Applied Geography 89 (2017) 52–60

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Cultivating climate justice: Green infrastructure and suburban disadvantage in Australia

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ARTICLE INFO

Keywords:
Green infrastructure
Inequality
Climate justice
Adaptation
Planning
Social disadvantage

ABSTRACT

Green infrastructure has recently risen to international prominence for its purported capacity to enhance urban sustainability, and particularly to modulate ambient temperatures in the context of climate change. We assess whether residents in a sub-tropical Australian city perceive green infrastructure as an effective climate adaptation response for reducing vulnerability to heat stress. Gold Coast City has pursued urban densification policies, such as reducing block sizes and increasing building heights, to accommodate rapid population growth. Little attention has been given to the combined impact of local heat island effects and global climate change upon lower-income residents in the city's suburban fringe, including rising energy costs associated with cooling homes. The study has three aims: to assess whether social disadvantage is associated with (1) concern about climate change impacts; (2) perceptions about the potential of green infrastructure to offer potential climate-adaptive benefits; and (3) the desire for more urban greening in a working class suburb. We used a mail-back survey to elicit information related to cooling dwellings, awareness of, and concern about, climate change impacts, perceptions of the benefits of green infrastructure, and desire for more urban greening. Results indicate that despite their vulnerability to heat stress, comparatively disadvantaged residents are no more concerned about climate change; nor are they any more inclined to encourage local government to enhance neighbourhood greenery. These residents are, if anything, *less* likely to perceive benefits of urban greening. Our findings indicate that cultivating support for green infrastructure in disadvantaged neighbourhoods will require parallel efforts to redress inequality.

1. Introduction

Green infrastructure is receiving growing international attention as a way to improve the environmental performance and liveability of cities. Increasingly, green infrastructure is regarded as a potential intervention to help adapt built environments to increased heat associated with climate change (Gaffin, Rosenzweig, & Kong, 2012). Green infrastructure refers to vegetation that is intentionally managed to benefit humans (e.g. open spaces, parks, street trees, green roofs and walls) (Beer, 2010; Byrne, Lo, & Jianjun, 2015). Green infrastructure is said to provide a range of biogenic services including: modulating ambient temperatures (Alexandri & Jones, 2008; Hall, Handley, & Ennos, 2012; Hamada & Ohta, 2010), lessening stormwater runoff, intercepting particulate pollution (Byrne et al., 2015), sequestering carbon, attenuating noise pollution (Tiwary et al., 2016), and fostering biological diversity (Tzoulas et al., 2007). These services have been linked to a range of positive social outcomes, such as reduced energy consumption (Akbari, Pomerantz, & Taha, 2001), improved public health (Wolch, Byrne, & Newell, 2014), enhanced economic productivity (Matthews, Lo, & Byrne, 2015) and improved neighbourhood amenity (Watkins, Palmer, & Kolokotroni, 2007).

Urban greening initiatives may offer the capability to adapt some built environments to heat-related impacts of anthropogenic climate change (Moser, 2010). Green infrastructure can potentially also remedy some of the unintended consequences of urban densification (hereafter urban consolidation). Specifically, increased residential densities often

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http://dx.doi.org/10.1016/j.apgeog.2017.10.002
Received 23 February 2017; Received in revised form 24 September 2017; Accepted 1 October 2017
Available online 13 October 2017
0143-6228/

mean less vegetation, more impervious surfaces and higher temperatures (e.g., from transportation, building cooling and heat absorption). These elements combine to increase the frequency and intensity of extreme heat events and exacerbate the vulnerabilities of urban dwellers in a warming climate, with deleterious consequences for human health and wellbeing (Lee & Maheswaran, 2011; Weber, Sadoff, Zell, & de Sherbinin, 2015).

The cooling potential of green infrastructure is promising. Evidence suggests that increasing tree canopy cover by up to 5% may reduce diurnal temperatures by as much as 2.3 °C (Hall et al., 2012; Hamada & Ohta, 2010). Some studies report that densely greening parking lots could achieve in-situ cooling of up to 7 °C (Onishi, Cao, Ito, Shi, & Imura, 2010). Green walls and roofs have been reported to potentially cool built environments by up to 8 °C (Alexandri & Jones, 2008). And greenspaces as small as 0.24 ha are reportedly able to reduce temperatures by as much as 6.9 °C (Oliveira, Andrade, & Vaz, 2011). Such cooling may translate into reduced energy consumption, especially for cities in hotter climates. Akbari et al. (2001, p. 296) for example, have noted that: "electricity demand in cities increases by 2–4% for each 1 °C increase in temperature". Moreover, urban greening may reduce mortality during heatwaves. Researchers have reported health impacts from heatwaves across different cities in different climates. For example, for every 1 °C increase in temperature above 21.5 °C in London, Kovats, Hajat, and Wilkinson (2004) reported an associated increase mortality up to 3% among very young and elderly. Similarly Gouveia, Hajat, and Armstrong (2003) reported a 2.6% increase in mortality above 20 °C in São Paulo; and Son, Lee, Anderson, and Bell (2012) note a 3.5% increase in heatwave-related mortality for every 1 °C increase in temperature above daily averages for several Asian cities, including Seoul. Green infrastructure may thus potentially reduce health-care and energy expenses.

However, for the benefits of green infrastructure to be distributed equitably, it is vital that urban greening be planned with social justice outcomes in mind. There is a longstanding environmental justice literature documenting how marginalised and vulnerable communities (e.g. ethno-racial groups and low-income earners) are disproportionately exposed to greater environmental harms (e.g. landfills, polluting factories and contaminated sites) and have reduced access to environmental benefits, including greenspaces (Byrne, 2017). The concept of climate justice has been used to trace global spatial dynamics in the distribution of environmental goods and harms (Adger, 2001). In the urban context, the unequal distribution of greenspace can exacerbate the vulnerability of already disadvantaged residents (Steele, Maccallum, Byrne, & Houston, 2012). Following Weber et al. (2015), we conceptualise vulnerability to heat stress as a function of residents' exposure to high temperatures combined with their sensitivity to such temperatures, in the absence of adaptive capacity (i.e. the their ability to prepare for, respond to, and cope with extreme heat (see Fig. 1)).

A concern with socially just outcomes from green infrastructure also directs attention to potential problems arising with urban greening activities. For a start, some of the recognised services of urban greening may have paradoxical effects. For example, the ability of urban greening to lower wind speeds may reduce pollution dispersal (Salmond et al., 2016). Green infrastructure may also create a range of disservices, such as vegetation-related hazards. These range from human health and safety (e.g. pollen allergies and tree limb fall), to engineering and design (e.g. traffic hazards, damage to buildings and soil desiccation) to environment (e.g. fire risk, wildlife behaviours and obstruction of views) to legal (e.g. conflict between neighbours, jurisdictional disputes and public liability) concerns (Davison & Kirkpatrick, 2014; Mortimer & Kane, 2004; Roy, Byrne, & Pickering, 2012). The provision, apportioning and opportunity-cost associated with economic and other resources invested in green infrastructure may also have social justice implications (Braverman, 2008). Furthermore, deprivation may actually accentuate one's perception of the disamenities associated with urban trees and other vegetation (Kirkpatrick, Davison, & Daniels, 2013; Kitchen, 2013; Lohr, Pearson-Mims, Tarnai, & Dillman, 2004).

Although a growing body of green infrastructure research has focused on inner-city locales, less research has examined suburban environments. This knowledge gap is particularly acute for Australian suburbs, where most Australians live – but also for North American, some South American cities, and South African cities with proportionally higher suburban populations. Over the past two decades, many Australian suburbs have been transformed by urban consolidation, with backyards subdivided for new housing, leaving little or no yard space (Hall, 2010). Scant attention has been given to the combined effects of urban consolidation and climate change on lower-income residents in the suburban fringe, including heat island impacts and rising energy prices (associated with cooling homes) due to reduced tree canopy cover (Mitchell & Chakraborty, 2015). This paper speaks to these knowledge gaps through a place-based analysis of a working class suburb in Australia, where urban consolidation priorities and reduced greenery combine to shape and condition suburban design and thermal comfort.

The study has three aims: to assess whether social disadvantage[1] is associated with (1) concern about climate change impacts; (2) perceptions about the potential of green infrastructure to offer potential climate-adaptive benefits; and (3) the desire for more urban greening in a working class suburb. The findings of our study offer new evidence about the capacity of green infrastructure policy and practice to create climate-just cities. In what follows, we overview the findings from studies assessing thermal inequity (Section 1.1), present our hypotheses (Section 1.2), outline the materials and methods employed (Section 2), and report the results of our study (Section 3). In Sections 4 and 5 we discuss these results, offer policy suggestions, and identify questions in need of further research, particularly within geography.

1.1. Green infrastructure and thermal inequity

A now considerable environmental justice literature suggests that greenspaces in many cities are unequally distributed. This has implications for urban heat (Mitchell & Chakraborty, 2014, 2015). While a detailed review of that literature is beyond the scope of this paper, a comprehensive review by Byrne (2018) concluded that, aside from a few notable exceptions, patterns in the inequitable socio-spatial distribution of urban greenspace – including green infrastructure – are internationally consistent. Greenspace disparities have been observed in the United States, Canada, China, South Africa, India and Australia – among other countries (Wolch et al., 2014). A growing literature on energy poverty and thermal inequity points to similar disparities. Byrne and Portanger (2014, p. 315) for example, found that: '[h]igher electricity costs associated with 'climate proofing' energy network infrastructure may exacerbate 'fuel poverty''. Similarly, Bickerstaff, Walker, and Bulkeley (2013) observed that climate change and energy generation produce spatially uneven impacts that disproportionately harm marginalised and vulnerable populations (also see Fuller & McCauley, 2016). And Steffen, Hughes, and Perkins (2014, p. 20) have observed that climate change is increasing the frequency and intensity of heatwaves, heightening their 'impacts on people, property, communities and the environment', in turn driving increased energy use for thermal comfort.

Surprisingly, less research has investigated the nexus between

[1] Throughout this study the expression 'comparatively disadvantaged residents' is a measure of socio-economic disadvantage related to fuel poverty and captures an energy cost-induced burden, which is very relevant for the study. It is used to refer to residents who spend a higher percentage of their income on energy. This is operationalized using the variable 'Resident's percentage of household income spent on energy' (0.23%–26.96%) described in Table 1. Pairwise correlations are included as additional supplementary material to provide interested readers with more information on the characteristics that correspond to being comparatively disadvantaged.

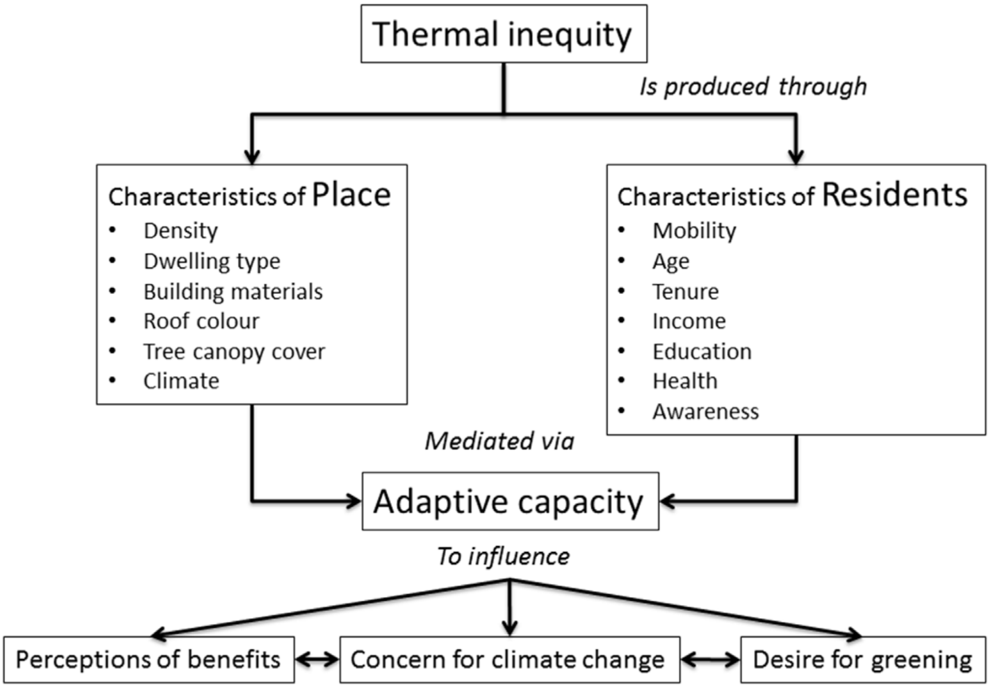

Fig. 1. Thermal inequity conceptual model.

climate change, household energy costs, and green infrastructure distribution. In one of the few studies on this topic, using remote sensing and analysis of population characteristics from census data, Mitchell and Chakraborty (2014, p. 459) found that temperatures in Pinellas County, Florida were significantly higher 'in census tracts characterized by higher percentages of certain racial/ethnic minorities and higher poverty rates'. In a follow-up study (Mitchell & Chakraborty, 2015) examined New York, Los Angeles and Chicago, reporting the same 'consistent and statistically significant' pattern of inequitable heat distribution related to greenspace cover. But scant research has considered the 'equity effects' of the implementation of green infrastructure policies designed to combat climate change related impacts in built environments and how these policies might shape the lived experiences of socio-economically disadvantaged populations at the household scale.

1.2. Hypothesised relationships

Researchers have theorised that disparities in the distribution and accessibility of green infrastructure (e.g. parks) are a function of residents' financial status, cultural predilections and level of social inclusion (Byrne & Wolch, 2009). Historical factors, governance processes, and the political economy of urban development can influence the socio-spatial distribution of green infrastructure (Wolch et al., 2014). Studies assessing the climate adaptive benefits of green infrastructure have reconceptualised its spatial distribution as the product of the interplay between socio-cultural and biophysical factors (Matthews et al., 2015). As illustrated in Fig. 1, we theorise that a resident's potential thermal (dis)advantage is related to the socio-spatial distribution of green infrastructure, and will be a function of place and person-based characteristics – that is, where a resident lives and who they are (see Fig. 1) (cf. Weber et al., 2015).

Economic disadvantages, for example, might reinforce concern over climate change, as poorer individuals and families have fewer resources to cope with environmental stressors and may tend to worry about their harmful impacts (Fairbrother, 2013; Lo, 2016; Marquart-Pyatt, 2012). The adaptive capacity of both people and places is dependent upon awareness of climate change impacts, the levels of existing green canopy cover (and benefits it confers) and receptiveness to neighbourhood-scale urban greening. Therefore, the study has three aims: to assess whether social disadvantage is associated with (1) concern about climate change impacts; (2) perceptions about the potential of green infrastructure to offer potential climate-adaptive benefits; and (3) the desire for more urban greening in a working class suburb. Knowledge of residents' concerns, perceptions and desires is important if policy makers are to make informed decisions about employing green infrastructure to combat local climate change impacts.

2. Material and methods

The detailed methods are reported as supplementary material. This study sought to answer three research questions: (RQ1) are comparatively disadvantaged residents more likely to be aware of, and concerned about, climate change impacts; (RQ2) are comparatively disadvantaged residents more likely to perceive green infrastructure as offering potentially efficacious climate-adaptive benefits, and (RQ3) are comparatively disadvantaged residents more likely to desire more green infrastructure in their neighbourhood? To answer these questions we selected a case study suburb based on five criteria: (i) a study area experiencing increasing heat load associated with climate change, (ii) with lower tree canopy cover, (iii) and elevated levels of comparative disadvantage, (iv) exhibiting a range of dwelling types vulnerable to heat impacts and (v) managed by a local government receptive to using urban greening to combat heat.

We devised the social survey, evaluated the extent of the comprehension and cognitive burdens on participants and administered a social survey in 2015, following the Dillman technique (Dillman, De Leeuw, & Hox, 2008). Survey methods register variation across residents, serving to highlight 'people's characters, attitudes, values, beliefs, behaviour and opinions' and offer insights into social experiences and community values 'from varying perspectives and across a range of different respondents' (Walter, 2010, p. 152). The mail-back survey design permitted a wide range of responses (230 respondents, achieving a 12% response rate). Bourque and Fielder (2003, p. 17) note that 'even in the best case, response rates for mail questionnaires are lower than … telephone and in-person interviews … currently response rates in the range of 10%–20% are common for online surveys'. Further, Dillman (2017) notes that telephone survey response rates have recently fallen to around 9% and even sophisticated Web-push systems can only achieve in the order of a 43% response rate. Results are based on the variation within the sample, and should be interpreted accordingly.[2]

2.1. Case study area: Upper Coomera, Australia

The case study area of Upper Coomera is situated within the northern growth corridor of Gold Coast City. This subtropical coastal city has one of the faster growth rates in Australia. The city's northern growth corridor has undergone extensive land clearing to accommodate more dwellings on smaller sized lots – an urban consolidation strategy (Gold Coast City Council, 2011). Land clearing has substantially reduced existing vegetation cover.

We chose to study Upper Coomera, Australia because it is an in-situ exemplar of the confluence of: larger houses; compactly built neighbourhoods; and smaller open spaces. This has become characteristic of modern development throughout Australia (Hall, 2010). It is useful to understand concerns, perceptions and desires as they relate to climate justice among residents of a working class suburb in this increasingly ubiquitous environment, notwithstanding the relevance of these findings for the Gold Coast City Council's draft 2030 Greenspace strategy for the northern growth corridor of the city (Gold Coast City Council, 2011).

Upper Coomera has a population of 21,136 residents, which is expected to grow over the coming decades (Australian Bureau of Statistics, 2013). It is presently the fastest growing suburb in Queensland. The suburb is comprised of mainly detached houses (68%) lining the narrow interlinking streets, and duplexes (17%), which are positioned on the corners of cul-de-sacs. There are also three complexes of townhouses (14%), and several low-rise apartment buildings (1%), dispersed throughout the study area (Fig. 2). Dwellings are typically constructed of brick and tile and are built on concrete slabs (Fig. 3). Around a third of dwellings have dark roofs (34.0%). Such construction materials are associated with intensified urban heat island effects (Watkins et al., 2007).

The study area is a working class suburb comprised of residents who are potentially more vulnerable to heat due to the proportion of lower income service-sector and construction workers, larger numbers of children and older residents, and higher mortgage costs when compared to household expenditure (Byrne et al., 2016). Many residents face higher energy costs related to cooling their dwellings. There are however, pockets of both higher relative advantage and disadvantage in the suburb.

Table 1 provides further detail and descriptive statistics regarding the variables employed throughout this study. Supplementary material provides further detail regarding the survey instrument, the variables employed and a comparison with the most closely aligned and available census data.

2.2. Estimation strategy

In order to investigate research questions 1 to 3 the following models are estimated.

Fig. 2. Upper Coomera study area.

2.2.1. Are comparatively disadvantaged residents concerned about climate change? (RQ1)

Research question 1 is examined estimating a Probit model for Equation (1):

$$Concern_r = \omega_1 + \sum_{j=1}^{m} \beta_{1j} z_{jr} + \varepsilon_{r1} \tag{1}$$

where $Concern_r$ represents whether or not a resident reports being concerned about climate change (1) or not (0). z_{jr} denotes socio-economic and demographic characteristics j … m, including, age, gender and so forth. Finally, ε_{r1} is the error term.

2.2.2. Do comparatively disadvantaged residents recognise the benefit of green infrastructure? (RQ2)

Research question 2 is explored by estimating an Ordered Probit model for Equation (2):

$$Percieved\ benefit_r = \omega_2 + \sum_{j=1}^{m} \beta_{2j} z_{jr} + \varepsilon_{r2} \tag{2}$$

where $Percieved\ benefit_r$ is a resident's perceived benefit of urban greening. All other variables are as defined in Equation (1).

2.2.3. Do comparatively disadvantaged residents desire more green infrastructure in their neighbourhood? (RQ3)

Research question 3 is examined estimating a Probit model for Equation (3):

$$Desire_r = \omega_3 + \sum_{j=1}^{m} \beta_{3j} z_{jr} + \varepsilon_{r3} \tag{3}$$

where $Desire_r$ represents whether or not a resident reports being desiring more greening in their neighbourhood (1) or not (0). All other variables are as defined in Equation (1).

3. Results

This section presents the results for Equations (1)–(3) that address research questions 1 to 3. To begin with, it is worth noting that the variance inflation factors provide no indication of worrisome multicollinearity. Specifically, in Equation (1), the highest variance inflation factor is 2.44 for the variable "University" and mean variance inflation factor is 1.55. Equation (2), the highest variance inflation factor is 2.48 for the variable "University" and mean variance inflation factor is 1.58.

[2] The equation below illustrates the calculation of the ideal sample size (cf. Selvanathan, Selvanathan, & Keller, 2011):

$$n = \frac{z_{\alpha/2} \cdot p \cdot (1-p)}{E^2}$$

where n is the sample size, $z_{\alpha/2}$ is the z-critical value (1.96) for a two-tailed test, p is the expected proportion (0.50 or 50% is used in lieu of knowledge regarding the expected proportion (this conservative approach maximises the standard deviation of the estimate of p)) and E is the error of estimation (± 0.05 or ± 5%). The target size for a sample of residents from Upper Coomera was 196. A total of 230 surveys were returned during the 37-day survey collection period. A suitable sample size was achieved.

Fig. 3. Typical dwelling construction in Upper Coomera.

Table 1
Variable definitions and descriptive statistics.

Variable name	Definition	Mean (std. dev.)	%
Dependent variables			
Percentage of household income spent on energy[a]	Resident's percentage of household income spent on energy (0.23%–26.96%)	3.04 (3.51)	
Concern	Resident is worried about climate change (0–1)		68.6%
Desire	Resident desires more urban greening in their neighbourhood (0–1)		59.5%
Perceived benefit	Resident's perceived benefits of urban trees (0–5)	1.89 (1.57)	
Independent variables			
Awareness	Resident is aware of climate change (0–1)		100.0%
Confidence	Resident thinks that people can stop climate change impacting cities (0–1)		24.5%
Weather changes	Resident's perceived weather changes in their neighbourhood due to climate change (0–5)	2.65 (1.53)	
Economic disruptions	Resident's perceived economic disruptions in their neighbourhood due to climate change (0–6)	2.90 (2.03)	
Effective mitigation actions	Resident's perceived mitigation actions people can take to mitigate climate change impacts (0–7)	4.83 (2.35)	
Park use	Resident's number of park uses (0–20)	4.47 (2.60)	
Age	Resident's years of age (16–73)	44.29 (15.17)	
Male	Resident is male (0–1)		30.4%
Equalised household income	Resident's household income ($5199.50-$128,559.50)	$72,323.57 ($38,276.48)	
Year 12	Resident's highest level of educational attainment is year 12 (0–1)		44.5%
University student	Resident is a university student (0–1)		9.1%
University degree	Resident's highest level of educational attainment is a university degree (0–1)		28.6%
Children	Resident's number of children under 18 years of age (0–4)	0.74 (1.05)	
Ecocentric	Resident's degree of ecocentric values based on items from (Rossi, Byrne, Pickering, & Reser, 2015) derived using factor analysis and rescaled (1–5)	2.72 (0.84)	
Anthropocentric	Resident's degree of anthropocentric values based on items from (Rossi et al., 2015) derived using factor analysis and rescaled (1–5)	3.18 (0.81)	

[a] Note that this dependent variable is also an independent variable.

Equation (3), the highest variance inflation factor is 2.44 for the variable "University" and mean variance inflation factor is 1.53. This means that there is enough variation in the dataset to distinguish separate associations for each of the independent variables with the relevant dependent variables. Pairwise correlations, reported in the supplementary material, indicate that percentage of income spent on energy is not statistically significantly associated with concern about climate change, the perceived benefits of urban greening, or a desire more green infrastructure in their neighbourhood. This result may reflect a number of interceding variables unaccounted for in this initial analysis. Hence, in what follows a number of control variables are employed. While all of these control variables are reported, the main focus of this investigation is addressing the research questions posed.

Table 2
Equation (1) Probit regression (Dependent variable: Concern).[a]

Variable name	Marginal effect (Standard error)
Awareness	0.0000 (0.000)
Confidence	−0.0842 (0.0714)
Weather changes	0.0207 (0.0273)
Economic disruptions	0.0700*** (0.0185)
Effective actions	0.0275* (0.0142)
Park use	0.0077 (0.0113)
Age	−0.0031 (0.0023)
Male	−0.0038 (0.0827)
Percentage of household income spent on energy	**0.0114 (0.0135)**
Year 12	0.1025 (0.0943)
University student	0.1553 (0.1159)
University	0.1483 (0.0953)
Children	0.0193 (0.0331)
Ecocentric	−0.0502 (0.0402)
Anthropocentric	0.0489 (0.0475)
Summary statistics	
Observations	130
Wald statistic	Wald χ^2 (14) = 40.3600
Prob > χ^2	0.0000
Pseudo R^2	0.2964

Unconditional standard errors in parentheses.
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.
[a] Average marginal effects are reported and the interpretation of these effects is in terms of the probability of reporting the outcome given a one-unit in the independent variable. For instance, the marginal effect for 'Economic disruptions' is interpreted as 7% greater likelihood of reporting concern about climate change for a one-unit increase in the 'Economic disruptions' variable.

3.1. Are comparatively disadvantaged residents concerned about climate change? (RQ1)

The results for research question 1 (Equation (1)) are reported in Table 2. The link between the percentage of income spent on energy and concern about climate change is not statistically significant at conventional levels.

3.2. Do comparatively disadvantaged residents recognise green infrastructure benefits? (RQ2)

The results for research question 2 (Equation (2)) are reported in Table 3, columns 1 to 6. While the percentage of income spent on energy is not found to be statistically significant in association with greater perceived benefits of urban greening, it is almost statistically significantly linked to perceiving no benefits associated with urban greening ($p < 0.10$). For a 1% increase in the amount of income spent on energy, residents are 0.96% more likely to perceive no benefits associated with urban greening.

3.3. Do comparatively disadvantaged residents desire more green infrastructure in their neighbourhood? (RQ3)

The results for research question 3 (Equation (3)) are reported in Table 4. These results are marginal effects. The link between the percentage of income spent on energy and a desire more green infrastructure in their neighbourhood is not statistically significant at conventional levels.

4. Discussion

This study has investigated whether social disadvantage is associated with (1) concern about climate change impacts; (2) perceptions about the potential of green infrastructure to offer potential climate-adaptive benefits; and (3) the desire for more urban greening in a working class suburb. We hypothesised that comparatively disadvantaged residents would be disproportionately adversely impacted by heat and would therefore be more likely to: (1) be concerned about climate change; (2) recognise the benefits of urban greening; and (3) desire more green infrastructure in their neighbourhood. Some of our findings are consistent with fuel poverty literature (Byrne & Portanger, 2014). In stark contrast to *a priori* expectations, we found that increasing socio-economic disadvantage was not positively correlated with: (a) concern about climate change; (b) interest in additional neighbourhood urban greening; or (c) perception of benefits of green infrastructure. Instead it appears that disadvantaged residents are if anything *less* likely to perceive benefits of green infrastructure. *Prima facie*, this result is surprising given the greater vulnerability of comparatively disadvantaged residents to urban heat – and anticipated future heat impacts associated with climate change.

In part, this result may reflect confusion about climate change risk and its amelioration (Barnes, Islam, & Toma, 2013), as well as the relationship between such confusion and socio-demographic variables (e.g. education) (Leiserowitz, 2006). However, it is also important to consider whether this result could reflect other more salient factors, such as the lack of immediacy of climate change issues in the experience of social disadvantage. This relational reasoning is conveyed by Gowdy, Rosser, & Roy's (2013) description of hyperbolic discounting, in which they report on the time inconsistent discounting of risks perceived to be distant in time. More generally, the relative character of perception raises the question of whether perceived importance of one need (or severity of one problem) may lessen the perceived importance of another need (or severity of another problem). For instance, comparatively disadvantaged residents may be more concerned about how to pay for rising energy costs (which represent a relatively larger share of their income) and how to allocate a smaller percentage (and likely smaller absolute value) of their household income between competing needs (e.g. food, education, health, transport, or housing expenses).

Our results indicate that comparatively disadvantaged respondents are no more likely to perceive benefits associated with green infrastructure. They are marginally more likely to report that there are no perceived benefits. Perhaps these residents are more cognisant of, and experience more acutely, some ecosystem disservices associated with urban greening, such as increased maintenance costs (e.g. possibly higher water bills associated with watering new trees in their streetscape), allergies and asthma (see Mitchell & Chakraborty, 2014, 2015). For these same reasons, it is understandable that disadvantaged respondents did not express a desire for green infrastructure in their neighbourhood that is any stronger than other respondents. These findings have implications for practitioners. If planners and policymakers are seeking to 'future proof' suburbs against anticipated heat impacts, they must understand that green infrastructure provision requires actions to redress not only thermal inequity, but also actions to address other impacts stemming from relative disadvantage. In practical terms, this may involve for example, maintenance assistance for tending urban greenery, financial support for improving household energy efficiency, and/or steps to ensure better access to affordable renewable energy (e.g. substantial photovoltaic solar panel subsidies, building insulation subsidies, and/or health care interventions).

There are some limitations to the research. Despite the numerous controls consistently employed throughout this study (see supplementary material), it is difficult to entirely rule out possible confounders. In this regard, further research employing a difference-in-difference research design is encouraged. Following the same households over time would help to limit the risk of omitted variable bias (through the use of household-specific fixed effects). Finally, a larger and longitudinal sample would potentially provide an opportunity to extend on these findings and to see how urban greening affects different households over time.

Table 3
Equation 2 Ordered Probit regression (Dependent variable: Perceived benefit)).[a]

	(1) Perceived benefit = 0 Marginal effect (standard error)	(2) Perceived benefit = 1 Marginal effect (standard error)	(3) Perceived benefit = 2 Marginal effect (standard error)	(4) Perceived benefit = 3 Marginal effect (standard error)	(5) Perceived benefit = 4 Marginal effect (standard error)	(6) Perceived benefit = 5 Marginal effect (standard error)
Awareness	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)	0.0000 (0.000)
Concern	0.0311 (0.0606)	0.0140 (0.0272)	−0.0018 (0.0041)	−0.0113 (0.0215)	−0.0182 (0.0355)	−0.0138 (0.0277)
Confidence	0.0000 (0.0490)	0.0000 (0.0220)	−0.0000 (0.0028)	−0.0000 (0.0178)	−0.0000 (0.0287)	−0.0000 (0.0217)
Weather changes	0.0110 (0.0199)	0.0050 (0.0089)	−0.0006 (0.0015)	−0.0040 (0.0073)	−0.0065 (0.0116)	−0.0049 (0.0087)
Economic disruptions	−0.0226* (0.0128)	−0.0102* (0.0059)	0.0013 (0.0020)	0.0082* (0.0047)	0.0132* (0.0079)	0.0100* (0.0059)
Effective actions	−0.0348*** (0.0102)	−0.0156*** (0.0055)	0.0020 (0.0028)	0.0126*** (0.0041)	0.0203*** (0.0061)	0.0154** (0.0066)
Park use	−0.0261*** (0.0090)	−0.0117*** (0.0038)	0.0015 (0.0022)	0.0095** (0.0039)	0.0153*** (0.0053)	0.0115*** (0.0042)
Age	−0.0047*** (0.0015)	−0.0021** (0.0008)	0.0003 (0.0004)	0.0017** (0.0007)	0.0028** (0.0011)	0.0021*** (0.0008)
Male	−0.0310 (0.0493)	−0.0139 (0.0227)	0.0018 (0.0038)	0.0113 (0.0185)	0.0182 (0.0291)	0.0137 (0.0219)
Percentage of household income spent on energy	**0.0096* (0.0057)**	**0.0043 (0.0028)**	**−0.0005 (0.0008)**	**−0.0035 (0.0022)**	**−0.0056 (0.0035)**	**−0.0042 (0.0028)**
Year 12	−0.0302 (0.0618)	−0.0135 (0.0288)	0.0017 (0.0043)	0.0110 (0.0229)	0.0177 (0.0363)	0.0134 (0.0282)
University student	−0.0110 (0.0689)	−0.0049 (0.0311)	0.0006 (0.0042)	0.0040 (0.0252)	0.0064 (0.0403)	0.0049 (0.0304)
University	−0.0317 (0.0662)	−0.0142 (0.0302)	0.0018 (0.0046)	0.0115 (0.0245)	0.0185 (0.0387)	0.0140 (0.0296)
Children	0.0139 (0.0216)	0.0063 (0.0096)	−0.0008 (0.0017)	−0.0051 (0.0079)	−0.0082 (0.0125)	−0.0062 (0.0096)
Ecocentric	0.0736*** (0.0249)	0.0330*** (0.0121)	−0.0042 (0.0060)	−0.0268*** (0.0099)	−0.0431*** (0.0161)	−0.0326** (0.0129)
Anthropocentric	0.0312 (0.0287)	0.0140 (0.0134)	−0.0018 (0.0032)	−0.0114 (0.0110)	−0.0183 (0.0165)	−0.0138 (0.0132)
Summary statistics						
Observations	130					
Wald statistic	Wald χ^2 (15) = 65.97					
Prob > χ^2	0.0000					
Pseudo R^2	0.1086					

Unconditional standard errors in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
[a] Average marginal effects are reported and the interpretation of these effects is in terms of the probability of reporting the outcome (e.g. perceived benefit = 0 or perceived benefit = 1 and so on) given a one-unit in the independent variable. For instance, the marginal effect for 'Effective actions' (for perceived benefit = 5 in column 6) is interpreted as 1% greater likelihood of reporting the outcome 'Perceived benefits = 5' for a one-unit increase in the 'effective actions' variable.

Table 4
Equation (3) Probit regression (Dependent variable: Desire).[a]

	Marginal effect (standard error)
Awareness	0.0000 (0.000)
Concern	0.1747* (0.1038)
Confidence	0.0045 (0.0929)
Weather changes	−0.0292 (0.0362)
Economic disruptions	0.0345 (0.0266)
Effective actions	−0.0061 (0.0191)
Park use	0.0298* (0.0173)
Age	−0.0007 (0.0034)
Male	0.0353 (0.1033)
Percentage of household income spent on energy	**0.0014 (0.0144)**
Year 12	−0.0967 (0.1284)
University student	0.0375 (0.1743)
University	−0.0731 (0.1392)
Children	−0.0041 (0.0420)
Ecocentric	−0.0194 (0.0492)
Anthropocentric	−0.0443 (0.0555)
Summary statistics	
Observations	129
Wald statistic	Wald χ^2 (15) = 13.7000
Prob > χ^2	0.5487
Pseudo R^2	0.0841

Unconditional standard errors in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.
[a] Average marginal effects are reported and the interpretation of these effects is in terms of the probability of reporting the outcome given a one-unit in the independent variable. For instance, the marginal effect for 'Concern' is interpreted as 17% greater likelihood of reporting a desire for more urban greening in the neighbourhood for a discrete change in the 'Concern' variable from not concerned about climate change to concerned about climate change.

5. Conclusions

Australia, like many other countries, is experiencing increasing extreme heat events, thought to be related to climate change (Steffen et al., 2014). This is occurring against a backdrop of rapid urban population growth. Urban planning policies designed to increase residential densities are amplifying urban heat island effects, partly due to reduced urban tree canopy cover (Lin, Meyers, & Barnett, 2015). However, relatively few studies, in Australia and internationally, have assessed the impact of green infrastructure on household-scale exposure to heat and cooling expenses – termed thermal inequity. In this study we assessed residents' concern about climate change, their perceptions of the benefits of green infrastructure and their desire for more green infrastructure. We tested a conceptual model that operationalized thermal inequity as a function of the characteristics of both people and places.

Our study has yielded a new (and somewhat unexpected) understanding of how green infrastructure could be used to redress thermal inequity. Despite their greater vulnerability, more disadvantaged residents appear to be no more concerned about climate change than others in their community; nor are they any more inclined to encourage local government to improve neighbourhood greening. Rather, it seems that disadvantaged residents are if anything *less* likely to perceive benefits of urban greening. These findings alone though are unlikely to be the final word on how green infrastructure could be used to cultivate climate justice. Instead, the evaluation of our conceptual model in different places would help to build a body of evidence upon which a consensus could be formed. The results presented in this study though, suggest that if efforts to use green infrastructure to combat thermal inequity are to be successful, planners, policy-makers and tree managers may need to employ a broader suite of policy measures, designed to improve the life chances of residents.

Increasing awareness of green infrastructure services and disservices through educational programs, might improve residents preparedness to support urban greening. Policy makers could also consider complementary measures such as rent assistance, electricity subsidies, home insulation programs and even physical interventions such as window treatments (e.g. blinds or awnings) and enhanced roof reflectivity (e.g. painting rooftops) to reduce exposure to heat. Combined with neighbourhood greening, such measures could lessen thermal inequity in Australia and other countries (e.g. China, United States, South Africa). Place-based studies like this one have the potential to improve the life chances of residents experiencing thermal inequity. Future research on this topic might consider: whether different types of green infrastructure (e.g. green walls, green roofs) deliver the same thermal benefits (or have disservices); if different built forms can deliver higher density without sacrificing tree canopy cover, and whether thermal inequity is spatially distributed across diverse urban landscapes in different countries.

Ethics approval

Ethics approval was required and the research undertaken for this study was approved by Griffith University's Human Research Ethics Committee (approval reference number ENV/07/15/HREC).

Acknowledgements

An earlier version of this manuscript was presented at the Institute of Australian Geographers Annual Conference 2016. The authors are grateful to conference participants for their useful comments and feedback. We gratefully acknowledge the assistance of the City of Gold Coast Council in funding survey printing and mailing, and note that the views reported here do not necessarily reflect the perspective of the City of Gold Coast Council. The authors are grateful to survey respondents for their participation, to Event Cinemas for providing movie ticket incentives for survey participation, and we appreciate the helpful comments of the anonymous reviewers. Griffith University partially funded data analysis as part of financial support for an Honours thesis. All errors remain those of the authors.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2017.10.002.

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