vegetation cover was located on public parkland, and this was only weakly positively related to socio-economic status. These results suggest that municipal management of remnant vegetation can support equity in access to high quality nature experiences across the socio-economic gradient. However, the results also highlight the important role of residential yards in providing access to nature in general, as these areas provide the majority of overall tree cover. Thus, while public policy can enhance equity in access to nature on public lands, strategies such as social marketing and incentives that enhance nature within private spaces are important particularly within more disadvantaged neighbourhoods.

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1. Introduction

The world's urban population is continuing to grow rapidly (World Health Organization, 2013), intensifying the challenges of maintaining green spaces and natural areas in and around cities (Bekessy et al., 2012; McDonald, Kareiva, & Forman, 2008). There is emerging concern that people are becoming increasingly disconnected from nature, undergoing an 'extinction of experience' (Pyle, 1978) associated with urbanization and sedentary lifestyles. Coupled with this is the growing understanding that human interactions with nature are important for physical, social, and mental wellbeing (Bodin & Hartig, 2001; Dearborn & Kark, 2010; Han, 2009; Keniger, Gaston, Irvine, & Fuller, 2013; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Shinew, Glover, & Parry, 1984; Ulrich, 1984). However, given that urban landscapes are biologically heterogeneous (Luck & Smallbone, 2010; McKinney, 2006) and land access arrangements are highly variable, it is inevitable some people will have greater access to nature experiences in their local neighbourhoods than others (Pickett et al., 2008). An important question is therefore whether there is 'environmental equity' in access to this resource in urban landscapes; in other words, do all socio-economic groups have similar opportunity to experience nature in the city (Cutter, 1995)? Moreover, given that some of the benefits that can be derived from nature may be greater in areas with higher species richness (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007), are there socio-economic biases in access to the most natural green areas within urban landscapes? Answers to these questions could have significant policy implications as socio-economic biases in the availability of green space could be a symptom of, or even exacerbate, disadvantage (Heynen, Perkins, & Roy, 2006).

There is some evidence, particularly from the northern hemisphere, of inequality in access to green space. Socio-economically disadvantaged neighbourhoods have been found to have less overall vegetation cover in many instances (Iverson and Cook, 2000; Pham, Apparicio, Seguin, Landry, & Gagnon, 2012; Talarchek, 1990; Tooke, Klinkenberg, & Coops, 2010), and in some cities advantaged neighbourhoods have more public parkland (Boone, Buckley, Grove, & Sister, 2009), a greater number of street trees (Landry & Chakraborty, 2009) and relatively higher species richness and vegetation abundance (Clarke, Jenerette, & Davila, 2013; Martin, Warren, & Kinzig, 2004; Strohbach, Haase, & Kabisch, 2009; van Heezik, Freeman, Porter, & Dickinson, 2013). These patterns may arise for a diverse range of reasons. More advantaged populations can potentially afford larger properties in older neighbourhoods, thus higher levels of vegetation cover could be driven by the availability of space and the presence of more mature vegetation (Kirkpatrick, Daniels, & Zagorski, 2007; Lowry, Baker, & Ramsey, 2012; Mennis, 2006; Pham, Apparicio, Landry, Seguin, & Gagnon, 2013; Smith, Gaston, Warren, & Thompson, 2005). However, socio-economic indicators have been found to explain additional variation beyond that addressed by neighbourhood age and availability of space (Mennis, 2006; Pham et al., 2013). Social factors suggested to drive this relationship include different levels of participation in neighbourhood greening activities (Conway, Shakeel, & Atallah, 2011), as well as differences in land management behaviours influenced by culture, demographics, housing type and ownership (Grove, Troy, & et al., 2006; Perkins, Heynen, & Wilson, 2004; Talarchek, 1990; Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007). Differences in green space management can also be driven by top-down regulation and public policy; for example, tree removal might be considered more important to create the perception of safer spaces in socio-economically disadvantaged areas if crime rates are higher (Forsyth, Musacchio, & Fitzgerald, 2005), and unequal power relationships between communities and local governments could influence investment in and provision of public areas (Heynen, 2006; Heynen et al., 2006; Pedlowski, Da Silva, Adell, & Heynen, 2002).

Nature provision can differ notably between public and private locations (Mennis, 2006; Pham et al., 2013), yet the observed patterns in these areas do not always vary in a similar fashion across socio-economic gradients. Barbosa et al. (2007) found that in Sheffield, UK, public parkland was in fact well provided for socially disadvantaged groups and older people, though there was less space available for vegetation cover within residential yards than in more advantaged neighbourhoods. Conversely, disparities in vegetation cover across the socio-economic gradient in Montreal, Canada were more pronounced on public than private land, with higher levels provided for more advantaged groups (Pham et al., 2012). Such differences in the availability of nature within public and private spaces could have important public policy implications as the initiatives that aim to enhance vegetation within these locations will necessarily take different forms.

In addition to inequalities in nature provision, public and private spaces can play a different role in people's lives. Public parkland is accessible to all yet only a low proportion of the population actually visits public parks; visitation rates are strongly influenced by factors such as park characteristics, age, gender, cultural background, preferences, and socio-economic advantage or disadvantage (Elmendorf, Willits, Sasidharan, & Godbey, 2005; Jones, Hillsdon, & Coombes, 2009; Lin, Fuller, Bush, Gaston, & Shanahan, 2014; McCormack, Rock, Toohey, & Hignell, 2010; Reis, Lopez-Iborra, & Pinheiro, 2012). For example, Jones et al. (2009) found that while over 40% of people in the most advantaged socio-economic group visited parks in Bristol, UK, only 27% of those in the least advantaged group visited parks despite greater provision. On the other hand, private residential yards offer an immediate and easily accessible opportunity for people to access nature (Lachowycz & Jones, 2012). A number of studies have demonstrated the importance of nature close to the home. For example, Hanski et al. (2012) found a reduced incidence of allergies in Finnish children where biodiversity was greater around the home, and Kaplan (2001) showed that a view of green space through a home window was associated with improved psychological wellbeing. A study in the Netherlands found that greener residential areas promote social cohesion, stress reduction and physical activity (Groenewegen, van den Berg, Maas, Verheij, & de Vries, 2012).

In addition to the different roles that public and private spaces have for people, these spaces are managed in very different ways which will inevitably influence the availability of nature itself. The biodiversity within private spaces is heavily influenced by individual behaviours and circumstance, such as garden management, house ownership, wildlife feeding or availability of space (Daniels & Kirkpatrick, 2006; Fuller, Warren, Armsworth, Barbosa, & Gaston, 2008; Grove, Troy, & et al., 2006; Head & Muir, 2005; Loram, Warren, Thompson, & Gaston, 2011; Smith et al., 2005; Smith, Gaston, Warren, & Thompson, 2006; Smith, Warren, Thompson, & Gaston, 2006; Talarchek, 1990). Conversely, public parkland is usually directly controlled through top-down planning and management by local municipalities (Kendal, Williams, & Williams, 2012), and public policy objectives commonly aim to ensure a minimum target area of parkland is available to each resident (e.g. Brisbane City Council, 2000), typically within a minimum walking distance (Barker, 1997; Harrison, Burgess, Millward, & Dawe, 1995; Wray, Hay, Walker, & Staff, 2005). Thus, public parkland and residential yards inevitably provide highly different arenas for nature experiences, and understanding these differences will allow planners to address inequalities in access to urban nature.

While there is a growing body of research exploring environmental equity issues associated with the availability of vegetation cover across urban landscapes, there is only a limited

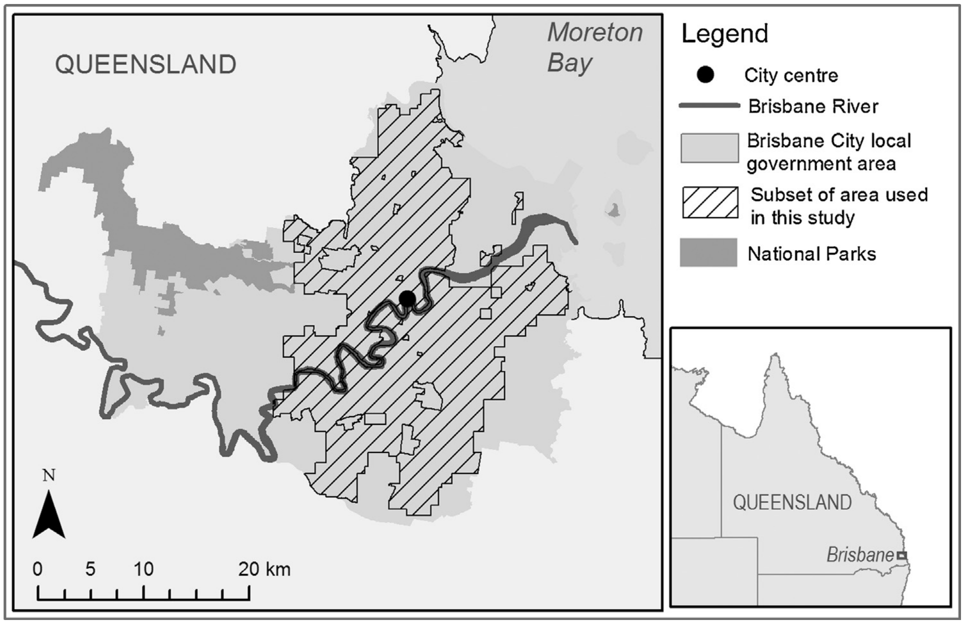

Fig. 1. Location map of the study area in Brisbane, Australia.

understanding of how access to patches of native vegetation varies along the socio-economic gradient, and whether any biases occur within both public and private lands. Australia provides an interesting opportunity to address these questions. Important natural ecosystems commonly occur within and around Australian cities (Bekessy et al., 2012; Newton et al., 2001), and intact areas of native remnant vegetation commonly remain (or have been rehabilitated or revegetated) throughout the city scape. Though the isolation of such remnant patches can lead to local extinctions or declines in some species (Catterall, 2009; Piper & Catterall, 2003), populations of native forest birds, mammals and plants have persisted where landscape context and habitat characteristics permit (Brady, McAlpine, Miller, Possingham, & Baxter, 2011; Daniels & Kirkpatrick, 2012; Moxham & Turner, 2011; Shanahan, Miller, Possingham, & Fuller, 2011; Shanahan, Possingham, & Martin, 2011; Stagoll, Lindenmayer, Knight, Fischer, & Manning, 2012). It seems plausible that these highly natural remnant areas are especially important for delivering human well-being benefits, and indeed Pyle (1978) highlights that even small, humble natural areas such as those found in urban environments can be as powerful as big reserves in providing meaningful experiences with nature.

In this study we address two central questions using the rapidly growing city of Brisbane, Australia as a case study:

(1) Is there environmental equity across the socio-economic gradient in the availability of (i) tree cover, which includes native and non-native species providing a measure of general greenness, and (ii) natural remnant vegetation cover, which are native stands of vegetation, providing a measure of access to naturally vegetated areas?
(2) Is there similar environmental equity in the availability of tree cover and natural remnant vegetation cover on both public parkland and private residential yards?

We examine these questions at a scale relevant to spatial planning policy of public parkland within the city, while also accounting for potential variability driven by the availability of space and neighbourhood age.

2. Methods

2.1. Study area

Brisbane is a subtropical city located in Queensland, Australia (Fig. 1), settled in the mid 1800s. The city government area spans 1380 km^2, and in 2011 had an estimated population of 1,090,000 residents. The region has significant projected population growth, with 156,000 additional dwellings forecast to be required within the greater Brisbane area by 2031 (up from a total of 397,000 dwellings in 2006; Queensland Government, 2009). Most dwellings in the city are detached houses with lot sizes that range widely from 80 m^2 to 217,578 m^2. To date most of the development has been sprawling on the outskirts of the city (including outside of the current study area), and so newer neighbourhoods tend to be on the outer edges of the city. The majority of the population is concentrated in a strip through the centre (Fig. 2b). For this study we focus on a subset of the city covering 567 km^2 for which socio-economic data were available from the 2006 census and within which the individual residential properties have been delineated (Fig. 1 shows the study area extent). This study area covers the most populated parts of the city, including approximately 881,000 residents.

We created a 1 km × 1 km grid layer in which to summarize the socio-economic and green space characteristics of neighbourhoods across the city. This grid cell size was selected to reflect public parkland policy and planning guidelines within Brisbane; park area targets are set based on minimum distances from homes, and for local parks this distance target is a 500 m straight line radius of residential lots (Brisbane City Council, 2000). The 1 km grid cell width was therefore an appropriate scale for detecting biases associated with park design and vegetation cover that may arise within these policy guidelines. The same grid cells were used to examine variation in vegetation within residential yards and public parkland to maximize comparability between the analyses, and because the predominant housing provided in Brisbane is single dwelling houses with minimal diversification across the city. A total of 592 grid cells were created. Because of the irregular shape of the study area, these grid cells comprised 336 inner cells of 1 km^2 and 256 edge cells between 0.2 km^2 and 1 km^2. Spatial operations were carried out in ArcGIS (v. 10.0), and statistical analyses were performed in R v2.13.0 (R Core Team, 2012).

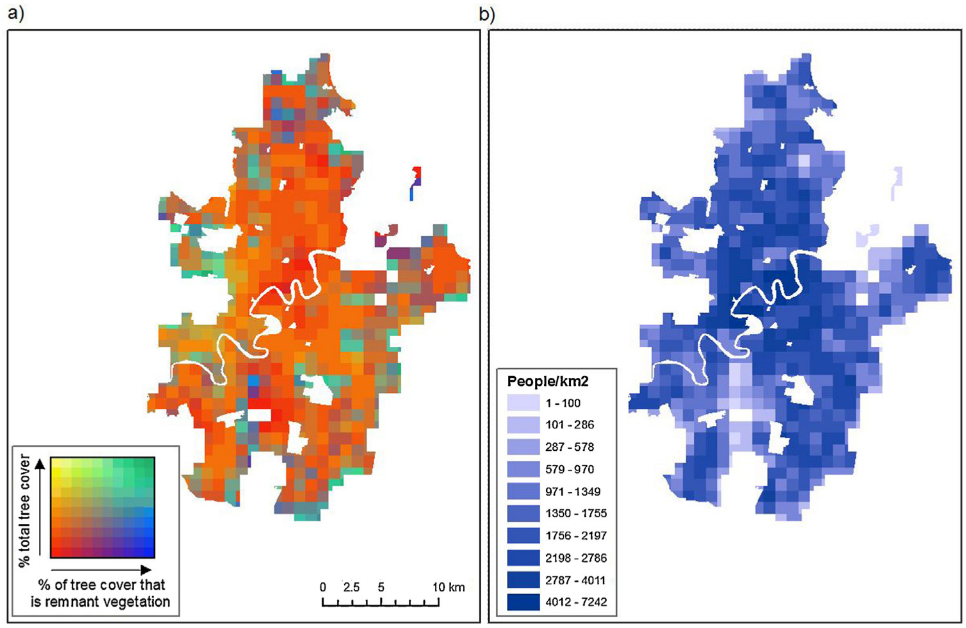

Fig. 2. Map a) illustrates the variation in neighbourhood vegetation cover across Brisbane. It shows the percentage of tree cover in each neighbourhood as well as the percentage of that tree cover that is classified as remnant vegetation. Red squares highlight areas with both low tree and remnant vegetation cover, and green areas highlight neighbourhoods with a high level of tree cover most of which is remnant vegetation. Conversely orange and yellow areas indicate high tree cover but only a small proportion of this is remnant, and blue areas indicate low tree cover but a large proportion of this is remnant. For comparison b) illustrates the variable population density across the city within grid cells of 1 km × 1 km. There was no information on the Index of Relative Socio-economic Disadvantage for blank areas within the city and so they have been excluded from all analyses.

2.2. The relationship between green space availability and socio-economic disadvantage

We assessed whether two vegetation cover variables were equitably provided across the socio-economic gradient in Brisbane. This included:

(i) total tree cover (inclusive of remnant vegetation, hence forward referred to as 'tree cover') as a measure of general 'greenness' of the landscape, including all trees, native or non-native; and
(ii) native remnant vegetation tree cover (hence forward referred to as 'remnant vegetation cover'), which represented the opportunity for people to experience a natural ecosystem similar to that of the pre-urbanized local environment. This vegetation type includes predominantly native species, and can include rehabilitated or revegetated areas.

We assessed whether tree cover and remnant vegetation cover were equitably provided across the socio-economic gradient first within all land-use types (i.e. including street trees and commercial treed areas), and then within public parkland and private residential yards. We chose these two land-use types as both include areas of tree cover and remnant vegetation cover. Remnant vegetation can persist in private yards where areas encroach from adjoining lands, or where yards are large enough for remnant vegetation patches to persist. We also tested for the effects of two potential confounding factors, neighbourhood age and the availability of space in these respective environments. Below we describe the data-sets used for this analysis, and then the approach for the analysis itself.

2.2.1. Socio-economic disadvantage

We used a general index of socio-economic disadvantage, the Index of Relative Socio-economic Disadvantage (IRSD), within this study as it summarizes a range of factors that contribute to disadvantage (Australian Bureau of Statistics, 2006, 2008). This Index was developed by the Australian Bureau of Statistics as a 2006 census output, and it provides a robust estimate of disadvantage as principal component analysis is used to incorporate a comprehensive range of variables including income, education, ethnicity, and housing arrangements (Australian Bureau of Statistics, 2008; a full list of the census variables used to calculate IRSD is provided in the supplementary material). Low IRSD values correspond to greater socio-economic disadvantage, and high values indicate lesser disadvantage. The IRSD values were originally provided for spatial zones that were defined by the population distribution and so varied enormously in size, ranging from 0.7 ha in the city centre to 289 ha (median area of 15 ha) on the outskirts of the study area. To overcome biases associated with the irregular shapes of these zones, as well as the fact that park areas altered population density within the zones of which they were part, we assigned each grid cell an adjusted IRSD value based on the proportional coverage of different zones and the population density within. This adjusted IRSD value is:

$$\text{Adjusted IRSD} = \frac{\sum_i^n \text{area}_i(\text{density}_i \text{IRSD}_i)}{\sum_i^n \text{area}_i \, \text{density}_i}$$

where area_i is the area of the grid cell with IRSD value i, and density_i is the population density per square kilometre in that same area. To normalize the IRSD variable we carried out a reflected square root transformation. We reflected this transformed data set again so the results represented the true direction of the relationship.

2.2.2. Vegetation cover measurements

Tree cover was derived from a data layer developed by the Brisbane City Council from an over-storey foliage projective cover (FPC) map produced from LiDAR data for the region (acquired between March and June 2009; Armston, Denham, Danaher, Scarth, & Moffiet, 2009). As part of the development of the tree cover layer, Brisbane City Council compared the foliage projective cover maps against a mosaic of high resolution satellite images of the city produced from the WorldView2 instrument (0.5 m resolution) between 22nd March and 21st June 2010. This allowed the removal of misclassified areas from the FPC data layer, as well as updating of areas that were cleared between 2009 and 2010. The foliage projective cover grid was then converted by the Council to a simple tree cover data layer: areas where FPC was greater than zero were considered as 'tree cover', and 'non-tree' where FPC was zero. The spatial resolution of the resulting tree cover layer was 2 m. We checked the overall accuracy of the tree cover data layer using visual assessment of 1000 randomly located points against high resolution Google Earth satellite imagery (Google Earth V6.2, 2012; image captured 16 June 2009). The layer correctly classified 94% of the points as either 'tree cover' or 'non-tree cover' (the full confusion matrix is provided in Table S1 in the supplementary material). As intended, this combined layer did not capture lawns or low herbaceous plantings in residential yards.

To examine the distribution of remnant vegetation cover we used remnant vegetation mapping (Regional Ecosystems V1.0; Brisbane City Council, 2004) which was developed by the Queensland Government and Brisbane City Council following ecosystem classification methods outlined by Sattler and Williams (1999). The remnant vegetation layer was originally created by interpreting satellite imagery and aerial photographs, and was later groundtruthed and classified. Remnant vegetation patches from 0.5 h in size and greater are represented in this dataset, and it includes native vegetation that remained as the city developed as well as vegetation that has been restored to remnant or near remnant status. In the development of the remnant vegetation layer 1000 site surveys were performed by Council and Government staff to confirm classification accuracy. We updated this regional ecosystem map to reflect recent clearing based on the 2010 tree cover map described above. We then classified the tree cover data set according to its remnant status. On examination of the combined data set we found that open eucalypt woodland remnant vegetation was commonly mapped as a mosaic in the tree cover layer such that many individual pixels within the vegetation type were classified as non-tree (open eucalypt woodlands have a grassy or herbaceous understorey); we therefore reclassified these individual cells as 'remnant vegetation'. Note that for consistency in analysis and to ensure the vegetation between grid cells was comparable, the small area occupied in less than 1% of grid cells by non-tree remnant vegetation categories was not included within this analysis (this includes grassland, herbland, healthland, sedgeland and freshwater swamps; see the supplementary material Table S2 for further details).

2.2.3. Provision of green space in public and private locations

To examine where green space was provided within the landscape we spatially identified residential yards and public parkland. Residential yards were identified based on a cadastral map for Queensland (Department of Environment and Resource Management, 2006) in conjunction with the Queensland Valuation and Sales dataset (QVAS), which provides the statutory valuations of all land parcels in Queensland (Department of Environment and Resource Management, 2006; see Sushinsky, Rhodes, Possingham, Gill, & Fuller, 2013 for further details of the data set). We define 'residential' as all properties with at least one dwelling and/or any associated properties that are used for private yards. We also created a combined public parkland data set that maps all publicly accessible outdoor parkland areas provided in the region. For each grid cell we calculated the percentage of tree cover and remnant vegetation cover both overall and within each land-use type (Table 1, variables 1–6) by tabulating the relevant areas within ArcGIS. This provided an adjusted measurement robust to any variation in the total area of residential yards or public parkland.

2.2.4. Neighbourhood age and availability of space

Both neighbourhood age and availability of space have been found to be important correlates with vegetation cover (Mennis, 2006; Troy et al., 2007; Pham et al., 2013). We therefore additionally assessed the correlation of these variables with vegetation cover because they could confound the detection of, or even explain, any differences that occur across the socio-economic gradient. To measure available space in private areas we calculated average lot size for residential properties within each grid cell (variable 8 in Table 1), which in a previous study was found to have a very strong correlation with the non-built area of a residential property in Brisbane (Sushinsky et al., 2013). For public parkland, available space was simply measured as the total available area of parkland within a grid cell (variable 7 in Table 1).

To determine neighbourhood age (variable 8 in Table 1), estimates were made of the year range through which each neighbourhood transitioned from rural to urban based on the historical information compiled by the Centre for the Government of Queensland (2013). The neighbourhood age variable was calculated as the middle year of the estimated year range, and the median of these values was 45 years, reflecting the recent development of much of the city.

2.3. Statistical analysis

Where appropriate we transformed the vegetation variables to comply with the assumption of normality for all regression analyses (transformations are shown in Table 1). We then assessed the correlation between IRSD and each of the neighbourhood age and available space measures using Pearson's correlation coefficient.

The correlation between predictor variables and the response variables tree cover and remnant vegetation cover was tested for (1) the entire study area, (2) within residential yards only, and (3) within public parkland only. Predictor variables for all models included IRSD and neighbourhood age. Additionally, because previous studies have found that neighbourhood age can in some instances have a non-linear influence on vegetation cover (e.g. Grove, Cadenasso, & et al., 2006; Landry & Pu, 2010; Pham et al., 2013), we also tested models that included the square term of this variable. For the models that focused on residential yards and public parkland, relevant available space variables were also included (average residential lot size and total park area respectively). We checked to ensure the scale of multicollinearity between the predictor variables was acceptable using the variance inflation factor, and ensured there were no important outliers.

We first carried out ordinary least squares regression and tested the residuals of these models for spatial autocorrelation using Moran's I. We then used spatial regression models using the spdep package (Bivand et al., 2011) where Moran's I had indicated significant spatial dependence was present. These models accounted for spatial autocorrelation among grid cells by incorporating a spatially lagged dependent variable derived from a matrix of relationships between immediately adjoining grid cells. We reassessed whether any residual spatial autocorrelation remained following these regression analyses using Breusch–Godfrey serial correlation Lagrange multiplier (LM) test values and Moran's I statistic. Akaike's Information Criterion (AIC) was calculated for both the ordinary least squares and spatially lagged regression models to compare between model types.

3. Results

There was marked variation in tree cover across Brisbane (Fig. 2a). Fig. 2b shows human population density across the city for comparison, highlighting that while most remnant vegetation

Table 1
Independent variables examined for their relationship with socio-economic status within grid cells across Brisbane, Australia. Table indicates whether any transformation was required for non-normal data.

Variable number	Variable name	Transformation	Description
1	Total tree cover	Not required	Total percentage of grid cell covered by trees in any land-use type, including any remnant vegetation cover. Provides a general indication of the level of opportunity to experience nature within a neighbourhood
2	Total remnant vegetation cover	$\log(x+1)$	Total percentage of grid cell covered by remnant vegetation in any land-use type. Provides an indication of the level of opportunity to experience more natural areas within a neighbourhood
3	Tree cover – residential yards	Not required	Percentage of the total residential yard area within a grid cell that is covered by trees, including any remnant vegetation cover. Provides a general indication of the level of opportunity to experience nature within the immediate environment of households
4	Remnant vegetation cover – residential yards	$\log(x+1)$	Percentage of the total residential yard area within a grid cell that is covered by remnant vegetation only. Provides a general indication of the level of opportunity to experience relatively natural areas within the immediate environment of households
5	Tree cover – public parkland	Not required	Percentage of the total public parkland area within a grid cell that is covered by trees, including any remnant vegetation cover. Provides an indication of the level of opportunity to experience nature on publicly accessible land
6	Remnant vegetation cover – public parkland	$\log(x+1)$	Percentage of the total public parkland area within the grid cell that is covered by remnant vegetation. Provides an indication of the level of opportunity to experience relatively natural areas on publicly accessibly land
7	Total public parkland area	$\log(x+1)$	Percentage of the grid cell that is covered by public parkland (including areas provided by the council and state government)
8	Average residential lot size	$\log(x)$	The average area of all residential lots within the grid cell
9	Neighbourhood age	Not required	The age of each neighbourhood determined as the median year from the estimated year range through which the transition from rural to urban occurred

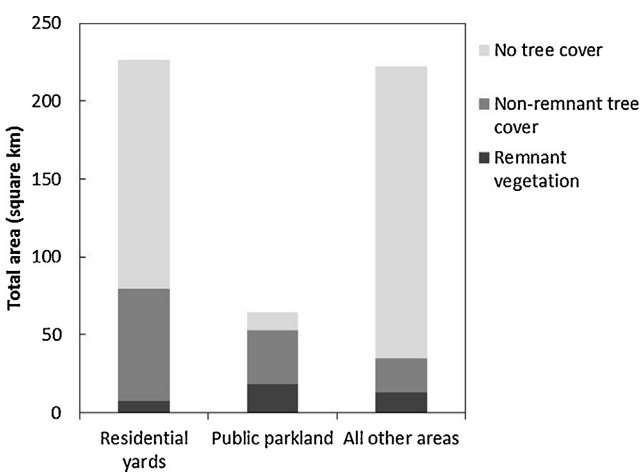

Fig. 3. The total area of remnant vegetation cover and all other tree cover occurring within residential yards, public parkland and other areas in Brisbane.

is available in the least densely occupied areas of the city, there are still areas of high cover within some of the more dense areas. The majority of the study area supported no tree cover (345.6 km^2, or 67% of the land area). Of the remaining 33% of land that was covered by trees, a total of 38.8 km^2 (7.6% of the study area) was classified as remnant. While more tree cover was provided within residential yards than public parkland, the majority of remnant vegetation was found in public parkland (Fig. 3). The remaining tree and remnant vegetation cover (6.8% of the total land area) was located on areas with other land uses, which included industrial and commercial land, roads, road verges and educational institutions.

There was some evidence that more advantaged neighbourhoods had slightly more park area and greater lot sizes (Pearson's correlation coefficients between IRSD and total area of parkland, $r = 0.13$, $p = 0.001$; average residential lot size, $r = 0.09$, $p = 0.02$). However, the level of multicollinearity between neighbourhood age, IRSD, average lot size and total park area was low enough (variance inflation factors measuring between 1.02 and 1.2) to include all together within relevant regression analyses. There was significant spatial autocorrelation among residuals in all of the ordinary least squares regression models (as indicated by Moran's I in Table 2). However, no significant level of spatial autocorrelation remained when using spatially lagged regression models (non-significant Moran's I values, Table 2). The AIC values were lower for all spatially lagged models compared to their ordinary least squares counterparts.

Based on the spatial regression models, tree cover and remnant vegetation cover both varied significantly across the socio-economic gradient in Brisbane, with more cover in more advantaged locations (Table 2, Fig. 4a and b). However, the correlation coefficients indicate the effect was much weaker and the figures showed much more scatter for remnant vegetation cover. There was also a positive correlation between remnant vegetation cover and tree cover along the socio-economic gradient within both private residential yards and public parkland (Table 2, Fig. 4c–f), and this correlation was much stronger for tree cover than remnant vegetation.

The available space (i.e. park area and average lot size) was an important predictor of both tree cover and remnant vegetation cover within public parkland and residential yards (Table 2). Neighbourhood age was negatively correlated with both remnant vegetation and tree cover in all instances.

4. Discussion

Our data show that people who live in socio-economically disadvantaged areas in Brisbane have reduced access to nature in their neighbourhood. However, the magnitude of this relationship varied markedly across the two different types of vegetation cover measured here, with remnant vegetation cover being more equitably provided than overall tree cover. Given that tree cover is the dominant form of nature across the city, the consequences of this difference are important. More limited access to experiences

Table 2
The results from linear regression models (ordinary least squares) and spatially lagged regression models for the tree and remnant vegetation cover response variables for a) across all of Brisbane city, b) within residential yards, and c) within public parkland. Moran's I and LM test values (derived from the Breusch–Godfrey serial correlation LM test) indicate whether spatial autocorrelation remains in the model residuals.

		Ordinary least squares regression				Spatial regression			
Dependent variable	Predictor variables	Coefficient (t-value)	R^2	AIC	Moran's I	Coefficient (z-value)	AIC	LM test value	Moran's I
a) Across all public and private spaces:									
Tree cover	IRSD	1.81 (11.02)***	0.22***	4617	0.31***	0.92 (6.03)***	4472	0.058	−0.002
	Neighbourhood age	0.11 (0.06) (p = 0.06)				0.04 (0.69)			
	Neighbourhood age^2	−0.001 (−4.17)***				−0.0008 (−2.02)*			
Remnant vegetation cover	IRSD	0.09 (6.34)***	0.23***	1769	0.27***	0.060 (4.47)***	1661	0.896	0.008
	Neighbourhood age	−0.019 (−12.65)***				−0.009 (−6.21)***			
b) Within residential yards:									
Tree cover	IRSD	1.16 (9.15)***	0.31***	4301	0.35***	0.38 (3.69)*	4087	6.89**	−0.03
	Neighbourhood age	0.05 (10.97)*				0.27 (6.56)**			
	Neighbourhood age^2	−0.003 (−10.62)***				−0.001 (−6.05)***			
	Average lot size	7.04 (10.06)***				5.49 (0.63)***			
Remnant vegetation cover	IRSD	0.07 (6.81)***	0.47***	1340	0.22***	0.04 (4.88)***	1276	0.05	−0.003
	Neighbourhood age	0.0002 (0.65)				0.005 (1.50)			
	Neighbourhood age^2	−0.00006 (−2.273)*				−0.00006 (−2.23)*			
	Average lot size	0.99 (17.34)***				0.85 (15.19)***			
Within public parkland:									
Tree cover	IRSD	1.69 (5.77)***	0.18***	5302	0.19***	1.23 (4.28)***	5250	2.65	−0.01
	Neighbourhood age	−0.19 (−6.53)***				−0.11 (−3.90)***			
	Park area	5.54 (6.45)***				4.94 (6.09)***			
Remnant vegetation cover	IRSD	0.07 (4.02)***	0.40***	1994	0.15***	0.05 (2.78)**	1950	0.05	−0.002
	Neighbourhood age	−0.02 (−10.53)***				−0.01 (−5.91)***			
	Park area	0.78 (14.83)***				0.71 (13.98)***			

NS = not significant.
* Indicates $p < 0.05$.
** Indicates $p < 0.01$.
*** Indicates $p < 0.001$.

of nearby nature could create further disparities in quality of life for already disadvantaged groups (Heynen et al., 2006) and a range of other benefits and services provided by tree cover are also likely to be reduced, including regulation of temperature and buffering noise pollution (Dearborn & Kark, 2010; Pauleit, Ennos, & Golding, 2005). All such ecosystem services are likely to have important implications for the physical and mental health of urban populations (Maas et al., 2006).

The relatively equitable availability of remnant vegetation cover along the socio-economic gradient, coupled with the fact that most of this natural vegetation cover was provided on public parkland, is a positive finding from our analysis. In fact, our results show that available space was a more important predictor of remnant vegetation cover on both public and private land than socio-economic status or neighbourhood age. These results suggest that people from different socio-economic backgrounds have similar opportunity to access the potential benefits supplied by higher quality nature experiences. The higher level of provision of remnant vegetation cover on public land is likely to be driven by the development process within these land types, as well as ongoing management regimes. First, remnant vegetation is commonly cleared to accommodate buildings as residential developments are established, and so the need for cleared land is much lower within public park areas. Second, top-down management of remnant vegetation in Brisbane is likely to ensure the patterns of provision that arise due to development pressures are maintained, as it includes strict regulation of clearing and protection of biodiversity values (Brisbane City Council, 2000, 2003).

Non-remnant tree cover in Brisbane is subject to much less legal regulation than remnant vegetation (Brisbane City Council, 2003). This perhaps explains the relatively high correlation we observed between tree cover and socio-economic measures here as the influence of local residents on this vegetation type is likely to be more pronounced. A similar pattern has been found for tree cover in other Australian cities, for example Melbourne parks in more socio-economically advantaged neighbourhoods contain greater shade

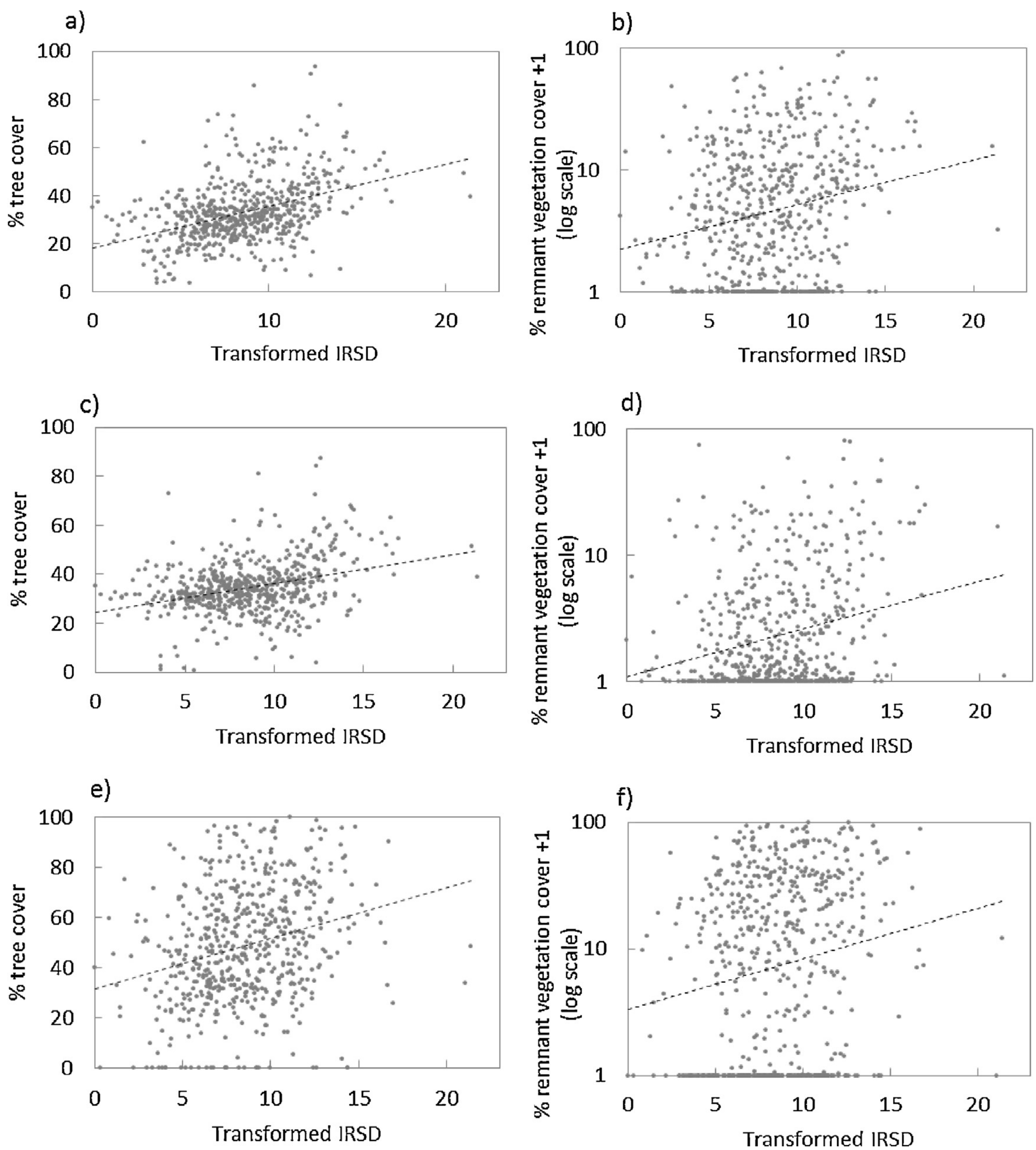

Fig. 4. The relationship between the Index of Relative Socio-economic Disadvantaged (IRSD) and vegetation cover indices measured within grid squares cross the city of Brisbane. Vegetation indices include: a) percentage tree cover (which includes remnant vegetation) across public and private lands; b) percentage remnant vegetation cover alone across public and private lands; c) percentage tree cover within residential yards only; d) percentage tree cover within public parkland only; e) percentage remnant vegetation cover within residential yards only; and f) percentage remnant vegetation cover within public parkland only. Based on spatially lagged regression the relationships are significant at $p < 0.00001$.

tree cover (Crawford et al., 2008). Several social and behavioral factors could explain this relationship. For example, local residents in more advantaged areas may have a greater interest in participating in 'greening' activities in local parks (Conway et al., 2011), tree removal might be considered more important in disadvantaged areas if crime rates are higher to create the perception of safer spaces (Forsyth et al., 2005), or unequal power relationships between residents and local governments could influence investment in public areas (Heynen et al., 2006; Pedlowski et al., 2002). On private land people in socio-economically advantaged areas may have a greater desire or financial capacity to protect, improve and maintain vegetation around their homes (Heynen et al., 2006). Indeed, household income was the best predictor of the occurrence of trees in front yards in Hobart, Tasmania (Kirkpatrick et al., 2007), and in Ballarat, New South Wales, neighbourhoods with more university graduates had greater tree cover (Kendal et al., 2012). Similar to the results for remnant vegetation, we found that available space again showed the highest level of correlation with tree cover relative to neighbourhood age and socio-economic status.

Our results show that the large bulk of vegetative cover in Brisbane is supported within private residential yards, and that socio-economic advantage is correlated with tree cover in these spaces. This is an important finding as residential yards present one of the most immediate and convenient places for people to access nature (Lachowycz & Jones, 2012). Residential yards are generally left to the house occupants to design and manage, presenting a policy challenge for promoting equity in access to experiences with nature close to the home. However, there are opportunities for intervention through education or the provision of trees for people to plant, as well as other compensatory approaches such as the targeted planting of street trees in nature depauperate neighbourhoods.

The overall levels of correlation between vegetation cover and socio-economic status observed in this study were low, which suggests that the policies in place within Brisbane may now be delivering reasonably high environmental equity in the provision of natural resources. In addition, a range of factors beyond those considered here are likely to be additionally influencing where vegetation cover is over-provided. However, the scale of the correlation coefficients seen here are not dissimilar to those observed in other studies. For example, Landry and Chakraborty (2009) found similar or lower correlations between tree cover and socio-economic factors and tree cover in Tampa, Florida, as did Pham et al. (2012) when assessing the relationship between income and vegetation cover in Montreal, Canada. Considering the growing body of knowledge on the influence of socio-economic status on vegetation cover, a useful next research step would be a comparison of the different levels of correlation seen throughout different cities, and the policies and social factors that form these relationships.

In this study we have specifically considered two measures of nature; general tree cover as well as remnant vegetation cover. There are a range of other measures of nature that are both important providers of ecosystem services and known to vary across socio-economic gradients, for example, plant species richness and diversity (Luck, Smallbone, & Sheffield, 2013; Martin et al., 2004) and bird species richness (Strohbach et al., 2009). An interesting avenue for future research would be to examine how these different factors vary within the same city on public and private lands.

5. Conclusions

The variation in access to green space observed in this study highlights an important environmental equity issue for cities (Heynen et al., 2006), representing a systematic reduction of access to natural, green areas within socio-economically disadvantaged neighbourhoods. This problem will be challenging to address as a much of the city's vegetation is managed within private residential yards. However, our results do suggest that regulation of vegetation clearance can play an important role in ensuring equitable access to nature. Additional strategies that encourage positive management of vegetation within private spaces could be employed, such as social marketing and incentive programs.

It will be important to continue to monitor the correlations observed here into the future as community-led greening activities are ongoing. Given that these activities can be more common in socio-economically advantaged neighbourhoods (Conway et al., 2011), specific support and encouragement of community activities in disadvantaged areas could be one approach to help mitigate further inequalities. To enhance this type of information further for planning purposes, research could examine whether opportunities to access green space result in actual experiences with nature, as this could also influence how and where green space should be provided in different communities.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2014.06.005.

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