Cultural and environmental drivers of plant diversity in Bengaluru city, India

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Abstract

Social and cultural processes play key roles in shaping urban green spaces, enabling urban residents from diverse backgrounds to interact with and experience nature. A better understanding of biocultural diversity and cultural ecosystem services (ES) is, therefore, important to maintain the urban green infrastructure in rapidly growing megacities, particularly in developing countries where economic development takes precedence over green infrastructure. Alternate approaches based on traditional cultural practices and beliefs are being recognised as effective conservation strategies, including nature worship in sacred sites. In India, as in many parts of the world, sacred sites are known for their biological richness and cultural ES. Yet, analyses from urban sacred sites (USS) are largely missing.

In this thesis, the connections between urban biodiversity, socio-cultural values and human well-being were explored in USS and slums of Bengaluru, an Indian megacity. First, the biodiversity and habitat functions of USS were assessed in relation to environmental variables for different plant groups (native vs. non-native, and cultivated vs. spontaneous). Most species were native (81%) and spontaneous in growth (51%). Results revealed that site variables (site type and site area) were key predictors of diversity patterns in USS, while urbanity parameters had limited influence on plant diversity.

Second, species assemblages of different plant groups were assessed in USS in relation to biological and cultural features, and urban matrix parameters. Culturally relevant species with religious, medicinal and ornamental values, prevailed in the species pool (89%). Urban matrix parameters and size and type of sacred sites were related to differences in species assemblages. These results demonstrate the potential of USS in harbouring both native and culturally significant species that can support urban living in developing countries.

Finally, the socio-cultural significance of plant species (both sacred and non-sacred) in enhancing livelihoods in slums was assessed. Again, culturally significant plants prevailed in the species pool. Slum residents identified a wide range of perceived ecosystem services that they received from plants in their neighbourhood including thermal regulation, nutrition, plant based medicine and spiritual well-being. Results highlight the potential of culturally significant plant species in providing an inclusive, inexpensive and sustainable approach towards poverty alleviation in cities, furthering a deeper understanding of the connections between people and nature. This thesis contributes towards novel insights and the development of new approaches, both representing important steps towards unravelling the connections between biodiversity, socio-cultural processes and human well-being, in an effort towards strengthening urban green infrastructure and making cities more sustainable.

Zusammenfassung

Soziale und kulturelle Prozesse spielen eine Schlüsselrolle bei der Gestaltung urbaner Grünräume, die es ermöglichen, die Stadtbewohnern mit unterschiedlichen Hintergründe mit der Natur zu interagieren und diese zuerleben. Ein besseres Verständnis der biokulturellen Vielfalt und der kulturellen Ökosystemdienstleistungen (ÖD) ist daher wichtig, um die städtische grüne Infrastruktur in schnell wachsenden Megastädten, insbesondere in Entwicklungsländern, zu erhalten. Alternative Ansätze, die auf traditionellen kulturellen Praktiken und Überzeugungen basieren, werden als wirksame Naturschutzstrategien anerkannt, einschließlich der Naturverehrung in heiligen Stätten. In Indien, wie in vielen Teilen der Welt, sind heilige Stätten für ihren biologischen Reichtum und ihre kulturellen ÖD bekannt. Dennoch fehlen weitestgehenden Analysen von urbanen heiligen Stätten (UHS).

In dieser Arbeit wurden die Verbindungen zwischen städtischer Biodiversität, soziokulturellen Werten und menschlichem Wohlergehen in UHS und Slums von Bengaluru, einer indischen Megastadt, untersucht. Zunächst wurden die Biodiversitäts- und Habitatsfunktionen von UHS in Bezug auf Umweltvariablen für verschiedene Pflanzengruppen (nativ vs. nicht-nativ und kultiviert vs. spontan) bewertet. Die meisten Arten waren heimisch (81%) und spontan (51%) im Wachstum. Die Ergebnisse zeigten, dass Standort variablen (Standorttyp und Standortbereich) wichtige Prädiktoren der Diversitätsmuster bei UHS waren, während Urbanitätsparameter einen begrenzten Einfluss auf die Pflanzenvielfalt hatten.

Zweitens wurden die Arten assoziationen verschiedener Pflanzengruppen in UHS in Bezug auf biologische und kulturelle Merkmale und urbane Matrixparameter bewertet. Kulturell relevante Arten mit religiösen, medizinischen und ornamentalen Werten dominierten im Artenpool (89%). Urbane Matrixparameter, die Größe und die Art der heiligen Stätten wurden mit Unterschied in den Artengemeinschaften in Verbindung gebracht. Diese Ergebnisse zeigen das Potenzial von UHS, die heimische und kulturellbedeutende Arten zubeherbergen, die das Leben in Städten der Entwicklungsländern unterstützen können.

Schließlich wurde die soziokulturelle Bedeutung von Pflanzenarten (sowohl heiligen als auch nicht-heiligen) bei der Verbesserung der Lebensgrundlagen in Slums bewertet. Slumbewohner identifizierten eine breite Palette von wahrgenommenen Ökosystemleistungen, die sie von Pflanzen in ihrer Nachbarschaft erhielten, einschließlich der thermischen Regulierung, der Ernährung, der pflanzlichen Medizin und dem spirituellen Wohlbefinden. Die Ergebnisse unterstreichen das Potenzial kulturell bedeutender Pflanzenarten, indem sie einen integrativen, kostengünstigen und nachhaltigen Ansatz zur Armutsbekämpfung in Städten bieten. Diese Arbeit trägt zu neuen Erkenntnissen und zur Entwicklung neuer Ansätze bei, um die grüne Infrastruktur der Städte zu stärken und Städte nachhaltiger zu machen.

Acknowledgements

First and foremost, I would like to thank my supervisors: Ingo Kowarik, for the opportunities I was given to conduct my research, for the guidance and feedback, for being patient during my 'PhD hysteria,' for always being there, for guiding me through the administrative procedures, and for pushing me to think better and write better; and Moritz von der Lippe for making me 'statistically' sound and for the thoughtful insights. I am so grateful to both of you.

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To the fortune cookie from the neighbourhood Asian restaurant that gave me some perspective, during a particularly overwhelming period in a PhD student's life, with innumerable tasks at hand. It read: *The secret of getting ahead is getting started*.

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Contents

Chapter 1: Introduction

Urbanization as a process has constituted the city and the countryside, society and nature, a "unity of opposites" constructed from the integrated, lived world of human social experience. At the same time, the "urbanization of consciousness" constitutes Nature as well as Space.

(Fitzsimmons, 1989: 110)

Cities represent mosaics of ecosystems that function as shared habitats of humans, plants and animals. Urban ecosystems are strongly shaped by human – nature interactions beyond natural environmental factors. Social and cultural processes are important in shaping urban ecosystems as people of different sociocultural background may interact differently with urban greenspaces (Kinzig *et al.*, 2005). The links between biodiversity and culture, referred to as biocultural diversity involves the "diversity of life in all its manifestations—biological, cultural, and linguistic—which are interrelated (and likely co-evolved) within a complex socio-ecological system" (Buizer, Elands and Vierikko, 2016, p. 9). It captures the reciprocal human-nature interactions that play a crucial role in planning, designing and managing urban green spaces (Vierikko *et al.*, 2016). Urban nature is internalized into social and cultural processes such that nature is physically reconstituted: for example, plant species composition in cities is determined to a larger extent by social preferences of residents than environmental processes (Grimm *et al.*, 2015). Integrating human-social systems into urban planning frameworks is, therefore, crucial to ensure the maintenance of biodiversity and human well-being in cities. Urban population is rapidly increasing world over with more than half the world's population living in cities (United Nations, 2014). Continual population growth and urbanization increase people's dependence on the entire range of ecosystem services provided by urban green spaces that need to be multifunctional, heterogeneous and accessible, simultaneously (Lovell and Taylor, 2013). Urban nature is therefore gaining prominence for sustainable urban living and is a timely research issue.

Urban green spaces are known to have distinct species assemblages (Kowarik, 2011; Concepción *et al.*, 2016). Response of plant species to environmental variables including urbanization gradients have been well documented for urban parks (Nielsen et al., 2014). Effective nature conservation in urban areas requires the involvement of the entire range of urban ecosystems (Kowarik, 2011), beyond designated green spaces such as urban parks and forests. Habitat functions and plant assemblages have been demonstrated for a range of urban land-use types. These include conventional green spaces such as parks (Li *et al.*, 2006; Fischer *et al.*, 2016), urban woodlands (Vallet *et al.*, 2008; Blood *et al.*, 2016) and domestic gardens (Smith *et al.*, 2006;

Galluzzi, Eyzaguirre and Negri, 2010); as well as unconventional green spaces such as wastelands (Muratet *et al.*, 2007; Bonthoux *et al.*, 2014), green roofs (Dvorak and Volder, 2010) and business sites (Serret *et al.*, 2014). Sacred sites in urban settings remain understudied despite their vital cultural and ecological importance in many cultural contexts (Ishii *et al.*, 2010; Nagendra, 2016; Jackson and Ormsby, 2017). The inclusion of the entire range of urban greenspaces not only contributes to the conservation of urban nature, but also increases opportunities for people to interact with nature (Standish, Hobbs and Miller, 2013).

In accordance with previous studies on global urban biodiversity research, the existing scientific knowledge on conservation of urban ecosystems is strongly limited to studies from developed countries in the temperate zone, while the pressing need lies in Asia, Africa and Latin-America which face rapid urban development (Shwartz *et al.*, 2014). Most megacities are located in the global south (United Nations, 2014). India is one of the most rapidly urbanizing countries in the world, followed by China and Nigeria (United Nations, 2014). Rapid unplanned growth of urban areas is leading to loss of green cover in many cities in the global south (Pauchard *et al.*, 2006; Nagendra *et al.*, 2013).

In general, urban green spaces in developing countries are under enormous pressure (Pauchard *et al.*, 2006). Urban development and conservation of biodiversity and green spaces in cities from these regions often appear to be seemingly opposing ideologies. Scientists, conservationists and urban planners are therefore adopting diverse strategies, including traditional cultural practices and beliefs in protecting and managing urban biodiversity (Xu *et al.*, 2005; Garnett, Sayer and Toit, 2007). A better understanding of environmental drivers and cultural ecosystem services are important to maintain the urban green infrastructure as well as enhancing well-being in quickly growing megacities. This study, therefore, aims to fill gaps in basic knowledge about urban sacred sites and drivers of biodiversity in the context of megacities from developing countries.

Environmental drivers of biodiversity in cities

A detailed understanding of urban biodiversity requires insights into the functioning of both social and environmental drivers. Environmental variables are often nested within one another forming convoluted ecological gradients that may result in contrasting responses of species or communities to these variables. For a better understanding of urban processes on biodiversity, a wide range of environmental variables need to be incorporated into studies, considering the complexity of urban ecosystems (McDonnell and Hahs, 2008). The influence of environmental variables on biodiversity patterns have been demonstrated for urban parks (LaPaix and Freedman, 2010; Nielsen *et al.*, 2014; Fischer *et al.*, 2016), urban woodlands/forests (Trentanovi *et al.*, 2013; Avolio *et al.*, 2015) and domestic gardens (Thompson *et al.*, 2004; Smith *et al.*, 2006). Environmental variables identified in these studies range from urban matrix variables such as urbanity scores, temporal factors (age of urban development), spatial distribution (along the urban-rural gradient), population density and population growth; to site characteristics such as patch size, edge effect, maintenance intensity and differences in land-use within the patch. In addition, socio-economic variables including personal wealth and population demographics have also been related to plant diversity patterns in cities (Hope *et al.*, 2003). Urban sacred sites are remarkable green spaces within cities but are clearly understudied. Insights into the impact of urbanization on urban sacred sites backed by empirical data could help assess the extent of their contribution to conservation of urban greenery.

Links between cultural practices, biodiversity and conservation

The rapid rate of urban development world over is leading to decline in biodiversity and loss of natural habitats (Aronson *et al.*, 2014). Scientists and policy makers are exploring new avenues and alternate practices to improve biodiversity conservation (Xu *et al.*, 2005). In recent times, traditional cultural practices and value systems are garnering attention in an effort to protect and manage biodiversity (Berkes and Davidson-Hunt, 2006; Lee and Krasny, 2017) as demonstrated by the concept of sacred sites. Sacred sites are culturally and/or spiritually significant sites and include both elements of natural landscapes like groves, forests, mountains and water bodies; and aspects of the built environment like places of worship (temple and shrines), cemeteries and heritage sites (Verschuuren *et al.*, 2010; Jackson and Ormsby, 2017), often referring to those present in rural environments (henceforth referred to as rural sacred sites). Their counterparts in cities are referred to as urban sacred sites. The sanctity attributed to these sites may originate from various sources including location of key historic events, burial sites, utility of sites, association of certain deities with the sites and/or references in local mythologies and folklore (Ishii *et al.*, 2010; Gao *et al.*, 2013; Krishna and Amirthalingam, 2014). Studies have demonstrated the contribution of rural sacred sites towards biodiversity conservation in many parts of the world including sacred forests and groves in India (Bhagwat and Rutte, 2006; Bhagwat, 2009), Zimbabwe (Byers, Cunliffe and Hudak, 2001) and China (Hu *et al.*, 2011; Gao *et al.*, 2013); burial places, heritage sites and many more across Asia, Africa and the Americas (Verschuuren *et al.*, 2010).

Traditional practices, cultural, spiritual and religious values and sentiments of local communities have protected these sites for centuries as logging is forbidden in these sites. In addition to the ecological services provided by rural sacred sites, local communities depend on them for non-timber forest products that support their livelihoods (Mandal *et al.*, 2010).

The cultural value of these sites is perhaps the most crucial factor that facilitates community support, consequently stressing the significance of cultural ecosystem services. Cultural ecosystem services are “the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience” (Millennium Ecosystem Assessment, 2005; p. 29).

Many ecosystem services provided by green spaces may seem invisible to residents (for example, regulation of microclimate, carbon sequestration, air quality improvement, etc.) and require people to understand ecological processes. Cultural ecosystem services, on the other hand, can be directly comprehended and experienced by local communities and are, therefore, appreciated to a greater extent (Andersson *et al.*, 2015). Local communities have an incentive to conserve culturally significant sites as seen in Figure 1.

The concept of cultural ecosystem services is perceived and applicable in urban areas as well. Studies on cultural ecosystem services in European and North American cities have mainly been associated with social and psychological aspects, such as recreation (Bertram and Rehdanz, 2015), place association (Andersson, Barthel and Ahrné, 2007) and well-being (Daniel *et al.*, 2012). Provision of these services could ensure feedback pathways as seen in Figure 1, wherein people comprehend (cultural) ecosystem services more easily and understand the need to protect and manage the source (green space, sacred site, etc.) (Andersson *et al.*, 2015). In Western cultures, association of spiritual values with urban ecosystems is less prevalent as they are mostly attributed to religious structures like churches and cemeteries (Gómez-Baggethun and Barton, 2013). In other parts of the world, however, spiritual and religious values are more prominent as demonstrated by urban sacred sites encompassing a wide range of urban landforms / land-use types (Jackson and Ormsby, 2017).

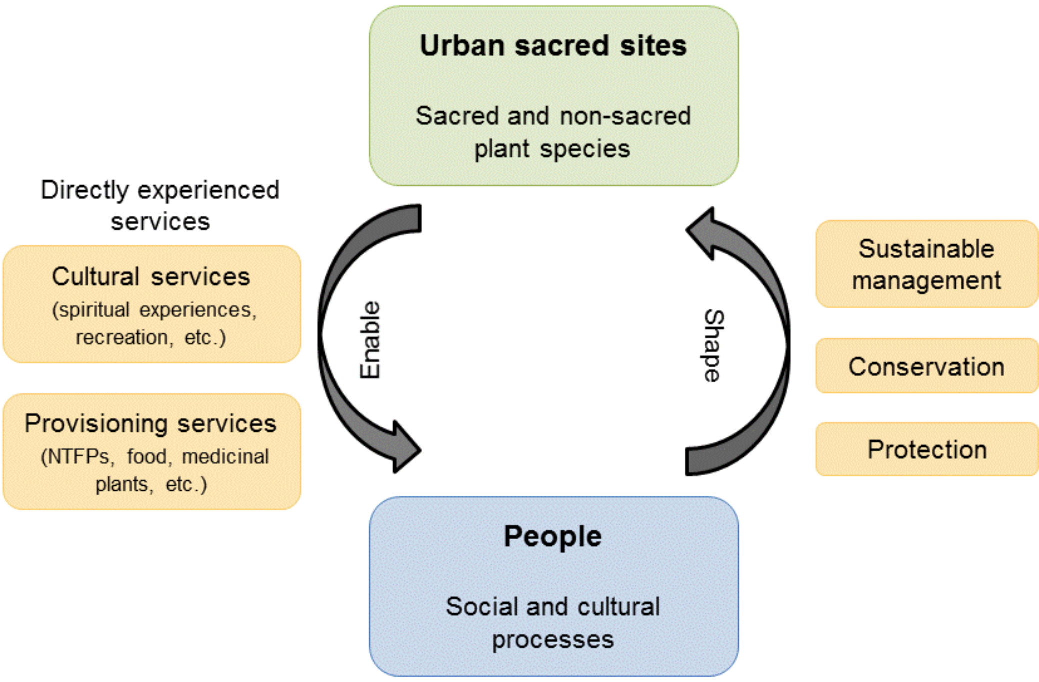

Figure 1. Conceptual framework of the feedback loop that links people with urban sacred sites. (NTFP – non-timber forest products). This thesis addresses the directly perceived ecosystem services that urban sacred sites enable people to experience.

Urban sacred sites and tree worship

Nature conservation practices in Western societies often follow the conventional approach of creating protected areas through government policies. While the creation of protected areas is derived from scientific knowledge, applying the same approach in traditional societies in other parts of the world could be counterproductive. The imposition of Western values in traditional societies could lead to alienation of local communities, thereby having an adverse impact on conservation efforts (Bhagwat and Rutte, 2006; West, Igoe and Brockington, 2006). Studies have demonstrated the potential of sacred sites in maintaining a delicate balance between Western science while appealing to traditional societies, ultimately benefitting conservation efforts (Bhagwat *et al.*, 2005; Bhagwat, 2009). These conclusions, however, are derived from studies on sacred sites in non-urban areas. In dense urban settings, is there any room for traditional values and nature worship?

Much like their rural counterparts, sacred sites in cities encompass elements of both green and blue infrastructure including sacred water bodies, shrines, churches, cemeteries, shrine forests and heritage sites (Jackson and Ormsby, 2017). The presence of shrine and temple forests in Japanese cities (Ishii *et al.*, 2010) indicate the perpetuation of traditional values despite changes in lifestyle that accompany transition from rural to urban backdrops. In other parts of the world, cemeteries have been identified as important urban sacred sites that additionally function as repositories of biodiversity (Kowarik *et al.*, 2016; de Lacy and Shackleton, 2017). Despite the wide presence of sacred sites in cities across the Indian sub-continent, biodiversity studies on urban sacred sites from this region are missing.

To address this gap of knowledge, this study focuses on greenery (individual trees and green spaces) associated with places of worship (temples and kattes) in an Indian megacity. Urban sacred forests and woodlands represent larger habitats while temples and kattes are tiny isolated fragments scattered throughout cities in many Asian countries. In dense urban areas, the habitat function of these tiny patches play a crucial for supporting biodiversity (Angold *et al.*, 2006). Thus, biodiversity and habitat functions of temples and kattes (henceforth referred to as urban sacred sites) and related environmental drivers need to be revealed.

Temples and kattes (Figure 3) are Hindu places of worship widely present in the Indian sub-continent and many parts of South-East Asia. In India, temples and kattes seem to be repetitive elements in the urban fabric existing in several neighbourhoods across cities. Kattes are tree shrines with serpent stones on a raised platform. Kattes are mostly associated with *Ficus religiosa* (sacred fig or Pipul) and *Azadirachta indica* (neem), but other *Ficus* species may also be found in kattes. The worship of plants is probably the oldest form of worship in India and stems from the socio-economic and health concerns of ancient societies (Krishna and Amirthalingam, 2014). Attributes of plant species, including nutritional value and medicinal properties, added to their sanctity in ancient times. Temples, on the other hand, were later constructions. Both kattes and temples have endured the test of time with new sites continuing to emerge in dense urban settings. Kattes in cities often stand in isolation and are managed by local communities.

Native species in cities

The response and survival of native species in urban regions is of increasing concern world over (McKinney, 2002; Kowarik, 2011; Shwartz *et al.*, 2014). In many developing countries, European landscape designs and colonial heritage are known to have a strong influence on urban green space design, planning and composition (Ignatieva *et al.*, 2015). Consequently, many of these green spaces are characterized by a high proportion of planted non-native species as seen in Bandung, Indonesia (Abendroth *et al.*, 2012); Bangalore, India (Nagendra and Gopal, 2010, 2011); Chonju, Korea (Zerbe, Choi and Kowarik, 2004) and Santiago de Chile (Fischer *et al.*, 2016).

Previous work has demonstrated that sacred sites in non-urban areas are known to contribute to conservation of native species (Bhagwat and Rutte, 2006). Yet vital questions about the functions of urban sacred sites remain: Do urban sacred sites have the potential as their non-urban counterparts, in providing habitats for native species in rapidly urbanizing cities? How do native species enhance urban living, especially in the context of urban poverty?

Socioeconomics and biodiversity

Socioeconomic factors have been identified as one of the drivers of urban biodiversity patterns. Plant diversity is known to increase significantly with economic status of residents (Kinzig *et al.*, 2005). Hope et al. (2003) referred to this phenomenon as the "luxury effect." Further, high-income neighbourhoods have been associated with an increase in exotic plants and more intense landscaping (Hope *et al.*, 2003). Residents of low-income neighbourhoods, therefore, are less likely to enjoy diverse plant communities as their wealthier counterparts. This raises concerns about inequitable access to natural resources.

Dai (2011) observed that residents in low-income neighbourhoods of Atlanta had poor access to urban green spaces. Access to green spaces has critical implications for physical - mental health, quality of life and environmental justice (Akpinar, 2016; Rigolon, 2016; Scopelliti *et al.*, 2016), as these facilitate physical activities, opportunities for social cohesion and the restorative properties of nature. Residents in low-income neighbourhoods may need greater access to urban green spaces, as they may not have the financial resources to create domestic gardens or travel to enjoy such amenities.

This thesis, thus, addresses the following questions. How do socioeconomic variables relate to patterns in plant diversity and composition in sacred sites? In adverse conditions like urban poverty, which material and non-material benefits of urban greenery do residents of low-income neighbourhoods enjoy in intensively human-managed urban landscape? How do residents of lower socioeconomic status interact with and utilize the available green spaces and plant species? Do plant species – sacred and otherwise – have the potential to enhance livelihoods of the urban poor like their rural counterparts? How do cultural and traditional practices (e.g., tree worship, spirituality, traditional ecological knowledge on utility of available natural resources and social activities) manifest themselves in the urban realm? The answers to these questions could further improve our understanding of the complex interactions between the social and ecological systems in play in urban landscapes and improve urban living.

Research area

The southern Indian city of Bengaluru is the administrative, commercial and cultural hub of the state of Karnataka (Figures 3 and 4). Bengaluru is one of the fastest growing megacities with an increase in population from 4.1 million in 1991 to 8.4 million as per the 2011 Census (Census of India, 2011). With the liberalization of India's economic policies in the 1990s, adopting the motto 'liberalization, privatization and globalization,' a significant influx of private industries, multinational companies and the Information Technology industry was witnessed. In the late 1990s, Bengaluru experienced an 'IT boom' and is often referred to as the IT hub of India. Ever since, the city has grown phenomenally both spatially and demographically (Sudhira, Ramachandra and Subrahmanya, 2007). The demand for real estate has escalated with tremendous pressure on infrastructure and resources including water, energy, land and public transport.

As the city continues to grow, public spaces are being encroached upon. Apart from illegal encroachments, many lakes and open green spaces in Bengaluru are undergoing a transformation into residential areas, roads, bus/metro stations, etc. through formal sanctions from the government. Once famed for its greenery with plenty of parks and tree lined avenues, Bengaluru has witnessed massive tree logging in the last two decades, to make way for infrastructure development to support the ever growing city. However, in the midst of this 'greying' of the city, temples and kattes seem to have been sustained as a response to people's cultural and religious beliefs. For instance, while many streets in Bengaluru have been widened to reduce traffic congestion by felling the trees along the pavements, one could find tiny islands of greenery within temples or kattes, often standing in isolation, jutting out on to the roads (Figure 2). These sacred sites have survived the test of time by demonstrating the ability to endure both legal and illegal land-use transformations in dense urban agglomerates and are therefore, important urban ecosystems that require to be studied in detail. In addition to cultural beliefs that shape Bengaluru's environment, citizen movements in Bengaluru have been strong with a wide network of citizen groups, individuals and NGOs that focus on environmental awareness, citizen science, green governance and protests against tree felling and encroachment of water bodies. The rapid growth of Bengaluru from a moderate urban centre in the early 1990s to a megapolis while retaining its cultural and religious fabric that shape its environment, makes it a model city for this study.

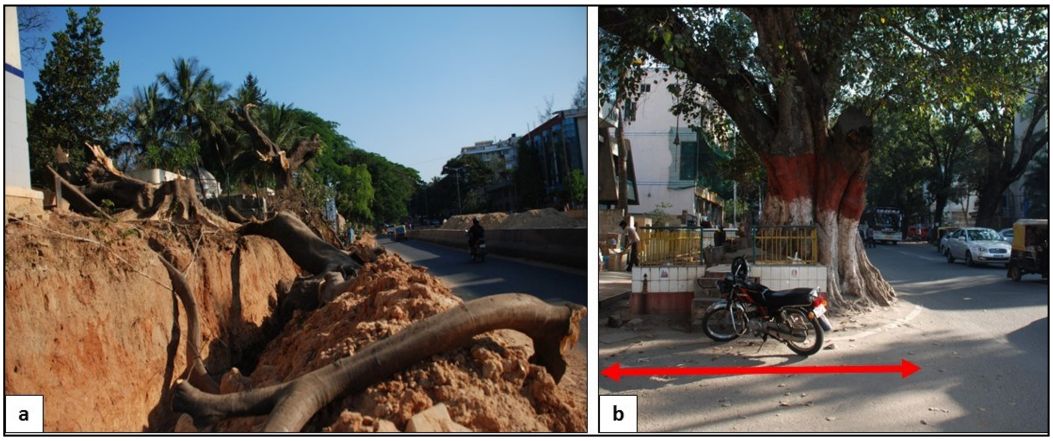

Figure 2. (a) A street in Bengaluru that was widened by logging trees along the pavement. (b) A sacred tree (katte) standing in isolation, protruding into the street after the latter was widened. Red line shows the extent to which the street was widened.

Synthesis: Gaps in knowledge and research questions

A wide range of studies have assessed various aspects of sacred sites in non-urban landscapes including biodiversity function, habitat function and ecosystem services. Yet, little is known about urban sacred sites (Ishii *et al.*, 2010; Nagendra, 2016; Jackson and Ormsby, 2017). Urban sacred sites may have the potential to cater to a plethora of ecosystem services in cities, similar to their non-urban counterparts. Although there are few studies on urban cemeteries (Barrett and Barrett, 2001; Kowarik *et al.*, 2016; de Lacy and Shackleton, 2017) and urban shrine forests (Ishii *et al.*, 2010, 2016); these are too few and on distinct types of sacred sites. Places of worship are widely present within urban areas in the Indian sub-continent and perhaps, in other parts of the world as well. Yet, even basic information including species data, species composition and diversity, is lacking.

This research, therefore, aims to improve our understanding of urban sacred sites. Based on the key gaps outlined, this dissertation addresses the following research questions.

1. Which environmental parameters (urban matrix variables and site variables) relate to vegetation diversity patterns in urban sacred sites in a megacity?

2. What is the species composition of urban sacred sites? How are plant species assemblages influenced in urban sacred sites in relation to biological and cultural features, and underlying environmental variables?

3. What are the socio-cultural ecosystem services provided by plant species in general, and sacred sites / sacred species in particular, in the context of urban poverty in slums of a rapidly growing city?

Methodological approaches

Two sampling approaches were adopted for achieving the research goals of this thesis. To address research questions 1 and 2 (Chapters 2 and 3), field inventories were carried out for plant species in urban sacred sites (temples and kattes) using a plot based stratified random sampling approach, characterising environmental drivers. Study sites were selected such that they represented each combination of the factor levels of predictor variables (9 stratas). This approach ensured that the data collected is robust in nature and a good representation of the population. Following this, appropriate statistical methods were employed including distance matrices and multinomial regression to identify predictor variables that explain patterns in plant diversity and distribution of key species. Ordination techniques were used to identify drivers of patterns in species composition.

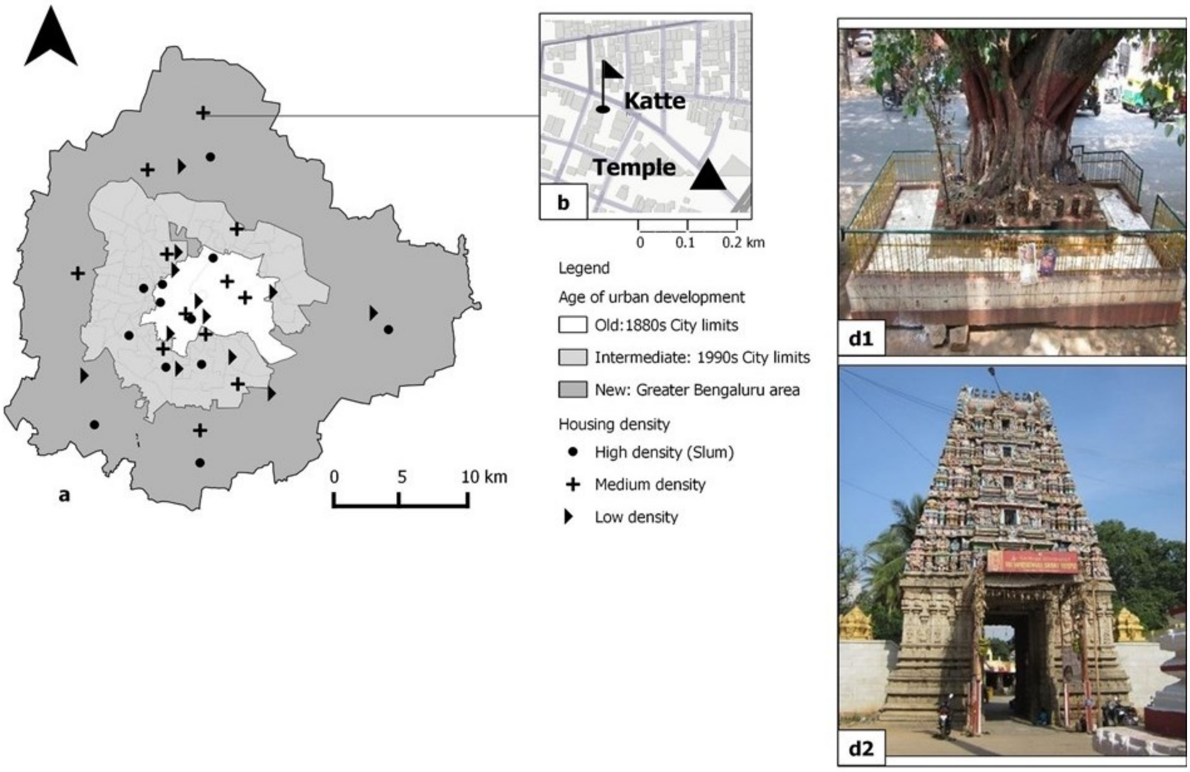

Figure 3. (a) Location of 36 neighbourhoods across Bengaluru representing 9 strata identified from stratified random sampling approach for urbanity predictors - age of urban development and housing density. (b) In each neighbourhood, a pair of temple (n = 36) and katte (n = 33) with a maximum distance of 0.5 km from each other were selected randomly, resulting in 69 study sites. (d) Example of a katte (d1) and a temple (d2).

Addressing research question 3 (Chapter 4), field studies were carried out in slums of Bengaluru using three approaches: plant species inventories, observation data (of activities) and interviews. These approaches helped gain insights into the socio-cultural significance of plant species in the context of urban poverty as perceived by slum residents and the observer conducting the survey (me). Literature review was used to further understand these ties between people, nature and culture. Field methods involved a complete inventory of all slum in Bengaluru.

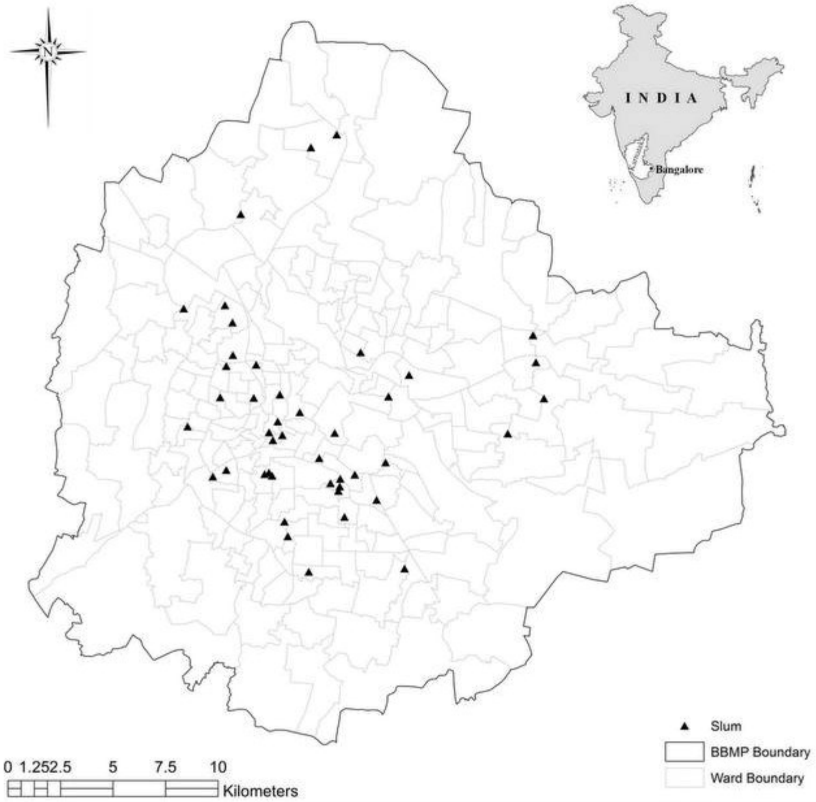

Figure 4. Location of surveyed slums in Bangalore with reference to the administrative boundary.

Outline

The key questions highlighted above, are dealt with in the three chapters (journal articles) included herein. The conceptual focus area of each chapter is indicated in Figure 5, within the general theoretical framework guiding this dissertation.

Chapter 2 summarizes the richness and diversity of plant species in sacred sites. It then examines how environmental variables relate to both alpha and beta diversity of plant species. A particular focus is given to the habitat function of urban sacred sites for native, non-native, spontaneous (wild growing) and cultivated species.

The second article in **Chapter 3** deals with plant species assemblages in urban sacred site in relation to biological and cultural features, and underlying environmental variables. This chapter characterises the floral composition in urban sacred sites through their utility and socio-cultural significance in society, while examining the response of patterns in species composition to environmental variables.

The third article in **Chapter 4** highlights the social and cultural relevance of plant species in an adverse situation – urban poverty. Perceived ecosystem services provided by plant species in slums is examined. Services that directly and indirectly support livelihoods as well as socio-cultural needs are discussed.

Finally, **Chapter 5** gives a synthesis of the main results and draws general conclusions on biodiversity-, habitat- and cultural functions of urban sacred sites. The potential of urban sacred sites as a vital part of the green infrastructure of rapidly urbanizing cities is highlighted. Further, the chapter includes recommendations for future management.

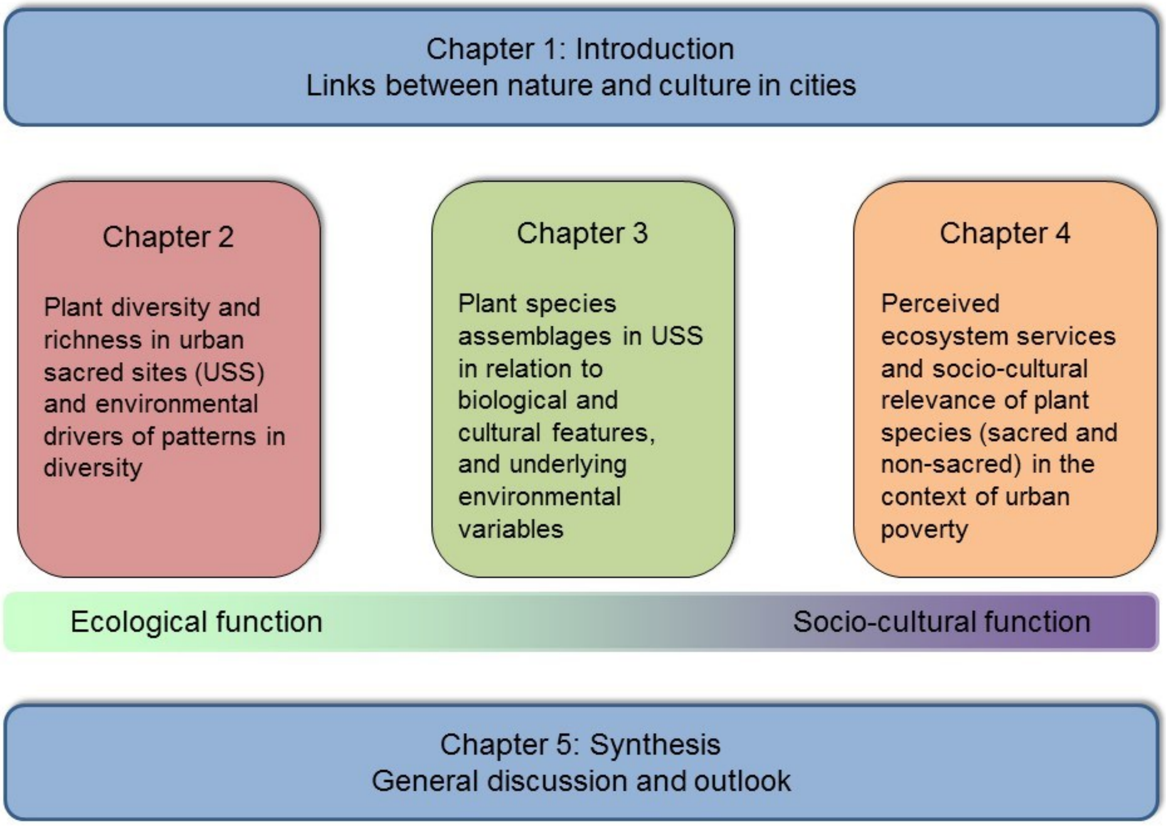

Figure 5. Overview of the dissertation.

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Chapter 2: Sacred sites, biodiversity and urbanization in an Indian megacity

Sacred sites, biodiversity and urbanization in an Indian megacity

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Abstract

In an era of rapid urban growth, the conservation of biodiverse urban greenspaces is challenging, especially in developing countries. Culturally protected areas such as sacred sites are known to contribute to biodiversity conservation in semi-urban and rural areas, but their role in densely populated urban areas is critically understudied. We therefore assessed the habitat function of sacred sites (temples and kattes) and underlying environmental parameters in the Indian megacity of Bengaluru. We analysed how different variables – age of development, housing density, types and areas of sacred sites – related to biodiversity measures (species abundance, richness, beta diversity) for cultivated, spontaneous, native and non-native plant species in 69 study plots. Results revealed that urbanity parameters had limited influence on plant diversity. Site-specific variables (site type and site area) were retained in most models and were key predictors of diversity patterns in sacred sites. Most species were native (81%) and of spontaneous growth (51%). Unlike previous studies, non-native species diversity did not relate to the urban-rural gradient or site area. Our results suggest that sacred sites have a great potential as habitats for native and spontaneous vegetation. Culturally protected areas including sacred sites provide outstanding examples of unconventional greenspaces that could contribute significantly towards biodiversity conservation within the urban green infrastructure.

Keywords

Unconventional greenspaces; Traditional conservation practices; Native species; Urban greenery; Biodiversity conservation

1. Introduction

Cities are the places where most people, today, encounter nature (Soga and Gaston 2016), and urban habitats that harbour a surprisingly high biodiversity (Shwartz et al. 2014). Yet, accelerating urban growth coupled with cities becoming more compact, pose major threats to extant greenspaces, in particular in *developing* countries (Lin and Fuller 2013).

While there is substantial research regarding the impact of urbanization on biota in *developed* countries, the same for *developing* countries is not as well studied (Pauchard et al. 2006). Cities in North America and Europe are better planned and characterized by peripheral suburbanization, lowering population density around the urban core (Irwin and Bockstael 2007). However, the crux of urbanization is still centred on the urban core in *developing* countries (Lambin et al. 2001). The desire for rapid economic growth coupled with high population density and the general low environmental standards could adversely affect urban biodiversity in many developing countries including Chile and India (Pauchard et al. 2006; Nagendra et al. 2012). With such different patterns of urbanization, conservation approaches need to be tailored to incorporate regional differences.

There is a wealth of evidence that a wide range of sacred sites, driven by religious and cultural beliefs, contribute significantly to biodiversity conservation around the world. Previous studies largely cover natural or rural areas including sacred groves and forests of India (Bhagwat and Rutte 2006); shrines of central Italy (Frascaroli et al. 2016); culturally protected forests in China (Gao et al. 2013) and Ethiopia (Woods et al. 2016); burial places in Morocco (Frosch and Deil 2011); and many more across South-East Asia, South America and Africa (Verschuuren et al. 2010). Yet, much less is known on biodiversity functions of sacred sites in urban environments (but see Kowarik et al., 2016 on old urban cemeteries).

Given that many greenspaces risk being transformed, degraded or disappear within cities (Lin and Fuller 2013; Sudhira and Nagendra, 2013), culturally protected ecosystems such as sacred sites may function as resilient ecosystems rapidly changing urban environments, contributing to biodiversity conservation in areas where urban people have limited access to nature.

India has a long, rich tradition of conservation associated with religious and cultural beliefs. While sacred groves are conserved in many peri-urban areas and smaller towns; it is quite common to find massive, centuries-old sacred trees being protected in densely congested urban neighbourhoods across India (Nagendra 2016). There are cultural taboos that forbid cutting down sacred forests, groves and individual (sacred) tree and plant species (Bhagwat and Rutte 2006; Nagendra 2016). While sacred sites could include places of worship, institutions, forests, cemeteries and heritage sites, we looked at places of worship in urban areas. In this context, sacred sites (particularly, places of worship) can be broadly classified based on organizational structure as temples and *kattes* (described in Methods). With Bengaluru as a model city for a rapidly growing Indian megacity, we analysed habitat functions of sacred sites for different groups of plant species (native, non-native, spontaneous and cultivated).

In particular, we were interested in how urbanization relates to biodiversity patterns of sacred sites. The interactions between the two have often been studied using gradient analyses, which however, might not capture the spatial complexity, non-linearity or temporal dynamics of rapidly growing megacities (McDonnell and Hahs 2008; Ramalho and Hobbs 2012). Distinctions between urban and rural are hard to define in the context of developing countries (Montgomery 2008). Studies, therefore, suggest a more comprehensive approach in assessing urbanity, using a combination of urban indices including spatial gradient, age of urban development, socio-economic variations, housing – population density and site-specific environmental variables (Trentanovi et al. 2013; Fischer et al. 2016).

Due to data limitations in Bengaluru, we focus on density of housing as an urbanization indicator of socio-economic variations. As historical land use changes and legacies have been identified as highly relevant for urban biodiversity patterns (Ramalho and Hobbs 2012), we included spatial-temporal factors in differentiating the city based on age of urban development. Apart from these, we also checked for differences within sacred ecosystems – temples and kattes – that form unique habitat types.

With this background, we aimed to study and identify drivers of vegetation diversity patterns in urban sacred sites. Specifically, whether (i) age of urban development and (ii) density of housing are related to (iii) abundance and species richness, and (iv) beta diversity in different groups of plant species (native, non-native, spontaneous and cultivated); and whether these relationships differ with (v) area of sites, and (vi) between temples and kattes.

2. Methods

2.1. Study area

The study was carried out in the southern Indian megacity of Bengaluru, with an area of 741 km^2. In the last two decades, Bengaluru has witnessed rapid and unplanned urbanization, with a population growth from 3.5 million in 1992 to around 10 million, currently (Census of India 2011). Loss of green spaces within the city, including parks, home gardens, avenue trees and open spaces, is high due to the immense pressure on land for infrastructure development. Despite laws protecting

Bengaluru's greenery (Karnataka Preservation of Trees Act, 1976), large scale logging of trees continues (Sudhira and Nagendra 2013).

2.2. Sacred sites

Temples and kattes are two types of sacred sites (particularly, places of worship) that we considered for our study. Temples are places of worship with an architectural structure/buildings dedicated to a deity, often with a clear physical boundary. An institution or a government body often manages it, taking decisions about land-use/land management; including gardening, watering plants, choice of plants and weeding. While, *kattes* are community managed traditional religious structures that include serpent stones and a combination of *Ficus religiosa* and other sacred trees (Fig. 1). Structurally, the katte is often a raised platform without a clear physical fence or a wall around it. While a gardener may actively manage flora in temples, individual users maintain kattes. Differences within sacred sites – temples and kattes, were accounted for and included in the study design.

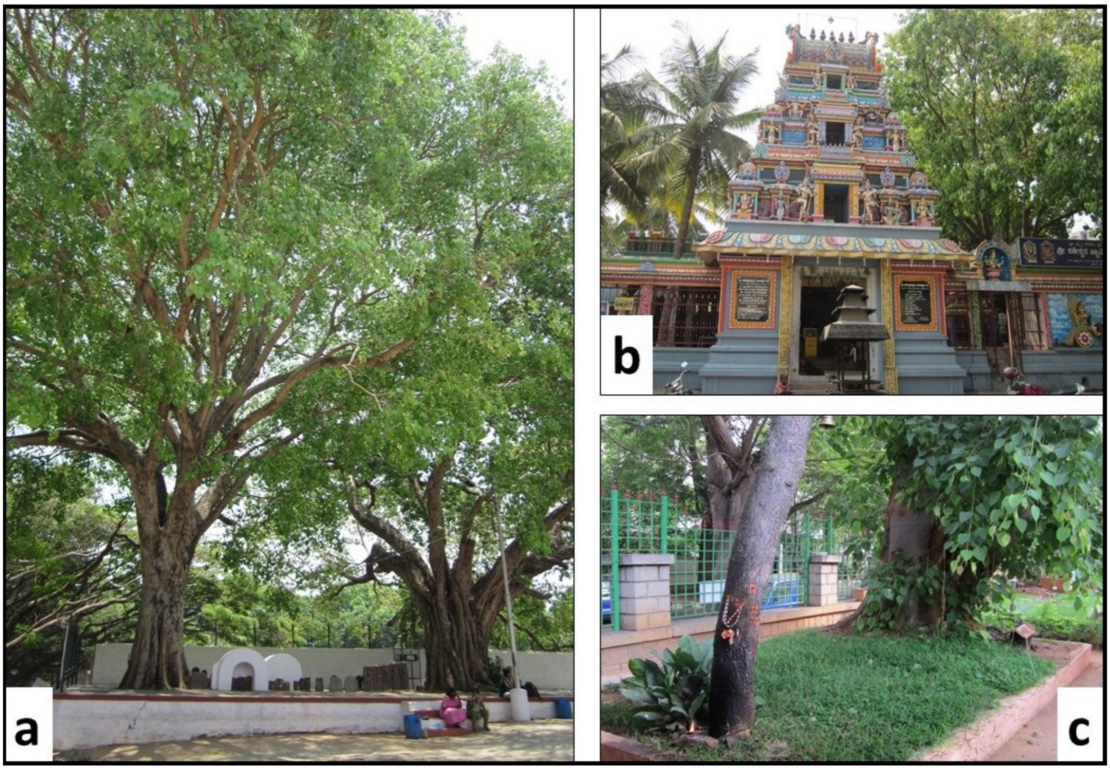


Fig. 1. (a) Katte – sacred trees on a raised platform in Bengaluru; (b) Temple facade with trees within the premises; (c) Lawn with ornamental species inside a temple

2.3. Study design

The urban – rural gradient is often non-linear with pockets of urbanity and rurality randomly spread across urban areas (McDonnell and Hahs 2008). Acknowledging this non-linearity, we use a stratified random sampling approach to account for major parameters that have been shown to often shape biodiversity patterns: Age of urban development (classified according to the three main development eras of Bengaluru city as old, intermediate and new; see Table 1) and housing density (categorized according to the number of housing units per hectare as high, medium and low). Housing density gives a rough estimate of socio-economic status with higher household income indicating bigger houses, implying lesser number of housing units per hectare and vice versa (detailed definitions in Table 1).

Table 1. Overview of environmental variables used to analyse biodiversity patterns in urban sacred sites of Bengaluru

Environmental variables	Scale	Data source
Age of urban development	*Old*: city boundary in 1941, representing the colonial era of the city. *Intermediate*: area between 1941 – 1991 administrative boundaries, representing the post-independence to pre-globalization era. *New*: area between 1991 to present administrative boundaries, representing the globalization - privatization era.	Sudhira, Ramachandra, and Subrahmanya 2007
Housing density / socio-economic status	*High*: slum areas with high more than 80 housing units / ha. Household income – low (rough estimate). *Medium*: housing quarters (with ~ 20-40 housing units / ha. Household income – moderate (rough estimate). *Low*: housing quarters with ~ 8-10 housing units / ha. Household income – high (rough estimate).	Eicher Goodearth Pvt. Ltd. 2002; National Institute of Urban Affairs 2008
Sacred site type	*Temples*: Structured institutions with a formal governing body. High intensity gardening practices (planting, landscaping, mowing, irrigation). Site area = 0.11 ± 0.20 ha. *Kattes*: Traditional systems of worship. Often community managed. Low intensity gardening practices. Site area = 0.05 ± 0.11 ha.	Nagendra 2016
Site area	Range: 0.01 ha – 2.56 ha	Direct assessment

The combination of the three factor levels of the two predictors (i.e. age x housing density) resulted in 9 strata, in each of which 4 neighborhoods were selected randomly. As both types of sacred sites (temple and katte) are frequently encountered in the urban area of Bengaluru, a pair of temple and katte with a maximum distance of 0.5 km were selected randomly for each neighborhood (in every stratum) to ensure comparable environmental conditions in each pair. However, three localities did not have *kattes,* thus, resulting in 69 study sites across Bengaluru city (Fig. 2). Since total area of sacred sites varied, within each site, a 10 x 10 m^2 plot was randomly located and sampled to maintain uniform plot size across the study. In addition to the assignment of each plot to definite levels of both urbanization variables, the size of the total area of each sacred site (henceforth referred to as site area) was measured by GIS analysis.

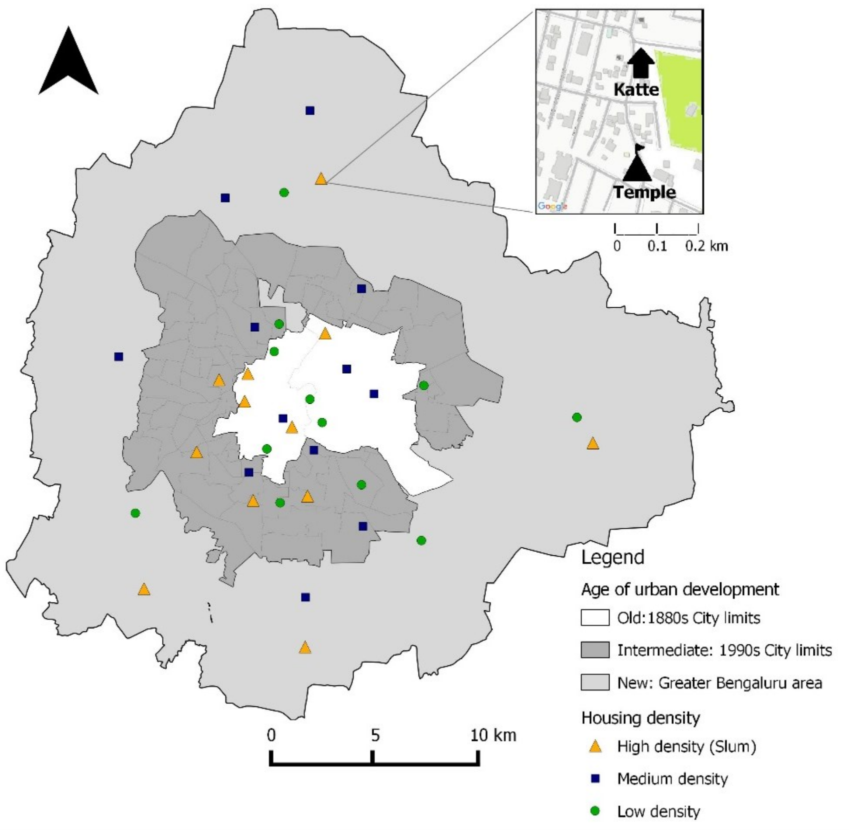


Fig. 2 Location of 36 neighborhoods across Bengaluru, identified from stratified random sampling approach for all combinations of urbanity predictors - age of urban development and housing density. Map inset: In each neighborhood, a pair of temple (n = 36) and katte (n = 33) with a maximum distance of 0.5 km from each other were selected randomly, resulting in 69 study sites.

2.4. Data collection

Field studies were carried out between March and May 2014. Within each plot, all vascular plants (trees, saplings, shrubs, herbs and vines) were recorded. All plant species were identified and differentiated as native and non-native species in southern India based on Kehimkar (2000), Krishen (2006), Kurian (2004) and Neginhal (2006). Individual plants were counted and each individual was classified as either cultivated (planted) or spontaneous (wild growing), based on our observations and information from caretakers or gardeners in temples; and community members in kattes.

2.5. Statistical analyses

Statistical analysis was carried out separately for total species, spontaneous species, cultivated species, native species and non-native species. Species richness, abundance of individuals within the different species groups (henceforth referred to as abundance) and beta diversity were taken as response variables to analyse the effects of urbanization parameters and type of sacred site on biodiversity.

Beta diversity was calculated to estimate species variation among communities, using Bray-Curtis dissimilarity on count data. Each plot was compared to all other plots within the same factor level; i.e., to either all old, intermediate or new plots based on age of urban development. Similarly, beta diversity was calculated for factor levels based on housing density and site type.

The impact of urbanization on species richness and abundance was analyzed by negative binomial generalized linear models (GLM); with age, housing density and site type as predictors and area of the sacred sites as a control variable. Negative binomial GLM was used to account for zero inflation in count data (Zuur et al. 2009). With site area as a control, we included only predictor variables and two-way interactions in the models. Models were simplified by stepwise backward selection based on AIC.

To test for the influence of environmental variables on difference in beta diversity between the factor levels, we carried out K-sample permutation test based on 9999 Monte Carlo permutations for each predictor group. This was followed up by a Nemenyi-Damico-Wolfe-Dunn (NDWD) post hoc test (Hollander et al. 2015). This test was also used for pairwise comparisons after GLMs when there were significant environmental variables with more than two factor levels.

Statistical tests were conducted using R, version 3.1.3 (R Development Core Team, 2015). All diversity indices, dissimilarity measures, regression and ordination techniques were computed using the packages BiodiversityR (Kindt and Coe 2005), *vegan* (Oksanen et al. 2009) and MASS

(Venables and Ripley, 2002). The K-sample test was computed through the *coin* package, and the NDWD test with the *multcomp* package.

3. Results

Field sampling revealed that sacred sites in Bengaluru harbor 121 plant species, with differences in species assemblages related to characteristics of the surrounding urban areas and the types of sacred sites. Overall, there were 2913 individuals belonging to different plant groups. As seen in Table 2, both native species richness and abundance were higher than non-natives. Even within the cultivated species and spontaneous species pools, a similar pattern was noticed, i.e. cultivated native species and spontaneously growing native species had more species and individuals than cultivated non-natives and spontaneous non-natives.

The control variable – site area, positively related to abundance and species richness of most plant groups, except for non-native species (Fig. 3 and 4). That is, despite maintaining uniform plot size (100 m^2) across all study sites, the number of species and individuals per unit area increased with total area of sacred sites (site area).

Table 2. Overall species numbers, abundance (number of individuals) and mean species richness found in sacred site plots in Bengaluru calculated for different plant groups, and results of Welch *t*-test for differences between means.

	Total species richness	%	Abundance (%)	Species richness Mean ± SD	
				Katte	Temple
Total species	121	100	100	4.3 ± 3.7	7.7 ± 6.0
Native species	84	69	81	3.5 ± 3.0	6.1 ± 4.6
Non-native species	37	31	19	0.8 ± 1.2	1.7 ± 2.7
Cultivated species	104*	-	49	3.1 ± 3.0	5.7 ± 4.7
• Native	69	66	64	2.3 ± 2.4	4.2 ± 3.3
• Non-native	35	34	36	0.6 ± 1.2	1.5 ± 2.6
Spontaneous species	30*	-	51	1.4 ± 1.6	2.1 ± 2.4
• Native	28	93	97	1.4 ± 1.5	2.0 ± 2.4
• Non-native	2	7	3	0.1 ± 0.3	0.1 ± 0.2

3.1. Age of urban development

Age of urban development did not relate to abundance and species richness (Fig. 3 and 4) across all species pools. Sacred sites located within new areas of the city had higher Bray-Curtis dissimilarity of species assemblages than study sites in the old and intermediate areas of the city, for the total and native species pools (Table 3). The NDWD post-hoc test further revealed that these differences were significant ($p < 0.05$). That is, species composition in new areas of Bengaluru was least similar (implying higher beta diversity) compared to other parts of the city.

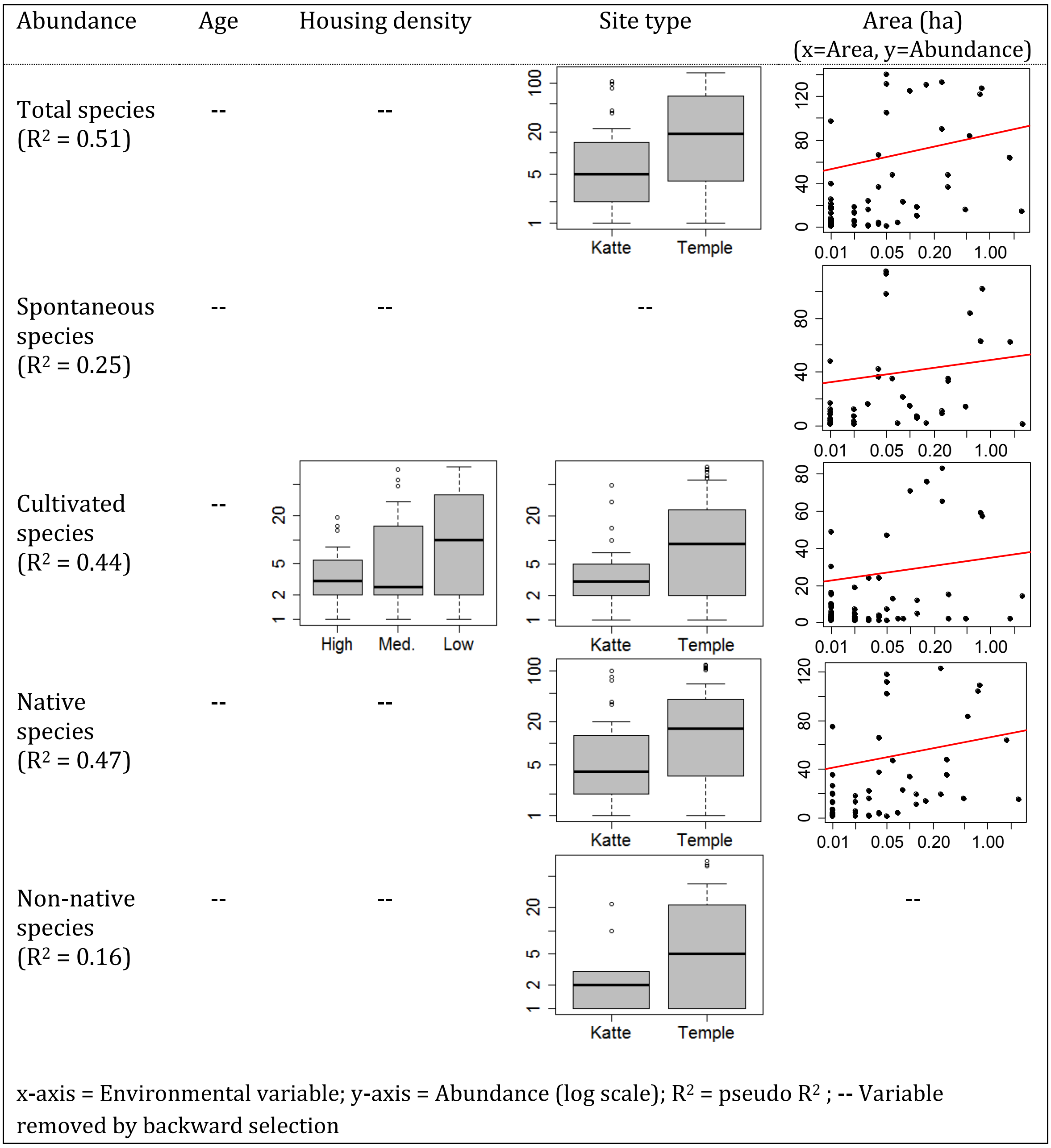


Fig. 3 Effects of environmental variables (predictors) on abundance of individual plants in Bengaluru's sacred sites. Overview of significant results (at $p < 0.05$) from negative binomial generalized linear models.

3.2. Housing density

Sacred sites located within low density housing areas had more individuals (higher abundance) of cultivated species than sites embedded in more dense quarters of the city (Fig. 3). However, the NDWD post-hoc test revealed that the differences between the factor levels were not significant ($p = 0.75$). Species richness of non-native species significantly related to housing density (Fig. 4) with low density housing quarters having more species than sites embedded in more dense quarters of the city; value for low density housing being significantly higher than medium density class ($p = 0.03$) as revealed by the NDWD post-hoc test. Beta diversity was higher in sacred sites within low density quarters than sites in denser parts of the city for the total, cultivated and native species pools (Table 3).

3.3. Sacred site type

Temples had more species and individuals across total, native, non-native and cultivated species pools than kattes (Fig. 3 and 4). Similarly, study plots in temples had significantly higher beta diversity ($p < 0.001$) than kattes (Table 3).

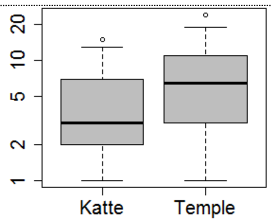
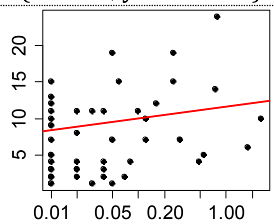
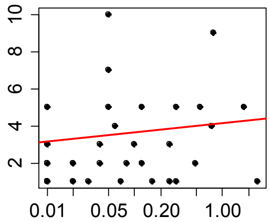
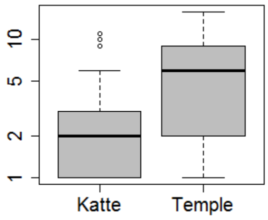
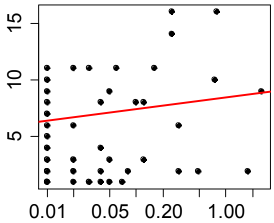
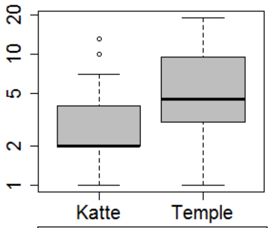
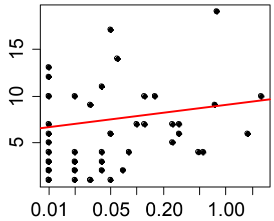
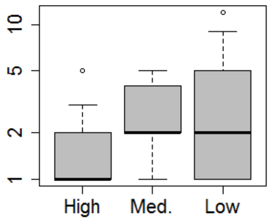
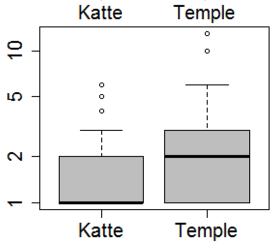
4. Discussion

While the importance of sacred sites for biodiversity conservation has been largely demonstrated for rural areas (i.e. sacred groves and forests, Bhagwat et al., 2005), one of the main insights from this study on urban sacred sites is that small sites within a quickly growing megacity can harbor, in total, a considerable richness of plant species. Applying a stratified sampling design revealed that assemblage of cultivated or spontaneous and native or non-native species were differently related to the age and density of urban development. Further, formally organized sites (temples) showed different biodiversity patterns than community managed sites (kattes).

4.1. Age of urban development

As a surprising result, species richness and abundance did not relate to the spatial-temporal position of sacred sites within the city of Bengaluru. This clearly contrasts with previous studies that have shown that age of development / establishment relates to plant diversity, with higher plant diversity in newer localities (Luck et al. 2009; Wang et al. 2012). In this context, sacred sites seem to be constant in time and space with no impact of age on species richness and abundance. Changing historical preferences for plant species have had an influence on diversity patterns in Bengaluru's parks and slums (Nagendra and Gopal 2010; Gopal et al. 2015). However, these preferences do not seem to influence diversity in sacred sites – perhaps due to the long-established traditional structure of these ancient ecosystems.

In contrast, beta diversity related to age of urban development in the total and native species pools with species assemblages in old and intermediate sites being more similar in composition than that in new sites. This suggests that new communities are more heterogeneous and are homogenizing with age which could be an effect of higher variation in site conditions and opportunities for colonization in newly developed sacred sites compared to older ones.

Species richness	Age	Housing density	Site type	Area (ha) (x=Area, y=Richness)
Total species (R^2 = 0.23)	--	--		
Spontaneous species (R^2 = 0.22)	--	--	--	
Cultivated species (R^2 = 0.14)	--	--		
Native species (R^2 = 0.28)	--	--		
Non-native species (R^2 = 0.31)	--			--

x-axis = Environmental variable; y-axis = species richness (log scale); R^2 = pseudo R^2 ; -- Variable removed by backward selection

Fig. 4 Response of species richness to environmental variables (predictors) in sacred sites of Bengaluru. Results (at $p < 0.05$) of negative binomial generalized linear models.

4.2. Housing density

Richness of non-native species in low-density housing quarters was higher than that in the other two density classes. Human population density (housing density used as a proxy for the same) has been identified as a predictor for non-native species richness (Sharma et al. 2010; Fuentes et al. 2015; Fischer et al. 2016), as noticed in our study (Fig. 4). Diversity measures were highest in low-density quarters, which have the highest social-economic status in Bengaluru. This could be attributed to the "luxury effect" – the positive association of wealth with plant diversity (Hope et al. 2003). The relevance of this effect was further supported by the abundance of cultivated species, increasing from high to low density housing quarters (Fig. 3). Consequently, high density housing quarters, mainly comprising of slums with lower household incomes, had lower plant diversity and abundance (data not shown). This further reflects on the role of socio-economics, including access to resources (land, finances, etc.) and lifestyle choices (gardening practices, etc.); in modulating plant diversity patterns.

4.3. Sacred site type and site area

The higher diversity measures for temples compared to kattes can be related to different gardening practices (Table 1). Studies have shown an increase in non-native species with increasing management intensities including mowing, watering and pruning (Boughton et al. 2011; Tomasetto et al. 2013). In contrast, diversity of both native and non-native species was higher for temples (high management intensity) than kattes (low management intensity). Therefore, sacred site area might be a more relevant factor than management intensity to explain the differences in diversity patterns between temples and kattes with temples being larger in area than kattes.

Studies on parks have shown park area as a key predictor for plant diversity (Cornelis and Hermy 2004; Li et al. 2006; Fischer et al. 2016). Likewise, total area of sacred sites positively influenced most diversity measures in sampled plots, which were uniform in (plot) size. This may be explained by a higher heterogeneity of larger sacred sites in terms of land use types (e.g. flower beds, lawns, plantings of native and non-natives ornamentals) and management intensities. Parks with larger area are often associated with higher exotic species richness (Cornelis and Hermy 2004). In contrast, there may be a preference for selective breeding of native species over non-native species in larger sacred sites, explaining the absence of an association between site area and diversity of non-natives.

Table 3. Effects of environmental variables on mean Bray-Curtis dissimilarity - Results of approximative K-sample permutation test for total, spontaneous, cultivated, native and non-native species pools.

	Mean Bray-Curtis dissimilarity			Chi-square	K-sample p value	NDWD Pairwise comparison Significant differences at $p < 0.05$
Age	Old	Int.	New			
Total	0.84	0.83	0.89	13.85	0.001	Old vs. New; Int. vs. New
Spontaneous	0.84	0.78	0.81	3.25	0.19	-
Cultivated	0.87	0.86	0.87	0.28	0.87	-
Native	0.81	0.81	0.88	16.98	< 0.001	Old vs. New; Int. vs. New
Non-native	0.92	0.93	0.95	0.89	0.65	-
Housing density	High	Med.	Low			
Total	0.79	0.84	0.89	31.74	< 0.001	High vs. Low
Spontaneous	0.72	0.87	0.84	14.05	< 0.001	-
Cultivated	0.79	0.82	0.94	45.14	< 0.001	High vs. Low; Med. vs. Low
Native	0.76	0.83	0.87	37.49	< 0.001	High vs. Low
Non-native	0.94	0.95	0.93	0.14	0.94	-
Site type	Katte	Teml		z		
Total	0.80	0.88		- 6.88	< 0.001	
Spontaneous	0.79	0.80		- 0.72	0.47	
Cultivated	0.81	0.90		- 5.89	< 0.001	
Native	0.78	0.86		- 6.33	< 0.001	
Non-native	0.97	0.94		1.10	0.28	

NDWD - Nemenyi-Damico-Wolfe-Dunn test; Int. – Intermediate age class; Med. – Medium housing density; Tmpl = Temple

4.5. Implications for management and conservation

Our study highlights sacred sites as habitats for native and spontaneous plant species (Table 2) with minimal impact of urbanization on these plant groups (Fig. 3 and 4). There is a higher proportion of native species (69 %) within the total species found in sacred sites as compared to other land-use types in Bengaluru (Gopal et al. 2015) and green spaces in other cities including Bandung (Abendroth and Kowarik 2012), Santiago (Fischer et al. 2016) and Chennai (Muthulingam and Thangavel 2012). Surprisingly, the overwhelming majority (99%) of spontaneous species were native (Table 2). This illustrates that sacred sites in Bengaluru function as habitats of wild growing native species, but not as invasion foci despite considerably high numbers (36 %) of cultivated non-native species. While there is higher acceptance of 'wild' elements in urban green spaces in other parts of the world (eg. Weber et al. 2014; Rupprecht et al. 2015), manicured gardens with lawn and species of aesthetic value seem to be preferred in most land-use types in Bengaluru (Nagendra 2016), providing an example for conflicting views between natural ecosystem development (natural succession) and ideals of neatness.

In contrast, kattes have great potential for spontaneous regeneration due to low management intensity. However, the openness (no fences) of kattes increases the potential impacts of edge effect and herbivory (cattle and goats). Temples, therefore, seem to provide better conditions as sites for urban biodiversity. Perhaps, providing an array of differently managed sections within sacred sites may cater to a wide range of user groups. While some sections can be visitor friendly and regularly managed; others can be less-attended, allowing a higher level of natural ecosystem processing as proposed for old cemeteries in Europe (Kowarik et al. 2016).

Additionally, information about native, spontaneous wilderness and the associated local fauna they support, should be shared with visitors. Sharing such knowledge along with public involvement could raise awareness among visitors, augmenting acceptance of these 'wild' natural elements; further enhancing biodiversity (Shwartz et al. 2014) and experience of natural elements that is generally decreasing in urban populations (Soga and Gaston 2016).

4.6. Relevance of sacred sites within urban green infrastructure

Sacred sites are cultural heritage sites with an inherent conservation value, often protected by cultural taboos (Verschuuren et al. 2010). With cities in many developing countries losing green cover over infrastructure development, sacred sites can function as stable components of the urban green infrastructure. Cultural taboos associated with cutting down sacred plant species often seem to be more effective in saving trees and plant species, than formal systems of governance (Nagendra 2016).

In developing countries where economic growth takes precedence over urban green cover (Pauchard et al. 2006), culturally significant urban ecosystems could augment conservation efforts. Unconventional green spaces including cemeteries (Kowarik et al. 2016), private gardens (Goddard et al. 2010), business sites (Serret et al. 2014), wastelands (Bonthoux et al. 2014) and sacred sites could contribute to ecological networks in highly fragmented urban areas and provide access to nature experience for urban people.

While urban centres in the Indian sub-continent have existing sacred spaces with immense community support, policy makers need to highlight the biodiversity value of these spaces and recognize them as crucial green spaces within the urban green infrastructure which would further enhance their protection and management. At the global scale, Bengaluru's sacred spaces present excellent examples of unconventional green infrastructure maintained by urban communities.

5. Conclusions

Our study demonstrates the potential of sacred sites in urban biodiversity conservation. With limited influence of age of urban development and housing density on plant diversity, sacred sites appear to be stable harbours of biodiversity across varying levels of urbanity. While policies and practices need to be tailored in accordance with country-specific political and socio-economic components; existing (traditional) conservation practices need to be identified, integrated and empowered to pave new avenues towards enriching urban biodiversity. Sacred spaces are often present in many cities across the globe. Community acceptance and co-operation in managing sacred spaces could be high due to their cultural relevance, as seen in Bengaluru, enhancing urban biodiversity conservation. Further research on faunal diversity in sacred spaces and influence of sacred spaces on microclimate could supplement the relevance of these unconventional green spaces.

Acknowledgements

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Chapter 3: Sacred sites as habitats of culturally important plant species in an Indian megacity

Sacred sites as habitats of culturally important plant species in an Indian megacity

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Abstract

Cultural ecosystem services related to urban green spaces contribute significantly to liveable cities. While previous studies highlight the intersection of cultural ecosystem services with societal values, spiritual or religious values associated with urban nature have received less attention. In India, as in other parts of the world, sacred sites are known for their biological richness, but analyses from urban sacred sites are largely missing. Based on a stratified random sampling approach, we analysed the cultivated and wild plant species assemblages of 69 sacred sites in the megacity of Bengaluru, India, in relation to biological and cultural features, and parameters related to the urban matrix and type of sacred sites (temple vs. katte). Unlike other urban studies, we found a dominance of native species in the cultivated and spontaneous species pools (121 species in total), with Ficus religiosa and Azadirachta indica as most frequently planted species. Culturally relevant species prevailed in the species pool (89%), with overlaps between religious (36%), medicinal (50%) and ornamental (62%) plants; only 11% of species were weeds. Urban matrix parameters (age of development, housing density) and size and type of sacred sites were related to differences in species assemblages. We identified key species for different classes of age and housing density, and for types of sacred sites. Our study demonstrates that urban sacred sites have an important potential in harbouring both native and culturally significant species that can support urban livelihoods in developing countries by a range of cultural and provisioning ecosystem services, including medicinal uses. As such sites are conserved by communities for spiritual or cultural beliefs; local biodiversity can be enhanced, e.g. by adapting management practices, through community participation. This would strengthen the important contribution of sacred sites within the green infrastructure of rapidly growing megacities.

Keywords

Cultural ecosystem services, Plant invasions, Spiritual-religious values, Urban biodiversity, Urbanization

1. Introduction

With accelerating urbanization, urban green spaces become increasingly important for liveable cities due to a range of ecosystem services they provide for urban inhabitants (Bolund and Hunhammar, 1999; Haase et al., 2014). Cultural ecosystem services, i.e. “the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience” (Millennium Ecosystem Assessment, 2005; p. 894), contribute significantly to the quality of life in cities (Gómez-Baggethun et al., 2013). Human values critically matter for understanding cultural ecosystem services as the latter can be generally conceptualized as an outcome of people’s interaction with ecosystems (Chan et al., 2012; Fish et al., 2016). Yet, values vary among and within societies and have rarely been acknowledged in studies on the intersection of urban people and urban nature (Botzat et al., 2016), despite their importance for environmental management (Ives and Kendal, 2014). From a western perspective, cultural ecosystem services have been largely associated with social and cultural values such as place values, sense of community and identity, physical and mental health, social cohesion, and educational values (Chan et al., 2012; Gómez-Baggethun and Barton, 2013). In European urban park studies, for example, it is recreational ecosystem services that are most prominent (Bertram and Rehdanz, 2015). In contrast, spiritual or religious values are expected to be less associated with urban nature as they are mostly attributed to built-structures like churches or monuments (Gómez-Baggethun and Barton, 2013). Consequently, indicators for spiritual or religious values related to cultural urban ecosystem services are critically underrepresented in previous studies (La Rosa et al., 2016).

Beyond the western world, however, spiritual and religious values associated with nature are much more prominent among cultural ecosystem services as demonstrated by the concept of sacred sites. Sacred sites encompass a wide range of natural elements, sometimes in combination with built structures, including burial places, sacred groves, sacred forests, mountains and water bodies (Verschuuren et al., 2010). The cultural values attributed to sacred sites may be derived from historic events that occurred in a particular site, mythological and local folklore references, and the existence of burial sites (Jackson and Ormsby, 2017; Krishna and Amirthalingam, 2014). Conserving sacred sites due to their inherent cultural values clearly contributes to biodiversity conservation – making these sites repositories of biocultural diversity (Bhagwat et al., 2005; Bhagwat and Rutte, 2006; Ishii et al., 2010; Pungetti et al., 2012; Verschuuren et al., 2010). While a wealth of studies have disclosed important biodiversity functions of sacred sites in non-urban landscapes (e.g, Bhagwat et al., 2005; Jamir and Pandey, 2003), little is known about the biodiversity of sacred sites within cities (Ishii et al., 2010; Jackson and Ormsby, 2017; Nagendra, 2016), except few studies on urban cemeteries (Barrett and Barrett, 2001; de Lacy and Shackleton, 2017; Kowarik et al., 2016).

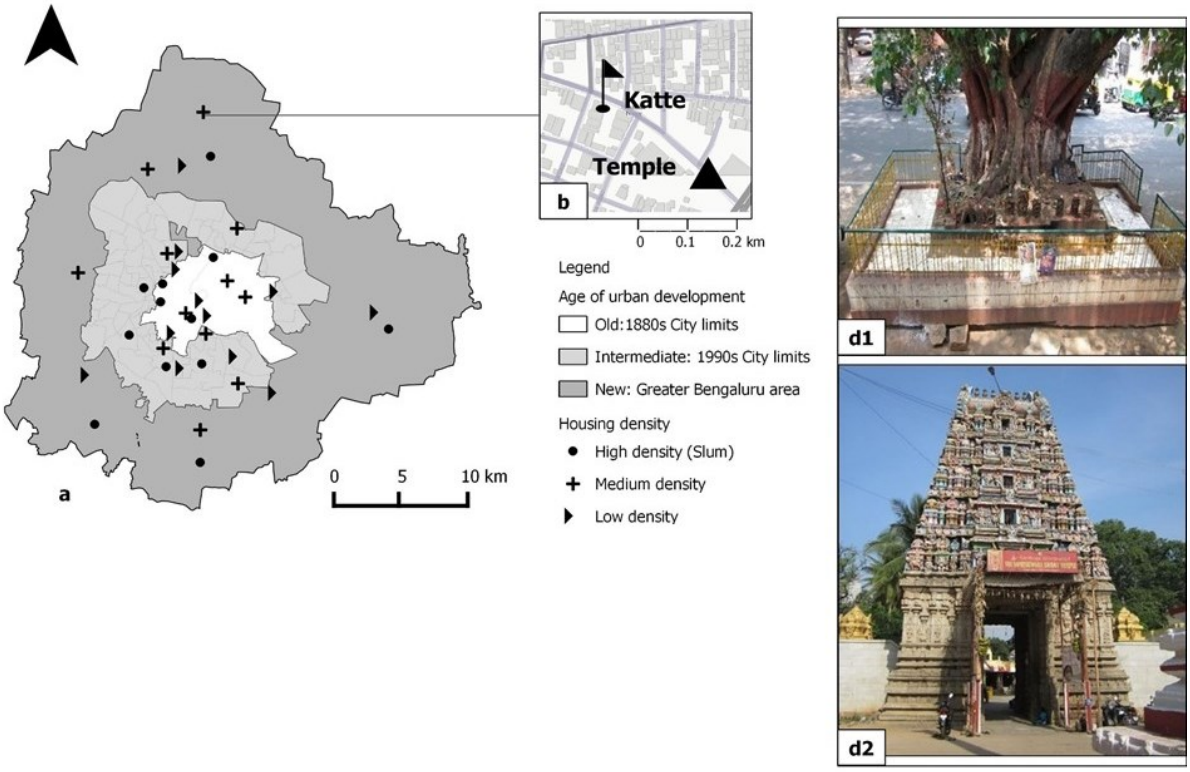


Figure 1. (a) Location of 36 neighbourhoods across Bengaluru representing 9 strata identified from stratified random sampling approach for urbanity predictors - age of urban development and housing density. (b) In each neighbourhood, a pair of temple (n = 36) and katte (n = 33) with a maximum distance of 0.5 km from each other were selected randomly, resulting in 69 study sites. (d) Example of a katte (d1) and a temple (d2).

In a quickly urbanizing world, urban biodiversity is of increasing importance as cities in general (McKinney, 2002; Shwartz et al., 2014); and conventional (Fischer et al., 2016; Galluzzi et al., 2010) and unconventional (Bonthoux et al., 2014; Dvorak and Volder, 2010) green space types in particular; have been shown to harbour a considerable biological richness. The total range of urban land-use types, thus, matters for biodiversity conservation (Kowarik, 2011; Shwartz et al., 2014) as well as for opportunities for urban people to encounter nature (Kowarik, 2017; Soga and Gaston, 2016). Due to accelerated urban growth, however, urban green spaces are increasingly under pressure (Lin and Fuller, 2013; Soga et al., 2014). This specifically holds for megacities in developing countries (Pauchard et al., 2006), including India (Nagendra et al., 2013).

As a paramount exception from this trend, sacred sites largely remain untouched and thus might function - due to their cultural importance - as permanent ‘islands’ within the swiftly changing land-use patterns of growing megacities. This has been indicated for the environments of temple and shrine forests in Japanese cities that represent natural remnants in urban regions (Ishii et al., 2010) and for sacred sites in Indian cities (i.e., temples and kattes; Nagendra, 2016; Nagendra et al., 2013). Due to a long-standing tradition of nature worship in India (Krishna and Amirthalingam, 2014) cultural beliefs and traditional practices protect and conserve these urban sacred sites.

Sacred sites are omnipresent in cities of the Indian subcontinent, and beyond. The species assemblages of such sites and their cultural significance however, have not yet been disclosed despite growing knowledge of plant species composition of different green space types in Indian cities, including comprehensive studies on a wide range of land-use types (Bhalla and Bhattacharya, 2015; Chaturvedi et al., 2013; Muthulingam and Thangavel, 2012; Sudha and Ravindranath, 2000); as well as specific studies on parks (Nagendra and Gopal, 2011), tree lined streets (Bhat et al., 2016; Nagendra and Gopal, 2010), domestic gardens (Jaganmohan et al., 2012), and slums (Gopal et al., 2015; Gopal and Nagendra, 2014). Given the prevalence of non-native species in many urban ecosystems (Fischer et al., 2016; Kowarik, 2011; Nagendra and Gopal, 2011, 2010), it is an open question whether urban sacred sites in India function as habitats for native species as do sacred groves and forests outside of cities (e.g., Bhagwat et al., 2005; Jamir and Pandey, 2003). We, therefore, aim to fill this gap in basic knowledge about the species composition of urban sacred sites in India, using the fast-growing megacity of Bengaluru as a model city.

In a companion study, we have addressed the influence of urbanization on biodiversity measures (e.g. diversity indices and richness measures) in urban sacred sites. In this study, we disclose the occurrence of different groups of cultivated and spontaneous (i.e., non-cultivated) plants in urban sacred sites, with a focus on culturally important plant species that may functions as indicators of cultural ecosystem services. As other urban studies have revealed the importance of a range of parameters – related to the type or pace of urbanization – for the composition of urban species assemblages (Fischer et al., 2016; Nielsen et al., 2014; Zhao et al., 2010), we also aimed at a better understanding of environmental drivers that underlie the species composition of urban sacred sites. In particular, we (1) aim to explore to what extent plant species groups with different ecological and cultural features contribute to the species assemblages of sacred sites; and (2) analyse how key species (individual plant species contributing to most of the differences within sub-groups of environmental variables) and plant species assemblages, in general; are affected by environmental variables (i.e. age of urban development, housing density and differences within sacred sites as temples and kattes).

2. Methods

2.1. Study area

The study was carried out in Bengaluru city, India with a population of around 10 million people spread across an area of 741 km^2. The governing bodies in Bengaluru have focussed more on economic development at the cost of green spaces and water bodies, as seen in many other cities from developing countries. Yet, civil society has played a significant role in shaping Bengaluru's environment protection efforts, in recent years (Sudhira and Nagendra, 2013).

2.2. Sacred sites and sacred plants

Globally, sacred sites range from places of worship, sacred forests, and landscapes to cemeteries and heritage sites (Verschuuren et al., 2010). We studied Hindu places of worship in Bengaluru, broadly classified as temples and kattes. Kattes are ancient places of worship with open-air shrines (mostly serpentine forms) placed under trees (often belonging to the *Ficus* genera), on raised stone-platforms. Temples are later constructions with a clear boundary, enclosing a built structural element and managed by a formal organizing body (Table 1 and Figure 1). Kattes continue to be managed mainly by local communities.

Most sacred sites are associated with plants that often have mythological and religious associations. In ancient times, plant species were considered sacred if they had medicinal qualities, economic value (e.g. Coconut tree), ecological importance (sacred forests and mangroves) and/or socio-cultural relevance (e.g. Banyan tree as a business hub) (Krishna and Amirthalingam, 2014); and were integrated into mythologies and folklore. However, plant species within a sacred forest or a sacred site are not limited to sacred species; often including ornamental species, fruiting varieties and wild-growing plants.

Table 1. Descriptions of environmental variables included to assess patterns in species composition in sacred sites of Bengaluru.

Environmental variables	Levels		
Age of urban development	*Old*. City limits as of 1941 (Colonial period).	*Intermediate*. City limits of 1991 (pre globalization era).	*New*. Current city limits (post-globalization).
Housing density	*High*. Slum area with 80 housing units / ha. Low household income (rough estimate).	*Medium*. ~ 20 – 40 housing units / ha. Moderate household income.	*Low*. Wealthier residential areas with ~ 8-10 housing units / ha.
Site-type	*Temples*. - Built structures, often with sacred plant species, ornamental plants and/or a lawn. Area: 0.11 ± 0.20 ha. - Often managed by a gardener (high management intensity – watering, mowing and planting). - Formally governed by an institution.	*Kattes*. - Raised platform with sacred trees and plants (mainly *Ficus religiosa*). - Smaller in area (0.05 ± 0.11 ha). - Low / infrequent management intensity. - Community managed.	
Site-area	Range: 0.01 ha - 2.56 ha.		

2.3. Study design and sampling

We used a stratified random sampling approach to characterize drivers of species composition patterns in sacred sites of Bengaluru. At the city-scale, we included urbanity gradients – age of urban development (characterised by predominant urban development eras of Bengaluru as old, intermediate and new; see Table 1) and housing density (characterised by number of housing units per hectare as high, medium and low; see Table 1) – both parameters often used to describe urbanization (Luck, 2007; Wang et al., 2012). In the absence of socio-economic data, housing density was used as a surrogate where size of housing unit roughly increases with household income, implying a decrease in number of housing units per hectare with increasing household income and vice versa. Combining the factor levels of the two predictors – age and housing density, resulted in 9 strata of urbanity. In each stratum, four neighbourhoods were selected randomly from each of which, a pair of temple and katte (collectively referred to as site-type) within a distance of 0.5 km from each other were randomly selected (ensuring comparable local environmental conditions for each pair). As a result, we had 69 study sites (sacred sites) across Bengaluru city (Figure 1). To account for variations in total area of sacred sites (site-area measured by GIS analysis), a 10 X 10 m^2 plot was randomly located and sampled in each sacred site to maintain uniform plot size across the study.

Field studies were conducted between March and May 2014. In each plot, all vascular plants were recorded and identified with reference to literature (Kehimkar, 2000; Krishen, 2006; Kurian, 2004; Neginhal, 2006). Species composition is often assessed based on incidence data (presence/absence of species), wherein species abundance (number of individuals of each species) is not taken into account, thus treating both abundant and rare species equally (Chao et al., 2006). Further, tests based on incidence data are sensitive to clumped distributions as was noticed in our data (Plotkin and Muller-Landau, 2002). Therefore we recorded abundance of each species to allow for more robust analyses of species composition. Individual counts were noted for herbs, shrubs and trees. For graminoids, a 1 X 1 m^2 quadrat within each 100 m^2 plot was randomly placed and sampled for graminoid counts, i.e. counts of tillers as proxy for individuals in clonal growing graminoids. Then, species cover (percentage cover of each graminoid species in each plot) was determined and the two were used to extrapolate abundance data for graminoids in each plot.

We grouped plant species based on their different ecological and cultural features as follows.
Life forms. Life forms illustrate the differences in assemblages of species based on their growth habits namely; perennial graminoids, annual herbs, perennial herbs, shrubs and trees.

Introduction status. Origin of plant species as native or introduced to southern India, were distinguished with reference to literature (Kehimkar, 2000; Krishen, 2006; Kurian, 2004; Neginhal, 2006).

Wild growing species. Plant individuals were differentiated as spontaneous (wild growing) and cultivated (planted) with information from gardeners and community members present at the study sites. Information about spontaneous species would indicate whether sacred sites functions as habitats for native species or as invasion foci for introduced species that escape cultivation.

Species with cultural significance. We assigned attributes to species according to their cultural importance: plants with religious associations, medical plants, ornamental plants, and weeds, the latter as species without obvious cultural relevance. Many species had multiple attributes/values which have been represented in Table 2 and Figure 2 to demonstrate the diverse qualities of culturally significant species.

2.4. Statistical analysis

We conducted separate statistical tests for total species, native species, non-native species, cultivated species and spontaneous species. SIMPER analysis was carried out to identify the most influential species contributing to 70% of differences between groups, for each of the predictor variables – age of urban development, housing density and site-type. We then checked for individual responses of key species (21 species as identified by SIMPER analysis) to environmental variables using generalized linear models (GLM) with age, housing density and site-type as predictor variables and site-area as a control variable. To account for over-dispersion, quasi-Poisson and negative binomial GLMs (Zeileis, Kleiber, and Jackman 2008) were used. The most appropriate models were selected through stepwise backward selection using AIC. Goodness-of-fit for the models were determined by calculating the pseudo R^2 value (Zuur et al., 2009). Significant results were followed up with general linear hypotheses (*glht* with Tukey's all-pairwise comparisons) as a post-hoc test for pairwise comparisons of factor levels (Hothorn et al., 2008).

The influence of environmental drivers on species composition was assessed with non-metric multidimensional scaling (NMDS) ordination technique (using *metaMDS* function for community ordination; Oksanen et al. 2009) based on Bray-Curtis distance matrix. We included species that occurred in at least three sites or more to reduce statistical noise (McCune and Grace, 2002). Abundances of plant species were standardized using Wisconsin double standardization and square root transformation. The fit of environmental variables with the resulting ordination was determined using the *envfit* function of the *vegan* package in R.

Statistical tests were conducted using R, version 3.1.3 (R Development Core Team, 2015). Ordination, SIMPER analysis and regression techniques were computed using the packages BiodiversityR (Kindt and Coe, 2005), *vegan* (Oksanen et al. 2009) and MASS (Venables and Ripley, 2002); and post-hoc tests with the *multcomp* package.

Table 2. Plant species in sacred sites of Bengaluru (n = 69) with information on introduced species (indicated by *); life from (tree, shrub, perennial herb (P.Hrb), perennial graminoid (P.Gr.), annual herb (A.Hrb)); cultural attributes (religious associations (R), medicinal (M) and ornamental (O)); species frequency (*f*); species abundance (SA); spontaneity ratio (proportion of spontaneous individuals per all counts of the respective species) and key species (SIMPER results). The list includes species occurring in at least 3 sites (n = 44), collectively adding up to 75% of all individuals. Affiliations of key species contributing to 70% of differences between factor levels for each of the environmental variables (Table 1) – age, housing density and site-type – are shown.

Scientific Name	**Life form**	**Attri- -butes**	**Species**		**Spont- -aneity ratio**	**Key species for**		
			f **(%)** (n=69)	**SA** (%) (n=2913)		**Age**	**Housing**	**Site type**
(a) Culturally significant plants (n = 35)								
Cynodon dactylon	P.Gr.	R, M, O	23.2	35.9	0.60	Int	Low	Temp
Nerium indicum	Shrub	R, M, O	17.4	0.6	-	.	.	Temp
Hibiscus rosa-sinensis	Shrub	R, M, O	15.9	1.6	-	New	Low	Temp
Cocos nucifera	Tree	R, M, O	15.9	0.5	-	.	.	Temp
Tabernaemontana divaricata	Shrub	R, M, O	10.1	0.6	-	.	.	.
Michelia champaca	Tree	R, M, O	8.7	0.3	-	New	Med	.
Jasminum sambac	Shrub	R, M, O	7.2	0.3	-	.	.	.
Rosa damascena	Shrub	R, M, O	5.8	0.3	-	New	Med	.
Ficus drupacea pubescens	Tree	R, M, O	5.8	0.1	0.25	.	Med	.
Pongamia pinnata	Tree	R, M, O	5.8	0.1	-	.	.	.
Musa paradisiaca	Tree	R, M, O	4.3	0.3	-	.	.	.
Clitoria ternatea	P.Hrb	R, M, O	4.3	0.1	-	.	.	.
Ficus religiosa	Tree	R, M	60.9	3.1	0.62	Int	Med	Temp
Azadirachta indica	Tree	R, M	40.6	1.0	-	.	Hi; Med	.
Ocimum tenuiflorum	P.Hrb	R, M	11.6	0.4	-	.	.	.
Ficus racemosa	Tree	R, M	11.6	0.3	0.13	.	.	.
Prosopis cineraria	Tree	R, M	8.7	0.2	0.14	.	.	.
Citrus medica	Tree	R, M	7.2	0.3	-	.	.	.
Aegle marmelos	Tree	R, M	7.2	0.2	-	Old	.	Temp
Desmostachya bipinnata	P.Gr.	R, M	4.3	0.5	-	New	Hi	.
Artocarpus heterophyllus	Tree	R, M	4.3	0.1	-	.	.	.
Mangifera indica	Tree	R, M	4.3	0.1	-	.	.	.
Calotropis gigantea	Shrub	R, M	4.3	0.1	0.25	.	.	.
*Epiphyllum oxypetalum**	Shrub	R, O	4.3	0.1	-	.	.	.
Hibiscus schizopetalus	Shrub	M, O	4.3	0.2	-	.	.	.
Leucas aspera	A.Hrb	M	4.3	0.2	1.00	.	.	.
*Aloe vera**	P.Hrb	M	4.3	0.1	-	.	.	.
*Codiaeum variegatum**	Shrub	O	10.1	0.8	-	.	.	.
*Dracaena reflexa**	Shrub	O	8.7	0.6	-	.	Low	Temp
*Aglaonema commutatum**	Shrub	O	7.2	0.9	-	.	.	.
*Dypsis lutescens**	Shrub	O	7.2	0.9	-	Int	Low	.

*Zephyranthes rosea**	P.Hrb	O	7.2	0.8	-	.	.	.
Syngonium podophyllum	Shrub	O	4.3	1.5	-	Int	Low	.
*Duranta goldiana**	Shrub	O	4.3	1.2	-	.	Low	.
*Anthurium andraeanum**.	Shrub	O	4.3	0.2	-	.	.	.
(b) Garden weeds (n = 9)								
Oxalis corniculata	P.Hrb		18.8	6.9	1.00	Int	Med	Temp
Synedrella nodiflora	P.Hrb		17.4	8.1	1.00	Int	Med	Temp
Amaranthus spinosus	A.Hrb		15.9	1.2	1.00	.	.	Temp
Conyza bonariensis	A.Hrb		11.6	0.8	1.00	.	.	.
Amaranthus viridis	A.Hrb		7.2	0.7	1.00	New	.	.
Parthenium hysterophorus	A.Hrb		5.8	1.3	1.00	Old	Low	Katte
*Lantana camara**	Shrub		5.8	0.3	1.00	.	.	.
Portulaca oleracea	A.Hrb		4.3	1.1	1.00	.	.	.
Euphorbia microphylla	A.Hrb		4.3	0.7	1.00	.	Med	.
(c) Species < 3 sites (n = 77)			< 4.3	24.6				

Int – Intermediate age class; Hi – High density housing; Med – Medium density housing; Temp - Temples

3. Results

3.1. Biological richness and species assemblages in sacred sites

Overall, we encountered 121 plant species with 2913 individuals during field sampling. The tree species, *Ficus religiosa* and *Azadirachta indica*, were the most frequent occurring species present in 61% and 41% of sites (n = 69), respectively, followed by *Cynodon dactylon* (perennial graminoid) present in 23% of study sites (Table 2). With regard to species abundance, *Cynodon dactylon* was the most abundant accounting for about 36% of all counts (n = 2913), followed by *Zoysia tenuifolia* (12%) and *Synedrella nodiflora* (8%); all three belonging to the herbaceous layer.

Life forms, introduction status and wild growing species

Tree species dominated the species pool, accounting to about 38% of all species (n = 121), followed by shrubs (28%), perennial herbs (22%), annual herbs (9%) and perennial graminoids (2%). Despite the low species richness of graminoids, they accounted for 49% of all individual counts (n = 2913), while trees accounted for only 9%.

Native plants dominated the species pool with 69% of all species (n = 121) and 81% of all individual counts (n = 2913). The most frequently occurring and most abundant native species again were *Ficus religiosa* and *Cynodon dactylon*, respectively. Of the non-native species, *Codiaeum variegatum* (an ornamental shrub) was the most frequent, present in 10% of study sites; while *Zoysia tenuifolia* (a perennial graminoid) was the most abundant (12% of all individual counts, occurring in 3% of sites).

Spontaneous and cultivated species had a nearly equal presence in sacred sites (51% and 49% of all counts, respectively). Notably, all garden weeds were of spontaneous growth, while most ornamentals (except *Lantana camara*, often considered a weed when growing wildly) were cultivated (Table 2). Native species accounted for 97% of all spontaneous individual counts (n = 1436) and 64% of all cultivated individual counts (n = 1477).

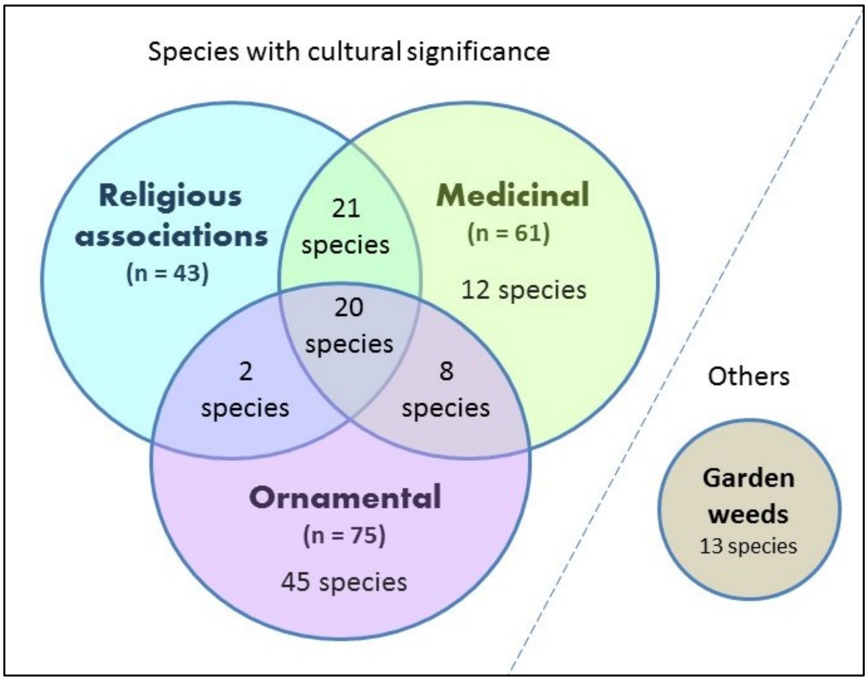


Figure 2. Attributes of plant species (n = 121) with reference to their cultural significance in urban sacred sites of Bengaluru.

Species with cultural significance

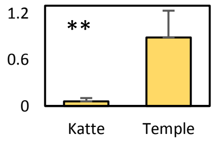
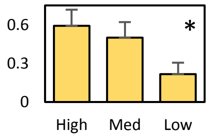
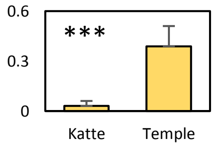
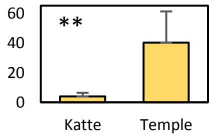
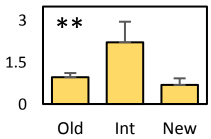
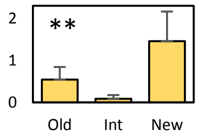
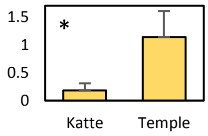
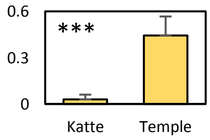
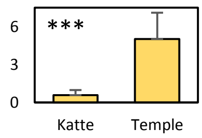
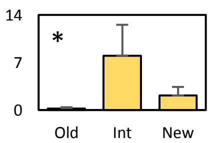
Culturally significant species included those with religious associations, medicinal uses and ornamental value (often with overlaps), collectively accounting to 89% of all species (n = 121). Including overlaps of attributes, ornamental species accounted for 62% of all species (n = 121) and 69% of all individual counts (n = 2913); followed by medicinal species (50% of all species and 53% of all individual counts); species with religious associations (36% of all species and 50% of all individual counts); and garden weeds (11% of all species and 22% of all individual counts). Details regarding species in sacred sites can be found in Table 2.

The diverse and overlapping attributes of culturally significant species are represented in Figure 2. 17% of species (n = 121) were associated with all three attributes - religious significance, medicinal uses and ornamental value - *Cynodon dactylon* being the most frequently encountered and the most abundant species. In particular, species with religious associations invariably had medicinal uses, ornamental value or both.

3.2. Key species and drivers of abundance at the species scale

We included species that occurred in at least three or more sites for SIMPER analysis and ordination, resulting in 44 species with 2199 individuals (Table 2). In total, 21 species of plants have been identified as key species in sacred sites, contributing to 70% of differences between groups for each of the three environmental variables. Of these, 52% had religious associations, 29% were garden weeds and 19% were ornamentals (n = 21). *Aegle marmelos* and *Parthenium hysterophorus* were key species for sacred sites in the oldest parts of the city; while five species occurred preferentially in newer parts of the city (*Hibiscus rosa-sinensis, Rosa damascena, Michelia champaca, Ficus drupacea pubescens* and *Amaranthus viridis)*. Most key species that were sensitive to housing density (87%, n = 16) occurred predominantly in higher income neighbourhoods (medium and low density housing); while only two species (*Azadirachta indica* and *Desmostachya bipinnata*) were characteristic of sacred sites located in slums (high density housing). Lastly, key species that contributed to differences in species composition between the two site-types revealed that most key species (except *Parthenium hysterophorus*) occurred preferentially in temples as opposed to kattes (Table 2).

While SIMPER results provided an overview of key species and their associations with individual environmental variables, GLMs assisted in refining these responses by including the collective influence of environmental variables (age, housing density and site-type) on these species, making the results more robust. Site-type was identified as a dominant environmental driver with temples consistently having a positive influence on abundance of most species (Figure 3). Urban matrix variables also influenced assemblages of a few species, in different ways. While *Ficus religiosa* and *Synedrella nodiflora* were identified as typical species for the intermediary age class, *Hibiscus rosa-sinensis* was more abundant in temples, in newer parts of the city. *Azadirachta indica* was most abundant in high density housing neighbourhoods. Thus, the influence of urban matrix variables varied, depending on the species; unlike the consistent pattern observed for site-type.

Plant species	Age	Housing	Site-type	Post-hoc test
Amaranthus spinosus [1] (R^2 = 0.46)	--	--		
Azadirachta indica [2] (R^2 = 0.25)	--		--	Housing: High vs. Low *
Cocos nucifera [3] (R^2 = 0.50)	--	--		
Cynodon dactylon [2] (R^2 = 0.57)	--	--		
Ficus religiosa [1] (R^2 = 0.28)		--	--	Age: Int vs. New *
Hibiscus rosa-sinensis [1] (R^2 = 0.44)		--		Age: Int vs. New *
Nerium indicum [3] (R^2 = 0.56)	--	--		
Oxalis corniculata [1] (R^2 = 0.55)	--	--		
Synedrella nodiflora [1] (R^2 = 0.33)		--	--	Age: Old vs. Int * Old vs. New *

x axis: Environmental variable; y axis: Mean abundance; Significance levels of responses: * <0.05; ** <0.01; *** <0.001; [1] Negative binomial GLM; [2] quasi-Poisson GLM; [3] Poisson GLM

Figure 3. Relationship between abundance of key plant species and environmental variables using generalized linear models (GLM). Only species with significant responses are displayed. Species without significant results: *Aegle marmelos, Amaranthus viridis, Desmostachya bipinnata, Dracaena reflexa, Duranta goldiana, Dypsis lutescens, Euphorbia microphylla, Ficus drupacea pubescens, Michelia champaca, Parthenium hysterophorus, Rosa damascene* and *Syngonium podophyllum*.

3.3. Drivers of species composition at the community scale

The only significant predictors that were associated with species composition were type of sacred sites (temple vs. katte) and size of sacred site (site-area) (Figure 4). When significant, site-area increased in the direction of temples which merely reflects that temples were larger in area than kattes. Only the species composition of the cultivated species pool varied significantly between temples and kattes, but remained uninfluenced by the size of sacred sites.

4. Discussion

Our study is likely the first analysis of cultivated and spontaneous species assemblages of urban sacred sites based on a broad, stratified sampling approach, using abundance data. Overall, our results reveal the importance of culturally significant species (groups) and underlying drivers of species assemblages of sacred sites which vary at the species and community levels.

4.1. Biological richness and species assemblages in sacred sites

Our study highlights the positive habitat function of urban sacred sites for a wide range of plant groups including native species, spontaneous species and culturally relevant species; and for different plant-life forms. Green spaces in cities are often dominated by non-native species (Aronson et al., 2017), a pattern noticed in Bengaluru as well (Nagendra and Gopal, 2011; Sudha and Ravindranath, 2000). Surprisingly, the species pool of urban sacred sites, both cultivated and spontaneous, were clearly dominated by native species in both species richness and species abundance. Even amongst the key species identified, 86% were native, further highlighting the dominance of native species in sacred sites.

The propagule pressure of non-native species in urban green spaces is generally high, often resulting in the dominance of wild growing non-native species (Duguay et al., 2007; Kowarik, 2011; Lockwood et al., 2005). This holds for urban sacred sites in other regions as well. In a Japanese city, for example, a shrine forests showed abundant populations of introduced species (Ishii et al., 2016). In contrast, the propagule pressure of cultivated non-native species in sacred sites of Bengaluru, seemed to be low, evident from the dominance of natives in the spontaneous species pool (Table 2). *Lantana camara* and *Parthenium hysterophorus* were the only two non-native species growing spontaneously in our study sites. Both species have been assigned to an invasive species status in India (Reddy et al., 2008). *Lantana camara* (an ornamental species) is an abundant invader in South

India (Sundaram et al., 2015) and had not been planted at our study sites. We thus conclude that sacred sites in Bengaluru do not function as invasion foci as do many other plantations in urban greenspaces (Dehnen-Schmutz and Touza, 2008; Kowarik, 2011). In contrast, these sites represent spots where urban people can access native species, both cultivated and wild growing. As opportunities to experience nature generally decrease in growing cities (Soga and Gaston, 2016), sacred sites thus offer opportunities for urban people to access not only natural elements in a megacity that is largely characterized by a loss of green cover (Sudhira and Nagendra, 2013), but also to experience native species.

The prevalence of native species at our study sites can be explained by their cultural significance as sacred species. All species with religious associations are native, except the rarely occurring American cactus, *Epiphyllum oxypetalum*, and these form an important part of the ecological heritage of the Indian sub-continent as in many south-east Asian countries (Krishna and Amirthalingam, 2014). Acknowledging the cultural value of ornamental and medical species as well, the vast majority of the species pool (89 %) of sacred sites is of cultural significance and thus supports cultural ecosystem services in Bengaluru (Table 2). Interestingly, many of these species have overlapping cultural functions (Figure 2) – as also highlighted for other parts of India (Lohidas et al., 2014). The coinciding presence of species related to a range of cultural values at urban sacred sites is in consistence with non-urban sacred forests and grooves (Dudley et al., 2010) and highlights the cultural importance of species assemblages of sacred ecosystems.

4.2. Key species and drivers of abundance at the species scale

Our study identified 21 plant species as key species in sacred sites – a majority being those with religious associations (Table 2) – and these can be addressed as indicators for religious values related to cultural urban ecosystem services (La Rosa et al., 2016) . Further analysis with GLMs gave a better understanding of the relationships of key species to environmental variables. Urban matrix variables (age of urban development and housing density) and site-type were related to assemblages of key species (Fig. 3).

Influence of site-type on species abundance followed a consistent pattern with the abundance of *Amaranthus spinosus, Cocos nucifera, Cynodon dactylon, Hibiscus rosa-sinensis, Nerium indicum* and *Oxalis corniculata* being higher in temples than in kattes (Figure 3). *Hibiscus rosa-sinensis* and *Nerium indicum* are ornamental species with religious and medicinal associations. *Cynodon dactylon* is a lawn species, while *Amaranthus spinosus* and *Oxalis corniculata* are weeds often associated with gardening practices. While we sampled a uniform plot size across all sacred sites, temples harbour more heterogeneous and vegetated microsites (including lawns and garden elements) than kattes which may explain the positive relationship between temples and the abundance of culturally significant key species.

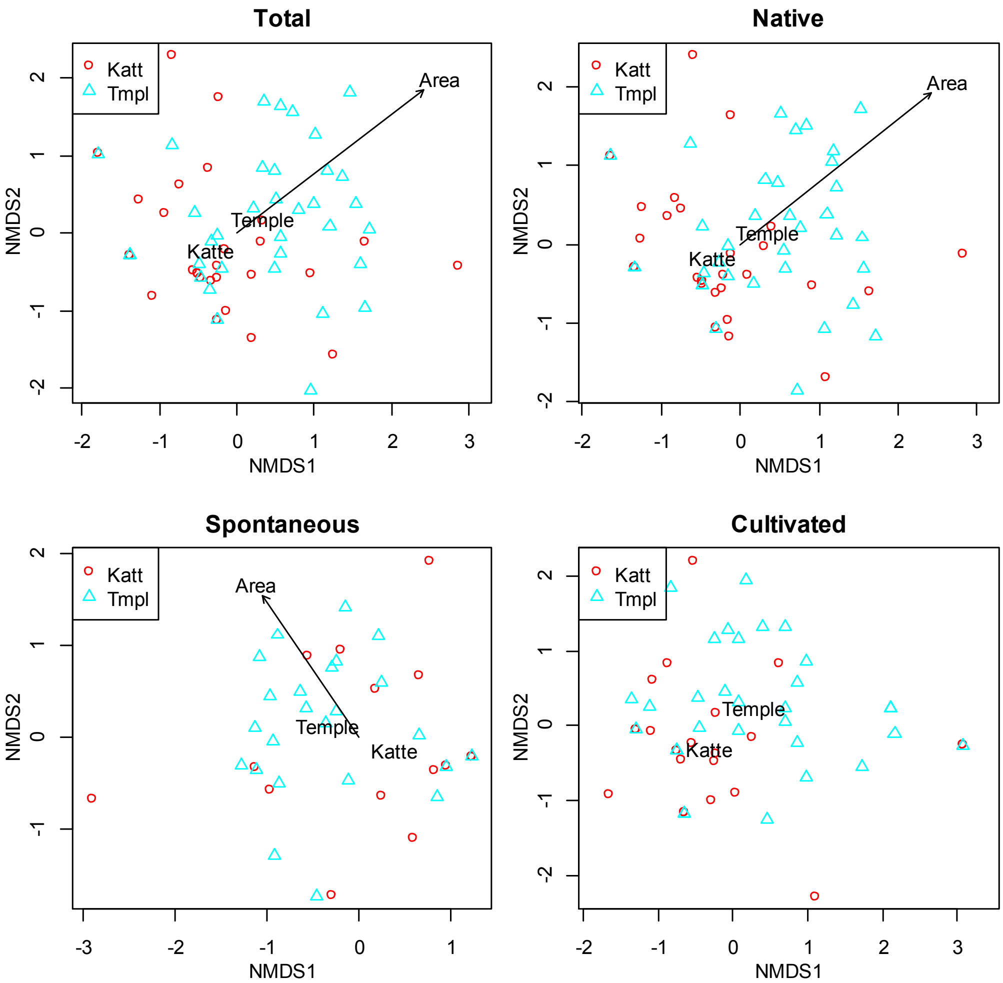


Figure 4. NMDS ordination plots that relate species composition of 69 sacred sites in Bengaluru to age of development, housing density, site-type and site-area. Only significant predictors are shown for total (stress = 0.22, p = 0.001 for site-type, p = 0.02 for site-area), native (stress = 0.22, p = 0.002 for site-type, p = 0.006 for site-area), spontaneous (stress = 0.18, p = 0.02 for site-type, p = 0.01 for site-area) and cultivated species (stress = 0.17, p = 0.01 for site-type). Positions of the labels (i.e. temple or katte) relate to the centroid of the respective factor levels in the ordination space.

Urban matrix variables affected some species, and in different ways. Housing density was negatively related to the abundance of *Azadirachta indica* (neem) with higher abundance in high density sites (slums). In slums of Bengaluru, both neem and *Ficus religiosa* have been identified as important species that contribute to improving health and well-being, and strengthening social capital (Gopal and Nagendra, 2014). Neem is particularly cultivated in slums due to its immense uses in traditional plant-based medicine (Gopal and Nagendra, 2014), which is still the most easily accessible primary health care available to the urban poor (World Health Organization, 2002).

Ficus religiosa (sacred fig) was more abundant in sacred sites in older parts of Bengaluru. Sacred figs, as other *Ficus* species (Jim, 1998), are often known to grow well on old buildings and in derelict sites (Sitaramam et al., 2009), both associated with older parts of the city. This may result in a significant propagule pressure and subsequent dispersal by birds (Corlett, 2005). Consistently, a high percentage of *Ficus religiosa* and two other, less frequent *Ficus* species, were the only tree species growing spontaneously in our study sites (Table 2). Many *Ficus* species being large in size, provide ample shade from the scorching subtropical heat, with *F. religiosa* being well adapted to urban air pollution (Pandey et al., 2015). Apart from their medicinal uses, *Ficus* species have been identified as centres for culture and business for the informal labour class (Gopal and Nagendra, 2014).

Gardening practices seemed to be more prevalent in sacred sites in newer localities, which probably explain the association of *Synedrella nodiflora* and *Hibiscus rosa-sinensis* with younger parts of the city. The former is a garden weed associated with disturbance while the latter is a species with both religious associations and ornamental value.

4.3. Drivers of species composition at the community scale

Species composition at the community scale was strongly influenced by site-type and site-area. The dominant influence of these variables over urban matrix variables could be due to the consistent structural features of sacred sites either as temples or as kattes, across Bengaluru. For instance, parks from the colonial period may have a different structural design as opposed to those developed at a later time period (Abendroth and Kowarik, 2012; dos Santos et al., 2010). Similarly, parks in wealthier neighbourhoods have more structural elements of landscape design and ornamental species (Hope et al., 2003) than those in deprived neighbourhoods (if there is a park at all). Green spaces including parks, open areas, avenue trees and lakes, are being constantly transformed into different landforms in Bengaluru (Sudhira and Nagendra, 2013). In contrast, there is a core element of continuity in sacred sites in terms of their appearance and usage. This structural constancy across the city (either as temples or as kattes), along with the cultural and religious significance of these sites, could explain the lack of influence of urban matrix variables on species composition in urban sacred sites.

The influence of site-type and site-area have been illustrated in Figure 4. Gardening practices (Politi Bertoncini et al., 2012) and park area (Fischer et al., 2016; Li et al., 2006) have been identified as a predictor of species composition in urban parks. Difference in species compositions of the two site-types – temples and kattes – could be due to structural variations between the two. As mentioned earlier, temples were larger in size (site-area increased in the direction of temples as seen in Figure 4) and often had gardens and lawns present within the establishment. Gardening practices including watering, mowing and pruning were noticed in green spaces within temple; and were more intensely managed than kattes. A combination of all these factors perhaps explain the different levels of heterogeneity in urban sacred sites.

Native species composition was also influenced by site-type and site-area with native plant species occurring preferentially in temples (SIMPER results, Table 2); while assemblages of non-natives were not significantly related to our predictor variables. Higher management intensity has also been associated with the replacement of native with non-native species in urban parks and cemeteries (Kowarik et al., 2016; LaPaix and Freedman, 2010). In contrast, despite higher levels of maintenance, temples did not show a more pronounced performance of non-native species compared to less managed kattes.

Another insight pertains to the importance of site-area (in combination with site-type) as a predictor of composition of spontaneous species, but not cultivated ones. The dominant spontaneous species were mainly perennial graminoids, and perennial and annual herbs including garden weeds (Table 2). These species (including *Cynodon dactylon*, *Synedrella nodiflora* and *Oxalis corniculata*) are typical of lawns and gardens, growing in abundance in larger temples.

5. Conclusions

Our study illustrates the potential of urban sacred sites as habitats for both native and culturally significant plant species. The dominance of species with religious, medicinal and ornamental values demonstrates the cultural ecosystem services provided by these sites. Associated spiritual and religious values prompt community support and the willingness to participate. This offers opportunities to enhance both biodiverse and culturally significant species assemblages at sacred sites, e.g. by adapting management practices. As socio-cultural values are diverse across the world, it is important to build a strong scientific database enumerating the broad range of ecosystem services provided by urban sacred sites. Further research on human-biodiversity interactions, regulating ecosystem services (e.g., climate regulation, reduction of air pollution and noise) and habitat function for animals could give a more detailed understanding of both tangible and intangible services provided by these sites. Insights into the multiple functions of urban sacred sites, backed by data on biodiversity and related ecosystem services, could pave way for new approaches in enforcing the urban green infrastructure in megacities of developing countries that often grow at the expense of green spaces.

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Chapter 4: Vegetation in Bangalore’s slums: Boosting livelihoods, well-being and social capital

Vegetation in Bangalore's slums: Boosting livelihoods, well-being and social capital

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Abstract

Urban greenery provides ecosystem services that play an important role in the challenging context of urban deprivation and poverty. This study assesses the social importance of vegetation through empirical assessment of 44 urban slums in the rapidly developing southern city of Bangalore, India. Vegetation played a major role in supporting nutrition by its role in food consumption, and in promoting health through the planting of species with medicinal use. Trees in slums also formed nodes for social activities including conversing and playing, domestic activities such as cooking and washing dishes, and livelihood activities such as the manufacture of broomsticks and tyre repair. Innovative methods of gardening were widely adopted, with kitchen gardens found planted in plastic bags, paint cans, old kitchen utensils and buckets, indicating the importance given to planting in environments with limited finances. Short and narrow trunked trees with medium sized canopies and high economic value, such as *Pongamia*, were preferred. A greater focus on greening in slums is needed, and can provide an invaluable, inexpensive and sustainable approach to improve lives in these congested, deprived environments.

Keywords

India – Livelihood – Slum dwellers – Urban poverty – Social ecological systems – Urban ecology – Urban vegetation

1. Introduction

Green spaces occupy an important function in the urban context and provide critical ecosystem services in congested urban environments, where more than half of the world's population is located (United Nations, 2012). Sustainable cities depend on a healthy ecosystem that influences both human well-being and most economic activities (TEEB - The Economics of Ecosystems and Biodiversity, 2011). Trees in cities absorb vehicular air pollutants, buffer noise, regulate temperature and provide much needed shade from the sun in tropical and sub-tropical belts (Nowak, Crane and Stevens, 2006; Bowler and Buyung-Ali, 2010; Wong *et al.*, 2010). Greenery near residential areas promotes walking, thereby improving the cardio-vascular system and reducing obesity (Sugiyama *et al.*, 2008). Green surroundings and home gardens reduce morbidity, increasing mental peace (Maas *et al.*, 2009). In countries like South Africa and India, green spaces including home gardens are often composed of socio-culturally important medicinal, sacred and culinary plants (Jaganmohan *et al.*, 2012).

However, the benefits provided by trees and shrubs are not spatially homogeneous in cities. In particular, the availability of green spaces is limited in pockets of urban poverty, where access to private green spaces is often non-existent. Under such conditions, what is the role played by green spaces in the challenging context of urban deprivation and poverty?

While some studies have assessed the impact of greenery on poverty employing a psychological approach, others have enumerated its role in terms of food security. Kuo (Kuo, 2001) suggests that neighbourhood greenery reduces mental fatigue, and provides greater psychological resources that can equip residents in low income districts to cope with poverty in the United States of America. van den Berg et al. (van den Berg *et al.*, 2010) add that access to green space can help residents cope better with stressful life events, especially related to poverty, in a study in the Netherlands. With regard to food security, studies have shown that home gardens and community gardens in low income areas are the most economic and readily available sources of nutrition (Ninez, 1985; van Leeuwen, Nijkamp and de Noronha Vaz, 2010; Gallaher *et al.*, 2013). Thus, it seems possible that greenery within neighbourhoods is of great importance in the urban poverty context.

Further, Gallaher et al. (Gallaher *et al.*, 2013) suggest that community gardening in and around residential areas increases social capital. This form of capital refers to the social relationships such as networks, norms and social trust within communities that promote cooperation for mutual benefit (Krishna, 2002). Further, it is the social resource upon which people depend while pursuing their livelihoods (Rakodi, 2002). Social capital contributes to resilience by strengthening friendship and cooperation with neighbours and promoting household safety and survival (Krishna, 2002; Martin *et al.*, 2004).

We seek to e explore the socio-cultural importance of urban greenery in the poverty context. This aspect of urban greenery has been ignored in the research context, yet it is especially important in rapidly developing countries like India, where challenges of urban inequality are severe and accelerating. Squatter settlements in Indian cities are often small, and interspersed with other wealthier neighbourhoods, to which they provide important services, including labour. Yet Indian slums are very densely populated, containing at least as many as 40 million inhabitants (Aggarwal and Butsch, 2012).

Based on empirical assessments of 44 slums in Bangalore, India, we seek to understand the socio-cultural ecosystem services provided by vegetation in the urban poverty context. Our first objective is to assess the species-specific characteristics (medicinal, culinary, ornamental, shade-giving etc.) of the vegetation encountered in slums, relating this to their contribution towards health and well-being. Second, we evaluate the contribution of trees towards social capital, by recording the occupations and activities carried out under their canopy, as well as the role played by trees beyond their inherent characteristics, in providing facilities such as physical support. Third, we assess the cultural services provided by trees in slums that strengthen the social capital, by focusing on the sacred species found in slums. Fourth, through interviews with slum residents, we identify their requirements of urban greenery, using these to propose strategies for the improvement of the livelihoods of slum dwellers. Our findings enable us to add to our understanding of the socio-cultural importance of vegetation in the context of urban poverty, an aspect that has been insufficiently characterized so far.

2. Study area and methods

A small village in the 12thcentury, Bangalore has grown both horizontally and vertically ever since, with a population that has recently crossed 10 million. The city is dealing with the challenges of rapid and unplanned urbanization, including high traffic density, immense pressure on land, and an increasing number of slums (Sudhira, Ramachandra and Subrahmanya, 2007). Although there are more than half a million people living in slums of Bangalore (Jawaharlal Nehru National Urban Renewal Mission, 2009), none of the government departments have an updated and complete slum profile. The composition and structure of urban greenery in parks, avenues, residential areas and other institutions in Bangalore have been well described (Sudha and Ravindranath, 2000; Nagendra and Gopal, 2010, 2011; Jaganmohan *et al.*, 2012), but there has been little research on the role played by green spaces in poor areas, especially slum settlements. This study is the second part of a project that deals with greenery in slums of Bangalore.

Surveys were conducted using the administrative boundary of greater Bangalore or the Bruhat Bengaluru Mahanagara Palike. Procuring reliable data on the number of slums in Bangalore and the profile of each slum was challenging, as various assessments have been carried out by a variety of Government agencies and NGOs that do not concur with each other. One of the most recent and detailed reports is that published by the National Institute of Urban Affairs (National Institute of Urban Affairs, 2008), with a non-exhaustive but detailed assessment of 114 slums within the city. Using this information, all slums mentioned in the report were visited. Given the extremely dynamic nature of urban growth in Bangalore (Sudhira, Ramachandra and Subrahmanya, 2007; Nagendra *et al.*, 2012), we found some slums to have been legalized and converted to residential areas, and others to have been razed. Further, we found a number of areas that were identified as slums, but in reality, were village settlements that had been engulfed by the rapid growth of the city. These locations were excluded from the study. In total, we surveyed a set of 44 slums identified in the report, covering a total area of 51.63 hectares (Fig. 1). Field studies were carried out in May and June, 2011.

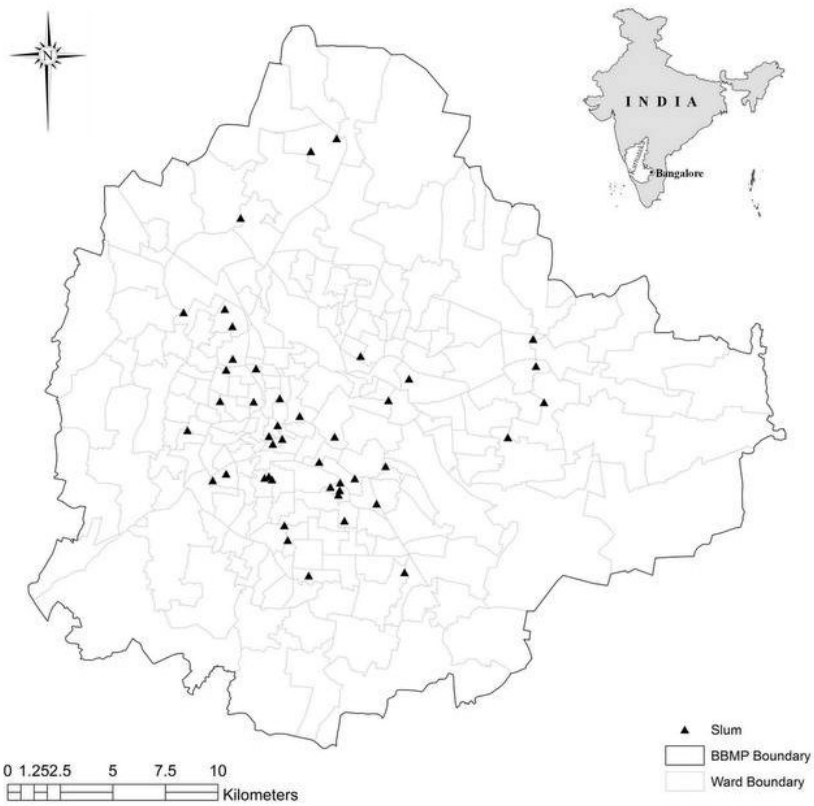

Fig. 1. Location of surveyed slums in Bangalore with reference to the administrative boundary.

Typically, the slums in this study had densely packed housing units (including shacks, huts, tents, *pukka* (made of durable materials such as concrete and brick) houses and *kacha* (made of natural materials such as mud and thatch) houses with narrow lanes, randomly interspersed trees, and potted plants placed in and around the restricted space associated with most households. A complete census of the vegetation within the core structure of the slum as well as that around the slum periphery was carried out where in all trees and plants were identified to the species level.

Visual observations of the utility of trees by slum dwellers were documented. Utility refers to the usage of trees as objects that can act as storage space, support, etc. as well as a platform for performing various day-to-day activities. These were documented based on our visual observations as well as those mentioned by the slum dwellers. However, the occupations and activities observed were limited to those carried out in the dry summer season. Bangalore receives copious sunshine throughout the year, with about 60 rainy days per annum (Sudhira, Ramachandra and Subrahmanya, 2007). Except for the short monsoon period, it is possible that most of the outdoor occupations are carried out throughout the year. Despite this, we acknowledge the fact that certain activities may vary over time and therefore, limit our claims to the summer months, when the solar radiations are severe and the dependence on tree shade is maximum.

The study of the socio – cultural component would be incomplete without including the sacredness of nature in the Indian context. Therefore, sacred trees in slums – those described in sacred texts as well as those with holy symbols (dots of *kumkum* or the holy red powder and turmeric powder) and garlands – were recorded separately, and identified to the species level. The attributes of tree species such as origin and uses were assessed with reference to Neginhal (Neginhal, 2006) and Krishen (Krishen, 2006). Further, relative abundance was calculated for the tree species giving an insight into the overall sum of abundance across the 44 slums.

Shrubs, herbs and creepers, referred to as plants hereafter, were also identified to the species level in each slum – except for nine genera of highly hybridized ornamental plants. The presence of plant species were documented instead of abundance. The species richness, i.e. the number of species per study site, was recorded for each slum. The attributes of plants were identified with reference to Kehimkar (Kehimkar, 2000) and Kurian (Kurian, 2004). We also documented the types of pots used to grow these species.

Additionally, we carried out open ended group interviews in all the slums to understand the preferences of slum inhabitants for vegetation in their neighbourhood (i.e. if they want more greenery and the reason for their choice), and preferences for specific species, if any. The respondents were mainly women (homemakers), with a group size of 5 - 8 individuals per slum.

Table 1. Overview of the ten most dominant tree species in slums of Bangalore – abundance, attributes and activities (non-exhaustive) observed under the canopy.

Scientific name	Common name	Relative Abundance	Uses	Activities observed (non-exhaustive)
Moringa oleifera	Drumstick tree	16.0	Fruits Medicinal	Adults playing Children playing Cooking Grooming Socializing
Cocos nucifera	Coconut tree	12.9	Fruits Coir Oil, etc.	Cooking Tea stall
Azadirachta indica	Neem tree	8.3	Medicinal Sacred	Children playing Tea stall
Ficus religiosa	Sacred fig	7.6	Sacred Medicinal	Children playing Eating (lunch) Flower vendor Socializing Washing clothes Washing dishes
Albizia saman	Rain tree	6.5	Ornamental Shade	Breaking stones Making incense sticks Playing Cricket Socializing Washing clothes
Muntingia calabura	Singapore cherry	6.5	Fruit	Cooking Washing dishes
Pongamia pinnata	Pongam tree	5.6	Shade Medicinal	Cooking Grooming Making incense sticks Socializing Washing clothes
Mangifera indica	Indian mango tree	4.0	Fruit	Children playing Playing Carrom Socializing
Swietenia macrophylla	Big-leaved mahogany	3.3	Shade	Playing Carrom
Psidium guajava	Guava tree	3.1	Fruit	Making Brooms

3. Results

3.1 Species attributes

A total of 553 trees belonging to 46 species were encountered in the 44 slums that we surveyed. In addition, we recorded 95 species of shrubs, herbs and creepers. The most dominant tree encountered was *Moringa oleifera* (drumstick tree), widely used in cooking (Table 1). It is native to Bangalore and highly valued in southern India. Nearly half the tree population in slums had medicinal properties, while 1/3rd were grown for their fruits. Singapore cherry tree (*Muntingia calabura*) and Indian mango tree (*Mangifera indica*) were the most popular fruiting trees. Rain tree (*Albizia saman*) was the most dominant ornamental tree found, while *Pongamia pinnata* (pongam tree) was the tree largely grown for shade. The categories based on attributes, however, were not mutually exclusive with some species having more than one use (Table 1).

The most common plants were *Ocimum sanctum* (holy basil) and *Aloe vera* (Indian aloe), both with important medicinal properties (the holy basil, is also a very important sacred plant in the Indian context). Plants with ornamental and medicinal uses were almost equal in proportion (Fig. 2). *Epipremnum aureum* (money plant), *Rosa* species (rose) and *Jasminum* species (Jasmine) were the most common ornamental plants, present in more than 60% of slums. A small proportion of plants were grown for their fruits such as papaya (*Carica papaya*), banana (*Musa paradisiaca*), bitter gourd (*Momordica charantia*), hyacinth bean (*Dolichos lablab*) and tomato (*Solanum lycopersicum*). Plants grown for consumption included castor (*Ricinus communis*), common sorrel (*Oxalis corniculata*), and betel plant (*Piper betle*). Notably, almost all the plants encountered were actively planted by the slum residents.

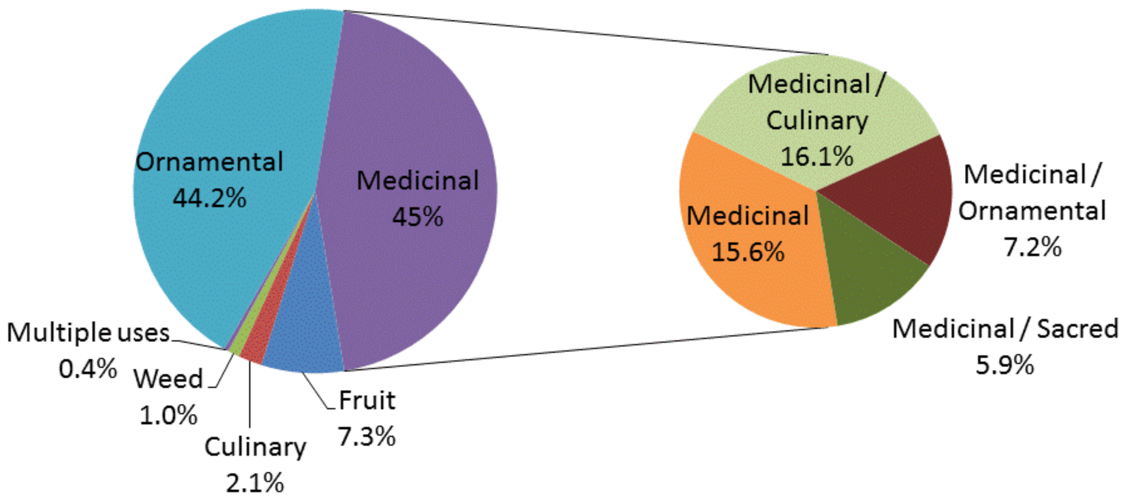

Fig. 2. Proportional distribution of attributes of shrubs, herbs and creepers in slums of Bangalore. The second pie is a further breakdown of the plants used for medicinal purposes with multiple uses

3.2 Sacred species

There were 6 species of flora in slums that were sacred (in the Hinduism tradition): 4 species of trees, and two species of herbs. Sacred trees accounted for about 10% of the total tree population across slums with 63 individuals as enumerated in Table 2. As many as 61% of slums had at least one sacred tree. Sacred trees were most frequently encountered next to temples, and had the largest canopy cover amongst all trees in slums. In addition to the trees known to be sacred in the Hindu religion, we encountered 7 individuals from 5 species of trees: rain tree (*Albizia saman*), pongam tree (*Pongamia pinnata*), gulmohar (*Delonix regia*), gumhar (*Gmelina arborea*) and Nile tulip (*Markhamia lutea*), with symbols of sacred worship such as the presence of garlands, sacred threads, or anointing with vermilion and turmeric. These species are not commonly believed to be sacred, but were being worshiped due to the personal faith/belief of the slum dwellers.

Table 2. Sacred trees in slums of Bangalore.

Scientific Name	Common Name	No. of individuals
Ficus religiosa	Sacred fig	32
Azadirachta indica	Neem tree	18
Ficus racemosa	Cluster fig	2
Ficus religiosa + Azadirachta indica	Sacred fig + neem	2
Pithecellobium dulce	Manila tamarind	2
Albizia saman	Rain tree	2
Pongamia pinnata	Pongam tree	2
Delonix regia	Gulmohar	1
Gmelina arborea	Gumhar	1
Markhamia lutea	Nile tulip	1

The sacred herbs encountered were holy basil and *Ruta graveolens* (common rue). Of the 44 slums surveyed, holy basil (locally known as *tulsi*) was present in 41 slums, while common rue was present in 4. As mentioned earlier, holy basil was the most commonly found species of plants across slums. The wide presence of the plant and the fact that it is cultivated by slum residents (and not growing spontaneously) indicates the crucial role it plays in the Indian culture.

3.3 Utility of tree species

Trees appeared to have an important utility function as physical entities, beyond their species-specific sacred, cultural or other properties. Most trees were observed to support clothes lines. Other practical uses include supporting tents, wires, and more (Table 3). Tree shade was noted to be a sought after quality in slums providing respite from the sun. Trees in slums were brimming with life and hotspots of activity. A range of occupations were observed taking place under tree canopies, include the sale of flowers, making of brooms and incense sticks, and the operation of mechanic shops, tea stalls and telephone booths. Women in slums were observed conducting domestic chores such as cooking (using fuel wood), washing clothes and dishes, and grooming (such as oiling each other's hair, combing and removal of lice) under tree canopies; while children were often found to be playing under the shade of trees. However, the most commonly observed activity was of groups of people sitting under the canopy and conversing/socializing. These activities were also tabulated against the tree species under which they were observed, some mentioned in Table 1. Sacred fig (*Ficus religiosa*) was the tree species with the most number of activities observed, followed by pongam tree (*Pongamia pinnata*) and rain tree (*Albizia saman*).

Table 3. Overall utility of trees in slums of Bangalore.

Utility	Percentage of total tree population
Clothes line	35.3
Holy symbols	6.9
Clothes line + Tent support	6.1
Wire support	4.9
Tent support	4.5
Clothes line + Wire support	3.1
Tent support + Wire support	0.7
Photograph stand	0.5
Switch board support	0.5
Tent support + Holy symbols	0.4
Hoardings	0.2
Lamp post	0.2
Puncture shop	0.2
Storage area	0.2

3.4 Green preferences

The slum dwellers responded positively to the survey regarding their preferences of a green neighbourhood. Most respondents were women who were keen on improving their neighbourhood. About half of the respondents wanted more trees in their surroundings, preferably *Pongamia pinnata* (pongam tree). Others did not desire more trees, citing land issues such as lack of space and ownership (Table 4). However, all the respondents preferred potted plant species and wanted more of these in their neighbourhood.

Table 4. Tree preferences in slums of Bangalore – response of slums dwellers to an open ended survey.

Tree of Choice	No. of Slums	Reason
None	23	No space / Ownership issues / Plenty of trees
Pongamia pinnata	14	Shade
Azadirachta indica	7	Shade / Health
Mangifera indica	3	Fruits
Michelia champaca	2	Fragrance / Flowers
Cocos nucifera	1	No space
Flowering trees	1	Flowers
Muntingia calabura	1	Fruits
Shade - giving	1	Shade
Syzigium cumini	1	Fruits

3.5 Innovative gardening

With space constraints being a characteristic feature of slums, there were more potted plants than those growing directly from the ground. The pots used were highly innovative addressing key issues such as limitation of space and finances. The types of pots seen were earthen pots, plastic pots, cemented structures, plastic bags, discarded paint containers, earthen water pots, plastic buckets, metallic cans, hindalium pots (an alloy of aluminium), battery cans and aluminium buckets. The potted plants were located on windowsills, parapets, roofs, etc. (Fig. 3). Although some slums had no trees, all of them had plants with a species richness range of 1 – 39.

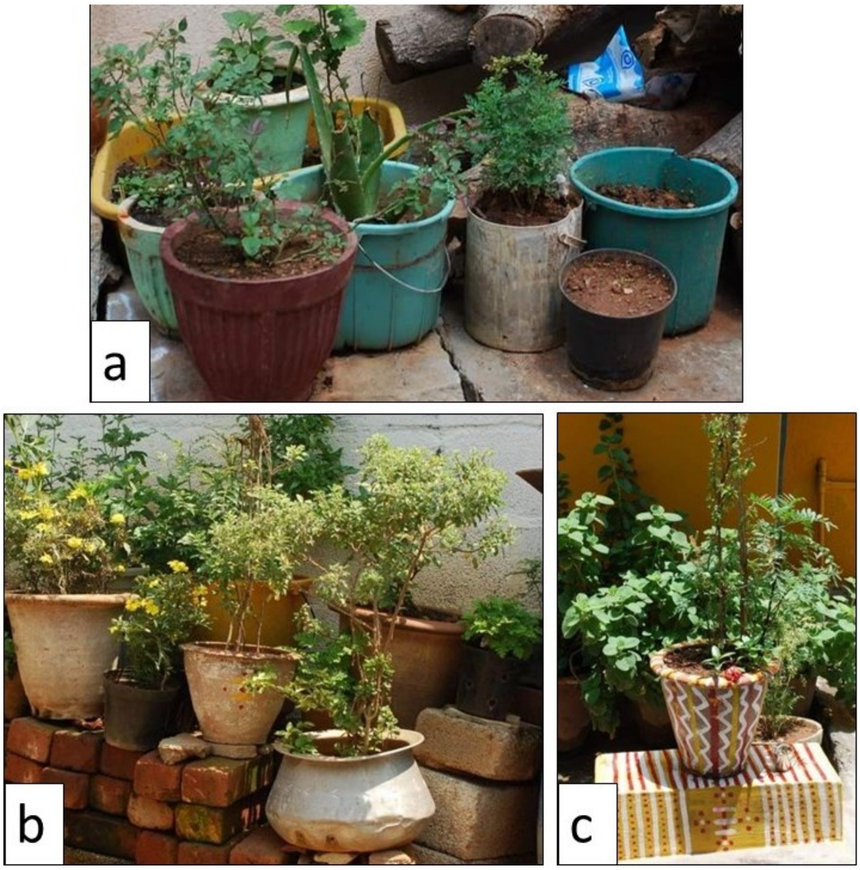

Fig. 3. Types of pots for plants in slums of Bangalore—(a) Plastic buckets, plastic tub and discarded paint can. (b) Hindalium (aluminium) container, earthen and plastic pots. (c) Holy basil in an earthen pot with sacred markings.

4. Discussion

Our results suggest that species distribution and composition are strongly interrelated with social, cultural and economic activities in slums. Urban greenery is a resource that benefits the urban poor as well and is not limited to the upper strata of the society (Kuo and Sullivan, 2001; Maas *et al.*, 2009).

4.1 Health and well-being

Urban greenery is often positively correlated with better health and mental well-being for city dwellers (Guite, Clark and Ackrill, 2006; Sugiyama *et al.*, 2008; Maas *et al.*, 2009; van den Berg *et al.*, 2010). Nearly half the tree population we encountered in slums have medicinal properties, while every 1 out of 3 trees we encountered is fruit bearing. The drumstick tree provides an excellent example of this, being the most frequently encountered species, with medicinal as well as culinary uses. Also known as a '*miracle tree,*' drumstick fruits and leaves provide rich sources of proteins, vitamins and minerals, and are known to play a vital role in meeting nutritional deficiencies and alleviating poverty (Krishen, 2006; Neginhal, 2006; Pandey *et al.*, 2006). Some slum residents and nature enthusiasts in Bangalore indicate in disussions that drumstick trees were intentionally planted in slums during the 1980s, to reduce malnutrition. However, we could not trace any official records that verify this claim. The coconut tree, accounting for 13% of the sampled population, is widely known as '*Kalpavriksha*,' meaning the tree which provides everything. It is nutritious, medicinal and provides many products used for various daily needs including coconuts for consumption, coconut husk for fuel, and fibre for constructing broomsticks (Neginhal, 2006). The third most frequently found tree species – neem – is sacred and medicinal. Every part of the tree is used in traditional medicine. Thus, we find that the majority of the trees found in slums have multiple uses, and are of high economic value.

This pattern is observed in shrubs, herbs and creepers as well. Most plant species in slums have medicinal properties and are used for treating various discomforts and ailments of the digestive system (Kurian, 2004). The most commonly encountered plant species such as holy basil, Indian aloe and country borage address stomach disorders (Kurian, 2004). Ailments of this kind frequently plague the urban poor in South Asian cities (Gupta and Baghel, 1999; National Institute of Urban Affairs, 2008; Vashishtha, 2009). According to the World Health Organization (World Health Organization, 2002), nearly 65% of the Indian population is dependent on traditional herbal medicine for primary health care. Kassam et al. (Kassam *et al.*, 2010) further maintain that the usage of medicinal plants contributes to health security and sovereignty.

Sacred species were important features in most study sites. *Ficus religiosa* is sacred to both Hinduism and Buddhism, and indispensable in many Hindu rituals. The species has been referred to in many ancient holy texts in India. It has therapeutic properties and is extensively used in traditional medicine to treat a wide range of ailments of the nerves, stomach, intestine, skin and reproductive system (Krishen, 2006; Neginhal, 2006; Sitaramam, Jog and Tetali, 2009; Singh, Singh and Goel, 2011). The wide dominance of holy basil can also be attributed to its sacredness. We find that most sacred plants encountered in our study have important medicinal properties. The presence of trees and plants that heal is extremely crucial in slums as it provides an economical and readily available source of health care for common ailments suffered by the urban poor and promotes health security and sovereignty.

4.2 Boosting livelihoods

We observe that trees in slums are used beyond their innate qualities and act as livelihood components as discussed in the results, including Table 3. Trees act as pillars of support in such settlements – figuratively and literally by bearing tents, clothes lines, wires, etc. The role they play, although basic, is extremely critical in cramped squatter settlements, where community space is at a premium, and heavily used for multiple roles. Daily chores such as cooking, washing dishes and clothes, and maintaining personal hygiene are carried out under the canopy. Trees clearly play a critical role in the daily routine of slum residents and can be considered as an extended part of their dwelling area. Additionally, these spaces provide a platform for residents to carry out various economic activities such as selling flowers, tea, making incense sticks, etc. Considering the fact that a majority of the below-poverty-line (BPL) population of Bangalore live in slums (National Institute of Urban Affairs, 2008), income generating activities as mentioned above contribute to improving livelihoods. While most slum residents are employed by the volatile informal sector that can be exploitative with unhealthy working conditions and low pay, home based enterprises, as mentioned above, should be encouraged in order to maintain a stable household income (UN-HABITAT, 2003).

Apart from low income, coping with food shortage is an integral part of poverty alleviation and improving livelihoods. Slum residents are known to spend over 60 – 80% of the monthly household income on basic food in the Lima slums of Peru and the Kibera slums of Nairobi (Ninez, 1985; Pascal and Mwende, 2009; Gallaher *et al.*, 2013). However, in both countries, urban agriculture has contributed positively towards food security in slums. For instance, in the Lima slums, families involved in urban agriculture have been able to add an indirect income of almost 10% with their garden produce, which is considerably significant in relationship to the household economies. However, urban agriculture is difficult to practice in densely populated slums with lack of space. The residents of the congested Kibera slums have adapted to space constraints by actively pursuing a new form of urban agriculture called sack gardening, where in vegetables are planted into large sacks filled with soil. Similar to the Kibera slums, there is severe space constraint in Bangalore's slums. This form of agriculture might be of relevance to Bangalore as glimpses of innovative gardening were observed in the city's slums too. Apart from using readily available materials for creating small home gardens, the slum residents showed enthusiasm for increasing potted plants in their neighbourhoods. Moreover, our results suggest that close to 25% of plants encountered were grown for food or had other culinary uses. Recognizing this affiliation with home-gardening, Bangalore's slum inhabitants should be encouraged and guided to adopt more lucrative techniques such as sack gardening which might help enhance food sovereignty, ultimately improving livelihoods.

4.3 Social capital

Social capital encompasses social relationships that nurture mutually beneficial actions within communities, improving productivity (Krishna, 2002). Studies suggest that social capital contributes to economic growth and household food security, consequently, reducing poverty (Krishna, 2002; Gallaher *et al.*, 2013). Strong social relationships within communities facilitate resource sharing, ultimately benefiting the community and facilitating the access to financial, natural and human capital (Bebbington and Perreault, 1999). In some poor communities in Bangkok, both environmental targets and social development goals were met at the same time due to high social capital (Fraser, 2002).

Socializing with neighbours is an important aspect of increasing social capital (Krishna, 2002). Slum dwellers in Bangalore were often seen gathering together under tree canopies and communicating. Social interaction in green spaces can improve bonding and create a better sense of community (Kweon, Sullivan and Wiley, 1998; Cattell *et al.*, 2008). Greenery in low income areas of the city provides a platform for older residents to integrate socially, improving their mental health and longevity (Kweon, Sullivan and Wiley, 1998). Both greenery and social interactions in such surroundings can significantly reduce outrage and aggression (Sampson, Raudenbush and Earls, 1997; Kuo and Sullivan, 2001), which can be quite high in the urban slum context in South Asia (Sambisa *et al.*, 2011). Cattell et al. (Cattell *et al.*, 2008) further suggest that social ties can improve tolerance among neighbours and increase vitality of the community as a unit. Our research demonstrates the importance of tree canopies in providing community spaces for socializing in cramped urban slums, and thus green spaces can play a critical role in increasing social cohesion in the poverty context.

Apart from normal social interactions amongst communities, knowledge sharing is a crucial resource that may aid community building (Mchombu, 2004). Traditional ecological knowledge can be an important tool in resource management and distribution (Berkes, Colding and Folke, 2000). Social learning is necessary collaborative management of resources (Schusler, Decker and Pfeffer, 2003). In the context of Bangalore's slums, this knowledge could range from information on farming / gardening to sharing health wisdom. Usage of traditional medicine within households is informally acquired knowledge, passed on from one generation to another (Verma, Singhal and Singh, 2010). Similar to the importance of social – ecological memory for better management of urban gardens (Barthel, Folke and Colding, 2010), health remedies in squatter settlements might be rooted in such memory. Although there are several texts that describe ailments and the appropriate remedies for the same, this knowledge is not inclusive as illiteracy is high among the poor (National Institute of Urban Affairs, 2008). Health wisdom in India is often an oral tradition, with community structure and social interactions being imperative for its existence and transmittance (Verma, Singhal and Singh, 2010). Tree-canopy created community centres in Bangalore's slums may play a major role in facilitating the survival and transmittance of this wealth of knowledge.

5. Conclusion

Vegetation in slums of Bangalore appears to play a significant role in improving social capital, livelihoods, health and nutrition. Yet despite the evident socio – cultural dependency of slum dwellers on greenery, vegetation in slums remains low. With severe space and financial constraints, the urban poor still manage to grow potted plants using innovative resources, planting in discarded battery cans, plastic buckets, cooking vessels, tyres, etc. Sacred fig and pongam tree were noticed to be hotspots of social activities and interestingly, most slum dwellers indicated a preference for planting more pongam trees in their surroundings. For a narrow trunked tree, pongam has a medium sized, dense canopy that most slum dwellers seek, for respite from heat. Policy makers, government agencies, NGOs, and other agencies working towards the alleviation of urban poverty need to acknowledge the significance of greenery and include a green agenda in the strategies they employ. For instance, policy makers could organize workshops in sack gardening and other forms of urban agriculture that might further enhance the livelihoods of the city's poor. A well thought and inclusive strategy of greening should be employed wherein the choice of the slum residents is acknowledged for sustainability and success of the programme. Vegetation in slums functions as a common pool resource and should be increased in number and managed accordingly.

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Chapter 5: Synthesis

This is one of the first studies that systematically address ecological and cultural aspects of plant diversity in urban sacred sites and slums in an Indian megacity. The overarching objective of this study was to understand societal - environmental drivers of plant diversity, and use and function of plant species in socio-cultural contexts. Based on the research questions posed in the Introduction (Chapter 1), this chapter discusses research results and gives recommendations for future investigations, management and policies for conservation of urban sacred sites (accounting for socioeconomic disparities).

Research question 1 (Chapter 2): *Which environmental parameters (urban matrix variables and site variables) relate to vegetation diversity patterns in urban sacred sites in a megacity?*

Chapter 2 highlights the biodiversity function of urban sacred sites for different plant groups – native species, non-native species, cultivated species and spontaneous species, in one of the first studies on biodiversity patterns in urban sacred sites in an Indian megacity. Using a stratified sampling design, 121 plant species were encountered in urban sacred sites, overall, with mean species richness of 7.7 and 4.3 in temples and kattes, respectively. Urban matrix variables (age of urban development and housing density) had limited influence on plant diversity (species abundance, richness and beta diversity). Overall, site variables (site type and site area) were retained in most models and were key predictors of diversity patterns in sacred sites. Temples had more species and individuals, as well as higher alpha and beta diversity than kattes, across total, native, non-native and cultivated species pools.

Age of urban development was associated with beta diversity patterns where sacred sites in newer neighbourhoods were more heterogeneous compared to the older neighbourhoods. Similarly, housing density was related to beta diversity with higher diversity in low-density housing neighbourhoods in comparison to the others (high and medium density neighbourhoods). With regard to site type, temples had higher beta diversity than kattes. While beta diversity related to all three environmental variables, site type and site-area were key predictors of alpha diversity (species abundance and richness). Additionally, species abundance and richness increased with site-area, despite maintaining uniform plot size.

Results further highlight the habitat function of urban sacred sites for native and spontaneous species. Native species constituted 81% of the total species pool and 99% of the spontaneous species pool. Further, urban matrix variables did not relate to diversity patterns in both plant groups (urbanity variables were not retained in the final model for both plant groups). This is especially important as many land-use types in cities – in general and in India in particular – are dominated by non-native species.

Despite species numbers (species richness) being much lower in urban sacred sites than sacred groves and forests in non-urban areas (Jamir and Pandey, 2003; Bhagwat *et al.*, 2005; Gao *et al.*, 2013) (the differences could be attributed to the latter being larger, continuous habitats), small green patches have been identified to play a pivotal role in urban biodiversity conservation through urban green networks (Angold *et al.*, 2006).

Results of this study thus provide insights on biodiversity patterns in culturally significant sites in relation to urbanization and site parameters for different plant groups. Culturally protected areas including sacred sites provide outstanding examples of unconventional green spaces that could contribute significantly towards biodiversity conservation within the realm of urban green infrastructure.

Research question 2 (Chapter 3): *What is the species composition of urban sacred sites? How are plant species assemblages influenced in urban sacred sites in relation to biological and cultural features; and underlying environmental variables?*

Building upon the previous research question on biodiversity patterns in urban sacred sites, Chapter 2 focuses on the species in these sites. Culturally relevant species prevailed in the species pool (89%), and had diverse uses including religious, medicinal and ornamental. Only 11% of plant species were weeds. Native species dominated both the cultivated and spontaneous species pools. This chapter demonstrates that urban sacred sites have an important potential in harbouring both native and culturally significant species that can support urban livelihoods in developing countries.

Urban matrix variables (age of development, housing density) and size and type of sacred sites were related to differences in species assemblages in distinct ways. Results revealed that community composition was related to site type and site-area (size) in urban sacred sites, while urban matrix variables did not relate to the same. The concentric city model on which urban matrix gradients (age of urban development) rely could not explain vegetation composition appropriately. Even the socio-economic factor of urban matrix (housing density) could not explain community composition in urban sacred sites highlighting the resilience of sacred sites to urban processes. However, at the species level, all environmental variables - urban matrix variables, site-type and site-area - related to abundance of key species (see Chapter 3).

Research question 3 (Chapter 4): *What are the socio-cultural ecosystem services provided by plant species in general, and sacred sites / sacred species in particular, in the context of urban poverty in slums of a rapidly growing city?*

Chapter 4 demonstrates the social and cultural importance of plant species in relation to urban poverty in slums of Bengaluru, through identification of perceived ecosystem services. Slum residents identified a wide range of ecosystem services that they received from plant species within their neighbourhoods, including regulating, provisioning and cultural services. Regulating service identified by residents included thermal regulation (of the micro climate) through shade provided by trees and other plant species with dense foliage, against the scorching daytime heat in sub-tropical zones. The heat is further intensified within slum tenements as these are often made with metal / tin roofs. Tree shade is, therefore, highly desired by slum residents. Further, slum residents carried out many domestic activities such as laundry, cooking, playing (adults and children), grooming, etc., under the shade of trees.

Provisioning services included raw materials (e.g., cooking fuel, tree trunks as support for crude housing units), food source (e.g., fruits and vegetables) and medicinal resources (e.g., medicinal plant materials and herbs used in traditional medicine). Cultural services included religious and spiritual well-being, social cohesion, recreation and mental well-being. Sacred plant species and sacred sites were commonly present in most slums. Apart from the spiritual services provided by sacred plants and sacred sites, these were also identified as hotspots of both social and livelihood activities. Plant species, sacred and otherwise, supported livelihoods of slum residents as many commercial activities (e.g., fruit and vegetable vendors and flower vendors) were carried out under the shade of trees (Figure 1).

While the ecosystem services identified by slum residents were mainly the ones that were directly visible or experienced by them, there could probably be a lot more. Chapter 4 demonstrates the immediate and directly experienced ecosystem services provided by plant species in slum settlements. A greater focus on greening in slums is needed, and can provide an invaluable, inexpensive and sustainable approach to improve lives in these congested, adverse environments.

Figure 1. Vendors selling fruits, flowers and vegetables under the canopy of sacred trees in Bengaluru.

Native species in cities

Most of the native species encountered in this study were of cultural importance (Chapters 3 and 4). Dominant species (in both slums and sacred sites) such as *Ficus religiosa, Azadirachta indica*, *Moringa oleifera* and *Cocos nucifera* have multiple uses. All these species (and many more mentioned in Chapters 3 and 4) have important medicinal properties and are extensively used in traditional medicine. Plant-based medicine is the most easily accessible and feasible form of primary health care in slums, even now (World Health Organization, 2002). *Moringa oleifera* has been identified as a key species for combating malnutrition (Gopalakrishnan, Doriya and Kumar, 2016) which is highly prevalent in slums of many Asian, African and South American countries (UNICEF, 2016). Apart from the medicinal uses of *Ficus religiosa* and *Azadirachta indica*, these species have been identified as socio-cultural hotspots in slums. In comparison to their abundance, native species seem to provide enormous ecosystem services to residents in slums and otherwise. Many of these species have been internalized into local traditions, cultural practices, ecological heritage, traditional knowledge and routine activities, both intentionally and unintentionally.

Chapters 3 and 4, therefore, demonstrate the diverse uses of native species and their significance in society, particularly in the context of urban poverty. Both diversity and abundance of native species were higher than that of non-natives in urban sacred sites (Chapter 2 and 3). In comparison, many cities in developing countries have a higher proportion of non-native species (compared to natives within specific land-use types such as parks, streets, etc.), often planted for aesthetics, as mentioned in Chapter 1. Plant species composition in different land-use types of Bengaluru alone, have a dominance of non-native species (Sudha and Ravindranath, 2000; Nagendra and Gopal, 2010, 2011; Jaganmohan *et al.*, 2012). The abundance of native species in urban sacred sites, therefore, provides opportunities for urban residents to interact with their indigenous natural heritage and augment their livelihoods in the process.

Implications for biodiversity management and urban subsistence

Overall, the findings of this study provide insights into the links between socio-cultural processes, biodiversity, ecosystem services and human well-being in complex urban ecosystems. These human – nature interactions are crucial in enabling conservation of urban greens through positive feedback mechanisms (as seen in Chapter 1, Figure 1) facilitated by cultural ecosystem services. Knowledge of the links between people, biodiversity and conservation is important for developing informed policies and management strategies that meet the key challenge of cities: to protect urban nature, ensure adequate supply of essential ecosystem services and economic progress, while enhancing human well-being.

Biocultural diversity could be a useful tool for socially inclusive and ecologically sound urban green infrastructure (Vierikko *et al.*, 2016). Cultural connections to urban nature contribute to stability and environmental stewardship through local actors, offering potential for supporting more inclusive pathways towards nature conservation. In particular, the role of culture and nature in the context of urban poverty demonstrates the direct links between them, in turn facilitating poverty alleviation. Further, many plant species in slums and urban sacred sites in this study, were identified as food sources with nutritional values. These sites, thus, could also play a vital role as part of the 'edible green infrastructure.' Russo *et al.* (2017) argue that the edible green infrastructure framework intertwines social, environmental and economic co-benefits while improving food security and quality of life in cities: an issue of particular importance in the urban poverty context in developing countries.

Studies have found that informal urban green spaces are utilized more often than designated green areas with user groups comprising of a wide range of urban residents, often including marginalized groups (Rupprecht and Byrne, 2014; Rupprecht *et al.*, 2015). Informal and unconventional urban green spaces, therefore, seem to provide opportunities to marginalized groups for interacting with urban nature with implications for environmental justice. Results of this study demonstrate the extensive spatial presence of urban sacred sites in Bengaluru (and perhaps holds true in many other cities across Asia) as it does for slums. This study, therefore, highlights the potential of urban sacred sites as unconventional green spaces that could enhance urban green infrastructure and human well-being through ecological networks of these tiny (in size) but spatially abundant cultural green pockets.

Reflections on the research approach

While a robust stratified random sampling method was applied in Chapters 2 and 3, and a complete census of slums was carried out in Chapter 4; future studies could account for some methodological limitations of this study. Chapters 2 and 3, described biodiversity in urban sacred sites and drivers of patterns therein. The conclusions in this pilot study are drawn from three environmental variables – age of urban development, housing density and site-type. Due to unavailability of socio-economic and demographic data for the selected study sites, further environmental variables could not be included in the study. Despite this, the results on biodiversity patterns in this study provide first insights into this subject in an Indian megacity. Future studies could incorporate a wider range of environmental variables (depending on data availability) to refine results and throw further light into biodiversity patterns. These include urban matrix variables such as urbanization score (Seress *et al.*, 2014), human population density and population growth; socio-economic variables (Luck, Smallbone and O'Brien, 2009) such as mean household income, household demographics (e.g., number of family members in the house, average age, levels of formal education, and residence time in the community) and ecological knowledge (regarding usage of species for health, nutrition, etc.); and site variables such as management intensity, habitat type (e.g., wooded area, grassland, etc.) and percentage of built area (to understand edge effect).

The conclusions of the slum study (Chapter 4) are drawn from a brief overview as data were collected based on observations during a short time frame. While this pilot study gives novel insights about the crucial role of plant species in neighbourhoods of low socio-economic status, future studies based on observations (of activities) could follow a systematic observation protocol using the System for Observing Play and Recreation in Communities (SOPARC) (McKenzie *et al.*, 2005) to deepen these insights. Systematic observations should be repeated for a set time period (e.g., 1 hour), several times per day (e.g., 3-4 times), over many days (e.g., 1 week). This could reduce sampling errors, observer bias and ensure comparability. Tree shade was identified as an important ecosystem service. Again, activities associated with shade may be subject to seasonal variations. For example, residents may seek canopy shade to a greater extent in summer months and during monsoons. With regard to questionnaires, the statistical conclusions could greatly benefit from increasing the number of participants/ respondents in each slum.

Future directions

This thesis illustrates social and ecological drivers of biodiversity in culturally significant urban ecosystems and unravels important linkages between biodiversity and a range of ecosystem services. During the course of this study, several interesting issues for further research evolved, beyond the scope of this thesis.

Future studies could examine the relationships and feedbacks between biophysical environmental variables and plant species in sacred sites and slums. These could include studies on micro-climate – ambient temperature and air pollution. Air quality is very poor in urban centres of many countries including the Indian sub-continent, China and Nigeria (Lelieveld *et al.*, 2015). This is especially critical in slums due to their location in environmentally vulnerable areas (Jawaharlal Nehru National Urban Renewal Mission, 2009; Karolien *et al.*, 2012). Studies could assess the potential of plant species in mitigating suspended particulate matter, sulphur dioxide and carbon sequestration. Since canopy shade has been identified as desired ecosystem service, ambient air temperature can be measured to quantify this ecosystem service.

Further, functional traits of plant species can be examined in future studies. Plant functional traits of species and communities facilitate generalisation of ecological knowledge across species (Keddy, 1992) and can be applied to similar habitats, assessed through relatively easy methods across eco-regions (Vandewalle *et al.*, 2010). Standardised measures of plant traits independent of taxonomical identity enables generalizations, applicability and comparisons, particularly relevant in response to global processes such as urbanization (Williams, Hahs and Vesk, 2015). Assessing functional traits could provide insights into relative dispersal and competitive abilities of plant species (seed size); light capture, precipitation interception and radiation uptake (leaf area index); photosynthesis (nutrient concentration), competitive ability (plant size), and many more. Further, planting species with diverse functional traits (increasing functional diversity) could augment ecosystem services. For example, diversity in plant heights within communities is known to enhance light capture (Vojtech *et al.*, 2008). In the urban context, plant traits such as woodiness, seed mass and height have increased in response to urbanization (Faucon, Houben and Lambers, 2017). The relationships and feedbacks between functional plant traits and their diversity, and urbanization and urban ecosystem services, are far from being fully understood. This knowledge could enhance sustainable management of urban ecosystems.

Another aspect to explore is the valuation of ecosystem services provided by urban sacred sites. This thesis highlights the potential of urban sacred sites in biodiversity conservation and delivery of ecosystem services in cities as well as its relevance in socio-cultural processes, including urban poverty. Some important ecosystems services were identified, that slum residents directly experienced. A comprehensive understanding of the complete range of ecosystem services could augment urban living. In many cities from developing countries including Bengaluru, government policies place rapid economic growth and infrastructure development above environmental policies and protection (Pauchard *et al.*, 2006; Sudhira and Nagendra, 2013). Scientists, conservationists and environmental enthusiasts, therefore, should present a strong case by providing economic values of ecosystem services, which have proved to be effective in rural landscapes. Economic valuation could be conducted both at the species level (identifying species providing multiple ecosystem services and of high economic value) as well as at the ecosystem level. The TEEB approach for urban ecosystems (TEEB - The Economics of Ecosystems and Biodiversity, 2011) and other techniques discussed by Gómez-Baggethun and Barton (2013) could be adopted for sacred sites and other green spaces, supplementing decision making and environmental policies for informed urban planning through ecosystem services. Further, the social value of ecosystem services and biodiversity can be assessed based on the approach developed by Cáceres *et al*. (2015). While contributing to decision and policy making, social valuation could foster biodiversity needs in view of social demands, ensuring sustainable management of public commons by local communities.

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Appendix

Appendix: List of species mapped in the study plots of Bengaluru's sacred sites with information on life forms (tree, shrub, perennial herb (P.Hrb), perennial graminoid (P.Gr.), annual herb (A.Hrb)); origin (natv – native, intro – introduced); species abundance (SA – no. of individuals); frequency of occurrence (*f*, n = 69) and spontainity ratio (proportion of spontaneous individuals per all counts of the respective species), summarized overall for all sites and for temples and kattes.

Scientific Name	Life form	Origin	Total			Temple		Katte	
			SA	*f*	Spont. ratio	SA	*f*	SA	*f*
Achyranthes aspera	P Herb	Natv	2	2	-	2	2	0	0
Aegle marmelos	Tree	Natv	6	5	-	4	3	2	2
Aglaonema commutatum	Shrub	Intro	25	5	-	23	4	2	1
Albizia saman	Tree	Intro	2	2	-	1	1	1	1
Allamanda blanchetii	Shrub	Intro	3	1	-	3	1	0	0
Aloe vera	P Herb	Intro	3	3	-	1	1	2	2
Alstonia macrophylla	Tree	Intro	1	1	-	0	0	1	1
Alternanthera ficoidea	P Herb	Intro	6	1	-	6	1	0	0
Amaranthus gangeticus	P Herb	Natv	3	1	-	0	0	3	1
Amaranthus spinosus	A Herb	Natv	34	11	1.00	32	9	2	2
Amaranthus viridis	A Herb	Natv	21	5	1.00	17	3	4	2
Anthurium andraeanum	Shrub	Intro	7	3	-	7	3	0	0
Araucaria columnaris	Tree	Intro	1	1	-	1	1	0	0
Areca catechu	Tree	Natv	10	2	-	10	2	0	0
Artocarpus heterophyllus	Tree	Natv	3	3	-	1	1	2	2
Asparagus officinalis	P Herb	Intro	1	1	1.00	1	1	0	0
Azadirachta indica	Tree	Natv	30	28	-	13	12	17	16
Barleria cristata	Shrub	Natv	51	1	1.00	0	0	51	1
Bergera koenigii	Tree	Natv	13	2	0.85	4	1	9	1
Bougainvillea glabra	Shrub	Intro	6	2	-	0	0	6	2
Calotropis gigantea	Shrub	Natv	4	3	0.25	2	2	2	1
Calyptocarpus vialis	P Herb	Intro	6	3	1.00	0	2	6	1
Canna spp.	P Herb	Intro	1	1	-	1	1	0	0
Carica papaya	Tree	Natv	1	1	-	0	0	1	1
Caryota urens	Tree	Intro	2	1	-	0	0	2	1
Cassia fistula	Tree	Natv	1	1	-	1	1	0	0
Cassia tora	Shrub	Natv	10	2	0.90	9	1	1	1

Scientific Name	Life form	Origin	Total			Temple		Katte	
			SA	*f*	Spont. ratio	SA	*f*	SA	*f*
Catharanthus roseus	P Herb	Natv	4	2	-	1	1	3	1
Chlorophytum comosum	P Herb	Intro	23	2	-	23	2	0	0
Chrysanthemum indicum	P Herb	Natv	8	2	-	4	1	4	1
Citrus medica	Tree	Natv	8	5	-	7	4	1	1
Clitoria ternatea	P Herb	Natv	3	3	0.33	1	1	2	2
Cocos nucifera	Tree	Natv	15	11	-	14	10	1	1
Codiaeum variegatum	Shrub	Intro	23	7	-	21	6	2	1
Colocasia esculenta	Shrub	Natv	4	1	-	4	1	0	0
Conyza bonariensis	A Herb	Natv	22	8	1.00	11	3	11	5
Cordia dichotoma	Tree	Natv	1	1	-	1	1	0	0
Costus igneus	Shrub	Natv	5	1	-	0	0	5	1
Crinum powellii	P Herb	Intro	4	1	-	4	1	0	0
Crossandra infundibuliformis	P Herb	Natv	4	2	-	3	1	1	1
Cynodon dactylon	P Gr	Natv	1044	16	0.60	931	13	113	3
Desmostachya bipinnata	P Gr	Natv	15	3	0.60	6	2	9	1
Dieffenbachia sp.	Shrub	Intro	5	2	-	5	2	0	0
Dracaena reflexa	Shrub	Intro	18	6	-	15	4	3	2
Duranta goldiana	Shrub	Intro	34	3	-	34	3	0	0
Duranta variegata	Shrub	Intro	13	1	-	13	1	0	0
Dypsis lutescens	Shrub	Intro	30	6	-	16	4	14	2
Embelia ribes	P Herb	Natv	1	1	-	0	0	1	1
Epiphyllum oxypetalum	Shrub	Intro	3	3	-	3	3	0	0
Epipremnum aureum	P Herb	Natv	6	1	-	0	0	6	1
Euphorbia microphylla	A Herb	Natv	21	3	1.00	21	3	0	0
Euphorbia milii	Shrub	Intro	6	1	-	6	1	0	0
Euphorbia tirucalli	Tree	Natv	1	1	-	1	1	0	0
Ficus benghalensis	Tree	Natv	2	2	1.00	1	1	1	1
Ficus benjamina	Tree	Natv	4	2	-	3	1	1	1
Ficus drupacea pubescens	Tree	Natv	4	4	0.25	2	2	2	2
Ficus racemosa	Tree	Natv	8	8	0.13	3	3	5	5
Ficus religiosa	Tree	Natv	89	42	0.62	50	19	39	23
Gomphrena globosa	A Herb	Intro	9	2	-	9	2	0	0

Scientific Name	Life form	Origin	Total			Temple		Katte	
			SA	*f*	Spont. ratio	SA	*f*	SA	*f*
Grevillea robusta	Tree	Intro	3	2	-	2	1	1	1
Hibiscus rosa-sinensis	Shrub	Natv	47	11	-	41	8	6	3
Hibiscus schizopetalus	Shrub	Natv	5	3	-	5	3	0	0
Impatiens balsamina	A Herb	Natv	5	1	-	5	1	0	0
Jasminum auriculatum	Shrub	Natv	2	1	-	2	1	0	0
Jasminum officinale	Shrub	Natv	5	1	-	5	1	0	0
Jasminum sambac	Shrub	Natv	8	5	-	6	3	2	2
Lantana camara	shrub	Intro	9	4	1.00	6	2	3	2
Launaea nudicaulis	P Herb	Natv	1	1	1.00	0	0	1	1
Leucas aspera	A Herb	Natv	5	3	1.00	3	1	2	2
Mangifera indica	Tree	Natv	3	1	-	3	1	0	0
Manilkara zapota	Tree	Natv	1	3	-	1	3	0	0
Markhamia lutea	Tree	Natv	3	1	-	0	0	3	1
Mentha spicata	P Herb	Natv	2	1	-	2	1	0	0
Michelia champaca	Tree	Natv	8	6	-	4	4	4	2
Mimosa pudica	P Herb	Natv	15	2	-	14	1	1	1
Monstera deliciosa	Shrub	Intro	1	1	1.00	1	1	0	0
Mukia maderaspatana	A Herb	Natv	1	1	1.00	1	1	0	0
Musa paradisiaca	Tree	Natv	8	3	-	8	3	0	0
Neolamarckia cadamba	Tree	Natv	1	1	-	1	1	0	0
Nephrolepis exaltata	P Herb	Intro	1	1	-	1	1	0	0
Nerium indicum	Shrub	Natv	17	12	-	16	11	1	1
Nyctanthes arbor-tristis	Tree	Natv	2	2	-	2	2	0	0
Ocimum tenuiflorum	P Herb	Natv	11	8	-	7	5	4	3
Oxalis corniculata	P Herb	Natv	200	13	1.00	181	11	19	2
Parthenium hysterophorus	A Herb	Natv	38	4	1.00	6	1	32	3
Pelargonium graveolens	Shrub	Intro	1	1	-	1	1	0	0
Phoenix sylvestris	Tree	Intro	1	1	-	0	0	1	1
Phyllanthus acidus	Tree	Natv	1	1	-	1	1	0	0
Phyllanthus emblica	Tree	Natv	1	1	-	0	0	1	1
Piper betle	Shrub	Natv	2	1	-	2	1	0	0
Platycladus orientalis	Tree	Intro	1	1	-	1	1	0	0

Scientific Name	Life form	Origin	Total			Temple		Katte	
			SA	*f*	Spont. ratio	SA	*f*	SA	*f*
Plectranthus amboinicus	P Herb	Natv	2	2	-	2	2	0	0
Plumeria rubra	Tree	Natv	3	2	-	3	2	0	0
Polyalthia longifolia	Tree	Natv	11	2	-	0	0	11	2
Pongamia pinnata	Tree	Natv	4	4	-	2	2	2	2
Portulaca oleracea	A Herb	Natv	32	3	1.00	32	3	0	0
Prosopis cineraria	Tree	Natv	7	6	0.14	7	6	0	0
Psidium guajava	Tree	Natv	2	2	0.50	2	2	0	0
Raphanus sativus	A Herb	Natv	10	1	-	10	1	0	0
Ricinus communis	Shrub	Natv	13	2	1.00	1	1	12	1
Rosa damascena	Shrub	Natv	9	4	-	3	2	6	2
Santalum album	Tree	Natv	1	1	-	1	1	0	0
Schefflera arboricola	Shrub	Intro	1	1	-	1	1	0	0
Sedum adolphii	P Herb	Intro	2	2	-	0	0	2	2
Solenostemon scutellarioides	P Herb	Natv	5	1	-	5	1	0	0
Spathodea campanulata	Tree	Intro	1	1	-	0	0	1	1
Swietenia macrophylla	Tree	Intro	1	1	-	1	1	0	0
Synedrella nodiflora	P Herb	Natv	236	12	1.00	183	10	53	2
Syngonium podophyllum	Shrub	Natv	44	3	-	35	2	9	1
Syzygium cumini	Tree	Natv	3	2	-	3	2	0	0
Syzygium nervosum	Tree	Natv	1	1	-	1	1	0	0
Tabebuia aurea	Tree	Intro	2	2	-	1	1	1	1
Tabebuia rosea	Tree	Intro	2	2	-	1	1	1	1
Tabernaemontana divaricata	Shrub	Natv	17	7	-	16	6	1	1
Tagetes erecta	Shrub	Natv	10	2	-	6	1	4	1
Tamarindus indica	Tree	Natv	1	1	-	0	0	1	1
Terminalia catappa	Tree	Natv	1	1	-	1	1	0	0
Tinospora cordifolia	P Herb	Natv	1	1	-	1	1	0	0
Tridax procumbens	P Herb	Natv	8	1	1.00	8	1	0	0
Zephyranthes rosea	P Herb	Intro	24	5	-	20	3	4	2
Zoysia tenuifolia	P Gr	Intro	360	2	-	360	2	0	0