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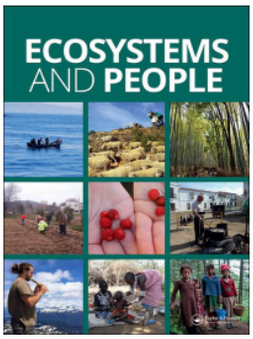

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RESEARCH

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Green in grey: ecosystem services and disservices perceptions from small-scale green infrastructure along a rural-urban gradient in Bengaluru, India

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ABSTRACT

Ecosystem services provided by green infrastructure are often discussed for their potential to address the societal challenges of urbanization. However, green infrastructure, particularly small-scale types (e.g. trees), is vulnerable to loss through urbanization and is often passed over during scientific investigations. Studies on the perceptions of ecosystem services and disservices (hereafter called ecosystem (dis)services) dynamics along the rural-urban gradient are particularly rare in the literature. Therefore, this study assessed the perceived importance of ecosystem (dis)services associated with small-scale green infrastructure along a rural-urban gradient in Bengaluru, India. Based on photos of the five most common types of small-scale green infrastructure and the three most common tree species associated with them, we conducted a photo-elicitation survey of 649 residents from 61 towns in Bengaluru. We found significant differences in the perceptions of all ecosystem (dis)services among the types of green infrastructure. The most appreciated services were air/climate regulation from platform trees and aesthetic values from farm trees. Regulating services were most appreciated in urban areas while provisioning and cultural services were most appreciated in transitional areas, and disservices were most strongly perceived in rural areas. Gender, age, education, caste, and income from agriculture significantly affected the use and valuation of the ecosystem (dis)services within the local communities. Our study reveals the crucial role of small-scale green infrastructure as a multifunctional element, which is highly relevant for the supply of provisioning, regulating, and cultural ecosystem services in Bengaluru.

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Multifunctionality; photo-elicitation; socio-economic preferences; trees; urbanization

1. Introduction

Increasing urbanization in the Global South has often reduced the extent of green infrastructure coverage in urban landscapes and triggered multiple negative effects on the environment and society at different spatial scales (Nagendra et al. 2018; Thapa et al. 2021). Green infrastructure consists of networks of natural and semi-natural areas that are designed and managed together with other environmental features (Lafortezza et al. 2013). It consists of multifunctional elements that deliver diverse ecosystem services simultaneously (Mouchet et al. 2017) and help reduce the societal challenges caused by urbanization (Pauleit et al. 2021). Multiple case studies around the world have demonstrated the opportunities that green infrastructure offers to improve human well-being in cities (e.g. Budruk et al. 2009; de Macedo et al. 2021; Koyata et al. 2021; Sultana and Selim 2021). For instance, the restoration or introduction in green infrastructure to urban landscapes has the potential to foster interactions between urban dwellers and nature (Mell 2018). Food and water for people and animals, and recreation and aesthetic values are some of the services that people derive from urban green infrastructure (Andersson et al. 2014). Green infrastructure mitigates some of the negative impacts of urban expansion, such as urban heat island effects or water pollution (Mundoli et al. 2017). At the same time, urban green infrastructure may also be a source of ecosystem disservices, causing for instance, crop damage by tree-dwelling monkeys or birds, or providing habitat for dangerous animals such as poisonous snakes and disease-transmitting rodents (Lyytimäki and Sipilä 2009).

As a geographic frontier of urbanization, we focus our study on rural-urban gradients. A rural-urban gradient refers to the gradual increase or decrease in

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the degree of urbanization within a specific geographical space. It is dynamic and represents the variation of spatial environmental patterns that influence the respective structure and functions of social-ecological systems in urbanizing contexts (Mcdonnell and Pickett 1990). Of two common gradient patterns in practice – concentric ring gradients (Kroll et al. 2012) and a transect gradient (Zhou and Wang 2011), we employed a transect gradient in this study. Studies on social-ecological systems along the rural-urban gradient are rare. Therefore, learning about social-ecological systems, in particular, the association of ecosystems services with human perceptions along the rural-urban gradient fills this literature gap. In addition, most research has focused on large-scale green infrastructure, for instance, forests, parks, and grasslands. However, small-scale green infrastructure, e.g. individual trees, are often most vulnerable to destruction during urban expansion (Laghai and Bahmanpour 2012). These types of green infrastructure are rapidly disappearing from rural areas in the peri-urban interface as urban areas expand. Thus studying variations in their perceived importance across the rural-urban gradient becomes important and timely. Such studies offer a unique learning opportunity and can inform sustainable urban planning in rapidly urbanizing countries like India.

Bengaluru, India's fastest-growing megacity, hosts a diversity of (small-scale) green infrastructure that has shaped the city for a long time. These are comprised of individual trees in different locations, e.g. around houses, farms, streets, or temples that contribute to people's well-being by providing food, timber, and medicine (Gopal and Nagendra 2014) and by cooling and purifying air and water (Nagendra and Gopal 2010). Some trees (e.g. peepal and banyan) mostly supply cultural ecosystem services, while others (e.g. neem) offer both cultural and provisioning ecosystem services (Gopal et al. 2019). The loss of these trees to urbanization in Bengaluru affects the physical and cultural ambiance of the city and its surroundings (Keswani 2017). It is therefore important to understand the uses and dynamics of green infrastructure in relation to urbanization.

Singh (2018) indicates five aspects to be considered while integrating green infrastructure in the urban context, namely quantity, quality, connectivity, accessibility, and attractiveness. In this study, we focus on two of these aspects: quality and attractiveness of different types of small-scale green infrastructure located in private (e.g. home garden, margins of farmland) and public areas (e.g. avenues of the street). The aspect of quality includes the potential of green infrastructure to provide ecosystem services. The uses of green infrastructure in daily life are typically influenced by socio-economic factors such as education level (Iniesta-Arandia et al. 2014) and gender (Johnson et al. 2004). Understanding how differences in the uses of green infrastructure are associated with different socio-economic groups of people enables inclusive management, policy-making, and governance of green infrastructure (Enqvist et al. 2014).

Against this background, this study aims to assess the perceived importance of ecosystem (dis)services associated with types of small-scale green infrastructure along a rural-urban gradient around Bengaluru. Our specific research questions are:

- What are the differences in people's perceptions of ecosystem services and disservices associated with different types of green infrastructure?
- How do these perceptions of ecosystem services and disservices supplied by green infrastructure vary between rural, transitional, and urban areas?
- How do socio-economic factors influence variations in people's perceptions of ecosystem services and disservices associated with green infrastructure?

2. Materials and methods

2.1 Study area

Bengaluru, the capital of the Indian state of Karnataka, was previously a small marketplace or *'pete'* distinguished by four towers when founded by Kempe Gowda in 1537 CE. It has been continuously expanding in terms of area and population throughout history (Nagendra et al. 2014). This growth accelerated substantially after India's independence in 1947 (Venkatarayappa 1957). Between 2001 and 2023, the population doubled from 6.5 million to 13.6 million and the population density increased from 7,881 persons/km^2 to 19,180 persons/km^2 within an area of 709.5 km^2 (World Population Review 2023). The built-up area has expanded to the surrounding areas, creating an urban, transitional or peri-urban, and rural area, and thus forming a rural-urban gradient. Livelihood patterns in the area have changed significantly from agriculture as a major occupation to employment in the IT industry, service, and business sectors. Bengaluru has thus evolved into the 'Silicon Valley of India' (Narayanareddy 2011). With rapid urbanization, vegetation cover has been substantially reduced, with subsequent effects on ecosystem services provided by small-scale green infrastructure (Ramachandra et al. 2017).

Bengaluru was long considered the 'Garden City of India' and is famous for its green infrastructure. Studies show that various rulers and residents of Bengaluru planted trees along the sides of roads, and created gardens, wooded orchards, and home gardens, promoting the expansion of green vegetation as a protective barrier around the towns since the

beginning of settlement growth within the Bengaluru landscape (Nagendra 2016b). Though the landscape around Bengaluru has remained dynamic for centuries, green infrastructure has always been a central element to city planning, with a significant spurt in tree plantation after the colonial occupation of Bengaluru by the British, from the mid–19th century onwards. Common types of green infrastructure include wooded streets, home gardens, residential gardens, neighborhood parks, traffic islands/medians, heritage parks, and sacred greenspaces (Gowda et al. 2008). People have been benefiting from this investment in green infrastructure for a long time; for instance, harvesting of firewood, grazing, fishing, and other activities sustaining local livelihoods, as well as nurturing deep-rooted sacred and spiritual associations (Nagendra 2016b). With urbanization, some estimates indicate that the vegetation cover has been reduced by 78% in four decades (1973–2014) (Ramachandra et al. 2017). With its rich historical abundance of green infrastructure, coupled with the rapidly decreasing trend of green infrastructure in a rapidly urbanizing context, Bengaluru is a prime case study of global relevance.

Bengaluru is a socio-economically diverse city. Socio-economic factors such as modes of living and livelihoods have an important role in shaping relationships with green infrastructure (Nagendra et al. 2014). With the expansion of the city, equitable access to green infrastructure, which was originally accessible as urban common areas, has been restricted due to the privatization or fencing of green infrastructure like parks and trees (Mundoli et al. 2017). This is a consequence of growing gentrification, as observed in other parts of the world (Schell et al. 2020).

This study was conducted in the Northern and Southern parts (hereafter called Northern and Southern transects) of the Bengaluru Metropolitan Region (Figure 1). The Northern transect is a rectangular band with a width of 5 km and a length of 50 km between the towns of Doddaballapur and Devanahalli. The Southern transect is a polygonal area located in the Southwest of Bengaluru, covering an approximate area of 300 km^2 along the Kanakpura Road, from the Vrishabhavarthi water reservoir in the West to Bannerghatta National Park in the East. Mostly, the parts towards central Bengaluru have more urban characters and those towards peripheral Bengaluru comprise of rural characters, thus both the transects straddle a rural-urban gradient. Parts with mix of both urban and rural characters form the transitional areas (Hoffmann et al. 2017).

2.2 Green infrastructure types and ecosystem (dis)services considered in this study

Our study considered the five most common types of small-scale green infrastructure in Bengaluru in different locations and natural surroundings: domestic trees (Jaganmohan et al. 2012), farm trees, street trees, temple trees, and platform trees (Nagendra and Gopal 2010; Gopal et al. 2019) (Figure 2). The

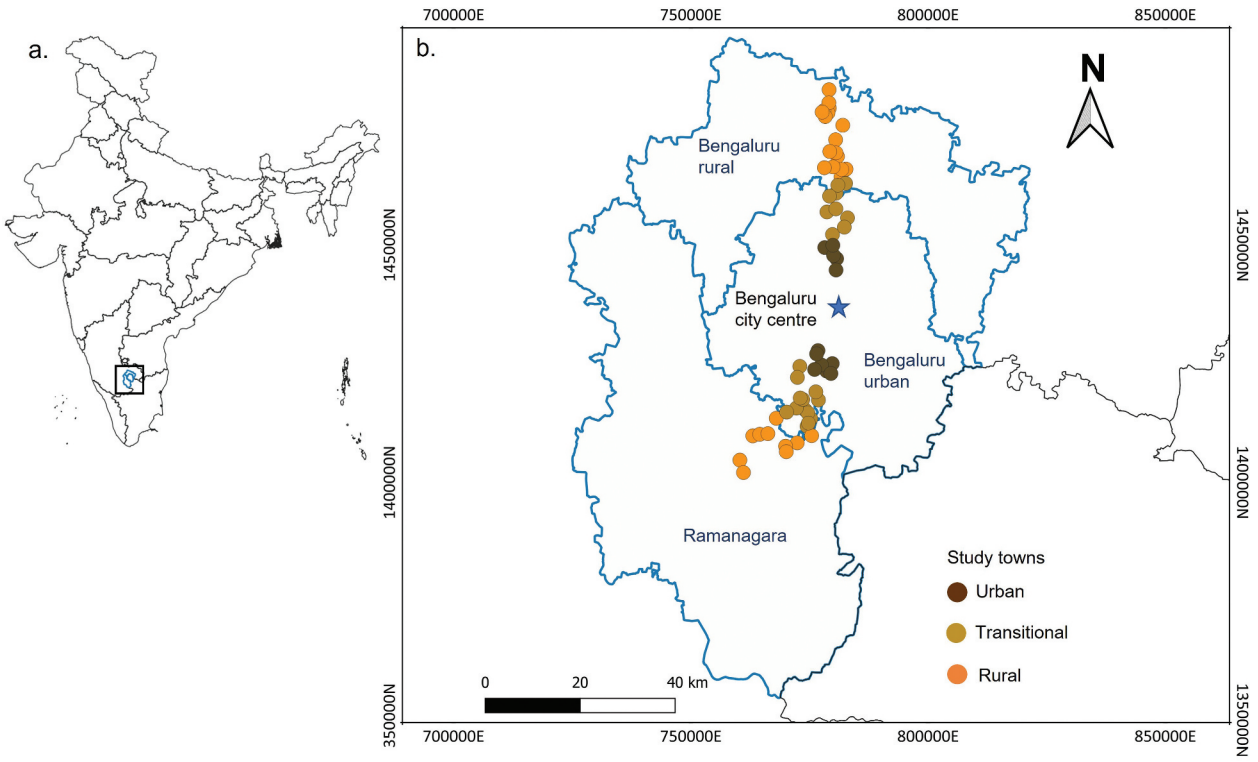

Figure 1. a. Map of India with state borders. Bengaluru Metropolitan Region is highlighted inside a box in the state of Karnataka, and b. the three districts of the metropolitan region showing the study towns along the rural-urban gradients.

final selection was based on a combination of field explorations, published literature on the topic (Nagendra 2016a, 2016c, 2016d), and the long-term experience of two co-authors (H.N., D.B.) in the study area. Domestic trees are found in home gardens and private spaces near homes. Farm trees are situated in the margin of farms, a private space. Street trees are located in avenues that are public spaces. Lastly, temples and platforms are types of Hindu places of worship. Temple trees are the trees that are typically found on the periphery of temples. Platform trees refer to those trees which are found in (informal) community-managed platforms[1] of worship associated with serpentine idols (Gopal et al. 2019).

Previous studies show how users of green infrastructure often have preferences towards specific tree species (Avolio et al. 2015; Shackleton and Mograbi 2020). Therefore, we considered the three most common tree species present in each type of the selected green infrastructure in Bengaluru. The major focus of the survey was to investigate the people's perceptions of benefits (as ecosystem services) and harms (as ecosystem disservices) from the green infrastructure

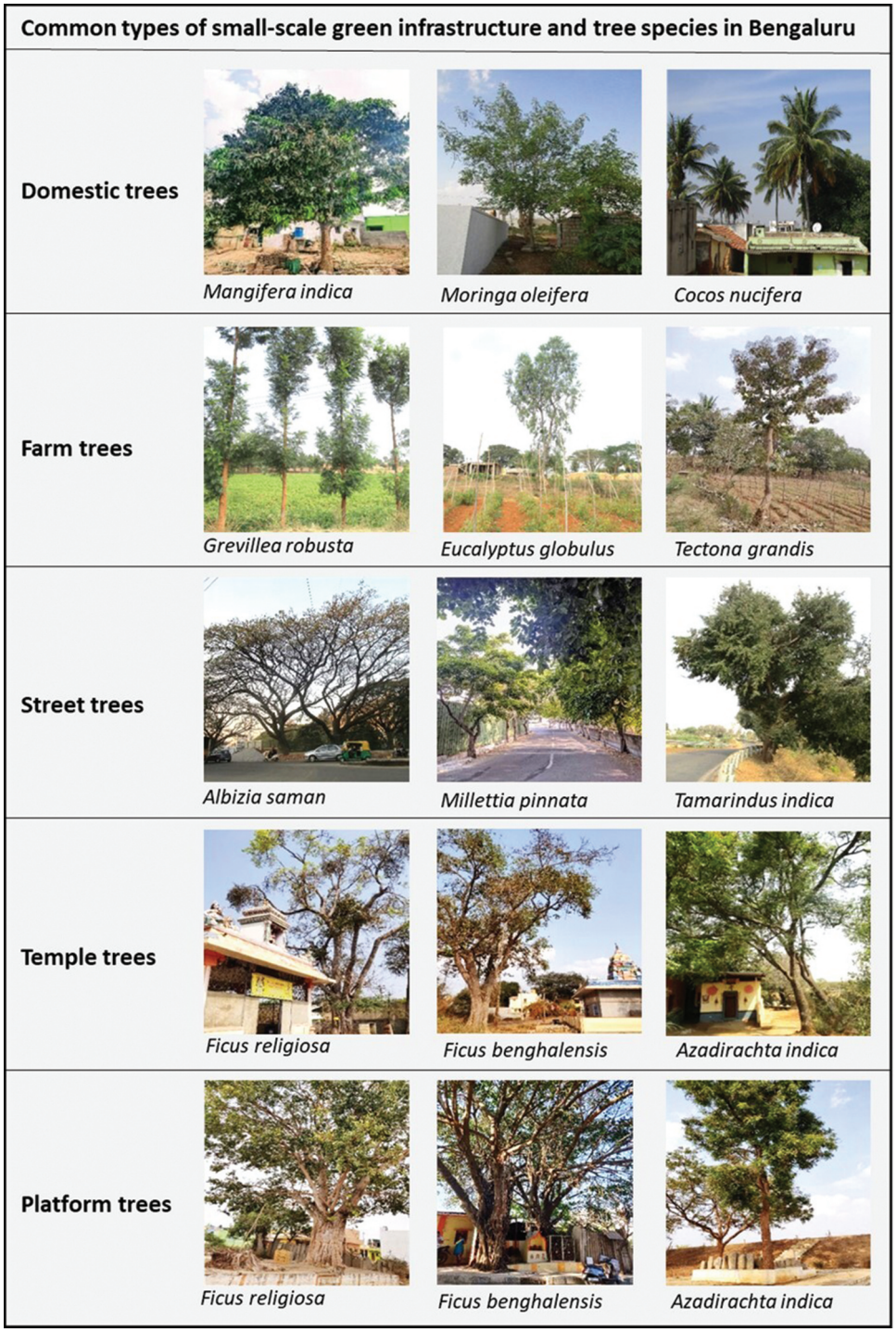

Figure 2. Types of small-scale green infrastructure and tree species considered in this study.

Table 1. The ecosystem (dis)services of green infrastructure assessed in the study.

Ecosystem service category	Individual ecosystem services or disservices	Definitions
Provisioning services	Food/feed	Food for humans or domesticated animals
	Ornamental flowers	Flowers or other plant parts used for decorative or ornamental purposes
	Timber/firewood	Wood used as construction materials or firewood
	Medicinal resources	Medicinal, veterinary, and pharmacological resources
Regulating services	Air/climate regulation	Mitigating air pollution, cooling air
	Water purification	Water purifying or filtering water from unwanted particles, pathogens, and excess nutrients
	Soil improvement	Maintenance or enhancement of soil fertility, and soil retention
Cultural services	Social interaction	Spend time with other people or join social events
	Aesthetic values	Visual appreciation of natural scenery/beauty
	Spiritual values	Meditative, religious, and reflective values
	Sense of place	A sense of attachment, belonging, or connectedness to the place
Ecosystem disservices	Crop damage	Damage to crops by tree-dwelling monkeys or birds
	Dangerous animals	Encroachment by dangerous or unpleasant animals such as snakes or rodents
	Space for nuisances	Open defecation/dumping of garbage/sewage
	Space for anti-social activities	Noise, alcohol/drug consumption in groups, etc.

in their day-to-day life with a pre-defined set of ecosystem (dis)services (Table 1). The initial selection of tree species and ecosystem (dis)services considered in the questionnaire was based on the published literature and then adapted to local conditions after the initial field explorations in a series of iterative discussions with residents and green infrastructure experts from different towns before the survey. We categorized ecosystem (dis)services from these types of green infrastructure into four groups: provisioning, regulating, and cultural services, and ecosystem disservices (de Groot et al. 2002; Millennium Ecosystem Assessment 2003; du Toit et al. 2018).

2.3 Survey design and data collection

We employed a photo-elicitation survey to assess the importance of green infrastructure for the local population. Photo-elicitation is a method that uses photos in surveys or interviews to trigger reactions and responses (Harper 2002). The photos presented during interviews help respondents sharpen their memories, reduce misunderstandings, and overcome respondent fatigue. Photos of trees and their surroundings were taken in the study areas in February and March 2020. The light, weather conditions, angle, and distance between the trees and the photographer were kept as consistent as possible. The photos were taken and selected to look natural and representative to reduce any potential bias. An image of the whole tree was depicted in the photo whenever possible and inclusion of distracting elements that would influence the responses were avoided. To avoid a potential bias in responses due to specific tree species, we took photos of all the considered three tree species per green infrastructure, making a total of 15 photos (Figure 2). A laminated, A4-sized, good-quality color-printed photo of each type of green infrastructure was used in the photo-elicitation to rate the perceived importance of the green infrastructure. These photos were divided into three separate sets. Each photo set was presented with a similar frequency to respondents. Cross-tabulation analysis showed that the use of different sets of pictures with different tree species did not influence the answers of the respondents (Annex 1). Before performing the survey, the questionnaire and the photos were validated through a pretest outside of the study sites.

For the survey, each transect of the study area was divided into three strata called urban, transitional, and rural strata based on their distance from Bengaluru city center and their share of built-up areas (Hoffmann et al. 2017). From each stratum of a transect, approximately 10 towns were chosen for the survey, summing up to 61 towns of both transects in total (~30% of the total towns). The household lists of the towns were obtained from local child health care centers (*Aganwadi centers)*. From the list, our samples were stratified based on gender, age, and caste because these are the potential factors influencing people's perception of ecosystem service uses (Zoderer et al. 2016). The education level was categorized as illiterate or no formal education, up to the 12th class, and a diploma or more. A diploma is a two-year technical degree program, usually done after the 12th class but not equivalent to a bachelor's or master's degree. Caste was categorized as general, other backward class (OBC), and scheduled caste and scheduled tribe (SC/ST). General caste includes communities of priests, rulers/fighters, businesspersons, and farmers. OBC are socially and educationally backward classes of citizens defined by the Government of India. SC is the bottommost stratum of the social hierarchy. ST is the indigenous or tribal communities (de Zwart 2000). In line with the latest available data of the Census of Karnataka 2011, respondent number per town was maintained proportional to the population of the town.

Locally trained research assistants collected the data from January to February 2021. The survey started with an introduction of the research and the researchers, the aim of the project, COVID−19 precautionary measures, and ethical guidelines. After informed consent was obtained, the paper-based survey was conducted with one respondent per research assistant at a time. Questions were asked in the local language (Kannada) and later translated into English. The questionnaire (ref. Supplementary Material) was divided into three parts: 1. information on socio-demographics (age, gender, education level, caste, and income sources of respondent's household); 2. importance of ecosystem service uses from the green infrastructure in daily life; 3. importance of ecosystem disservices associated with the green infrastructure in daily life. The respondents were asked to give their responses on ecosystem (dis)services along a Likert scale ranging from 1 (not important) to 5 (very important). At the end of the assessment of the perceived benefits or harm derived from each type of green infrastructure, people were asked if that type of green infrastructure had been the source of any other benefit or harm to them in the past. The raw data obtained from the survey is available here on the Zenodo repository. It took approximately 20 minutes to finish a survey.

2.4 Data analysis

To assess respondents' perception of the importance of ecosystem (dis)services, mean values of ranks were calculated based on the respondents' valuation. Individual ecosystem (dis)services, and the larger ecosystem (dis)services categories were then assessed per (1) type of green infrastructure and (2) degree of urbanity (Hoffmann et al. 2017). Friedman's test was applied to check if the perceived ecosystem (dis)services were significantly different among the types of green infrastructure. The effect size of Friedman's test – Kendall W was also calculated. Subsequently, a Wilcoxon signed-rank test with Bonferroni correction was applied to assess if the pairwise valuation of ecosystem (dis) services from green infrastructure were significantly different from each other. We used the Kruskal-Wallis test to analyze if the perceived use of the ecosystem (dis)services varied significantly among the types of green infrastructure across the rural-urban gradient. Finally, we used a generalized linear regression model to assess the association of the perception of ecosystem service categories with the social-cultural characteristics (e.g. gender, age, education, caste, and farming background as the variable of income from agriculture) of the respondents.

3. Results

3.1 Differences between ecosystem service perceptions among multiple types of small-scale green infrastructure

A total of 649 residents assessed the importance of green infrastructure for the supply of ecosystem (dis) services in their daily life. Overall, the ecosystem service category that was most valued by residents was cultural services ($\overline{x} = 2.99$, SD = 0.73), followed by regulating services ($\overline{x} = 2.97$, SD = 0.83), and provisioning services ($\overline{x} = 2.09$ and SD = 0.67). We found that the specific importance of each green infrastructure type was different for all the ecosystem (dis) services categories (Table 2).

Farm trees were the most relevant green infrastructure type in relation to provisioning services ($\overline{x} = 3.42$ and SD = 1.28), followed by domestic trees ($\overline{x} = 2.51$ and SD = 1.03). Street trees ($\overline{x} = 1.91$ and 0.90), temple trees ($\overline{x} = 1.33$ and SD = 0.54), and platform trees ($\overline{x} = 1.30$, and SD = 0.54) had comparatively less importance for the provision of material goods. Farm trees and domestic trees were also the most valued in regulating services (respectively, $\overline{x} = 3.83$ and SD = 1.26; and $\overline{x} = 3.13$ and SD = 1.12), while temple trees ($\overline{x} = 2.89$ and SD = 1.00), platform trees ($\overline{x} = 2.81$ and SD = 1.08), and street trees ($\overline{x} = 2.21$ and SD = 1.09) were perceived as less important in this ecosystem service category. Temple trees stood out in relation to cultural ecosystem services ($\overline{x} = 3.61$ and SD = 0.99). They were followed by domestic trees ($\overline{x} = 3.21$ and SD = 1.17), farm trees ($\overline{x} = 3.17$ and SD = 1.18) and platform trees ($\overline{x} = 3.15$ and SD = 1.19), all with similarly high values. Respondents indicated low importance of cultural ecosystem services for street trees ($\overline{x} = 1.79$ and SD = 0.69). As for ecosystem disservices, values were relatively homogeneous among all green infrastructure types. Farm trees were perceived as the most important source of disservices among the green infrastructure types ($\overline{x} = 2.32$ and SD = 1.14), followed by street trees ($\overline{x} = 2.25$ and SD = 0.95) and domestic trees ($\overline{x} = 2.07$ and SD = 0.87). Platform trees ($\overline{x} = 1.41$ and SD = 0.60) and temple trees ($\overline{x} = 1.41$ and SD = 0.82) were perceived as relatively less relevant sources of ecosystem disservices.

Friedman's test showed that the perception of ecosystem (dis)services varied significantly among the five types of green infrastructure ($p < 0.001$). Their effect sizes were relatively low to medium, ranging from 0.15 in the case of air/climate regulation to 0.47 in the case of firewood/timber. However, some types of green infrastructure were perceived as particularly important for specific ecosystem services. Among them were soil improvement ($\overline{x} = 4.32$, SD = 1.33) and food/feed supply ($\overline{x} = 4.01$, SD = 1.57) from farm trees. Also relevant was the importance of temple trees for aesthetic ($\overline{x} = 3.72$, SD = 1.25) and spiritual values ($\overline{x} = 3.70$, SD = 1.54). Green infrastructure was not generally perceived as a source of

Table 2. Respondents' perception of ecosystem (dis)services from the five green infrastructure types. Significant differences were tested using Wilcoxon signed rank tests with Bonferroni correction.

	Domestic tree	Farm tree	Street tree	Platform tree	Temple tree	Overall	Friedman test	Effect size (Kendall's W)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	X^2	
Provisioning services								
Overall provisioning services	2.51[a] (1.03)	3.42[b] (1.28)	1.91[c] (0.90)	1.30[d] (.54)	1.33[d] (.54)	2.09 (0.67)	1312.96***	0.51
Food/feed	2.55[a] (1.55)	4.01[b] (1.57)	1.95[c] (1.35)	1.33[d] (.86)	1.35[d] (.88)	2.24 (0.68)	1160.72***	0.45
Firewood/timber	1.78[a] (1.24)	3.69[b] (1.74)	2.06[b] (1.42)	1.07[d] (.40)	1.06[d] (.39)	1.93 (0.62)	1231.31***	0.47
Ornamental flowers	2.85[a] (1.58)	3.17[b] (1.74)	1.94[c] (1.36)	1.33[d] (.87)	1.52[e] (1.09)	2.16 (0.66)	712.01***	0.27
Medicinal resources	2.85[a] (1.63)	2.79[a] (1.74)	1.68[b] (1.16)	1.47[c] (1.03)	1.39[c] (.94)	2.04 (0.71)	637.64***	0.25
Regulating services								
Overall regulating services	3.13[a] (1.12)	3.83[b] (1.26)	2.21[c] (1.09)	2.81[d] (1.08)	2.89[d] (1.00)	2.97 (0.83)	644.10***	0.25
Air/climate regulation	3.02[a] (1.47)	3.62[b] (1.54)	2.39[c] (1.45)	3.81[d] (1.44)	3.58[b] (1.32)	3.28 (0.72)	386.27***	0.15
Water purification	3.25[a] (1.63)	3.55[b] (1.67)	1.96[c] (1.36)	2.11[d] (1.41)	2.52[e] (1.50)	2.68(0.88)	563.58***	0.22
Soil improvement	3.13[a] (1.47)	4.32[b] (1.33)	2.29[c] (1.42)	2.51[d] (1.48)	2.56[d] (1.43)	2.96 (0.89)	807.33***	0.31
Cultural services								
Overall cultural services	3.21[a,c] (1.17)	3.17[a] (1.18)	1.79[b] (0.69)	3.15[c] (1.19)	3.61[a] (.99)	2.99 (0.73)	769.37***	0.30
Social interaction	3.46[a] (1.55)	2.93[b] (1.58)	1.52[c] (1.05)	2.78[b] (1.62)	3.46[d] (1.46)	2.83 (0.69)	593.23***	0.23
Aesthetic values	3.23[a] (1.48)	3.85[b] (1.50)	2.57[c] (1.47)	3.51[c] (1.43)	3.72[b] (1.25)	3.38 (0.68)	332.06***	0.13
Spiritual values	2.64[a] (1.60)	2.22[b] (1.46)	1.37[c] (1.00)	3.36[d] (1.62)	3.70[e] (1.54)	2.66 (0.71)	758.46 ***	0.29
Sense of place	3.52[a,b] (1.66)	3.68[a,c] (1.65)	1.71[d] (1.15)	2.93[e] (1.60)	3.57[b,c] (1.47)	3.08 (0.83)	719.27***	0.28
Overall ecosystem services	2.95 (0.91)	3.47 (1.10)	1.97 (0.63)	2.42 (.61)	2.61 (.72)	2.68 (0.74)	844.45***	0.33
Disservices								
Overall disservices	2.07[a] (0.87)	2.32[b] (1.14)	2.25[c] (0.95)	1.48[d] (.62)	1.41[d] (.60)	1.41 (0.82)	825.03***	0.32
Crop damage	2.31[a] (1.64)	2.79[b] (1.81)	1.57[c] (1.12)	1.70[c] (1.25)	1.75[d] (1.25)	1.75 (0.99)	405.19***	0.16
Threat posed by dangerous animals	2.93[a](1.59)	2.89[a] (1.71)	1.97[b] (1.24)	1.53[c] (.95)	1.55[c] (.98)	1.55(0.88)	715.08***	0.28
Space for nuisances	1.65[a](1.23)	1.58[a] (1.18)	3.03[b] (1.80)	1.25[c] (.77)	1.23[c] (.77)	1.23 (0.69)	811.86***	0.31
Space for anti-social activities	1.39[a] (0.93)	2.03[b] (1.52)	2.42[c] (1.66)	1.43[a] (1.07)	1.12[d] (.53)	1.12 (0.72)	515.26***	0.20

X^2 presents the Z value of the Friedman Test at the level of significance ***p value < 0.001. For each ecosystem (dis)service, mean values marked with a different letter are significantly different ($p < 0.05$) between the types of green infrastructure.

disservices, except for nuisances like open defecation around the base of street trees ($\bar{x} = 3.03$, SD = 1.80). However, encroachment by dangerous animals ($\bar{x} = 2.89$, SD = 1.71) and crop damage by animals dwelling in farm trees ($\bar{x} = 2.79$, SD = 1.81) were reported as important disservices. The least important disservice reported was space for anti-social activities such as taking alcohol or drugs around temple trees ($\bar{x} = 1.12$, SD = 0.53).

3.2 Differences between rural, transitional, and urban areas

The importance of ecosystem (dis)services from among the five types of green infrastructure varied across the rural-urban gradient (Figure 3). Overall, ecosystem services were assessed most highly in transitional areas; ecosystem disservices were perceived most intensely in rural areas. Respondents in transitional areas perceived cultural services as the most important contribution ($\bar{x} = 3.05$ and SD = 0.71) from small-scale green infrastructure and valued cultural services higher compared to respondents in urban ($\bar{x} = 3.03$ and SD = 0.63) and in rural ($\bar{x} = 2.94$ and SD = 0.71) areas. Provisioning services were also assessed higher in transitional areas ($\bar{x} = 2.13$ and SD = 1.00) than in urban ($\bar{x} = 2.09$ and SD = 1.02) and rural areas ($\bar{x} = 2.04$ and SD = 0.77). Respondents from urban ($\bar{x} = 3.01$ and SD = 0.63) and transitional ($\bar{x} = 3.00$ and SD = 0.64) areas perceived regulating services as more important than rural respondents ($\bar{x} = 2.94$ and SD = 0.55). However, higher levels of disservices were perceived in rural areas ($\bar{x} = 1.94$ and SD = 0.42) than in urban ($\bar{x} = 1.88$ and SD = 0.43) and transitional ($\bar{x} = 1.87$ and SD = 0.47) areas.

As for the importance of ecosystem service categories from green infrastructure types, although absolute Likert scale values differed, patterns in perceived ecosystem (dis)services derived from specific tree types were similar. For example, farm trees were all appreciated the most (compared to other tree types) for their provisioning and regulating services across the rural-urban gradient. The pattern for cultural services was different. The highest appreciation for cultural services came from farm trees in urban areas ($\bar{x} = 3.43$ and SD = 0.96), whereas cultural services from farm trees were considered significantly lower ($p < 0.01$) in rural areas ($\bar{x} = 2.97$ and SD = 1.26). Nearly all other types of trees, except street trees, were assessed as providing higher levels of cultural services in rural areas. Generally, regulating services from all types of green infrastructure were mostly appreciated higher in urban than in rural and transitional areas, except for temple trees ($\bar{x} = 2.64$ and SD = 0.97). More specific differences between regions include provisioning services from farm trees in transitional areas ($\bar{x} = 3.71$ and SD = 1.07) being perceived more strongly ($p < 0.001$) than in urban areas ($\bar{x} = 3.67$ and SD = 1.04). In rural areas,

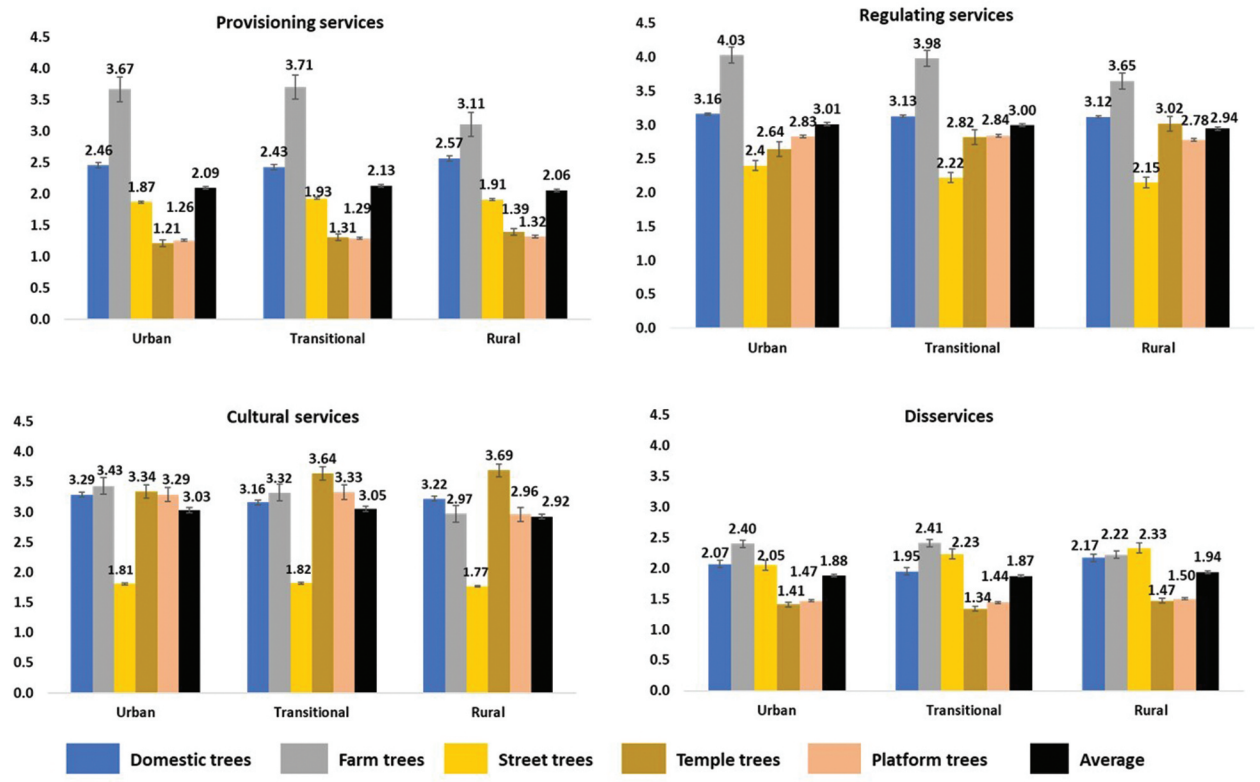

Figure 3. Perception of ecosystem (dis)services from green infrastructures along rural, transitional, and urban areas.

regulating services from temple trees ($\bar{x}$ = 3.02 and SD = 1.03) were appreciated more ($p < 0.001$) than in urban areas ($\bar{x}$ = 2.64 and SD = 1.05). Cultural services from farm trees ($\bar{x}$ = 2.97 and SD = 1.26) and temple trees ($\bar{x}$ = 3.69 and SD = 0.94) in rural areas, were significantly different ($p < 0.05$) from the respective green infrastructure types in transitional areas (farm trees: $\bar{x}$ = 3.32 and SD = 1.11; temple trees: $\bar{x}$ = 3.64 and SD = 0.96). Disservices from domestic trees in rural areas ($\bar{x}$ = 2.17 and SD = 0.90) were perceived higher ($p < 0.01$) than those in transitional areas ($\bar{x}$ = 1.95 and SD = 0.87). Likewise, perceived disservices from street trees in urban areas ($\bar{x}$ = 2.05 and SD = 0.83) were lower ($p < 0.05$) than those in rural areas ($\bar{x}$ = 2.33 and SD = 0.99).

3.3 Influence of socio-economic factors on people's perceptions of the ecosystem (dis) services from green infrastructure

Several socio-economic factors significantly affected the importance assigned to types of green infrastructure in all ecosystem (dis)services categories (Table 3). In terms of gender, female respondents attributed significantly less importance to regulating services than male respondents (OR = 0.94, $p < 0.05$). Perception of other ecosystem services categories was not significantly different between males and females. Compared to young and middle-aged respondents, elderly respondents appreciated cultural services (OR = 0.94, $p < 0.05$) to a lesser extent. The uses of provisioning and regulating services and disservices were similarly perceived by all age groups. As for education, respondents with higher education (i.e. diploma or more) perceived provisioning services significantly more intensely than respondents with education only up to 12th grade (OR = 1.07, $p < 0.05$). Caste was a relevant factor for all categories. Respondents belonging to the general caste category attached less importance to provisioning (OR = 0.93, $p < 0.05$) and regulating services (OR = 0.92, $p < 0.05$) than respondents belonging to the scheduled caste and scheduled tribe (SC/ST) categories. Similarly, respondents belonging to other backward classes (OBC) perceived less importance of provisioning (OR = 0.93, $p < 0.05$) and more importance of regulating (OR = 1.12, $p < 0.001$) and cultural services (OR = 1.06, $p < 0.05$) than respondents from the SC/ST. Finally, our analysis reveals that respondents working in non-agricultural sectors assigned significantly less importance to green infrastructure for all ecosystem service categories (provisioning services: OR = 0.92, $p < 0.01$; regulating services, OR = 0.90, $p < 0.001$; and cultural services: OR = 0.83, $p < 0.001$) than respondents working in the agricultural sector.

4. Discussion

4.1 Green infrastructure is perceived as key multifunctional element in the urban context

Our analyses reveal the vital multifunctional roles of green infrastructure in the context of rapid

Table 3. Results from generalized linear regression model to test for the main effect of socio-economic factors on the perception of each ecosystem (dis)services category from green infrastructure.

	Provisioning service		Regulating service		Cultural service		Disservice	
	B (SE)	OR	B (SE)	OR	B (SE)	OR	B (SE)	OR
Gender								
Male	-	-	-	-	-	-	-	-
Female	0.01 (0.02)	1.01	**−0.06 (0.03)**	**0.94***	−0.05 (0.03)	0.94	−0.03 (0.03)	0.96
Age								
Middle-aged: 30–59 years old	-	-	-	-	-	-	-	-
Elderly: > 59 years old	−0.06 (0.03)	0.93	−0.06 (0.04)	0.93	**−0.05 (0.04)**	**0.94***	0.02 (0.04)	1.02
Young: 19–29 years old	−0.05 (0.03)	0.943	0.00 (0.04)	1.00	−0.04 (0.04)	0.961	0.03 (0.04)	1.03
Education								
Up to 12th grade	-	-	-	-	-	-		-
Higher education: diploma or more	**0.07 (0.03)**	**1.07***	0.03 (0.04)	1.03	0.03 (0.04)	1.03	−0.05 (0.04)	0.94
Illiterate/no formal education	0.02 (0.03)	1.02	−0.01 (0.03)	0.09	0.04 (0.03)	1.05	0.02 (0.08)	1.02
Caste								
Scheduled caste or scheduled tribe	-	-	-	-	-	-	-	-
General	**−0.07 (0.03)**	**0.93***	**−0.08 (0.03)**	**0.92***	−0.01 (0.03)	0.98	0.07 (0.04)	1.07
Other backward class (OBC)	**−0.06 (0.02)**	**0.93***	**0.11 (0.03)**	**1.12*****	**0.06 (0.03)**	**1.06***	−0.02 (0.03)	0.97
Income source: agriculture								
Agriculture as income source	-	-	-	-	-	-	-	-
Agriculture not as an income source	**−0.07 (0.02)**	**0.92****	**−0.09 (0.03)**	**0.90*****	**−0.18 (0.02)**	**0.83*****	0.00 (0.03)	1.03

B = coefficient, SE = standard error (in brackets), or = Odds Ratio. Coefficients and odds ratios are shown in bold and marked with *** $p < 0.001$, ** $p < 0.01$, or * $p < 0.05$ levels of significance.

urbanization. We found that green infrastructure simultaneously supplies multiple ecosystem services, similar to the findings from Meacham et al. (2022) and Gullino et al. (2018). One example of these ecosystem services is a variety of food materials supplied by coconut trees (including coconut water and oil) mango (fruit), and drumstick[2] (vegetable). These mango trees typically have additional uses, such as medicinal, spiritual, and aesthetic values. Similarly, the neem tree is appreciated simultaneously as a source of medicine and for air purification (Nagendra 2016c).

Comparatively, the respondents appreciated provisioning services from green infrastructure types to a lower degree than regulating and cultural services. This shift in the importance from provisioning to regulating and cultural services is consistent with the literature and has been associated with changes in lifestyles and individual needs through urbanization (Nagendra 2016a). However, the importance of provisioning services should not be underestimated. Our analysis suggests that provisioning services are the most appreciated category by people who maintain their livelihoods through (peri-)urban farming. Another study also reports that vulnerable urban communities (e.g. slum dwellers) strongly depend on provisioning services from urban trees (Shackleton et al. 2015). Thus, further promotion of the use of green infrastructure in cities to extract material goods and services, without interfering with the values of regulating and cultural services, could potentially become an important tool in their maintenance.

In our study, regulating services were among the highest-ranked ecosystem services. Our findings confirm those of Kabisch et al. (2021) and Battisti et al. (2019) by showing that most trees in the study areas are important to people because of their air-regulating properties. In the context of Bengaluru, trees are particularly appreciated for removing air pollutants emitted by vehicles and supplying a cool environment. Residents recognize how trees positively contribute to their well-being. Local businesses, e.g. street vendors, who sell their products such as flowers/plants, clothes, or food under the shade of trees, also appreciate the benefits of trees in mitigating warm temperatures. The vendors reported that the shade prevented flowers and plants from wilting, clothes from fading, and food from being ruined by rain and sun (Nagendra 2016d). Green infrastructure also provided important cultural services in Bengaluru. Many of the respondents in the survey were Hindus. Trees like banyan and peepal, which are considered incarnations of Hindu Gods and Goddesses, are regarded as indispensable in Hindu rituals (Gopal and Nagendra 2014). Thus, regulating and cultural services were highly appreciated among others due to livelihood choices and spirituality. However, some studies have reported that small-scale green infrastructure has a lower potential of supplying regulating services than larger-scale green (Peschardt et al. 2012), which contrasted with our findings.

Small-scale green infrastructure was also perceived as a source of direct and indirect nuisances. Our study revealed that disservices were relatively less important to people compared with ecosystem services, yet green infrastructure may shelter pests and wildlife (such as monkeys) that encroach into adjacent areas, eat crops, or spread disease in fields, as was observed by Anand et al. (2018). Since most respondents in our study were farmers, this may have influenced the high ranking of human-wildlife conflicts in association with farming. Agarwal et al.

(2016) also reported that crop and personal damage by wildlife was a major ecosystem disservice in Bengaluru and other cities in India.

4.2 Different types of green infrastructure play unique roles and contribute to the supply of ecosystem services

Our analyses go beyond a general assessment of green infrastructure and show how different types of green infrastructure contribute to ecosystem (dis)services in unique ways. Among the five types of green infrastructure, farm trees were valued the highest for provisioning and regulating ecosystem services. In contrast, street trees were perceived as least important for the supply of ecosystem services but rather were revealed to be the most important source of disservices. Temple and platform trees were perceived as particularly relevant for cultural services.

Domestic and farm trees, which are generally in private spaces, were perceived as the most relevant green infrastructure types for the supply of most ecosystem services. The fact that these trees are privately owned and that the majority of our respondents were farmers who had income from agriculture, might have contributed to the higher valuation of the ecosystem services from these types of trees. Previous studies have demonstrated the influence of tenancy and ownership on the perception of ecosystem service supply in the private-public urban domain (Ossola et al. 2018). We found that people appreciate regulating services, for example, soil and water regulation, by farm trees more than by other types of trees. Similarly Long and Nair (1999) showed that farm trees planted on the margins of farmland support crop growth by maintaining the nutrient and moisture content of the soil. Beyond regulating and provisioning services, Rolf et al. (2020) highlighted that farm trees also have the potential to enhance aesthetic, visual, and cultural amenities. In this line, policies and projects that encourage farmers to plant diverse trees at their field margins or around their residences should be promoted so that the farmers continue getting a wide range of benefits from those types of trees.

Despite their well-recognized benefits, such as air/climate regulation, surprisingly, our respondents perceived street trees as relatively less valuable than other small-scale green infrastructure types. Possibly, many residents do not have a personal attachment to street trees, which might keep these trees at risk of loss through urbanization. Those who benefit from the ecosystem services provided by street trees are mostly landless people, street vendors, and daily wage laborers – they often have a greater sense of attachment to street trees (Basu and Nagendra 2020). Also, street trees – in contrast to farm trees – belong to the public domain, due to which people might use them as space for open defecation and other antisocial activities like consuming alcohol. Some street trees host dangerous animals such as poisonous snakes, disease-spreading rodents, and insects. For example, honeydew from aphids feeding on street trees can leave unwanted marks on cars and leave a sticky residue on streets (Cameron 2022). Thus, attention should be given to minimizing the perceived disservices associated with street trees and promoting the use and conservation of street trees in megacities like Bengaluru.

We found that temple and platform trees play a similarly important role in the supply of cultural services, such as aesthetics, and also regulate microclimate, which was also revealed by Derkzen et al. (2017). Platforms are hubs of human activities and interconnections, along with being sites associated with sacred values (Jaganmohan et al. 2012; Keswani 2017) and social norms. Our results showed that these types of green infrastructure were the least associated with ecosystem disservices. This indicates the existence of a set of social norms about keeping sacred places clean might prevent disservices, e.g. open defecation at the base of sacred trees. In an urbanizing context, maintaining and promoting these traditional values might be a powerful strategy for conservation of green infrastructure.

Overall, our results show how different types of green infrastructure are important and complementary in urban contexts, each type fostering different dimensions of human well-being. Thus, our results suggest that planning strategies should go beyond the sole promotion of green infrastructure abundance, to additionally promote diversity in type.

4.3 Ecosystem service category preferences vary along the rural-urban gradient

Our analysis shows that although there are differences in the perception of ecosystem services along the rural-urban gradient, these differences are less relevant than differences that exist between green infrastructure types. Overall, different types of green infrastructure are perceived similarly and consistently positively regarded, despite their location.

However, subtle differences in perceptions exist among urban, transitional, and rural areas. Provisioning and cultural services were found to be more preferred in transitional areas than in urban and rural areas (Figure 3). This finding is different from Nagendra et al. (2014), where both regulating and cultural services were perceived as more important in urban areas. Transitional areas are often settled by poor migrants that typically depend on

provisioning services from that area (Kombe 2005) unless they find off-farm or non-farm means of livelihood. Our findings also differ from Lapointe et al. (2021) who revealed that the appreciation of provisioning and cultural services had diminished in urban areas. This highlights that the perception of ecosystem services is tied to the respective local contexts. In Bengaluru, the socio-economic context of the residents living in either rural, transitional, or urban areas might have played a role in the differences in the perception of the ecosystem (dis)services based on their access to and use of the types of green infrastructure.

We found regulating services to be appreciated higher in urban areas vs. rural and transitional areas. This higher appreciation of regulating services compared with other ecosystem (dis)services could be associated with urban heat islands due to grey infrastructure. This could be a key reason that, in most parts of Bengaluru, street trees are observed being used for shade and creating a cooler micro-climate (Nagendra 2016d). Perhaps planting common fruit trees in the streets of Bengaluru would help people also realize the importance of provisioning services along with regulating services in urban areas.

Regarding cultural services, in urban areas, the most highly ranked categories were space for social events and aesthetic values. This finding is in line with what Battisti et al. (2019) found that urbanites value the green infrastructure for aesthetics. However, Battisti et al. (2019) considered larger green infrastructure such as gardens and lawns, which were often well-maintained. Efforts should also be made to keep small-scale infrastructures, which have the potential to offer multiple cultural services to urbanities to promote their cultural identity (Peschardt et al. 2012). We also found that green infrastructure in transitional areas had been associated with social cohesion among residents more so than in urban and rural areas, as revealed by Battisti et al. (2019). However, Ye et al. (2018) reported an increase in cultural services with an increase in rurality. Thus, efforts should be made to increase the number of trees along the rural-urban gradient to foster social cohesion and other cultural ecosystem services in the respective rural, transitional, and urban areas.

Contrary to our expectations, ecosystem disservices were not perceived more strongly in urban areas compared to those in rural areas. Perhaps the potential services of urban green infrastructure outweigh their disservices to such a degree that the latter is hardly noticed (Lyytimäki and Sipilä 2009). In rural areas where farming is more prevalent, damage to crops from wildlife could be an important reason for higher concern about disservices from the green infrastructure. Thus, respective authorities should encourage farmers to farm wildlife-repelling crops and to diversify income sources so that human-wildlife conflict is perceived to a lower degree and household income is maintained despite the wildlife habitation in surrounding green infrastructure.

4.4 Perception of green infrastructure is influenced by socio-economic factors

Our study found that the perceived importance of a specific ecosystem service category was influenced by socio-economic factors such as gender, age, education level, caste, and income from agriculture, in line with Shirazi and Kazmi (2016). These results unveil a complex picture in which the socio-economic context of the individual has an impact on the use/values of and access to green infrastructure.

We found that middle-aged male respondents appreciate regulating and cultural services more intensely than female respondents did. Regulating services are key factors for successful farming in Bengaluru, where the dominant working force is often male. In addition, there is likely a gendered use of the urban environment in Bengaluru, where women are usually homemakers, thus using mostly provisioning services, e.g. food for the household members and livestock (Gopal and Nagendra 2014). However, Lin et al. (2017) and Collins et al. (2019) found that elderly people were more likely to use the ecosystem services from gardens, local parks, etc. by spending time with family, which can be related to 'feeling at home' under ecosystem services category in our study. Kabisch and Haase (2014) reported that youths were mostly associated with small green infrastructure in city centers, which might be linked to their professional or educational training being located in these areas and the social cohesion that the small-scale green infrastructure fosters more than the large-scale green infrastructure (Peschardt et al. 2012).

The perception of ecosystem services was also influenced by education, income, and caste. We found that people with higher education and from disadvantaged socio-economic groups appreciated all ecosystem services categories more intensely than illiterate people and those from the general caste. Lin et al. (2017) showed that households with higher education levels had larger greenery in their yards mainly for cultural ecosystem services. Dobbs et al. (2014) found that people with a higher level of education can access better ecosystem services because of their higher wealth levels, while in the Bengaluru context higher livelihood dependence of the marginalized caste groups on green infrastructure might have driven their higher appreciation of ecosystem services. Often these marginalized communities are the first to be refused their traditional rights to commons when

urbanization-led privatization and gentrification take place. Chaudhary et al. (2018) reported that low-income disadvantaged groups with females as household heads have less access to green infrastructure, such as community forests, and consequently less access to the ecosystem services they provide. Policies that permit and facilitate underprivileged groups (usually landless, poor, and/or of oppressed castes) to participate in planning and access green infrastructure for the ecosystem services of their choice would support green infrastructure conservation.

The types of provisioning services appreciated in our study also differed among the castes. The disadvantaged groups mainly appreciate wild food for self-use and sales, whereas people from general castes are mainly focused on harvesting feed for livestock and fuelwood. This difference might be related to land ownership and income from agriculture. Since a considerable share of our respondents did not have income from agriculture, they might have a lower appreciation of tangible ecosystem services. In contrast, slum-dwellers, who are often landless still rely on provisioning services from green infrastructure (Gopal and Nagendra 2014) may tend to appreciate ecosystem services more highly. Integrating edible urban green infrastructure in urban planning may help the urban poor who otherwise have limited access to food and would foster environmental justice (Fisher et al. 2021).

5. Conclusion

Green infrastructure is gaining increasing attention as an efficient tool to relieve some of the most unwanted effects of urbanization. Our study supports the importance of green infrastructure in providing vital provisioning, regulating, and cultural ecosystem services. However, in our study, each type of green infrastructure served a unique purpose and was situated in a particular context. Diverse socio-economic factors affect green infrastructure context and appreciation and thus mediate the use, access, and valuation of green infrastructure in public spaces. In the case of Bengaluru, having green infrastructure has been an important practice for a long period to supply ecosystem services. These ecosystem services have consistently supported the well-being of the community along the rural-urban gradient. While our results show how types of small-scale green infrastructure are relevant for residents, they are often overlooked in favor of larger-scale green infrastructure. Additional attention is needed on the emerging nuisances and disservices of small-scale green infrastructure, which hamper and limit use. In that sense, plans, and policies should consider the specific context of implementation to maximize the benefits provided by green infrastructure.

Notes

1. Such platforms are locally known as somberi katte, somberi meaning 'idle person' and are often close to a roadside tea stall (Gopal et al. 2019).
2. The pods, leaves, and flowers are used mostly in South Indian dishes.

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Annex

Annex 1. Results from cross-tabulation showing that mean values of ecosystem (dis)services were similarly perceived among tree species within the green infrastructure types among the tree species per green infrastructure. The scientific names are mentioned in italics in parenthesis against the common names.

Green infrastructure	Tree species	Provisioning services	Regulating services	Cultural services	Disservices
Domestic trees	**Coconut** *(Cocos nucifera)*	2.14	2.98	3.03	2.09
	Drumstick *(Moringa oleifera)*	2.05	2.94	2.93	2.05
	Mango *(Mangifera indica)*	2.08	3.01	3.00	2.06
Farm trees	**Eucalyptus** *(Eucalyptus globulus)*	3.38	3.83	3.13	2.27
	Silver Oak *(Grevillea robusta)*	3.50	3.80	3.20	2.46
	Teak *(Tectona grandis)*	3.37	3.86	3.19	2.22
Street trees	**Pongemia** *(Millettia pinnata)*	1.87	2.22	1.79	2.20
	Raintree *(Albizia saman)*	1.94	2.20	1.81	2.33
	Tamarind *(Tamarindus indica)*	1.92	2.22	1.79	2.20
Temple trees	**Banyan** *(Ficus benghalensis)*	1.34	2.92	3.61	1.37
	Neem *(Azadirachta indica)*	1.36	2.95	3.71	1.50
	Peepal *(Ficus religiosa)*	1.29	2.79	3.52	1.37
Platform trees	**Banyan** *(Ficus benghalensis)*	1.31	2.84	3.19	1.60
	Neem *(Azadirachta indica)*	1.28	2.77	3.08	1.44
	Peepal *(Ficus religiosa)*	1.30	2.83	3.17	1.39