REMOTE SENSING OF URBAN ECOLOGICAL INFRASTRUCTURE IN DESAKOTA ENVIRONMENTS: A REVIEW OF CURRENT APPROACHES

S HAWKEN 1, G METTERNICHT 2, C W CHANG 3 S C LIEW 3, A GUPTA 4

1: Faculty of Built Environment, UNSW Australia. Email: s.hawken@unsw.edu.au

2. Institute of Environmental Studies, School of Biological, Earth and Environmental Sciences, UNSW Australia, Sydney. Email: g.metternicht@unsw.edu.au

3. Centre for Remote Imaging, Sensing and Processing, National University of Singapore, Singapore

4. School of Earth and Environmental Sciences, University of Wollongong Australia

KEY WORDS : Urban Ecology, Urban Heterogeneity, Southeast Asia, Ho Chi Minh City, Ecosystem Services.

ABSTRACT

The semi-aquatic, aquatic and green spaces of emerging Southeast Asian mega-cities act as ecological infrastructure, providing diverse ecosystem services to rapidly, growing, urban populations.. The cultural and natural biodiversity integrated within urban ecological infrastructure is a key to metropolitan sustainability. However, rapid urban development has left stream systems, urban agriculture, wetlands and urban forests as fragmented spaces vulnerable to future development.

This paper addresses such issues by reviewing methods for mapping and monitoring urban ecological systems through multi-sensor earth observation for urban planning. The potential of various satellite sensors is discussed in relation to their ability to reveal different aspects of ecological infrastructure. We conclude that the synergistic combination of data from multiple sensors can provide more reliable and accurate information especially when classifying complex systems such as ecological infrastructure. The potential advantages of integrating information from multiple sensors include improved timeliness, complementarity, cost-effectiveness and better certainty when compared to information from single sensors. Classifications need to recognize the complexity of the urban-rural continuum and highly heterogeneous desakota environments. This issue is explored with reference to Ho Chi Minh City, Vietnam.

Framing the issue: The Challenge of Emerging Megacities and the Desakota Phenomenon

Emerging Southeast Asian Megacities, such as Yangon and Ho Chi Minh City are set to double in size over the next few decades. The aquatic and green spaces surrounding these cities are under pressure because of rapid and misguided urban expansion. These ecological spaces act as ecological infrastructure, defined as the landscape patterns and structures required to sustain the provision of ecosystem services (Tzoulas *et al.* 2007). Ecosystem services are "the benefits people obtain from ecosystems" (Hassan *et al.* 2005a p. 49) and have been classified into four categories by the Millennium Ecosystem Assessment, namely: 1) provisioning services including such goods as food and water; 2) regulating services such as flood control, microclimate modulation and disease control; 3) supporting services such as nutrient cycling, genetic maintenance and pollination that maintain the conditions for life in cities and on earth and 4) cultural services, that is values associated to urban biodiversity and ecosystem services, including emotional, affective and symbolic views attached to urban nature, as well as local ecological knowledge. A wetland may provide edible plants and animals, may regulate climate, waste water and mitigate flood impacts, supports the life cycles of fish species through providing nursery habitats and finally provides aesthetic value and recreational opportunities (de Groot *et al.* 2010 p. 263).

Ecosystem services have been defined as fulfilling specific human needs and rights. However, better understanding is needed on how these services are related and delivered in urban settings. Conventional divisions between "urban" spaces and "rural" spaces hinder such an understanding. These two coarse land-use classifications have an enormous impact on the way cities are conceived, designed and managed. Urban-rural divisions are built into the statistical collections and mapping of nations around the world. They form the decision making basis for the United Nations and other global institutions ultimately influencing the global development agenda (Davis 2011; Brenner 2013).

McGee (2008, 2009) has argued against general acceptance of the conventional trajectories of development where societies move from underdevelopment to development. In contrast to western development trajectories McGee asserts that Southeast Asian Cities have developed more rapidly, in a much more fragmented pattern that integrates land-uses typically considered rural or "non-urban". Desakota areas are typically found on the periphery of large industrialising Southeast Asian Cities or in within city regions. They integrate a patchwork of highly productive and diverse agricultural systems, aquaculture, wetlands, recreational landscapes, vast factory enclaves with attendant

worker housing, informal development, hi-tech industrial parks, elite housing enclaves and more traditional urban villages in a complex spatial arrangement. This combination of industrial landscapes, ecological systems and traditional villages has been attributed to a telescoping of new industrial technologies into traditional patterns of living to form startling and unexpected combinations.

The scale, speed and geographic location of urbanisation in Southeast Asia make understanding such landscapes critical. The rapid urbanisation of Vietnam over the past two decades has resulted in the decisive transformation of urban ecosystems. During this period Vietnam's urban population has increased by 40% and most of this population has been accommodated within the dynamic emerging megacity of Ho Chi Minh City. Ho Chi Minh's official population in 2007 was 6.6 million but its actual population is likely to be much closer to 8 million as statistics don't capture the large floating migrant population (Dapice *et al.* 2009 pp. 1–5). Since the *Doi Moi* (Vietnam's economic reforms introduced in the late 1980s) estimates suggest that up to up to 80% of all private construction in Ho Chi Minh City took place without any regulation or permit due in part to the rapid transition to a market based system, without adequate planning and licensing land systems, to guide development (Waibel *et al.* 2007 p. 63). In this context ecosystems have come under increasing pressure. A prominent example is the removal of wetlands and flood receiving areas in the South and East of Ho Chi Minh, in areas such as District 7, District 2, Nha Be Can Gio and Binh Chanh. As the city's main drainage direction is North to South, development of these downstream areas has influenced the ability of floodwaters to freely drain from central areas of the city. Recent studies warn that climate change will exacerbate such urbanisation impacts making them more severe and frequent (ADB 2010; Storch and Downes 2011).The populations most affected include socio-economically vulnerable residents occupying informal housing in low lying areas.

There is an acknowledged need for spatial information to address the complex urban issues associated with rapid urbanisation (Doytsher et al. 2010 p. 26). Remote sensing can provide urban professionals, with evidence to make spatially-explicit decisions.

This paper discusses the significance of monitoring and mapping urban ecological infrastructure in emerging Southeast Asian megacities. A theoretical position for effectively undertaking this task is outlined and this is followed by examples of different remote sensing technologies available for the mapping of ecological infrastructure. This discussion is explored through an examination of high and very high resolution optical imagery to highlight the various issues involved in the task of defining ecological infrastructure. Two 2 x 2 km study areas on the periphery of the Vietnamese city of Ho Chi Minh were selected, one in the north and one in the south. Criteria for site selection were based on prevalence of ecological infrastructure such as urban agriculture, wetlands and street tree avenues and high heterogeneity.

Classifying Heterogeneous Urban Environments: Desakota Systems and Ecological Infrastructure

The linkages between ecosystems and human societies in desakota environments are changing in fundamental ways that are not well understood (Desakota Study Team 2008). To further ecological understanding of urban-ecological systems, fine scale heterogeneity and the structural relationships between them need be quantified (Pickett and Cadenasso 2008).

The spatial patterning of urban ecological infrastructure can be patchy or consist of a network of corridors. Urban ecological infrastructure is defined and modified in relation to the city. Such modifications need to be understood and managed so that infrastructure can continue to provide ecosystem services on a sustainable basis. Such infrastructure can be defined through delimiting relatively straight forward elements such as stream corridors, vegetation patches, water bodies, wetlands and cultivated urban areas. Ecological infrastructure such as micro-plots of urban agriculture and unique or specialised ecosystems, are more difficult to identify.

Sophisticated measures involving a fusion of different data sources are needed to define and value elements linking landscape structure with ecosystem services. Major land cover classification schemes relevant to conservation and ecological studies include those defined by Anderson (1976), designed for Landsat and aerial photography as well as various land classification schemes by the FAO (Gregorio 2005). In urban settings the land-cover/land-use systems have been designed to distinguish urban from non-urban land-uses, rather than elaborate the close linkages between them. Land-cover based classification systems, such as Anderson's, are useful across continental and global scales but are not adequate to understand the complex ecological functioning of urban systems. Approaches using high resolution imagery have been developed at finer scales suited to the high-heterogeneity of urban environments. These fine grained studies identify the biotic and individual components of the landscape, but not how those elements are arranged and interact in relation to each other. Cadenasso (2013) asserts that rather than moving between the extremes of coarse and fine resolution to gain insights into ecological infrastructure, it is more important to emphasise the interactions present between classes at each of the various scales. Heterogeneity is then not only a descriptor of the spatial arrangement of the urban landscape, but it forms an explanatory classification.

Classification systems that incorporate awareness of, or characterise, different structural patterns may also suggest more or less efficient ways to integrate ecological infrastructure. This structural component of classification

systems requires further development because urban decision-makers need clear, easy to interpret guidelines to form designs in relation to urban ecosystems. Detailed ecological knowledge, focused on individual species or ecosystems, often fails to be integrated into city shaping visions as urban planners rely on broad ecological principles and theories at the scale of the urban district or metropolis. Suitable information is critical in fast paced decision-making environments.

Data Fusion : Integrating Urban and Conservation Ecology Remote Sensing Paradigms

New satellite remote sensors and algorithms are available for mapping and monitoring applications on conservation ecology and urban areas. However, specialist approaches in the application of urban remote sensing and ecological or conservation based remote sensing, need to be re-assessed and integrated.

Recent advances in very high resolution satellite sensors now rival the spatial resolution of aerial photography, with the added advantage of carrying greater spectral information. To date conventional methods of mapping detailed urban ecological elements at the scale of the ecotope or patch (the smallest ecological units in landscape ecology) have relied on combining colour infrared aerial images with fieldwork. Other high resolution satellite imagery previously used on urban areas, such as SPOT-4 and Landsat TM and ETM+, lack the spatial resolution necessary to detect fragmented vegetation patches that characterise urban and desakota environments.

Ikonos and other very high resolution sensors such as GeoEye-1 and WorldView-2 and 3 provide very high resolution products able to capture ecological infrastructure such as street trees, urban agriculture micro-plots and in some cases bio-swales (see Table 1). Ikonos also presents the opportunity to derive vegetation information through its green/red ratio (i.e., the Chlorophyll Index), which is claimed to have greater sensitivity than the NDVI in detecting multiple layering within the vegetation canopy (Nichol and Lee 2005).

Medium resolution optical sensors such as SPOT-5, ALOS AVNIR-2 (no longer operational) and Landsat offer greater swath size and the capability to characterise aspects of vegetation such as biomass patterns in urban areas (Goh *et al.* 2014). Although not suitable for very fine grain analyses they are suited for metropolitan or district scale analyses. Furthermore Landsat data has the benefit of being provided free of charge as a public good by NASA, in addition to providing a historical archive of land-cover of the earth's surface for 40-years, with extensive temporal coverage of urban areas.

Emerging megacities such as Ho Chi Minh City are growing within the context of urbanising regions that cover many thousands of square kilometres (Forman 2008; McGee 2009). Urban mapping from medium and coarse satellite sensors (e.g Terra ASTER, MODIS) do not capture the detailed structure of urban areas but are useful in establishing regional spatial frameworks and regional urban ecology (Engel-Cox *et al.* 2004; Jin *et al.* 2005; Schneider *et al.* 2010). These instruments are useful for describing regional climate impacts of urbanising regions by using their capacity to measure thermal emissivity, and radiative temperatures (ASTER and Lansat-8). Such sensors could help derive proxies for mapping ecosystem services of certain ecological infrastructure as various ecosystems act as heat sinks to counter the heat island impacts of urban areas.

Microwave sensors, such as PALSAR and PALSAR-2 on board of ALOS/ALOS-2, offer capabilities useful for mapping ecological infrastructure in Southeast Asian contexts particularly for applications related to regular monitoring of flood dynamics. These applications can provide planners and decision makers with spatial-temporal maps of monsoon dynamics and flood waters, as well as being suitable for biomass estimation during rainy and dry seasons in wetland environments.

Rapid progress has been made in mapping the three dimensional topography of cities using airborne active sensors such as LiDAR (Lefsky *et al.* 2002; Secord and Zakhor 2007; Omasa *et al.* 2008; Tooke *et al.* 2009). Such instruments are able to provide three-dimensional information on tree canopies and the topographic structure of streets, fields and landscapes at a level of detail useful for flood mapping.

Table 1: Current very high, high and medium resolution sensors and their cartographic potential of urban ecological infrastructure.

Satellite / Sensor	spatial	spectral	Potential Ecological Infrastructure mapping
Landsat 8 (OLI) and (TIRS) sensors	15 / 30 m (OLI); 100m (30) TIRS	VIS – NIR - SWIR (7); TIR (2), 1 pan	Urban forest, wetlands; wildlife corridors, core reserves; parks
SPOT -5	2.5m - 5m, 10m, 20m	Pan; VIS-NIR; SWIR (5 bands)	parks, open spaces, playing fields, woodlands, stormwater retention ponds; wildlife corridors, core reserves; wetlands; urban watercourses

SPOT-6	1.5 (Pan); 6m (multispectral)	Pan; VIS-NIR (5 bands)	parks, open spaces, playing fields, woodlands, street trees, canals, ditches; urban tree canopy; vegetated ephemeral waterways; urban watercourses
Ikonos	1m pan; 4m multispectral	Pan; VIS-NIR (5 bands)	parks, open spaces, playing fields, woodlands, street trees, canals, ditches; vegetated ephemeral waterways; urban watercourses.
GeoEye-1	0.5m (pan); 2 m (multispectral)	Pan, VIS-NIR (5 bands)	Bioswale; urban agriculture micro-plots, parks, open spaces, playing fields, woodlands, urban tree canopy, canals, ditches; green roofs; street-side swales; planter boxes; urban watercourses; gardens.
WorldView-2 & 3	0.5m/0.31m (pan); 2m/1.24m (multispectral)	Pan; VIS-NIR (8 bands)	Bioswale; urban agriculture micro-plots; parks, open spaces, playing fields, woodlands, street trees, canals, ditches; green roofs; street-side swales; urban tree canopy; planter boxes; urban watercourses; gardens.
Terra ASTER	15; 30; 90m	VIS-NIR-SWIR;TIR (14 bands)	Canals, ditches; parks and green recreational areas; golf courses; wetlands; urban watercourses
ALOS-2 / PALSAR	10m	L-band (microwave)	urban watercourses; open green space, parks; storage ponds, lakes and reservoirs.

Source: Authors' compilation; Geoimage (www.geoimage.com.au) and eoPortal Directory for sensors characteristics.

**Remote Sensing Desakota Environments in Ho Chi Minh City's Periphery**

Diverse ecosystem services are delivered in a variety of spatial patterns throughout Ho Chi Minh City's metropolitan area. Many of these spatial patterns are under threat or changing with unknown consequences. Two sites were selected as test areas to investigate the relationship between desakota landcover/landuse patterns and ecological infrastructure. A land-use/land cover-classification was applied to the 2 subsets of Landsat 8 and Ikonos imagery (Figure 1), and ground data was collected to identify desakota patterns. Landsat 8 imagery proved useful for identifying general land-cover patterns and the Ikonos imagery was optimal for identifying fine grained structural patterns and specific land-cover classes at the scale of the ecotope.

The two chosen sites are located in contrasting environments. The areas of interest (AOI), 2 x 2km in dimension for the Ikonos and 10 x 10km for the Landsat 8, were selected for desakota characteristics such as high heterogeneity, the presence of aquatic ecological networks, intense agricultural land-use and proximity to varying scales of urban development. Medium resolution Landsat-8 imagery and very high resolution Ikonos imagery were both classified using complementary land-cover classifications and several field visits verified the conditions of the landscape. The data from Ikonos and Landsat-8 were converted to top-of-atmosphere reflectance and were atmospherically corrected by assuming an atmosphere with molecular Rayleigh scattering. After correction the 4m resolution Ikonos scenes were resampled to 1-meter resolution and sharpened by the 1-meter panchromatic band, preserving the spectral shape of the corrected ground reflectance. A standard unsupervised ISODATA classification was used identify possible classes and supervised methods (mixed methods) were applied to refine the results.

The northern area of interest (AOI-1 - Figure 2) is situated south of the upper reaches of the Dong Nai River in a heavily vegetated, semi-aquatic landscape, transformed over the past few decades from a mix of forest and low intensity agriculture to an intricate agricultural mosaic of ricefields, pasture crops, vegetable crops and orchards. The landscape consists of two major spatial conditions 1.) a large landscape mosaic of diverse agriculture divided by canals and roads and 2.) a large patch of formal/informal settlement interspersed with agricultural micro-plots. The productivity of the large agricultural mosaic is evident in natural colour images and the mixed methods classifications. However, the high productivity of the densely built up area was only apparent after ground-truthing. Micro-plots of vegetables and ornamental nurseries were common throughout the dense urban settlement. Agricultural activities that occurred within the micro-plots and interstitial spaces between structures were distinctly different from the agriculture distributed within the large agricultural expanse that dominates the majority of the northern AOI. Both landscape conditions present distinct structural patterning with diverse ecosystem services integrated in the patterns.

Figure 1 – Location of AOI-1 and AOI-2

Data Sources : Landsat 8 Scene :LC81250522014085LGN00, Date Acquired 2014/03/26, Open Street Map Data
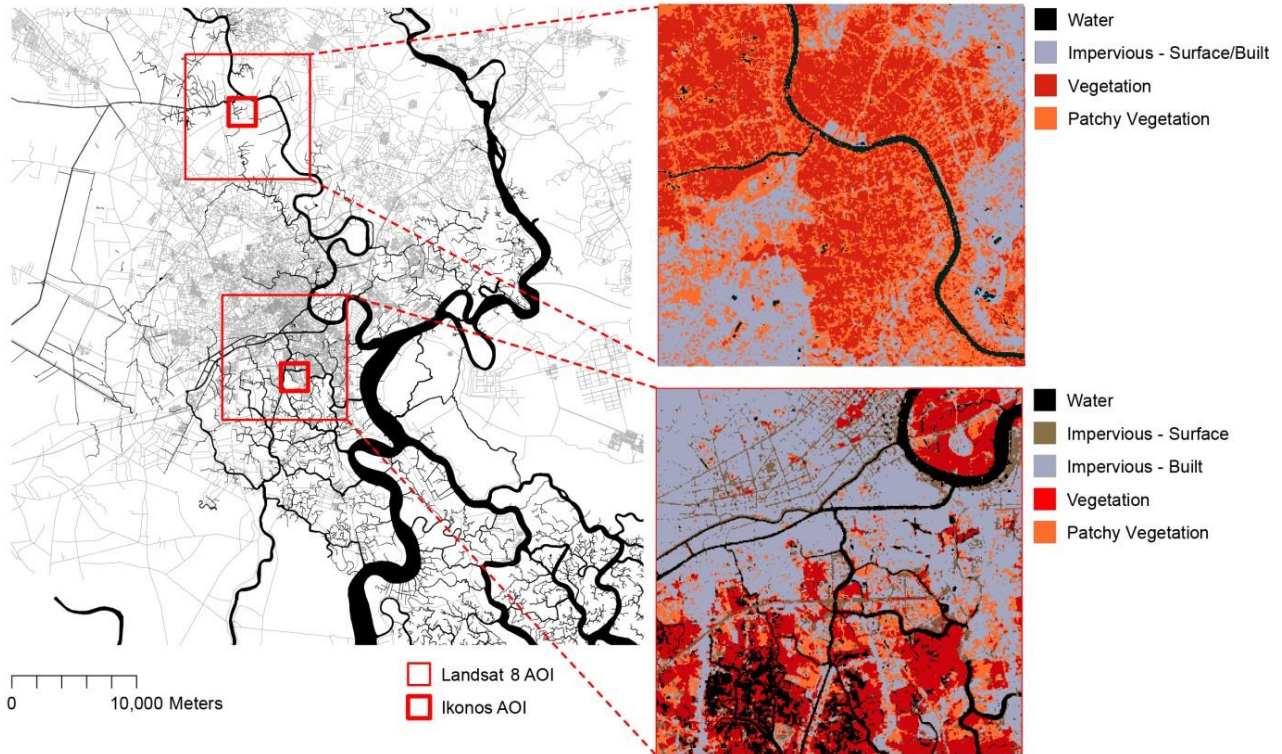
The southern area of Interest (AOI-2 - Figure 3) is a completely different ecological landscape situated at the edge of a dense network of stream systems and distributaries that eventually drain into the Nha Be River. The site abuts the Phu My Hung "mega-development" area. It is traversed by two major arterial roads, the east-west running Nguyen Van Linh Parkway and the North South running Nguyen Huu Thọ Parkway. The land consists of modified wetlands and a patchwork of new development built on land reclaimed from the semi-aquatic wetlands that still largely characterises the area. Much of the land is fallow and awaiting development. The sensitive ecological infrastructure in the area includes a fine tracery of streams, wetland systems, and expanses of aquaculture ponds used for recreational fishing by office workers after hours. These recreational landscapes and large expanses of overgrown wetland areas are frequently fringed by informal settlements similar to those found in AOI-1. These settlements are interspersed with a productive and fine pattern, of micro-plots with vegetables, fruit trees and aquaculture ponds. The middle class villa landscapes also feature agricultural plots inserted in the wide-open spaces between the houses. However most of the landscapes between the expensive new villas remain grassy fallow.

In both AOI-1 and AOI-2 fine grained ecological infrastructures are evident as generalised patterns in the classifications. These ecological infrastructures include small scale agricultural micro-plots and aquaculture ponds. Ecological infrastructure is not able to be identified as distinct homogenous land-cover classes, in remote sensed imagery, but is part of an intense mix of different uses. Initial results suggest that areas of high intermixing of impervious and vegetation classes (as classified in the Ikonos images) or the patchy vegetation class (as classified in the Landsat 8 images) are likely to have a greater amount of certain types of ecological infrastructures such as micro-plots. For example within the study areas there is a strong likelihood that areas of informal development will also contain agricultural micro-plots although such features vary independently of each other. Investigation of the mixed pixel "patchy vegetation" zones in Landsat and the highly heterogeneous zones mixed classes zones in Ikonos requires additional investigation to test the premise that certain urban patterns correlate with distinct types of urban ecological infrastructure.

This premise can potentially be investigated in the following six ways: 1.) monitoring of desakota areas using remote sensed products of different spatial and spectral resolutions and data fusion techniques; 2.) refinement of

urban vegetation classes through a combination of vegetation indices and object based classification; 3.) identification of consistent patterns of land-cover as a proxy for ecological infrastructure at the scale of the eco-tope; 4.) identification of consistent patterns of land-cover as a proxy for accurately locating ecological infrastructure at the scale of the metropolis; 5.) measurement of soil moisture, high biodiversity areas and biomass, as indicators of ecological infrastructure. 6.) development of a urban ecological heterogeneity index based on the work of Cadenasso (2013)

Figure 2 – North AOI

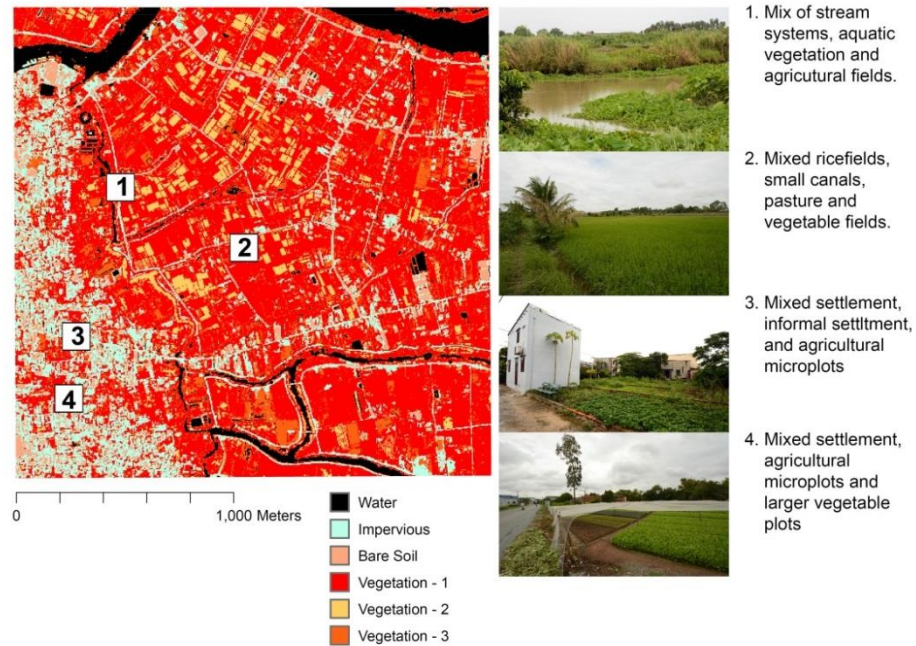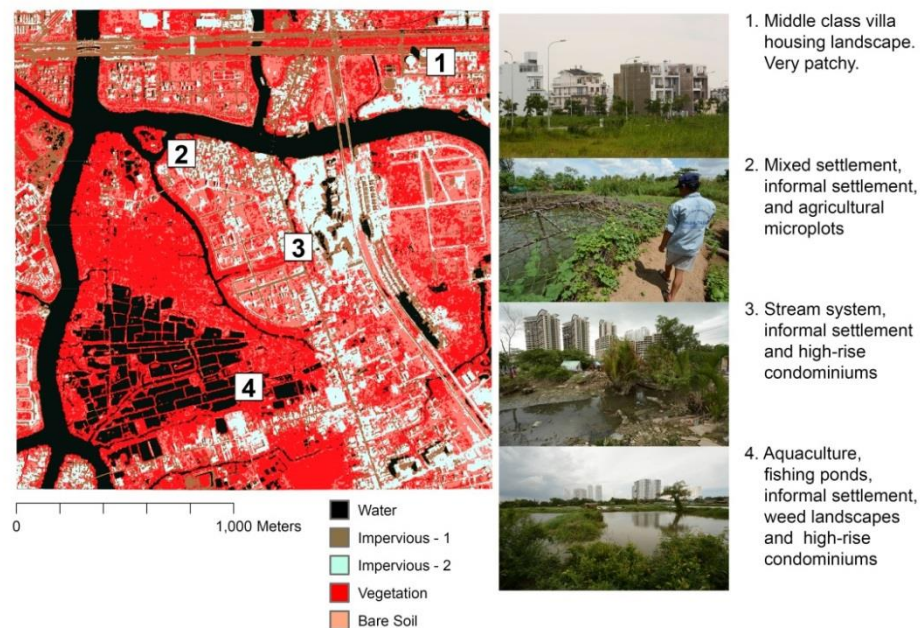**Data source:**

Satellite Ikonos Date/Time 2011-02-10 03:30:10.0

1. Mix of stream systems, aquatic vegetation and agricural fields.

2. Mixed ricefields, small canals, pasture and vegetable fields.

3. Mixed settlement, informal settltment, and agricultural microplots

4. Mixed settlement, agricultural microplots and larger vegetable plots

Legend: Water · Impervious · Bare Soil · Vegetation - 1 · Vegetation - 2 · Vegetation - 3

0 — 1,000 Meters

Figure 3 – South AOI

Data source:

Satellite Ikonos Date/Time 2011-02-10 03:30:10.0

1. Middle class villa housing landscape. Very patchy.

2. Mixed settlement, informal settlement, and agricultural microplots

3. Stream system, informal settlement and high-rise condominiums

4. Aquaculture, fishing ponds, informal settlement, weed landscapes and high-rise condominiums

Legend: Water · Impervious - 1 · Impervious - 2 · Vegetation · Bare Soil

0 — 1,000 Meters

Conclusion

Ecological Infrastructure is a novel concept that is gaining momentum within the urban design and the planning professions. It as infrastructure that can be optimised in-situ through networking different patches of the same ecosystem, or, through building synergies between different patches(such as those of informal settlements and micro-plots). Modification of existing urban landscapes may also better deliver ecosystem functions. There is the potential for urbanising landscapes to integrate ecological infrastructure frameworks as the foundation for tomorrow's megacities. Advances in techniques from both urban and conservation remote sensing science need to be combined with the structural language of landscape ecology and integrated into GIS systems to support urban decision making. The range and capabilities of sensors now available can help capture the diverse spatial dimensions and biophysical qualities of urban ecosystems. The challenge remains to integrate such diverse capabilities in a way that can add depth and functional meaning to current land-cover and land-use maps. The feasibility of such technology for generating up-to-date decision making maps for urban planning authorities relies on this fusion of data.

Urbanisation in Southeast Asia is unique in its development trajectory and urban ecology. Southeast Asian urbanisation demonstrates particular characteristics that have been described effectively using the desakota concept. Despite the ecological implications of this transformation social-ecological relationships remain obscure and require considerable new research. The quantitative measurement of the two sites studied highlights the need go beyond sharp urban-rural-urban distinctions. Remote sensing is an essential tool in understanding the rapid and irreversible changes now occurring in such desakota areas in emerging megacities throughout the region.

References

ADB. 2010. Ho Chi Minh City Adaptation to Climate Change: summary report. Manila: Asian Development Bank.

Anderson JR. 1976. A land use and land cover classification system for use with remote sensor data. US Government Printing Office.

Bennett EM, Peterson GD, and Gordon LJ. 2009. Understanding relationships among multiple ecosystem services. *Ecol Lett* **12**: 1394–404.

Brenner N. 2013. Implosions /Explosions: Towards a Study of Planetary Urbanization. Berlin: Jovis.

Cadenasso ML. 2013. Designing Ecological Heterogeneity. In: McGrath B (Ed). Urban Design Ecologies. Chichester, West Sussex: Wiley.

Dapice D, Gómez-Ibáñez JA, Nguyen, *et al.* 2009. Ho Chi Minh City: the challenges of growth. [Ho Chi Minh City]: United Nations Development Programme in Vietnam.

Davis K. 2011. The urbanization of the human population. *City Read*: 20.

Engel-Cox JA, Holloman CH, Coutant BW, and Hoff RM. 2004. Qualitative and quantitative evaluation of MODIS satellite sensor data for regional and urban scale air quality. *Atmos Environ* **38**: 2495–509.

Forman RTT. 2008. Urban Regions: Ecology and Planning Beyond the City. Cambridge, UK: Cambridge University Press.

Goh J, Miettinen J, Chia AS, *et al.* 2014. Biomass Estimation in Humid Tropical Forest Using a Combination of ALOS PALSAR and Spot 5 Satellite Imagery. *Asian J Geoinformatics* **13**.

Gregorio A di. 2005. Land cover classification system: classification concepts and user manual : software version 2. Rome: FAO.

Groot RS de, Alkemade R, Braat L, *et al.* 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol Complex* **7**: 260–72.

Hassan R, Scholes R, Ash N, *et al.* 2005. Ecosystems and human well-being: current state and trends, volume 1 : findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment. Washington, DC: Island Press.

Jin M, Dickinson RE, and Zhang D. 2005. The Footprint of Urban Areas on Global Climate as Characterized by MODIS. *J Clim* **18**: 1551–65.

Lefsky MA, Cohen WB, Parker GG, and Harding DJ. 2002. Lidar Remote Sensing for Ecosystem Studies. *BioScience* **52**: 19–30.

McGee T. 2008. Managing the rural–urban transformation in East Asia in the 21st century. *Sustain Sci* **3**: 155–67.

McGee TG. 2009. The Spatiality of Urbanization: The Policy Challenges of Mega-Urban and Desakota Regions of Southeast Asia. Institute for Environment and Development, Universiti Kebangsaan Malaysia.

Nichol J and Lee CM. 2005. Urban vegetation monitoring in Hong Kong using high resolution multispectral images. *Int J Remote Sens* **26**: 903–18.

Omasa K, Hosoi F, Uenishi TM, *et al.* 2008. Three-Dimensional Modeling of an Urban Park and Trees by Combined Airborne and Portable On-Ground Scanning LIDAR Remote Sensing. *Environ Model Assess* **13**: 473–81.

Schneider A, Friedl MA, and Potere D. 2010. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on "urban ecoregions." *Remote Sens Environ* **114**: 1733–46.

Secord J and Zakhor A. 2007. Tree Detection in Urban Regions Using Aerial Lidar and Image Data. *IEEE Geosci Remote Sens Lett* **4**: 196–200.

Storch H and Downes NK. 2011. A scenario-based approach to assess Ho Chi Minh City's urban development strategies against the impact of climate change. *Cities* **28**: 517–26.

Tooke TR, Coops NC, Goodwin NR, and Voogt JA. 2009. Extracting urban vegetation characteristics using spectral mixture analysis and decision tree classifications. *Remote Sens Environ* **113**: 398–407.

Tzoulas K, Korpela K, Venn S, *et al.* 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landsc Urban Plan* **81**: 167–78.

Waibel M, Eckert R, Bose M, and VOLKER M. 2007. Housing for Low Income Groups in Ho Chi Minh City, between Re-integration and Fragmentation. *Asien* **103**: 59.