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Using agent-based modelling and landscape metrics to assess landscape fragmentation in Iskandar Malaysia

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Abstract

Introduction: Special economic zones (SEZs) emerge as new forces driving Asian economic transformation and triggering rapid landscape fragmentation. It is imperative to map out the present and future spatial patterns of SEZs in order to understand how they undermine sustainability. Drawing from the experience of Iskandar Malaysia, one of the most successful SEZs in Southeast Asia, this study measures how biophysical and cultural landscapes are being affected by the most recent accelerated land development in the area.

Methods: With aid of a hybrid model, namely the special economic zone landscape fragmentation measurement (SeLaFragment), which combines Geographic Information System (GIS), FRAGSTATS and NetLogo, the current and future fragmentation dynamics were analysed using land use data of the study area from the beginning of intensive landscape transformation in 2007 until 2010. Iskandar Malaysia's cultural and biophysical landscapes were extensively fragmented.

Results: The analysis showed that urban built-up areas increased from 13% in 2006 to 24% in 2010. Mangrove swamps were the worst affected ecosystem as they lost 20% of their areal coverage between 2006 and 2010. The simulation of the future scenarios suggested that, in the future, fragmentation and landscape homogenisation will intensify and pose more risks to landscape quality, functions and socio-ecological services.

Conclusions: It is obvious that rapid landscape fragmentation compromises sustainability of a wide range of ecosystems and their functions and services in and around urban areas. It is difficult to see how existing environmental strategies have been effective in addressing the emerging sustainability challenges of rapid landscape change. The best way to respond to this kind of situation in the SEZs is by focusing on holistic approach to landscape sustainability.

Keywords: *Desakota*; Sustainability; Landscape; Special economic zones; Urban transformation

Introduction

It is a common knowledge that landscape fragmentation is a direct outcome of land use and land cover change. This process affects landscape functions, services and sustainability when the quality of landscape services diminishes. In highlighting the implications of fragmentation, Alberti (2008) notes that converting natural landscapes into urban land use affects hydrological system, nutrient cycles, energy flow, and species composition. However, such threats are not restricted to natural landscapes; cultural landscapes with their outstanding aesthetic, social, economic, heritage and ecological values are also at risk (Vos and Meekes 1999; Wrbka et al. 2004). More pressures on landscapes are anticipated in the developing countries which presently experience the highest rate of population growth and urbanisation, and seemingly, the trend is expected to continue in the future (Wu 2008). In the case of Asia, it is not only the most populous continent in the world but it also has the highest concentration of medium and large cities (United Nations, 2012). Since the 1980s, the Asian city-regions have been identified with proliferation of special economic zones (SEZs) of different sizes and economic development

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targets (Farole and Akinci 2011). The SEZs are mostly private- and foreign investment-driven geographic expressions such as export processing zones (EPZs), free trade zones (FTZs), economic cities and technology and industrial parks. The proliferation of the SEZs in Asia largely follows policies and aspirations of various countries to attract foreign investments to induce national growth and development (Wan et al. 2014). Thus, SEZs constitute a new layer of urban and peri-urban spatial systems that could have significant spatial, ecological, and socio-economic implications. Invariably, one cannot simply ignore the socio-ecological and spatial implications of the SEZs.

In contrast to many developed countries where urban development and other land use changes increased incrementally (Feranec et al. 2010; Biro et al. 2013; De Block 2013), the present experience of mot countries in Asia is about rapid landscape change. Some studies argued that the recent economic development activities in and around Asian urban areas are responsible for the intensified landscape fragmentation (Laquian, 2008; Wu 2009; Su et al. 2010, Young et al. 2011, Qureshi et al. 2014). One of the major concerns raised is that the implications of such landscape changes could persist for several decades (Qureshi et al. 2010). Despite this challenge, only a few countries in the region have developed broad-based landscape research traditions that support a wide range of landscape research (Uuemaa et al. 2013). In the interest of sustainability, it is important to explore present and future patterns and implications of Asian emerging special economic zones. In an attempt to give an alternative view to the western concept of urban sprawl, which centres on unwanted growth from the urban core. McGee (1991) coined the term *desakota* from the Indonesian language words for city (*kota*) and rural (*desa*) to explain landscapes emerging in between agricultural and core city-regions. Thus, a typical *desakota* encompasses a seamless mixture of biophysical habitat, rural settlements, agricultural, industrial, recreational and cultural land uses that intersperse within and around Southeast Asian cities (Ginsburg 1991; Firman 2009; Wu 2009).

McGee's (1991) original explanation represented human geography perspectives. Thus, trade, labour, high-density population, mobility, poverty and globalisation were the key parameters explained. Eventually landscape ecology dimensions of *desakota* attracted researchers' attention (Sui and Zeng 2001; Xie et al. 2006; Laquian 2008; Moench and Gyawali 2008). In short, the emergence of the *desakota* symbolises the dynamics of urban economic and spatial transformation of the Southeast Asian region (Montgomery et al. 2003; Marshall et al. 2009). Many studies have explained the emerging *desakota* landscapes in Indonesia, China, Taiwan, Thailand and the Philippines in different socio-ecological contexts (Firman 2009; Keilly and McGee, 2003; McGee 2008; Wu 2009; Ortega 2012). In the opinion of Rackham (1994), contemporary landscape researchers must avoid vague generalisation, and instead, focus on identifiable details that mark different landscapes characteristics.

Several studies have explained spatial patterns and ecological implications of urban-induced landscape fragmentation in many global regions (Forman 1995; MacKillop and Boudreau 2008; Li et al. 2010). However, in many parts of Asia, there is little dichotomisation of rural-urban, and natural-cultural landscapes. Consequently, many researchers viewed the recent rapid landscape changes that emanated from urban growth as a threat to sustainability of biophysical and cultural landscapes (Jongman 2002; Zing and Wu 2005; Ghazali, 2013; Qureshi et al. 2010; 2013; 2014). In general, understanding urban-induced landscape fragmentation could help researchers to gain insights into institutional and ecological dynamics of landscape change (Tannier et al. 2012).

For certain, the SEZs have created a niche for themselves by virtue of being vehicles for economic transformation and sustainability stresses in Asia (Chaudhuri and Yabuuchi 2010, Wang 2013). Interestingly, some of the SEZs are being developed based on passion for sustainability and expressed support for principles of green growth (Sheng and Tang 2013). Prior to this, it was widely held that SEZs in Asia endanger some of the rare and unique ecosystems and cultural landscapes (Liu et al. 2007; He et al. 2011). Therefore, this problem would need a combination of theoretical explanations, computer-aided spatial measurements and simulations to explain the extent of such critical threats to sustainability. In this case, the time-space telescoping theory posits that the newly industrialising countries experience faster and sooner industrialisation process, intensified pollution and noticeable concern to sustainability at the same time (Marcotullio 2003, 2008).

This study developed an integrated model called the special economic zone landscape fragmentation measurement (SeLaFragment). The purpose of the model is to measure short-term spatio-temporal patterns, characteristics and ecological implications of investment-driven landscape fragmentation in Iskandar Malaysia. The model also simulates long-term landscape fragmentation patterns and implications in the region.

Methods

Study area

Iskandar Malaysia is located between latitudes 1.4833° to 1.6667° N and longitudes 103.4500° to 103.9094° E (Figure 1). This special economic region covers an area of 2,216.3 km^2 tripling the size of Singapore and doubling the size of Hong Kong (Ho and Fong 2011; Ho et al. 2013). This region is part of the multinational extended

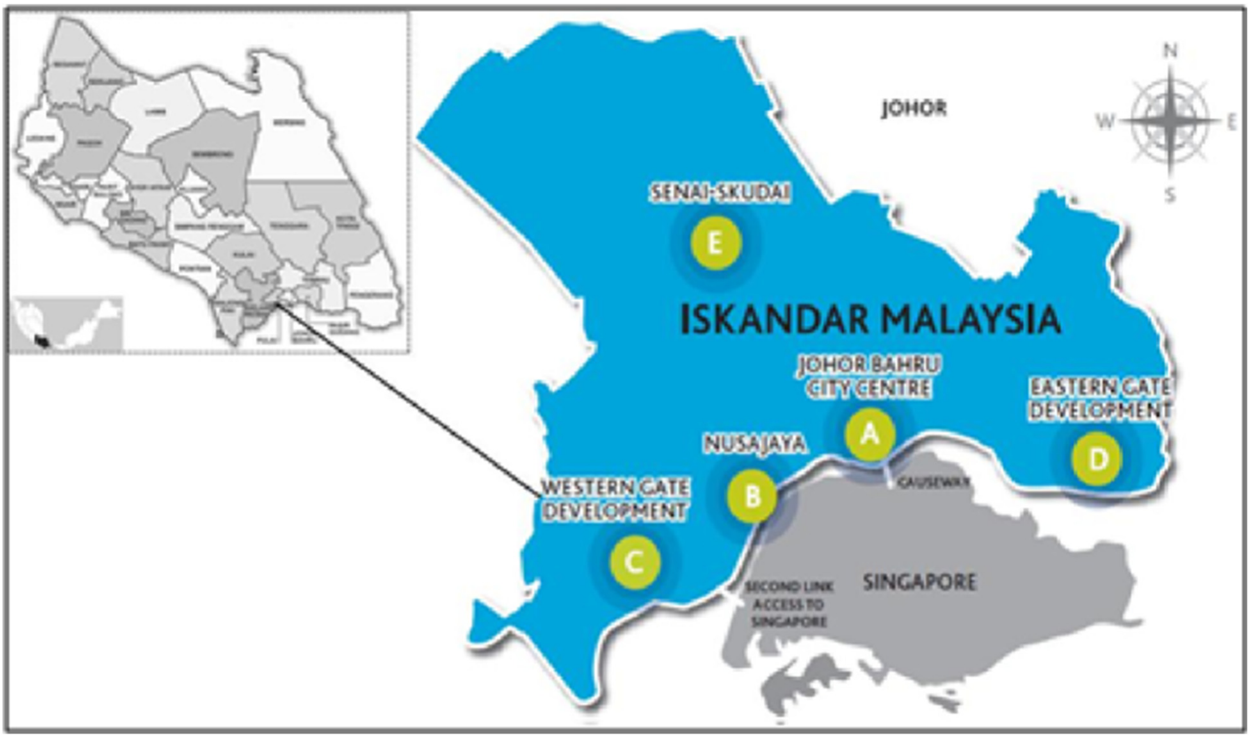

Figure 1 Map of Iskandar Malaysia (source: IRDA).

metropolitan region comprising Singapore, Johor Bahru in Malaysia and Riau in Indonesia (Macleod and McGee 1996; Ho et al. 2013). With an average relief of 200 m above sea level, the area's complex geology is formed by rocks and other deposits of the Quaternary, Tertiary, Jurrasic, Triassic and Cretaceous ages (Gupta 2005). While its climate does not significantly differ from what Chuan (2005) called 'insular' and 'maritime continent' climate of Malaysia, the climate of Iskandar Malaysia is influenced by two monsoon wind systems. Between November and April, the amount of rainfall received is around 1,000 mm, and between March and October, it receives around 500 mm, which is lower than other parts of the Peninsular Malaysia. According to Hope (2005), the climate and geological stability of the area enabled it to maintain the highest flora diversity (about l2,000 species) per unit area, which is higher than anywhere in Southeast Asia. The region has a number of protected ecosystems including three Ramsar sites, namely Pulau Kukup, Tanjung Piai, and Sungai Pulai in addition to some parks.

According to the World Bank (2014), Malaysia's opened economy with a per capita US$8,770 shows its steadfastness to move from high upper-middle income into a high-income economy. Malaysia's most successful SEZ, namely, Iskandar Malaysia, is possibly one of the vehicles to ferry it to an advanced economy status. Interestingly, the region's planning and policy documents firmly stress allegiance to sustainability principles (Shen et al. 2011). Similarly, Ho and Fong (2011) observed that agriculture, forestry and mining constitute the primary sector of its economy; while manufacturing and services dominate the secondary sector. However, following its designation as special economic region in 2007, many things have changed. For instance, the Malaysian Government supported the region with an entry point capital of about US$2.1 billion to develop infrastructure; while the total expected investments are put at US$100 billion, of which, the periodic target for 2011 was even exceeded (IRDA 2011). Some of the recent land-related developments in the five flagships are shown in Table 1.

The region's estimated population of 1.6 million has an average density of 174 persons per km^2 across the core city of Johor Bahru and satellite towns (IRDA 2012). However, urban *kampungs* (villages) provide a good example of cultural landscapes of the region. These urban villages which have been in existence for quite a long time represent the Malaysian people's cultural values, conservatism and rural nostalgia (Bunnell, 2002). Presently, most of these urban *kampungs* are vulnerable to urban growth affecting Malaysia (Ghazali 2013). As shown in Figure 1, this economic region is divided into five flagship areas, and within each flagship, there are special cities, industrial parks, education hubs, health parks, etc.

Table 1 List of priority development projects and investments in Iskandar Malaysia (2007–2010)

Flagships	Projects realised from 2007 to 2010
Johor Bahru city centre (A)	• Central business district projects
	• Danga Bay integrated waterfront city
	• Upgrading of central business district
	• Tebrau-Plentong mixed development
	• Customs, immigration and quarantine complex
	• Johor-Singapore Causeway and Lido Boulevard
	• Conservation and heritage zones
Nusajaya (B)	• Kota Iskandar
	• Puteri Harbour
	• Medini
	• EduCity
	• Southern Industrial Logistic Clusters (SiLC)
	• Afiat Health Park
	• Housing and Residential Projects
Western Gate Development (C)	• Port of Tanjung Pelepas
	• Tanjung Bin Power Plant
	• Malaysia - Singapore Second Link
	• RAMSAR World Heritage
	• Tanjung Piai - Southernmost Tip of Mainland Asia
	• Free trade zone
Eastern Gate Development (D)	• Tanjung Langsat Industrial Complex
	• Tanjung Langsat Port
	• Johor Port
	• Pasir Gudang Industrial Park
	• APTEC (Lakehill Resort City)
Senai-Skudai (E)	• Senai International Airport
	• Senai Cargo Hub
	• Senai High-Tech Park
	• Sedenak Industrial Park
	• MSC Cyberport City
	• Johor Technology Park
	• Johor Premium Outlets

In line with its vision of becoming a strong sustainable metropolis (Shen et al. 2011), a number of proposals and blueprints have been developed to foster sustainability. These initiatives include about 30 blueprints on land use, urban planning, water and hydrology, walkable streets, integrated transport, energy efficiency, building and waste recycling and management, and the most ambitious of this is the low-carbon project (IRDA 2011; Ho et al. 2013).

SeLaFragment model development

A good explanation of complexities of landscape fragmentation and sustainability implications would need coupling of various methods. Thus, the authors designed the SeLaFragment through integration of several other models as depicted in Figure 2. Each of the component models generated different results which together built the findings of the study. In the first step, landscape metrics for measuring landscape fragmentation were identified. In the second stage, the land use data were analysed and rasterised in ArcGIS 9.3. In the third step, the FRAGSTATS model analysed the rasterised data to quantify landscape fragmentation. While the fourth stage involved simulation of the results in NetLogo-agent-based modelling software to project the future dimension of the landscape fragmentation impact.

Most of the previous studies that investigated urban growth patterns in parts of Iskandar Malaysia focused on mapping of land use and land cover change via remote sensing and Geographic Information System (GIS) tools (Amir 2006). However, such studies also conceptualised the land use change impact as urban sprawl. Following McGee's (1991) conceptualisation of urbanisation in Southern Asia, this study also assumes that SEZs in the region play an important role in changing spatial patterns including fragmentation of landscapes. For analysis of this situation, the researchers acquired two datasets for the 2006 and 2010 Johor State land use. The local planning authorities in conjunction with Iskandar Malaysia Regional Development Authority (IRDA) GIS unit compiled these land use datasets. The authors reclassified the datasets in ArcGIS 9.3 by merging the different land use into four broader land use classes, namely agriculture, urban built-up areas, green areas (forests, scrublands, protected ecosystems) and wetlands (mainly mangrove swamp areas). The merger and reclassification of the various classes harmonised the wide differences between the 2006 and 2010 land use datasets.

Though GIS has spatial analysis tools that can analyse spatial patterns; however, this capability is weakened by low correlation statistics that usually arise from mapping

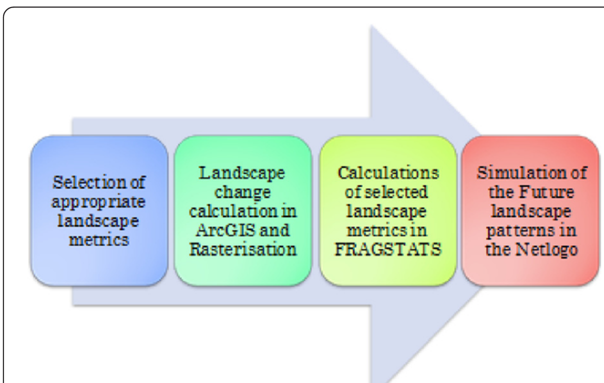

Figure 2 SeLaFragment-integrated model development process.

mistakes (Raines 2002). Consequently, the researchers found an alternative in landscape metrics whose comprehensive quantitative mapping capabilities can make up for such weaknesses (Hai and Yagamuchi 2008; Hao et al. 2010). The advantage of landscape metrics is that they are sensitive to patch-, class- and landscape-level fragmentation dynamics.

In stage two of the SeLaFragment model, the vector data were rasterised as the reclassified vector-based land use datasets in ArcGIS 9.3, and then, the output was exported into FRAGSTATS 4.1 model for calculation of the selected landscapes metrics for quantitative analysis of landscape fragmentation patterns (following McGarigal et al. 2012). A total of five landscape metrics were selected for analysis of the four landscape classes (Table 2).

In the fourth and final stage of the SeLaFragment model, the future implications of investment-driven landscape fragmentation were simulated using Netlogo's Sprawl Effect model. Some studies have used this agent-based modelling software to estimate urban sprawl dynamics (Lagarias, 2012) and for landscape management purposes (Dion and Lambin, 2012). In reflecting emergence of the *desakota*, the origin of fragmentation in the simulation interface was selected to be at the bottom left-hand side (Figure 3a) which represents growth from outside the core city of Johor Bahru. The selected parameters that determined the simulation include population, which was kept low at 178 to represent the actual population of the region; while values for attraction and smoothness parameters were kept high (17 and 18, respectively) to represent openness and fast influx of investments. The speed value was adjusted to a faster level to represent the unprecedented short-time landscape fragmentation. On the other hand, the model was allowed to run for 3,030 ticks to represent long-term interaction between landscape-based investments and the four classes of landscape.

Table 2 Selected metrics and distribution statistics for landscape fragmentation analysis

Landscape metrics/units	Purpose of measurement/units
Total Area/Class Area (TA/CA)	Landscape and class composition and patch types in Iskandar Malaysia
	Unit = m^2
Percentage of Landscape (PLAND)	Landscape composition and abundance proportion for class analysis
	Unit = percent
Largest Patch Index (LPI)	Measure of dominance of largest patch in landscape or class
	Unit = percent
Edge Density (ED)	Edge segments in relation to border of patches for class and landscape boundary
	Unit = metres per hectares
Area Mean (Area_MN)	Measures all patches within total class/landscape area
Area Standard Deviation (Area_SD)	Shows extent of variation/dispersion of the mean values for patches within class or landscape

Results

Spatio-temporal patterns of landscape fragmentation in Iskandar Malaysia

The purpose of this study is to examine spatio-temporal patterns, characteristics and ecological implications of investment-driven landscape fragmentation in Iskandar Malaysia This section outlines results of fragmentation dynamics of the four landscape classes (agriculture, urban, protected ecosystems and mangrove swamps) for 2006 and 2010 representing, respectively, the periods before and after establishing Iskandar Malaysia. In the context of this analysis, agricultural landscapes included oil palm, plantations and all other food- and cash-crop-growing fields of various spatial sizes as well as some spontaneous vegetation located within agricultural landscapes. These landscapes constituted 1,480.5 km^2 or 70% of the region in 2006 and subsequently declined to 1,243.1 km^2 or 61% in 2010 (Figure 4). Thus, agricultural landscapes declined by about 10% from their 2006 total size.

On the other hand, Iskandar Malaysia has witnessed a major shift in the spatial patterns of its urban landscapes since 2006. In 2006, the urban areas of the region covered some 266.39 km^2 or 13% of its total area. This figure grew dramatically in 2010 when urban areas constituted 497.11 km^2 or 24% of Iskandar Malaysia (Figure 4). New urban growth covered public housing projects, commercial and industrial layouts, tourism and recreational areas that emerged over agricultural landscapes, informal settlements, open spaces, mangrove swamps, etc.

The green areas of Iskandar Malaysia included protected ecosystems such as Ramsar sites and few forest reserves that are found across Iskandar Malaysia. According to the ArcGIS analysis shown in Figure 4, these areas covered 248.7 km^2 or about 12% of the total area of Iskandar Malaysia in 2006 and subsequently they declined to 210.48 km^2 or about 10% in 2010. Invariably, this suggested that the land development activities rapidly encroached on locations previously occupied by forests and other forms of greenery.

The spatio-temporal patterns of mangrove swamps in Iskandar Malaysia are given in Figure 4, which indicated that these ecosystems covered an area of 91.236 km^2 or 5% of the total area in 2006, and subsequently declined to 90.435 km^2 or 4%. The size of the mangrove swamp areas fragmented or lost between at 2010 was 20% lower than the total size of these landscapes at 2006.

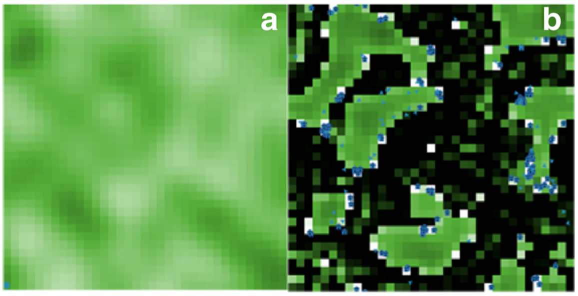

Figure 3 Simulated future landscape fragmentation in Iskandar Malaysia. a - urban landscape, **b** - rapidly fragmented urban landscape.

Characteristics and implications of landscape fragmentation

Although, GIS could undertake a satisfactory analysis of spatio-temporal patterns of landscape change in Iskandar Malaysia, it could hardly give clues for researchers to explain details of the characteristics and implications of the fragmentation. The selected metrics from FRAGSTATS (Tables 3) mapped out underlying characteristics and implications of the fragmentation through Class Area (CA), Percentage of Landscape (PLAND), Largest Patch Index (LPI), Total Edge (TE), and distribution statistics - Mean Area (AREA_MN) and Area Standard Deviation (AREA_SD).

The PLAND value of FRAGSTATS at 73.7 for 2006 and 59.4 for 2010 was almost similar to the ArcGIS results for agriculture (Figure 4). Invariably, this indicates the dominance of agricultural landscapes at 2006 and their subsequent vulnerability due to accelerated fragmentation after establishment of Iskandar Malaysia. It was obvious that, due to increased fragmentation, the distribution of agricultural landscapes became more uneven recently. Similarly, the LPI values for the two periods suggested that sizes of individual agricultural plantations also decreased recently. On the other hand, differences in Area_Mean, Total Edge and Edge Density between 2006 and 2010 indicated the overwhelming nature of speed and spatial implications of fragmentation on the agricultural landscapes.

The ArcGIS-calculated size of urban landscapes was 13% and 24% for 2006 and 2010, respectively. In contrast, the FRAGSTATS' PLAND value for the urban areas measured 9.1 and 25.9 for 2006 and 2010, respectively. The difference could be due to the sophisticated capability of FRAGSTATS to calculate edges of landscape classes with higher precision. Unlike agricultural

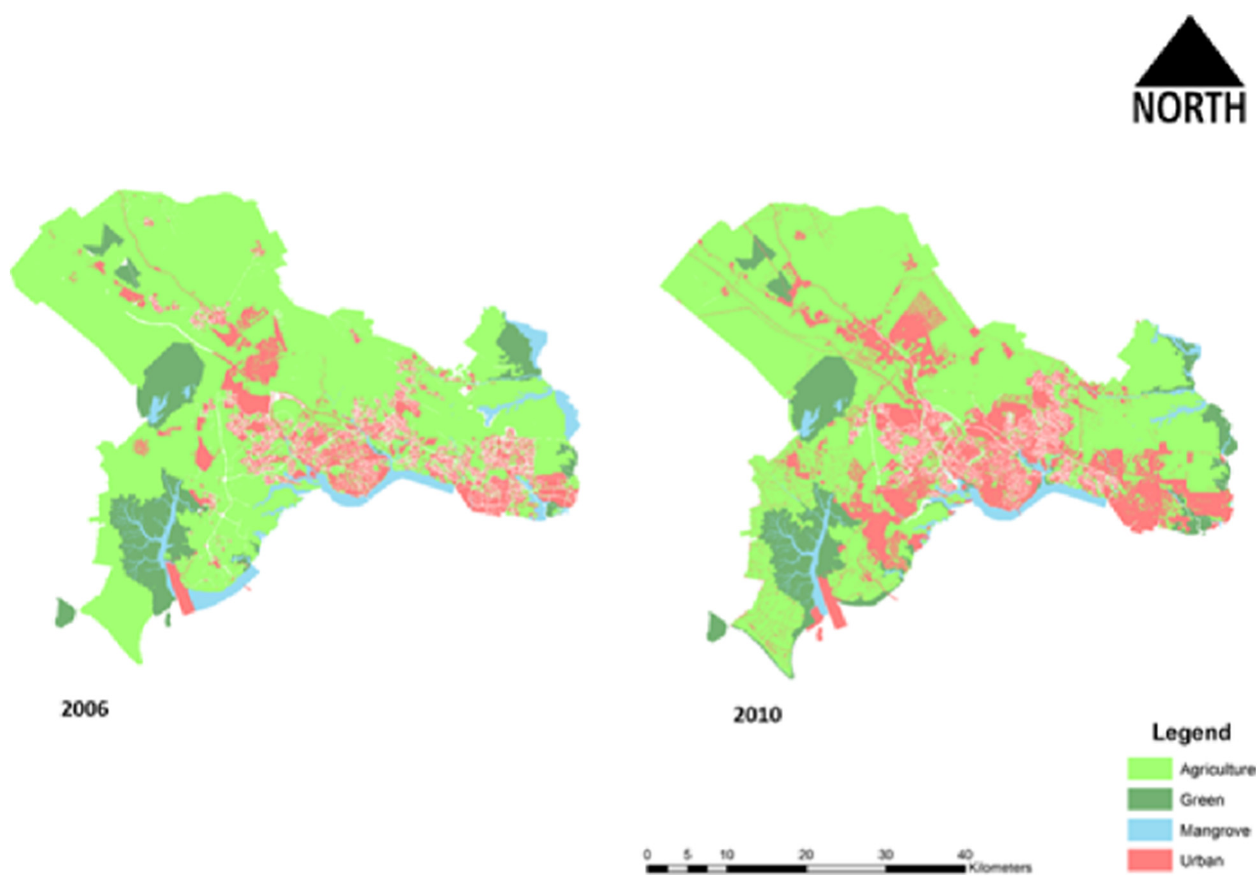

Figure 4 Spatio-temporal patterns of landscape change in Iskandar Malaysia.

Table 3 2006 and 2010 landscape fragmentation characteristics

Land use activity	Landscape metrics	2006	2010
Agriculture	CA	158,520.90	119,944.8
	PLAND	73.7	59.4
	LPI	69.5	50.5
	TE	1,000,320.0	2,168,437.1
	ED	4.97	10.7
	AREA_MN	1,124.2	528.3
	AREA_SD	11,763.0	6,769.2
Urban	CA	18,466.56	52,544.9
	PLAND	9.1	25.9
	LPI	1.5	14.3
	TE	680,400	2,419,620.4
	ED	3.38	13.8
	AREA_MN	63.9	140.3
	AREA_SD	253.5	1751.6
Forests	CA	14,428.80	20,932.6
	PLAND	12.6	10.3
	LPI	4.0	3.7
	TE	344,640	2,419,620.4
	ED	1.71	13.8
	AREA_MN	343.5	140.3
	AREA_SD	1,235.5	1,317.6
Mangrove	CA	9,855.36	8,626.8
	PLAND	4.8	4.2
	LPI	1.5	1.5
	TE	349,200	478,352.9
	ED	1.73	
	AREA_MN	138.8	73.1
	AREA_SD	429.95	317.4

CA, Class Area; PLAND, Percentage of Landscape; LPI, Largest Patch Index; TE, Total Edge; ED, Edge Density; AREA_MN, Mean Area; AREA_SD, Area Standard Deviation.

landscapes, the characteristics of urban growth indicated that the LPI of urban landscapes jumped from 1.9% in 2006 to 14.9% in 2010. This suggested a rapid expansion of built-up areas and how they spilled rapidly into other landscapes. Another evidence of this has to do with an unprecedented increase in the number of edges that arose from increased fragmented landscapes in 2006 compared to how it rose dramatically in 2010. The increase in the mean area of urban landscape class in comparison to 2006 and 2010 suggested that larger urban land development projects emerged recently in this region. For instance, several property development clusters, infrastructural development projects, business, industrial layouts and recreational spots were developed across its five flagship zones (Table 1).

The forest reserves and protected ecosystems have a PLAND value of 12.6 and 10.3 for 2006 and 2010, respectively. This is almost similar to the 12 and 10% that ArcGIS calculated. The decline of about 3% in the total size of green landscapes indicated a significant level of fragmentation. Similarly, the decline of the 2010 LPI value suggested an increased level of fragmentation in entire landscape areas observed. In other words, the effects of these changes in landscape metric values implied an overall increase in fragmentation.

The mangrove swamps in Iskandar Malaysia constituted 5% and 4% for 2006 and 2010 respectively. However, the decline in mangrove swamp distribution was shown to be very significant. While the LPI value remained unchanged (at 1.5 m^2) for 2006 and 2010; other metrics showed significant levels of change that directly affected the quality, patterns and distribution characteristics of the mangrove swamps.

In summary, the quantitative findings of the FRAGSTATS model illustrate the characteristics and implications of landscape fragmentation in Iskandar Malaysia. These include the following: accelerated landscape change patterns, increasing role of individual land uses in affecting landscape fragmentation, dominance of urban land use activities, degradation of vital ecosystems, increased encroachment to ecosystem, and diminishing cultural landscapes through the newly emerging land development projects.

Simulation of future landscape fragmentation scenarios in Iskandar Malaysia

The impact of investments on landscape fragmentation within 4 years after Iskandar Malaysia's takeoff was obvious from Figure 4 and Tables 2 and 3. The patterns that the simulation reveals in Figure 3a,b represent the likely future patterns of landscape fragmentation by year 2025 when the region is expected to be fully developed.

The hues and shades in Figure 3a represent the four classes of landscape in Iskandar Malaysia. After running the simulation for a long time (3,030 ticks), the new patterns of landscape emerged as shown in Figure 3b. This simulation suggested that, in the future, there would be increased rates of fragmentation induced by the anticipated investment influx. The implication of these projected scenarios is that the ecological functions of all the three classes of landscapes (agricultural lands, mangroves and forests) could be adversely affected through increased fragmentation. In other words, spatial patterns, ecosystem services and values of cultural landscape would diminish, and landscape homogenisation would set in progressively. Thus, if the current trends continue as represented by this simulation, it means the future landscape morphology of the region would progressively reduce its landscape ecological diversity and functions. The situation may also endanger protected ecosystems as more urban land use activities come closer to them, and this situation may create series of sustainability problems.

Discussion

The purpose of this study is to explain the spatio-temporal dynamics of investment-driven landscape fragmentation in the context of present and future sustainability of Iskandar Malaysia. This section highlights sustainability implications of the identified patterns and characteristics of rapid landscape fragmentation. For a broader understanding of sustainability implications of this problem, it is essential to consider it from socio-ecological systems point of view. This is because cities are nested in human and ecological realities which become even more complex in urban areas (Barau et al. 2013; Villamor et al. 2014). In this regard, it is possible to say that rapid fragmentation of agricultural landscapes, forests and mangroves undermines the long-time resilience of this region. The situation is likely to aggravate its vulnerability to climate change events such as flooding. This is true considering the fact that Iskandar Malaysia has experienced one of the worst floods in 2007/2008 which caused serious damage to property including a few deaths and risks to public health (Hisham et al. 2009).

In a related vein, Jha et al. (2012) posit that human-induced degradation of mangroves is one of the major triggers of urban flooding in Asian coastal cities. It is clear from the results of this study that urban land use is fast encroaching into agricultural lands, green spaces and mangroves. This development may affect air quality and microclimate of the area. A recent study of a similar situation in China's Beijing city reveals that the decrease in cultivated land as a result of rapid urbanisation causes decrease in wind speed, raising temperature and urban heat island phenomenon (Cui and Shi, 2012). Besides this, the problem of increasing landscape fragmentation constitutes a new source of urban CO^2 emissions. This is based on study findings which indicate that scattered residential land use is responsible for increase in the per capita rate of emissions in small- and medium size cities (Makido *et al.* 2012).

As a wet tropical region, the area covering Iskandar Malaysia is reported as one of the highest hubs of biodiversity whose landscapes have ecological endemism for some species (Hope 2005). Hence, the ecological implications of rapid fragmentation in terms of species habitat loss could be very high in this region. It is obvious that any reduction in size of landscapes could have destructive effects on fauna and flora species distribution and composition within each landscape fragment. Connectivity is one of the key determinants of sustainability that relates and responds very well to changes in urban form (Tannier et al. 2012). In other words, increased fragmentation creates tension between human land use and biodiversity.

Even though some researchers view urbanisation as one of the drivers of the Anthropocene (Barau and Ludin, 2012), this may be true in particular for this region considering the speed of massive transformation of urban form and landscape composition, functions and services. Thus, in a situation whereby investment-driven land use change causes substantial decline in the size of green areas and mangrove swamps within 4 years, this could be described as daunting. In contrast, the situation in the urban areas of the more developed economies is such that they currently experience incremental patterns of landscape fragmentation (Batisani and Yarnal, 2009; Feranec et al. 2010; Biro et al. 2013).

In effect, the present patterns of landscape fragmentation witnessed in Iskandar Malaysia confirm and conform to the time-space telescoping theory's argument on the industrialisation behaviours of the emerging economies (Marcotullio 2003, 2008). It makes this theory more relevant in this situation, if the speed and irreversible large scale damage inflicted on the cultural and ecological wellbeing are taken into consideration. Therefore, there is urgent need for governments and investors to adopt more innovative strategies for sustainability in SEZs. Traditionally, SEZs express commitment to sustainability (Shen et al. 2011; Ho et al. 2013); however, it is not difficult to understand that there are weaknesses that possibly arise from a lack of integrated approach to sustainability. In the case of Iskandar Malaysia, it is obvious that there is no evidence that the region's menu of sustainability best practices has been able to protect landscapes adequately or effectively.

In relation to economic development, Malaysia's Department of Statistics (2011) reports that, as of 2010, Johor State, whose recent economic prosperity owes its strength to Iskandar Malaysia, has a GDP of about US $20,000, a growth rate of 9.8%, and an unemployment rate of 2.4%. These figures suggest high-income status and higher prospects for this SEZ. While the patterns of rapid landscape fragmentation within a short period have been established by this study, the argument of environmental Kuznets curve on the eventual decline of sustainability pressures (Liu et al. 2007; Franklin and Ruth, 2012) may not hold in the case of landscape fragmentation; this is because such impacts are often irreversible in the case of urban landscape change. For instance, development of luxury hotels and marinas on previously mangrove covered landscapes (Figure 4) may be a good example of irreversibility.

In respect of the characteristics and implications of landscape fragmentation outlined in Table 3, there are important issues that arise from this table. For instance, for all the four classes of landscapes studied, it appears that the process of landscape fragmentation can be categorised into two, namely active and passive types of landscape fragmentation. Urban landscapes are the active agents of landscape fragmentation in the sense that they induce fragmentation by replacing one form of land use or land cover with another. On the other hand, passive fragmentation covers agricultural landscapes, forests, mangrove swamps and cultural landscapes. These vulnerable landscapes possibly contribute invaluable aesthetic, economic and social benefits (Vos and Meekes 1999; Wrbaka et al. 2004) more than the landscapes fragmenting them. In a large SEZ like Iskandar Malaysia, it is difficult to separate between new investment projects and conventional urban growth patterns. However, it is better to group all of them together since all of them fall within the boundaries of this SEZ.

It is important to discuss the results of this study in the light of *desakota* which continues to raise interest in Asian urban land use change studies (Sui and Zheng 2001; Firman 2009; Wu 2009). For most of these studies the emergence of desakota is identified with areas of high population density. This situation is in contrast with what is obtained in Iskandar Malaysia, where the population is low and is 174 persons/km^2 (IRDA 2012). This situation of rapid urban growth and landscape change in low-density population area presents an interesting area for further studies on how capital influx affects people's experiences with landscapes including their rights to use landscape resources. This is important because in some *desakota* regions people are dispossessed of lands by the powerful investors (Ortega 2012). Sometimes the effects of land development by investors increase siltation and sedimentation of rivers upon which local communities earn livelihoods through fishing (Joeman 2011). In other words, the issue of landscape change and investment influx in developing countries could be critically understood through socio-ecological prism.

In respect of the future patterns of landscape fragmentation, the result of the simulation (Figure 3) indicates that, going by the present pace of investment influx in Iskandar Malaysia, landscape fragmentation would lead to homogenisation of landscape type and increased vulnerability of various types of ecosystems. This economic region has abundant landscapes covering an area of over 2,000 km^2. Its strategic position and proximity to Singapore, and by virtue of being at the heart of the multinational extended metropolitan region (Macleod and McGee 1996; Ho et al. 2013), makes the prospects of its future growth more realistic. In contrast to other Asian countries, since 2009, domestic investors have sunk more investments than foreign direct investors (IRDA 2011). In other words, both local and foreign investments play a role in changing landscape patterns in Iskandar Malaysia. Considering the fact that landscape fragmentation affects forest reserves (Figure 4), then, it is possible to predict that even the protected ecosystem and most of the cultural landscapes are prone to the effects of increasing investments in the various sectors of the economy.

One of the limitations of this study is that, though it has been able to establish the pace of the accelerated landscape fragmentation, it fails to measure or scale thresholds for its collapse. There is need for more studies on comparative vulnerability and resilience of the four classes of landscapes identified in this research. This research has shown the identifiable details (Rackham 1994) that define multiple sustainability challenges that characterise the SEZs in Asia and the threats they pose to cultural and biophysical landscapes.

Conclusion

This study investigates the short-term sustainability implications of special economic zones in Asia based on the Malaysian experience. The study posits that the phenomenon of SEZs has constituted a new layer of pressure for biophysical and cultural landscape systems in Asia. Enjoying good support, liberty and goodwill of governments in Asia and other parts of the Global South, SEZs are more often than not celebrated for their economic breakthroughs and written commitments to sustainability.

By and large, it is rather difficult to pass judgement on Iskandar Malaysia's state of sustainability particularly in the context of landscape change impact. Nevertheless, the findings of this study have clearly revealed the implications of special economic zones on the present and future landscape systems of the region. The anticipation from SEZs and all economic systems is to strike a balance between economic and ecological interests of the present and future population (Griggs et al. 2013). Therefore, it is not enough to celebrate growth of GDP as an indicator of development; this is because in the opinion of Costanza et al. (2014), GDP is not a good measure of a national development success. However, considering the fact that landscape sustainability hinges on their ability to retain their process and patterns (Wiens 2013), then, based on the findings of this study, it is not spurious to conclude that the landscapes of Iskandar are far from being sustainable under present circumstances.

Compared to other landscapes types of the region, the protected ecosystems of Iskandar Malaysia were less affected by the impact of recent landscape fragmentation. Hence, this study strongly recommends that civil societies in collaboration with planning authorities and policymakers should propose reforms that will strengthen institutions and local communities against overriding influences of investments that deface landscape composition and quality within a short period. In other words, innovative landscape governance is a vital vehicle that can mitigate the unprecedented footprints of investments threatening landscape sustainability.

This research is important for geographers, landscape ecologists, urban planners, landscape architects, policy-makers, civil society groups, development institutions and industry leaders. It shows that landscape sustainability in all economies and businesses needs to anchor local people and local landscapes in order for it to be truly sustainable. Therefore, investors and corporations that move capital from one global region to another investing in land development projects need to heed this point in order to foster sustainable development in and around urban areas. On a final note, considering the findings of this study on how SEZs cause dramatic change in landscape quality, researchers and policy makers in the emerging economies need to pay attention to an inter-disciplinary and holistic approach. This can help them to effectively understand and address the challenges of human impact on the natural-cultural and rural-urban landscapes.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
AB developed the idea for this research and wrote substantial parts of the paper including model development. SQ organised the flow and establish theoretical linkages and arguments. He also developed the title of the paper and rewrote several parts of the paper. Both authors read and approved the final manuscript.

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