Landscape and Urban Planning xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Urban ecological research in Singapore and its relevance to the advancement of urban ecology and sustainability

Puay Yok Tan*, Abdul Rahim bin Abdul Hamid

Department of Architecture, National University of Singapore, Singapore

HIGHLIGHTS

- Urban flora and fauna studies dominated past two decades of ecological research.
- Studies on *ecology in Singapore* far exceeded studies on *ecology of Singapore*.
- Mechanistic understanding of urban ecological patterns and processes is lacking.
- Studies on ecology of Singapore are needed to improve local urban sustainability.
- A framework and key strategies are proposed to encourage such studies in Singapore.

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Urban ecology
Urban ecosystems
Singapore
Urban sustainability
Resilience
Livability

ABSTRACT

The drastic changes in the natural environment of Singapore from the beginning of recorded settlements to the present day present numerous opportunities for understanding how urbanization has affected the ecology of the island city-state. On the one hand, the almost complete clearing of the original tropical lowland forests and the ensuing catastrophic extinction of the original biodiversity, suggest how cities ought to avoid the same developmental pathway. On the other hand, the relatively high percentage of vegetation cover that the city has achieved due to effective urban greening policies suggest that opportunities still exist to restore functions associated with a healthy urban ecosystem. This paper reviewed urban ecological research on Singapore conducted between 1991 and 2012, and summarized the key findings according to the state factors of an urban ecosystem. The review showed that the large majority of the studies were focused on biodiversity, and were on the ecology in a city. It revealed gaps in urban ecological knowledge of Singapore, especially in relation to how studies on the ecology of the city need to link urban ecological research to issues of urban sustainability. Three key strategies are suggested to advance knowledge in this area. These are, to focus on long-term ecological studies in Singapore as an example of a high-density equatorial urban ecosystem, to consciously treat the built component of the urban environment as a key component of urban ecological studies, and to leverage the strong interests in eco-city development as field experimental sites for urban ecological studies.

1. Introduction

The growth of urban populations is projected to occur most rapidly in Asia over the next four decades (Montgomery, 2008). From a socioeconomic perspective, this is likely to bring about marked changes in the demographic, cultural and political dimensions of societies, which will require adaptive urban governance and urban planning to bring about inclusive development and sustainable economic development (Yap, 2011). From an ecological perspective, drastic land use changes that accompany urban population growth can lead to sustained ecological impacts in air and water quality, city and regional climate, and biodiversity loss (Elmqvist, Alfsen, & Colding, 2008; Grimm et al., 2008), often with impacts that extend beyond the immediate boundaries of urbanized regions. Within urban areas, these adverse impacts often manifest in poor urban living conditions which may not be reversed by further growth in per capita income (Ooi, 2007; Yap, 2011). Urbanization is therefore a key driver of socio-economic and environmental changes that affect large regions of Asia, directly

* Corresponding author at: Department of Architecture, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore. Tel.: +65 65163531; fax: +65 67793078.
E-mail addresses: akitpy@nus.edu.sg (P.Y. Tan), a0066455@nus.edu.sg (A.R.b. Abdul Hamid).

http://dx.doi.org/10.1016/j.landurbplan.2014.01.019
0169-2046/

and indirectly, and which leads to significant concerns of the future sustainability of these areas. Yet, being large agglomerations with high concentrations of financial resources, innovation, human resources, and efficient resource use, urbanization should also not be neglected as a possible solution in the quest for sustainability (Rees & Wackernagel, 1999; Wu, 2010). Therefore, understanding the patterns of urbanization and its attendant impacts on the social, economic and environmental functions of cities is critical in the development of solutions for urban sustainability.

Within Southeast Asia, Singapore represents an extreme case of urbanization, which is perhaps a condition of it being a city and a state. As a state, Singapore currently has the lowest amount of its original forest area left intact compared to its Southeast Asian neighbours (Zhao et al., 2006). Of the original lowland tropical rainforest that almost entirely covered the island before the founding of modern Singapore in 1819, only 200 hectares (Corlett, 2011), or 0.28% of its current total land area of 714 km^2 remains. This massive transformation occurred within a century from its modern founding as a British trading post, initially driven by land clearing for the cultivation of cash crops (Corlett, 1992). In fact, when H.N. Ridley, the first director of the Singapore Botanic Gardens published the first compilation of the flora of Singapore in 1900, he reported that "a great deal" of the original forest had been felled, "... and every year still sees the disappearance of some woodland, so that in several of the localities ... few traces of any native plants can now be found" (Ridley, 1900). Subsequent land clearing was driven by urbanization in response to population growth and economic development. Land developments for commercial, industrial and infrastructure needs were greatly intensified during the period of rapid industrialization between the 1960s and 1980s (Neville, 1993). By 1965, Singapore's population was already considered to be 100% urbanized (McGee & Greenberg, 1992). This was in contrast to urban populations ranging from 13% to 36% in Malaysia, Thailand, Indonesia and the Philippines at the same period. As a city, its urbanization profile is also comparatively rapid and extensive. The percentage of built-up area (broadly equivalent to the definition of "urban area"), was about 49% in 1999, which had almost doubled from 27.9% in 1960 (derived from Wong & Yap, 2004). The rate of urbanization is high even when compared to the exponential increase in urban areas of Phoenix and Las Vegas, two of the fastest growing metropolitan regions in the United States (Wu, Jenerette, Buyantuyev, & Redman, 2011). The growth in urban areas in Singapore does not seem abated. Although the built-up areas was projected to reach 60% by 2030 (Neville, 1993), it was seemingly attained by 2012, accompanied by significant changes in its land cover (Tan, Wang, & Sia, 2013). Given that urbanization continues to be the most significant cause of land use change in Singapore, it is critical to understand how its impacts could be better managed, particularly in relation to the two fundamentally important pursuits of urban sustainability and livability.

How can the impacts of urbanization in Singapore be studied? Following the significant progress made in the past two to three decades on how a city is also a novel or hybrid ecosystem (Alberti, 2009; Grimm, Grove, Pickett, & Redman, 2000; Pickett et al., 2011, 2001), we suggest the approach of understanding the impacts of urbanization by focusing on Singapore as an urban ecosystem. In this ecosystem, which is in essence, a tightly coupled socio-ecological system, the biophysical and socioeconomic components interact with each other, driving changes and responding to disturbances. Urban ecological studies, or urban ecology as an emerging integrative discipline (Pickett et al., 2008) provide the scientific underpinnings to understand the patterns, processes and functions within cities or any urban area, as well as the regional and global effects of cities (Grimm et al., 2008). Treating a city as an urban ecosystem allows a highly complex system to be studied through conceptual frameworks and models, from which a better understanding of how its internal processes affect its properties can emerge. For instance, societal consumption of materials and resources can be studied as aggregated flows of energy and materials occurring in and out of an urban ecosystem, and this knowledge can in turn be applied to understand a city's sustainability (Kennedy, Pincetl, & Bunje, 2011) and livability (Newman, 1999). The role of changing patterns of urbanization on the delivery of ecosystem functions through biophysical processes can also reveal the impact of different urban patterns on resource consumption (Alberti, 2010), which is intimately linked to sustainability concerns of urban regions. Taking such a systems approach also allows drivers of change and the impacts of such changes to be understood through a common currency of energy or material that reside as stock in the ecosystem, or which flows in and out of the ecosystem using urban metabolic analyses. Foundational knowledge in various aspects of landscape and urban ecology, such as in characterizing patterns of urbanization, urban ecosystem services, and human ecology can then be integrated and explicitly linked towards the fulfilment of urban sustainability objectives (Wu, 2010) (see also Breuste & Qureshi (2011)).

As the most urbanized state in Southeast Asia, and an example of a high-rise, high-density and compact city, Singapore can present a snapshot of what rapidly developing cities could be like in the future, and therefore lessons that are applicable to other fast growing urban regions of the world. However, there is to-date no review undertaken on the range of urban ecological research conducted in Singapore, or a synthesis of how the research can be used to develop a picture of Singapore as an urban ecosystem. This paper aims to address these gaps. The objectives of the paper are to: (1) summarize the past two decades of urban ecological research in Singapore, (2) describe how urban ecological research can be better linked to promote urban sustainability, and (3) identify strategies for further research to enable such functional relationships to be forged.

2. Two decades of urban ecological research in Singapore

Using the approach of Pickett et al. (2011) as well the human ecosystem framework described therein, we examine the past two decades of urban ecological research in Singapore, categorized according to the state factors of the ecosystem. As described in Amundson & Jenny (1997), ecosystems are "human constructs that break the continuum [of the earth's surface] into manageable and differing segments for study". Different ecosystems can be distinguished by different assemblages of state factors, which in all ecosystems include the factors of climate, organisms, topography, parent material, time and humans, as well as other locally important factors such as fire, coastal conditions, etc. (Amundson & Jenny, 1997). We selected papers published between 1991 and 2012 (please see Table A.1 of the Appendix for more information on the selection of papers), and examined urban ecological research in Singapore according to the following state factors: (1) *urban climate*, which refers to air and surfaces temperatures, atmospheric compositions, wind and solar radiation; (2) *urban flora*, which comprises both managed and spontaneous vegetation; (3) *urban fauna*, which comprises taxa of the animal kingdom; (4) *urban soils*, which is a simplification of the state factor of parent material, and will primarily be on disturbed urban soils; (4) *urban biogeochemistry*, which is focused on the flux and budgets of water, energy, nutrients, carbon, and pollutants, and (5) *urban social factors*, which refer to humans as the dominant organisms of the urban ecosystem, and the social, economic and cultural institutions created by them. The review is limited to the terrestrial ecosystem, including the inter-tidal ecosystem of mangroves, and excludes studies on the coastal and marine ecosystem of Singapore. As an island nation, its marine ecosystems should be considered as an integral

Please cite this article in press as: Tan, P. Y., & Abdul Hamid, A.R.b. Urban ecological research in Singapore and its relevance to the advancement of urban ecology and sustainability. *Landscape Urban Plan.* (2014), http://dx.doi.org/10.1016/j.landurbplan.2014.01.019