Integrating Remote Sensing and GIS for Ecological Capacity Assessment: The Case of Regional Planning in Melbourne, Australia

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Abstract

Two prominent and alternate approaches, ecological carrying capacity and ecological footprint, link the production of ecosystem services with their consumption by societies. An overlapping goal of both approaches is to promote the sustainable use of ecosystem services – especially in urban areas – such that cities and towns can be continuously liveable. Yet, little integration of these perspectives and their emphasis on distinct units has been attempted. In this paper, these two approaches are combined to provide knowledge to inform the planning and management of future urban growth in Melbourne, Australia. Using a GIS, statistical and remotely sensed data are used to calculate ecological carrying capacity and ecological footprint for metropolitan Melbourne. Spatially explicit modelling of ecological surplus or deficit is then conducted to identify land suitable for future urban development. Result from this analysis is then compared with the government's urban growth plan (Melbourne 2030) which nominated urban growth areas simply from the city structure perspective. Such analysis can help generate public and decision makers' awareness of biophysical accounting tools such as ecological carrying capacity and ecological footprint analysis which could be included in metropolitan planning practice to inform decision making for better urban growth management concerning sustainability. This in turn should increase interest in establishing improved urban planning regimes to maintain idealized structure as well as the ecological function of cities and urban regions.

1 Introduction

Ecological Capacity (EC) reflects the capability of an environmental system to support human society by providing food, fuel, fibre, shelter, and so on. Ecological Footprint (EF), more appropriately called environmental footprint is frequently used to characterize human impacts on the regenerative capacity of an environment systems by identifying the amount of biologically productive land required to support a person's average annual consumption and waste production (WACKERNAGEL & REES 1996). In general, EFA categorizes biologically productive land into one of six types: energy, arable land, forest, pasture, built, and sea. Land that does not meet one of these six categories is deemed non-productive and is not included in EF accounting (CHAMBERS et al. 2000). EF analysis calculates the supply (EC) of land available to support a population and the demand (EF) a population places on these six land categories by estimating how much land is being used to support the population. The EC in a given region is compared to the EF of the population by subtracting demand from supply. Examining this balance sheet over time will reveal if there is an EC

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reserve or deficit and if a population is moving toward or away from sustainability as defined by the EF analysis method.

Melbourne, the capital city of the State of Victoria and the original national capital of Australia, has a long tradition in the management of its urban growth since its early years of settlement in 1820s to the city's dramatic growth following the discovery of gold in 1851. The most recent endeavour in this evolution, entitled Melbourne 2030: Planning for Sustainable Growth, has set a broad blueprint for long term urban growth by restricting development with an urban growth boundary (UGB) and delineated areas for growth within the UGB (see Figure 1). This metropolitan strategic plan was development by the Victorian State Government to accommodate long term urban growth issues across the greater Melbourne region. However, the nomination of future urban growth areas in the plan lacks spatial evidence from a robust analysis of environmental factors such as ecological carrying capacity of the urban region, or the ecological footprint of the proposed development. In this study, remotely sensed data and GIS technologies are applied to simulate the ecological carrying capacity and footprint for metropolitan Melbourne in a spatially explicit manner. Areas with high EC reserves are mapped and compared with the growth areas plan of Melbourne 2030 to contrast the outcomes of two different planning approaches. The case of Melbourne could shed light on efforts of managing urban growth of other cities worldwide.

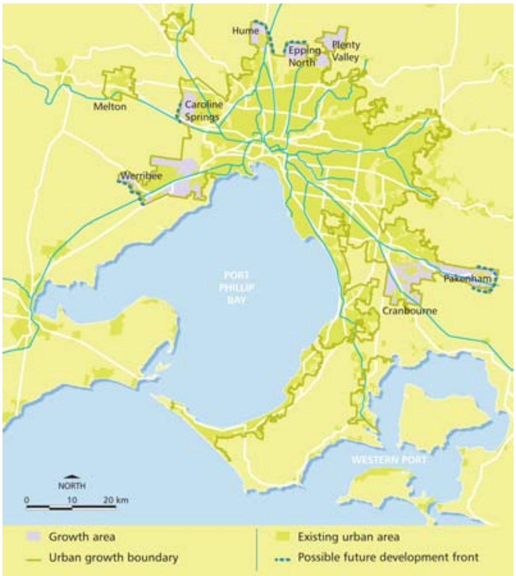

Fig. 1:
UGB and urban growth area (UGA) of Melbourne by Melbourne 2030 (DEPARTMENT OF INFRASTRUCTURE 2002). The state government spent $ 5 million and years of time to create this planning report. Melbourne 2030 now forms part of the State Planning Policy Framework and is referenced within all planning schemes in the State of Victoria.

2 Input Data and Data Processing

Remotely sensed satellite image data are widely used in urban and landscape planning studies. Following the same approach of digital image processing by CHEN et al. (2003), four scenes of Landsat ETM+ images were used to map the productive land types in Melbourne (Fig. 2). The total areas of the six productive land types are listed in Table 1.

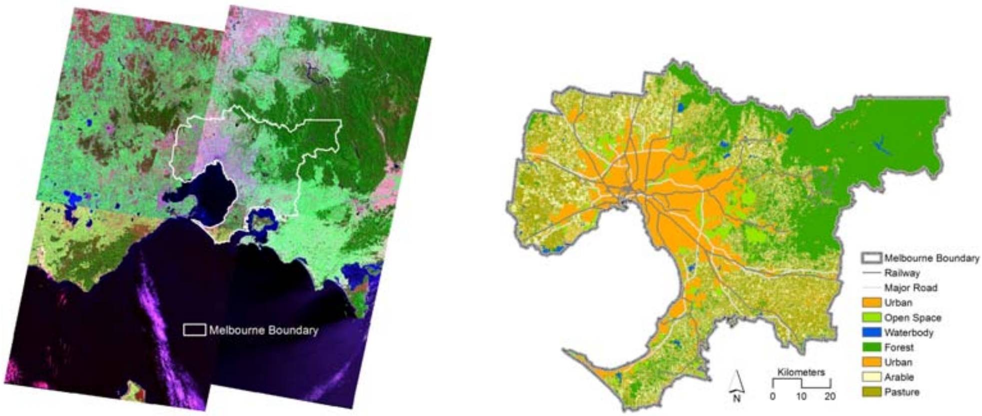

Fig. 2: Four scenes of Landsat TM+ images were merged together (left) and cookie-cut for land use classification of metropolitan Melbourne area (right).

Table 1: Land use types and their total area in metropolitan Melbourne

Type	Area (km^2)	% of Total Area
Forest	3126	35.4
Urban	1163	13.2
Arable	1677	19.0
Pasture	2125	24.1
Water	140	1.6
Open space	592	6.7
Total	**8823**	**100**

3 GIS-based EC Reserve or Deficit Calculation

3.1 Global Hectare (gha)

A global hectare is one hectare of biologically productive space with world-average productivity. In 2002 the biosphere had 11.4 billion hectares of biologically productive space. This includes: (1) 2.0 billion hectares of ocean; and (2) 9.4 billion hectares of land. One global hectare is a hectare representing the average capacity of one of these 11.4 billion hectares. Global hectares allow the meaningful comparison of the ecological footprints of different countries, which use different qualities and mixes of cropland, grazing land, and forest. Once all global hectares of bio-productive land and sea are divided by the total global population, we end up with our fair earth share (1.8 gha for 2002). Both EF and EC are measured against global hectare.

3.2 Mapping EC of Metropolitan of Melbourne

EC measures the biological productivity of land resources in relation to global hectare. EC can be calculated using the equation below (MONFREDA et al. 2005)

$$EC = \Sigma\, y_i w_i A_i \qquad \text{Eq. 1}$$

where

EC is the total ecological capacity.

y_i is the yield factor, which accounts for countries' differing levels of productivity for particular land use types. Yield factor provides comparability between various countries' EC and EF calculations. Yield factors used in this study for Melbourne are listed in Table 2.

w_i is the equivalence factor, which converts the actual areas in hectares of different land use types into their global hectare equivalents. Equivalence factors used in this study for Melbourne are listed in Table 2.

A_i is the total bio-productive land to produce the *i*-th consumption.

Table 2: Yield factor, equivalence factor and the calculation of average EC for Melbourne using Eq. 1

Land Type	**Area (sq. m)**	y_i	w_i	**EC (gha)**
Arable	1677177768	2	2.64	885549.8615
Forest	3125571914	0.8	1.33	332560.8516
Pasture	2124990094	2.5	0.5	265623.7618
Build-up	1163203011	1.66	2.64	509762.0874
Water	140492935	1	0.4	5619.7174
Open space	591986481	0.8	1.33	62987.36158
Total	**8823422203**	--	--	**2107830.758**
Average EC	**2.389 gha**			

Results in Table 2 are combined with the spatial distribution of productive land types and their areas to map the spatial pattern of EC for metropolitan Melbourne (Fig. 3).

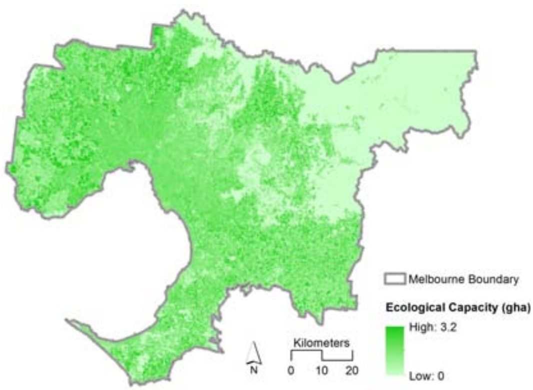

Fig. 3:
Spatial pattern of EC in metropolitan Melbourne area

3.3 Mapping EC reserve or deficit of Metropolitan of Melbourne

EF tracks natural resources consumption of a nation, a region or an individual, and translates the resource consumption into biologically productive land area, which is required (1) to produce the resources again, and (2) to assimilate the wastes. Available land per capita and available EC per capita for Melbourne, whose total population is 3.9 million, are calculated (using results in Table 2) as follows:

Available land per capita = 8823 km^2 / 3,900,000 = 0.226 ha

Available EC per capita = 2.389 × 0.226 = 0.53 gha

Using the potential total EC (production) in Fig. 3 to subtract available EC per capita (consumption), the EC reserve or deficit for Melbourne is calculated as shown in the Fig. 4. An aggregation operation is applied to highlight the regional pattern of EC reserve or deficit (Fig. 4), where the lighter colour represents areas with high EC reserve, while the darker colour represents areas with low EC reserve, or EC deficit.

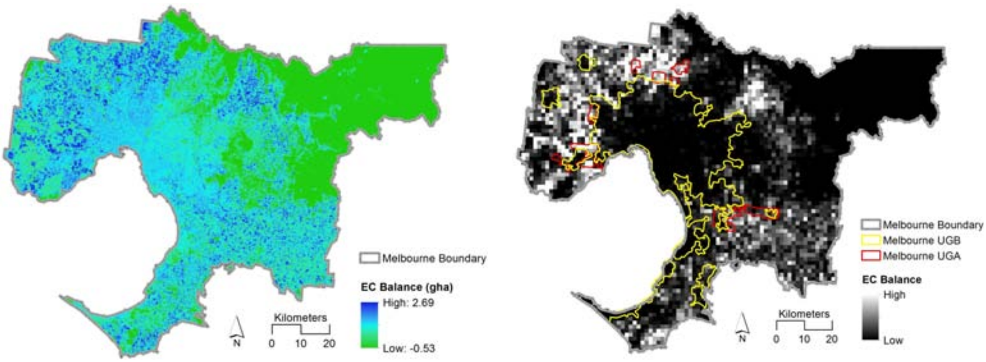

Fig. 4: Mapping EC reserve of metropolitan Melbourne: EC reserve on 30m × 30m grid (left); aggregated EC on 1,200m × 1,200m grid (right) overlaid with Melbourne 2030 urban growth boundary (UGB) and the designated urban growth areas (UGA).

4 Results

As illustrated in Fig. 4, the spatial variation of EC reserve of the metropolitan area partially matches the urban growth areas nominated by the government's plan, except that on the upper-right area adjacent to UGB where there is a large light coloured area indicating substantial EC surplus. Other such areas alike delineated through this spatially explicit modelling process may be used as suitable land for future urban growth after Melbourne 2030, based on the assumption that EC (production) is consumed locally. The government agencies in charge of urban growth planning and management may be benefited from this study because, on the one hand, provides solid evidence to support the government's publication Melbourne 2030 that some of the designated urban growth areas are located in areas with high EC reserves; on the other hand, many large tracts of land adjacent to the current UGAs can be used to accommodate urban growth in the future when a longer term visionary blueprint is sought for Melbourne, e.g., Melbourne 2100 (or even Melbourne 2200); this is necessary, inescapable and sometimes commendatory as the solution to many pressing issues such as climate change does require strategic considerations across larger temporal scales (HEBERLING et al. 2012).

5 Conclusion and Outlook

Although EF or EC are associated with national or global measures, this research demonstrated that coupled with high resolution spatially explicit datasets, ecological carrying capacity assessment can be used to innovate and direct sustainable land use and urban development, and plan and manage urban growth toward more sustainable outcome as demonstrated in this remote sensing and GIS-based approach. This study is based on the assumptions that population is evenly distributed across the metropolitan area (e.g., to be more specific, the EF of each pixel of the land should be calculated based on the actual distribution of population and their actual individual EF). The approach to apply population 'spatialisation', using demographic datasets, is more complex and thus is not reported here. The comprehensive approach may be applied to other world cities and can be reported in another occasion as an extended full paper.

The proposition may be questionable since urban life is normally going on beyond the fine scale at the aggregated cell size, however, the increasingly growing awareness in the public that local food production and consumption decreases carbon footprint in the post-oil age will eventually make more citizens embrace the new low-carbon life style. This is evident in the recent eco-village movement which is a worldwide phenomenon that has arisen in response to the effects of the modern lifestyle on both our social and ecological environments (KIRBY 2003) by defining eco-villages as a self-supporting area in which both a productive economy and the maintenance of semi-natural environmental systems can be realized (WALKER 2005). The eco-village idea may be considered in the future UGAs in Melbourne in conjunction with their local geographical and cultural contexts to further test this urban planning methodology based on ecological carrying capacity assessment.

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